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Handbook on estimation of external cost in the transport sector

Produced within the study
Internalisation Measures and Policies for All external Cost of Transport (IMPACT)

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Report

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Contents

Summary

Internalisation of transport external costs: policy background

Transport activities give rise to environmental impacts, accidents and congestion. In contrast to the benefits, the costs of these effects of transport are generally not borne by the transport users. Without policy intervention, these so called external costs are not taken into account by the transport users when they make a transport decision. 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 by 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.

Internalisation of external cost of transport has been an important issue for transport research and policy development for many years in Europe and worldwide. A substantial amount of research projects, including with support of 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 document issued by the European Commission, notably the 2006 mid-term review of the White paper on the European Transport Policy.

When amending Directive 1999/62/EC on charging heavy duty vehicles for the use of certain Infrastructure, 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 is to serve as a basis for future calculations of Infrastructure charges. The model must be accompanied by an impact analysis on the internalisation of external costs for all modes of transport, a strategy for stepwise implementation and where appropriate a legislative proposal to further review the Eurovignette Directive.

The IMPACT study

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

Handbook on external cost

This Handbook presents the state of the art and best practice on external cost estimation to make this accessible for those who are not familiar with the issue. It covers all environmental, accident and congestion costs and considers all transport modes. The focus is on 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 handbook is based on the existing scientific and expert work mainly done at EU level and within European countries. It has been reviewed by a panel of more than thirty experts, including experts who were designated by Member States.

The handbook recommends:

- Methods for calculating external cost figures.
- Best available input values for such calculation (e.g. value of one life year lost).
- Estimated default unit values of external cost for different traffic situations (e.g. air pollution cost of a vehicle in Euro per kilometre).

Methods for estimating external costs

Although the estimation of external costs have 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 approach is broadly acknowledged as the preferred approach, using Values of Statistical Life based on Willingness to Pay. Marginal accident cost can be estimated by the risk elasticity approach, also using Values of Statistical Life. Given long-term reduction targets for CO_2 emissions, the avoidance cost approach 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.

Available input values and EU default unit values

It is concluded that external costs of transport activities depend strongly on parameters like location (urban, interurban), time of the day (peak, off-peak, night) as well as on vehicle characteristics (EURO standards). Within the same Member State, the cost of one lorry kilometre in urban areas at peak hour can be at least five times higher than the 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 the literature assessment made by the study. These input values can be used to produce own output values, with relatively high level of accurateness. 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.

1 Introduction

1.1 Internalisation of external cost

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 noise and ships to air pollution. In contrast to the benefits, the cost of these effects of transport are generally not borne by the transport users and hence not taken into account when they make a transport decision. Therefore these effects are generally labelled as external effects. Important examples of external effects of transport are congestion, accidents, air pollution, noise and impacts on climate change. The cost associated to these effects are called the external cost.

The internalisation of these effects 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 better incentives to transport users, namely with market-based instruments (e.g. taxes, charges, emission trading). Combinations of these basic types are possible: for example, existing taxes and charges may be differentiated, e.g. to Euro standards.

Internalisation of external costs by 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 cost, which is the subject of this handbook.

1.2 The policy context

1.2.1 Internalisation of external cost as a policy request at EU level

Estimation and internalisation of external cost of transport have been important issues for European transport research and policy development for many years. The European Commission has raised the issue of internalisation in several strategy papers, such as the Green Book on fair and efficient pricing (1995), the White Paper on efficient use of Infrastructure, the European Transport Policy 2010 (2001) and the it's midterm review of 2006. Following a number of research projects, the approaches of the Commission are based on the economic theoretical concept of marginal social cost pricing. The EC White book of the overall transport strategy (Time to decide, 2001) and the midterm review (Keep Europe moving, 2006) underline the need of fair and efficient pricing considering external costs.

Research projects have shown that internalisation of external costs by pricing measures can be an efficient way to reduce the negative impacts of transport. In general it may:

- Improve transport efficiency (e.g. efficient use of scarce Infrastructure, energy and environmentally efficient rolling stock, efficient use of different transport modes).
- Guarantee fairness between transport modes, that means fair prices considering the overall performance and potentials of the different transport modes. and
- Improve safety and reduce environmental nuisances in the transport sector.

1.2.2 The Eurovignette Directive

The introduction of market-based instruments for internalisation of external cost has been discussed for different transport modes. To some extent it is also been substantiated in EU Directives, particularly related to Infrastructure cost pricing.

Within the rail sector, the marginal cost oriented pricing approach is considered as a basis for track pricing (Directive 2001/14/EC). Charges may be differentiated with respect to environmental impacts as long as this does not lead to additional revenues for the Infrastructure manager. Additional revenues are only allowed if in competing modes a comparable level of charging of environmental costs takes place[1].

For the road sector, in the amendment of Directive 1999/62/EC (Eurovignette Directive) on road charges, adopted on 27 March 2006, the European Union allows Member States to levy tolls on all roads. This Directive is a significant step towards the implementation of a European road charging policy.
One constraint of the current Directive is the requirement that revenues may not exceed related Infrastructure costs. The Directive only allows a limited *differentiation* of charges according to capacity or environmental criteria. Only for mountainous areas, a mark up (up to 25%) is possible, considering the higher level of Infrastructure costs.

To ensure that the next step is taken, the European Parliament insisted in the Directive that further analysis is necessary to ensure that all impacts and obstacles to the internalisation of external costs are addressed:

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[1] The Directive also allows Member States to introduce time-limited compensation schemes for the use of railway Infrastructure for the demonstrably unpaid environmental, accident and Infrastructure costs of competing transport modes in so far as these costs exceed the equivalent costs of rail.

Article 11
(…)

No later than 10 June 2008, the Commission shall present, after examining all options including environment, noise, congestion and health-related costs, a generally applicable, transparent and comprehensible model for the assessment of all external costs to serve as the basis for future calculations of Infrastructure charges. This model shall be accompanied by an impact analysis of the internalisation of external costs for all modes of transport and a strategy for a stepwise implementation of the model for all modes of transport.

The report and the model shall be accompanied, if appropriate, by proposals to the European Parliament and the Council for further revision of this Directive.'.

More precisely, the Directive requires the Commission to *examine* the full range of external costs for all modes of transport, to *present* a basis for assessing all external costs, to *analyse* the impact of the internalisation of external costs and to *prepare* a strategy for a stepwise implementation of this model for all modes of transport.

Since many studies have been carried out, these proposals can be based on sound know how, both at the EU-level and within the Member states. The following approaches and basic documents might illustrate that:

– EU-Research projects of several framework programmes to estimate external costs (such as UNITE, ExternE, GRACE, etc.)
– Other EU projects on external and Infrastructure costs, particularly *Marginal costs of Infrastructure use – towards a simplified approach*, CE Delft, 2004.
– National research projects and studies on external costs (particularly for the UK, the Netherlands, Switzerland, Austria, Germany).
– International estimates of external costs (such as by UIC, ECMT).
– EU-proposals to standardize marginal cost estimation (High level group approaches).
– EU-Networking projects to discuss pricing instruments (CAPRI, IMPRINT, MC-ICAM).
– National pricing strategies (e.g. HGV charging in several countries, HGV-fee in Switzerland, urban road pricing schemes such as London and Stockholm congestion charges).
– Several studies on internalization policies at different levels (such as the mentioned strategy papers at EU-level, policy proposals at national level.

1.3 The aim and contents of the IMPACT project

In the light of the mandate from the EU legislator, the European Commission has commissioned the IMPACT study in order to summarise the existing scientific and practitioner's knowledge on approaches for estimating and internalisation external cost of transport.

This IMPACT Deliverable, the Handbook at hand, is to provide a comprehensive overview of approaches for estimation of external cost and to recommend a set of methods and default values for estimating external costs when conceiving and implementing transport pricing policy and schemes. It presents the best practice methodologies and figures for the different external cost components in the transport sector. It covers all environmental, accidents and congestion costs. Infrastructure costs are not included in this handbook, because of it's different nature and the mandate of the Eurovignette Directive which also focuses on examining the environment, noise, congestion and health related costs.

1.4 Contents and structure of the Handbook

1.4.1 Aim and contents

This Handbook provides information how to generate quantitative information 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:

1 **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 to use the results for internalisation strategies?

2 **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?

3 **Output values**: Which 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 EU and as well at national level.

1.4.2 The procedure: evaluation and choice of methodologies

The elaboration of the Handbook is based on the following main issues:

- The values shown within this Handbook are representing today's state of the art on the estimation of external cost. Thus the evaluation focuses on most recent studies considering the scientific value and the transferability of results. Most important in this context is the road sector, due to the fact, that road transport is responsible for the major part of social costs. In those cases where there is no real scientific consensus on methodology, the different approaches are shown.
- The values and bandwidths presented are mainly based on estimates at EU-level since recently many meta-analysis have been carried out seeking for scientific consensus and delivering representative and transferable results.

- For every cost category, a short discussion of the value of available studies is shown. There is a brief discussion on the most important values and the arguments for best practice in the main text. The evaluation of available studies is shown in the Annex Report.
- The Handbook does not compute own figures. Thus the reader should consider that the figures shown are not intrinsically the 'right ones' for his purpose but those currently available from the most appropriate and extensive studies.
- The estimation of values for external costs and different traffic situations involves many assumptions, such as valuation of risks, short and long term effects often in the face of scarcity of appropriate data. Thus the questions of required and feasible accuracy are major issues when applying these monetary values for practical ends. There are mainly two levels of accurateness to distinguish: Accurateness of the valuation part and accurateness of data input. Both issues are addressed.

The handbook has been reviewed by a panel of more than thirty experts, including experts who were designated by Member States, and been discussed with these experts at a meeting on 22 November 2007[2].

1.4.3 Presentation of the results

The output figures are shown for a common base year (if possible and applicable the year 2000) in order to increase comparability. The bandwidths shown are representing in general the influence of different cost drivers and uncertainties in the cost drivers.

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. 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 cost that are strongly related to fuel consumption, also output values expressed in Euro per litre of fuel are presented. In order to compare different modes, a transfer in cost per passenger or tonne kilometre has been carried out. Where relevant and useful, other output unit values are shown.
The figures presented are in general representative for average Western European countries. The value transfer approach shown provides the information to transfer these figures to other countries and specific traffic situations.

1.4.4 Overview of the structure and practical use

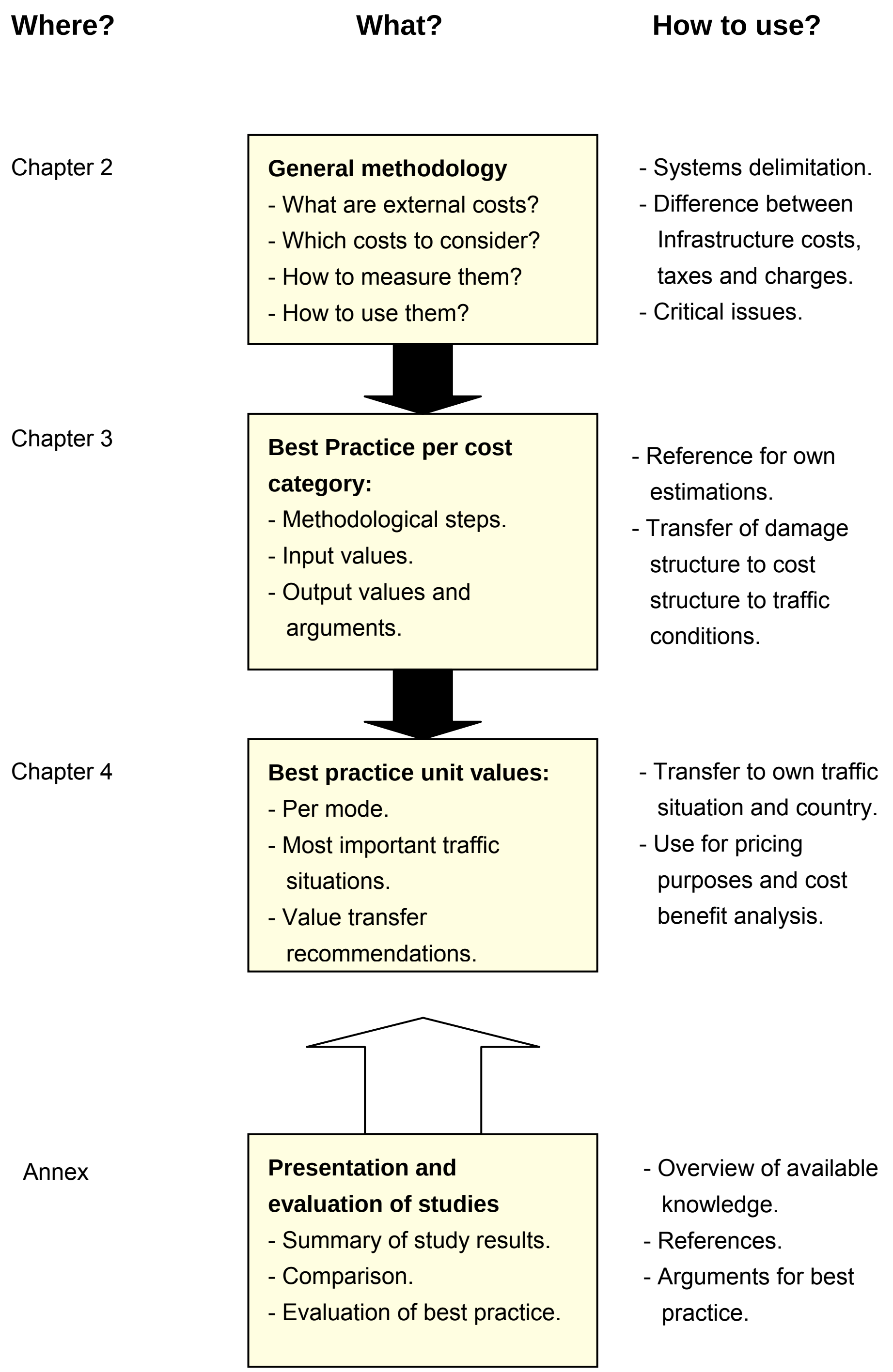
For retrieving cost estimates for specific countries and traffic situations, this handbook includes guidelines at three different levels: methodology, input values and output values. The accurateness of the values depend a lot on the level chosen:

2 The authors of this handbook would like to thank all reviewers for their useful comments and suggestions.

- First level: Most accurate is the use of the methodology proposed in order to produce own differentiated figures, based on own valuation input and own disaggregated data. Even more differentiated approaches than proposed (e.g. valid for specific countries and traffic situations) can be applied.
- Second level: If a transfer of existing values to specific areas and traffic situations will do, 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 proposed.

Figure 1 presents the structure and contents of the handbook.

Figure 1 Structure of the Handbook on external costs



The main text shows the most important methodologies and values which are based on the data collection and evaluation described more fully in the Annex Report. The Annex Report also contains a glossary and the list of references.

2 General methodology

2.1 Definition of external costs

External costs are costs to society and - without policy intervention - they are not taken into account by the transport users. Transport users are thus faced with incorrect incentives for transport supply and demand, leading to welfare losses.

In order to define external costs properly it is important to distinguish between
- Social costs reflecting all costs occurring due to the provision and the 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. Only parts of these costs are monetary relevant. Some parts (such as time losses, health damages, etc.) are social welfare losses.

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 have to consider as well the financing of Infrastructure extension. The distinction between short and long run marginal costs requires a clear statement on how to treat existing fixed and variable Infrastructure cost 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 marginal external costs of the use of Infrastructure (monetary relevant and other costs) as a basis for market based instruments to set transport prices right. Variable and fixed infrastructure costs and related charges are not addressed in this handbook.

2.2 The link between external cost information and pricing

2.2.1 Existing marginal external costs and optimal pricing

Economic theory suggests that optimal prices should reflect external costs in an optimal traffic situation. That means: The optimal price is where marginal external damage costs are equal to marginal avoidance costs. In practice the unit cost rates shown in this Handbook are a basis for optimal prices, but not the optimal prices themselves. By using the values recommended in this Handbook, the reaction of traffic demand has therefore to be considered. This is especially important for congestion costs, where optimal prices can be considerably lower than the actual congestion costs. The effect is shown in the respective section.

2.2.2 How to use the results? The link to internalisation strategies

We can distinguish the following possibilities to transfer the information of the Handbook into internalisation strategies:

- Input for differentiation of existing taxes and charges. For the use of the existing Eurovignette, the values presented in this Handbook can be used to differentiate existing taxes and charges. For example the differentiation of the existing network according to capacity or scarcity or the consideration of air pollution costs to differentiate road charges by type of EURO-class. It has to be considered however that changes of the traffic volume and fleet mix will influence the total revenue of such differentiations.
- Input for efficient Infrastructure pricing with taxes or charges: The unit costs presented can be translated to taxes or charges, e.g. to charges for the use of Infrastructure (such as road or track pricing; e.g. mark ups to the Eurovignette). This is especially true for accident and environmental costs. By doing this, one has to consider the claim of optimal pricing (anticipation of the traffic reaction).
  In addition the balance of Infrastructure costs and taxes and charges has to be taken into consideration: Applying the methodologies and figures for efficient charges, one has to make a link to the Infrastructure balance and to the existing financing schemes. The introduction of new charges covering external costs has to consider the existing tax structure.
- Input for the improvement of insurance systems in the transport sector: The internalisation of accident costs is not only related to Infrastructure pricing, but provides also inputs for an improvement of the insurance systems (e.g. differentiation of Bonus-Malus Systems).
- Input for climate change policy: the internalisation of climate change costs goes beyond optimal infrastructure pricing and other approaches are discussed at political level. The climate change costs shown can be used to design policy instruments (such as fuel taxation, emission trading systems) in the transport sector. However, it should be noted that these cost figures should be treated with some care, because of the high bandwidths in valuation of climate cost.
- Cost benefit analysis of Infrastructure projects or policy instruments: The unit costs presented in this Handbook can be used for cost benefit analysis of

infrastructure projects or regulatory measures, such as driving bans, speed limits, or emission or safety standards. In several cases regulations are very effective instruments to reduce externalities. The question remains if such strategies are efficient: Thus the figures provided can be used to compare the costs of such measures with the benefits of decreased social costs of transport. Doing so, it should be noted that this report focuses on *marginal* external cost.

2.3 Overview of state of the art

Several attempts have been made to estimate external costs in the transport sector. Most important are the results of several research projects, especially within the 4th, 5th, and 6th EU-framework programmes. We can distinguish different type of output.

As regards **pricing information** based on marginal costs (being most relevant for this Handbook), the most important work has been developed at EU-level. The CAPRI project (1999) and the High Level group on transport Infrastructure charging (1999a-c) have made recommendations for best practice approaches, within a dialogue between researchers and policy experts. These have been further developed and used within the two research projects UNITE (2003) and GRACE (2007), in order to provide cost figures for different modes, mainly based on representative case studies.

As regards **information for cost benefit analysis**, there are attempts at EU and at national level. HEATCO (2006) has made recommendations for unit cost figures for externalities which can be used for the evaluation of transport related projects at EU level. For air pollution, the figures are compatible with the approach developed for the CAFE CBA standards (CAFE, 2005a), with unit costs per country and per air pollutant, as a basis for Cost Benefit Analysis of air pollution related measures. At national level, the sources are heterogeneous. The most recent recommendations have been developed in Germany, with the Methodological Convention to estimate environmental costs (UBA, 2006).

As regards **total cost figures and transport accounts for different countries**, UNITE (2003) is the most important study at EU-level containing transport accounts and total external cost estimates for most Western European countries. The INFRAS/IWW study (2004a) commissioned by the railways is also presenting total and average cost figures per country. At the same time several national studies have estimated costs for different transport modes. Most advanced are the attempts carried out by UK, the Netherlands and Switzerland.

Considering all this work, it can be said, that scientists have done their job. Although the estimation of external costs have to consider several uncertainties, there is consensus at scientific level, that external costs of transport can be measured by best practice approaches and that general figures (within reliable bandwidths) are ready for policy use. This does however not mean that all cost categories are treated at the same level of accuracy, and all modes are covered equally. The transfer of available values into transport price levels for instance needs additional decisions made by policy makers. This refers to the value transfer, the level of differentiation and the general final aim and design of the internalisation measures.

2.4 Scope of external costs and level of externality

The following Table 1 provides an overview on the external costs treated 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.	Within non-scheduled transport (road), the external part is the difference between marginal cost and average cost based on a congestion cost function. Within scheduled transport (rail, air), the external part is the difference of the willingness to pay for scarce slots and the existing slot charge.
Accident costs	All direct and indirect costs of an accident (material costs, medical costs, production losses, suffer 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 cost of a self accident a matter of (proper) individual risk anticipation or a collective matter? Besides there are different levels of liability between private insurances (private road transport) and insurances 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 is differing between modes.

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 waiting and delay costs of the users, others, 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 are considered as external part, 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 itself 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). As discussed in chapter 2.1, the allocation of environmental charges in the transport sector may be arbitrary (e.g. climate change and fuel taxes). Therefore the Handbook focuses on gross environmental costs.

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 well-identifiable individuals (victims of an accident and their families), congestion costs are imposed to the collective of transport users caught in a traffic jam or having been crowded out. This holds 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 well-identifiable individuals may ask for recommending a more tailor-made (individual) approach of internalisation.

2.5 Best practice methodologies

2.5.1 Valuation approaches

Individual preferences are the most important indicator to value costs imposed on society (externalities). The first best solution is to estimate damage costs. For some externalities, like long term risks also *collective* preferences 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 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 is directly measuring 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.

In order to estimate the costs for a long term environmental problem (e.g. global warming), it is necessary to consider different risk scenarios: These contain direct and indirect costs to decrease and repair environmental damage and further costs of damages which cannot be repaired. A major recommended approach is the **impact pathway approach** (such as used by the ExternE model specifically developed for air pollution) which follows the dose-response function considering several impact patterns on human health and nature. The German methodological convention (UBA, 2006) for example is recommending seven steps to carry out such an approach. Sometimes the lack of certain information on 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 is summarising 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 for the estimation of the value of time (based on stated preference approaches). Alternatively: WTA. WTP for scarce slots (based on SP with real or artificial approaches). Alternatively: WTA.
Accident costs	Resource costs for health improvement. WTP for the estimation of 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) base. 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	WTP approach based on hedonic pricing (loss of rents – this reflects WTA) or SP for noise reduction. Impact pathway approach for human health using WTP for human life.
Climate change	Avoidance cost approach based on reduction scenarios of GHG-emissions; damage cost approach; shadow prices of an emission trading system.
Nature and Landscape	Compensation cost approach (based on virtual repair costs).

WTP = Willingness to pay. SP = Stated preference approach. WTA = willingness to accept.

2.5.2 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).

In order to get (national averages) of marginal cost, the estimation of average (or average variable costs) are based on top-down approaches using national data. Such approaches are more representative on a general level, allowing also a comparison between modes for example. 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 aggregated. Therefore the extraction of marginal cost is rather difficult.

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

The following table is showing 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: Difference is relevant to define external costs.	Estimation of marginal cost based on standardised curves for specific traffic clusters (urban-interurban, peak-off-peak). Top-down approaches are hardly 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).

Cost component	Difference between marginal and average costs	Practical implementation and proposed differentiation
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.

2.6 Commons and differences between modes of transport

As already mentioned, 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 specification of different costs according to 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 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.	No major issue.
Air pollution costs	Roads and living areas are close together.	The use of diesel and electricity should be distinguished.	Air pollutants in higher areas have to be considered.	Air pollutants in harbour areas are complicated to allocate.

Cost component	Road	Rail	Air	Water
Noise	Roads and living areas are close together.	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 GHG relevant.	All GHG relevant, considering use of diesel and electricity production.	All GHG relevant (Air pollutants in higher areas to be considered).	All GHG relevant.
Nature and landscape	Differentiation between historic network and motorways extension.	Differentiation between historic network and extension of high speed network.	No major issue.	New inland waterways channel relevant.

2.7 Summary and overview

We can summarize the most important recommendations as follows:

- Cost of scarce Infrastructure (congestion for road, scarcity for other modes), parts of accident costs, and environmental costs are treated as external costs of transport according to the welfare-theory approach.
- Infrastructure costs and related taxes and charges are treated separately and are not part of the Handbook. The level of existing taxation (mainly fuel taxation and vehicle taxation) has to be taken into consideration in order to define optimal charges levels and internalisation of external costs.
- The level of externality is different according to cost categories and 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 like the estimation of avoidance costs can be appropriate.
- The differences between transport modes are specifically relevant for congestion/scarcity costs and the consideration of the production of electricity of 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 is showing the main issues and cost drivers per cost component. The following chapter is presenting 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 Add. 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 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 Definition 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[4]
Noise costs	Rent losses Annoyance costs Health costs	Valuation of annoyances	Declining marginal cost curve in relation to traffic amount	Noise exposure data (persons)	Population and settlement density Day/Night Noise emissions level, depending on: – Type of Infrastructure – Type and condition of vehicle
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 cost 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
Up- and downstream processes	Costs of the whole energy cycle (environmental and risk effects of energy supply)	Valuation of long term energy risks, such as climate change and nuclear risk	Rather proportional correla-tion with traffic amount and (marginal cost close to average costs)	Data on energy processes and electricity mix	Level of indirect energy need Electricity mix (level of non renewables)

[4] Not all cost drivers will be applicable as a basis for incentives.

3 Best Practice per Cost Category

This chapter gives an overview of best practice approaches per cost category. The main results are presented, per cost category, being:
- Type of costs and main cost drivers.
- General approach and an overview of the steps for calculating external cost figures.
- Best available input values for such calculation (e.g. value of one life year lost).
- Estimated default unit values of external cost for different traffic situations (e.g. air pollution cost of a vehicle in Euro per kilometre).

This chapter has been based on the evaluation of available studies and data described more fully in the Annex Report.

3.1 Congestion and scarcity costs

3.1.1 Type of costs and main drivers

Congestion arises from the mutual disturbance of users competing for limited transport system capacity. Depending on the mode of transport, type of users, Infrastructure characteristics, local travel time and activity alternatives, excess demand can cause several effects:
- **Travel time increases** constitute the most important component of congestion. Applying standard valuations of travel time losses this category commonly accounts of 90% of economic congestion costs. The Value of Time (VOT) or Value of Travel Time Savings (VTTS) can be distinguished between trip purposes, modes and journey length in passenger travel and mode and commodity type in freight transport.
- **Vehicle provision and operating costs**, including depreciation, driving personnel and increased wear and tear under congested travel patterns are highly important for commercial transport. But there they are commonly included in the values attributed to travel time increases.
- **Disamenities in crowded systems** are relevant for passenger transport and appear on congested roads as well as in public transport systems. The Value of Travel Time under crowded conditions is thus increased by roughly 50% compared to normal travel conditions.
- **Additional fuel costs** arise from the fact that fuel consumption of vehicles under stop-and-go conditions and of planes in holding stacks are above fuel consumption in free flow traffic. Commonly this category consists of 10% of congestion costs.
- **Reliability**: The higher valuation of delay time compared to standard in vehicle time commonly relates to the unreliability of travel times caused by congestion. In particular in freight transport this is considered much more of a problem than the pure increase of average travel times. Specific indicators like the buffer time index (Schrank and Lomax, 2005) aim at describing the

recovery margins which travellers and shippers consider keeping their desired arrival time under various traffic conditions.

- **Scarcity of slots** is a particular phenomenon on access regulated Infrastructures, i.e. on railway networks, airspace and airports. Scarcity costs denote the opportunity costs to service providers for the non-availability of desired departure or arrival times. The value of scarcity effects strongly depends on market conditions and internal cost structures of the service provider. Auctioning processes or the application of operational models are thus commonly recommended to value them. Besides the costs of scarce slots, additional costs such as delay costs (due to unstable service conditions, in form of additional operating and time costs) can arise. The current debate is on whether both elements can be part of a capacity fee and how to deal with the different valuation of displaced services from both a social and an entrepreneurial perspective (Nash et al., 2006).
- Positive externalities of improved or additional services inflicted by new users but providing benefits to passengers or shippers already using the system are commonly entitled as **Mohring-effect**. These positive externalities may balance or even over-compensate for some congestion and scarcity costs (UNITE, 2002c).

Congestion costs consist of internal and external components. Internal or private congestion costs are those increasing time and operating costs experienced by an operator when approaching or exceeding system capacity. External congestion costs are those costs experienced by all other system users due to the entrance of this operator into the system. External congestion costs are commonly not taken into account by transport users and decrease social welfare. They are thus subject to corrective pricing measures.

On access-regulated Infrastructures, the presence of ‘big players’ can significantly decrease the share of congestion costs that are externals, because those costs imposed on other users of the same company are internal to this company. Congestion externalities are thus higher for small companies (Johnson and Savage, 2006). In the extreme case of only one operator, e. g. in the case of national railway carriers, external congestion costs might become zero (INFRAS/IWW, 2004). In this case only scarcity costs are present, expressing the insufficiency of Infrastructure capacity.

According to the type of Infrastructure facility, congestion effects can be separated into two types (AFFORD, 2000).

- **Bottleneck congestion** appears at road junctions, railway stations, ports and airports. Additional user costs are driven by the capacity and load-dependent processing time of the facility, including queuing effects. The kilometres travelled by vehicles are irrelevant for this type of congestion. In road transport, bottleneck effects are most relevant in urban networks. For a comparison to the network approach see De Palma and Lindsey, 2006.
- **Flow congestion** denotes the exceeding of carrying capacities of links. On the macroscopic level this type of congestion can easily be described by speed-flow diagrams, micro simulation models face the challenge of the

partial dependency of vehicle speeds on each other. In urban networks and in case of blocking access links on high order roads, real networks commonly face a mixture between bottleneck and flow congestion (Parry et al., 2007).

According to the type of Infrastructure facility congestion, different types of measures are necessary. The much higher importance of flow congestion on interurban roads calls for distance-dependent internalisation measures, while access charges may suite better in urban areas, ports or airports.

The internalisation of the external costs of congestion (e.g. by congestion charging) requires computing **marginal social costs** (MSC). They express the change in total external costs for all transport users when an additional user enters the system. They can be determined mathematically by deriving total user costs by the number of users or experimentally by field observations or macro simulation model applications. As levying the external costs to transport users will affect the level of demand and thus the level of congestion itself, price-relevant marginal social congestion costs are to be computed for the equilibrium of demand and supply (external congestion costs at the optimal traffic level).

For monitoring purposes of transport system quality, different **delay or excess cost indicators** are commonly used. Their concept is to compute the average user costs or travel times above a certain threshold level of the minimum acceptable quality standard. This concept requires less data than the MSC approach, but does not allow a distinction between private and external congestion costs. Delay based indicators can thus hardly be used as a substitute for marginal social congestion or scarcity costs.

Total congestion cost figures can be interesting for monitoring purposes. The total welfare loss due to not having external costs internalised is called deadweight loss. It computes by integrating the difference between social marginal congestion costs (private plus external) to users' willingness-to-pay from current to equilibrium demand. The internalisation of external costs prevents the occurrence of a deadweight loss and leads to a social efficiency gain. The social efficiency gain can also be displayed via calculating a congestion fee which establishes an equilibrium state or via calculating the total delay or access costs.
A comparison of these three values for European road transport is given in INFRAS/IWW, 2004.

Besides these quantitative concepts congestion can be expressed by qualitative measures, such as Level-of-Service indicators. Such information is, however, not helpful for price setting and will not be considered in detail in the subsequent presentation of results.

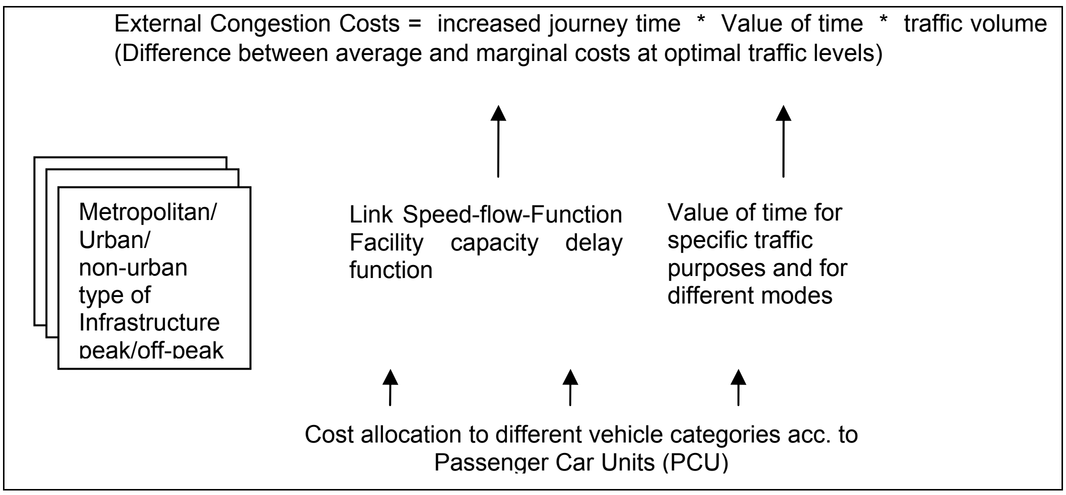
Out of the above concepts the elaborations will concentrate on marginal social congestion costs and on delay valuations.

3.1.2 General approach: Overview of steps

Among many other theoretical publications on modelling and estimating congestion (e. g. AFFORD, 2000 or De Palma et al., 2006 for introduction), the recent works carried out within UNITE, TRENEN-II-STRAN, MC-ICAM GRACE, INFRAS/IWW and COMPETE are considered most valuable for deriving values for practical applications. All these studies have provided methodologies and have quantified marginal external congestion costs for specific traffic situations, especially for road transport. For other modes more general studies on price regulation (e. g. Johnson and Savage, 2005) have been used where European congestion studies are not available.

Comparing the methodologies, there is consensus on the basic approach valuing the time losses based on speed-flow characteristics (interurban road transport), bottleneck and queuing functions (urban road and aviation) and on applying opportunity cost approaches for scarce tracks and slots (rail and aviation). The evidence for congestion costs on road networks is much more elaborated than for congestion and scarcity in scheduled transport, in particular for regulated rail networks. Nevertheless, the difference between the proposed values for road is quite significant, depending on the type of Infrastructure, the speed-flow characteristics and the input values such as the value of time. The level of detail that is required depends very much on the internalisation strategy to be applied (e.g. road or track pricing schemes). Very detailed values can be estimated by a bottom-up approach considering standardised capacity use at roads and rail tracks (flow congestion) or at junctions, ports, locks or airports (bottleneck approach).

For the measurement of unit congestion costs (marginal congestion costs for specific traffic situations), the following steps are proposed:



1 Classification of the traffic network: metropolitan/urban/interurban, single/multiple lanes. This depends very much on the specific network conditions.
2 Speed-flow curves for different traffic network segments or entire areas and/ or capacity functions of intersections. Speed-flow functions describe the development of average travel speeds on a network segment with the traffic volume. Most recent speed-flow functions for single links are provided for example by the German EWS manual (FGSV, 1997). In urban areas, capacity restraints are rather caused by bottlenecks at intersections. For reasons of simplicity area-wide speed-flow curves are proposed by Newbery and Santos, 2002 as a cost efficient alternative to sophisticated urban road network models (e. g. the SATURN model, UNITE, 2002c). These have to be estimated individually for the area considered. In rail and air transport operational settings call for individual model setups to capture the effect of additional traffic units throughout the networks. An overview of approaches and theoretical issues are given in AFFORD, 2000 and De Palma et al., 2006.
3 Valuation of travel time savings. The valuation of changes in speeds or travel times, amongst others, depends on the mode, the length and the purpose of a trip or shipment and on the prevailing traffic condition. For setting marginal social congestion charges, time values under congested conditions – which are usually 50% to 150% above the free flow time valuation – should be selected. Time values should further contain the direct valuation by the traveller/operator plus the anticipated preference of affected people or companies (secondary effects). Wherever available, differentiated local values should be used.
4 Computation of marginal external cost functions (mathematical step) based on the speed flow curves (steps 3) and local estimates of travel time (Step 4). The formulae are given at the next page.
5 Estimation of local elasticities of demand and traffic reaction patterns. These values are ideally used within or provided by sophisticated traffic models. They depend heavily on the user reactions in that specific situation, which depend for instance on density of the network, trip purposes (e.g. business, leisure), options for mode- and time-shift and transport alternatives. In case this is not possible, default cost elasticities of traffic demand (usual range: -0,25 to -0,35) may be applied, but local values are preferable. The elasticities refer to generalised user costs including charges, operating costs and perceived time costs.
6 Calculation of the optimal charge levels by iteratively modelling external congestion charges and adjusting demand until the equilibrium is obtained between the marginal congestion cost and the charge level.

In a formal way marginal external congestion costs at a given traffic volume Q compute as:

$$MEC_{Cong}(Q) = \frac{VOT \cdot Q}{v(Q)^2} \cdot \frac{\partial v(Q)}{\partial Q}$$

With: VOT: Value of Time (€ / veh.-hour)
Q: Current traffic level (veh./hour)
v(Q): Speed-flow function (km/hour)
MEC_{Cong}: Marginal external congestion costs

Depending on the price elasticity of demand and the slope of the speed-flow function v(Q) the resulting equilibrium congestion charges MEC_{Cong}(Q”) at the equilibrium traffic flow Q* will be 50% or less of MEC_{Cong}(Q). Q^* fulfils the condition that the Demand- or willingness-to-pay curve D(Q*) equals the average time costs (VOT / v(Q*) plus marginal external costs MEC_{Cong}(Q*).

For other modes than road transport, delay and scarcity costs are of major importance. An appropriate way to estimate scarcity costs is the willingness to pay for specific tracks, which has been used within the GRACE project. In practice however, scarcity costs are easier to apply by trial and error methods used for slot or track prices considering demand components within the pricing schemes often applied in European track charging systems. Thus it is much more difficult to estimate unit values for scheduled than for non-scheduled transport.

Critical aspects

All steps are depending strongly on the level of differentiation and the quality of data available, specifically the speed-flow relations (congestion data) and the value of time. The empirical basis for the value of time can be considered as sufficient, given the many national and international studies available. Methodological uncertainties are comparably low, as regards congestion costs for roads. Less evidence is available for scarcity costs. An additional issue is the treatment of congestion costs due to traffic accidents. It is useful to allocate these costs within the cost category traffic accidents since they are not caused due to Infrastructure scarcity, unless there is a link between the scarcity and the accident risks.

3.1.3 Input values

Estimating the economic costs of congestion and the opportunity costs of slot scarcity requires a number of parameters and assumptions as they can not be measured in physical terms. The most important ones are:

- The value of Travel Time (VOT) required for translating time losses and/or reduced reliability and comfort into monetary units.
- Speed-flow relationships describing the effect of an additional vehicle on the transport system and thus on the costs of other users and of society.
- Demand elasticities describing the likely reaction of users on the internalisation of external congestion costs.

There is a huge amount of **Value of Time** studies available. Although there are many national conventions of Value of Time (especially used for cost benefit analysis of Infrastructure projects), the European approaches are more in line with congestion measurement and better transferable from one country to another as they reflect willingness-to-pay values rather than unit costs derived form macro-economic indicators. The latter is the case for some national values.

UNITE has used a Value of Time for road transport of € 21 per person-hour (1998/business) and € 4 per person-hour (private and leisure). Other studies (such as INFRAS/IWW) have used higher values in order to consider as well possible indirect costs of congestion to affected employers, customers or others (especially for business and freight transport). These indirect costs are fully price-relevant as they constitute the transport-sector external component of congestion.

HEATCO, 2006a recommends similar time values based on vehicle instead of passenger hours. Differences occur in particular for commuting (8.48-10.89 €/vkm) and for private trips (7.11-9.13 €/vkm, compare Table 6) for delays due to congestion or late arrivals in public transport. It is recommended to value the time in congested situation in road transport 1.5 times higher than standards in-vehicle-time. For freight transport, the factor is 1.9. For public transport, it is recommended to value the delays 2.5 times higher than standard in-vehicle-time. These increased valuations mainly relate to the reduced reliability of average travel times under congested conditions.

Finally the values of travel time saving proposed by the HEATCO project by country, mode, travel purpose and trip length are recommended as default values as they include most recent evidence on willingness-to-pay surveys. However, if possible, local values should be used. The results for the EU-25 countries by mode and travel purpose are presented in Table 6. For retrieving values for specific countries or different years value, transfer should be carried out by GDP/capita with PPP adjustment and an elasticity of 1.0 (INFRAS/IWW 2004a; UNITE, 2001). Other studies use lower income elasticities, e. g. Wardman, 1998 finds a value of 0.7 for the UK.

$$VOT_{K,C} = VOT_{K,EU25}\left(\frac{GDP/capita_{K,i}\cdot PPP_i}{GDP/capita_{K,EU25}\cdot PPP_{EU25}}\right)^{1.0}$$

With VOT Value of Time.
k Transport mode and traffic condition.
i: Country.

Table 6 Recommended values of Time in passenger and freight transport (EU-25 average)

Sector/purpose	**Unit**	**Car/HGV**	**Rail**	**Bus/Coach**	**Air**
Passenger transport	€$_{2002}$/passenger, hour				
– Work (business)		23.82		19.11	32.80
– Commuting, short distance		8.48		6.10	*
– Commuting, long distance		10.89		7.83	16.25
– Other, short distance		7.11		5.11	*
– Other, long distance		9.13		6.56	13.62
Freight transport	€$_{2002}$/ton, hour	2.98	1.22	/	n. a.

* Values presented by HEATCO (70% of long distance values) have been removed, because short distance air transport (below 50 km) does not happen.

Source: HEATCO, Deliverable 5: Tables 0-6 to 0-8.

Remark: The VOT in commercial transport contains all components of a full cost calculation including vehicle provision, personnel, fuel and second-order effects on customers.

Speed-flow relationships depend on Infrastructure characteristics, topography, weather conditions, the network arrangement, available travel alternatives, regulations (speed control, ramp metering, etc.) and on driving habits. Thus, local evidence should be used if available. In absence of local information the speed-flow curves from the German 'Recommendations for the Economic Appraisal of Roads' EWS (FGSV, 1997) may be used as a starting point as the functions have been calibrated on a rich sample of speed and flow data. Figure 2 and Figure 3 present examples of the EWS functions for motorways with varying HGV shares and gradients. Their detailed formulation is presented in the annex to this report.

Figure 2 EWS speed-flow curves for passenger cars on a three lane motorway

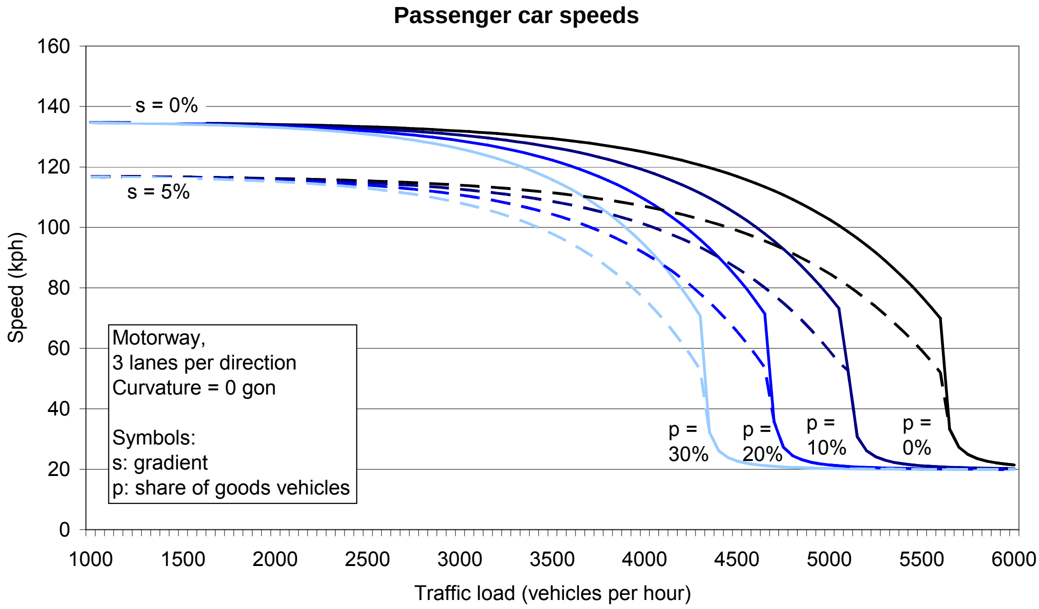
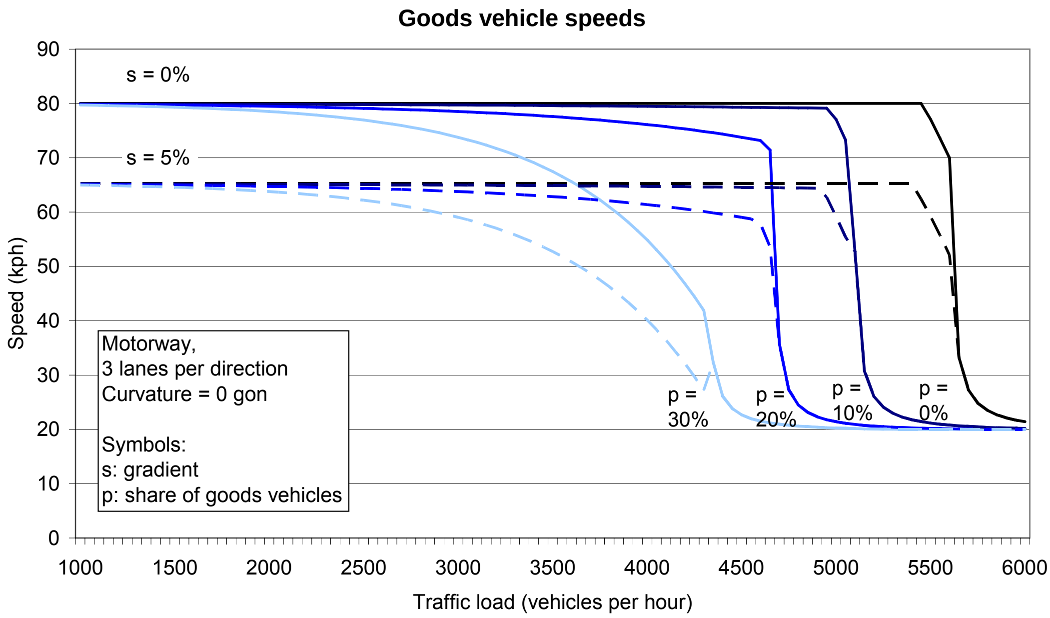


Figure 3 EWS speed-flow curves for goods vehicles on a three lane motorway



A difficulty of these and other speed-flow curves arises when traffic flow reaches road capacity limits. In this case the development of travel speeds gets unpredictable; a further increase of traffic density even causes a reduction of the actual flow served. It is therefore recommended to maintain the levels of marginal social cost prices of congestion beyond the capacity limit at the maximum level before this point.

Network wide speed-flow curves can be estimated by taking different observations on traffic levels and travel speeds across various times of day, days of the week, month or year (MC-ICAM, 2004; Proost and Van Dender, 1998). The charm of the simple application is contrasted by the limited ability of area speed-flow functions to predict user reactions on pricing and regulatory measures. These usually take place by deviations to different network levels and thus are better described by network models. The comparison of models in Figure 4 indicates that congestion costs derived by area speed-flow functions are in most instances clearly higher than network model results.

Price elasticities of demand are even more dependent on local conditions as they directly describe the alternatives of users, inducing the replacement of trips by other activities. In the absence of sophisticated multi-modal elastic demand transport models, values of -0.3 for interurban roads (according to UNITE) and between -0.5 and -0.7 for dense road networks are recommended. The latter recommendation emerges from the difference between single link and network estimates of marginal congestion costs by INFRAS/IWW (2004a) and UNITE. Eventually, the magnitude of price elasticities of demand depends on the capability of the traffic simulation model used. In case all possible user reaction patterns (route-, mode- and time shift, destination choice, trip replacement, etc.) are captured by the model, no external demand elasticity has to be considered.

3.1.4 Output values

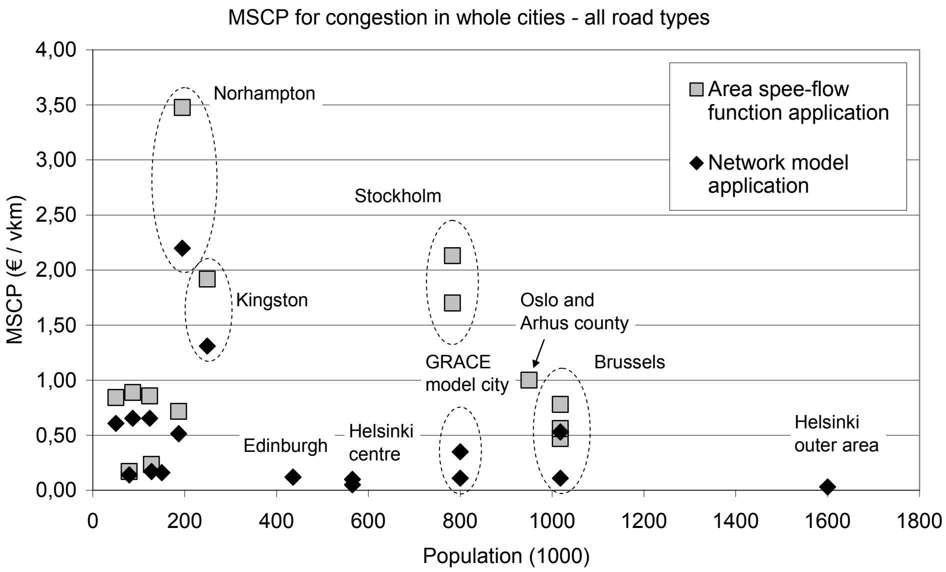
Road Transport

In the following we concentrate on existing estimates of marginal social congestion cost prices ($MSCP_{Cong}$). Marginal social external costs describe the effect which an additional user or vehicle imposes on all other users without taking them into account in his/her travel decision. When charging users for these external costs, traffic volume will react and congestion and the externality itself will decrease. The final prices $MSCP_{Cong}$ thus result from an equilibrium process between the marginal congestion cost and the demand function. In any case the price elasticity of demand plays a crucial role for the level of these equilibrium or 'optimal' congestion charges.

Several studies have estimated the $MSCP_{Cong}$ based on different models for urban areas and rural roads. Although the results vary significantly due to different model settings, aggregation levels, parameters, local characteristics and traffic conditions, they allow concluding on bandwidths of marginal social congestion cost prices in Europe across various methodologies and traffic situations.

Most of the available MSCP estimates for congestion costs stem from European or UK studies; continental studies are often restricted to reporting delays, speeds and total cost indicators. Figure 4 shows compiled estimates for entire urban areas, where it gets obvious that on this aggregation level and given the sample of small to medium sized towns, the size of the cities is not a significant driving factor for $MSCP_{Cong}$.

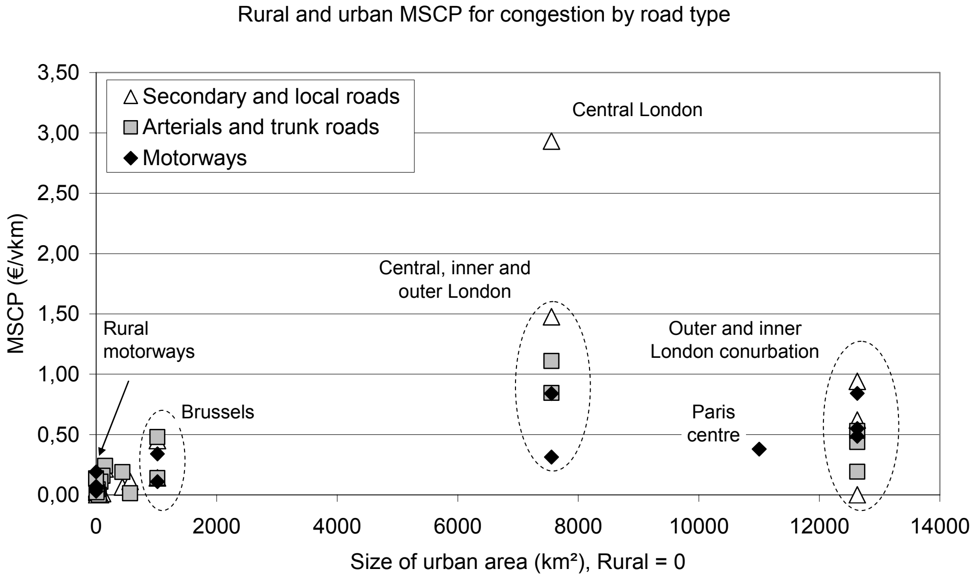
Figure 4 Marginal social congestion costs in urban areas according to different studies



Source: Compilation to €2,000/vkm using UNITE, 2002c; TRENEN-II-STRAN, 1999; GRACE, 2006a; Newbery and Santos, 2002; Prud'home and Kopp, 2006. MC-ICAM, 2004.

Figure 5 differentiates available results by road type and city size and for some interurban corridors. Here it gets obvious that in particular for local streets the city size matters.

Figure 5 Marginal social congestion costs by road and area according to different studies



Source: Compilation to €2,000/vkm using UNITE, 2002c; ITS, 2001; Newbery and Santos, 2002., MC-ICAM, 2004.

The results of the most important studies are shown in Annex B. In order to develop a baseline of external congestion costs, we concentrate on the main cost drivers and the recommended input values. Out of the analysis above ranges of marginal social cost estimates by road class and size of area are derived.

The values consider the following structure and sources:

- The values based on different modelling approaches in various studies are considered being robust against varying parameters and assumptions. However, a better geographical coverage of European areas would be desirable.
- The distinction between ‘large’ and ‘small and medium sized’ urban areas (2 million inhabitants) is rather arbitrary and might be handled flexible.
- The costs are presented in Euro (2005) per vehicle kilometre in morning peak traffic. Afternoon peak and off-peak values are respectively lower; Sansom et al. (ITS, 2001) suggests off-peak $MSCP_{Cong}$ figures being about half of peak values for major urban roads. This, however, depends on the city’s demand characteristic. Rural off-peak values are reported being close to zero.
- The costs of freight vehicles are calculated relative to those of passenger cars in proportion to their passenger car unit (PCU) value (see technical glossary). Due to speed limits and the freedom to overtake, these PCUs vary by road class between 2 and 3.5 for heavy trucks. Light lorries have respectively lower PCUs, for motorcycles a value of 0.5 is commonly applied.

This approach reflects the responsibility for congestion in proportion to the road space consumed.

These broad assumptions lead to ranges of benchmark values for morning peak road traffic in different areas and road types for cars and heavy goods vehicles (HGVs) in Table 7. In this table the column 'centr.' denotes the central estimate recommended for application in case local estimates are not available. It has to be emphasised that these values can not replace local estimates, in particular because of differing local price elasticities of demand. Values for scheduled transport are not given as they are even more depending on local and managerial conditions.

Table 7 Proposed ranges of marginal social cost prices (optimal external costs) of congestion by road class and type of area (€/vkm 2000)

Area and road type	Passenger cars			Goods vehicles			HGV
	Min.	Centr.	Max	Min.	Centr.	Max.	PCU
Large urban areas (> 2,000,000)							
Urban motorways	0.30	0.50	0.90	1.05	1.75	3.15	3.5
Urban collectors	0.20	0.50	1.20	0.50	1.25	3.00	2.5
Local streets centre	1.50	2.00	3.00	3.00	4.00	6.00	2
Local streets cordon	0.50	0.75	1.00	1.00	1.50	2.00	2
Small and medium urban areas (< 2,000,000)							
Urban motorways	0.10	0.25	0.40	0.35	0.88	1.40	3.5
Urban collectors	0.05	0.30	0.50	0.13	0.75	1.25	2.5
Local streets cordon	0.10	0.30	0.50	0.20	0.60	1.00	2
Rural areas							
Motorways*	0.00	0.10	0.20	0.00	0.35	0.70	3.5
Trunk roads*	0.00	0.05	0.15	0.00	0.13	0.23	2.5

vkm = vehicle-kilometre, HGV = Heavy Goods Vehicle, PCU = Passenger Car Unit.
* Calculated with a price elasticity of demand of -0.3.

Several options exist to transfer the presented congestion costs per vehicle kilometre into practical internalisation schemes under different traffic conditions:

- Cordon pricing: In this case trips or entire daily travel activities are to be priced. For transforming km-charges into cordon tolls, literature suggests assuming trip lengths around 5 km in smaller towns and above 10 km in big agglomerations. But as user reaction patterns differ from town to town and agglomeration to agglomeration, a separate assessment of appropriate toll levels and structures appears necessary. In case prices should not vary by time of day charges computed for peak hours need to be reduced somewhat to reflect a certain share of off-peak driving.
- Link-based and time variant tolls: Marginal social cost prices directly derived from speed-flow curves usually show a very sharp rise when demand approaches road capacity. This might be technically difficult to implement and makes trip costs unpredictable for the users. A stepwise definition of the congestion toll appears to be more user-friendly. Example:
  - Zero toll until demand equals 50% to 60% of capacity (Schade et al. 2006).
  - Between 50% - 60% and 100% of capacity: either gradually increase toll up to e. g. the maximum MSCP levels recommended in Table 7. or

- Introduce a flat rate e. g. equal to the mean value out of the ranges proposed above.
- According to the recommendations in the HEATCO project a 50% cost increase is to be considered in case of over-use of road capacity.

Other transport modes
There are no best practice figures ready for other modes e.g. for scheduled traffic especially for rail and air transport. The existing evidence shows that scarcity is indirectly included in some existing pricing schemes by considering demand or quality level of tracks or slots.

Rail: UNITE D7 suggests marginal external congestion figures in rail transport around 0.20 €/train-km in morning peak based on UK and Swiss evidence. The positive externality of additional demand (Mohring effect) based on Swedish data is round to be 5 to 10 times higher amounting roughly to one Euro per train-km. The Mohring effect excludes the positive effect of additional rail passengers or rail shipments relieving congested roads. The very low level of external rail congestion costs are in line with the findings of the COMPETE country results, stating that congestion in rail transport is often eliminated by respective adoptions of time tables. For this reason the High Level Group, 1999; Nash et al., 2006 and others suggest to better use the value which train operators put on the scarcity of tracks as a measure of Infrastructure capacity utilisation. The GRACE case studies show that scarce tracks in peak hours might be around 10 times more expensive than tracks in off-peak (GRACE, 2006a). But the total level of scarcity values is treated as confidential information and is not provided by the study. A comprehensive overview of current access charge systems is provided by ECMT (2005).

Aviation: From the UNITE case studies (UNITE, 2002c) marginal external congestion costs around € 10/plane-km for an average flight operated at Madrid airport can be estimated. This includes airport as well as airspace congestion. Johnson and Savage, 2006 estimate congestion costs up to 17,000 US$ per departure in the afternoon peak at Chicago O'Hare airport. According to the AEA punctuality report 2005 (AEA, 2006) Madrid has held rank no. 23 in the punctuality comparison of the 27 major European airports with a share of 25.9% delayed flights (rank 1: Düsseldorf: 13.8%). This implies that marginal congestion costs in average are somewhat lower than the UNITE figures. These marginal external congestion costs can be compared with Mohring benefits of additional traffic between € 2 and € 16/flight-km throughout the EU.

Maritime shipping: By considering cargo handling and port logistics (stevedoring) costs and wait time records at several international ports of the 1970s UNITE, 2002c concludes that there are no external congestion costs in seaport operations. The analysis of EU and US ports in the COMPETE project, 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. GRACE D4 (GRACE, 2006d) estimates the additional (marginal) crew costs of a vessel having to wait to call at a port of € 185 per hour.

But as ports usually do not keep records of vessel waiting times the computation of price relevant marginal external congestion costs in maritime transport is hardly possible.

Inland navigation: COMPETE results suggest that European countries do not face any capacity problems in their inland waterway networks. However, the GRACE case studies find a number of local bottlenecks at locks, although they are much depending on local conditions. Delay times range between zero and 160 minutes, in the latter case passage costs per ship are found to increase € 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,cm at Kaub and € 0.65 to € 1.25/TEU,cm at Duisburg.

3.2 Accident costs

3.2.1 Type of costs and main costs drivers

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.

The most important accident cost categories are material damages, administrative costs, medical costs, production losses 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.

The most important cost drivers in **road transport** are, besides vehicle kilometres, vehicle speed[5], type of road, drivers' characteristics (such as driving behaviour, experience, speeding), traffic speed and volume, time of day (day/night) and interaction with weather conditions. The maintenance level of Infrastructure, the degree of Infrastructure capacity use and the level of segregation between road lanes play also an important rule together with technological developments in vehicles (active and passive security measures) as well as in Infrastructure (e.g. traffic management).

Main cost drivers in **rail transport** are traffic volumes, weather conditions, level of maintenance and level of segregation between systems, especially between road and rail and between different type of trains. Hereby the type of level

5 Traffic speed correlates especially with the severity of injuries as well as with the probability of fatal accidents. Recent studies conducted in Australia and Great Britain find higher accident risks for faster drivers however no evidence was found yet for higher accident risks for slower drivers (see ERSO, 2006 for details).

crossing with road Infrastructure is an important cost driver (the less protected the higher the risk of accidents (see UNITE D9)).

For **aviation** the level of maintenance of aircraft and guiding systems, weather conditions and the education and training level of the pilots are the key cost drivers.

For **inland waterways** and **maritime transport** information on accident costs is almost entirely lacking.

3.2.2 General approach: Overview of steps

Reviewing the literature on accident costs, there are many studies and conventions available on total (social) accident costs, as information for the assessment of optimal safety measures in the transport sector. Not many studies so far have however focussed on (marginal) external accident costs.
There are two main issues to consider:

- Bottom-up or top-down: The bottom-up approach (used in UNITE and GRACE) aims at estimating marginal accident costs depending on traffic volumes. The magnitude of the costs depends on the risk elasticity (correlation between traffic levels and accidents) and on the assumption of risk values. This approach is in line with the social marginal cost approach and efficient pricing. Considering the fact however, that traffic volumes and type of Infrastructure are only two cost drivers amongst many others, not all aspects of the externality are covered.
  The top-down approach (UNITE, IWW/INFRAS, OSD) estimates total and average accident costs considering national accident statistics and insurance systems. It focuses on material damages and administrative costs (usually covered by the insurance premiums), medical costs (including other insurance systems), production losses and societal valuation of risks (usually external). This approach compares the total social costs with covered and uncovered parts by risk insurance. It considers mainly the production losses and the value of human life as external.
  Since only parts of total accident costs are considered, the bottom-up approach leads to lower values than the top-down approach.
- Risk anticipation and level of externality: Which part of accident costs is external? This crucial question depends on two assumptions. Firstly the difference between individual and collective risk behaviour, secondly the allocation of insurance premiums.
  For both assumptions different views are possible. Rational behaviour suggests that individuals should be able to anticipate their own risk. However it is questionable if there is a difference between a willingness to pay to reduce the own risk or the risk for others (such as relatives and friends). If there is a significant difference, self accidents with fatalities would have rather low external costs, since ‘only’ the costs for relatives and friends are relevant. If there is no difference, the willingness to pay is collective and there is no difference in external costs levels between self accidents and accidents with other actors involved, or in other words: The willingness to pay for the own

risk is similar than the willingness to pay of relatives and friends.

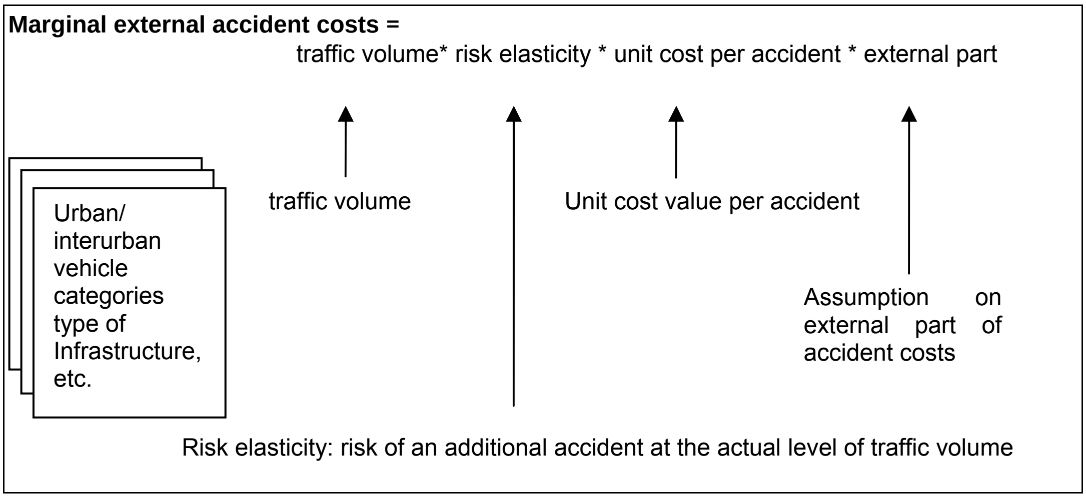
As regards the allocation of risk insurance premiums, two views are to consider. The first view focuses on transport individuals and does only consider risk dependent premiums, such as bonus-malus-systems, etc. The other view focuses on the total transport systems considering the total cost recovery. Within this approach, all insurance premiums (as well not transport related ones, such as health care insurances) are considered to cover accidents costs. Thus the values of the second approach are considerably lower.

The bottom-up approach combined with the assumption of full risk anticipation leads to the lowest values, whereas the top-down approach with a risk oriented allocation of individual insurance premiums leads to rather high values. There is no scientific consensus on a best practice approach. The following questions are issues for discussion:

- Is there a difference between individual and collective risk behaviour?
- Do they regard insurance costs as fixed or do insurance costs influence behaviour?
- What part of costs is neither their own risk nor covered by insurance?
- How far does extra traffic increase or reduce risks for other transport users?

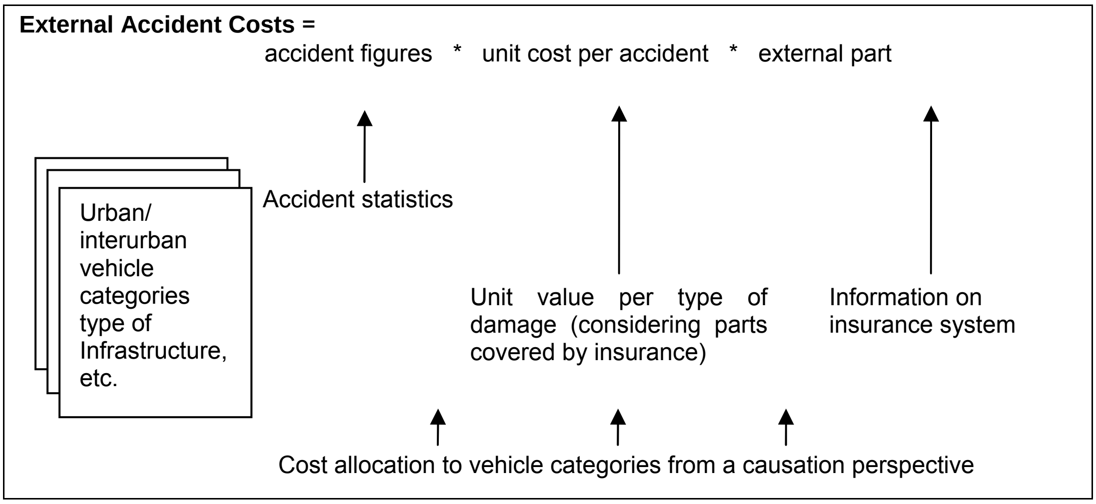
Moreover it has to be considered that the choice of approaches is very sensitive in regard to values and type of internalisation. Therefore both approaches can be recommended.

If the focus is on Infrastructure pricing, the marginal cost approach based on a bottom-up procedure is in the foreground. This **bottom-up approach** consists of the following steps (acc. to UNITE, 2000d; GRACE, 2006a).



1 Apply a *risk elasticity approach* (calculation of additional accidents per vkm diff. by vehicle- and road category). The information on risk elasticity can be taken from case study estimates, literature review or planning models.
2 Apply *cost estimates*. If available, cost estimates for each Member State should be used. When necessary a benefit transfer function can be applied to transfer values to areas were values are missing.
3 Estimation of *external* marginal cost based on the best estimates (assumptions regarding the risk perception of individual transport users and information of transfer payments of insurance or due to legal action) and to apply a sensitivity test.

If the focus is on all types of accident externalities (not just Infrastructure pricing related), the **top-down approach** can be applied, generally resulting in *average* accident cost figures. It consists of the following steps.



1 *Accident statistics*: collection of statistical data, correction for underreporting in road accident statistics.
2 *Valuation*: valuation of accident casualties and material damages, considering transfer payments form insurances and due to legal court action.
3 *Total cost calculation*: calculation of total accident costs per mode and allocation of total costs to different vehicle categories. We recommend cost allocation based on responsibility for an accident (polluter pays principle). If this data is not available for a specific country, data of comparable countries should be used.
4 *Average cost calculation*: average cost calculation based on total cost per mode and vehicle country and vehicle mileage. If disaggregated data is available, average cost for different Infrastructure types could be estimated.

3.2.3 Input values

Underreporting

The number of fatalities and injuries in official statistics and databases does not reflect the total number of accidents, fatalities and injuries. For some countries, figures are available, however sometimes based on rather outdated estimation approaches.

In HEATCO European average correction factors are presented (HEATCO, 2005):

Table 8 Recommendation for European average correction factors for unreported accidents

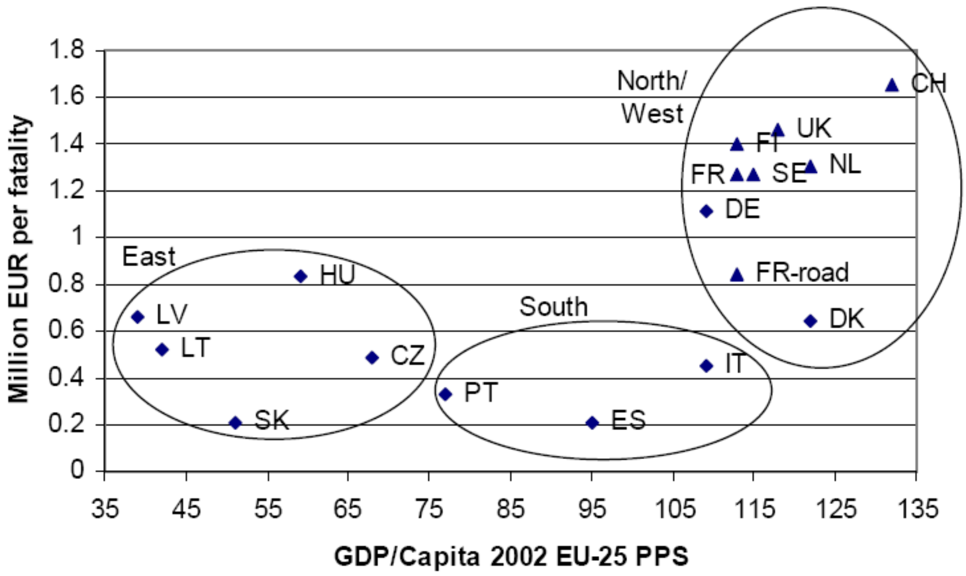
	Fatality	Serious injury	Slight injury	Average injury	Damage only
Average	1.02	1.50	3.00	2.25	6.00
Car	1.02	1.25	2.00	1.63	3.50
Motorbike/ moped	1.02	1.55	3.20	2.38	6.50
Bicycle	1.02	2.75	8.00	5.38	18.50
Pedestrian	1.02	1.35	2.40	1.88	4.50

Source: HEATCO (2005).

Risk value (Value of statistical life VSL)

In the GRACE project (GRACE, 2006b) the biases of different methodologies to estimate the risk value/VSL are discussed. Throughout the world empirical estimates of VSL diametrically differ between different studies, ranging from a value of less than 200 000 to 30 million US dollars (De Blaeij, 2003). HEATCO made a survey of the current European practice; the result is shown in Figure 6.

Figure 6 Values of accident fatalities by GDP/capita (EUR 2002 factor prices, PPS = purchasing power standard)



Source: HEATCO (2005).

In order to overcome the huge differences between countries, a uniform approach has been elaborated in EU wide research studies. Looking at the practice in different external cost estimates (UNITE, INFRAS/IWW), an average value of € 1.5 million (bandwidth between 1 and 3 million, based on different valuation methods and uncertainty ranges) has been used. This average value is more state of the art than the partially old figures used in several countries. Therefore it is recommended to use an average value per fatality of € 1.5 million which is adjusted according to GDP/capita PPP to different countries.

The basis for the valuation of the road accident risk is the value of statistical life of € 1.5 million as defined for all UNITE studies in UNITE (2000a). Risk values for severe injuries (13% of VSL) and slight injuries (1% of VSL) were derived from VSL.

In addition to the risk value, further direct and indirect economic costs (medical cost, net production losses, administrative costs, etc.) have to be considered. HEATCO (HEATCO, 2006a) presents a table with the risk value as well as direct and indirect economic costs for 27 countries.

Table 9 Estimated values for casualties avoided (€2002, factor price)

	Value of safety per se			Direct and indirect economic costs			Total		
Country	Fatality*	Severe injury	Slight injury	Fatality	Severe injury	Slight injury	Fatality	Severe injury	Slight injury
Austria	1,600,000	208,000	16,000	160,000	32,300	3,000	1,760,000	240,300	19,000
Belgium	1,490,000	194,000	14,900	149,000	55,000	1,100	1,639,000	249,000	16,000
Cyprus	640,000	83,000	6,400	64,000	9,900	400	704,000	92,900	6,800
Czech Republic	450,000	59,000	4,500	45,000	8,100	300	495,000	67,100	4,800
Denmark	2,000,000	260,000	20,000	200,000	12,300	1,300	2,200,000	272,300	21,300
Estonia	320,000	41,000	3,200	32,000	5,500	200	352,000	46,500	3,400
Finland	1,580,000	205,000	15,800	158,000	25,600	1,500	1,738,000	230,600	17,300
France	1,470,000	191,000	14,700	147,000	34,800	2,300	1,617,000	225,800	17,000
Germany	1,510,000	196,000	15,100	151,000	33,400	3,500	1,661,000	229,400	18,600
Greece	760,000	99,000	7,600	76,000	10,500	800	836,000	109,500	8,400
Hungary	400,000	52,000	4,000	40,000	7,000	300	440,000	59,000	4,300
Ireland	1,940,000	252,000	19,400	194,000	18,100	1,300	2,134,000	270,100	20,700
Italy	1,300,000	169,000	13,000	130,000	14,700	1,100	1,430,000	183,700	14,100
Latvia	250,000	32,000	2,500	25,000	4,700	200	275,000	36,700	2,700
Lithuania	250,000	33,000	2,500	25,000	5,000	200	275,000	38,000	2,700
Luxembourg	2,120,000	276,000	21,200	212,000	87,700	700	2,332,000	363,700	21,900
Malta	910,000	119,000	9,100	91,000	8,800	400	1,001,000	127,800	9,500
Netherlands	1,620,000	211,000	16,200	162,000	25,600	2,800	1,782,000	236,600	19,000
Norway	2,630,000	342,000	26,300	263,000	64,000	2,800	2,893,000	406,000	29,100
Poland	310,000	41,000	3,100	31,000	5,500	200	341,000	46,500	3,300
Portugal	730,000	95,000	7,300	73,000	12,400	100	803,000	107,400	7,400
Slovakia	280,000	36,000	2,800	28,000	6,100	200	308,000	42,100	3,000
Slovenia	690,000	90,000	6,900	69,000	9,000	400	759,000	99,000	7,300
Spain	1,020,000	132,000	10,200	102,000	6,900	300	1,122,000	138,900	10,500
Sweden	1,700,000	220,000	17,000	170,000	53,300	2,700	1,870,000	273,300	19,700
Switzerland	2,340,000	305,000	23,400	234,000	48,800	3,700	2,574,000	353,800	27,100
United Kingdom	1,650,000	215,000	16,500	165,000	20,100	2,100	1,815,000	235,100	18,600

Notes: Value of safety per se based on UNITE (see Nellthorp et al., 2001): fatality € 1,50 million (market price 1998 - € 1,25 million factor costs 2002); severe/slight injury 0.13/0.01 of fatatlity; direct and indirect economic costs; fatality 0.10 of value of safety per se; severe and slight injury based on European Commission (1994).
* Benefit transfer for EU value of € 1,25 million based on GDP per capita ratios (income elasticity of 1.0).
Source: HEATCO, 2006a.

Other important input assumptions

- The assumption on internal and external parts of the risk value (linked to the two methodological approaches shown in section 3.2.2) is very sensitive. Within the UNITE case studies, the range of the internal part varies between 59 and 76% for road transport. For detailed analysis, it is necessary to consider the national insurance systems.
- Inclusion of risk values for relatives and friends: in most studies (UNITE, INFRAS/IWW, GRACE) a risk value for relatives and friends is not accounted due to methodological reasons. Different early studies assume the WTP and

thus the risk value of relatives and friends as a share of one's own risk value (between 10 - 50%).

- Accident risks (different results in different case studies), relevant for the estimation of marginal costs. The values of studies (e.g. compiled in UNITE) differ widely. A range between 1.3 up to 38 accidents per million vkm can be observed.
- Risk elasticity: as the number of vehicles increases, the number of possible interactions increases with the square. This suggests that accident risk should increase with traffic volumes. However, different case studies conducted e.g. in the UNITE project suggested that risk decreases with traffic volume.
- Accidents and congestion: There is evidence that there is a link between accidents and congestion shown in the UNITE case studies. A generalisation however is difficult.
- Cost allocation to different vehicle categories: Linked to the top-down approach, there are several possibilities, like allocation based on involvement in accidents, the causer of accidents, the number of victims or more simplified approaches like allocation based on vehicle kilometres[6]. An allocation approach that takes into account the responsibility is to be preferred from a methodological point of view. However, allocation based on number of victims or vehicle kilometres is easier to apply, whereas the causer perspective must be based on detailed analysis of police reports and even allocation based on involvement requires data which is usually not available.

3.2.4 Output values

Road Transport

Due to the different evidence and specifications (network, mode, insurance system, and methodological approaches), a generalisation and transfer of external accident costs is difficult. We base our recommendations on the case studies carried out in UNITE (UNITE, 2002d), due to the following reasons:

- UNITE and GRACE are the most important studies carried out at European level.
- The studies are based on a differentiated bottom-up approach using the recommended input values.
- The comparison of different studies shows that the UNITE case study applied for roads in Switzerland is most representative and most differentiated. Further on it fits into the range of study results of different bottom-up and top-down approaches.

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6 In countries as Germany and the Netherlands the share of accidents with HGV involvement is considerably higher than the vehicle mileages share of HGV (CE Delft, 2004a).

Average(d) representative values for road transport can be taken from the UNITE Case Study 8a Marginal External Accident Costs in Switzerland (UNITE, 2002d)[7]. This case study provides values for Switzerland 1998 with a high differentiation with respect to network type (motorways, inside settlement areas, outside settlement areas) and vehicle types. For the central estimate the assumption was made that the risk value of a non-responsible victim is considered to be external. Although the traffic relation might be different, the figures are transferable to other countries by considering the specific differentiation of input values. In addition two sensitivity scenarios are calculated within the case study. For the lower margin the assumption was made that the average accident risk is internalised by the transport users. Based on this assumption and due to the under proportional increase in the number of accidents with increasing traffic volumes and the fact that payments of insurances and social security to traffic accident victims are considered, the results are negative marginal costs. The upper margin is calculated following the assumption that the average accident risk is **not** internalised.
Table 10 gives an exemplary overview on marginal accident costs for passenger cars, motor cycles and HGV for different countries differentiated by network type.

Table 10 Unit values for accidents for different network types in (€ct/vkm) for passenger cars, motor cycles and heavy duty vehicles (€2000)

	Passenger cars			Motor cycles			HDV		
	Urban roads	Motorways	Other roads	Urban roads	Motorways	Other roads	Urban roads	Motorways	Other roads
	€ct/vkm	*€ct/vkm*	*€ct/vkm*	*€ct/vkm*	*€ct/vkm*	*€ct/vkm*	*€ct/vkm*	*€ct/vkm*	*€ct/vkm*
Austria	5.7 (-0.41-8.95)	0.41 (-0.68-0.68)	2.17 (-2.58-3.53)	41.92 (-2.58-119.64)	0.27 (-0.81-0.81)	7.46 (-15.06-21.16)	14.51 (-0.54-19.26)	0.41 (-0.41-0.41)	3.66 (-3.53-4.88)
Belgium	6.58 (-0.47-10.35)	0.47 (-0.78-0.78)	2.51 (-2.98-4.08)	48.43 (-2.98-138.25)	0.31 (-0.94-0.94)	8.62 (-17.4-24.45)	16.77 (-0.63-22.26)	0.47 (-0.47-0.47)	4.23 (-4.08-5.64)
Bulgary	1.24 (-0.09-1.95)	0.09 (-0.15-0.15)	0.47 (-0.56-0.77)	9.11 (-0.56-26.01)	0.06 (-0.18-0.18)	1.62 (-3.27-4.6)	3.16 (-0.12-4.19)	0.09 (-0.09-0.09)	0.8 (-0.77-1.06)
Switzer-land	4.36 (-0.31-6.85)	0.31 (-0.52-0.52)	1.66 (-1.97-2.7)	32.05 (-1.97-91.48)	0.21 (-0.62-0.62)	5.7 (-11.51-16.18)	11.1 (-0.41-14.73)	0.31 (-0.31-0.31)	2.8 (-2.7-3.73)
Cyprus	5.08 (-0.36-7.98)	0.36 (-0.6-0.6)	1.93 (-2.3-3.14)	37.35 (-2.3-106.62)	0.24 (-0.73-0.73)	6.65 (-13.42-18.86)	12.93 (-0.48-17.17)	0.36 (-0.36-0.36)	3.26 (-3.14-4.35)
Czech Republic	3.33 (-0.24-5.23)	0.24 (-0.4-0.4)	1.27 (-1.51-2.06)	24.5 (-1.51-69.94)	0.16 (-0.48-0.48)	4.36 (-8.8-12.37)	8.48 (-0.32-11.26)	0.24 (-0.24-0.24)	2.14 (-2.06-2.85)
Germany	4.12 (-0.29-6.47)	0.29 (-0.49-0.49)	1.57 (-1.86-2.55)	30.29 (-1.86-86.45)	0.2 (-0.59-0.59)	5.39 (-10.88-15.29)	10.49 (-0.39-13.92)	0.29 (-0.29-0.29)	2.65 (-2.55-3.53)
Denmark	4.44 (-0.32-6.97)	0.32 (-0.53-0.53)	1.69 (-2.01-2.75)	32.65 (-2.01-93.21)	0.21 (-0.63-0.63)	5.81 (-11.73-16.49)	11.31 (-0.42-15.01)	0.32 (-0.32-0.32)	2.85 (-2.75-3.8)
Estonia	3.24 (-0.23-5.09)	0.23 (-0.39-0.39)	1.23 (-1.47-2.01)	23.84 (-1.47-68.05)	0.15 (-0.46-0.46)	4.24 (-8.56-12.04)	8.26 (-0.31-10.96)	0.23 (-0.23-0.23)	2.08 (-2.01-2.78)
Spain	5.24 (-0.37-8.24)	0.37 (-0.62-0.62)	2 (-2.37-3.25)	38.57 (-2.37-110.08)	0.25 (-0.75-0.75)	6.86 (-13.85-19.47)	13.35 (-0.5-17.72)	0.37 (-0.37-0.37)	3.37 (-3.25-4.49)
Finland	3.43 (-0.25-5.4)	0.25 (-0.41-0.41)	1.31 (-1.55-2.13)	25.27 (-1.55-72.12)	0.16 (-0.49-0.49)	4.5 (-9.08-12.76)	8.75 (-0.33-11.61)	0.25 (-0.25-0.25)	2.21 (-2.13-2.94)
France	6.69 (-0.48-10.52)	0.48 (-0.8-0.8)	2.55 (-3.03-4.14)	49.25 (-3.03-140.56)	0.32 (-0.96-0.96)	8.77 (-17.69-24.86)	17.05 (-0.64-22.63)	0.48 (-0.48-0.48)	4.3 (-4.14-5.74)
Greece	5.29 (-0.38-8.32)	0.38 (-0.63-0.63)	2.02 (-2.39-3.28)	38.94 (-2.39-111.14)	0.25 (-0.76-0.76)	6.93 (-13.99-19.66)	13.48 (-0.5-17.89)	0.38 (-0.38-0.38)	3.4 (-3.28-4.54)
Hungary	2.78 (-0.2-4.37)	0.2 (-0.33-0.33)	1.06 (-1.26-1.72)	20.44 (-1.26-58.36)	0.13 (-0.4-0.4)	3.64 (-7.34-10.32)	7.08 (-0.26-9.4)	0.2 (-0.2-0.2)	1.79 (-1.72-2.38)

7 Sommer, H., Marti, M. and Suter, S. (Ecoplan), Deliverable 9: Accident Cost Case Studies, Case Study 8a: Marginal external accident costs in Switzerland (UNIfication of accounts and marginal costs for Transport Efficiency) Deliverable 9. Funded by 5th Framework RTD Programme. ITS, University of Leeds, Leeds, 2002.

	Passenger cars			Motor cycles			HDV		
	Urban roads	Motorways	Other roads	Urban roads	Motorways	Other roads	Urban roads	Motorways	Other roads
	€ct/vkm	*€ct/vkm*	*€ct/vkm*	*€ct/vkm*	*€ct/vkm*	*€ct/vkm*	*€ct/vkm*	*€ct/vkm*	*€ct/vkm*
Ireland	6.2 (-0.44-9.74)	0.44 (-0.74-0.74)	2.36 (-2.8-3.84)	45.59 (-2.8-130.12)	0.3 (-0.89-0.89)	8.11 (-16.38-23.01)	15.79 (-0.59-20.95)	0.44 (-0.44-0.44)	3.98 (-3.84-5.31)
Italy	4.78 (-0.34-7.51)	0.34 (-0.57-0.57)	1.82 (-2.16-2.96)	35.17 (-2.16-100.39)	0.23 (-0.68-0.68)	6.26 (-12.63-17.76)	12.18 (-0.46-16.16)	0.34 (-0.34-0.34)	3.07 (-2.96-4.1)
Lithuania	3.45 (-0.25-5.43)	0.25 (-0.41-0.41)	1.32 (-1.56-2.14)	25.4 (-1.56-72.51)	0.16 (-0.49-0.49)	4.52 (-9.13-12.83)	8.8 (-0.33-11.67)	0.25 (-0.25-0.25)	2.22 (-2.14-2.96)
Luxem-bourg	10.81 (-0.77-16.99)	0.77 (-1.29-1.29)	4.12 (-4.89-6.69)	79.54 (-4.89-227.05)	0.51 (-1.54-1.54)	14.16 (-28.57-40.16)	27.54 (-1.03-36.55)	0.77 (-0.77-0.77)	6.95 (-6.69-9.27)
Latvia	3.49 (-0.25-5.49)	0.25 (-0.42-0.42)	1.33 (-1.58-2.16)	25.69 (-1.58-73.33)	0.17 (-0.5-0.5)	4.57 (-9.23-12.97)	8.9 (-0.33-11.81)	0.25 (-0.25-0.25)	2.24 (-2.16-2.99)
Malta	1.28 (-0.09-2.01)	0.09 (-0.15-0.15)	0.49 (-0.58-0.79)	9.4 (-0.58-26.84)	0.06 (-0.18-0.18)	1.67 (-3.38-4.75)	3.26 (-0.12-4.32)	0.09 (-0.09-0.09)	0.82 (-0.79-1.1)
Nether-lands	3.2 (-0.23-5.03)	0.23 (-0.38-0.38)	1.22 (-1.45-1.98)	23.56 (-1.45-67.25)	0.15 (-0.46-0.46)	4.19 (-8.46-11.89)	8.16 (-0.3-10.83)	0.23 (-0.23-0.23)	2.06 (-1.98-2.74)
Norway	3.92 (-0.28-6.16)	0.28 (-0.47-0.47)	1.49 (-1.77-2.43)	28.85 (-1.77-82.34)	0.19 (-0.56-0.56)	5.13 (-10.36-14.56)	9.99 (-0.37-13.26)	0.28 (-0.28-0.28)	2.52 (-2.43-3.36)
Poland	3.25 (-0.23-5.1)	0.23 (-0.39-0.39)	1.24 (-1.47-2.01)	23.89 (-1.47-68.19)	0.15 (-0.46-0.46)	4.25 (-8.58-12.06)	8.27 (-0.31-10.98)	0.23 (-0.23-0.23)	2.09 (-2.01-2.78)
Portugal	6.35 (-0.45-9.98)	0.45 (-0.76-0.76)	2.42 (-2.87-3.93)	46.73 (-2.87-133.4)	0.3 (-0.91-0.91)	8.32 (-16.79-23.59)	16.18 (-0.6-21.48)	0.45 (-0.45-0.45)	4.08 (-3.93-5.44)
Romania	1.14 (-0.08-1.8)	0.08 (-0.14-0.14)	0.44 (-0.52-0.71)	8.41 (-0.52-24.01)	0.05 (-0.16-0.16)	1.5 (-3.02-4.25)	2.91 (-0.11-3.87)	0.08 (-0.08-0.08)	0.74 (-0.71-0.98)
Sweden	2.68 (-0.19-4.21)	0.19 (-0.32-0.32)	1.02 (-1.21-1.66)	19.72 (-1.21-56.28)	0.13 (-0.38-0.38)	3.51 (-7.08-9.95)	6.83 (-0.26-9.06)	0.19 (-0.19-0.19)	1.72 (-1.66-2.3)
Slovenia	4.45 (-0.32-6.99)	0.32 (-0.53-0.53)	1.69 (-2.01-2.75)	32.73 (-2.01-93.42)	0.21 (-0.64-0.64)	5.83 (-11.76-16.52)	11.33 (-0.42-15.04)	0.32 (-0.32-0.32)	2.86 (-2.75-3.81)
Slovakia	2.61 (-0.19-4.1)	0.19 (-0.31-0.31)	0.99 (-1.18-1.61)	19.19 (-1.18-54.78)	0.12 (-0.37-0.37)	3.42 (-6.89-9.69)	6.65 (-0.25-8.82)	0.19 (-0.19-0.19)	1.68 (-1.61-2.24)
United Kingdom	2.61 (-0.19-4.1)	0.19 (-0.31-0.31)	0.99 (-1.18-1.61)	19.19 (-1.18-54.77)	0.12 (-0.37-0.37)	3.42 (-6.89-9.69)	6.64 (-0.25-8.82)	0.19 (-0.19-0.19)	1.68 (-1.61-2.24)

Other modes

It is important to consider that the insurance systems for individual (road) transport differ from insurance systems for other modes, generally resulting in a lower external part of accident costs for the non-road modes.

For **rail transport** only few studies on marginal (and average) accident costs exist. The results represent hereby rather average than marginal costs because there are no studies available concerning risk elasticities for rail transport. In INFRAS/IWW, 2004a average external accident costs for rail transport are calculated based on up-to-date UIC accident statistics. The Swiss Case study within UNITE (UNITE, 2002d) also present values for average external accident costs for rail transport. Costs for accidents between rail and other modes are allocated based on a causation perspective (and therefore mostly attributed to road transport). European average external accident costs for rail transport amount to € 0.08 - € 0.30/train-km.

For **air transport** average costs from INFRAS/IWW, 2004a are recommended. Values are transferred from €/pkm to €/LTO using average pkm values from the TRENDS Database and ICAO data for the number of LTO. A value adjustment according to GDP/cap. PPP should be applied to derive values for the different countries. Values for different countries range from € 12 to around € 309/LTO.

3.3 Air pollution cost[8]

3.3.1 Type of costs and main cost drivers

Air pollution costs are caused by the emission of air pollutants such as particulate matter (PM), NO_x, SO_2 and VOC and consist of health costs, building/material damages, crop losses and costs for further damages for the ecosystem (biosphere, soil, water). Health costs (mainly caused by PM, from exhaust emissions or transformation of other pollutants) are by far the most important cost category. The state of research on these costs is much more advanced than for the other components, mainly based on estimations carried out by the ExternE model funded by several EU-research projects.

Air pollution costs arise not only from transport related air pollutant emissions but also from other sources like industry, agriculture and private households. Especially in top-down approaches (see below) the share of transport related air pollutants in total pollutant concentrations has to be estimated or modelled.

Transport related air pollution causes damages to humans, biosphere, soil, water, buildings and materials. The most important pollutants are the following:

- Particulate matter: PM_{10}, $PM_{2.5}$.
- Nitrogen oxides: NO_x, NO_2.
- Sulphur oxide: SO_2.
- Ozone: O_3.
- Volatile organic compounds: VOC.

Studies on air pollution costs cover in general the following impact categories:

- *Health costs*: Impacts on human health due to the aspiration of fine particles ($PM_{2.5}$/PM_{10}, other air pollutants). Exhaust emission particles are hereby considered as the most important pollutant. In addition Ozone (O_3) has impacts on human health.
- *Building and material damages*: Impacts on buildings and materials from air pollutants. Mainly two effects are of importance: soiling of building surfaces/facades mainly through particles and dust. The second, more important impact on facades and materials is the degradation through corrosive processes due to acid air pollutants like NO_x and SO_2.
- *Crop losses in agriculture and impacts on the biosphere*: crops as well as forests and other ecosystems are damaged by acid deposition, ozone exposition and SO_2.
- *Impacts on biodiversity and ecosystems (soil and water/groundwater)*: the impacts on soil and groundwater are mainly caused by eutrophication and acidification due to the deposition of nitrogen oxides as well as contamination with heavy metals (from tire wear and tear).

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8 We want to thank Dr. Peter Bickel from the IER Stuttgart for his valuable contributions to this chapter.

Key cost drivers for most air pollution costs and all modes is the receptor density close to the emissions source which is a proxy to the population exposed to transport related pollutants.

For **road transport** the most important other cost drivers are the emission standards of the vehicle which again depend partly on the age of the vehicle. Emissions of a road vehicle then depend on vehicle speed, fuel type and the related combustion technology with its specific applicable end-of-pipe exhaust gas cleaning technology, the load factor, vehicle size, the driving pattern and the geographical location of the road.

In **rail transport** vehicle speed, fuel type, the load factors, the power plant mix for electricity generation as well as geographical location of power plants are key cost drivers.

In **air transport** the type of engine and the engine mode are the most important cost drivers. For **inland waterways** and **maritime transport** key cost drivers are engine type, vessel type, fuel quality, operation mode and (for inland waterways) driving direction (upstream/downstream).

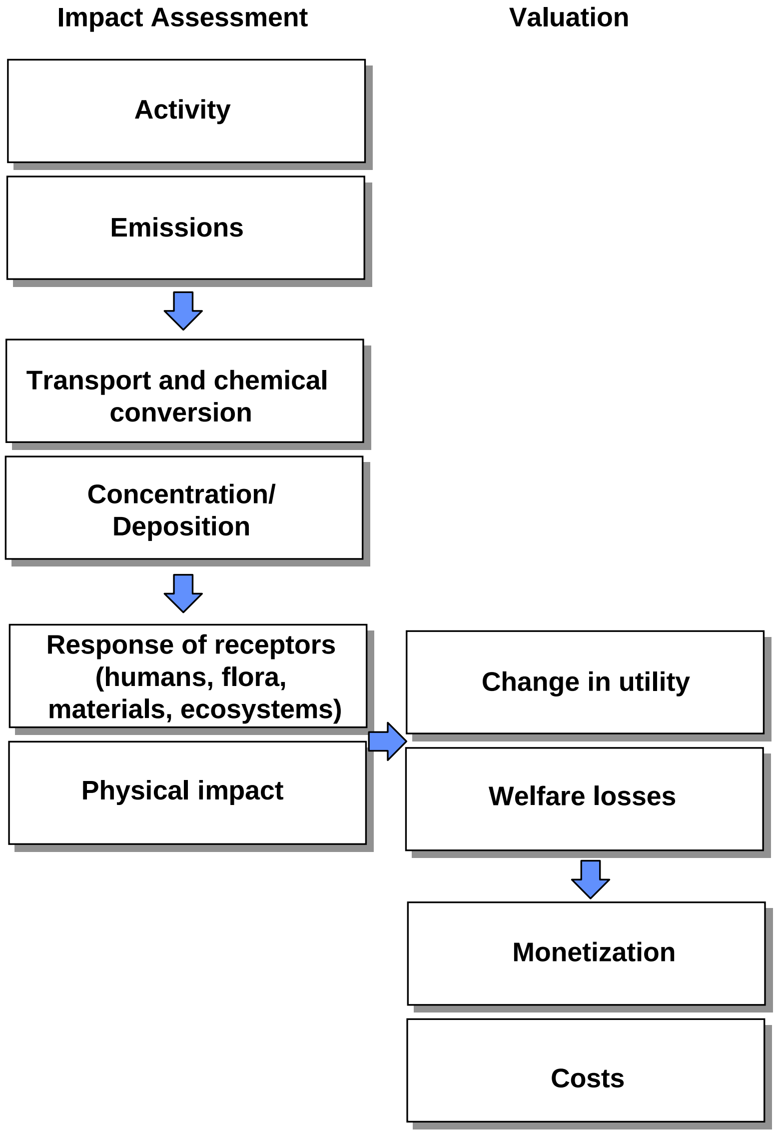
3.3.2 General approach: Overview of steps

Air pollution cost is a core external cost category. A considerable amount of studies on methodology as well as studies on total, average and marginal air pollution costs is available. Within European research projects the Impact Pathway Approach established within the ExternE project (ExternE, 1997; Friedrich and Bickel, 2001) and CAFE CBA, 2005 are commonly used tools and already very advanced. Ongoing research is conducted in order to update this methodology, such as NewExt, 2005 or Methodex, 2007. This approach can be regarded as the most advanced approach for the estimation of air pollution costs and thus is recommended as a best practice methodology.

The ExternE approach is a bottom-up approach originally aiming at estimating marginal costs for different traffic situations. The strength of this approach is its consistency and the consideration of different detailed input variables. However it is rather costly in order to derive average(d) and representative figures at national level. Thus simplified top-down approaches have been developed as an alternative (especially used in Switzerland (OSD, 2004a)). Although the dose response assumptions are similar, the final values might differ, due to the use of different air pollution concentration models and different emission characteristics (e.g. the consideration of exhaust and other particles due to abrasion and resuspension).

The following picture gives an overview on the most important steps of the Impact Pathway Approach established within ExternE.

Figure 7 The Impact Pathway Approach for the quantification of marginal external costs caused by air pollution and noise



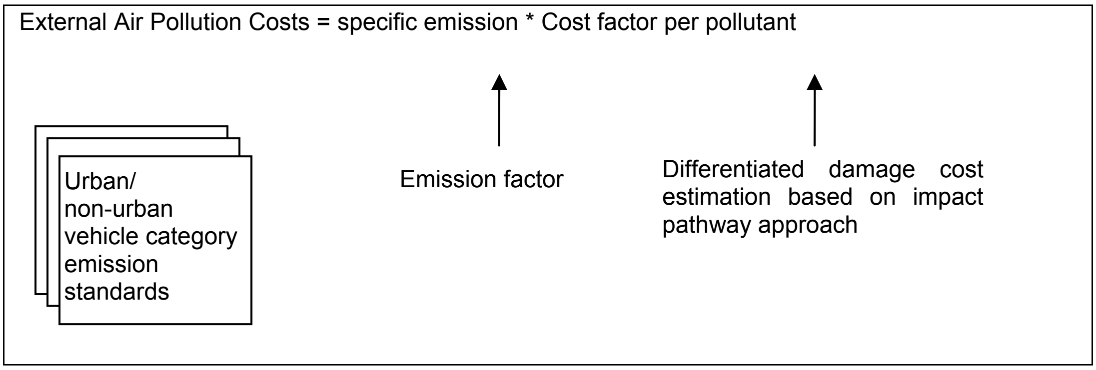
Source: HEATCO, 2005.

Each step requires inputs:

- **Transport flows**: data required range from traffic models relevant to specific route(s), or corridor(s), to data at the aggregated level for the geographic unit considered (a country, a region, etc.). Disaggregating by vehicle technology is systematically needed. Requirements are less demanding for specific analysis of a single vehicle on a specific link.
- **Emissions**: emission factors (by technology) for all vehicle, train, aircraft or ship technologies are needed including the emission factors for the main up- and downstream processes[9]. For modelling the chemical transformation of the pollutants in the atmosphere, emission data bases covering all emission sources are needed for the different spatial scales.

[9] Note that in this Handbook, up- and downstream cost are treated in a separate cost category.

- **Concentrations and impacts**: in addition to transport flows and emissions, data requirements cover two main areas: i) receptor data (geographical co-ordinates, population density, other geo-morphological information, such as built environment pattern for urban situations, building surfaces, etc.), ii) meteorological data (mainly wind speed and direction). Impacts are derived from the application of exposure- or dose-response functions, whose knowledge is therefore a prerequisite.
- **Monetary valuation,** finally, requires the availability of WTP/WTA, damage costs and restoration/reparation cost data.



Critical aspects and uncertainties

Critical aspects and uncertainties can be grouped according to NewExt, 2005 into four categories. Most of these points apply to both major approaches in external air pollution cost calculation:

- *Data uncertainties*: e.g. slope of dose-response functions, cost of a day of restricted activity, deposition velocity of a pollutant, emission factors for different vehicle categories and traffic situations.
- *Model uncertainties*: e.g. assumption about causal links between pollutant and health impact (e.g. consideration of other emission sources), assumption about the form of a dose-response function (with/without threshold), choice of models for atmospheric dispersion and chemistry, underlying model parameters (e.g. meteorological input parameters).
- *Policy/ethical choices*: e.g. discount rates for intergenerational costs, value of statistical life.
- *Interpretation* of incomplete and ambiguous information.

3.3.3 Input values[10]

Increased mortality and morbidity

Based on most recent research by ExternE (NewExt, 2004; ExternE, 2005, results of NEEDS upcoming soon), figures for a life year lost of € 50,000 (chronic effects) to € 75,000 (acute effects) are recommended. These values correspond to a VSL of ca. 1.0 million €. This value is lower than the respective VSL or risk value for accidents. New research within NewExt focused for the quantification of the VSL or the VOLY respectively on mortality risks related to air pollution. While recent studies on social health costs adopted this lower VSL, studies on accident costs still stick on GDP/cap. adjusted value of 1.5 million € (see HEATCO outputs as an example). The main reasons for the differences of VSL in health and accident cost estimation are different WTP research designs and the fact that accident risk perception (sudden fatalities) is different to air pollution related long-term mortality risks (loss of life years). Furthermore – perhaps more important – the number of life years lost differs considerably between both cases.

Detailed EU-25 average values for health effects, crop losses and building/material damages can be found in HEATCO, 2006a. The values listed in the following table have been used within the HEATCO project.

Table 11 Monetary values (European average) used for economic valuation (€2002 factor costs)

Impact	**$€_{2002}$ per unit**
Human health, effects in respective units	
Acute mortality - Years of life lost due to acute exposure	60,500
Chronic mortality - Years of life lost (YOLL) due to chronic exposure	40,300
New cases of chronic bronchitis	153,000
Hospital admissions (respiratory and attributable emergency cardiac)	1,900
Restricted activity days	76
Minor restricted activity days; cough days; symptom days (lower respiratory symptoms including cough); days of lower respiratory symptoms, including cough, in children in the general population, i.e. extra symptoms days	31
Days of bronchodilator usage	1.0

Source: HEATCO D5 Annex D (HEATCO, 2006a).

Remarks: Value transfer to different base years acc. to GDP/cap. For value transfer to different countries GDP/cap, PPP should be used as an indicator.

Within CAFE CBA (CAFE, 2005a) basic values for VOLY and VSL are based on the same source (NewExt) as HEATCO. In addition, CAFE CBA presents ranges of results which take into account different valuation methods for VOLY and VSL (use of median and mean estimates). Compared to HEATCO, CAFE CBA does not take into account material and building damages. The following table shows the most important monetary values for impacts on human health used within the CAFE CBA project.

10 For a detailed description of CAFE CBA, HEATCO and ExternE the reader is referred to Annex D.

Table 12 Summary of health valuation data for the CAFE CBA (CAFE, 2005b) – market prices

Mortality	**Based on median values (€)**		**Based on mean values (€)**
Infant mortality	1,500,000/death		4,000,000/death
Value of statistical life	980,000/death		2,000,000/death
Value of a life year	52,000/death		120,000/year
Morbidity	**Low (€)**	**Central (€)**	**High (€)**
Chronic bronchitis	120,000/case	190,000/case	250,000/case
Respiratory, cardiac hospital admission		2,000/admission	
Consultations with primary care physicians		53/consultation	
Restricted activity day (day when person needs to stay in bed		130/day	
Restricted activity day (adjusted)		83/day	
Minor restricted activity day		38/day	
Use of respiratory medication		1/day	
Symptom days		38/day	

Remark: For ozone induced damages to crops similar cost values are presented in CAFE CBA.

3.3.4 Output values

The basic sources

Based on the impact pathway approach unit cost per ton air pollutant can be elaborated. Most important are the costs for $PM_{2.5}$ and for NO_x.

CAFE CBA (CAFE, 2005a) has produced general figures for all EU countries. The values per tonne for $PM_{2.5}$ are varying between € 8,600-25,000 (low/high value for Greece) and € 63,000-180,000 (low/high value for the Netherlands. The values per tonne of NO_x are for most countries considerably lower.

Several other studies have produced specific figures for the transport sector. UBA, 2006, based on ExternE calculations, shows values between € 92,000 (interurban) and € 450,000 (big cities) per tonne of PM_{10} emission for exhaust particles and € 58,000 up to € 180,000 (abrasion and re-suspension). In HEATCO, 2006a, unit cost values per emitted amount of $PM_{2.5}$ are given for all European countries, differentiated by urban/metropolitan and rural regions. The values range from 140,000 $€_{2002}$ to 730,000 $€_{2002}$ per ton of $PM_{2.5}$ emitted for metropolitan urban areas and from 22,000 $€_{2002}$ to 104,000 $€_{2002}$ for interurban areas (Germany: 400,000 $€_{2002}$ per ton of $PM_{2.5}$ in metropolitan urban areas and 78,000 $€_{2002}$ per ton in interurban areas).

Also the ranges of damage costs in the most important and up-to-date studies HEATCO and CAFE CBA are in the same order of magnitude, there are some important differences with respect to different aspects (cost categories covered, toxicity of different pollutants, especially primary and secondary $PM_{2.5}$ and PM_{10}, inclusion of local damages, valuation factors for mortality and morbidity).

- **Crop losses and material damages**: CAFE CBA values only cover health costs and ozone caused crop losses. However, with respect to total costs the exclusion of material damages in CAFE CBA has only minor effects.

- **Toxicity of $PM_{2.5}$/PM_{10} from different sources**: Whereas HEATCO applies the ExternE Methodology and treats secondary particles (nitrates and sulphates) differently than primary exhaust emissions, CAFE CBA argues based on its WHO review that there is less scientific evidence to establish different risk rates for different kind of particles.
  - CAFE CBA (CAFE, 2005a+b): In the core analysis of CAFE CBA it is assumed that all particles are equally aggressive per unit mass, irrespective of their physical or chemical characteristics. This builds on the fact that the only risk factor for long-term effects due to fine particles uses the mass metric $PM_{2.5}$ with no differentiation by particle composition. There is additional information on the increased hazard from toxicological studies of various fractions such as the content of metals, organic matter and endotoxins. However, there is a lack of a quantitative base from which to establish different risk rates for different particles. As a result, experts, including those working on the WHO Review CAFE CBA, have declined to take a position on the differences in risk between particles per unit mass.
  - HEATCO: In the HEATCO project the ExternE methodology is applied which bases on the increasing evidence that underline the high toxicity of combustion particles and especially of particles from internal combustion engines (ExternE, 2005). In addition they state that the evidence for secondary particles is not that convincing. In particular for nitrates there is still not much evidence for harmful effects, whereas for sulphates quite a few studies do find associations. ExternE and HEATCO therefore treat the different particle fractions and sources as follows (ExternE, 2005):
    - Nitrates as equivalent to 0.5 times the toxicity of PM_{10}.
    - Sulphates as equivalent to PM_{10} (or 0.6 times $PM_{2.5}$).
    - Primary particles from power stations as equivalent to PM_{10}.
    - Primary particles from vehicles as equivalent to 1.5 times the toxicity of $PM_{2.5}$.
    - PM_{10} equivalent to 0.6 times $PM_{2.5}$.
- **Inclusion of local effects**: HEATCO also considers local effects of $PM_{2.5}$ on human health in densely populated areas and therefore presents values differentiated by urban and interurban traffic situations. This is for $PM_{2.5}$ the main difference to CAFE CBA which does not take into account local effects of $PM_{2.5}$ emissions[11].
- **Health valuation**: the above mentioned differences regarding the used valuation factors lead to wider ranges of results of CAFE CBA compared to HEATCO. The HEATCO results correspond to the median VOLY results of CAFE CBA. In addition it has to be considered that HEATCO uses a factor cost approach, whereas CAFE CBA valuation is based on market prices.

[11] The differences between CAFE CBA and HEATCO with respect to $PM_{2.5}$/PM_{10} are mainly due to the fact that in CAFE CBA no local dispersion model is applied in order to quantify local effects of transport related $PM_{2.5}$ emissions (Dispersion modelling in CAFE CBA is based on the EMEP model with a 50 x 50 km resolution and a air chemistry and meteorology module). A local dispersion model is applied in HEATCO in order to generate damage cost factors for urban areas.

The discussion of the differences between both major approaches (CAFE CBA and HEATCO) shows that both approaches have their advantages. Whereas HEATCO provides differentiated values for different types of networks and regions especially regarding $PM_{2.5}/PM_{10}$, CAFE CBA provides for other pollutants results on the basis of a peer reviewed project which are considered to be robust. With respect to the valuation of secondary particles (nitrates, sulphates) CAFE CBA is together with WHO more cautious and values these particles equally as primary exhaust particles.

We therefore recommend a combined approach, using the HEATCO results for the valuation of $PM_{2,5}/PM_{10}$ emissions and the CAFE CBA project results for the valuation of the emissions of other pollutants.

Costs per unit of air pollutant

The following Table 13 is summarising the recommendations for road, rail, air and inland waterway transport and separately for maritime transport (unlike the others not per country but per sea region). The presented values base on model calculations which consider different population densities in the respective countries as well as country-specific meteorological conditions and traffic patterns (distribution of exhaust emissions).

Table 13 Air pollution costs in €/tonne of pollutant for road, rail, waterways

	Factor costs in €, 2000 prices, Unit: € 2000/t of pollutant								
Pollutant	NO_x	NMVOC	SO_2	$PM_{2.5}$ (exhaust)			PM_{10} (non-exhaust)		
Source	CAFÉ CBA	CAFÉ CBA	CAFÉ CBA	HEATCO	UBA transferred to HEATCO[1)]	HEATCO/ CAFÉ CBA (for maritime)	HEATCO	UBA transferred to HEATCO[1)]	HEATCO
CAFÉ CBA sensitivity	VOLY median *(PM/O3)*	VOLY median *(PM/O3)*	VOLY median *(PM/O3)*						
Unit	*€ 2000 (emissions 2010)*	*€ 2000 (emissions 2010)*	*€ 2000 (emissions 2010)*	*€ 2000*	*€ 2000*	*€ 2000*	*€ 2000*	*€ 2000*	*€ 2000*
Local environment				*Urban Metropolitan* [2)]	*Urban*[3)]	*Outside built-up areas*	*Urban metropolitan* [2)]	*Urban*[3)]	*Outside built-up areas*
Austria	8,700	1,700	8,300	415,000	134,300	69,600	166,200	53,700	27,800
Belgium	5,200	2,500	11,000	422,200	136,200	91,100	169,900	54,500	36,500
Bulgaria	1,800	200	1,000	43,000	13,800	11,000	17,200	5,500	4,400
Cyprus	500	300	2,000	243,700	78,700	20,600	97,500	31,500	8,200
Czech Republic	7,300	1,000	8,000	252,600	81,400	62,700	101,000	32,600	25,100
Denmark	4,400	700	5,200	386,800	124,700	45,500	154,700	49,900	18,200
Estonia	800	100	1,800	133,400	43,400	22,500	53,400	17,300	9,000
Finland	800	200	1,800	337,100	108,600	28,100	134,800	43,400	11,200
France	7,700	1,400	8,000	392,200	126,300	78,400	156,900	50,500	31,400
Germany	9,600	1,700	11,000	384,500	124,000	75,000	153,800	49,600	30,000
Greece	800	300	1,400	248,700	80,100	35,000	99,500	32,100	14,000
Hungary	5,400	900	4,800	203,800	65,600	52,300	81,500	26,200	20,900
Ireland	3,800	700	4,800	391,000	126,200	40,900	156,400	50,500	16,400
Italy	5,700	1,100	6,100	371,600	120,100	67,600	148,600	48,000	27,100
Latvia	1,400	200	2,000	115,700	37,200	21,500	46,300	14,900	8,600
Lithuania	1,800	200	2,400	143,100	46,500	28,600	57,200	18,600	11.400
Luxembourg	8,700	2,700	9,800	671,500	216,200	95,700	268,600	86,500	38,300
Malta	700	400	2,200	245,400	78,700	20,400	98,200	31,500	8,200
Netherlands	6,600	1,900	13,000	422,500	136,400	82,600	169,000	54,500	33,000
Norway	2,000	300	2,500	309,600	99,600	30,100	123,800	39,900	12,000
Poland	3,900	600	5,600	174,500	56,000	52,400	69,800	22,400	20,900
Portugal	1,300	500	3,500	259,500	83,600	38,500	103,800	33,500	15,400
Romania	2,200	400	2,000	29,200	9,400	7,500	11,700	3,800	3,000
Slovakia	5,200	700	4,900	194,200	62,100	52,400	77,700	24,900	21,000
Slovenia	6,700	1,400	6,200	262,900	84,500	54,500	105,200	33,800	21,800
Spain	2,600	400	4,300	299,600	96,400	41,200	119,900	38,600	16,500
Sweden	2,200	300	2,800	352,600	113,400	34,300	141,000	45,400	13,700
Switzerland	9,200	1,800	8,800	444,800	143,100	73,500	177,900	57,200	29,400
United Kingdom	3,900	1,100	6,600	389,100	125,300	60,700	155,700	50,100	24,300
EU-25	4,400	1,000	5,600			26,000			
Baltic Sea	2,600	500	3,700			12,000			
Mediterranean Sea	500	300	2,000			5,600			
North East Atlantic	1,600	400	2,200			4,800			
North Sea	5,100	1,900	6,900			28,000			

Source: $PM_{2.5}$/PM_{10} HEATCO, values adjusted to € 2000 values using GDP/cap. PPP. development. Other pollutants: CAFE CBA (CAFE, 2005a).

Notes: 1) Derived based on personal communication with Peter Bickel April 5, 2007.
2) Urban metropolitan: cities with more than 0.5 million inhabitants
3) Urban: smaller and midsized cities with up to 0.5 million inhabitants.

The approach can be used for all transport modes. For rail transport, the emission factors due to abrasion are very sensitive.

Table 14 presents the cost factors for emissions from electricity generation.

Table 14 Air pollution costs in €/tonne of pollutant for electricity generation

	Factor costs in €, 2000 prices, Unit: €2000/t of pollutant				
Pollutant	NO_x	NMVOC	SO_2	PM_{10} exhaust	
Source	CAFÉ CBA	CAFÉ CBA	CAFÉ CBA	HEATCO	HEATCO
CAFÉ CBA sensitivity	VOLY median (PM03)	VOLY median (PM03)	VOLY median (PM03)		
Unit	€ 2000 (emissions 2010)	€ 2000 (emissions 2010)	€ 2000 (emissions 2010)	€ 2000	€ 2000
Local environment				Urban metropolitan	Outside built-up areas
Austria	8,700	1,700	8,300	14,500	11,600
Belgium	5,200	2,500	11,000	16,300	13,400
Bulgary	1,800	200	1,000	1,700	1,300
Cyprus	500	300	2,000	3,700	1,900
Czech Republic	7,300	1,000	8,000	9,400	8,400
Denmark	4,400	700	5,200	7,700	4,800
Estonia	800	100	1,800	3,300	2,500
Finland	800	200	1,800	5,600	2,800
France	7,700	1,400	8,000	13,400	10,500
Germany	9,600	1,700	11,000	11,500	8,700
Greece	800	300	1,400	4,600	2,800
Hungary	5,400	900	4,800	8,000	6,200
Ireland	3,800	700	4,800	6,200	3,600
Italy	5,700	1,100	6,100	9,500	6,700
Latvia	1,400	200	2,000	2,500	1,700
Lithuania	1,800	200	2,400	3,600	2,700
Luxemburg	8,700	2,700	9,800	14,700	11,000
Malta	700	400	2,200	4,100	2,000
Netherlands	6,600	1,900	13,000	16,300	13,400
Norway	2,000	300	2,500	5,000	2,500
Poland	3,900	600	5,600	8,300	7,300
Portugal	1,300	500	3,500	6,700	4,800
Romania	2,200	400	2,000	3,300	2,600
Slovakia	5,200	700	4,900	7,800	6,800
Slovenia	6,700	1,400	6,200	7,500	5,600
Spain	2,600	400	4,300	5,600	3,700
Sweden	2,200	300	2,800	5,700	2,900
Switzerland	9,200	1,800	8,800	15,500	11,600
United Kingdom	3,900	1,100	6,600	12,300	9,500

Source: $PM_{2.5}/PM_{10}$ HEATCO, values adjusted to € 2,000 values using GDP/cap. PPP development and CAFE CBA (CAFE, 2005a).

It is important to mention that the above presented average figures per country may not be adequate if case specific (pricing and internalisation) measures for a specific and well-defined regional or local entity have to be designed. However, this problem occurs mainly for pollutants with strong local effects like exhaust particles for which the HEATCO values at least give some damage cost figures for urban and rural areas. Otherwise case specific model calculations have to be made which are – considering the huge amount of necessary input data with respect to emission data, exposition and receptor density – costly and time consuming.

Results in Euro/vehicle-km

Air pollution costs are quantified based on values per tonne of pollutant. Definite unit cost rates per vehicle-km, train-km and LTO for different modes, vehicle categories and different countries are therefore an output of a modelling step.

The following tables present costs per vkm based on examples for different type of vehicles (valuation basis: Germany). Underlying emission data represent fleet average emission values for Germany for different vehicle categories, based on TREMOVE model outputs. Within each vehicle category (e.g. Passenger Car Petrol 1.4 – 2 L) values are representative for European average emissions in the respective category. For rail and inland waterway transport emission factors for Germany from the TREMOVE database have been used.

For road transport costs for passenger cars and trucks are presented, differentiated by vehicle-size, emission category (EURO-norm) and network type. Rail transport costs are differentiated by passenger and freight transport, traction type and type of network. For Inland waterway transport values for an average ship are presented.

The values represent different emissions factors for different emission concepts and different traffic situations CAFE CBA values are used to value the pollutants NO_x, NMVOC and SO_2. For $PM_{2.5}/PM_{10}$ HEATCO values are used. The values represent VOLY median values for mortality impacts.

In addition the fuel cycle has to be considered. Besides direct emission of Infrastructure use (directly at the transport source), there are additional air pollutant damages based on pre-combustion processes (well to tank emissions). The following tables are showing the direct costs only. The indirect costs are part of the cost of up- and downstream processes shown in chapter 3.6.4. An exception is railway electricity where direct costs (by diesel engines) and indirect costs (by electric traction) are shown in Table 16.

Road transport

The following table presents marginal air pollution costs for passenger cars and heavy duty vehicles.

Table 15 Air pollution costs in €ct/vkm (€2000) for passenger cars and heavy duty vehicles (Example Germany, Emissions from TREMOVE model, HEATCO and CAFE CBA cost factors for Germany used), Price base 2000

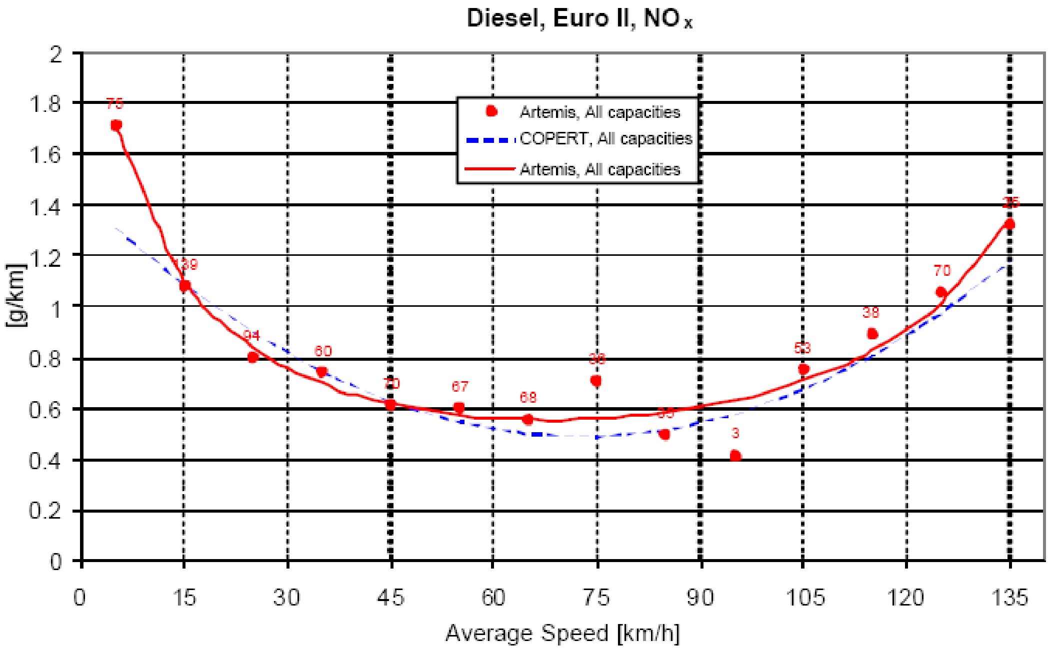
Vehicle	Size	EURO-Class	Metropoli-tan	Urban	Interurban	Motorways	Average
			(€ct/vkm)	*(€ct/vkm)*	*(€ct/vkm)*	*(€ct/vkm)*	*(€ct/vkm)*
Passenger Car Petrol	<1,4L	EURO-0	5.9	2.3	1.7	1.9	2.0
		EURO-1	1.7	1.4	0.6	0.8	0.9
		EURO-2	0.9	0.6	0.3	0.4	0.4
		EURO-3	0.3	0.2	0.1	0.1	0.1
		EURO-4	0.3	0.1	0.1	0.1	0.1
		EURO-5	0.3	0.1	0.1	0.0	0.1
	1,4-2L	EURO-0	5.1	1.8	1.4	1.6	1.6
		EURO-1	1.7	1.5	0.6	0.8	0.9
		EURO-2	0.9	0.6	0.3	0.4	0.4
		EURO-3	0.3	0.2	0.1	0.1	0.1
		EURO-4	0.3	0.1	0.1	0.1	0.1
		EURO-5	0.3	0.1	0.1	0.0	0.1
	>2L	EURO-1	1.4	1.2	0.6	0.8	0.8
		EURO-2	0.8	0.6	0.3	0.4	0.4
		EURO-3	0.3	0.2	0.1	0.1	0.1
		EURO-4	0.2	0.1	0.1	0.1	0.1
		EURO-5	0.2	0.1	0.1	0.0	0.1
Passenger Car Diesel	<1,4L	EURO-2	4.0	1.8	0.8	0.9	1.1
		EURO-3	3.1	1.5	0.9	1.0	1.1
		EURO-4	1.7	0.8	0.5	0.5	0.6
		EURO-5	0.7	0.4	0.3	0.3	0.4
	1,4-2L	EURO-0	13.8	4.8	1.4	1.5	2.4
		EURO-1	4.8	2.0	1.0	1.3	1.4
		EURO-2	4.0	1.8	0.8	0.9	1.1
		EURO-3	3.1	1.5	0.9	1.0	1.1
		EURO-4	1.7	0.8	0.5	0.5	0.6
		EURO-5	0.7	0.4	0.3	0.3	0.4
	>2L	EURO-0	14.1	5.1	1.7	1.8	2.7
		EURO-1	4.8	2.0	1.0	1.3	1.4
		EURO-2	4.0	1.8	0.8	0.9	1.1
		EURO-3	3.1	1.5	0.9	1.0	1.1
		EURO-4	1.7	0.8	0.5	0.5	0.6
		EURO-5	0.7	0.4	0.3	0.3	0.4
Trucks	<7.5t	EURO-0	20.1	11.3	9.1	9.0	9.1
		EURO-1	12.0	6.7	5.4	5.3	5.4
		EURO-2	8.1	5.6	5.0	5.0	5.0
		EURO-3	7.5	4.8	4.0	3.9	4.0
		EURO-4	3.2	2.5	2.3	2.3	2.3
		EURO-5	2.3	1.6	1.4	1.4	1.4
	7.5-16t	EURO-0	28.2	15.7	11.9	11.1	11.6
		EURO-1	18.4	10.6	8.1	7.6	7.9
		EURO-2	12.4	8.5	7.2	6.9	7.1
		EURO-3	10.2	7.2	6.0	5.5	5.8
		EURO-4	5.3	4.1	3.5	3.3	3.4
		EURO-5	3.8	2.7	2.2	2.0	2.1
	16-32t	EURO-0	29.0	16.5	12.7	11.8	12.1
		EURO-1	16.3	9.9	7.8	7.3	7.5
		EURO-2	12.9	9.1	7.5	7.1	7.2
		EURO-3	9.4	7.0	5.8	5.3	5.5
		EURO-4	5.2	4.1	3.5	3.2	3.3
		EURO-5	3.8	2.7	2.2	2.0	2.1
	>32t	EURO-0	38.3	22.3	16.8	14.9	15.3
		EURO-1	28.1	16.1	12.0	10.6	10.9
		EURO-2	18.9	13.2	10.7	9.6	9.8
		EURO-3	14.6	10.6	8.5	7.6	7.7
		EURO-4	7.4	6.1	5.1	4.5	4.6
		EURO-5	5.2	3.8	3.1	2.8	2.8

Source emission factors: TREMOVE Base Case (model version 2.4.1).
Note: metropolitan: cities with >0.5 million inhabitants, urban: cities with < 0.5 million inhabitants

Emissions of air pollutants vary considerably depending on average speed. The above presented values assume the following average speed for passenger cars on the different types of network: urban/metropolitan: 37 km/h, interurban: 75 km/h, motorways: 106-125 km/h, depending on vehicle size.

The following picture shows NO_x emissions of a Diesel passenger car depending on average speed. Total emissions of NO_x vary by more than a factor 2 depending on speed.

Figure 8 Emissions Factors NO_x from conventional Passenger Cars (EURO-2). Source: COPERT 4, Methodology and Software Updates



Source: Presentation held in Brussels, 2006-03-30.

Rail transport

Air pollution costs for railways are differentiated by traction type and indirect and direct emissions. Unit cost values are based on TREMOVE model outputs.

Table 16 Air pollution costs in €/train-km passenger and freight trains (Example Germany, HEATCO and CAFE CBA cost factors for Germany used)

			Metropolitan			**Other Urban**			**Non Urban**		
			Indirect emis.	Direct emis.	**Total**	Indirect emis.	Direct emis.	**Total**	Indirect emis.	Direct emis.	**Total**
			€ct/ train-km	*€ct/ train-km*	*€ct/ train-km*	*€ct/ train-km*	*€ct/ train-km*	*€ct/ train-km*	*€ct/ train-km*	*€ct/ train-km*	*€ct/ train-km*
Passenger	Electric	Locomotive	4.9	0.0	**4.9**	4.9	0.0	**4.9**	4.9	0.0	**4.9**
		Railcar	7.6	0.0	**7.6**	7.7	0.0	**7.7**			
		High Speed Train							9.2	0.0	**9.2**
	Diesel	Locomotive	8.7	204.7	**213.3**	8.7	108.8	**117.5**	8.7	90.7	**99.4**
		Railcar	11.5	271.0	**282.4**	11.5	144.8	**156.4**			
Freight	Electric	Locomotive	13.7	0.0	**13.7**	13.7	0.0	**13.7**	13.7	0.0	**13.7**
	Diesel	Locomotive	29.2	690.0	**719.2**	29.2	366.8	**396.0**	29.2	305.8	**335.0**

Source emission factors: TREMOVE Base Case (model version 2.4.1).

Notes:

1) Direct emissions do not include emissions of abrasion processes and thus only apply to diesel traction. Indirect emissions are caused by electricity production for electric traction and fuel production and transport for Diesel traction.
2) Metropolitan: cities with >0.5 Mill. inhabitants, other urban: cities with < 0.5 Mill. Inhabitants.
3) Values for metropolitan and other urban freight trains estimated based on the ratio 'metropolitan/non urban' and 'other urban/non urban' for passenger trains (electric and diesel locomotive traction). Values for metropolitan and urban freight trains are not included in the TREMOVE database.

Inland Waterways

Unit cost values for Inland Waterway vessels are differentiated by weight-class.

Table 17 Air pollution costs in €/ship-km for Inland Waterways (Example Germany, HEATCO and CAFE CBA cost factors for Germany used)

Ship Type	Direct Emissions
	€/ship-km
Dry Cargo <250 ton	0.89
Dry Cargo 250-400 ton	0.89
Dry Cargo 400-650 ton	1.22
Dry Cargo 650-1,000 ton	1.86
Dry Cargo 1,000-1,500 ton	2.54
Dry Cargo 1,500-3,000 ton	4.63
Dry Cargo > 3,000 ton	4.63
Push barge <250 ton	6.05
Push barge 250-400 ton	6.05
Push barge 400-650 ton	6.06
Push barge 650-1,000 ton	6.04
Push barge 1,000-1,500 ton	6.05
Push barge 1,500-3,000 ton	6.05
Push barge > 3,000 ton	12.60
Tanker <250 ton	0.89
Tanker 250-400 ton	0.90
Tanker 400-650 ton	1.22
Tanker 650-1,000 ton	1.86
Tanker 1,000-1,500 ton	2.54
Tanker 1,500-3,000 ton	7.28
Tanker > 3,000 ton	7.28

Source emission factors: TREMOVE Base Case (model version 2.4.1).

Air transport

For air transport unit cost values for air pollution costs have been estimated based on model calculations with the TREMOVE model. Air transport results are provided in €ct/pkm for different distance classes of aircrafts. Emissions are supposed to occur outside urban areas. Using average load factors and average flight distances costs in Euro per LTO-cycle were derived. Note that the air quality relevant pollutant emissions of aviation are restricted to the emissions in the LTO phase.

Table 18 Air pollution costs in €ct/pkm for Air Transport (Example Germany, HEATCO and CAFE CBA cost factors for Germany used)

Flight distance	Direct Emissions	
	€ct/pkm	*€/LTO*
<500 km	0.21	45
500-1,000 km	0.12	70
1,000-1,500 km	0.08	117
1,500-2,000 km	0.06	138
>2,000 km	0.03	300

Source emission factors: TREMOVE Base Case (model version 2.4.1).

3.4 Noise costs

3.4.1 Type of costs and main cost drivers

Noise costs consist of costs for annoyance and health. The annoyance costs are usually economically based on preferences of individuals (by stated or revealed preference methods), whereas health costs (especially due to increased risk of heart attacks) are based on dose response figures. Since marginal noise costs decrease with increasing traffic volumes, the definition and measurement of costs is quite crucial and needs differentiation.

Noise can be defined as the unwanted sound or sounds of duration, intensity, or other quality that causes physiological or psychological harm to humans. In general, two types of negative impacts of transport noise can be distinguished:

- *Costs of annoyance*: transport noise imposes undesired social disturbances, which result in social and economic costs like any restrictions on enjoyment of desired leisure activities, discomfort or inconvenience (pain suffering), etc.
- *Health costs*: transport noise can also cause physical health damages. Hearing damage can be caused by noise levels above 85 dB(A), while lower levels (above 60 dB(A) may result in nervous stress reactions, such as change of heart beat frequency, increase of blood pressure and hormonal changes. In addition, noise exposure increases the risk of cardiovascular diseases (heart and blood circulation). Finally, transport noise can result in a decrease of subjective sleep quality. It is recommended to estimate health effects by default values according to WHO guidelines on Noise Burden on Disease[12]. In addition, it is recommended to take vulnerable groups, like children and elderly, into account. The negative impacts of noise on human health result in various types of costs, like medical costs, costs of productivity loss, and the costs of increased mortality.

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.

For air transport an additional negative impact of transport noise can be identified. In many cases governments establish 'cordons sanitaires' around large noise sources such as airports. In these cordons sanitaires land use is restricted; for example, it may not be permitted to build new houses. This restricts use of land within this area compared to a situation without noise and indirectly also limits choices elsewhere, which lead to welfare losses. These costs are only partly related to actual flight movements. Also other aspects, like land prices and future potential flight paths, influence these costs. These aspects cannot be influenced by airlines. Therefore, effective internalisation strategies should also take other actors (e.g. air traffic control, spatial planning institutions) into account.

The basis measurement index for noise is the decibel (dB). This index has a logarithmic scale, reflecting the logarithmic manner the human ear responds to sound pressure. Since the human ear is also more sensitive at some frequencies

[12] The report will be published in December 2008.

than at others, a frequency weighting is applied to measurements and calculations. The most common frequency weighting is the 'A weighting', hence the use of dB(A).

The logarithmic nature of noise is also reflected in the relationship between noise and traffic volume. By halving or doubling the amount of traffic the noise level will be changed by 3 dB, irrespective of the existing flow. This means that an increase of traffic volume from 50 to 100 vehicles per hour will result in the same increase in the noise level (3 dB) as a doubling of the transport volume from 500 to 1,000 vehicles per hour.

Due to the logarithmic nature of the relationship between noise and traffic volume, marginal noise costs are extremely sensitive to existing traffic flows or more general to existing (background) noise. Marginal noise costs are defined as the additional costs of noise caused by adding one vehicle to the existing traffic flow. If the existing traffic levels are already high, adding one extra vehicle to the traffic will result in almost no increase in the existing noise level. Due to this decreasing cost function marginal noise costs can fall below average costs for medium to high traffic volumes. On the other hand, in road and air traffic they may in some cases exceed average costs since road traffic leads frequently through densely populated areas and the alternation of traffic loads over day vary considerably between the modes. The same holds for airports, where approach paths might lead directly over housing areas.

For the estimation of noise costs data on the number of exposed people is needed. For many European countries exposure numbers are not yet available. However, this will change by the introduction of the strategic noise maps required by Directive 2002/49/EC. These maps will provide data on exposure to noise (number of people per band of noise levels) in every agglomeration with more than 100,000 inhabitants, roads with more than 3 million vehicles per annum, railways with more than 30,000 trains per year and airports with more than 50,000 movements per year.

Marginal noise costs due to maritime shipping and inland waterway transport are assumed to be negligible, because emission factors are comparably low and most of the activities occur outside densely populated areas. For that reason, noise costs of shipping are not taken into account.

Key cost drivers

Three general key cost drivers for noise costs can be distinguished:

- *Time of the day*: noise disturbances at night will lead to higher marginal costs than at other times of the day. This is the reason that Directive 2002/45/EC on environmental noise requires that Member States among other things map environmental noise by using the L_{den} metric (EC, 2002c). This metric uses a weighted noise measure to take the impact of day of time into account (evening noise is weighted by 5 dB(A) and night-time noise is weighted by 10 dB(A) compared to day-time noise).
- *Receptor density close to the emission source*: this cost driver gives an indication of the population exposed to the noise. Generally spoken, the closer to an emission source, the more nuisances will appear, and the higher marginal costs will be. For example, the departure of an aircraft from an airport in a densely populated area will, ceteris paribus, cause higher marginal noise costs compared to the departure of the same aircraft from an airport in a more rural area. Closely related to the receptor density is the location and distance of the exposed persons in relation to the source.
- *Existing noise levels* (depending on traffic volume, traffic mix and speed): Along an already busy road the marginal noise costs of an additional vehicle are small in comparison with a rural road. The higher the existing background noise level, the lower the marginal costs of additional vehicles.

In addition to these general cost drivers, there are also some mode-specific cost drivers.

Road

In road transport the sound emitted is mainly made up by the sound of the propulsion system and the sound of rolling. The ratio of both sources depends on the speed of the vehicle. Besides vehicle speed, other important cost drivers are vehicle type (e.g. share of heavy trucks), the kind of tyres, and the vehicle's state of maintenance. Closely related to these are cost drivers like vehicle age, the slope of the road, and the kind of surface (including the presence of noise walls). In urban areas the driving behaviour (such as speeding up) is also a relevant cost driver.

Rail

The dominant component in the noise emissions of trains is the rolling surface of the steel wheel on the steel track (EC, 2003). These noise emissions are dependent on train speed, the coach/wagon type, surface conditions of both wheel and rail, and type of track (including the level of maintenance). Closely related to these are cost drivers like the type of brakes, the length of the train, and the presence of noise walls. Especially the type of brakes has a significant impact on the noise costs. For example, Andersson and Ögren, 2007 show that changing the brake blocks on freight wagons from iron to composite blocks, lowers the noise levels by 8 dB. Within this respect, freight train noise (especially during the night) is most relevant.

Aviation

Noise emissions of airplanes are mostly emitted during the landing and taking off (LTO) events. Thus the average approach and departure levels of an aircraft type are important indicators of the noise costs. Other important cost drivers for aviation are the noise classification of the aircraft type and the type of engine.

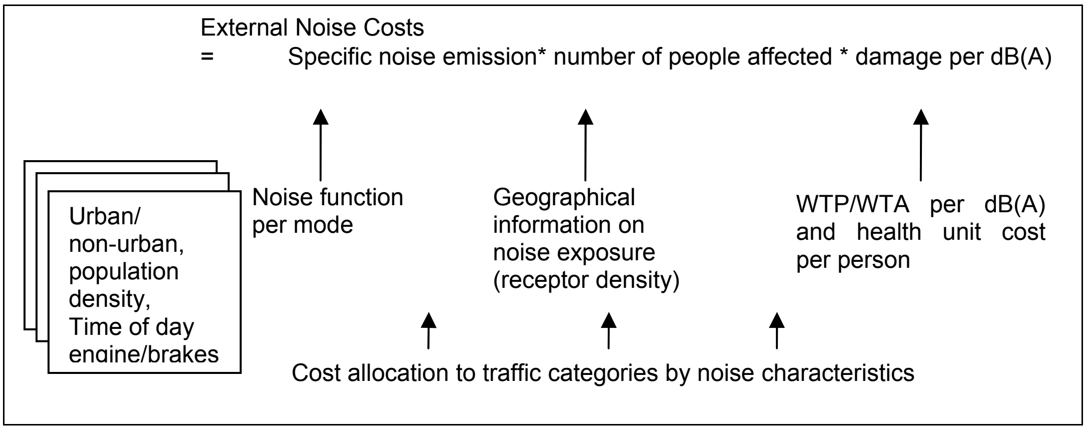
3.4.2 General approach: Overview of steps

As for other cost components, we can distinguish bottom-up and top-down approaches. INFRAS/IWW, 2003; 2004a and UNITE, 2003b provide estimates of marginal noise costs for all modes by using a bottom-up approach. Some methodological improvements to UNITE are proposed in GRACE, 2005. The bottom-up approach was also applied in several other case studies. From the top-down studies, ECMT, 1998 and INFRAS/IWW, 2004a are the most complete ones.

The bottom-up approach is developed in the ExternE-project and is generally called the 'Impact Pathway Approach'. The starting point of this approach is the micro level, i.e. the traffic flow on a particular route. Two scenarios are calculated: a reference scenario reflecting the present scenario with traffic volume, speed distribution, vehicle technologies, etc., and a marginal scenario which is based on the reference scenario, but includes one additional vehicle. The difference in damage costs of both scenarios represents the marginal external noise costs of that vehicle.

The top-down approach is using the willingness to pay or the willingness to accept (compensation) for more silence and the health effects and multiplies these unit values with the national data on noise exposure for different noise classes.

Although the results of the approaches are in a similar order of magnitude, there are two important differences. The bottom-up approach aims at estimating marginal costs which are considerably smaller for heavily frequented and noisy roads. The top-down approach on the contrary produces an average value. It uses the total noise exposure (differentiated for noise classes) and divides it by total mileage driven on that road. In addition the top-down approach considers exposure rates for a whole country and thus is able to produce average(d) figures.



The following issues are further important for the valuation of noise costs:

- The thresholds above which noise is considered a nuisance are somewhat arbitrary. In some studies 50 dB(A) is adopted to define a reasonable level of noise, while other studies choose 55 dB or even 60 dB(A). The impact of the threshold on marginal noise costs is substantial. ECMT, 1998 shows that changing the threshold from 50 dB(A) to 55 dB(A) reduces the average results for cars by almost 50%.
- The rail bonus[13] which is shown in some studies and used in several noise directives.
- Different methods can be applied to value the effects of transport noise. In some cases market prices can be used (cost of illness). However, for nuisance effects no market prices do exist, and WTP-values should be used. Hedonic pricing used to be the preferred method for quantification of amenity losses due to noise. The Noise Depreciation Sensitivity Index (NDSI) is a tool for applying this method which gives the average percentage change in property prices per decibel. Also the contingent valuation method[14] is applied in some studies to value noise costs. Other valuation methods, like abatement costs and avoidance costs, are hardly used to estimate the external costs of noise.
- Valuation of fatalities based on VSL or on life years lost, similar to the uncertainties described for health costs due to air pollution.

[13] A wide range of studies have shown that for a given decibel output, noise nuisance due to rail transport is experienced as less of a nuisance than road traffic noise. To correct for this effect, rail transport is often given a 5 dB ‘discount’.

[14] Valuation technique which asks people directly how much they are willing to pay/to accept for improving/deteriorating environmental quality. Method is based on the stated preference approach; it is the only method that allows the estimation of existence value. The values obtained are compared with other opportunities, in order to make visible a budget restriction.

3.4.3 Input values

To value the disutility due to traffic noise, it is recommended to use an annual WTP-value equal to 0,09% – 0,11% of capita income per dB, which is in line with the range of WTP-values Navrud recommended the EU in 2002 (Navrud, 2002). Although from a theoretical point of view WTP-values derived for different annoyance levels are preferred to WTP-values per dB, too few studies reporting this data are available to provide reliable mean values for Europe. HEATCO, 2006c provide such data, but it is still unclear how reliable these values are (see Annex E).

A value of 50,000 – 75,000 € for a life year lost is recommended, which corresponds to the most recent research by ExternE (NewExt, 2004 and ExternE, 2005., adopted as well in UBA, 2006). These values correspond to a Value of a Statistical Life (VSL) of ca. 1.0 Mill €.

Finally, there is a high agreement on the values for the medical costs. The state of the art values presented by studies such as UNITE, 2003b, UBA, 2006a+b and RECORDIT, 2001 are almost equal. In Table 19 we present the values provided by UNITE, 2003b (based on ExternE).

Table 19 Monetary values for impacts due to noise ($€_{2000}$)

Myocardial infarction (non-fatal, 8 days in hospital, 24 days at home)	
Medical costs	4,700
Absentee costs	2,800
WTP	15,000
Total per case	**22,500**
Angina Pectoris (severe, non-fatal, 5 days in hospital, 15 days at home)	
Medical costs	2,950
Absentee costs	1,750
WTP	9,400
Total per case	**14,100**
Hypertension (hospital treatment, 6 days in hospital, 12 days at home)	
Medical costs	1,800
Absentee costs	1,575
WTP	550
Total per case	**3,925**
Medical costs due to sleep disturbances (per year)	200

Note: Corrected for GDP per capita development by CE Delft (GDP per capita in PPP consumer price index from http://epp.eurostat.ec.europa.eu).
Source: UNITE (2003b).

3.4.4 Output values

Costs per person per dB(A)
For the noise costs per person per dB(A) per year we recommend the state-of-the-art values from HEATCO (2006a). As an example the values for Germany are presented in Table 20. Values for other countries can also be found in HEATCO (2006a).

Table 20 Noise costs for Germany per person exposed per year (in €2002)

Lden (dB(A))	Road	Rail	Aviation
≥ 51	9	0	14
≥ 52	18	0	27
≥ 53	26	0	41
≥ 54	35	0	54
≥ 55	44	0	68
≥ 56	53	9	82
≥ 57	61	18	95
≥ 58	70	26	109
≥ 59	79	35	122
≥ 60	88	44	136
≥ 61	96	53	149
≥ 62	105	61	163
≥ 63	114	70	177
≥ 64	123	79	190
≥ 65	132	88	204
≥ 66	140	96	217
≥ 67	149	105	231
≥ 68	158	114	245
≥ 69	167	123	258
≥ 70	175	132	272
≥ 71	233	189	334
≥ 72	247	204	354
≥ 73	262	218	373
≥ 74	277	233	393
≥ 75	291	248	412
≥ 76	306	262	432
≥ 77	321	277	451
≥ 78	335	292	471
≥ 79	350	306	490
≥ 80	365	321	509
≥ 81	379	336	529

Source: HEATCO (2006a)

Results in Euro/vehicle-km

Since HEATCO (2006a) do not present values in Euro/vehicle-km, these results are based on other sources (e.g. INFRAS/IWW 2003 and 2004). Therefore, the results in Euro/vehicle-km cannot be derived from the values in Euro per person per dB(A).

Road and rail transport

For road transport the comparison of different studies has shown that the values provided by INFRAS/IWW, 2004a are representing a useful European average based on state of the art noise exposure formula, input values and level of differentiation. In contrast to the average cost estimates provided by different studies these values are highly differentiated according to different traffic situations, local conditions and time of the day. Unfortunately, the differentiation to time of the day includes only two periods (day and night), while three periods (day, evening, night) would be preferable. However, there is almost no study that presents values that are differentiated to three time periods. Additionally, since these values from INFRAS/IWW, 2004a can be regarded as EU average values, they can be generalized to all route segments throughout Europe. Other studies estimating marginal noise costs for road transport use specific case studies, as a consequence of which generalization of results to other route segments is hardly possible. Finally, the proposed values are in line with the values found in other important studies, such as UNITE, 2003b and RECORDIT, 2001.

For rail transport marginal costs from INFRAS/IWW, 2003 are recommended. In general, INFRAS/IWW, 2003 is the only specific study for railways noise and applies the same approach as INFRAS/IWW, 2004a. However, INFRAS/IWW, 2003 use a more sophisticated method to estimate marginal noise costs for rail traffic compared to INFRAS/IWW, 2004a (especially for rail freight traffic, see the appendix). Since the results from INFRAS/IWW, 2003 do not include values for urban areas, these values are estimated by using the ratio between the marginal rail noise costs in interurban and urban areas from INFRAS/IWW, 2004a. By applying this ratio on the interurban values from INFRAS/IWW, 2003 the urban values for rail traffic were found.
The proposed values are in line with the values found in other important studies, such as UNITE, 2003b and RECORDIT, 2001.

The recommended output values[15] for road and rail noise are presented in Table 21.

[15] The input values used by INFRAS/IWW, 2004a and INFRAS/IWW, 2003 to estimate the output values are not exactly the same as the input values recommended in Table 19. Therefore it is not possible to compute the recommended output values based on the recommended input values. However, the input values used by INFRAS/IWW, 2004a and INFRAS/IWW, 2003 are in the same order of magnitude as the recommended input values.

Table 21 Unit values for marginal costs for different network types (€ct/vkm) for road and rail traffic

	Time of day	Urban	Suburban	Rural
Car	Day	**0.76** (0.76 – 1.85)	**0.12** (0.04 – 0.12)	**0.01** (0.01 – 0.014)
	Night	**1.39** (1.39 – 3.37)	**0.22** (0.08 – 0.22)	**0.03** 0.01 – 0.03
MC	Day	**1.53** (1.53 – 3.70)	**0.24** (0.09 – 0.24)	**0.03** (0.01 – 0.03)
	Night	**2.78** (2.78 – 6.74)	**0.44** (0.16 – 0.44)	**0.05** (0.02 – 0.05)
Bus	Day	**3.81** (3.81 – 9.25)	**0.59** (0.21 – 0.59)	**0.07** (0.03 – 0.07)
	Night	**6.95** (6.95 – 16.84)	**1.10** (0.39 – 1.10)	**0.13** (0.06 – 0.13)
LGV	Day	**3.81** (3.81 – 9.25)	**0.59** (0.21 – 0.59)	**0.07** (0.03 – 0.07)
	Night	**6.95** (6.95 – 16.84)	**1.10** (0.39 – 1.10)	**0.13** (0.06 - 0.13)
HGV	Day	**7.01** (7.01 – 17.00)	**1.10** 0.39 – 1.10	**0.13** (0.06 – 0.13)
	Night	**12.78** (12.78-30.98)	**2.00** 0.72 – 2.00	**0.23** (0.11 – 0.23)
Passenger train	Day	**23.65** (23.65 – 46.73)	**20.61** 10.43 – 20.61	**2.57** (1.30 – 2.57)
	Night	**77.99**	**34.40**	**4.29**
Freight train	Day	**41.93** (41.93 – 101.17)	**40.06** 20.68 – 40.06	**5.00** (2.58 – 5.00)
	Night	**171.06**	**67.71**	**8.45**

Central values in bold, ranges in brackets.

Note: The lower limit of the bandwidth is based on dense traffic situations, while the upper limit is based on thin traffic situations. Central values (in bold) chosen based on the predominant traffic situation in the respective regional cluster: urban: dense; suburban/rural: thin.

Air transport

The noise costs of air traffic depend heavily on local factors (e.g. population density around airports), flight path, aircraft type and technology, and time of the day. Therefore, it is not possible to present some general (range of) value(s) that can be applied for all situations. We recommend applying specific case studies to obtain these costs on individual airports. In this way airport-specific data, such as population density, flight paths, and aircraft type and technology could be taken into account.

For illustrative purposes we present here marginal cost estimates for various airports. First of all, the marginal noise costs differentiated by aircraft type, flight path and time of the day for Frankfurt Airport are presented in Table 22.

Table 22 Marginal noise costs at Frankfurt Airport (€ 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).

In Table 23 the results of TRL (2001) for Heathrow London are presented.

Table 23 Marginal noise costs at Heathrow London

Aircraft type	Marginal noise costs (€ 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).

UNITE, 2002d estimated the marginal noise costs for a Boeing 737-400 at London Heathrow at € 59 per LTO. TRL, 2001 investigated the marginal noise costs at airport Palma de Mallorca and East Midlands airport, both situated in sparsely populated areas. The marginal noise costs for Palma de Mallorca range from 0.17 to 2.02 € per LTO, while the marginal noise costs for East Midlands airport equals 1.4 to 11.7 € per LTO. Finally, in CE Delft, 2002 the marginal noise costs are estimated for Schiphol Amsterdam. The costs are differentiated to seize and technology of the aircraft (see Table 24).

Table 24 Marginal noise costs of aviation per LTO

		40 seater	100 seater	200 seater	400 seater
CE Delft, 2002	Fleet average technology	180	300	600	1,200
	State-of-the-art technology	90	150	300	600

An important factor explaining the wide ranges in marginal noise costs estimates for aviation is aircraft type. Öko-institut/DIW, 2004 show that noise costs can differ by a factor 700 between various aircraft types. Also the population density around airports is an important driver of noise costs. This is for example shown by the results for Schiphol Amsterdam (CE Delft, 2002) and airport Palma de Mallorca (TRL, 2001).

3.5 Climate change

3.5.1 Type of costs and main cost drivers

Climate change costs have a high level of complexity due to the fact that they are long term and global and that risk patterns are very difficult to anticipate. As a result there are difficulties to value the damages to be allocated to national transport modes. Therefore a differentiated approach (looking both at the damages and the avoidance strategy) is necessary. In addition long term risks should be included.

Climate change or global warming impacts of transport are mainly caused by emissions of the greenhouse gases carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). To a smaller extent emission of refrigerants (hydrofluorocarbons) from Mobile Air Conditioners (MAC) also contribute to global warming. In the case of aviation also other aircraft emissions (water vapour, sulphate, soot aerosols and nitrous oxides) at high altitude have an impact on global warming.

Various impacts of global warming causing external costs are listed in Table 25.

Table 25 The Social Costs of Climate Change: Key Areas Assessment in the Literature and the Models

The Social Costs of Climate Change: Key Areas of Assessment in the Literature and the Models
Sea level rise leads to costs of additional protection, or otherwise loss of dry land and wetland loss. The balance will depend upon future decisions about what protection is justified. Costs of protection are relatively well known and included in nearly all models, but other costs (e.g. rising sea levels increases the likelihood of storm surges, enforces landward intrusion of salt water and endangers coastal ecosystems and wetlands) are more uncertain and often excluded (or only partially captured in terms of valuation). Populations that inhabit small islands and/or low-lying coastal areas are at particular risk of severe social and economic effects from sea-level rise and storm surges. This raises the issue of migration (e.g. for those living on small island states). These costs depend on diverse social and political factors (so called socially contingent effects) but they are not captured in the current valuation models.
Energy use impacts will depend on average temperatures and range, but there will be a combination of increases and decreases in demand for heating (both in terms of overall energy supplied, and to meet peak demands). Benefits from increased winter temperatures that reduce heating needs may be offset by increases in demand for summer air conditioning, as average summer temperatures increase. The models capture these effects, although the reference scenario is difficult to project.
Agricultural impacts depend on regional changes in temperature and rainfall, as well as atmospheric carbon dioxide levels (and fertilisation). The key impacts will be crops changes in the cultivated area and yields. These effects depend on many factors and in some areas; the

area suitable for cultivation and potential yields will increase. Climate variability, as well as mean climate change, is an important consideration. Adaptive responses will be important - choice of crop, development of new cultivars and other technical changes, especially irrigation (see also water supply below). Most valuation studies capture the direct impacts, but it is important to note these do not fully determine damages - these will also depend on changes in demand and trade patterns driven by socio-economic factors - but also complex responses to climate variability, pests and diseases, etc.

Water supply impacts depend on changes in rates of precipitation and evapo-transpiration and demand changes – including those driven by climate change. The water demand of biological systems is affected by various climatic factors, including temperature and humidity. Water supply systems are usually optimised to meet (currently) extreme supply/demand conditions and the costs of shortage can be very high. Climatic variability is therefore important in determining damages. Climate change will exacerbate water shortages in many water-scarce areas of the world. There is the potential for water scarcity and severe socially contingent damages, which are not quantified at present. Water supply is included in some models, though coverage is often partial.

Health impacts include both an increase in (summer) heat stress and a reduction in (winter) cold stress, though as these are in opposite directions the net mortality impact (global) of direct temperature changes may be quite small. Direct health impacts from temperature changes are included and valued in many studies. The area amenable to parasitic and vector borne diseases, such as malaria, will expand and impacts could be large. The inclusion of disease burdens has been advanced through specific studies, and some models include partial coverage of such effects. Socially contingent damages to health (via other impacts such as food production, water resources and sea level rise) in vulnerable communities are difficult to estimate but could be very large, and these are not included in any of the valuation modelling frameworks. Overall, climate change is projected to increase threats to human health, particularly in lower income populations, predominantly within tropical/subtropical countries.

Ecosystems and biodiversity impacts are amongst the most complex and difficult to evaluate. Ecological productivity and biodiversity will be altered by climate change and sea-level rise, with an increased risk of extinction of some vulnerable species. Most of the major ecosystem types are likely to be affected, at least in parts of their range. Some isolated systems are particularly at risk, including unique and valuable systems (e.g. coral reefs). Recent evidence has also identified acidification of the oceans, which is an observable consequence of rising CO_2 levels in the atmosphere, with potentially large impacts on marine ecosystems and fluxes of greenhouse gases between the ocean and the atmosphere. The analysis of ecosystems effects is one of the most problematic areas, in terms of a comprehensive or reliable assessment of the impacts of climate change on ecosystems, and on valuations of ecosystems. Most studies do not capture ecosystems effects fully – with valuations relying on *ad hoc* estimates of species loss and contentious valuation studies. The value of ecosystem function may also be important, but has received even less attention, and is not included in valuation modelling.

Extreme weather events are also likely to increase, with heat waves, drought, floods, and potentially storms, tropical cyclones and even super-typhoons. However, the frequency and severity of extreme events may not be linearly dependent on average climate. Climate variability will also be important and there is no consensus on how this will change. Impacts and damages will also depend on the location and timing of the hazard and adaptive responses. For example, cyclone damage to property will tend to rise with wealth, but mortality effects may fall considerably. Extreme events are excluded from all but a few studies in relation to valuation.

Major Events, i.e. the risk of major effects - potentially catastrophic effects or major climate discontinuities are the most uncertain category. They include such potential events as loss of the West Antarctic ice sheet; loss of the Greenland ice sheet; methane outbursts (including runaway methane hydrates); instability or collapse of the Amazon Forest; changes in the thermo-haline circulation (loss or reversal of the gulf stream, changes in Atlantic deep water formation, changes in southern ocean upwelling/circumpolar deep water formation); Indian monsoon transformation; Change in stability of Saharan vegetation; Tibetan albedo change; ENSO triggering; reduced carbon sink capacity, and other events. Many have previously been thought to be longer-term events (i.e. that would occur at temperature changes >2˚C), though recent evidence (presented at The International Symposium on the Stabilisation of Greenhouse Gases, held in February –

Stabilisation 2005) indicates that in many cases the risks from major climate change impacts are greater than originally thought at the time of the Third Assessment Report 2001, and may actually occur at lower temperature thresholds. Major events are not captured in the models.

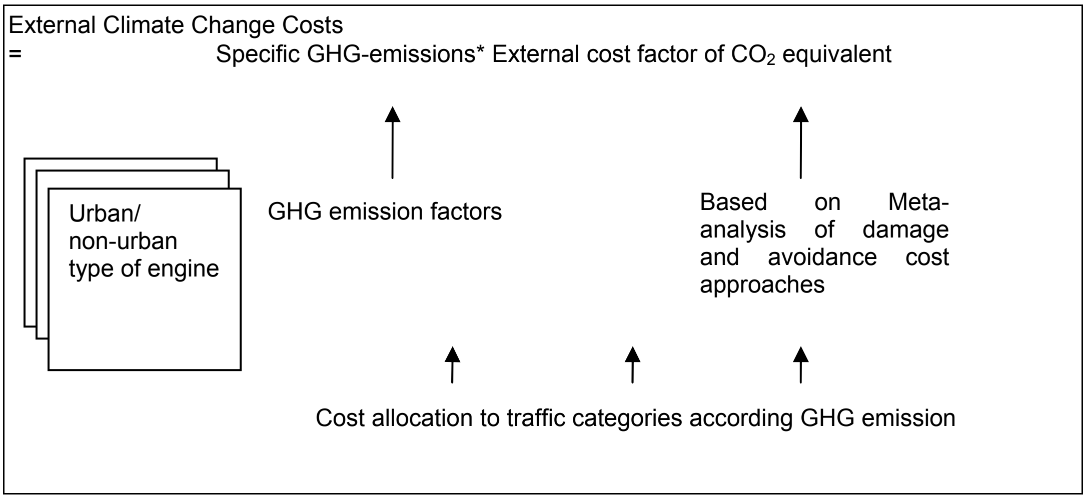
Source: Watkiss, 2005b.

In a damage cost approach a valuation of each of these effects needs to be carried out. In the avoidance cost approach the costs of avoiding these effects to a desired extent are estimated.

3.5.2 General approach: Overview of steps

The general approach for quantifying total external costs due to climate change impacts for the transport sector is to:

1 Assess total vehicle kilometres by type of vehicles of different categories for an area, region or country.
2 Multiplication of vehicle kilometres by emission factors (in g/km) for the various greenhouse gases.
3 Adding various greenhouse gas emissions to a total CO_2 equivalent greenhouse gas emission using Global Warming Potentials[16] [17].
4 Multiplication of the total tonnes of CO_2 equivalent greenhouse gas emission by an external cost factor expressed in €/tonne to estimate total external costs related to global warming.



[16] For CH_4 the GWP = 23, for N_2O GWP = 296. For refrigerants GWP-values are much higher, e.g. GWP = 120 for HFC-134a and GWP = 8'500 for CFC-12 (now banned but used in older MAC systems).

[17] This step is formally not correct. Watkiss, 2005b calculates separate costs for CO_2 and CH_4, and the ratio between these two is not the GWP and is not constant over time.

The main cost drivers for marginal climate cost of transport are the fuel consumption and carbon content of the fuel. Therefore, marginal climate cost are preferably expressed in Euro per litre of fuel[18]. For internalisation purposes the estimated external costs of CO_2 emissions can be factored in to the price of transport fuels on the basis of their respective CO_2 contents (direct emissions of burning a litre of fuel) or total well-to-wheel greenhouse gas emissions per litre of fuel used by multiplying the grams of CO_2 per litre with the external costs per gram of CO_2 emitted.

The damage cost approach follows the impact pathway approach and uses detailed modelling to assess the physical impacts of climate change and combines these with estimations of the economic impacts resulting from these physical impacts (see e.g. Watkiss, 2005a and 2005b). The costs of sea level rise could e.g. be expressed as the costs of land loss. Agricultural impact can be expressed as costs or benefits to producers and consumers, and changes in water runoff might be expressed in new flood damage estimates.

Using a monetary metric to express non-market impacts, such as effects on ecosystems or human health, is more difficult and requires dedicated methodologies. There is a broad and established literature on valuation theory and its application, including studies on the monetary value of lower mortality risk, ecosystems, quality of life, etc. However, economic valuation, especially in the area of climate change, is often controversial. First of all there is a general lack of knowledge about the physical impacts caused by global warming. Some impacts are rather certain and proven by detailed modelling, while other possible impacts, such as extended flooding or hurricanes with higher energy density are often not taken into account due to lack of information on the relationship between global warming and these effects. Secondary impacts such as socially contingent damages (e.g. regional conflicts) are even more difficult to assess.
Available damage cost estimations of greenhouse gas emissions vary by orders of magnitude due to special theoretical valuation problems related to equity, irreversibility and uncertainty. Concerning equity both intergenerational and intra-generational equity must be considered.

A recent detailed assessment of damage costs is realised by the Social Cost of Carbon project carried out by AEA Technology and the Stockholm Environment Institute on behalf of Defra, UK. The term Social Cost of Carbon (SCC) is used to denote damage cost as opposed to Marginal Avoidance Costs (MAC). The study reviews a large number of existing studies on damage cost estimates and compares these to own modelling results.

An alternative approach which avoids the uncertainties associated with assessing damage costs of climate control is to assess the costs of avoiding CO_2 emissions. These are often referred to as **avoidance costs or mitigation costs**. The method is based on a cost-effectiveness analysis that determines the least-cost option to achieve a required level of greenhouse gas emission reduction,

[18] To compare climate cost with other external cost, they can be translated to €/vkm, using data on average fuel consumption.

e.g. related to a policy target. The target can be specified at different system levels, e.g. at a national, EU or worldwide level and may be defined for the transport sector only or for all sectors together. This approach has been applied and recommended in several studies, such as UNITE and ExternE. A most recent estimation is summarized in the Stern report , 2006. Also EC, 2007b provides information on avoidance costs of reaching long term reduction targets.

Critical aspects determining uncertainties in valuation studies based on damage costs are:
- Assessment of the worldwide long term economic development, technological developments the associated greenhouse gas emissions for the baseline scenario compared to which the marginal external costs of additional CO_2 emissions are to be assessed.
- Assessment of the physical impacts of climate change and selection of the impacts included in the analysis; this is especially true for air transport emissions in high altitudes.
- Assessment of the economic impacts resulting from the estimated physical impacts and selection of the impacts valued in the analysis.
- The discount rate used.
- Consideration of major risks and dramatic changes of the climate (e.g. slowing down of the golf stream).
- The approach to weighting impacts in different regions (called equity weighting).
- The time horizon used.

Critical aspects determining the accuracy of avoidance cost estimates are:
- The choice of the target level that is used to assess avoidance costs, with regard to the:
  - System to which the target is applied (e.g. all sectors vs. specifically for the transport sector or a country/region vs. worldwide).
  - The numerical value of the target level, based on scientific evidence.
  - Political and public acceptance; formally only legally binding targets laid down in national law or international agreements can be considered as a valid indication of the (society's) willingness to pay.
  - Time horizon (short term versus long term).
- Estimation of the greenhouse gas reduction potential of technical and non-technical options (at the vehicle level as well as at the system level, incl. e.g. possible rebound effects).
- Assessment of the future costs of technical and non-technical options in various sectors to reduce greenhouse gas emissions.
- Assumptions on the energy costs used in the assessment of avoidance costs for the technical and non-technical options[19].

[19] It has to be considered, that due to future decrease of future supply of fossil fuels (peak oil), fuel prices will rise.

In many studies the avoidance cost approach is considered more feasible, since the approach is more transparent and refers to climate change policy. It has to be considered, however, that several political decisions, e.g. regarding the reduction target (short or long term) and the scope of reduction (transport or all sectors, national or international), are underlying the outcome of this approach. This leads to the conclusion that different external cost factors per tonne of CO_2 should be considered depending on the time horizon and the assumed reduction target.

A review of recent literature is carried out in the Annex (section F.5). Here some examples are presented to illustrate the spread in results and to highlight some important issues.

The equilibrium price of the European trading system within the second period (2008-2012) is a possible reference value for a relatively short term view (actually roughly 20 to 25 €/t CO_2)[20]. The ETS credit price is determined in relation to the Kyoto targets for the time being. An alternative is the use of the marginal avoidance costs for reaching the Kyoto targets (19 or 20 €/t CO_2). This approach was used in many studies so far but can not be used anymore. Recently tightened post-Kyoto targets (20 – 30% reduction in 2020 compared to 1990) have been proposed by the European Commission and various Member States, and new policies evaluated using external costs should be viewed in the context of post-Kyoto policy.

In EC, 2007a[21] an Impact Assessment is presented of a proposed EU strategy to reduce the global climate change to 2ºC compared to pre-industrial levels. Using the POLES and GEM E3 models the costs are calculated for a scenario in which global greenhouse gas emissions are reduced to 25% below the 1990 level in 2050. In the baseline scenario global greenhouse gas emissions are projected to increase by 86% in 2050 compared to 1990. Carbon prices resulting from CO_2 emissions trading in the policy scenario for different regions and over time more or less represent the development of the avoidance costs in the least cost path towards the 2050 target and are found to gradually increase from 15 €/tonne in 2010 to 65 €/tonne CO_2 in 2030.

Various recent studies move away from avoidance cost and instead use external cost factors based on damage costs. At the same time improved insight in the impacts of global warming leads to higher estimates of these damage costs. Recent recommended values for Germany and Switzerland (e.g. DLR, 2006) are a central value of € 70 per tonne of CO_2, with a range of € 20 (short term EU average, based on Kyoto targets[22]) to € 280 (long term strategy and risks). HEATCO (2006a) recommends an external cost factor for CO_2 which depends on the year of emission: for emissions between 2000 and 2009, an external cost

20 The CO_2 prices from the first period of the European trading system which were close to zero at the end of 2007 cannot be seen as representative as an over-allocation of allowances has been seen in all Member States.

21 SEC (2007) 8, Limiting Global Climate Change to 2 degrees Celsius The way ahead for 2020 and beyond, Impact Assessment Summary.

22 The post-2012 targets proposed recently by the Commission are more stringent and are likely to increase this unit estimate.

factor of € 22 per tonne CO_2 is recommended (with a lower value of € 14 and an upper value of € 51 per tonne CO_2). For emissions in the following decades, increasing external cost factors are recommended: € 26 per tonne for 2010-2019, € 32 per tonne for 2020-2029, € 40 per tonne for 2030-2039, etc. For emissions in 2050 an external cost factor of € 83 per tonne CO_2 is recommended (based on estimations of Watikiss). Using the PAGE2002-model Stern, 2006 arrives at a preliminary value for the social cost of carbon (damage costs) of 85 $/tonne CO_2 which is equivalent to around 70 €/tonne).

A further motivation for using a higher external cost factor for internalising the external costs associated with CO_2 emissions of transport is that various EU policies in the transport sector already promote the application of technologies with abatement costs that are significantly (up to a factor of 10) higher than 20 €/t CO_2. Examples are:

- The EU Biofuels Directive, aiming at a share of 5.75% biofuels in the energy use of transport in 2010, and the recent proposal to oblige fuel producers to reduce well-to-wheel greenhouse gas emissions from fuels with 1% p.a. between 2011 and 2020[23]. The first generation biofuels, that will be used to meet the target of the Directive, have CO_2 avoidance costs of several hundred Euro per tonne CO_2. For the 2nd generation biofuels avoidance costs will be lower but may still amount 50 to 100 €/t CO_2.
- The proposed EU policy to reduce CO_2 emissions from new passenger cars to 130 g/km in 2012[24]. CO_2 abatement costs of various technical measures available to improve fuel efficiency of passenger cars involve abatement costs of the order of 50 to 150 €/t CO_2 (although strongly dependent on the method of evaluation, (see e.g. TNO, 2006; ZEW, 2006 and EC, 2007b[25]).

Apparently in the decision process underlying these policies CO_2 emissions or other impacts from the transport sector have a value that is higher than the current external cost factor for CO_2 based on either abatement costs for meeting Kyoto-targets or marginal damage costs of present-day emissions. This can be seen as a 'stated preference' within the European Union motivating the use of higher external cost factors for greenhouse gas emissions for internalising external costs of the transport sector. It should be noted here, however, that the motivation for policies such as the Biofuels Directive may also include subsidies to emerging technologies and energy security considerations next to social costs of CO_2 emissions.

For policies aimed at internalisation of external costs of transport it suffices to derive external cost factors that are representative for greenhouse gas emissions occurring in the short to medium term. If external cost factors are used to assess costs and (environmental) benefits of policies, investment decisions or projects that affect future CO_2 emissions also external cost factors are necessary that are valid for future CO_2 emissions. Both for the avoidance cost approach and for the

[23] COM (2007) 18.

[24] COM (2007) 19.

[25] SEC (2007) 60: Results of the review of the Community Strategy to reduce CO_2 emissions from passenger cars and light-commercial vehicles, Impact Assessment, Commission Staff Working Document, February 2007.

damage cost approach these long term external cost factors for greenhouse gases will generally be higher than the short term values.

3.5.3 Input values

Specific input values for determining the **avoidance or mitigation costs** for CO_2 will not be discussed in this Handbook. These are different for the different type of approaches and studies that have been evaluated, and depend on the one hand on the definition and level of the target set and on the other hand on estimates of the costs and potential of measures that may contribute to reaching that target. For this the reader is referred to the quoted literature (see Annex section F.7).

Up to now there is no consensus on the appropriate values for both discount rate and equity weights. It is therefore recommended to use a range of values (sensitivity analysis) so as to arrive at a range of estimates.

Instead of specifying input values here, the approach is to come to a proposal for external cost factors on the basis of the evaluation of results from the different sources and recent trends in the scientific debate.

3.5.4 Output values

This Handbook, based on the reviewed original research reports and meta-studies does identify fundamental questions and uncertainties associated with determining unit values for climate change costs. However it is not in a position to resolve these issues. As a result many meta-studies, including this one, do present interesting and relevant reviews of existing studies but unavoidably fail to provide fully convincing motivation for the values they propose on the basis of the review.

With regard to transferring values to the transport sector, several remarks are necessary:

- A concentration on global damage values is most consistent with the valuation of external costs related to other impacts.
- The most recent studies on damage costs have estimated higher values than previous studies, due to more detailed modelling and more knowledge on sensitive risks. The values are in the range of 50 to 100 €/tonne CO_2. These costs do not consider very specific risks of abrupt climate change such as for example a sudden slow down or even stop of the Gulf Stream.
- Results of studies on damage costs still display a large spread, indicating the high level of uncertainty still attached to this approach.
- External cost of CO_2 based on avoidance costs are to be preferred when a (long-term) reduction target has been agreed. The spread of results from different studies assessing external costs based on avoidance costs is significantly smaller than for studies using the damage cost approach.

- Avoidance costs are strongly determined by the target level. Recently the European Commission has announced new target levels, but these are not fully implemented yet and a specific target for the transport sector has not yet been set. At the same time nations world-wide are engaged in preparation of an agreement on post-Kyoto targets. This means on the one hand that the relevance of avoidance cost estimates based on the Kyoto-target is diminishing, but on the other hand also that a new proper target level for estimating avoidance costs is currently not available.
- The avoidance costs for the economy as a whole are different from the avoidance costs for the transport sector. To avoid negative impacts on competiveness of certain sectors, different avoidance cost levels in different sectors may be acceptable or even to be preferred. From this perspective, in an efficient climate change policy, avoidance costs for the transport sector could be higher than the average avoidance costs.
- Looking at today's national avoidance costs estimates of EU Member States and at the long term avoidance cost figures from studies reviewed in the Annex, the values are between 50 and 100 €/tonne CO_2. The European Commission, 2007a assesses that long term stabilisation of climate change at 2ºC can be achieved at avoidance costs ranging from 15 €/tonne in 2010 to 65 €/tonne CO_2 in 2030. For costs beyond 2030 (EC, 2007b) does not provide information, but extrapolation of the trend in the results of (EC, 2007b) avoidance costs may be expected to increase linearly to around 120 €/tonne CO_2 in 2050.
- If the external cost factor should be based on the average avoidance costs associated with existing policy in the European Union, the CO_2 price under the ETS can be used as a proxy provided that the system is optimally functioning (e.g. definition of emission certificates, inclusion of different sector, quality control, etc.). However, if parts of the transport sector are required to participate in an enlarged emission trading system, the costs are not entirely clear yet. Recent estimates show that the inclusion of the air transport sector leads to ETS equilibrium prices above 30 €/tonne CO_2. In any case the present ETS CO_2 price can not be used as external costs for future emissions of the transport sector as only energy producers and big energy-intensive installations are currently included.

In this situation we recommend to base external cost factors for emissions in the short term on the avoidance cost approach and to use damage costs as a basis for assessing the external costs of greenhouse gas emissions occurring in the longer term. Indicating bandwidths is important, especially in the case of climate change impacts, to avoid that the proposed values will be seen as more true than is justified by the underlying science. This risk is not imaginary when these values are to be used in formal legislative procedures and frameworks to internalise external costs, and especially when this is done at a European scale.

At the present stage the choice of specific values for the valuation of external costs associated with climate change is highly political and cannot be made on scientific grounds alone. As climate change is becoming a more important part of policy making, in the transport sector as well as in other policy areas, and as the goals for greenhouse gas emission reduction are becoming more ambitious, improving the understanding of both damage and avoidance costs and the associated uncertainties will be of paramount importance.

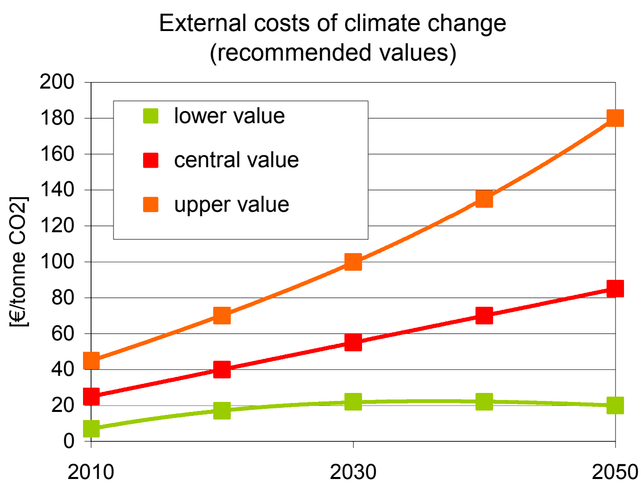
Recommended values

Based on the detailed assessments carried out in section F.7, recommended values are derived which are presented in Table 26, and in Figure 9.

Table 26 Recommended values for the external costs of climate change (in €/tonne CO_2), expressed as single values for a central estimate and lower and upper values

	Central values (€/tonne CO_2)		
Year of application	Lower value	Central value	Upper value
2010	7	25	45
2020	17	40	70
2030	22	55	100
2040	22	70	135
2050	20	85	180

Figure 9 Recommended values for the external costs of climate change (in €/tonne CO_2), expressed as single values for a central estimate and lower and upper values



The recommended values have been chosen on the basis of the following considerations:

– For the **short term** (2010 and 2020) the recommended values are based on the bandwidth of studies based on avoidance costs (see Figure 33 of Annex F). The central values for the short term are in line with the values used in SEC (2007) 8. The reasons for using values based on avoidance costs for 2010 and 2020 are the following:
  - For the 2010-2020 there are policy goals available to which avoidance costs can be related.
    - o For 2010 the targets set under the Kyoto-protocol are leading.
    - o Recently the European Commission and various Member States have announced ambitious and emission reduction goals for 2020 (20 to

30% reduction compared to 1990). The European Commission's target has been adopted by the European Council of March 2007. Reaching these post Kyoto targets will involve significantly higher abatement costs than the 20 €/tonne CO_2 value associated with the Kyoto target.

- The uncertainty range for avoidance costs is smaller than for damage costs. This makes the use of avoidance costs more acceptable from a political and practical point of view. The short term values are most relevant to internalisation policies to be developed by the European Commission or by EU Member States.
- The central value for 2010 is chosen somewhat higher than the 2010 value form SEC (2007) 8, to reflect the fact that for the transport sector measures are taken by the European Union which have higher avoidance costs than the measures taken in other sectors (EU Biofuels Directive, EU policy to reduce CO_2 emissions from new passenger cars to 130 g/km in 2012). As the external cost factors recommended in this report are intended for the purpose of internalisation of external costs in the transport sector, it seems reasonable to use external cost factors for greenhouse gas emissions that take account of the avoidance costs associated with existing policies for the transport sector.

– For the **longer term** (2030 to 2050) the recommended values are based on damage costs (see Figure 32 of Annex F). This is done for the following reasons:
  - From the perspective of consistency with external cost valuations of other environmental impacts the concept of damage costs is preferred over the use of avoidance costs. Also in the field of environmental cost-benefit analysis, in which external costs are used to derive a monetary value for the benefits of assessed policies or investment, a tendency is observed to move from avoidance costs to damage costs.
  - For the long term no agreed policy goals are available yet for which avoidance costs can be assessed.
  - As indicated in the review presented above, various recent studies have made meaningful attempts to determine external cost values based on damage costs. Despite the uncertainty still involved in this approach, the results of these studies appear useful for valuation of external costs of future greenhouse gas emissions.

– Improved insights in the impacts of global warming (as modelled e.g. in FUND or PAGE) indicate that the damage costs associated with global warming are higher than previously assessed (see e.g. Watkiss, 2005a and 2005b and Stern, 2006), especially in the light of possible non-linear, abrupt effects that may occur in the longer term. In recent literature therefore a trend towards higher damage cost values can be observed.

– Marginal damage costs depend on the assumed scenario describing the global emissions of greenhouse gases and increase over time in scenarios with growing emissions. For short term greenhouse gas policies one should use the present day marginal damage costs. For policies involving investments that determine CO_2 emissions for a longer period, it makes sense to use an external cost factor for CO_2 that is related to the costs of future CO_2 emissions. This value will be higher than the value for present-day emissions, although the level will depend on the amount of CO_2 emission reduction measures that are taken worldwide. As no worldwide long term targets and policies have been agreed yet, and as various developing economies are expected to increase their CO_2 emissions significantly over the next decades, it seems wise to use damage cost values related to business-as-usual projections rather than to scenarios in which drastic global greenhouse gas emission reductions are assumed.

Recommended values are specified for different years of application. Long term external costs based on marginal damage costs depend on the assumed scenario describing the development of global emissions of greenhouse gases and increase over time in scenarios with growing emissions. For short term greenhouse gas policies external policies can be based on current or near future avoidance costs. For policies that determine CO_2 emissions occurring in the future it makes sense to use a external cost factor for CO_2 that is related to the costs of future CO_2 emissions. This value will be higher than the value for present-day emissions, although the level will depend on the amount of CO_2 emission reduction measures that are taken worldwide.

It should be highlighted here that CO_2 reduction targets vary from country to country and that also the translation of national targets to targets per sector may be different between countries. Furthermore also CO_2 avoidance costs may differ from country to country. As such external costs defined on the basis of avoidance costs could be made country specific. The values presented in this handbook should be seen as a guideline at the European level for external costs associated with climate change.

Provisional results for road, rail and inland waterway transport in €/vkm

Climate change costs are quantified based on values per tonne of pollutant. By multiplying these with the well-to-wheel CO_2 emissions per unit of fuel, these external costs can be expressed in terms of cost per amount of fuel. Indicative values based on Table 26 are presented in Table 27. Well-to-wheel CO_2 emissions for the different fuels are based on data from (Concawe, 2007). For CNG the value for the European mix as well as the value for CNG based on natural gas imported from Russia or the Middle East over a distance of about 4,000 km is included.

Table 27 Climate change costs in €/litre or €/m^3 for different fuels used in road transport based on external cost values from Table 26 and well-to-wheel CO_2 emissions per litre derived from Concawe, 2007

		Petrol	**Diesel**	**LPG**	**CNG EU mix**	**CNG 4,000 km**
		(€/l)	(€/l)	(€/l)	(€/m^3)	(€/m^3)
2010	Lower	0,019	0,022	0,012	0,014	0,016
	Central	0,069	0,078	0,044	0,052	0,056
	Upper	0,124	0,140	0,078	0,093	0,101
2020	Lower	0,047	0,053	0,030	0,035	0,038
	Central	0,111	0,125	0,070	0,083	0,090
	Upper	0,194	0,218	0,122	0,145	0,157
2030	Lower	0,061	0,069	0,038	0,045	0,049
	Central	0,152	0,171	0,096	0,114	0,124
	Upper	0,277	0,311	0,174	0,207	0,225
2040	Lower	0,061	0,069	0,038	0,045	0,049
	Central	0,194	0,218	0,122	0,145	0,157
	Upper	0,373	0,420	0,235	0,279	0,303
2050	Lower	0,055	0,062	0,035	0,041	0,045
	Central	0,235	0,265	0,148	0,176	0,191
	Upper	0,498	0,561	0,314	0,372	0,404

Source: Concawe, 2007.

In EU Member States excise duties on petrol and diesel are generally of the order of 0.40 €/litre. The short term external costs per litre as presented in Table 27 are thus significantly lower than the excise duties levied on fuels. One might therefore argue that external costs related to greenhouse gases are already fully internalised in the price of fuels in Europe. As a matter of fact it is largely because of the relatively high taxes on fuels and vehicles that we drive cars in Europe that are smaller and especially more fuel efficient than e.g. is the case in the United States. As such, the existing taxes on fuels and vehicles act as an efficient pricing instrument for climate change mitigation, although they serve mainly other aims (like generating revenues with a Ramsey type of tax).

Nevertheless the transport sector, including passenger car transport, is expected to contribute its share to reach the short and medium term goals for CO_2 reduction in the European Union. If internalisation of external costs is to be used as a policy instrument to further improve the fuel economy of the European fleet, these external costs need to be internalised as an additional levy on fuels, vehicles or kilometres driven. In this context just regarding existing excise duties as yet internalising external climate costs will not contribute towards reaching the goal of reducing CO_2 emissions in the transport sector.

Table 28 presents costs per vkm based on examples for different types and sizes of vehicles. Emissions of road vehicles are based on TREMOVE model outputs. Underlying emission data represent fleet average 2005 emission values for Germany for different vehicle categories. Within each vehicle category (e.g. Passenger Car Petrol 1.4 – 2 L) values are representative for European average emissions in the respective category. For rail and inland waterway transport emission factors for Germany from the TREMOVE database have been used.

Table 28 Climate change costs in €/ct/vkm for **passenger cars and trucks**. The central value is based on costs factors (€/t CO_2) for 2010 (Table 26). Bandwidths arise from using the lower and upper values according to Table 26

Vehicle	Size	EURO-Class	Metropo-litan	Urban	Interurban	Motorways	Average
			(€ct/vkm)	*(€ct/vkm)*	*(€ct/vkm)*	*(€ct/vkm)*	*(€ct/vkm)*
Passenger Car Petrol	<1,4L	EURO-0	0.7 (0.2-1.2)	0.6 (0.2-1.1)	0.4 (0.1-0.8)	0.5 (0.2-1)	0.5 (0.1-0.9)
		EURO-1	0.6 (0.2-1.2)	0.6 (0.2-1.2)	0.4 (0.1-0.8)	0.4 (0.1-0.8)	0.5 (0.1-0.9)
		EURO-2	0.6 (0.2-1.1)	0.6 (0.2-1.1)	0.4 (0.1-0.7)	0.4 (0.1-0.7)	0.4 (0.1-0.8)
		EURO-3	0.6 (0.2-1.1)	0.6 (0.2-1)	0.4 (0.1-0.7)	0.4 (0.1-0.7)	0.4 (0.1-0.8)
		EURO-4	0.5 (0.1-0.9)	0.5 (0.1-0.9)	0.4 (0.1-0.6)	0.4 (0.1-0.7)	0.4 (0.1-0.7)
		EURO-5	0.5 (0.1-0.9)	0.5 (0.1-0.8)	0.3 (0.1-0.6)	0.3 (0.1-0.6)	0.4 (0.1-0.7)
	1,4-2L	EURO-0	0.9 (0.2-1.5)	0.7 (0.2-1.3)	0.5 (0.1-0.9)	0.7 (0.2-1.2)	0.6 (0.2-1.1)
		EURO-1	0.8 (0.2-1.4)	0.8 (0.2-1.4)	0.5 (0.1-0.9)	0.5 (0.1-0.9)	0.6 (0.2-1)
		EURO-2	0.7 (0.2-1.3)	0.7 (0.2-1.3)	0.5 (0.1-0.8)	0.4 (0.1-0.8)	0.5 (0.1-0.9)
		EURO-3	0.7 (0.2-1.2)	0.7 (0.2-1.2)	0.4 (0.1-0.8)	0.4 (0.1-0.8)	0.5 (0.1-0.9)
		EURO-4	0.6 (0.2-1.1)	0.6 (0.2-1.1)	0.4 (0.1-0.7)	0.4 (0.1-0.8)	0.5 (0.1-0.8)
		EURO-5	0.6 (0.2-1)	0.6 (0.2-1)	0.4 (0.1-0.7)	0.4 (0.1-0.7)	0.4 (0.1-0.8)
	>2L	EURO-1	1.0 (0.3-1.8)	1 (0.3-1.8)	0.6 (0.2-1.1)	0.6 (0.2-1.1)	0.7 (0.2-1.3)
		EURO-2	1.0 (0.3-1.7)	1 (0.3-1.7)	0.6 (0.2-1.1)	0.6 (0.2-1.1)	0.7 (0.2-1.3)
		EURO-3	0.8 (0.2-1.5)	0.8 (0.2-1.4)	0.5 (0.1-0.9)	0.5 (0.1-0.9)	0.6 (0.2-1)
		EURO-4	0.9 (0.2-1.6)	0.8 (0.2-1.5)	0.5 (0.1-0.9)	0.5 (0.1-0.9)	0.6 (0.2-1.1)
		EURO-5	0.8 (0.2-1.4)	0.8 (0.2-1.4)	0.5 (0.1-0.8)	0.4 (0.1-0.8)	0.5 (0.2-1)
Passenger Car Diesel	<1,4L	EURO-2	0.4 (0.1-0.8)	0.4 (0.1-0.8)	0.3 (0.1-0.6)	0.3 (0.1-0.6)	0.3 (0.1-0.6)
		EURO-3	0.4 (0.1-0.7)	0.4 (0.1-0.7)	0.3 (0.1-0.5)	0.3 (0.1-0.5)	0.3 (0.1-0.6)
		EURO-4	0.4 (0.1-0.7)	0.4 (0.1-0.7)	0.3 (0.1-0.5)	0.3 (0.1-0.5)	0.3 (0.1-0.5)
		EURO-5	0.4 (0.1-0.7)	0.4 (0.1-0.7)	0.3 (0.1-0.5)	0.3 (0.1-0.5)	0.3 (0.1-0.6)
	1,4-2L	EURO-0	0.5 (0.1-1)	0.5 (0.1-0.9)	0.3 (0.1-0.6)	0.4 (0.1-0.7)	0.4 (0.1-0.7)
		EURO-1	0.6 (0.2-1)	0.6 (0.2-1)	0.4 (0.1-0.8)	0.5 (0.1-0.8)	0.5 (0.1-0.9)
		EURO-2	0.6 (0.2-1)	0.6 (0.2-1)	0.4 (0.1-0.7)	0.4 (0.1-0.8)	0.5 (0.1-0.8)
		EURO-3	0.5 (0.1-0.9)	0.5 (0.1-0.9)	0.4 (0.1-0.7)	0.4 (0.1-0.7)	0.4 (0.1-0.8)
		EURO-4	0.5 (0.1-0.8)	0.5 (0.1-0.8)	0.3 (0.1-0.6)	0.4 (0.1-0.6)	0.4 (0.1-0.7)
		EURO-5	0.5 (0.1-0.9)	0.5 (0.1-0.9)	0.4 (0.1-0.6)	0.4 (0.1-0.7)	0.4 (0.1-0.7)
	>2L	EURO-0	0.7 (0.2-1.3)	0.7 (0.2-1.3)	0.5 (0.1-0.8)	0.5 (0.1-0.9)	0.5 (0.2-1)
		EURO-1	0.8 (0.2-1.4)	0.8 (0.2-1.4)	0.6 (0.2-1.1)	0.6 (0.2-1.1)	0.7 (0.2-1.2)
		EURO-2	0.8 (0.2-1.4)	0.8 (0.2-1.4)	0.6 (0.2-1)	0.6 (0.2-1.1)	0.6 (0.2-1.1)
		EURO-3	0.7 (0.2-1.3)	0.7 (0.2-1.3)	0.5 (0.1-0.9)	0.5 (0.1-0.9)	0.6 (0.2-1)
		EURO-4	0.6 (0.2-1.1)	0.6 (0.2-1.1)	0.5 (0.1-0.8)	0.5 (0.1-0.9)	0.5 (0.1-0.9)
		EURO-5	0.6 (0.2-1.2)	0.6 (0.2-1.2)	0.5 (0.1-0.8)	0.5 (0.1-0.9)	0.5 (0.1-0.9)
Trucks	<7.5t	EURO-0	1.3 (0.4-2.4)	1.3 (0.4-2.4)	1.2 (0.3-2.2)	1.2 (0.3-2.1)	1.2 (0.3-2.2)
		EURO-1	1.1 (0.3-2)	1.1 (0.3-2)	1 (0.3-1.9)	1 (0.3-1.9)	1 (0.3-1.9)
		EURO-2	1.1 (0.3-1.9)	1.1 (0.3-1.9)	1 (0.3-1.8)	1 (0.3-1.8)	1 (0.3-1.8)
		EURO-3	1.1 (0.3-2.1)	1.1 (0.3-2)	1.1 (0.3-1.9)	1.1 (0.3-1.9)	1.1 (0.3-1.9)
		EURO-4	1.1 (0.3-1.9)	1.1 (0.3-1.9)	1 (0.3-1.8)	1 (0.3-1.8)	1 (0.3-1.8)
		EURO-5	1.1 (0.3-2)	1.1 (0.3-2)	1 (0.3-1.8)	1 (0.3-1.8)	1 (0.3-1.8)
	7.5-16t	EURO-0	2 (0.6-3.7)	2 (0.6-3.7)	1.8 (0.5-3.2)	1.7 (0.5-3)	1.7 (0.5-3.1)
		EURO-1	1.8 (0.5-3.2)	1.7 (0.5-3.1)	1.6 (0.4-2.8)	1.5 (0.4-2.6)	1.5 (0.4-2.7)
		EURO-2	1.7 (0.5-3)	1.7 (0.5-3)	1.5 (0.4-2.7)	1.4 (0.4-2.6)	1.5 (0.4-2.6)
		EURO-3	1.8 (0.5-3.2)	1.8 (0.5-3.2)	1.6 (0.4-2.8)	1.5 (0.4-2.6)	1.5 (0.4-2.7)
		EURO-4	1.6 (0.5-3)	1.6 (0.5-2.9)	1.5 (0.4-2.6)	1.4 (0.4-2.5)	1.4 (0.4-2.5)
		EURO-5	1.7 (0.5-3)	1.7 (0.5-3)	1.5 (0.4-2.7)	1.4 (0.4-2.5)	1.4 (0.4-2.6)
	16-32t	EURO-0	2 (0.6-3.7)	2 (0.6-3.7)	1.8 (0.5-3.2)	1.7 (0.5-3)	1.7 (0.5-3.1)
		EURO-1	1.8 (0.5-3.2)	1.8 (0.5-3.2)	1.6 (0.4-2.8)	1.5 (0.4-2.6)	1.5 (0.4-2.7)
		EURO-2	1.7 (0.5-3)	1.7 (0.5-3)	1.5 (0.4-2.7)	1.4 (0.4-2.5)	1.4 (0.4-2.6)
		EURO-3	1.8 (0.5-3.2)	1.8 (0.5-3.2)	1.6 (0.4-2.8)	1.5 (0.4-2.6)	1.5 (0.4-2.7)
		EURO-4	1.6 (0.5-3)	1.6 (0.5-2.9)	1.5 (0.4-2.6)	1.4 (0.4-2.4)	1.4 (0.4-2.5)
		EURO-5	1.7 (0.5-3)	1.7 (0.5-3)	1.5 (0.4-2.7)	1.4 (0.4-2.5)	1.4 (0.4-2.5)
	>32t	EURO-0	2.9 (0.8-5.3)	2.9 (0.8-5.3)	2.5 (0.7-4.6)	2.3 (0.6-4.1)	2.3 (0.6-4.2)
		EURO-1	2.6 (0.7-4.7)	2.6 (0.7-4.7)	2.2 (0.6-4)	2 (0.6-3.6)	2 (0.6-3.7)
		EURO-2	2.5 (0.7-4.5)	2.5 (0.7-4.5)	2.2 (0.6-3.9)	2 (0.5-3.5)	2 (0.6-3.6)
		EURO-3	2.6 (0.7-4.7)	2.6 (0.7-4.7)	2.2 (0.6-4)	2 (0.6-3.6)	2 (0.6-3.7)
		EURO-4	2.4 (0.7-4.3)	2.4 (0.7-4.3)	2.1 (0.6-3.7)	1.9 (0.5-3.3)	1.9 (0.5-3.4)
		EURO-5	2.5 (0.7-4.4)	2.4 (0.7-4.4)	2.1 (0.6-3.8)	1.9 (0.5-3.4)	1.9 (0.5-3.5)

Source emission factors: TREMOVE Base Case (model version 2.4.1).
Note:

Table 29 Climate change costs in €ct/train-km for **passenger and freight trains**. Central value and bandwidths are derived by using cost factors for 2010 as illustrated in Table 26

			Metropolitan			**Other Urban**			**Non Urban**		
			indirect emis.	direct emis.	**total**	indirect emis.	direct emis.	**total**	indirect emis.	direct emis.	**total**
			€ct/ train-km	*€ct/ train-km*	*€ct/ train-km*	*€ct/ train-km*	*€ct/ train-km*	*€ct/ train-km*	*€ct/ train-km*	*€ct/ train-km*	*€ct/ train-km*
Passenger	Electric	Locomotive	11 (3.1-19.8)	0 (0-0)	11 (3.1-19.8)	11 (3.1-19.8)	0 (0-0)	11 (3.1-19.8)	11 (3.1-19.8)	0 (0-0)	11 (3.1-19.8)
		Railcar	17.1 (4.8-30.8)	0 (0-0)	17.1 (4.8-30.8)	17.2 (4.8-30.9)	0 (0-0)	17.2 (4.8-30.9)			
		High Speed Train							20.6 (5.8-37.1)	0 (0-0)	20.6 (5.8-37.1)
	Diesel	Locomotive	1.7 (0.5-3)	8.6 (2.4-15.5)	10.3 (2.9-18.5)	1.7 (0.5-3)	8.6 (2.4-15.5)	10.3 (2.9-18.5)	1.7 (0.5-3)	8.6 (2.4-15.5)	10.3 (2.9-18.5)
		Railcar	2.2 (0.6-4)	11.3 (3.2-20.4)	13.6 (3.8-24.4)	2.2 (0.6-4)	11.4 (3.2-20.6)	13.7 (3.8-24.6)			
Freight	Electric	Locomotive	30.7 (8.6-55.2)	0 (0-0)	30.7 (8.6-55.2)	30.7 (8.6-55.2)	0 (0-0)	30.7 (8.6-55.2)	30.7 (8.6-55.2)	0 (0-0)	30.7 (8.6-55.2)
	Diesel	Locomotive	5.6 (1.6-10.1)	29 (8.1-52.1)	34.6 (9.7-62.2)	5.6 (1.6-10.1)	28.9 (8.1-52.1)	34.6 (9.7-62.2)	5.6 (1.6-10.1)	28.9 (8.1-52.1)	34.6 (9.7-62.2)

Source emission factors: TREMOVE Base Case (model version 2.4.1)

Note: 1) Indirect emissions are caused by electricity production for electric traction and fuel production and transport for Diesel traction.

2) Values for metropolitan and other urban freight trains estimated based on the ratio metropolitan/nonurban and otherurban/non urban for passenger trains (electric and Diesel locomotive traction). Values for metropolitan and urban freight trains are not included in the TREMOVE database.

Table 30 Climate change costs in €ct/ship for freight transport on inland waterways. Central values and bandwidths are derived by using cost factors for 2010 as illustrated in Table 26

Ship Type	**Direct Emissions**
	€/ship-km
Dry Cargo <250 ton	0.08 (0.02-0.15)
Dry Cargo 250-400 ton	0.08 (0.02-0.15)
Dry Cargo 400-650 ton	0.11 (0.03-0.2)
Dry Cargo 650-1,000 ton	0.17 (0.05-0.3)
Dry Cargo 1,000-1,500 ton	0.23 (0.07-0.42)
Dry Cargo 1,500-3,000 ton	0.42 (0.12-0.75)
Dry Cargo > 3,000 ton	0.42 (0.12-0.75)
Push barge <250 ton	0.56 (0.16-1)
Push barge 250-400 ton	0.56 (0.16-1)
Push barge 400-650 ton	0.56 (0.16-1)
Push barge 650-1,000 ton	0.56 (0.16-1)
Push barge 1,000-1,500 ton	0.56 (0.16-1)
Push barge 1,500-3,000 ton	0.56 (0.16-1)
Push barge > 3,000 ton	1.14 (0.32-2.05)
Tanker <250 ton	0.08 (0.02-0.15)
Tanker 250-400 ton	0.08 (0.02-0.15)
Tanker 400-650 ton	0.11 (0.03-0.2)
Tanker 650-1,000 ton	0.17 (0.05-0.3)
Tanker 1,000-1,500 ton	0.23 (0.07-0.42)
Tanker 1,500-3,000 ton	0.65 (0.18-1.18)
Tanker > 3,000 ton	0.65 (0.18-1.18)

Source emission factors: TREMOVE Base Case (model version 2.4.1).

Climate change costs for aviation are expressed in €ct per passenger-km and €/flight for different flight distances. Emissions are derived from TREMOVE model. These values are based on a external cost value of €25 per tonne CO_2 in 2010. Taking the indirect climate impacts from emissions in cruising altitude into account, values would be by a factor 2-4 higher depending on the share of emissions in cruising altitude.

Table 31 Climate change costs in €ct/pkm and €/flight for air transport. Central values and bandwidths are derived by using damage costs for 2010 as illustrated in Table 26

Flight distance	**Direct Emissions (without climate impacts of non-CO2 emissions)**	
	€ct/pkm	*€/flight*
<500 km	0.62 (0.17-1.11)	130 (40-230)
500-1,000 km	0.46 (0.13-0.83)	280 (80-500)
1,000-1,500 km	0.35 (0.1-0.62)	530 (150-960)
1,500-2,000 km	0.33 (0.09-0.6)	790 (220-1430)
>2,000 km	0.35 (0.1-0.62)	3710 (1,040-6,680)

Note: Taking the indirect climate impacts from other emissions into account, values would be by a factor 2-4 higher.
Source emission factors: TREMOVE Base Case (model version 2.4.1).

3.6 Other external costs

Research about external cost calculation often focuses on the most important cost categories such as noise costs, air pollution costs, accident costs or climate change costs. Other external cost categories are often neglected. There are several reasons for that, such as:

- Complex impact patterns and uncertain valuation approaches for other environmental costs such as nature and landscape, soil and water pollution, costs in sensitive areas.
- No direct relation to Infrastructure use and thus to Infrastructure pricing, such as costs for Infrastructure related nature and landscape and urban areas.
- Difficult allocation to the transport system, such as costs of up- and downstream processes and costs of energy dependency.

Methodologies for calculating these cost categories have been developed only in very few studies. Therefore, the calculation methods are far from being as sophisticated as for the most important cost categories.

A critical aspect concerning the costs for nature and landscape as well as the costs for soil and water pollution are the very complex impact patterns of the natural ecosystems. Therefore, the knowledge about the detailed impact patterns and dose-response-relationships is less developed than for other cost categories. Often, negative impacts of transport activities on the natural environment can be proven. However, the detailed relationship between activity and impact can hardly be quantified. As a consequence, damage costs can often not be quantified and the calculation has to be done with second best approaches such as the estimation of repair cost based on specific local situations.

Only parts of the cost categories discussed in this chapter are directly related to Infrastructure use. In this respect especially the additional costs in sensitive areas, the cost category 'soil and water pollution' as well as parts of the cost category 'up- and downstream processes' (costs arising from energy and fuel production) are proportional to traffic volumes and hence Infrastructure use.

With regard to climate change costs and up- and downstream costs, the issue of dependency on fossil fuels could be considered as an external effect, too. Besides the costs of the fuel cycle (considering well to tank emissions), it can be expressed as the risk of sudden failures (e.g. due to political reasons) or the risk of a next generation to pay higher energy costs or to face energy production gaps. These costs are related to general long run energy policy issues and energy pricing. The link to transport externalities (and Infrastructure pricing) is therefore indirect. Due to the significant energy use of the transport sector, it is however important to address these energy related externalities as well in this Handbook.

3.6.1 Costs for nature and landscape

Three types of negative impacts are relevant (OSD, 2003): Habitat loss, habitat fragmentation and habitat quality loss. The estimation procedures are:

- Repair cost approach for ground sealing and other impacts on ecosystems (disturbance of animals and their biotopes by noise or barrier effects, visual disturbance, etc.) (INFRAS/IWW, 2000/2004).
- Standard price approach for quantifying the negative effects of airborne emissions on ecosystems and biodiversity (through acidification and eutrophication) (ExternE, 1999; NewExt, 2004).
- Two-stage approach for quantifying biodiversity losses: a. repair costs for reduced species diversity due to *land use change* and b. repair costs for negative effects of *airborne emissions* on ecosystems and biodiversity (through acidification and eutrophication) (NEEDS, 2005a).
- Two-stage approach for habitat loss and fragmentation: a) compensation costs for *habitat loss* due to transport Infrastructure (creating compensatory ecosystem) and b) compensation cost approach for *habitat fragmentation* (OSD, 2003).

The repair costs proposed (in INFRAS/IWW, 2004a) vary between 10 and € 40 per m^2. The costs for nature and landscape due to airborne pollutants (e.g. through acidification and eutrophication) do not belong to the cost category 'nature and landscape' but are covered within the cost category 'air pollution'.

Input values

Table 32 and Table 33 present compensation costs for different ecosystems and cost factors to remedy habitat fragmentation, based on a Swiss study (base year 2000).

Table 32 Habitat loss: compensatory costs for different ecosystems in € per square metre and year. Cost rates for Switzerland, in €2000

	Cost rates in EUR/(M^2*a)		
Ecosystem type	*Minimum*	*Medium*	*Maximum*
Standing water body	1.23	1.75	2.28
River narrow	0.95	1.18	1.40
River broad	0.48	0.59	0.70
Moor	1.35	2.00	2.66
Reed	0.79	0.98	1.22
Fen	1.59	2.87	4.17
Grassland, meadow	0.64	0.92	1.18
Acre, fallow land	0.12	0.20	0.29
Rock	0.51	0.58	0.66
Hedge	1.17	1.42	1.67
Tree avenue	0.11	0.12	0.14
Alluvial forest	0.94	1.22	1.50
Forest (deciduous, coniferous, mixed)	0.64	0.87	1.09

Source: OSD, 2003 (data for year 2000).

Table 33 Habitat fragmentation: specific cost factors for different Infrastructure types to remedy habitat fragmentation. Cost factors for Switzerland

	Cost factor (in 1'000 €/a), medium values					
Infrastructure type	*Motorway*	*1st class road*	*2nd class road*	*3rd class road*	*Rail single-lane*	*Rail multi-lane*
Wildlife overpass	66	28	23			18
Wildlife underpass	136	58	48			72
Stream passage for wildlife	150	64	53			72
Passage for stream animals	7.4	4.5	4.5	3.0	4.5	4.5
Small animal passage	3.7	2.2	2.2			2.5

Source: OSD, 2003 (data for year 2000).

Output values

The cost factors for Switzerland (OSD, 2003) are most elaborated. However, the average cost factors shown in Table 34 have to be adapted to other countries if no national or local estimates are available by taking into account a value transfer procedure looking at the costs of repair measures in the respective countries. It is obvious that the cost structure refers at least partially to the specific local situation in Switzerland (topography, alpine ecosystems, etc.) and transferability is limited, however, if no other national studies are available at least a rough estimation might be possible. In Table 35, the cost factors from the alternative methodology (INFRAS/IWW, 2004a) are presented.

All costs are basically related to Infrastructure and not its use. The marginal costs are very low. Therefore the values presented are related to the size of Infrastructure.

Table 34 Habitat fragmentation and habitat loss (main methodology): average costs per km Infrastructure for road and rail transport in Switzerland

	Average costs (in 1,000 EUR/(km*a)		
Transport mode	*Habitat loss*	*Habitat fragmentation*	*Total*
Road total	3.6	7.1	11
Motorways	19	92	110
1st class / national roads	3.2	13	16
2nd class / regional roads	4.2	2.7	6.9
3rd class roads	2.2	1.6	3.9
Railway total	6.0	10	16
Railway single track	3.3	5.6	8.9
Railway multi track	14	23	37

Source: OSD, 2003 (data for year 2000).

Table 35 Costs for nature and landscape (alternative methodology): average costs per km Infrastructure for road, rail and water transport in Europe (data for EU15 plus CH and N)

Transport mode	*Average costs (in 1,000 EUR/(km*a))*
Road total	4,1
Motorways	49
1st class / national roads	5,5
2nd class / regional roads	4,0
3rd class roads	3,1
Railway total	1,7
Railway single track	1,3
Railway multi track	2,1

Source: INFRAS/IWW, 2004a (data for year 2000).

3.6.2 Costs for soil and water pollution

The most important negative effects of traffic on soil come from the emission of heavy metals and polycyclic aromatic hydrocarbons (PAH) by different transport modes. These pollutants can lead to plant damage and decreased soil fertility along the transport Infrastructure and can sometimes even pose a threat to animals or human beings. The estimation procedures are:

- Repair cost approach for polluted areas (soil and water pollution) along transport Infrastructure (dependent on the Infrastructure length). (INFRAS/IWW, 2000/2004).
- Repair cost approach for the soil and water pollution by heavy metals, organic pollutants (e.g. polycyclic aromatic hydrocarbons, PAH), de-icing salt, herbicides and other agents along transport Infrastructure (dependent on the amount of emissions and the critical concentrations). (OSD, 2006).
- Damage costs approach: health costs for human beings due to the emission of toxic heavy metals into soil, water and air. (ExternE, 1999; NewExt, 2004).

Input values

Most important input values are critical soil and water concentrations of the most important pollutants. The following table gives an overview on repair costs based on the Swiss study mentioned.

Table 36 Repair costs for the disposal and replacement of the polluted soil

Data source, country	*Specific repair costs (in EUR/m³)*
OSD, 2006, Switzerland	58
UNITE, 2000c, EU	36

Source: OSD, 2006 (data for 2004), UNITE, 2000c (data for 1998).

Output values

Table 37 presents unit costs in €ct/vkm based on the results of a Swiss study (Base year 2004). For value transfer to other countries basically an adaptation of the repair cost rates is necessary (GDP/cap. PPP). A value transfer to other countries is sensitive to national and local specifications and should only be undertaken if no national studies are available. The respective results then represent rough estimates only.

Table 37 Soil and water pollution: unit costs for road and rail transport in Switzerland

	Transport mean	*Unit costs, in €ct/vkm*
Road	Passenger cars	0.06
	Busses (Public transport)	1.07
	Coaches	1.05
	Motorcycles	0.04
	Vans	0.17
	Heavy duty vehicles	1.05
Rail	Rail total	0.43
	Rail passenger	0.29
	Rail freight	1.02

Source: OSD, 2006 (data for the year 2004).

3.6.3 External costs in sensitive areas

Methodology and input values

The Eurovignette Directive (1999/62/EC and 2006/38/EC) allows for the possibility to apply mark-ups to tolls in the case of roads in sensitive areas, in particular in mountain regions (Alps, Pyrenees, etc.) for cross-financing the investment costs of other transport Infrastructures of a high EU interest in the same corridor and transport zone. However, there exists no clear EU-wide definition of sensitive areas so far. The recently launched and ongoing EU research project ASSET (Efficient transport and environmentally sensitive areas) aims at developing an EU-wide framework of definitions and assessment methods for transport sensitive areas (TSAs), surveying European TSAs and review existing policies affecting them and finally will produce common policy guidelines for the treatment of TSAs in developing transport systems. A specific case study of GRACE (GRACE, 2006c) dealt with external environmental, accident and other costs in sensitive alpine areas. Sensitive areas there are defined as:

- Areas where damages are higher.
  - Because of higher environmental pressures.
  - And/or because of more damaging effects of the same pressure level.

– And possibly where unique natural resources or cultural heritages are in danger.

The GRACE case study is focussing on cost differentials between an Alpine area and a flat, 'insensitive' area for road and rail transport and the reasons behind. The method is based on the impact pathway approach. For each step in the pathway a comparison is made between an Alpine area and a flat area. The factors for each step are added up to suggest a total cost difference between the Alpine and the flat area. The impact pathway steps considered is Emissions, Concentration and Impacts.

Basically different costs for sensitive areas arise from the following effects:
– Generally higher emissions (air pollutants and noise) due to:
  - Gradients (air pollutants and noise).
  - Higher altitudes (air pollutants).
– Higher concentrations of air pollutants due to:
  - Topographical and/or;
  - Meteorological conditions.
– Higher noise exposition due to temperature inversions and reflections.
– Slightly higher accident rates in alpine areas due to longer braking distances on descending roads.
– Different impacts of air pollution and noise exposure due to different population densities.

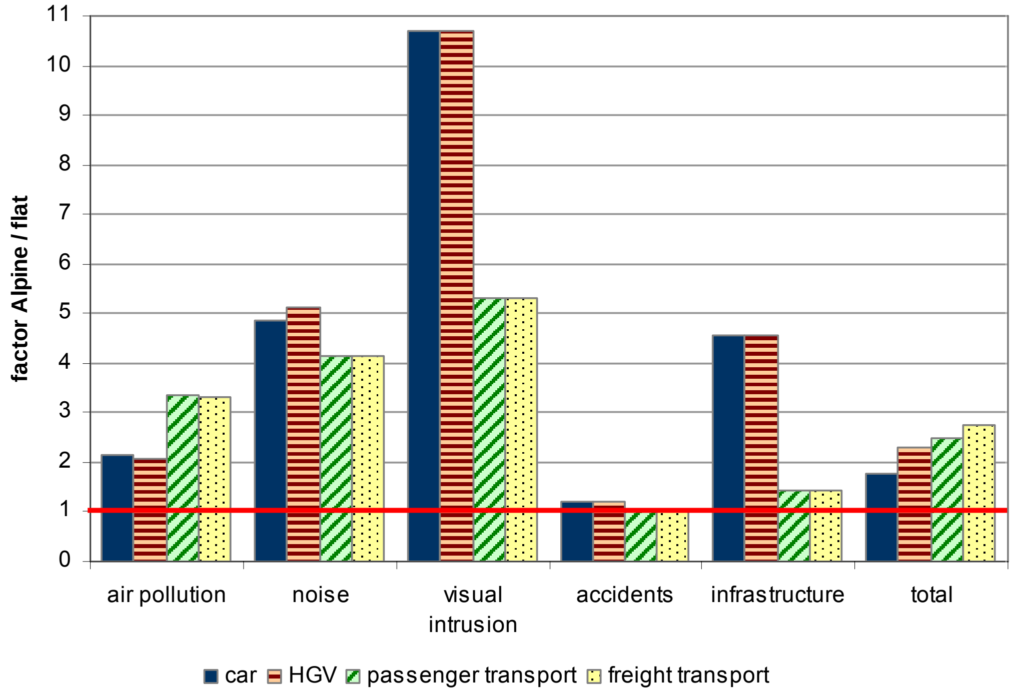
As the main result in GRACE, 2006c factors were derived between the costs in Alpine and flat areas – differentiated for passenger and goods transport and for different indicators (air pollution, noise, accidents and visual intrusion[26]).

Output values

Figure 10 summarizes all the results for the factors between Alpine and flat areas (reduced factors for total instead of local air pollution are used). For road transport the highest factor of more than 10 is observed for visual intrusion, however for marginal cost calculations the factor for visual intrusion is irrelevant due to the fact, that marginal costs of visual intrusion are zero. For noise and Infrastructure costs a factor of 5 is estimated. Effects of local air pollution are also in that magnitude. But due to the regional air pollutants (basically NO_x and SO_2 and secondary particles) the factor is about halved to 2.1. The factor for accidents of 1.2 is again about half of this.

[26] Marginal costs of visual intrusion are zero because these costs are caused by the presence or absence of a transport route, not by the vehicles driving on it.

Figure 10 Factors Alpine/flat for the different effects for road (car and HGV) and rail transport (passenger and freight transport)



Source: GRACE, 2006c.

The overall factor for road traffic is around 2 (weighted by the costs per vkm), the factor for rail transport is slightly higher with about 2.5. The main reason for that are the higher particle emissions of trains while braking in slopes.

The values presented above only refer to increased costs in alpine areas and cannot be transferred to other transport sensitive areas.

3.6.4 Costs of up- and downstream processes

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 than 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 type of energy is causing additional nuisances due to extraction, transport, and transmission. They depend directly on the amount of energy used. A critical issue is the production of electricity of the railways based on the different type of sources (renewable and non renewable). Whereas the air pollution related costs are shown in chapter 3.3, there are additional costs to consider. For this purpose the shadow values of ExternE are proposed. A specific issue is the treatment of nuclear energy risks. It is addressed in the German Handbook on methodology (summary of results in UBA, 2006b). External cost of nuclear energy amount to 0.2-0.3 €ct/kWh if actual risks and environmental damages are included (UBA, 2006b). If social risks of nuclear energy should be included, the political willingness-to-pay for the already decided nuclear power phase-out has to be included by applying external cost values of the next best generation technology. In case of Germany the next best technology would be black or brown coal power stations with external environmental costs between 2.4-7.0 €ct/kWh (black coal) and 3.3-9.5 €ct/kWh (brown coal) respectively. However, there is an ongoing discussion on that and the above cited values should not be considered as a result of economic risk analysis but rather as the first outcome of a basically political and ethical discussion.

- 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).

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 operating, mainly based on additional air pollution and climate change costs. The main difference between the studies is the different kind 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).

Input values

Most important input values are the total emissions of up- and downstream processes (e.g. emission of CO_2, PM_{10}, NO_x, SO_2, etc.). The type of pollutants 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 data can be found in life cycle inventories for transport (e.g. Ecoinvent database (www.ecoinvent.ch)).

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: ‘air pollution costs’ and ‘climate change costs’).

Output values for pre-combustion processes

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

Road transport

Table 38 is presenting the values for road transport.

Table 38 Costs of up- and downstream processes (fuel production, air pollution and climate change costs) in €ct/vkm for passenger cars and heavy duty vehicles (Example Germany, Emissions from TREMOVE model, HEATCO and CAFE CBA valuation factors for Germany used, climate change valuation based on costs factors (€/t CO_2) for 2010 (Table 26)), Price base 2000

Vehicle	**Size**	**EURO-Class**	**Metropolitan**	**Urban**	**Interurban**	**Motorways**	**Average**
			(€ct/vkm)	*(€ct/vkm)*	*(€ct/vkm)*	*(€ct/vkm)*	*(€ct/vkm)*
Passenger Car Petrol	<1,4L	EURO-0	0.81	0.85	0.63	0.78	0.74
		EURO-1	0.90	0.90	0.62	0.64	0.70
		EURO-2	0.83	0.83	0.56	0.58	0.64
		EURO-3	0.82	0.81	0.56	0.57	0.63
		EURO-4	0.74	0.74	0.52	0.54	0.58
		EURO-5	0.69	0.68	0.48	0.50	0.54
	1,4-2L	EURO-0	1.00	0.99	0.74	0.97	0.88
		EURO-1	1.08	1.07	0.71	0.72	0.81
		EURO-2	1.01	1.01	0.67	0.66	0.76
		EURO-3	0.97	0.97	0.65	0.66	0.74
		EURO-4	0.90	0.90	0.61	0.62	0.69
		EURO-5	0.83	0.83	0.57	0.57	0.64
	>2L	EURO-1	1.40	1.39	0.90	0.90	1.03
		EURO-2	1.38	1.37	0.91	0.90	1.03
		EURO-3	1.16	1.16	0.74	0.71	0.85
		EURO-4	1.25	1.24	0.78	0.73	0.89
		EURO-5	1.11	1.10	0.69	0.65	0.79
Passenger Car Diesel	<1,4L	EURO-2	0.51	0.50	0.38	0.40	0.42
		EURO-3	0.47	0.46	0.35	0.36	0.38
		EURO-4	0.43	0.42	0.32	0.33	0.35
		EURO-5	0.45	0.45	0.34	0.35	0.37
	1,4-2L	EURO-0	0.64	0.64	0.41	0.45	0.48
		EURO-1	0.69	0.69	0.52	0.55	0.58
		EURO-2	0.67	0.66	0.50	0.52	0.55
		EURO-3	0.61	0.61	0.45	0.47	0.50
		EURO-4	0.55	0.55	0.41	0.42	0.45
		EURO-5	0.58	0.58	0.43	0.44	0.48
	>2L	EURO-0	0.89	0.88	0.56	0.62	0.67
		EURO-1	0.96	0.95	0.72	0.76	0.80
		EURO-2	0.92	0.91	0.68	0.72	0.76
		EURO-3	0.83	0.83	0.62	0.64	0.68
		EURO-4	0.75	0.75	0.56	0.58	0.62
		EURO-5	0.76	0.76	0.57	0.59	0.63
Trucks	<7.5t	EURO-0	1.58	1.58	1.44	1.40	1.42
		EURO-1	1.34	1.34	1.24	1.24	1.25
		EURO-2	1.28	1.28	1.19	1.20	1.20
		EURO-3	1.35	1.35	1.26	1.25	1.26
		EURO-4	1.27	1.27	1.18	1.17	1.18
		EURO-5	1.30	1.30	1.20	1.19	1.20
	7.5-16t	EURO-0	2.46	2.45	2.16	2.01	2.09
		EURO-1	2.10	2.09	1.87	1.74	1.81
		EURO-2	2.03	2.02	1.81	1.70	1.76
		EURO-3	2.11	2.10	1.87	1.74	1.81
		EURO-4	1.97	1.96	1.75	1.63	1.69
		EURO-5	2.00	2.00	1.78	1.65	1.72
	16-32t	EURO-0	2.44	2.44	2.16	2.00	2.05
		EURO-1	2.10	2.09	1.86	1.74	1.78
		EURO-2	2.02	2.02	1.80	1.68	1.72
		EURO-3	2.11	2.10	1.87	1.74	1.78
		EURO-4	1.97	1.96	1.75	1.62	1.66
		EURO-5	2.00	2.00	1.78	1.65	1.69
	>32t	EURO-0	3.54	3.54	3.05	2.73	2.78
		EURO-1	3.11	3.10	2.69	2.41	2.46
		EURO-2	3.03	3.02	2.63	2.35	2.40
		EURO-3	3.11	3.11	2.68	2.39	2.44
		EURO-4	2.90	2.90	2.50	2.23	2.27
		EURO-5	2.95	2.95	2.54	2.26	2.31

Source emission factors: TREMOVE Base Case (model version 2.4.1).

Rail transport

Table 39 Costs of up- and downstream processes (fuel production and electricity generation, air pollution and climate change costs) in €ct/train-km for rail transport (Example Germany, Emissions from TREMOVE model, HEATCO and CAFE CBA valuation factors for Germany used, climate change valuation based on costs factors (€/t CO_2) for 2010 (Table 26)), Price base 2000

			Metropolitan	**Other Urban**	**Non Urban**
			€ct/ train-km	*€ct/ train-km*	*€ct/ train-km*
Passenger	Electric	Locomotive	4.9	4.9	4.9
		Railcar	7.6	7.7	
		High Speed Train			9.2
	Diesel	Locomotive	8.7	8.7	8.7
		Railcar	11.5	11.5	
Freight	Electric	Locomotive			13.7
	Diesel	Locomotive			29.2

Source emission factors: TREMOVE Base Case (model version 2.4.1).

Inland Waterways

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

Table 40 Costs of up- and downstream processes (fuel production, air pollution and climate change costs) in €/ship-km for inland waterway transport (Example Germany, Emissions from TREMOVE model, HEATCO and CAFE CBA valuation factors for Germany used, climate change valuation based on costs factors (€/t CO_2) for 2010 (Table 26)), Price base 2000

Ship Type	**Indirect Emissions**
	€/ship-km
Dry Cargo <250 ton	0.08
Dry Cargo 250-400 ton	0.08
Dry Cargo 400-650 ton	0.11
Dry Cargo > 3,000 ton	0.40
Dry Cargo 1,000-1,500 ton	0.22
Dry Cargo 1,500-3,000 ton	0.40
Dry Cargo 650-1,000 ton	0.16
Push barge <250 ton	0.52
Push barge 250-400 ton	0.52
Push barge 400-650 ton	0.52
Push barge 650-1,000 ton	0.52
Push barge 1,000-1,500 ton	0.52
Push barge 1,500-3,000 ton	0.52
Push barge > 3,000 ton	1.08
Tanker <250 ton	0.08
Tanker 250-400 ton	0.08
Tanker 400-650 ton	0.11
Tanker 650-1,000 ton	0.16
Tanker 1,000-1,500 ton	0.22
Tanker 1,500-3,000 ton	0.62
Tanker > 3,000 ton	0.62

Source emission factors: TREMOVE Base Case (model version 2.4.1).

Air transport

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

Table 41 Costs of up- and downstream processes (fuel production, air pollution and climate change costs) in €ct/pkm for Air Transport (Example Germany, HEATCO and CAFE CBA cost factors for Germany used, climate change valuation based on costs factors (€/t CO_2) for 2010 (Table 26))

Flight distance	**Indirect Emissions**	
	€ct/pkm	*€/flight*
<500 km	0,71	149
500-1,000 km	0,53	318
1,000-1,500 km	0,40	612
1,500-2,000 km	0,38	914
>2,000 km	0,40	4.265

Source emission factors: TREMOVE Base Case (model version 2.7).

Costs for Infrastructure and vehicle production, maintenance and disposal

This part of external air pollution and climate change costs is not directly Infrastructure use related. Different studies like INFRAS/IWW, 2004a show that the share of these costs for road transport is between 30-40% of total external costs of up- and downstream processes, for rail transport the share is highly dependent of the electricity generation mix (higher 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%.

3.6.5 Additional costs in urban areas

Motorised traffic in urban areas has different effects on non-motorised traffic participants (pedestrians, cyclists, etc.). The following two effects are quantified in certain external cost studies:

- Time losses for pedestrians due to separation effects of road Infrastructure.
- Scarcity problems (expressed as the loss of space availability for bicycles)[27].

Other possible effects (e.g. urban visual intrusion due to transport volume and Infrastructure) are very difficult to measure and no reliable estimates are known.

Different approaches are used for measuring the two effects in urban areas.

[27] It has to be noted that this scarcity effect can only serve as a proxy for external scarcity costs for non motorised transport in urban areas. It might be more efficient to use this argument for transport planning instead of pricing. Some regions are however earmarking road taxes to finance bicycle lanes.

- Damage costs due to *separation effects* of transport Infrastructure in urban areas can be measured through additional waiting time for pedestrians
- For *scarcity problems* due to transport Infrastructure a compensation cost approach can be used (construction of bicycle lanes) (INFRAS/IWW, 2000/2004a; OSD, 2006). These costs are however only then relevant if bicycle lanes really will be constructed as a result of increased traffic.

Input values

Table 42 and Table 43 present the most important input values.

Table 42 Separation effects: input values and cost factors for road and rail Infrastructure in urban areas. Data for Switzerland

	Road			**Rail**
	Type A: regional / communal road	Type B: main street, 2 or max. 3 lanes	Type C: city motorway (4 lanes or more)	
Average number of crossings per day and person	3	2	1.5	1.5
Average time lost per crossing (in s)	10	45	260	260
Time cost factor for pedestrians (road and rail)	6.5 €/hour			

Source: OSD, 2006 (data for year 2004).

Table 43 Scarcity problems: specific cost factors for the construction of bicycle lanes in urban areas. Data for Switzerland

Cost rates for bicycle lanes	*Cost rates*
Bicycle lane: painted lane on the road track	1,900 EUR/(km*a)
Bicycle lane: separate track	24,100 EUR/(km*a)

Source: OSD, 2006 (data for year 2004).

Output values

The results of INFRAS/IWW (2004a) are shown in Table 44.

Table 44 Additional costs in urban areas: unit costs for road and rail transport in Europe (EU-15 plus CH and NO, European average results)

	Transport mean	*Unit costs, in €ct/vkm*
Road	Passenger cars	0.26
	Busses and coaches	0.66
	Motorcycles	0.11
	Vans	0.37
	Heavy duty vehicles	0.77
Rail	Rail total	16.83
	Rail passenger	16.50
	Rail freight	17.93

Source: INFRAS/IWW, 2004a (data for year 2000).

3.6.6 Costs of energy dependency

The unequal distribution of mineral oil in the different world regions leads to another category of external costs of transport which arise through the high dependency on oil producing countries (mostly organised within the OPEC cartel). A number of studies have assessed the economic costs of oil dependency (i.e. in percent of GDP) but only few studies assess the external costs of oil dependency with a direct link to transport costs.

The study of Greene and Ahmad, 2005 has investigated the costs of U.S. oil dependence including three categories:

1 Costs due to transfer of wealth (transfer from oil consumers to oil producers due to market power).
2 Potential GDP losses: reduction of the maximum output an economy is capable of producing due to the increased economic scarcity of oil.
3 Macroeconomic adjustment costs: costs of adjusting to sudden, large price changes.

In addition, a study by Parry and Darmstadter for the U.S. National Commission on Energy Policy (Tol, 2004) gives a second assessment of the costs of oil dependency which also takes account of the fact that not only the oil producing nations have monopoly power but that the U.S. as largest oil importer partly needs to be seen as monopsony.

Output values

Most of the studies on the costs of energy dependence are U.S. studies on the costs of US oil imports and can thus only be used as indicative values for European countries (Leiby et al., 1997; NRC, 2002; Parry and Darmstadter, 2004; Leiby, 2007). The two major costs mentioned are economic losses as a result of oil prices above a competitive market level (due to market power of the oil suppliers) and costs of oil supply disruptions.

The results from the mentioned U.S. studies for the energy dependency costs range from 3.6 UDS per barrel (Leiby, 1997) to 5 USD/barrel (NRC, 2002, Parry and Darmstadter) to 13.6 USD per barrel in the latest study of Leiby, 2007.

Table 45 Marginal external costs of oil dependency from different studies in €/l mineral oil

Study	Baseyear for calculation	USD/barrel	€ct/l mineral oil**	Specific aspects considered
Leiby et al., 1997	1993	0.23 – 9.91	0.17 – 7.2	Different scenarios from 'zero probability of net disruption' to 'Monopsony of US and monopoly of OPEC'
NRC, 2002	Assumption: 1999	5	3.35	
Parry and Darmstadter, 2004	Based on NRC, 2002	5	3.35	Includes aspect of monopsony
Leiby, 2007	2004	13.6	10.63	Includes costs of enhancing oil security (strategic oil reservers, military presence in Middle East)

Notes: * The NRC 2002 study is an update of earlier work, the base year does not become clear.
** Values are transformed with the relevant annual exchange rate according to the Swiss National Bank.

Results on the external costs of energy dependence are at the moment only available for the U.S., as especially oil security is a major political issue in the U.S. Due to different economic structures and energy mixes, the U.S. values cannot directly be transferred into European values but need to be seen as indicative values only.

A Best Practice approach for Europe is not yet available and would need to include information on the degree of oil dependency of the relevant country, its energy intensity, the importance of energy intensive industries as well as the market position of the country or the European Union as a whole as market force on the demand side. One should take care when trying to assess the EU costs to take account of:

1 The risk premium already in the crude oil price.
2 The US estimates may include the related defence costs which are far lower for the EU.

4 Unit cost values and value transfer procedure

The unit costs presented in this chapter are based on the output values per cost component and mode discussed in chapter 3. It has to be considered that the figures are exemplary for a selection of vehicle categories, emission standards and traffic situations based on a pragmatic aggregation of output values. They serve as a magnitude and reference value for the further development of external cost estimation.

Due to the fact that for most cost categories country-specific valuation factors have to be applied and in order to improve readability only exemplary figures for one specific country (Germany as a large, central European country) are presented. The data for road transport refer to Euro-3 vehicles (referring to the most widely used vehicle at present). The values are expressed in Euro of 2000. In order to adjust and differentiate values for other countries, other vehicle categories, emissions standards or specific traffic situations we recommend using the output values presented for each cost component in chapter 3 and adjust them to the specific situation following the cost category specific recommendations for value transfer procedures presented in section 4.3.2.

Within the IMPACT project, external cost figures for all European countries have been calculated based on the available output values (see previous chapters). These values are used for the model calculations (TREMOVE, TRANSTOOLS, ASTRA) in the context of the impact assessment of different policy and internalisation strategies.

4.1 Level of differentiation

The level of disaggregation differs according to cost components and mode. Table 46 shows the most important differentiation per cost component and mode.

Table 46 Overview of differentiation of unit values per cost component

Cost component	**Road** **Passenger Car** **HDV** **Bus/Coach**	**Rail** **Passenger** **Freight**	**Air** **Passenger** **Freight**	**Waterways** **Inland Waterways** **Seaports**
Congestion costs (road)	Costs per vkm Type of Infrastructure (Interurban, urban, metropolitan) Peak – off-peak	-	-	-
Scarcity costs	-	*Costs per trainkm* *Peak-off-peak* *(Costs per train)*	*(Costs per aircraft-km* *Peak-off-peak)*	*(Cost per vessel and cm of water level)*
Accident costs	Costs per vkm Type of Infrastructure (urban-interurban)	Costs per train-km	Costs per LTO	Costs per vessel-km (Type of ship)
Noise costs	Costs per vkm Urban-Interurban Day - Night	Costs per train-km Urban-interurban Day - Night	Costs per aircraft (Landing & take-off: LTO) Day - Night Type of aircraft	-
Air Pollution	Costs per vkm Urban-interurban Peak-off-peak Euro standards Fuel type	Costs per train-km Urban-interurban Electric Diesel	Costs per aircraft (Landing & take-off: LTO) Aircraft-km Type of aircraft	Costs per vessel-km (Type of ship)
Climate change	Costs per vkm Urban-interurban Peak-off-peak Engine capacity Vehicle weight Fuel type	Costs per train-km Urban-interurban Electric Diesel	Costs per aircraft-km LTO, cruise Type of aircrafts	Costs per vessel-km (Type of ship)
Additional external costs	Costs per vkm Costs per km Infrastructure	Costs per vkm Infrastructure	Costs per aircraft-km	Costs per vessel-km (Type of ship)

4.2 Ranges and levels of accuracy per mode of transport

4.2.1 Unit cost values per vkm

The following tables and figures provide an overview of the range of the unit values recommended for the different cost categories and transport modes. They reflect marginal cost figures based on the studies examined and the recommended values in chapter 3.

Road transport

The following Table 47 presents the values for road transport. Note that values for the different cost components are not fully consistent as they are based on different base years. If values differ for EU countries, exemplary values have been taken for Germany as a large, central European country. The bandwidths presented correspond to the bandwidths discussed in the output value sections of each cost category in chapter 3.

Table 47 Road transport: exemplary unit values per cost component in €ct/vehicle-km for Germany (€2000)

Cost component		**Passenger car**	**Heavy duty vehicle (HDV)**
€ct/vkm		*Unit costs (bandwidths)*	*Unit costs (bandwidths)*
Noise	Urban, day	0.76 (0.76 - 1.85)	7.01 (7.01 - 17.01)
	Urban, night	1.39 (1.39 - 3.37)	12.8 (12.8 - 31)
	Interurban, day	0.12 (0.04 - 0.12)	1.1 (0.39 - 1.1)
	Interurban, night	0.22 (0.08 - 0.22)	2 (0.72 - 2)
Congestion	Urban, peak	30 (5 - 50)	75 (13 - 125)
	Urban, off-peak	0 (-)	0 (-)
	Interurban, peak	10 (0 - 20)	35 (0 - 70)
	Interurban, off-peak	0 (-)	0 (-)
Accidents	Urban	4.12 (0 - 6.47)	10.5 (0 - 13.9)
	Interurban	1.57 (0 - 2.55)	2.7 (0 - 3.5)
Air pollution	Urban, petrol	0.17 (0.17 - 0.24)	(-)
	Urban, diesel	1.53 (1.53 - 2.65)	10.6 (10.6 - 23.4)
	Interurban, petrol	0.09 (0.09 - 0.15)	(-)
	Interurban, diesel	0.89 (0.89 - 1.8)	8.5 (8.5 - 21.4)
Climate change	Urban, petrol	0.67 (0.19 - 1.2)	(-)
	Urban, diesel	0.52 (0.14 - 0.93)	2.6 (0.7 - 4.7)
	Interurban, petrol	0.44 (0.12 - 0.79)	(-)
	Interurban, diesel	0.38 (0.11 - 0.68)	2.2 (0.6 - 4)
Up- and downstream processes	Urban, petrol	0.97 (0.97 - 1.32)	(-)
	Urban, diesel	0.61 (0.61 - 1.05)	3.1 (3.1 - 6.9)
	Interurban, petrol	0.65 (0.65 - 1.12)	(-)
	Interurban, diesel	0.45 (0.45 - 0.92)	2.7 (2.7 - 6.7)
Nature & landscape	Urban	-	0 (0 - 0)
	Interurban	0.4 (0 - 0.4)	1.15 (0 - 1.15)
Soil & water pollution	Urban/Interurban	0.06 (0.06 - 0.06)	1.05 (1.05 - 1.05)
Total			
Urban	Day, peak	38.4 (8.4 - 63.9)	107.3 (33.7 - 187.4)
	Day, off-peak	7.9 (3.5 - 13.3)	34.8 (22.5 - 67)
	Night, off-peak	8.6 (4.1 - 14.8)	40.6 (28.2 - 80.9)
Interurban	Day, peak	14.1 (1.7 - 26.7)	54.4 (13.3 - 109)
	Day, off-peak	4.1 (1.7 - 6.7)	19.4 (13.3 - 39)
	Night, off-peak	4.2 (1.8 - 6.8)	20.3 (13.6 - 39.9)

Explanations by cost category:

Noise costs: Recommended output values from Table 21, p. 69, car/HGV, urban/suburban.
The lower limit of the bandwidth is based on dense traffic situations, while the upper limit is based on thin traffic situations. Unit cost value chosen based on the predominant traffic situation in the respective regional cluster: urban: dense; interurban: thin.

Congestion: Congestion Urban: Recommended output values from Table 7, p. 34, small and medium urban areas, urban collectors (2000 values).
Congestion Interurban: Recommended output values from Table 7**,** p. 34, rural areas, motorways (2000 values).

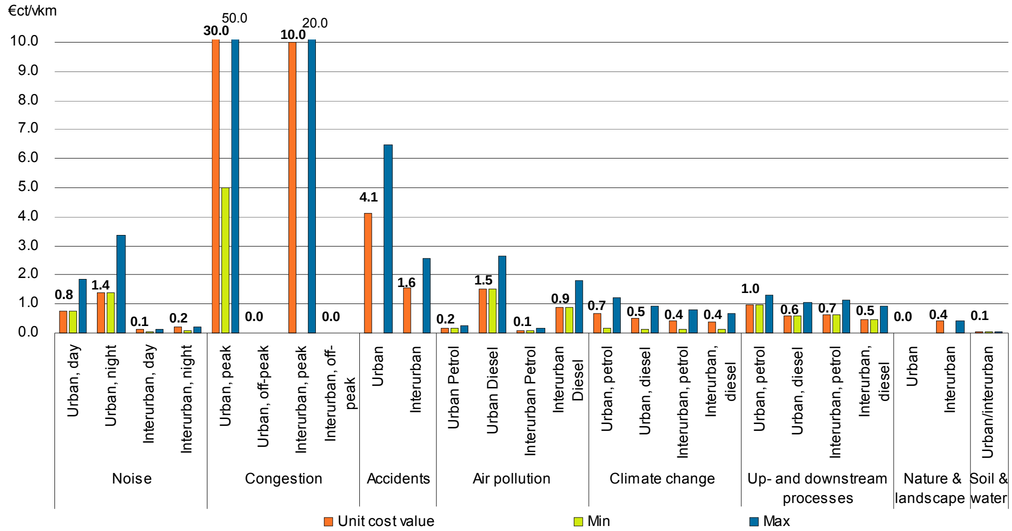
Accident costs: Accidents Urban: Exemplary values for Germany Table 10**,** p. 44, urban roads (2000 values).
Accidents Interurban: Exemplary values for Germany from Table 10**,** p. 44, other roads (2000 values).

Air pollution: Output values from Table 15, p. 57, exemplary for Germany, urban/interurban; for passenger car: medium vehicle (1.4-2 L), EURO 3, for HGV: truck >32 t, EURO-3. Ranges represent different sensitivity analysis carried out in CAFE CBA (e.g. different valuation of value of life years lost).

Climate change: Exemplary values for Germany Table 28, p. 84, for passenger car: medium vehicle (1.4-2 L), EURO-3, for HGV: truck >32 t, EURO-3, based on valuation for 2010. Note that climate cost increase over time.

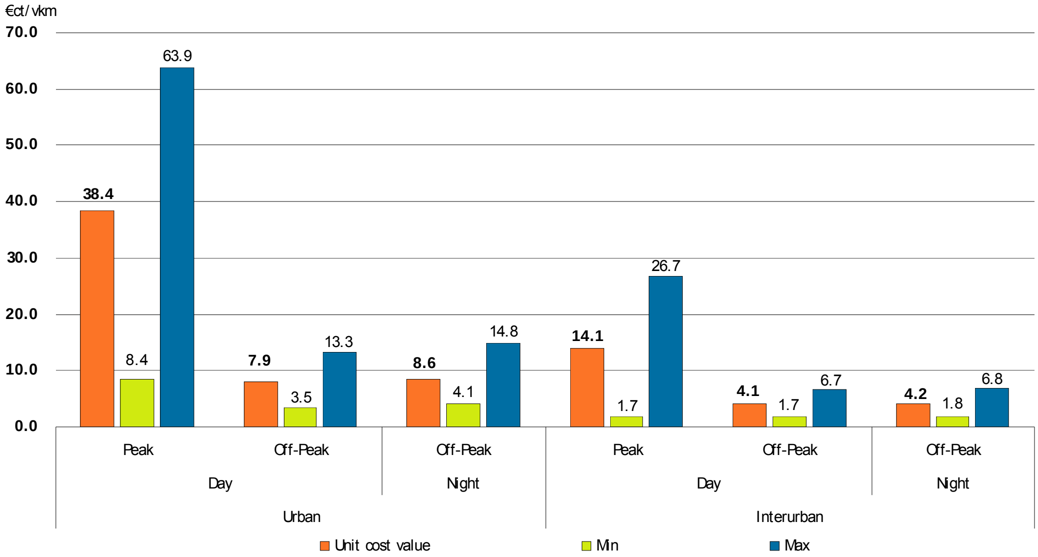
Up- and downstream:	Air pollution and climate change costs of well-to-tank emissions. Exemplary values for Germany from Table 38, p. 94. Passenger car: medium vehicle (1.4-2 L), EURO 3, for HGV: truck >32 t, EURO-3. Ranges represent different sensitivity analysis carried out in CAFE CBA (e.g. different valuation of value of life years lost).
Nature&Landscape:	Source: INFRAS/IWW, 2004. No external costs in urban and built-up areas. Ranges Interurban: Min: short run marginal costs, Max: long run marginal costs.
Soil&water:	Recommended values from Table 37, p. 90, values for Switzerland (2000 values).
Total	Total bandwidths are calculated by adding up the bandwidths of each cost category.

Figure 11 Passenger cars: Unit Values per cost category in €ct/vkm (in €2000) based on unit values for all cost components from Table 47.



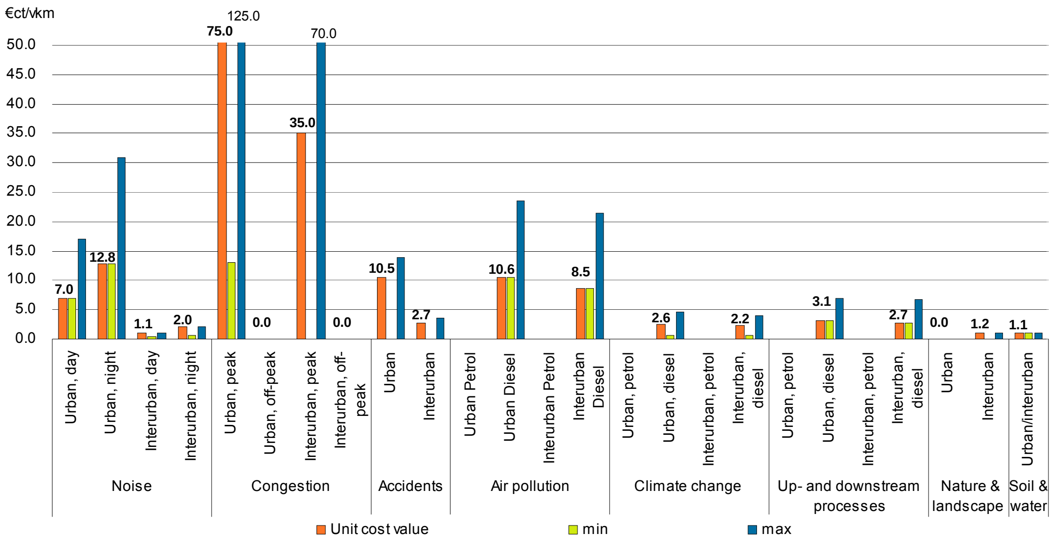
Notes: Unit cost values in **bold**.

Figure 12 Passenger cars (petrol): Unit Values per traffic situation in €ct/vkm (in €2000) based on unit values for all cost components from Table 47



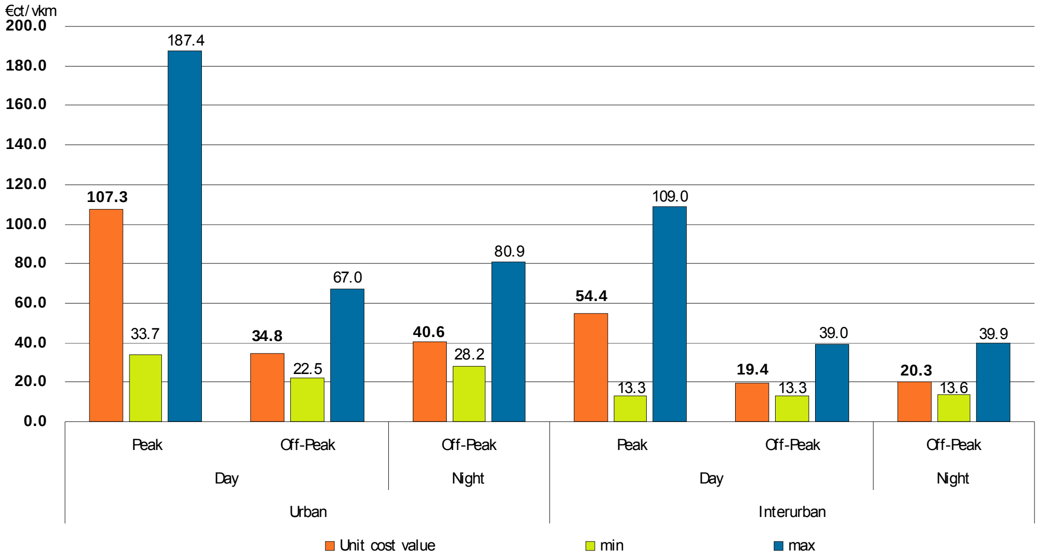
Note: for pricing purposes not all cost components might have to be considered (e.g. costs for nature and landscape)

Figure 13 Heavy goods vehicles: Unit cost per cost category in €ct/vkm (in €2000) based on unit values for all cost components from Table 47.



Notes: Unit cost values in **bold**.

Figure 14 Heavy goods vehicles: Unit values per traffic situation in €ct/vkm (in €2000) based on unit values for all cost components from Table 47.



Note: for pricing purposes not all cost components might have to be considered (e.g. costs for nature and landscape)

Rail transport

Values for the different cost components are not fully consistent as they are based on different base years. If values differ for EU countries, exemplary values have been taken for Germany as a large, central European country.

Table 48 Rail transport: exemplary unit values per cost component in €ct/train-km for Germany (€2000)

Cost component		*Rail passenger*	*Rail freight*
		Unit costs (bandwidths)	*Unit costs (bandwidths)*
Noise costs	Urban, day	23.7 (23.7 - 46.7)	41.9 (41.9 - 101.2)
	Urban, night	78 (78 - 78)	171.1 (171.1 - 171.1)
	Interurban, day	20.6 (10.4 - 20.6)	40.1 (20.7 - 40.1)
	Interurban, night	34.4 (34.4 - 34.4)	67.7 (67.7 - 67.7)
Scarcity costs	Peak	20 (0 - 20)	20 (0 - 20)
Accident costs	Urban/Interurban	8 (8 - 30)	8 (8 - 30)
Air pollution	Urban, electric	0 (0 - 0)	0 (0 - 0)
	Urban, diesel	144.8 (144.8 - 297.2)	366.8 (366.8 - 752.6)
	Interurban, electric	0 (0 - 0)	0 (0 - 0)
	Interurban, diesel	90.7 (90.7 - 203.6)	305.8 (305.8 - 686.4)
Climate change	Urban, electric	0 (0 - 0)	0 (0 - 0)
	Urban, diesel	11.4 (3.2 - 20.6)	28.9 (8.1 - 52.1)
	Interurban, electric	0 (0 - 0)	0 (0 - 0)
	Interurban, diesel	8.6 (2.4 - 15.5)	28.9 (8.1 - 52.1)
Up- and downstream processes	Urban, electric	24.8 (16.4 - 52.1)	44.4 (22.3 - 93)
	Urban, diesel	13.8 (12.2 - 27.7)	34.8 (30.8 - 70.1)
	Interurban, electric	15.9 (8 - 33.4)	44.4 (22.3 - 93)
	Interurban, diesel	10.3 (9.1 - 22.5)	34.8 (30.8 - 75.7)
Nature & landscape	Interurban	23.2 (0 - 23.2)	7.5 (0 - 7.5)
Soil & water pollution	Urban/Interurban	0.3 (0.3 - 0.3)	1 (1 - 1)
Total external costs			
Urban	**Day, electric, peak**	76.8 (48.3 - 149)	115 (73 - 245)
	Day, electric, off-peak	56.8 (48.3 - 129)	95 (73 - 225)
	Day, diesel, peak	222 (192.1 - 442)	502 (457 - 1027)
	Day, diesel, off-peak	202 (192.1 - 422)	482 (457 - 1007)
	Night, electric, off-peak	111.1 (102.6 - 160)	225 (202 - 295)
	Night, diesel, off-peak	256.3 (246.5 - 454)	611 (586 - 1077)
Interurban	**Day, electric, peak**	88 (26.7 - 127)	121 (52 - 192)
	Day, electric, off-peak	68 (26.7 - 107)	101 (52 - 172)
	Day, diesel, peak	181.7 (121 - 336)	446.2 (374 - 913)
	Day, diesel, off-peak	161.7 (121 - 316)	426 (374 - 893)
	Night, electric, off-peak	81.8 (50.7 - 121)	129 (99 - 199)
	Night, diesel, off-peak	175.5 (144.9 - 329)	454 (421 - 920)

Explanations by cost category:

Noise costs: Recommended output values from Table 21, p.69, passenger/freight train, urban/suburban. The lower limit of the bandwidth is based on dense traffic situations, while the upper limit is based on thin traffic situations. Unit cost value chosen based on the predominant traffic situation in the respective regional cluster: urban: dense; interurban: thin. For night time, no bandwidths are available. Marginal costs.

Scarcity: Based on values from UNITE D7: morning peak based on UK and Swiss evidence (see section 3.1.4).

Accidents Based on values from UNITE (see section 3.2.4)

Air pollution: Recommended output values from Table 16, p. 59, exemplary for Germany, urban (railcar/locomotive electric/Diesel)/interurban (locomotive electric/Diesel), Ranges represent different sensitivity analysis carried out in CAFE CBA (e.g. different valuation of value of life years lost).

Climate change: Exemplary values for Germany from Table 29, p. 85, urban/interurban.

Up- and downstream:	Exemplary values for Germany for air pollution and climate change costs of up- and downstream processes (well-to-tank emissions) of electricity generation and fuel production, from Table 39, p. 95).
Nature&Landscape:	Source: INFRAS/IWW, 2004. No external costs in urban and built-up areas. Ranges Interurban: Min: short run marginal costs, Max: long run marginal costs.
Soil&water:	Recommended values from Table 37, p. 90, values for Switzerland (2000 values).
Total	Total bandwidths are calculated by adding up the bandwidths of each cost category.

Figure 15 Rail passenger transport: Unit values per cost category in €ct/train-km (in €2000) based on unit values for all cost components from Table 48.

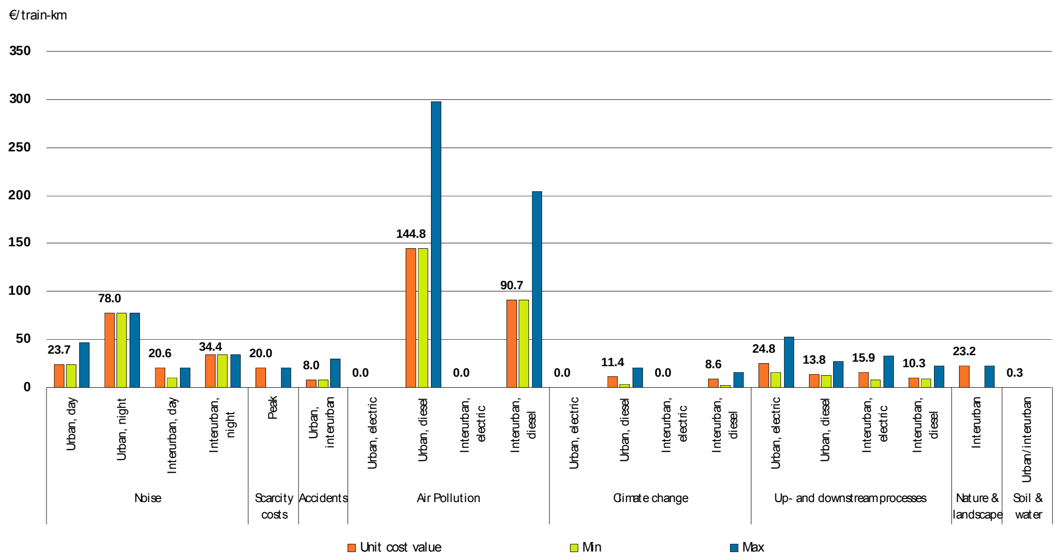
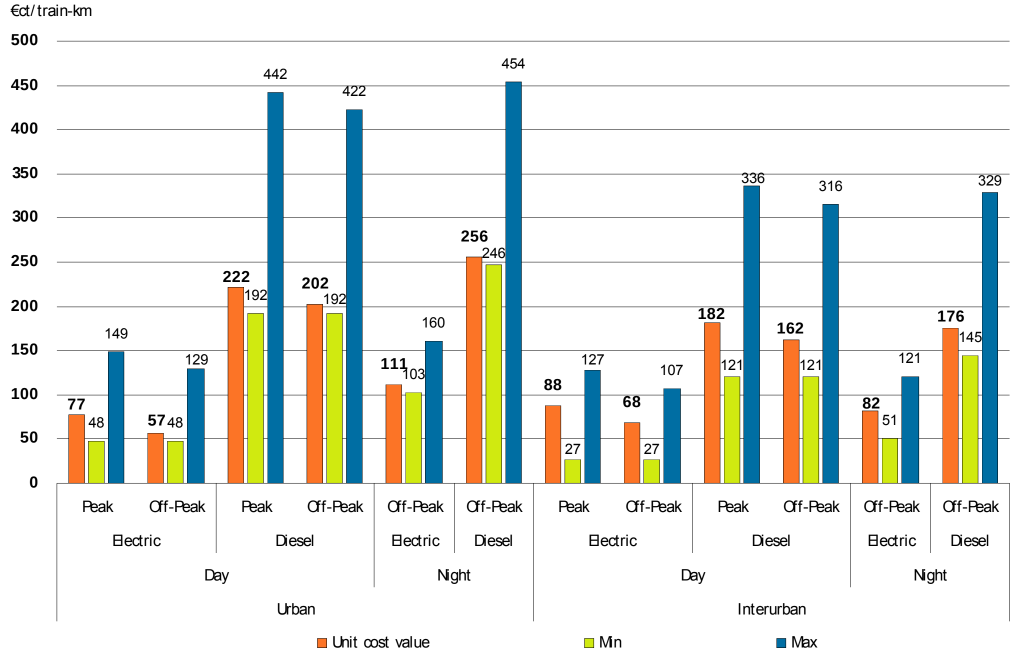


Figure 16 Rail passenger transport: Unit values per traffic situation in €ct/train-km (in €2000) based on unit values for all cost components from Table 48.



Note: for pricing purposes not all cost components might have to be considered (e.g. costs for nature and landscape)

Figure 17 Rail freight transport: Unit values per cost category in €ct/train-km (in €2000) based on unit values for all cost components from Table 48.

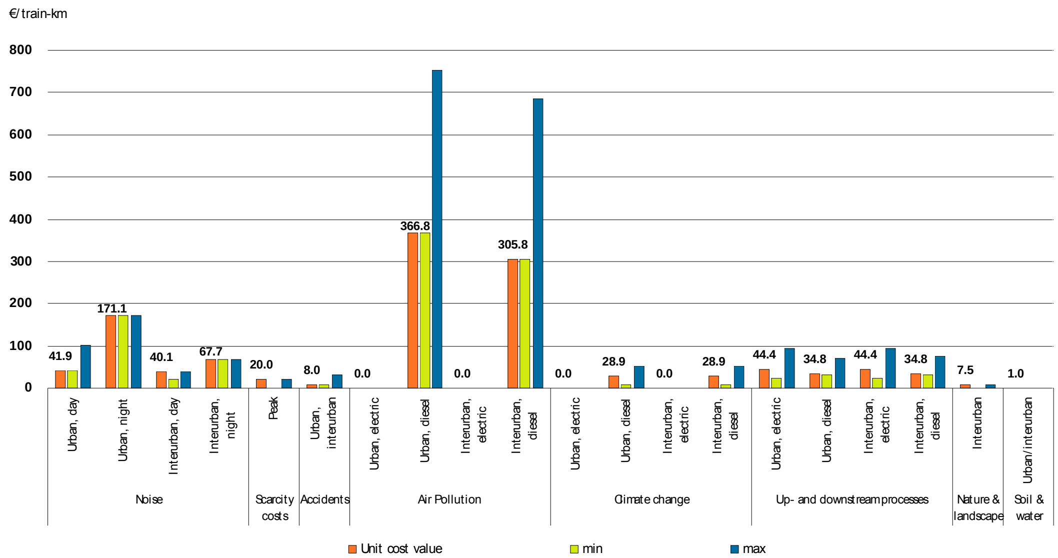
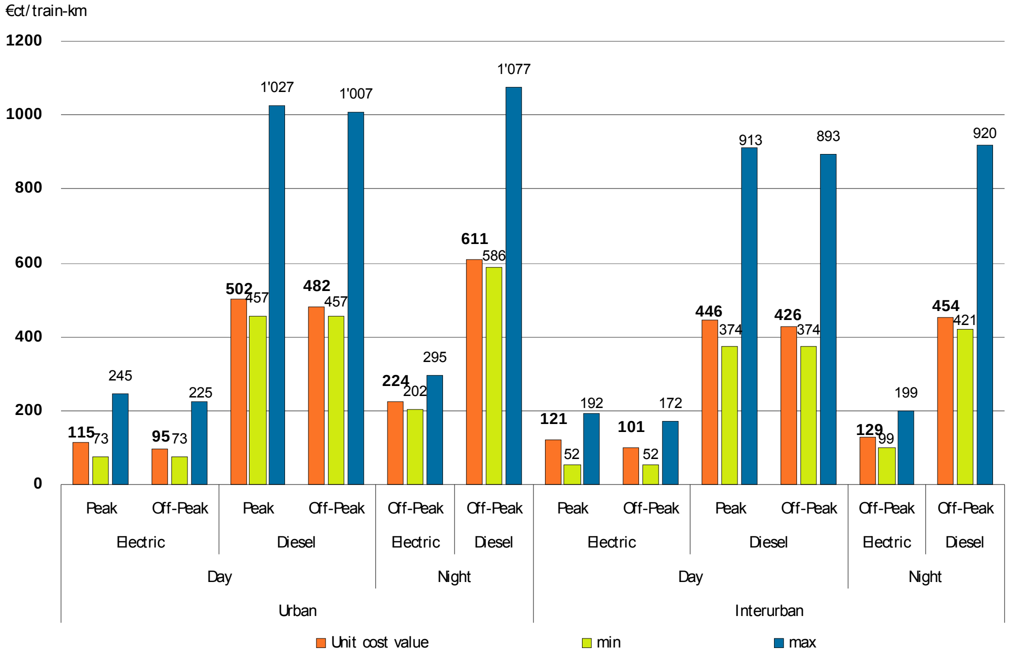


Figure 18 Rail freight transport: Unit values per traffic situation in €ct/train-km (in €2000) based on unit values for all cost components from Table 48.



Note: for pricing purposes not all cost components might have to be considered (e.g. costs for nature and landscape)

Air transport

Table 49 Air transport: Unit values per cost component in €/ flight in €2000

Cost component		*Air passenger*
		weighted EU-19 average values
Noise costs		228
Scarcity costs	Peak	n.a.
	Off-Peak	n.a.
Accident costs		118
Air Pollution		117
Climate change		530
Up- and downstream processes		612
Additional external costs (nature & landscape)		n.a.
Total external costs		**993**

Explanations by cost category:

Noise costs: Value can also be expressed in €/LTO since noise costs only occur during take-off and landing of an aircraft, Model results of TREMOVE model (EU-19 average values).

Scarcity costs: Not available.

Accident costs: Model results of TREMOVE model (EU-19 average values).

Air pollution: Distance class 1.000-1.500 km, Model results of TREMOVE model (valuation factors for Germany used).

Climate change: Distance class 1.000-1.500 km, costs correspond to the costs of a whole flight (from origin to destination), costs are without climate impacts of non-CO2 emissions, Model results of TREMOVE model (EU-19 average values).

Up- and downstream: Distance class 1.000-1.500 km, costs correspond to the costs of a whole flight (from origin to destination), Model results of TREMOVE model acc. to Table 41 (p. 96), valuation of air pollutants with valuation factors for Germany.

Nature&Landscape: Not available.

Waterways transport

Table 50 Inland waterways: unit values per cost component in €ct/ship-km (only comprehensive data for air pollution and climate change costs available) in €2000

Cost component	*Waterborne freight transport*
	weighted EU-19 average values
Noise	(–)
Scarcity	(–)
Accidents	(–)
Air pollution	89-1260
Climate change	8-114
Up- and downstream processes	8-108
Nature & landscape	(–)
Soil & water pollution	(–)
Total external costs	105-1482

Explanations by cost category:

Air pollution: Ranges correspond to costs of different ship types acc. to Table 17 (*Model results of TREMOVE model (valuation factors for Germany).*

Climate change: Ranges correspond to costs of different ship types acc. to Table 30, using the central value for climate change costs from Table 26, *Model results of TREMOVE model (EU-19 average values).*

Up- and downstream: Ranges correspond to costs of different ship types acc. to Table 40 (p. 95), Model results of TREMOVE model, valuation of air pollutants with valuation factors for Germany.

Total Total bandwidths are calculated by adding up bandwidths of all categories.

4.2.2 Comparison Road-Rail (in €/pkm and €/tkm)

Using the average load factors for road and rail transport, average costs per passenger-km and tonne-kilometre have been calculated.

Table 51 Comparison Road-Rail passenger transport: using average load factors

		Passenger transport (€ct/pkm)	
		Passenger Car Unit cost value	Train Passenger Unit cost value
Noise	Urban, day	0.46	0.25
	Urban, night	0.84	0.82
	Interurban, day	0.07	0.14
	Interurban, night	0.14	0.23
Accidents	Urban	2.50	0.05
	Interurban	0.97	0.05
Air pollution	Urban Petrol/Train Electric	0.10	0.00
	Urban Diesel/Train Diesel	0.93	1.51
	Interurban Petrol/Train Electric	0.05	0.00
	Interurban Diesel/Train Diesel	0.55	0.61
Climate change	Urban Petrol/Train Electric	0.40	0.00
	Urban Diesel/Train Diesel	0.31	0.12
	Interurban Petrol/Train Electric	0.27	0.00
	Interurban Diesel/Train Diesel	0.23	0.06
Up- and down-stream processes	Urban Petrol/Train Electric	0.60	0.26
	Urban Diesel/Train Diesel	0.37	0.14
	Interurban Petrol/Train Electric	0.40	0.11
	Interurban Diesel/Train Diesel	0.28	0.07
Nature and Landscape	Urban	0.00	0.00
	Interurban	0.25	0.16
Urban	Day (Petrol/Electric)	4.1	0.6
	Day (Diesel/Diesel)	4.6	2.1
	Night (Petrol/Electric)	4.5	1.1
	Night (Diesel/Diesel	5.0	2.6
Interurban	Day (Petrol/Electric)	2.0	0.5
	Day (Diesel/Diesel)	2.4	1.1
	Night (Petrol/Electric	2.1	0.5
	Night (Diesel/Diesel)	2.4	1.2

Explanations: Average load factors from TREMOVE Model outputs (EU19 average values):
Passenger car: urban: 1.65 persons/car, interurban: 1.62 persons/car.
Passenger train: urban: 96 passengers/train, interurban: 149 passengers/train.

Figure 19 Comparison road and rail passenger transport: cost per Pkm in €ct/pkm based on unit values for all cost components from Table 51.

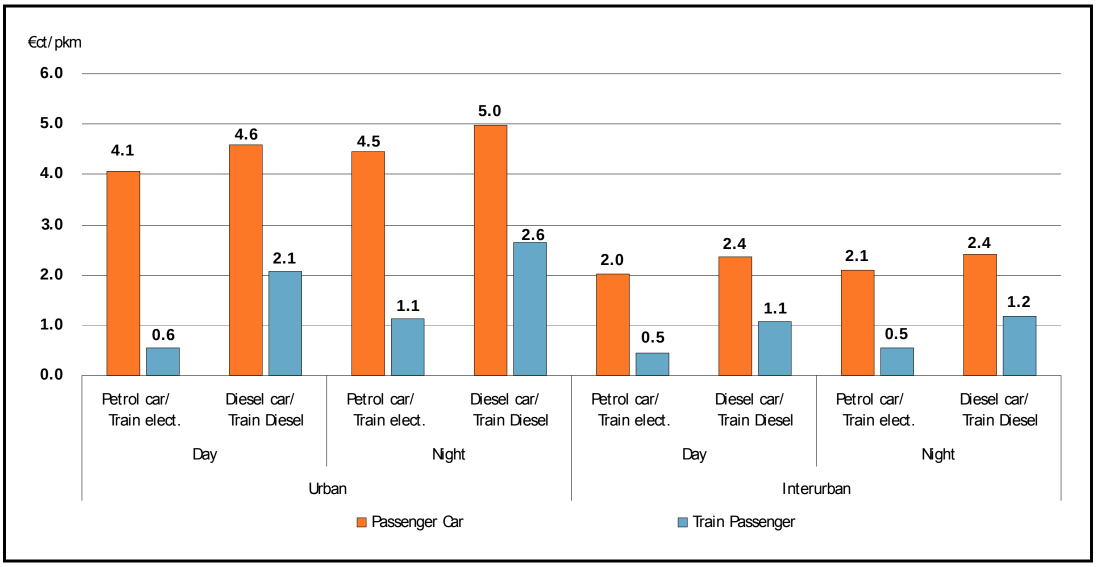
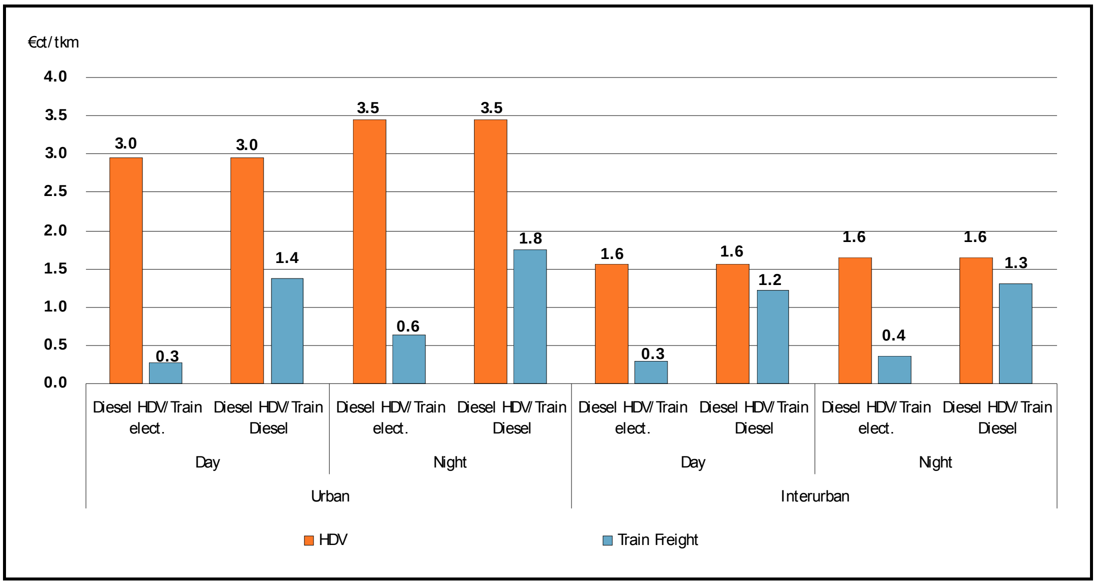


Table 52 Comparison Road-Rail freight transport: using average load factors

		Freight transport (€ct/tkm)	
		HDV Unit cost value	Freight Train Unit cost value
Noise	Urban, day	0.61	0.12
	Urban, night	1.12	0.49
	Interurban, day	0.09	0.11
	Interurban, night	0.17	0.19
Accidents	Urban	0.92	0.02
	Interurban	0.23	0.02
Air pollution	Urban Diesel/Train Electric	0.93	0.00
	Urban Diesel/Train Diesel	0.93	1.05
	Interurban Diesel/Train Electric	0.73	0.00
	Interurban Diesel/Train Diesel	0.73	0.88
Climate change	Urban Diesel/Train Electric	0.23	0.00
	Urban Diesel/Train Diesel	0.23	0.08
	Interurban Diesel/Train Electric	0.19	0.00
	Interurban Diesel/Train Diesel	0.19	0.08
Up- and down-stream processes	Urban Diesel/Train Electric	0.27	0.13
	Urban Diesel/Train Diesel	0.27	0.10
	Interurban Diesel/Train Electric	0.23	0.13
	Interurban Diesel/Train Diesel	0.23	0.10
Nature and Landscape	Urban	0.00	0.00
	Interurban	0.10	0.02
Urban	Day (Diesel/Electric)	3.0	0.3
	Day (Diesel/Diesel)	3.0	1.4
	Night (Diesel/Electric)	3.5	0.6
	Night (Diesel/Diesel)	3.5	1.8
Interurban	Day (Diesel/Electric)	1.6	0.3
	Day (Diesel/Diesel)	1.6	1.2
	Night (Diesel/Electric)	1.6	0.4
	Night (Diesel/Diesel)	1.6	1.3

Explanations: Average load factors from TREMOVE Model outputs (EU19 average values):
HDV: urban: 11.4 tons/vehicle, interurban: 11.7 tons/vehicle.
Freight train: 348 tons/train.

Figure 20 Comparison road and rail freight transport: cost per tkm in €ct/tkm based on unit values for all cost components from Table 52.



4.3 Value transfer procedure

4.3.1 General issues

The unit values are the basis for calculating the values for the various traffic situations, modes, types of vehicle and countries. To calculate the values for Member States, a value transfer is proposed. It has to be noted that a value transfer is only recommended, if regional figures cannot be provided. The value transfer procedures allow to safe resources and serve as plausibilisation for regional values compared to EU average values.

- Transfer of dose-response functions: A transfer is possible. For some cost components a transfer needs additional information.
- Congestion: Local Speed-Flow curves are useful, since traffic situations might differ between countries.
- Accidents: The national insurance systems have to be considered which might lead to different levels of externalities.
- Nature and landscape: The general settlement situation should be considered.
- Transfer of data: If possible local data (traffic, emissions, concentrations, etc.) should be used. Value transfers are only possible if specific clusters (e.g. specific traffic situations and exposure situation) can be defined.
- Transfer of unit values (VSL, VOT, etc.): The literature (UNITE, INFRAS/IWW, HEATCO) is proposing a value transfer based on GDP per capita (PPP adjusted). This implies the assumption that the unit values are linked with income with an elasticity of 1. For some countries, national values exist. The values of statistical life often do however not correspond with the recommendations of EU research projects. Therefore an update of national

values with reference to the EU values would be necessary. Compared to that the national values of time are more robust.

- For large countries a break down to smaller territorial level (e.g. NUTS 2) is possible provided that sufficiently disaggregated input values are available (traffic volumes, emissions, exposition to pollutants and noise, socio-economic data, etc.).
- It is important to consider the specific situation in the New Member States (NMS), where national data (e.g. detailed environmental and traffic data) is missing and the level of statistics not the same than in Western Europe. The value transfer to the NMS therefore has to be simplified concentrating on general values and using a transparent value transfer mechanism (such as the GDP per capita transfer). See the following chapter for a detailed discussion.

Table 53 presents PPP adjusted GDP/cap. values for European countries.

Table 53 GDP/cap. PPP adjust

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
EU25	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
EU15	109.6	109.5	109.5	110.2	110.0	109.6	109.3	109.0	108.6	108.3	108.1 (f)
Austria	126.5	123.8	122.9	125.2	125.8	122.1	120.0	120.3	121.7	122.5	122.4 (f)
Belgium	118.0	116.9	115.9	115.5	116.7	117.2	117.5	117.9	118.1	117.5	117.6 (f)
Bulgary	27.4 (e)	25.4 (e)	25.9 (e)	26.1	26.5	28.0	28.3	29.7	30.5	32.1	33.2 (f)
Switzerland	136.7	138.6	137.9	134.1	133.0	128.3	130.0	130.3 (f)	131.6 (f)	127.2 (f)	126.7 (f)
Cyprus	79.6 (e)	78.3 (e)	79.1 (e)	80.2	80.9	82.8	82.0	79.8	82.6	83.3	83.2 (f)
Czech Republic	71.0 (e)	68.8 (e)	66.5 (e)	66.1	64.9	65.8	67.7	68.3	70.5	73.8	76.1 (f)
Germany	118.1	115.8	114.2	113.7	111.9	110.0	108.5	108.1	108.0	109.3	109.0 (f)
Denmark	123.7	124.2	123.1	126.3	126.2	124.9	121.4	120.8	121.5	124.2	125.5 (f)
Estonia	34.7 (e)	38.1 (e)	39.2 (e)	38.8	42.1	43.7	46.8	50.3	53.0	60.1	64.4 (f)
Spain	87.0	87.0	88.6	923	92.3	93.2	95.2	97.4	97.7	98.6	98.5 (f)
Finland	103.9	108.9	112.1	112.7	114.3	115.5	114.7	112.6	113.7	113.3	114.9 (f)
France	112.8	113.5	113.9	113.6	113.6	113.9	112.0	111.6	109.5	108.8	108.1 (f)
Greece	69.8	70.5	70.3	70.8	72.9	73.2	77.2	80.9	81.8	82.0	82.9 (f)
Hungary	48.5 (e)	49.5 (e)	50.7 (e)	51.8	54.0	56.9	59.1	60.1	60.9	61.4	63.1 (f)
Ireland	102.3	111.7	116.3	122.1	126.3	128.5	132.3	133.7	135.8	137.5	138.4 (f)
Italy	115.6	114.0	114.6	114.0	113.3	112.0	110.0	107.6	105.5	102.6	101.7 (f)
Lithuania	35.2 (e)	37.0 (e)	38.7 (e)	37.4	38.0	40.2	41.9	45.2	47.8	52.1	54.5 (f)
Luxembourg	196.7	191.3	193.5	218.1	222.4	214.6	220.7	232.7	237.5	247.5	251.7 (f)
Latvia	30.7 (e)	32.8	33.7 (e)	34.1	35.4	37.1	38.7	40.8	42.8	47.2	50.3 (f)
Malta	:	:	78.2	78.1	78.7	74.6	75.6	73.7	70.2	69.5	68.6 (f)
Netherlands	119.2	121.3	121.5	122.9	124.3	127.0	125.3	124.7	124.4	124.2	124.8 (f)
Norway	136.6	138.7	130.9	139.8	158.9	155.1	146.6	145.9	153.2	164.5	164.3 (f)
Poland	42.1 (e)	43.9 (e)	44.9 (e)	46.0	46.8	46.1	46.3	46.9	48.7	49.8	51.0 (f)
Portugal	74.8	76.2	77.8	80.5	80.5	79.9	79.4	72.7	72.3	71.2 (f)	70.0 (f)
Romania	:	:	:	25.4	24.9	26.2	28.1	29.9	32.1	34.7	36.0 (f)
Sweden	115.7	114.6	113.6	118.0	119.0	115.2	113.6	115.6	117.1	114.5	115.6 (f)
Slovenia	69.0 (e)	70.6 (e)	71.6 (e)	73.8	72.9	73.9	74.5	75.9	79.2	80.6	82.2 (f)
Slovakia	46.7 (e)	47.1	47.4 (e)	47.0	47.5	48.5	51.0	51.9	52.9	55.0	57.1 (f)
United Kingdom	109.1	111.3	111.3	111.7	112.0	113.1	116.0	116.4	117.1	116.5 (f)	116.5 (f)

(:) Not available.
(e) Estimation.
(f) Forecast.
Source: EUROSTAT Yearbook, 2005.

Base year, update and dynamisation mechanisms
It is useful to present figures for a most actual base year. The more disaggregated the figures are presented the less important is a common base year, since structures can be shown in detail (e.g. Euro-classes).

Forecasts and changes in the future, e.g. the variation of external cost over time, depend on:
- Change in dose response functions. Usually this is only the case for long term risks such as climate change.
- Change in traffic patterns (volumes, structure, loading factors). This can influence averaged figures, depending on disaggregation of results.
- Change in technical performance (emission category, etc.). This can also influence averaged figures, depending on disaggregation of results.
- Change in income: According to the assumptions above, an increase of GDP per capita is also changing unit values. Similar to the value transfer approaches, an income elasticity of 1 can be assumed. Recent research (INFRAS, 2004) shows that a lower elasticity (e.g. 0.5) can be used as well. It has to be considered that the very sensitive unit values (such as VSL) are also depending on other factors like the change of risk aversion for individuals.

4.3.2 Issues for specific cost categories

The values in chapter 4.2 are presenting - if not other stated - exemplary figures for Germany for specific vehicle categories and emission standards.

In order to derive more differentiated and vehicle category specific output values it is recommended to use the output values presented in chapter 3 and adjust them to the situation in question.

The following passages are presenting value transfer procedures from one country to another (based on the values presented in chapter 3). These procedures have been used to derive the country-specific output values in chapter 3 and similar procedures can be applied in order to adjust output values to other countries or specific situations.

A Congestion
For the transfer to other countries the following procedure is recommended:
- Transfer to other vehicle categories using passenger car unit values (PCU).
- Transfer to different countries: acc. to VOT-values for EU-25 based on HEATCO D5 Annex (Shires and de Jong, 2006).

B Accidents
The following value transfer procedure is recommended in order to transfer the proposed unit cost values to other countries:
- Road transport:
  - Adjustment of values according to accident risk rates. Due to the fact, that accident rates for different vehicle categories in number of fatalities or

injuries per vehicle category are not available for all 27 countries, an indicator 'fatalities per inhabitant' for 1998 could be used. This indicator could be quantified for all 27 countries. This is a rather general indicator not taking into account different vehicle categories' specific accident risks. However, due to data availability no other indicator could be used in order to generate unit cost rates for different vehicle categories and network types.

- Values then should be adjusted to GDP/cap. PPP (values taken from EUROSTAT) for the different countries (see Table 53).
- To generate cost rates in $€_{2000}$ values from 1998 should be adjusted acc. to real GDP/cap. growth rates (EUROSTAT) using an elasticity of 1.
- Accident cost estimates for various countries, road vehicles and traffic situations have been calculated using this approach and were presented in Table 10.

– Rail transport:
  - Adjustment of EU-15 2000 average costs to the 27 countries acc. to accident risk rates (fatalities per pkm). As a proxy for the number of fatalities in rail transport a 7-years-average (1998 - 2004) should be used, since fatal accidents are rather seldom and influenced by single incidents.
  - Values then should be adjusted to GDP/cap. PPP (values taken from EUROSTAT) for the different countries (see Table 53).
  - To generate cost rates in $€_{2000}$ values from 1998 should be adjusted acc. to real GDP/cap. growth rates (EUROSTAT).

– Air transport:
  - Values in INFRAS/IWW 2004a are in €/pkm. Values should be adjusted to the different countries using GDP/cap. PPP (see Table 53). Probabilities of air transport accidents are assumed to be constant throughout the EU.
  - In a second step values should be translated from €/pkm into values in €/LTO using average figures from INFRAS, 2004 (pkm per LTO, data sources: TRENDS database for pkm and ICAO data for LTO). For some countries no data is available, therefore values from comparable countries should be used.

C Air pollution

The following value transfer procedure is recommended in order to transfer the proposed unit cost values to other countries:

– Values for $PM_{2.5}$ and PM_{10} from HEATCO (HEATCO, 2006a, Deliverable 5 (€2002 PPS factor prices, values in € per ton of pollutant,) should be adjusted to a common base year 2000 using GDP/cap. growth rates from EUROSTAT.

– Values from CAFE CBA for NO_x, SO_2 and VOC from CAFE CBA (CAFE, 2005a). Valuation data refer to the year 2000, population factors are specific to 2010 (no adjustment made to 2000).

– For Bulgaria, Norway and Romania no values are available in HEATCO (also CAFE CBA does not cover these countries), for Switzerland no data available from CAFE CBA. Therefore values from comparable countries should be transferred (for Bulgary and Romania values from Hungary are transferred, for Norway values from Sweden, for Switzerland values from Austria transferred). The following indicators have been used in order to transfer values for the missing countries considering especially population density and GDP/cap. PPP:

- GDP/cap. PPP (see Table 53).
- Population density (pop./km^2).

– If vehicle category specific emission factors are available, damage cost factors (in € per tonne of pollutant) presented in Table 13 (p. 54) can directly be used in order to calculate specific costs values in € per vkm.
– If no calculations with emission factors can be done, a good proxy for the air pollution and up & downstream cost can be retrieved by scaling the values presented in this chapter with the valuation of particulate emissions[28] from Table 13. However, in this case just a proxy will be retrieved for certain vehicle types (only Euro-3) and traffic situations.

D Noise

The following value transfer procedure is recommended in order to transfer the proposed unit cost values to other countries:

– A generalisation of marginal noise costs values is difficult if not hardly impossible. Marginal noise costs strongly depend on specific traffic situation, speed limits, vehicle composition, distribution of disturbed and annoyed inhabitants alongside roads and rail tracks. Since there is no general information available for all countries considered, a simplified value transfer could be carried out.
– Values presented in Table 21 (p. 69) could be considered to represent a EU-15 (incl. CH+NO) average for the year 2000.
– Transfer to values for all 27 countries acc. to GDP/cap. PPP values (see Table 53).

E Climate change

Calculation of cost per vehicle-km per traffic situation and vehicle type is in principle a trivial multiplication of emissions per vehicle-km and the cost factor for the specific emission type. This is worked out in detail in chapter 3.5.

To give some feeling of the overall impact of internalising climate change cost, the example for passenger cars can be analysed. For a present day passenger car with a typical real world CO_2 emission of e.g. 200 g/km the central value of 25 €/tonne CO_2 translates into 0,005 €/km. For a passenger car in 2030 with a typical real world CO_2 emission of e.g. 120 g/km the central value of 55 €/tonneCO_2 translates into 0,007 €/km. These amounts are fairly insignificant compared to the overall cost of ownership per vehicle kilometre.

The method by which general values can be translated to values per country is in essence also trivial for the case of global warming. It only involves estimating the total vehicle-km per traffic situation and vehicle type and multiplying these

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[28] The external cost of particulate emissions are very dominant in both the air pollution and up & downstream costs. To retrieve a more precise estimate, these cost can be calculated using emission data for the specific country and the valuation of the various emissions from Table 13.

numbers with the cost per vehicle-km per traffic situation and vehicle type as mentioned above.

4.4 Specific consideration of the situation in new member states (NMS)

New member states entering the EU in 2004 and 2007 have all (excluding Malta and Cyprus) a common historical background. The post-socialist past had influenced the economic situation of the countries and has still some impacts on different levels of the economic policy implementation, including transport policy. Special determinants and barriers resulting from the post-socialist background of the Central and Eastern European countries have been already a subject of the analysis in different EU international projects dealing with transport policy issues. Especially the **SPECTRUM** project has to be mentioned, where – beside other important matters – the transferability of solutions, methods and instruments from EU-15 to new member states was assessed and possible obstacles and barriers were identified. Then, in the **ASSESS** project the implementation of all transport policy measures of the 2001 White Paper were analysed also from a perspective of NMS, considering existing barriers or determinants (see: Annex XIX Enlargement of the Final Report). Moreover, the **GRACE** project should be added (still on-going), including the elaboration of transport accounts in new member states (see: Methodological Annex to Deliverable 5 *Monitoring pricing policy using accounts*). Focusing the attention on the special issue of internalisation of external costs of transport, it can be summarised that specific consideration of the situation of NMS concerns both the cost calculation and implementation and it is a result of the following problems:

On the level of external cost estimation:

- Pressure to act: Problems e.g. derived from quickly increasing levels of motorisation are still relatively new (e.g. congestion is still limited) and the pressure to act is still rather low.
- Statistics shortage.

On the level of implementation:

- Other than in the EU-15 hierarchy of transport policy objectives, NMS have put a priority on Infrastructure modernisation to support the transformation of their economy. Internalisation of external costs or optimal Infrastructure use has not been treated as a serious objective.
- Low social acceptability - barriers resulting from lower purchasing power of transport user.
- Lack of studies on impacts – fear of unmeasured or unwanted impacts.
- Lack of resources/implementation costs.

All the shortages lead to a conclusion that in the case of NMS it is difficult to give an appropriate weight to the problem of external costs calculation and internalisation. Though theoretically sustainable development is mentioned in transport policy documents, regional strategies or energy priorities, practically decision-makers displace the tasks to the background. Also low social consciousness and acceptability of implementation of economic instruments leading to the reduction of external costs of transport do not help in setting adequate priority to the cost estimation and implementation.

For the aims of this Handbook, the problems which appeared on the level of external costs estimation are crucial. If public institutions and decision-makers are not interested in the issue of external costs of transport estimations, it is difficult to expect that only researchers can take initiative, since this kind of studies have always substantial practical policy dimensions. The solution is to encourage transport policy decision-makers in NMS to deal with the problem of monetising external costs of transport and to include them to Infrastructure pricing schemes. Also the cooperation between policy makers of different countries, especially representing the EU-15 and NMS and the exchange of experiences and knowledge would be helpful.

In the context of internalisation of external costs of transport the fear of the unknown is a well visible phenomenon in all the countries, but especially in NMS. The difference between EU-15 and NMS is that for the first group of countries a lot of complex and comparative studies have been elaborated, while for the second group the level of knowledge seems to be rather limited. So it is important to disseminate results of existing studies on cost calculations. Within international projects, in several cases also NMS were included and calculations were based both on a top-down approach and individual case studies:

- Bottom-up approach: UNITE - Hungary and Estonia, GRACE - Hungary and Poland (marginal case studies and accounts), ExternE (model runs for cost elements for some NMS).
- Top-down approach - OECD/INFRAS/Herry, External costs of transport in Central and Eastern Europe (14 countries).
- Other studies: HEATCO (EU-25, cost rates, guidelines for including external costs in cost-benefit-analyses), COMPETE (congestion EU-25, but based on existing results), TREMOVE (a policy assessment model to study the effects of different transport and environment policies on the emissions of the transport sector, includes 4 NMS: Czech Republic, Hungary, Poland and Slovenia).

While considering projects on national level, it has to be noticed that only few studies can be enumerated (further studies have been conducted but are not publicly available):

- Estonia: External costs of transport in Estonia, 3rd Report, COWI, 2001. The project was undertaken by COWI on behalf of the Danish Ministry of Transport and was launched as a part of the environmental sector programme under the Danish Government's strategy for Aid for the Eastern and Central European countries focusing on the Baltic Region.
- Poland: Internalisation of external transport costs and Infrastructure costs. KBN, project no PBZ-009-10, Szczecin-Gdansk 1999. The project was ordered by Ministry of Transport and financed by the Polish Committee of Scientific Research.

– Czech Republic: Výzkum zátěže životního prostředí, z dopravy výroční zpráva za rok 2003, Ministerstvo dopravy a spojů ČR, project no CE 801 210 109, Leden, 2004.

The limited number of international studies referring to NMS and national studies on external transport costs in NMS as well as different countries included, different approaches, base years for calculations etc. may be an indication that some further work in the area of external costs calculations may be needed in the new Member States.

Another problem on the level of external cost calculation concerns statistics shortages. Due to the transformation of statistical systems, long series data, especially values, are unavailable.

Overviewing European studies we can notice that very often the situation concerning sectors or whole economies is often described separately for EU15 and EU-10 or even 12. This approach is caused by two different reasons. Firstly some trends or matters are presented in this way to show the differences between these two groups of countries, instead of presenting the whole perspective. Another reason is that quality and complexity of databases in new member states are worse in comparison to EU-15. Analysis of data availability and its quality conducted within the GRACE Project for new member states showed that the situation is not very optimistic. Below, the main findings of that analysis are presented, showing the social costs of transport: congestion, accident, air pollution, noise, climate change and also general transport data.

For the aims of any calculations, reliable and detailed general transport data are needed. Still some gaps in official statistics exist, especially in the range of disaggregated data by type of trip, type of Infrastructure or type of vehicle. Very often the methods of data aggregation and presentation applied in national statistics considerably differ from the methods on international level (e.g. in Eurostat). Also, complex data on private motorization (e.g. mileages, occupancy rates) is still a problem. The membership of the countries in the EU and dynamic evolution of statistical reporting to EU institutions could improve the situation soon.

In the case of congestion the quality of data is very poor. This is because in most new member states, still congestion has not been a crucial problem disturbing operation of transport system. Therefore, also available data on delays is generally poor, though some differences between countries can be observed (more information available in Hungary than in Poland). The most important barrier is the lack of political pressure to conduct any new data/studies in this area. It concerns all modes of transport, though in air sector, international reporting requirements cause that the level of information on punctuality, travel purposes etc. is satisfied.

For accident costs, the data availability concerning number of accidents is sufficient in road, rail and air transport while in inland waterway and sea transport these data is less accessible. The level of disaggregation differs considerably in individual countries. The CARE project created very detailed data bases for road accidents for the EU-15, so it will be useful to broaden it for NMS. In the case of accidents in rail and air traffic, data is gathered by international organisations like UIC or ICAO so the public access to the detailed databases is impeded. There are more problems with data for calculation of material accident costs: medical, material damage, administrative or costs due to production losses and the costs of suffering and grief (risk value). In some NMS such studies were or are conducted because of the very high burden for society from accidents but there is no public information about their results.

The cost category ‘environmental costs' contains four different aspects: air pollution, climate change, noise, and other external costs, where such categories as nature and landscape, soil and water pollution, up- and downstream processes or additional costs in urban areas are taken into consideration. Regarding availability of data in new member states, it can be stated that concerning air pollution and global warming data the situation looks good. This is because all countries have implemented the monitoring system of EMEP for air pollutants and of the UNFCCC for greenhouse gas emissions. The national inventories in NMS have been prepared in accordance with common methodologies used to calculate emissions and sinks of GHGs and atmospheric emissions data reported to UN ECE and EMEP. Main problems concern the level of data base construction. This need time to adjust the monitoring and data collection system to the UN or EMEP requirements.

Regarding noise category the quality of data offered by national official statistics on noise exposure is rather low. There is no data about percentage of population for which legally defined noise levels are exceeded. We should be optimistic and take into consideration that according to the Directive 2002/49/EC all member states – including new ones – have an obligation to inform society about noise conditions. A strategic noise map enables a global assessment to be made of noise exposure in an area due to different noise sources and overall predictions to be made for such an area.

Overall, it should be said that it is necessary to broaden the databases concerning specific matters for new Member States like it was made e.g. in TREMOVE project.

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Internalisation Measures and Policies for All external Cost of Transport (IMPACT)

Deliverable 1:
Handbook on estimation of external costs in the transport sector

ANNEX REPORT
Version 1.0

Report

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A Overview of major studies

The following list is presenting major studies and data sources. The symbols in column 'Relevance' means the following.

++	Very relevant
+	Relevant
0	Partly relevant

STUDIES ON EXTERNAL COSTS OF TRANSPORT OVERVIEW						
Author, Title, Year of Publication	**Scope**				**Output**	**Relevance**
	Base year(s) of results	**Countries covered**	**Cost categories covered**	**Transport modes covered**	**Methods and/or costs (total, average, marginal costs)**	
EU Projects and Programs						
High Level Group on transport Infrastructure charging, 1998/1999	- (method)	European Union	Infrastructure, congestion, environmental costs (air pollution, noise), accidents	Road, rail	Method: marginal costs, cost rates	+
UNITE (Unification of accounts and marginal costs for transport efficiency), 2003 Project coordinator: ITS, Leeds	1998, (1996, 2005)	EU-15, Hungary, Estonia, Switzerland	Infrastructure, accident, environment (air pollution, climate change, noise, nature & landscape, soil & water pollution, nuclear risks), congestion	Road, rail, urban public transport, air, water (inland waterways, maritime shipping)	Methods and results: Total and average costs (pilot accounts), marginal costs (case studies), cost rates (valuation convention)	++
RECORDIT (Real cost reduction of door-to-door intermodal transport), 2001 Project coordinator: ISIS, Rome	1998	3 selected European corridors	- Internal (resource) costs - External costs : air pollution, noise, accidents, congestion & scarcity, climate change	Intermodal freight transport: road, rail, ship	Total and average costs	+
CAPRI (Concerted Action on Transport Pricing Research Integration), 1999 Project coordinator: ITS, Leeds	1995	European Union	Congestion, accidents, air pollution, noise, water pollution, climate change	Road, rail, air	Results: Average costs (compilation of results from other EU projects and studies with a European scope)	+
PETS (Pricing European transport systems), 1999 Project coordinator: ITS, Leeds	-	European Union	Infrastructure (producer costs), congestion, air pollution, noise, climate change,	Road, rail, air	Method: Cost rates Results: compilation of other project results Case studies	0

STUDIES ON EXTERNAL COSTS OF TRANSPORT OVERVIEW						
Author, Title, Year of Publication	**Scope**				**Output**	**Relevance**
	Base year(s) of results	**Countries covered**	**Cost categories covered**	**Transport modes covered**	**Methods and/or costs (total, average, marginal costs)**	
			accidents			
COMPETE (Analysis of the contribution of transport policies to the competitiveness of the EU economy and comparison with the United States), 2006 Project coordinator: Fraunhofer-ISI, Karlsruhe	-	EU-25, USA, Switzerland	Congestion costs, operating costs	Road, rail, air, water	Congestion: no own calculation. Compilation of congestion costs from other studies Operating costs: results: total and average costs	++
HEATCO (Developing harmonised European approaches for transport costing and project assessment), ongoing Project coordinator: IER, Stuttgart	2002	EU-25	Infrastructure (investments, maintenance, operation, administration), congestion, accident, noise, air pollution	Road, rail, (air, sea)	Method: cost rates, guidelines for including external costs in cost-benefit-analyses	++
GRACE (Generalisation of research on accounts and cost estimation), ongoing Project coordinator: ITS, Leeds	n.a.	EU-25	Infrastructure, accident, noise, climate change, environment, congestion	Road, rail, air, water	Method and results: marginal costs (case studies), total and average costs	++
ExternE (Externalities of Energy), 1999 Project coordinator: IER, Stuttgart and updates	1995	EU-15 (without Luxembourg), Norway and some NMS (e.g. Poland)	Accidents, air pollution, soil & water pollution, climate change, noise	External costs of energy	Methods and results: Total and average costs	+
New Ext: ExternE (Externalities of Energy) Methodology Update 2005 Project coordinator: IER, Stuttgart	2004/5	EU	Accidents, air pollution, soil & water pollution, climate change	External costs of energy	Methodological update, revised cost indicators, WTP- and shadow prices and dose-response functions	++

STUDIES ON EXTERNAL COSTS OF TRANSPORT
OVERVIEW

Author, Title, Year of Publication	Scope				Output	Relevance
	Base year(s) of results	Countries covered	Cost categories covered	Transport modes covered	Methods and/or costs (total, average, marginal costs)	
EU Projects and Programs						
NEEDS (New energy externalities development for sustainability), ongoing Project coordinator: ISIS, Rome	2005	? (Study not yet available)	Air pollution, biodiversity losses & land use, climate change, soil & water pollution	External costs of energy	? (study not yet available)	++
CAFE CBA	2002/ 2020	European Union	Air pollution	-	Air pollution cost (cost-benefit analysis)	++
COPERT	2000/ 2020	EU-25	Air pollution	All modes	Emission data base	0
TREMOVE	2000/ 2020	EU-25	Most relevant external cost	All modes	Policy assessment tool	++
iTREN-2030	2007(?)-2030	EU-25	Most relevant external cost	All modes	Started in 2007. Network analysis tool for transport in the EU, scenario forecasts for 2030 covering transport, energy, environment and economy	(++)
Other studies with a European Scope						
INFRAS/IWW, External costs of transport, 2000	1995 Estimate for 2010	EU-15, Norway, Switzerland	Accident, noise, air pollution, climate change, nature & landscape, urban effects, up-/down stream processes, congestion	Road, rail, air, water (inland water transport)	Method and results: Total and average costs, marginal costs	0
INFRAS/IWW, External costs of transport – update study, 2004a	2000	EU-15, Norway, Switzerland	Accident, noise, air pollution, climate change, nature & landscape, urban effects, up-/down stream processes, congestion	Road, rail, air, water (inland water transport)	Results: Total and average costs, marginal costs (method adopted from the 2000 study)	+

STUDIES ON EXTERNAL COSTS OF TRANSPORT OVERVIEW						
Author, Title, Year of Publication	**Scope**				**Output**	**Relevance**
	Base year(s) of results	**Countries covered**	**Cost categories covered**	**Transport modes covered**	**Methods and/or costs (total, average, marginal costs)**	
Friedrich and Bickel, Environmental costs of transport, 2001	1995-1998 (dependent on the country)	Belgium, Finland, France, Germany, Greece, the Netherlands, United Kingdom	Air pollution, terrestrial ecosystems (nature & landscape, soil & water pollution), climate change, up-/downstream processes	Road, rail, air, inland shipping	Method and results: Marginal costs, total and average costs, cost rates	+
ECMT, Efficient transport for Europe – policies for the internalisation of external costs, 1998	1991	EU-15, Norway, Switzerland	Infrastructure, congestion, accident, noise, air pollution, climate change	Road, rail	Method: Results: compilation of European studies	0
OECD/INFRAS/Herry, External costs of transport in Central and Eastern Europe, 2003	1995 (2010)	Eastern Europe (CEI countries): Albania, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, Czech Republic, FYRO Macedonia, Hungary, Moldova, Poland, Romania, Slovak Republic, Slovenia, Ukraine	Accidents, noise, air pollution, climate change, nature & landscape	Road, rail, air, water	Results: total and average costs	+
TRL 2001, Study on the cost of transport in the European Union in order to estimate and assess the marginal costs of the use of transport	1995/2000	EU-15 (based on studies surveyed)	Social costs of transport: accidents, Infrastructure, environment, noise	Road, rail, air, maritime, inland waterways	Short run marginal costs, Survey of Results of existing studies, Cost Matrices Handbook, Case studies on maritime and air transport	+
CE Delft/ECORYS, Marginal costs of Infrastructure use - towards a simplified approach, 2004	- (methodological study)	EU-15	Infrastructure, congestion and scarcity, accident, air pollution, noise	Road, rail, aviation	Method: marginal costs, cost rates Comparison of results (marginal costs) of different studies	++

STUDIES ON EXTERNAL COSTS OF TRANSPORT OVERVIEW						
Author, Title, Year of Publication	**Scope**				**Output**	**Relevance**
	Base year(s) of results	**Countries covered**	**Cost categories covered**	**Transport modes covered**	**Methods and/or costs (total, average, marginal costs)**	
CE Delft, External costs of aviation, 2002	1999	European Union	Climate change, noise, air pollution	Air transport	Method and results: average costs	+
ECMT, Reforming transport taxes, 2004	2000	EU	Infrastructure, environment	Road, rail, water	Results: Marginal external costs for different countries. Basis for the calculation of welfare gains of different pricing schemes	0
EEA TERM, Fact sheet 25 – External costs and charges per vehicle type, 2005	2003/04 (2000)	EU-15	Accidents, noise, air pollution, climate change, Infrastructure	Road, rail, water (inland waterways)	Results: marginal costs and compilation of results of different European studies	+
Country specific studies						
CE Delft, Efficient prices for transport – estimating the social costs of vehicle use, 1999	2002 (rail: 2010) > forecast	The Netherlands	Infrastructure (upkeep, operation, construction), accidents, air pollution, climate change, noise, congestion	Road, rail, air, water (inland shipping)	Method and results: marginal social costs	0
OSD (Federal Office for Spatial Development), External costs of road and rail transport (6 studies for different cost categories), 2002-2006	2000 (Accidents: 1998)	Switzerland	Accident, noise, air pollution, nature & landscape, climate change, soil & water pollution, vibrations, sensitive areas (alpine regions), urban effects, up-/downstream processes	Road, rail	Method and results: total and average costs	+
Herry, Externe Kosten im Güterverkehr in Österreich (External costs of freight transport in Austria), 2000	1995	Austria	Accidents, noise, air pollution, climate change	Road, rail, water (inland waterways)	Total and average costs	0

STUDIES ON EXTERNAL COSTS OF TRANSPORT OVERVIEW						
Author, Title, Year of Publication	**Scope**				**Output**	**Relevance**
	Base year(s) of results	**Countries covered**	**Cost categories covered**	**Transport modes covered**	**Methods and/or costs (total, average, marginal costs)**	
Mathieu, Bilan environmental des transports en France en 2001 (Environmental costs of transport in France in 2001), 2002	2001 (2010, 2020)	France	Accidents, air pollution, climate change, noise, nature & landscape, urban effects, up-/down stream processes, congestion	Road, rail, air, water (inland waterways)	Results: total costs (Method and average costs taken from INFRAS/IWW, 2000a)	0
CE Delft, The price of transport - overview of the social costs of transport, 2004 (update of the 1999 study)	2002	The Netherlands	Infrastructure (upkeep, operation, construction), accidents, air pollution, climate change, noise, congestion, land take	Road, rail, air, water (inland shipping)	Method and results: total costs, variable social costs	+
ITS, Surface transport costs and charges – Great Britain 1998, 2001	1998	United Kingdom	Infrastructure (capital and operating costs, vehicle operation, congestion and scarcity, air pollution, noise, climate change	Road, rail	Method and results : marginal and average costs	+
UBA, Ökonomische Bewertung von Umweltschäden - Methodenkonvention zur Schätzung externer Umweltkosten (Economic valuation of environmental damages – method convention for estimating environmental costs), 2006	- (methodologic al study)	Germany	All types of environmental effects	Focus not only on transport, but also on energy, etc.	Method: general procedure for cost calculation (total, average, marginal costs), cost rates	++

STUDIES ON EXTERNAL COSTS OF TRANSPORT OVERVIEW						
Author, Title, **Year of Publication**	**Scope**				**Output**	**Relevance**
	Base year(s) of results	**Countries covered**	**Cost categories covered**	**Transport modes covered**	**Methods and/or costs (total, average, marginal costs)**	
Hvid, External costs of transport, 2004	2000	Denmark	Infrastructure, accidents, air pollution, climate change, noise, congestion	Road, rail, air, short sea shipping	Method and results: marginal costs (2nd report) and total costs (3rd report) Review of European studies for method comparison (1st report)	0
LEBER / INFRAS, External costs of transport in the Basque Country, 2006	2004	Basque Country	Accident, noise, air pollution, climate change, nature & landscape, urban effects, up-/downstream processes, congestion	Road, rail	Method and results: total and average costs	0
COWI, Tallinn Technical Univ., External costs of transport in Estonia, 3rd Report, 2001	2000 Scenarios 2020	Estonia	Accidents, air pollution, climate change, noise,	Road, rail,	Method and results: total and average costs	0
KBN, Internalisation of external transport costs and Infrastructure costs., 1999	1997	Poland	Climate change, air pollution, noise, accident	Road, rail,	Total and average external costs	0
Ministry of Transport, VaV 801/210/109 „Výzkum zátěže životního prostředí z dopravy“,2004	2003	Czech Republic	Climate change, air pollution, noise, accident, other costs	Road, rail	Methodology, total costs, modelling work	0
Boiteux Report 2001: Transports : choix des investissements et coût des nuisances	2000	France	Climate change, congestion, nature & landscape, air pollution, noise	Road, rail,	Methodological recommendations, average/marginal costs	0

STUDIES ON EXTERNAL COSTS OF TRANSPORT OVERVIEW						
Author, Title, Year of Publication	**Scope**				**Output**	**Relevance**
	Base year(s) of results	**Countries covered**	**Cost categories covered**	**Transport modes covered**	**Methods and/or costs (total, average, marginal costs)**	
Ministero delle INFRAStrutture 2006: Model applications for the estimation of external costs	2005	Italy	Accident, noise, air pollution, climate change, nature & landscape, urban effects, up-/downstream processes, congestion	Road, rail, air, maritime	Methodology, unit cost rates	0

B Congestion and scarcity costs

B.1 Overview of studies

Studies on congestion can be distinguished into two types: National congestion monitoring studies and more general research studies. National monitoring studies may be published regularly as one-off studies and they entirely apply the delay approach. Applied congestion monitoring systems on a regular basis only exist in the England, the Ile-de-France region in France and the Netherlands. Irregular one-off studies are carried out in Switzerland, Germany, Scotland, Denmark and in some southern French cities and regions. While it is not surprising that for southern and eastern Europe no studies on the level of traffic congestion exist, their absence in the case of Sweden and Finland underlines the hypothesis that Infrastructure capacity problems in these countries is not a real issue.

The second type of studies includes performance reports from transport Infrastructure or service operators. In the air transport even two cross-European data basis are provided by the Quality Reports of the Association of European Airlines (AEA) and by Eurocontrol's Central Office for Delay Analysis (CODA). In rail transport by far the best data base on performance is provided by UK Network Rail, followed by SBB (Switzerland) and the Czech Railways. Other countries only deliver very general annual punctuality figures, which give much room for speculation.

Thirdly, independent scientific reports provide a more general picture on congestion in terms of geographical scope and methodologies. The most important ones are the COMPETE, UNITE and GRACE studies financed by the European Commission and the external costs of transport reports commissioned by the International Union of Railways (UIC). But a unique data base or methodology for congestion and delays in all modes of transport is still missing for Europe.

Table 54 Review of studies on calculating and measuring congestion in Europe

Author, Title, Year of Publication	Base year(s) of results	Countries covered	Cost categories covered	Transport modes covered	Method used	Outputs, Result differentiation
EU Projects and Programs						
High Level Group on transport Infrastructure charging, (High Level Group, 1999b)	Method and unit costs only	Selected EU	Time costs	Road, rail	Marginal time costs using UK speed-flow functions	Country-wise functions by specific VOT for cars and HGVs
COMPETE (Fraunhofer/ INFRAS, 2006)	~2005	EU-25, CH, US	Delay and operating costs	Road, rail P. T. air, shipping	National/ business sector interviews, study reviews	Qualitative congestion trends, relative operating cost figures
UNITE (Nash et al., 2003)	1998, (1996, 2005)	EU-15, Hungary, Switzerland	Time and fuel costs	Road, rail aviation	Total cost accounts: additional costs against usual conditions; Marginal social costs	Total delay costs per country; MSC by case study
RECORDIT (Schmid, 2001 and Clas, 2002)	1998	3 selected European corridors	Depreciation, personnel, consumption, maintenance, insurance	Road haulage	Marginal external time costs based on speed-flow functions	Euro per Load Unit, corridor and country (all cost components)
GRACE (GRACE, 2006b)	2005 ongoing	Model city/ UK	Road: Delay costs; rail: operating costs	Urban road, interurban rail	Road: Optimal congestion charges; rail: scarcity operating losses	€/car-km; rail operating costs relative to base case
HEATCO (HEATCO, 2006b)	2004	General; case studies UK, Denmark, Greece	Time and operating cost savings		Hensher approach/ stated preference for VTTS	Unit values, national case study results
TRENEN-II-STRAN (TRENEN-II_STRAN, 1999)	2005	Brussels, Belgium	Social time, operating and environm. costs	Road, P.T.	CGE model with area speed-flow function	Generalised MSCP
TEN-STAC (NEA, 2003)	2000, 2020	EU-25	Delays due to congestion	Road	Delays against design speed	Total costs by investment scenario

Other studies with a European Scope						
External costs of Transport (INFRAS/IWW, 2000)	1995 Estimate for 2010	EU-15, Norway, Switzerland	Time + operating costs	Road	MSC, deadweight loss, delays with European road model	Total costs by country, MSC by traffic situation
External costs of Transport – update study (INFRAS/IWW, 2004a)	2000	EU-15, Norway, Switzerland	Time + operating costs	Road; rail and air from UNITE	MSC, deadweight loss, delays with European road model	Total costs by country, MSC by traffic situation
CE Delft/ ECORYS, Marginal costs of Infrastructure use - towards a simplified approach, 2004	Unit cost functions and rates for 2002	EU-15	Time costs as representative for total operating costs	Road, rail	Analysis of existing studies	Road type, time of day, vehicle class
Country specific studies						
CE Delft, The price of transport - overview of the social costs of transport, 2004 (update of the 1999 study)	2002	The Netherlands	Time costs as proxi for total operating costs	Road (car, HGV)	Marginal social external costs	Car and HGV in urban peak traffic
Surface transport costs and charges (ITS, 2001)	1998	United Kingdom	Time costs	Road	Proxi to MSEC by fictive linear speed-flow curves	€/PCU-km by 9 road classes
Estimating urban road congestion costs (Newbery, 2002)	2000	UK	Time costs	Road	Area speed-flow functions + network model	MSCP, MEC for 8 cities; all roads
Stockholm congestion charge (Prud'home, 2006)	2005/06	Stockholm	Time and operating costs	Road	Area speed-flow function	Current MEC, MSCP under various conditions
Congestion costs Switzerland (INFRAS, 1998)	1996	Switzerland	Time, energy, environment, accident costs	Road	Speed-flow and delay record analysis	Total costs 1996 by cost component
Congestion and slow travel costs in the Canton Zug (INFRAS, 2003)	2000	Switzerland, Canton Zug	Time, operating, environmental and accident costs	Road, passenger	Top-down approach, three calculation approaches (GIS based)	Total costs by corridor, travel purpose and time of day.
Traffic speeds in Great Britain (DfT, 2005a)	2004	England	Recurrent delays	Inter-urban car	Measured delays against off-peak speed	Delay/vkm by road classes
Traffic speeds in English urban areas (DfT, (2005b)	2002	England	Recurrent delays	Urban car	Measured delays against off-peak speed	Extra travel time by road type and city
Congestion on Scottish trunk roads 2004 (Scottish, 2005)	2004	Scotland	Recurrent delay + operating costs	Road passenger	Modelled and observed speeds	Time, op. costs, reliability by dorridor
Bottlenecks on German motorways (IVV/Brilon, 2004)	2000, 2015	Germany	Recurrent delay	Road passenger + freight	Modelled local speed-flow curves	Share of congested network, total delays

Traffic analysis in the PACA region (CETE Metditerranee, 2004)		France, PACA region	Time losses, recurrent	Road	Modelled delays against discomfort level	Hours per day/ year > discomfort, capacity
Delays in urban express roads of Ile-de-France (Prefecture 2005)		France	Delays, all purposes	Urban car	Assessment of counting post data	Speeds and delays by road class
Copenhagen traffic congestion costs (Hvid, 2004)	2000	Denmark	Delays, recurrent	Urban car, bus	Modelled delays against off-peak speed	Additional time by road type car, bus
Congestion monitor 2005 (AVV, 2005)	2003	Netherlands	Road occupancy		Assessment of counting post data	km of traffic jams by motorway
Urban Congestion (Munos de Escalona, 2004)	1995/ 2000	Spain	Time. operating and pollution costs	Urban road	Regression on existing studies	Total costs by city and vehicle type

The studies available can be grouped into two types:
- Descriptive studies measuring the scope of congestion in terms of network saturation, total delays, or extra fuel consumption.
- Marginal social cost studies investigating the external effects of additional traffic units on the network and by that recommending optimal prices.

Most of the national studies available are descriptive ones, of which some contain economic evaluations. A number of interesting studies can be found in North America (GRACE, 2006b; several state congestion studies, Transport, 2006): Studies of price-relevant marginal external congestion costs can be found in the UK (ITS, 2001; Newbery, 2003) and on the European level (UNITE, GRACE, TRENEN-II-STRAN; INFRAS/IWW, 2004a).

Time costs constitute the central element of congestion analysis considered by all studies. Excessive fuel use in stop and go traffic, rising private operating costs or transport sector external effects are usually, in particular in marginal social cost studies, ignored or treated in a more general way by adding a supplement around 10% to time costs.

An important point of most marginal cost studies is whether marginal external costs are expressed before or after they have been internalised and in how far user reaction patterns have been considered. For internalisation purposes, figures depicting (optimal) marginal social cost prices (MSCP) of congestion are more relevant than the marginal external costs (MEC) at current demand levels. MSCP values are provided by the UNITE (UNITE, 2002c), GRACE (GRACE, 2006b) and MC-ICAM, 2004 (De Palma et al., 2006b) case studies for various European cities and corridors, by ITS (2001) and by Newbery (2006) for UK cities and rural roads, by Prud'home, 2006 for Stockholm and by TRENEN-II-STRAN, 1999 for Brussels and Belgium. We will focus on these studies.
Studies also differ in their modelling approach. For reasons of a better description of user reaction patterns full-scale network models e. g. the application of the SATURN model in UNITE, 2002 and ITS, 2001 are preferred to area-wide speed-

flow model (TRENEN-II-STRAN, 1999; Prud'home, 2006; and partly Newbery, 2002). Nevertheless, both computation variants are considered to obtain a broader geographical coverage and to make results more robust.

The studies discussed concentrate on the computation and assessment of marginal social congestion costs. Pure valuation studies are not reviewed as the HEATCO project (HEATCO, 2006a) has recently published a contemporary overview of value of time studies.

Leaving the private road sector makes the studies more difficult to interpret and the results more diverse. Driven by the poor data situation in public transport usually rough measures are presented and the computation of marginal social congestion or scarcity costs is impossible. Here also the case studies of UNITE (UNITE, 2002) and GRACE (GRACE, 2006d) are most relevant.

Scientific accuracy

Assessing the quality of congestion studies is not always possible as the full documentations of model architectures are usually not given. Nevertheless, all studies using network simulation models reviewed have applied the SATURN traffic model, which constitutes state of the art in urban transport modelling. Concerning area speed-flow estimates a judgement is easier due to the simplicity of the approach. Here, no major methodological problems have been detected with the studies analysed.

Quality of data basis

The selection of input data and parameters also seems to be sound for all studies. Somewhat in-transparent is only the selection of demand elasticities with area speed-flow models.

Of critical nature is the quality for congestion and scarcity studies in public transport. Here often basic cost and preference data and speed-flow relationships are not or only poorly available. COMPETE (Schade et al., 2006) denotes the main reason for this shortcoming being the privatisation with the corresponding privacy regulations of rail, air and shipping industries.

Completeness

All studies reviewed consider traffic users being a homogeneous group. Newer research, however, points on the fact that a segmentation of user groups according to preference patterns or income levels leads to different results in the level and structure of optimal charges.

Concerning cost categories most studies refer to time costs only or do not make other cost categories included explicit (ITS, 2001, Newbery, 2002; UNITE, 2002). Only TRENEN-II_STRAN, 1999 and partly Prud'home, 2006 consider congestion in a more general context of cost drivers and effects.

Transferability

ITS, 2001; Newbery, 2002 and UNITE, 2002 demonstrate by the application of unique methodologies to similar but different cities that the transferability of congestion costs even within towns of the same country is very limited. This is due to the importance of local conditions for individual user reactions on increasing demand or on internalisation strategies.

Practical application

In the road sector the practical application of results is given as congestion charging is increasingly considered in European cities. In most cases, however, this will be designed in form of a cordon toll. In this case the distance-based values need to be transformed in daily charges by average travel distances.

In scheduled transport the range of study results is scattered. Moreover, the access to the respective networks (besides shipping) is managed. Therefore the internalisation of external congestion costs via corrective MSC prices is not necessary. The results of commuting congestion costs are thus more of an informative purpose.

Potential for aggregation

Besides the transferability, the possibility to aggregate congestion values is rather difficult. ITS, 2001 has made the attempt to give advice on the level of external congestion costs for different city sizes. However, the results did not follow a particular trend and thus do not lead to a systematic relation between urban sprawl and the level of congestion costs.

Conclusion

ITS, 2001 and the UNITE case studies (UNITE, 2002) applying the SATURN traffic model and Newbery, 2002 comparing SATURN results to area speed-flow curves provide the most comprehensive results for urban areas and rural corridors as the results differentiate between road classes and types of area. Although they are much biased by UK results they are taken as the basis for formulating best practice recommendations for Europe. The GRACE urban congestion case study (GRACE, 2006a,b) and Prud'home, 2006 and TRENEN-II-STRAN results (TRENEN-II-STRAN, 1999) are added to widen the geographical scope. With these sources recommendations of ranges of congestion costs for Europe are possible, but they do in no way replace local estimates.

In public transport the scene is much more difficult. The restricted data availability did not allow for a single sophisticated estimate of marginal social congestion costs in rail, air and water transport. Acknowledging this problem High Level Group, 1999b has already proposed to apply slot auctioning processes to close this gap. But there is no evidence on the level of slot values so far.

B.2 Main methodological approaches

The most important studies in terms of the assessment of congestion costs are:

The **GRACE** project has modelled marginal social external congestion costs for several variations of a model city and has estimated relative slot allocation costs for a railway stretch at the UK west coast line. With the latter the project starts to shed light on the problem of scarcity values.

The **COMPETE** project has not produced own monetary estimates, but has provided an overview of existing values and has classified country networks of all modes by the severity and the likely development of congestion in the future for the 25 EU Member States as prior to 1.1.2007, Switzerland and the USA. This information can be used as a valuable source for transferring and forecasting country results across the Community.

INFRAS/IWW, 2004a and its previous studies have for the first time estimated total external congestion costs, total delay costs and potential congestion pricing revenues for 17 European countries. Unit costs of marginal external costs are presented for example traffic conditions.

The **UNITE** project has modelled marginal social congestion costs for four interurban corridors, four cities, two railway networks and the European air transport sector and has thus contributed to the generation of new values in this field. In the country accounts the study has estimated total delay costs for road, rail and aviation in 10 out of 18 countries

B.3 Input values

The values of time used by the single studies were not clear in all cases. But the Impact of the VOT on the marginal cost results is 'only' linear. Variations in the network configuration or the representation of demand reaction functions will thus outweigh VOT variations and base year adaptations by far.

And even if all parameters and model settings would be identical – it is the nature of congestion costs to vary very strongly by time and location. All of the key cost drivers discussed in Section 3.1, including important regional specificities, will impact congestion costs. The presentation of default values for different situations is thus not possible.

Table 55 Comparison of total delay costs

Country	UNITE, GRACE 2001, 2002a, 2002b	External Costs of Transport, INFRAS/IWW et al. 2004	
	ACA	**ACA**	**DWL**
Austria	1,589	4,250	1,224
Belgium	:	8,901	2,186
Denmark	407	3,037	814
Estonia	:	Not covered	Not covered
Finland	:	1,472	462
France	:	43,873	9,500
Germany	17,506	65,383	16,54
Greece	5,239	4,199	931
Hungary	792	Not covered	Not covered
Ireland	:	1,228	337
Italy	:	28,752	8,019
Luxemburg	:	399	110
Netherlands	3,103	17,534	4,263
Norway	Not covered	1,862	468
Portugal	141	2,592	666
Spain	3,726	20,325	3,880
Sweden	:	2,372	761
Switzerland	651	3,349	936
UK	19,371	58,241	12,108

Source: UNITE and INFRAS/IWW, 2004a.

Alternative ways of expressing congestion is the so-called ‘travel time index’, which expresses the relative change in travel times due to the presence of congestion. An overview of some European and US urban areas is presented by Table 56. The values can not be used to derive marginal social external costs, but they can show areas sensitive to congestion. Table 56 reveals the results from ARUP/SRA on the high congestion problem in London.

Table 56 Travel time index in EU and US cities 2003

Area	Travel time index		
	1993	2004	1993 – 2004
Paris, Ile-de-France		1.34	
Greater Copenhagen area		1.40	
Greater London		1.84	
Average of other English cities	1.24	1.32	0.08
US 85 area average	1.28	1.37	0.09
US verly large average (13 areas)	1.38	1.48	0.10
US large average (26 areas)	1.19	1.28	0.09
US medium average (30 areas)	1.11	1.18	0.07
US small average (16 areas)	1.06	1.10	0.04

Source: Fraunhofer/INFRAS (2006).

Apart from numerical values, the level of congestion in different areas can also be described using LOS (level of service) parameters. Table 57 uses an indicator system for the current situation from A = no congestion to E = permanently congested and for the likely development in the future. The indicators reveal that congestion is rather an urban than an interurban problem.

Table 57 Synthesis of country reviews - interurban road

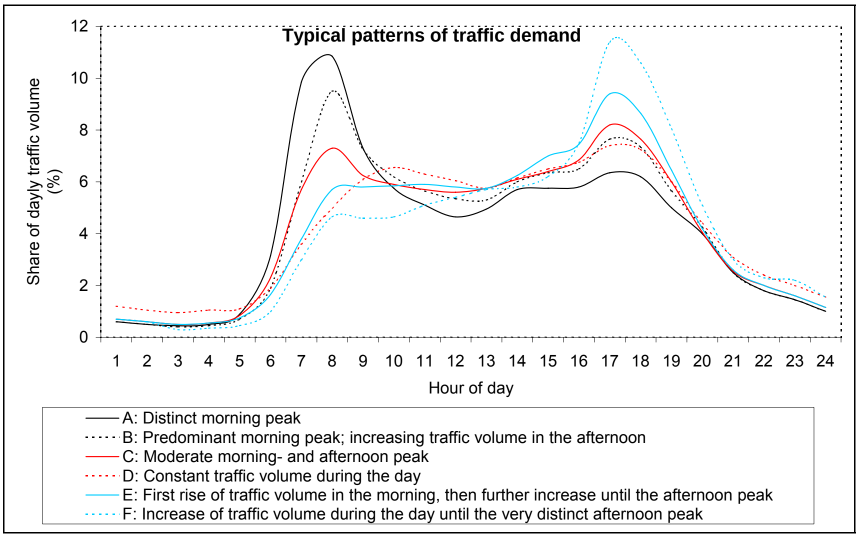
Region	Current state of congestion	Expected development of congestion	LOS slope
United States	Serious congestion on interstate highway crossings and where congestion is caused by metropolitan areas.	Increase due to lag of grade-separated junctions and access points. Particular problem for port access traffic.	B ↘
Germany and Alpine	High congestion in Ruhr area; Brenner corridor and urban access routes; no Problems in rest of Austria and Switzerland.	High increase in Germany, no severe problems in Alpine region due to rail investments and road charging.	B-D ↘
France and Benelux	Particular Randstad region (NL); international motorways are currently close to saturation.	Stagnating demand in BE; increasing border crossing traffic in FR, NL and LU.	B-E ↘
UK and Ireland	Perceived a major issue by government particularly in England, less severe in Ireland.	Stabilisation by policy measures in the UK; increase due to truck traffic in Ireland.	B-D ➔
Scandinavia and Baltic	Few times per year on holidays on limited network part on two lane roads.	No information, but due to Scandinavia's remote location no dramatic change expected.	B ➔
Central Europe	Good: Slovenia and Hungary; bad road quality in Poland and Slovakia; all: bottlenecks around big cities.	Pessimistic due to lag between fastly growing traffic and Infrastructure investments.	B-D ↘
Southern Europe	Only in specific parts under construction in fairy days and some weeks in summer.	No information for IT, No congestion predicted in the next 10-15 years.	C ➔

Source: Fraunhofer/INFRAS, 2006.

Congestion is a complex phenomenon and accordingly it consists of various important cost drivers. While they are all important for the quality of transport systems or for their monetary assessment, some of them are not relevant for setting welfare-optimal marginal social congestion costs.

Traffic volumes and mix: Congestion is a problem of demand exceeding capacity. Under current capacity and regulatory conditions demand is thus the factor determining traffic service quality. But demand is not a simple static variable; it changes over the hours of day, the days of the week and over the year. Different Infrastructure sections usually show different traffic patterns, depending how intensively they are used by commuters, commercial traffic or holiday travellers. Figure 21 shows some typical traffic patterns of German motorways and trunk roads.

Figure 21 Different traffic patterns on German motorways and trunk roads



Source: INFRAS/IWW, 2004a.

Demand is composed of different user groups or vehicle classes. Each of these groups requires a specific share of Infrastructure capacity and shows an individual pattern of behaviour when congestion arises or when policy measures to mitigate it are introduced. Capacity demand of particular vehicle types is expressed in 'passenger car units' (PCU)[29]. A vehicle's PCU is determined by its size, weight, engine power and maximum speed and by Infrastructure characteristics, such as gradient or speed limits. Driven by the development of vehicle technology PCU factors change over time. Table 58 shows the figures for different vehicle classes for Germany from the early 1970s and from 2002.

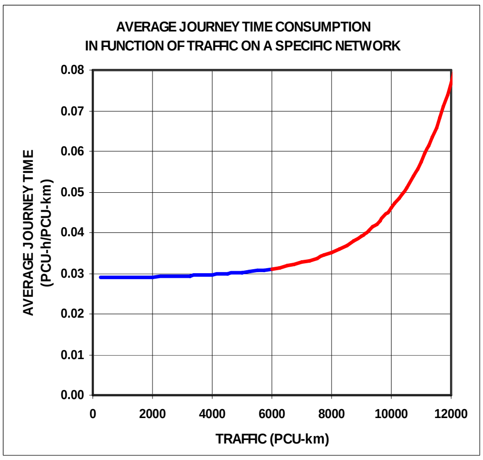
Table 58 Old and new passenger car units in Germany

Vehicle Category	Figures from (Enquête Commission 1969)	New figures from Prognos/IWW (2002)
Cars and station w.	1.0	1.0
Buses	3.0	2.5
Motorr cycles	0.5	0.5
HGVs		
– 3,5 t	1.7	1.2
3,5 – 12 t	2.2 – 2.7	1.5
12 – 18 t	4.3	2.5
18 – 28 t	5.8	3.5
28 –33 t	5.8	4.0
> 33 t	5.8	4.5
Articulated trucks	6.0	4.5
Special vehicles	6.0	2.0

[29] Or 'Passenger Car Equivalents' (PCE).

Infrastructure capacity: The relationship between the physical capacity of transport Infrastructures and the quality of service is most obvious in road transport. Here, measured speed-flow curves describe the development of travel speed and vehicle density at a given time as a function of traffic volume on a particular link. Road capacity depends on the number of lanes, the gradient, the curvature and the availability of side lanes. In dense networks, however, the application of these functions is not straight forward as demand will be served by multiple parallel routes. Thus, when talking about Infrastructure capacity the availability of alternatives appears to be an essential factor. The mathematical description of congestion on the basis of speed-flow functions is further complicated by the fact that they are, in particular under conditions of capacity utilisation, strongly non-linear. In some cases, e. g. in UK investment planning, this fact is approximated by defining speed-flow curves as a sequence of linear elements. In other cases, as e. g. in Germany, several hyperbolic functions are chained to receive a more realistic picture. In other cases, as in the US, capacity is described verbally only by so-called ‘levels of service’.
The graphs in Figure 22 show the development of average user costs (left) and marginal external congestion costs (right) on a road link.

Figure 22 Average and marginal external time costs



Source: CE, 2004.

Access, slot and speed regulation: In scheduled transport like railway networks, airports and air space the access, timing and routing of vehicles is regulated by a central authority. In this case the physical capacity limits of an Infrastructure are only one out of several delay reasons. Train or aircraft movements can also be delayed by the Infrastructure managers due to safety reasons or due to some pre-set priority rules. These access and management rules thus prevent parts of direct demand-driven delays from the networks, but cause demand which can not be satisfied due to the scarcity of slots. Observations on different European airports, flight regions and rail networks how, that the efficiency of flow management is a key factor in determining the capacity of scheduled transport networks.

In non-road modes, general capacity functions can not be provided; relationships of operating and time costs to demand, including the costs for non-satisfied demand, i. e. scarcity costs – need to be estimated on an individual basis. An example for a measured demand delay curve at Chicago O'Hare Airport at the afternoon peak is given by Johnson and Savage (2006). Under the assumption of $ 31.37 per passenger hour (all trip purposes) and total aircraft operating costs including both fixed and variable costs of $ 2,873 per hour for large carriers. Table 59 shows bottleneck congestion costs for different queue lengths under the condition that the bottleneck can totally be worked off. In particular in afternoon peaks at busy airports this is not the case, so that current congestion costs get much higher. The reduction of congestion costs for big airlines assumes that congestion costs within a company are anticipated and thus are not external.

Table 59 Estimated congestion fees when no additional aircraft join the queue until the congestion has dissipated at Chicago O'Hare Airport with good weather conditions

Queue length at time of take-off	Alaska Airlines Atomistic ($)	Delta, Northwest, Continental Each 2.3% market share ($)	United Airlines 40.5% market share ($)	American Airlines 48.8% market share ($)
5	29	28	17	15
10	121	118	72	62
20	563	550	335	288
30	1,632	1,594	970	835
40	4,140	4,043	2,462	2,117

Source: Johnson and Savage, 2006.

A classification and forecast of European airports according to three congestion levels (little or no excess demand, excess demand at peak hours, excess demand throughout the day) is given by NEAR, 2004. Currently most busy are Franfurt, Düsseldorf, London-Heathrow, London-Gatwick, Milan Linate, Paris Orly and Madrid.

Value of travel time: Congestion is experienced by its impacts on travel time, operating costs and external effects. Applying common valuation principles the value of travel time accounts for roughly 90% of total costs. Therefore, the value of travel time plays the key role in determining marginal or total congestion costs. The 'value of travel time' (VOT)[30]. The VOT in passenger transport widely differs by travel purpose and mode. It may even be differentiated by the length of the trip or by the crowding of vehicles or Infrastructures.

[30] Or 'Value of Travel Time Savings' (VTTS).

Table 60 Value of Travel time and vehicle operating costs for the HEATCO case studies

(Million Euro)	United Kingdom	Denmark	Greece
1 HEATCO	659	5,714	308
2 HEATCO (PPP)	587	4,752	392
3 National	1,086	4,714	138
HEATCOvs. National	–39%	45%	123%
HEATCO(PPP) vs. National	–46%	21%	184%

Source: HEATCO, 2006a.

Demand elasticities: When traffic conditions worsen or when pricing or regulatory instruments are applied, traffic users will react in order to avoid additional burdens as much as possible. The knowledge on this reaction is in particular important for the determination of welfare-optimal congestion internalisation charges. User reactions may be the omission of trips, detouring to other routes, shifting departure times or changing to other modes. Thus, as pointed out above, the availability of travel alternatives plays an important role in analysing congestion conditions. A practical problem is that demand elasticities are not constant over wider ranges of cost changes. Nevertheless, in literature usually iso-elastic demand curves, using a single value for demand elasticity, are applied to model user reaction patterns. Standard values for price elasticities of demand range between -0.2 and -0.4, in particular cases ranging down to -1.0 (Odek and Brathen, 2008).

Reference traffic condition: When monitoring delays in non-scheduled transport a particular reference speed or travel time, which is still considered as not congested, must be defined. In practice free flow travel speeds or a particular share (50% to 70%) of these are used for monitoring road congestion. Free flow can either mean the road's design speed or the actually measures speed at off-peak time. The lower the reference speed is selected the more of small delays are ignored and thus the more robust the monitoring system gets with respect to the occurrence of critical traffic conditions. In case of determining the pricing-relevant marginal social external costs (MSEC) of congestion, however, the reference or 'optimal' traffic situation is endogenously computed by speed-flow and demand elasticity functions. The more or less arbitrary reference traffic condition is not required in this case.

Non-capacity incidents: Congestion and delay measures are commonly classified into 'recurrent' (= capacity-related) and 'non-recurrent' (= all purpose) congestion. The level of recurrent congestion describes the usual level of delays or low traffic quality in case nothing special happens. Measures to fight recurrent congestion are capacity extension, traffic demand management (TDM) and/or congestion pricing. Non-recurrent congestion, in contrast, describes traffic conditions when considering unusual events, such as accidents, road works or bad weather conditions. They represent the real perception of users and are driven by the safety and the physical quality of the Infrastructure. Table 61 reveals that the share of non-capacity related congestion purposes is considerable for all modes of transport. Nevertheless, for the purpose of setting welfare-optimal charges only recurrent congestion is relevant as congestion pricing is meant as a tool to manage day-to-day traffic conditions.

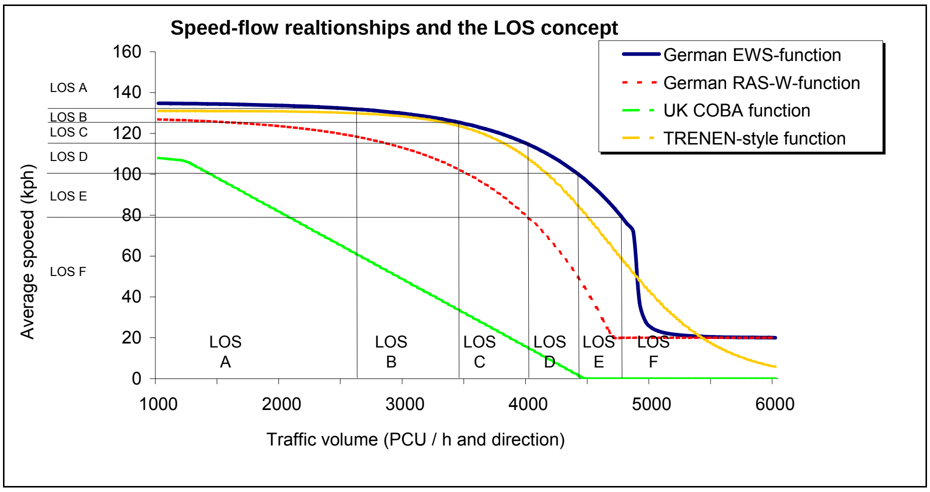
Table 61 Reasons of congestion according to multiple studies

Mode	Study, area	Congestion/delay cause				
		Capacity	Construction works	Accidents	Weather	Other
Road	TTI Urban Mobility Rep.	30%-60%		40%-70%		
	CEDR (2005)[1]:	40%	41%	18%	95%	9%
	Hessen, Germany	30%	30%	10%	30%	
	France, Ile de France	85%	4%	11%		
	Netherlands	82%	5%	13%		
Rail	UK Network Rail	32%[1]	44%[1]		10%	14%
Air	US, DOT	36%			4%	60%[3]
	Europe, AEA	30%			4%	66%[3]
	Europe, Eurocontrol[2]	11%	–	–	11%	78%[3]

1) Number of cases; 2) ATFM En-Route delays; 3) Airlines: 51%, Airport: 19%, security: 4%, miscellaneous: 4%, 3) network management, 4) asset defects.
Source: COMPETE (Fraunhofer/INFRAS, 2006).

One of the most critical aspects in determining the marginal social costs of road congestion is the description and the scope of the network considered. Speed-flow functions are usually strongly non-linear. The slope of the curves strongly impacts the level of marginal social costs – a particular level of demand. Thus, linear functions, as used in the UK, will in most cases lead to much less progressive congestion charges than German-style hyperbolic functions do. In urban environments, however, the description of capacities of intersections is more important than that of road sections, but their modelling is much more difficult. Figure 23 compares two types of the German speed-flow functions for a two lane motorway to the speed-flow curves provided by the UK COBA manual and with a TRENEN-style function (compare TRENEN-II-STRAN, 1999; MC-ICAM 2004).

Figure 23 Comparison of different speed-flow curves



Source: Doll, 2005.

The elaboration of different urban congestion case studies within the UNITE project has shown that the level of detail to which the road network is captured decisively influences the results – even though all case studies have applied the same model framework. The main reason is that a more dense traffic network permits the drivers to choose among a greater variety of detouring routes and thus to avoid highly priced congested links.

In this sense also the accurate consideration of alternative transport modes, possibilities of time shifts and non-transport options is important. A sophisticated congestion model should further consider the different behavioural schemes of different user groups. Due to the complexity and interference of the different transport and non-transport sectors it appears difficult to subsume all these reaction patterns within a single demand elasticity function. But for reasons of simplicity, this approach is applied by most studies.

The 'optimal' toll which shall be computed may denote cordon tolls, time invariant fees or congestion charges which vary by location and time of day. Accordingly, of course, the results vary strongly.

B.4 Output values

Congestion is strongly dependent on transport models and types of networks. Thus the following sections are devoted to interurban road transport, urban road transport, railways and aviation. Urban public transport and shipping are omitted due to a lag in reliable information.
Table 62 presents selected results of the studies analysed for passenger cars. HGV values can easliy bederived by useing the appropriate Passenger Car Units (PCUs).

Table 62 Marginal cost estimates for interurban roads (€/vkm, 2005)

Area	Road types, region	Output values	Range car		
			Low	Av.	High
Paris - Brussels	Motorway, total corridor	MSCP	0.00	0.03	0.05
	Motorway, single links		0.00	0.03	0.15
Paris - Vienna	Motorway, total corridor	MSCP	0.00	0.02	0.03
	Motorway, single links		0.00	0.02	0.15
Cologne - Milan	Motorway, total corridor	MSCP	0.00	0.00	0.00
	Motorway, single links		0.00	0.00	0.00
Duisburg - Mannheim	Motorway, total corridor	MSCP	0.00	0.00	0.00
	Motorway, single links		0.00	0.00	0.00
Belgium	Highway peak	MSCP		0.35	
	Highway off-peak			0.07	
	Other roads peak			0.12	
	Others off-peak			0.06	
UK	Motorway	MEC	0.19	0.19	0.19
	Trunk & principal	Single link	0.14	0.14	0.14
	Rural other		0.02	0.03	0.04

Table 63 presents the values (transferred to €/vkm 2005) of the most important studies for urban roads. Where possible differentiations of the values are given in Table 63.

Table 63 Marginal external cost estimates for urban roads (€/vkm, 2005)

Study (year)	Area	Road types, region	Output values	Unit	Range car	
					Low/Av.	High
GRACE (2007):	Model city	All roads	AC	€/vkm	0.24	0.35
			MSCP		0.11	0.35
UNITE (2002): Europ. case studies	Brussels	All roads / areas	MSCP	€/vkm	0.11	0.39
		Centre			0.14	0.53
		Rest of region			0.11	0.42
		Outside region			0.11	0.34
		Motorways			0.11	0.34
		Main roads			0.14	0.48
		Local roads			0.14	0.45
	Edinburgh	Average	MSCP	€/vkm	0.12	
		City centre			0.49	
		Main approaches			0.19	
		Strategic routes			0.06	
	Salzburg	Average	MSCP	€/vkm	0.16	
		City centre			0.08	
		Main approaches			0.24	
		Strategic routes			0.21	
	Helsinki	Average	MSCP	€/vkm	0.05	
		City centre			0.02	
		Main approaches			0.01	
		Strategic routes			0.11	
TRENEN-II-STRAN	Brussels	All roads, peak	MSCP, all externalities	€/vkm	0.55	0.78
		All roads, off-peak			0.42	
ITS (2001)	UK Cities	Major central peak	MEC	€/vkm	1.44	1.44
		Major central off-peak			0.78	0.79
		Maj. non-centr. peak			0.38	0.41
		Maj. non-cent. off-peak			0.19	0.23
		Other urban peak			0.08	0.14
		Other urban off-peak			0.01	0.08
	Central London	Motorways	MEC	€/vkm	0.84	
		Trunk roads			1.11	
		Other			2.93	
	Inner London	Motorways	MEC	€/vkm	0.31	
		Trunk roads			0.85	
		Other			1.48	
	Outer London	Motorways	MEC	€/vkm	0.49	
		Trunk roads			0.44	
		Other			0.62	
	Inner conurbation	Motorways	MEC	€/vkm	0.84	
		Trunk roads			0.53	
		Other			0.94	
	Outer conurbation	Motorways	MEC	€/vkm	0.55	
		Trunk roads			0.19	
		Other			0.00	
	Urban >25 km²	Trunk roads	MEC	€/vkm	0.16	
		Other			0.01	
	Urban 15-25 km²	Trunk roads	MEC	€/vkm	0.11	
		Other			0.00	
	Urban 10-15 km²	Trunk roads	MEC	€/vkm	0.00	
		Other			0.00	
	Urban 5-10 km²	Trunk roads	MEC	€/vkm	0.05	
		Other			0.00	

Study (year)	Area	Road types, region	Output values	Unit	Range car	
					Low/Av.	High
	Urban 0.01-5 km²	Trunk roads	MEC	€/vkm	0.02	
		Other			0.00	
	Rural	Motorways	MEC	Pence	0.06	
		Trunk & principal			0.13	
		Other			0.02	
Newbery (2002)	Northampton	All roads	MEC	€/vkm	4.92	7.73
			MSCP		2.20	3.48
	Kingston	All roads	MEC	€/vkm	2.59	3.26
			MSCP		1.31	1.92
	Cambridge	All roads	MEC	€/vkm	1.11	1.25
			MSCP		0.65	0.86
	Norwich	All roads	MEC	€/vkm	0.22	0.25
			MSCP		0.17	0.23
	Lincoln	All roads	MEC	€/vkm	1.05	1.22
			MSCP		0.65	0.89
	York	All roads	MEC	€/vkm	0.69	0.94
			MSCP		0.51	0.72
	Bedford	All roads	MEC	€/vkm	0.17	0.19
			MSCP		0.14	0.17
	Hereford	All roads	MEC	€/vkm	0.89	1.12
			MSCP		0.61	0.84
	Average	All roads	MEC	€/vkm	2.00	1.45
			MSCP		0.78	1.14
Prod'home (2006)	Stockholm	All roads	MEC	€/trip	2.53	
			MSCP		1.70	2.13
MC-ICAM, 2004	Paris centre	Motorways	MSCP	€/vkm	0.38	
	Brussels centre	All roads	MSCP	€/vkm	0.47	
	Helsinki centre	All roads	MSP	€/vkm	0.10	
	Helsinki agglomeration	All roads	MSCP	€/vkm	0.03	
	Oslo and Akershus county	All roads	MSCP	€/vkm	1.00	

Although the methodologies of the studies reviewed are similar, they distinguish in a decisive point: the representation of the networks and demand levels. While the UNITE and GRACE urban case studies and the ARUP/SRA investigations consider entire networks, INFRAS considers single links. The latter results are only of theoretical relevance as important reaction patterns of the users on the introduction of congestion pricing have been neglected. On the other hand, the speed-flow curves used by INFRAS seem to be more realistic than that ones used by the UNITE and GRACE urban simulations. This fact to some extent equals out the bias of the INFRAS results.

Estimates of marginal social costs in scheduled transport are rare. Using methods of regression analysis UNITE finds rather low costs in rail transport for the UK and Switzerland. But given the applied methodology these figures do not represent the pricing relevant costs.

Within the GRACE project (GRACE, 2006a) the scarcity cost approach has been tested for the UK West Coast Line. Different cost elements to be considered when an existing or a new operator can not run the trains they like due to the non-availability of tracks. The results are presented in Table 64. Due to reasons of confidentiality, the data could only be expressed relative to the existing operator at peak. The results suggest a substantial scarcity charge for peak slots, the charge for off-peak slots would only be some 10% of this value.

Table 64 Variations of rail scarcity costs (UK west coast line)

	Existing operator at peak		Existing operator off-peak		New operator at peak		New operator off-peak	
	Rail	**Other**	**Rail**	**Other**	**Rail**	**Other**	**Rail**	**Other**
Env+Safety	-0.9	13.4	-0.9	2.9	-0.9	4.8	-0.9	2.0
Infrastructure costs	0.0	1.0	0.0	0.2	0.0	0.4	0.0	0.1
Tax revenues	-12.4	-18.2	-3.1	-3.9	-4.8	-6.5	-1.1	-2.7
Consumer surplus	18.8	0.0	2.6	0.0	0.1	0.0	0.7	0.0
Congestion	0.0	52.7	0.0	11.3	0.0	18.8	0.0	7.7
Mohring	0.0	-1.7	0.0	-0.4	0.0	-0.6	0.0	-0.2
Operators profit	51.2	-4.1	-1.9	-0.9	2.0	-1.4	-19.3	-0.6
Full value	100.0		6.0		11.9		-14.1	

Source: Grace, 2006a.

US evidence on train delay and blocked crossings leads to an average train delay of 2 minutes per crossing, which is a total of 20 million delay hours per year. This is a total of $ 465 million per year or $ 0.34 per 1000 gross ton miles (Gorman, 2008).

In the **aviation** sector European estimates of marginal social congestion costs are rare, although the scarcity of airport slots, in particular at the London airports and several continental hubs (Frankfurt, Paris Orly, Madrid, Milan Linate) would benefit from peak load pricing (NERA, 2004). But in aviation the big airlines hold strong positions by using grandfather rights when it comes to slot allocation.

On the basis of daily flight patterns Johnson and Savage (2006) estimate the marginal external congestion costs by airline size at Chicago O'Hare airport in the afternoon peak much higher than the finite queue related values presented in Table 65.

Table 65 Current-traffic congestion fees in good weather

Gate departure time	Wheels off time	Queue length at time of take off	Alaska Airlines Atomistic ($)	Delta, Northwest, Continental Each 2.3% market share ($)	United Airlines 40.5% market share ($)	American Airlines 48.8% market share ($)
15:00	15:19	28	16,878	16,482	10,035	8,629
16:00	16:23	27	12,848	12,546	7,638	6,569
17:00	17:19	12	9,958	9,724	5,920	5,091
18:00	18:19	27	8,688	8,484	5,165	4,442
19:00	19:19	12	5,241	5,118	3,116	2,680
20:00	20:28	20	670	655	399	343

Source: Johnson and Savage, 2006.

B.5 Appendix: German EWS Speed-Flow Functions

1 EWS Road Types

Type	*Description*
1	**Grade-separated carriageways outside built-up Areas**
1.11	Ramps of single-level intersections (1 carriageway)
1.21	2 Carriageways, with emergency lane
1.22	2 Carriageways, without emergency lane
1.31	3 Carriageways, with emergency lane
1.32	3 Carriageways, without emergency lane
1.41	4 Carriageways, with emergency lane
1.42	4 Carriageways, without emergency lane
2	**Other rural roads**
2.11	1 Carriageway per direction, carriageway width above 10 m, single-or multi-level
2.12	1 Carriageway per direction, carriageway width 7 - 10 m, single-or multi-level
2.13	1 Carriageway per direction, carriageway width below 7 m, single-or multi-level
2.21	2 Carriageway per direction, double carriageways, single-level
2.22	2 Carriageway per direction, single carriageways, single-level
2.31	3 Carriageway per direction, double carriageways, single-level
2.32	3 Carriageway per direction, single carriageways, single-level
3	**Grade-separated carriageways within built-up areas (Urban highway)**
3.11	Ramp of multi-level intersections (1 Carriageways)
3.21	2 Carriageway per direction, with emergency lane
3.22	2 Carriageway per direction, without emergency lane
3.31	3 Carriageway per direction, with emergency lane
3.32	3 Carriageway per direction, without emergency lane
3.41	4 Carriageway per direction, with emergency lane
3.42	4 Carriageway per direction, without emergency lane
4	**Prioritised urban roads without obstacles**
.411	1 Carriageway per direction, outside residential areas (Vmax > 50 km/h)
4.12	1 Carriageway per direction, within residential areas
4.21	2 Carriageway per direction, double carriageways
4.22	2 Carriageway per direction, single carriageways
4.31	3 Carriageway per direction, double carriageways
4.32	3 Carriageway per direction, single carriageways
4.41	4 Carriageway per direction, double carriageways
4.42	4 Carriageway per direction, single carriageways
5	**Prioritised urban roads with obstacles (by influence of intersections, standing traffic or public transport)**
5.11	1 Carriageway per direction, open, multi-sorey building development
5.12	1 Carriageway per direction, closed building development
5.13	1 Carriageway per direction, commercial road
5.21	2 Carriageway per direction, double carriageways
5.22	2 Carriageway per direction, single carriageways
5.31	3 Carriageway per direction, double carriageways
5.32	3 Carriageway per direction, single carriageways
5.41	4 Carriageway per direction, double carriageways
5.42	4 Carriageway per direction, single carriageways
6	**Urban road with obstacles by missing priority and standing traffic/residential-, access road**
6.01	traffic-calmed road with open building development
6.02	Traffic calmed road with closed building development
6.11	Residential road, open building development
6.12	Residential road, closed building development

2 EWS Speed-Flow Functions for Inter-Urban Roads

TableAnnex 1: Speed functions for vehicle group P (passenger cars) on trunk roads

ST	V_P [km/h]	Range of traffic volume (veh./h per direction)		
		Empirical evidence	Transition at s=0, ku=0	Congestion
1.11,	$V_P = 208{,}5 - 105 \cdot \cosh\left(\frac{s+1}{10}\right) + 2 \cdot \left(1 - \exp\left(1{,}59 \cdot 10^{-3} \cdot (Q_P + 2 \cdot Q_{GV})\right)\right)$	≤1.800		
3.11	$V_P = \coth\left(\left((Q_P + 2 \cdot Q_{GV}) - 1.780{,}88\right) \cdot 10^{-3}\right) + 17{,}71$		>1.800	
	$V_P = 20$			>2.250
1.21, 1.22,	$V_P = 138{,}6 - 8 \cdot \exp(0{,}235 \cdot s) - 0{,}1 \cdot \exp\left(1{,}643 \cdot 10^{-3} \cdot (Q_P + 2 \cdot Q_{GV})\right)$	≤3.900		
3.21, 3.22	$V_P = \coth\left(\left((Q_P + 2 \cdot Q_{GV}) - 3.880{,}52\right) \cdot 10^{-3}\right) + 18{,}86$		>3.900	
	$V_P = 20$			>4.875
1.31, 1.32,	$V_P = 143{,}1 - 8 \cdot \exp(0{,}235 \cdot s) - 0{,}1 \cdot \exp\left(1{,}157 \cdot 10^{-3} \cdot (Q_P + 2 \cdot Q_{GV})\right)$	≤5.600		
3.31, 3.32	$V_P = \coth\left(\left((Q_P + 2 \cdot Q_{GV}) - 5.580{,}44\right) \cdot 10^{-3}\right) + 18{,}88$		>5.600	
	$V_P = 20$			>7.000
1.41, 1.42,	$V_P = 145{,}1 - 8 \cdot \exp(0{,}235 \cdot s) - 0{,}1 \cdot \exp\left(8{,}68 \cdot 10^{-4} \cdot (Q_P + 2 \cdot Q_{GV})\right)$	≤7.500		
3.41, 3.42	$V_P = \coth\left(\left((Q_P + 2 \cdot Q_{GV}) - 7.480{,}41\right) \cdot 10^{-3}\right) + 18{,}95$		>7.500	
	$V_P = 20$			>9.375
2.10	$V_P = \left(215{,}5 - 105 \cdot \cosh\left(\frac{s+1}{10}\right)\right) \cdot \exp(-10^{-3} \cdot KU) + 0{,}1 \cdot \left(1 - \exp\left(3{,}272 \cdot 10^{-3} \cdot (Q_P + 2 \cdot Q_{GV})\right)\right)$	≤1.900		
	$V_P = \coth\left(\left((Q_P + 2 \cdot Q_{GV}) - 1.880{,}84\right) \cdot 10^{-3}\right) + 7{,}81$		>1.900	
	$V_P = 10$			>2.375

ST	V_P [km/h]	Range of traffic volume (veh./h per direction) Empirical evidence	Transition at s=0, ku=0	Congestion
2.11	$V_P = \left(208{,}5 - 105 \cdot \cosh\left(\frac{s+1}{10}\right)\right) \cdot \exp(-10^{-3} \cdot KU) + 0{,}1 \cdot \left(1 - \exp\left(3{,}37 \cdot 10^{-3} \cdot (Q_P + 2 \cdot Q_{GV})\right)\right)$	≤1.800		
	$V_P = \coth\left(\left((Q_P + 2 \cdot Q_{GV}) - 1.780{,}88\right) \cdot 10^{-3}\right) + 7{,}71$		>1.800	
	$V_P = 10$			>2.250
2.12	$V_P = \left(202 - 105 \cdot \cosh\left(\frac{s+1}{10}\right)\right) \cdot \exp(-10^{-3} \cdot KU) + 0{,}1 \cdot \left(1 - \exp\left(3{,}472 \cdot 10^{-3} \cdot (Q_P + 2 \cdot Q_{GV})\right)\right)$	≤1.700		
	$V_P = \coth\left(\left((Q_P + 2 \cdot Q_{GV}) - 1.680{,}92\right) \cdot 10^{-3}\right) + 7{,}6$		>1.700	
	$V_P = 10$			>2.125
2.13	$V_P = \left(195{,}5 - 105 \cdot \cosh\left(\frac{s+1}{10}\right)\right) \cdot \exp(-10^{-3} \cdot KU) + 0{,}1 \cdot \left(1 - \exp\left(3{,}746 \cdot 10^{-3} \cdot (Q_P + 2 \cdot Q_{GV})\right)\right)$	≤1.600		
	$V_P = \coth\left(\left((Q_P + 2 \cdot Q_{GV}) - 1.576{,}47\right) \cdot 10^{-3}\right) + 7{,}5$		>1.600	
	$V_P = 10$			>2.000
2.14	$V_P = \left(188{,}5 - 105 \cdot \cosh\left(\frac{s+1}{10}\right)\right) \cdot \exp(-10^{-3} \cdot KU) + 0{,}1 \cdot \left(1 - \exp\left(4{,}666 \cdot 10^{-3} \cdot (Q_P + 2 \cdot Q_{GV})\right)\right)$	≤1.300		
	$V_P = \coth\left(\left((Q_P + 2 \cdot Q_{GV}) - 1.269{,}63\right) \cdot 10^{-3}\right) + 7{,}07$		>1.300	
	$V_P = 10$			>1.625
2.21, 2.22	$V_P = 118 - 8 \cdot \exp(0{,}235 \cdot s) - 5 \cdot \exp\left(6{,}58 \cdot 10^{-4} \cdot (Q_P + 2 \cdot Q_{GV})\right)$	≤3.500		
	$V_P = \coth\left(\left((Q_P + 2 \cdot Q_{GV}) - 3.480{,}55\right) \cdot 10^{-3}\right) + 8{,}6$		>3.500	
	$V_P = 10$			>4.375

ST	V_P [km/h]	Range of traffic volume (veh./h per direction)		
		Empirical evidence	Transition at s=0, ku=0	Congestion
2.31, 2.32	$V_P = 118 - 8 \cdot \exp(0{,}235 \cdot s) - 5 \cdot \exp\left(4{,}26 \cdot 10^{-4} \cdot (Q_P + 2 \cdot Q_{GV})\right)$	≤5.400		
	$V_P = \coth\left(\left((Q_P + 2 \cdot Q_{GV}) - 5.380{,}45\right) \cdot 10^{-3}\right) + 8{,}86$		>5.400	
	$V_P = 10$			>6.750

TableAnnex 2: Speed functions for vehicle group GV (goods vehicles) on trunk roads

ST	V_{GV} [km/h]	Range of traffic volume (veh./h per direction)		
		Empirical evidence	Transition at s=0, ku=0	Congestion
1.11,	$V_{GV} = 185{,}5 - 105 \cdot \cosh\left(\frac{s+1}{10}\right) + 2 \cdot \left(1 - \exp\left(3{,}045 \cdot 10^{-3} \cdot Q_{GV}\right)\right)$	≤1.000		
3.11	$V_{GV} = \coth\left((Q_{GV} - 995{,}24) \cdot 10^{-2}\right) + 18{,}99$		>1.000	
	$V_{GV} = 20$			>1.250
1.21, 1.22,	$V_{GV} = 86{,}1 - 6 \cdot \exp(0{,}248 \cdot s) - 0{,}1 \cdot \exp\left(9{,}218 \cdot 10^{-3} \cdot Q_{GV}\right)$	≤650		
3.21, 3.22	$V_{GV} = \coth\left((Q_{GV} - 645{,}26) \cdot 10^{-2}\right) + 18{,}93$		>650	
	$V_{GV} = 20$			>815
1.31, 1.32,	$V_{GV} = 86{,}1 - 6 \cdot \exp(0{,}248 \cdot s) - 0{,}1 \cdot \exp\left(4{,}609 \cdot 10^{-3} \cdot Q_{GV}\right)$	≤1.300		
3.31, 3.32	$V_{GV} = \coth\left((Q_{GV} - 1.256{,}18) \cdot 10^{-3}\right) + 17{,}17$		>1.300	
	$V_{GV} = 20$			>1.625
1.41, 1.42,	$V_{GV} = 86{,}1 - 6 \cdot \exp(0{,}248 \cdot s) - 0{,}1 \cdot \exp\left(3{,}994 \cdot 10^{-3} \cdot Q_{GV}\right)$	≤1.500		
3.41, 3.42	$V_{GV} = \coth\left((Q_{GV} - 1.455{,}58) \cdot 10^{-3}\right) + 17{,}48$		>1.500	
	$V_{GV} = 20$			>1.875

ST	V_{GV} [km/h]	Range of traffic volume (veh./h per direction) Empirical evidence	Transition at s=0, ku=0	Congestion
2.10	$V_{GV} = \left(166 - 85 \cdot \cosh\left(\frac{s+1,5}{10}\right)\right) \cdot \exp\left(-10^{-3} \cdot KU\right) + 0,1 \cdot \left(1 - \exp\left(1,998 \cdot 10^{-2} \cdot Q_{GV}\right)\right)$	≤300		
	$V_{GV} = \coth\left(\left(Q_{GV} - 296,83\right) \cdot 10^{-2}\right) + 8,47$		>300	
	$V_{GV} = 10$			>375
2.11	$V_{GV} = \left(166 - 85 \cdot \cosh\left(\frac{s+1,5}{10}\right)\right) \cdot \exp\left(-10^{-3} \cdot KU\right) + 0,1 \cdot \left(1 - \exp\left(1,998 \cdot 10^{-2} \cdot Q_{GV}\right)\right)$	≤300		
	$V_{GV} = \coth\left(\left(Q_{GV} - 296,83\right) \cdot 10^{-2}\right) + 8,47$		>300	
	$V_{GV} = 10$			>375
2.12	$V_{GV} = \left(146 - 85 \cdot \cosh\left(\frac{s+1,5}{10}\right)\right) \cdot \exp\left(-10^{-3} \cdot KU\right) + 0,1 \cdot \left(1 - \exp\left(2,121 \cdot 10^{-2} \cdot Q_{GV}\right)\right)$	≤250		
	$V_{GV} = \coth\left(\left(Q_{GV} - 246,85\right) \cdot 10^{-2}\right) + 8,26$		>250	
	$V_{GV} = 10$			>315
2.13	$V_{GV} = \left(146 - 85 \cdot \cosh\left(\frac{s+1,5}{10}\right)\right) \cdot \exp\left(-10^{-3} \cdot KU\right) + 0,1 \cdot \left(1 - \exp\left(2,652 \cdot 10^{-2} \cdot Q_{GV}\right)\right)$	≤200		
	$V_{GV} = \coth\left(\left(Q_{GV} - 196,88\right) \cdot 10^{-2}\right) + 7,94$		>200	
	$V_{GV} = 10$			>250
2.14	$V_{GV} = \left(136 - 85 \cdot \cosh\left(\frac{s+1,5}{10}\right)\right) \cdot \exp\left(-10^{-3} \cdot KU\right) + 0,1 \cdot \left(1 - \exp\left(3,536 \cdot 10^{-2} \cdot Q_{GV}\right)\right)$	≤150		
	$V_{GV} = \coth\left(\left(Q_{GV} - 145,56\right) \cdot 10^{-2}\right) + 7,48$		>150	
	$V_{GV} = 10$			>190

ST	V_{GV} [km/h]	Range of traffic volume (veh./h per direction) Empirical evidence	Transition at s=0, ku=0	Congestion
2.21, 2.22	$V_{GV} = 91 - 6 \cdot \exp(0{,}248 \cdot s) - 5 \cdot \exp(3{,}38 \cdot 10^{-3} \cdot Q_{GV})$	≤650		
	$V_{GV} = \coth\left((Q_{GV} - 646{,}79) \cdot 10^{-2}\right) + 8{,}92$		>650	
	$V_{GV} = 10$			>815
2.31, 2.32	$V_{GV} = 91 - 6 \cdot \exp(0{,}248 \cdot s) - 5 \cdot \exp(1{,}69 \cdot 10^{-3} \cdot Q_{GV})$	≤1.300		
	$V_{GV} = \coth\left((Q_{GV} - 1.269{,}63) \cdot 10^{-3}\right) + 7{,}07$		>1.300	
	$V_{GV} = 10$			>1.625

Symbols:

ST	Road Type
V_P	Speed of passenger cars (Kph)
V_{GV}	Speed of goods vehicles (kph)
	Traffic volume of passenger cars (veh./h)
Q_{GV}	Traffic volume of goods vehicles (veh./h)
s	Gradient (%)
KU	Curvature (gon/km)

C Accident costs

C.1 Overview of studies

Table 66 presents the most important studies on external accident costs.

Table 66 Overview studies on external accident costs

STUDIES ON EXTERNAL ACCIDENT COSTS OVERVIEW						
Author, Title, Year of Publication	**Base year(s) of results**	**Countries covered**	**Cost categories covered[1)]**	**Transport modes covered**	**Externality: which part of total accident costs is external?**	**Outputs, Result differentiation**
EU Projects and Programs						
High Level Group on transport Infrastructure charging, 1999c	only Marginal Cost Methodology	European Union	1, 2, 3, 4, 5	Road, rail	Users own Risk value internalised	marginal costs, cost rates
PETS (Pricing European Transport Systems), 2000	1995/98, pricing scenario 2010	EU-15, Switzerland, Case Studies	1, 2, 3, 4, 5	Road, rail, air, maritime	Users own Risk value internalised	Marginal social/ external costs
UNITE (Unification of accounts and marginal costs for transport efficiency), 2003 Project coordinator: ITS, Leeds	1998, (1996, 2005)	EU-15, Hungary, Estonia, Switzerland	1, 2, 3, 4, 5	Road, rail, urban public transport, air, water	Only transport system external costs treated as external costs (risk value internalised), no risk values for relatives and friends considered	total, average for all countries considered, marginal costs for specific countries (case studies)
RECORDIT (Real cost reduction of door-to-door intermodal transport), 2001 Project coordinator: ISIS, Rome	1998	3 selected European corridors	1, 2, 3, 4, 5	Intermodal freight transport: road, rail, ship	Only transport system external costs treated as external costs (risk value internalised), no risk values for relatives and friends considered	Total and average costs, sector results

STUDIES ON EXTERNAL ACCIDENT COSTS OVERVIEW						
Author, Title, Year of Publication	**Base year(s) of results**	**Countries covered**	**Cost categories covered[1)]**	**Transport modes covered**	**Externality: which part of total accident costs is external?**	**Outputs, Result differentiation**
HEATCO (Developing Harmonised European Approaches for Transport Costing and Project Assessment), Project coordinator: IER, Stuttgart	2004 ongoing	EU-25	1, 2, 3, 4, 5	Road, rail, air, water	Project on valuation of changes of accident risks (no differentiation between external and internal) incl. risk values based on WTP studies	Values for casualties avoided for EU 25 (2002 prices)
GRACE (Generalisation of research on accounts and cost estimation), ongoing Project coordinator: ITS, Leeds	2005 ongoing	EU-25	1, 2, 3, 4, 5	Road, rail, air, water	dep. on case study: Impact-Pathway and Top-Down Approach	Marginal costs based on literature survey
Other studies with a European Scope						
INFRAS/IWW, External costs of transport, 2000	1995 Estimate for 2010	EU-15, Norway, Switzerland	1, 2, 3, 4, 5	Road, rail, air, water (inland water transport)	Risk value external	Method and results: Total and average costs, marginal costs
INFRAS/IWW, External costs of transport - update study, 2004a	2000	EU-15, Norway, Switzerland	1, 2, 3, 4, 5	Road, rail, air, water (inland water transport)	Risk value external	Results: Total and average costs, marginal costs
OECD/INFRAS/ Herry), External costs of transport in Central and Eastern Europe, 2003	1995 (2010)	Eastern Europe	1, 2, 3, 4, 5	Road, rail, air, water	Risk value external	Results: total and average costs
CE Delft/ ECORYS, Marginal costs of Infrastructure use - towards a simplified approach, 2004	Unit cost rates for 2002	EU-15	1, 2, 3, 4, 5	Road, rail, aviation	2. Approaches: marginal costs: Own risk is internalised when entering the transport system average costs: risk value assumed to be external	Marginal and average costs for selected examples

STUDIES ON EXTERNAL ACCIDENT COSTS OVERVIEW						
Author, Title, Year of Publication	**Base year(s) of results**	**Countries covered**	**Cost categories covered[1)]**	**Transport modes covered**	**Externality: which part of total accident costs is external?**	**Outputs, Result differentiation**
TRL 2001: Cost Matrices Handbook: Estimates of the Marginal Costs of Transport, 2001	1995	EU-15, Norway, Switzerland	1, 2, 3, 4, 5	Road, rail, air, water	Meta analysis of existing results INFRAS/IWW 2000, PETS, ITS, 2001	Marginal costs for selected countries and modes
Country specific studies						
COWI: External Costs of Transport in Denmark (Hvid 2004)	1999-2001	Denmark	1, 2, 3, 4, 5	Road, rail	own Risk value internal, Risk values of victims external	Total and average costs
CE Delft, The price of transport - overview of the social costs of transport, 2004 (update of the 1999 study)	2002	The Nether-lands	1, 2, 3, 4, 5	Road, rail, air, water (inland shipping)	Risk value external	Method and results: total costs, variable social costs
ITS, 2001: Surface transport costs and charges – Great Britain 1998, 2001	1998	United Kingdom	1, 2, 3, 4, 5	Road only	own Risk value internal, risk value of relatives and friends (40% of own risk value) external	Method and results : marginal and average costs
OSD (Federal Office for Spatial Development), Accident costs for road and rail in Switzerland 1998, 2002	1998	Switzerland	1, 2, 3, 4, 5	Road, rail	2 perspectives: transport user external (risk value partially external), transport system external (risk value internal)	Total and average costs

Discussion of the studies available

In general two different kinds of studies on social and external accident costs are available:

- Studies on total or average accident costs. These studies account for total social and external costs of different transport modes and allocate them among transport means/vehicle categories according to different allocation methods (allocation according to victims of a specific transport mean (UNITE, allocation to the 'guilty' or responsible part of an accident or allocation to the transport mean/vehicle category acc. to their intrinsic risk of each vehicle category).
- Studies on marginal social and/or external accident costs. These studies deal with the question of the increased risk all others are exposed to when an

additional vehicle enters the traffic system. Transport users normally never include these small risk changes and their costs in their decisions. This ‘congestion-type' of externality is one part of marginal accident costs, some studies call it 'traffic volume externalitiy' (e.g. UNITE, 2000b, 2000d). Another important externality are costs which are system external: in some states the government finances medical cost and the cost of lost production capability from general taxation and will not ask for contributions from the user. These costs are thus never included in the users' decision. In addition, traffic category externalities can be found for changed accident risks in other modes. A detailed description of the idea of marginal external accident costs can be found in UNITE, 2000d.

Total social and external accident costs are dominated by the so called 'risk value' UNITE, 2001. The risk value represents the society's willingness to pay for avoiding death casualties or injuries in transport. It reflects the decrease in social welfare due to suffering and grief of the victims and their relatives and friends. The relevant cost elements are hereby the own risk value as well as the suffering and grief of relatives and friends. The cruel question of studies on total and average accident costs is which part of the risk value is considered to be internal and external respectively. This issue will be discussed later.

The following discussion of the studies examined predominantly focuses on those studies which compute own total, average and marginal accident costs. Studies transferring or just citing other studies are not discussed in detail.

Scientific accuracy

Scientific accuracy could be attested to most of the studies examined. Depending on the scope of the studies (countries and cost categories covered) the methodological approach is more or less focused on the estimation of external accident costs. A sound methodological approach is presented in the Paper of the High Level Group on Infrastructure Charging (High Level Group, 1999c) however without presenting result figures. The UNITE projects provides both, detailed suggestions for the estimation and calculation of total and average accident costs (UNITE, 2000b) as well as a methodological framework for the estimation of marginal external accident costs (UNITE, 2000d). The methodology was applied in different pilot accounts of UNITE as well as in 6 marginal cost case studies for mainly road and rail transport as well as for inland waterways and maritime transport. The Swiss case study on marginal accident costs for road and rail (results in UNITE, 2002c) is considered to be a very accurate, well based and highly differentiated study on marginal accident costs particularly for different road vehicle categories and types of network. The RECORDIT project draws heavily on values and valuation conventions from UNITE and the High Level Group. TRL Studies (e.g. TRL, 2001b) as well as COWI present and compute mainly outputs from other studies like RECORDIT, INFRAS/IWW, 2004a. INFRAS/IWW, 2004a presents as well total and marginal accident costs for 17 European countries computed with the same methodology and based on the IRTAD Data base on road traffic accidents and detailed UIC accident figures for rail. However, different cost components have been transferred from other countries as well as the cost allocation to different vehicle categories within a mode was made based on the detailed analysis of few well documented pilot countries. The GRACE case study on marginal accident costs (GRACE, 2006a) summarizes the actual discussion on external cost calculations, presenting up-to-date results from e.g. the HEATCO project without calculating own new values.

From the national studies on total or average external accident costs the study for Switzerland (OSD, 2002) has applied a well developed and differentiated methodology estimating all different cost components based on empirical and statistical results and is considered to be a best practice study for total or average accident costs.

Quality of data basis

The quality of the data basis is crucial for external accident cost calculation. Beginning from the statistical data normally provided by national statistical offices to data on material damages, on medical costs, legal, on police and administrative costs and on transfer payments of insurances and compensation payments for damages due to legal action, highly differentiated data is necessary for external cost calculations. Again, the UNITE project with national pilot accounts and marginal cost case studies used well based national data which was processed by the different local consortium members. In addition, the marginal cost case studies could dispose of an excellent data base (e.g. UNITE, 2002c). INFRAS/IWW, 2004a also uses up-to-date data of a European road and rail accident data base (IRTAD/UIC). The national studies focussing on total or average costs for Switzerland (OSD, 2002) or the Netherlands (CE Delft, 2004) use differentiated and prevailing data sources of the respective country.

Completeness

With respect to completeness two aspects are important: First completeness in terms of transport modes and second completeness in cost categories covered. Whereas the latter is normally given and all relevant cost categories are normally covered most studies only provide differentiated results for road transport and sometimes rail transport. For other modes (air transport, inland waterway transport) results are only fragmentary presented if at all. Rather complete data in terms of total costs for different transport modes can be found in UNITE (pilot accounts and marginal costs) and INFRAS/IWW, 2004a.

Transferability

Transferability of results of external accident costs in general is limited. Results of total and marginal cost studies highly depend on national and case specific characteristics (vehicle categories, risk elasticities, statistical definitions, etc.). The transfer of results per vehicle-kilometre between countries needs differentiated information on accident rates, risk elasticities (if possible differentiated by vehicle categories) of the countries concerned as well as information on the medical and insurance system. Due to the observed decrease of accident rates and decreasing number of accident casualties in most of European countries also the transfer of results between different points in time is not trivial but needs information of the development of accident and victim rates of the respective points in time. For marginal external accident costs highly differentiated data as presented in the Swiss case study for road and rail in UNITE (UNITE, 2002c) is a precondition for value transfer between countries.

Data for the valuation of avoided casualties in Cost Benefit Analysis (CBA) as presented in the HEATCO project (Deliverable 5, HEATCO, 2006a) is on the other hand easily transferable since results are presented per casualty avoided (fatalities and severe or slight injuries) and per country. However these data can only be directly used for the calculation of total costs.

Practical application
Here the same arguments as for transferability hold true. Values provided for CBA can easily be used for the valuation of accident costs; however, no specification of the external part of total accident costs can be made based on these results.

Potential for aggregation
Since marginal accident costs are highly case specific the need for aggregation of differentiated results is not immoderate.

Conclusion
Most studies can be considered as scientifically accurate and based on differentiated data (esp. UNITE pilot accounts and marginal cost case studies). Most studies cover road transport, for other modes the availability of differentiated results is rather low. However it has to be stated that transferability of results remains limited. For road transport the Swiss case study on marginal external accident costs in UNITE provides due to its differentiated results (per vehicle category and network category) a good basis for value transfer based on accident rates/accident elasticities as well as a value transfer of the most important cost components (esp. VSL/risk value) based on GDP/cap. PPP.

C.2 Main methodological approaches

A Total and average accident costs
This approach was used for different studies in Europe and for different states. On a European level total and average accident costs have been calculated within UNITE (methodology UNITE, 2000b, results e.g. UNITE, 2002a+b). Country specific results can be found in OSD, 2002 for Switzerland, Hvid (2004) for Denmark or CE Delft, 2004 for the Netherlands. All studies cover the following cost categories:
– Material damages: most of these costs are covered by insurance fees, deductibles or private funds (in case of unreported accidents) and therefore treated as internal costs. Only damages to public/private property covered by public funds are considered to be system external and therefore accounted for.
– Administrative costs (some studies (CE Delft, 2004) cover these costs under the term 'transaction and prevention costs'). This cost category covers costs of the police, the legal system as well as the insurance system. Again, parts

of these costs are covered by transfer payments from insurance companies and reimbursement of legal costs by legal insurance systems. However, a considerable amount of these costs remain external.

- Medical costs: Costs caused by first aid and ambulance, hospitalisation, occupational rehabilitation, etc. are partly covered by the liability insurance system and therefore partly internal. Total medical costs less the internalisation contribution from liability insurance and gratification payments or transfers from the party responsible are system external.
- Production losses or human capital costs: in general net production losses are considered to be external, since the lost output (gross production losses) is in generally covered within the risk value (gross output was then seen as part of the human cost (notably the loss of enjoyment of their lives in the case of deceased persons attributable to the consumption of goods and services (see UNITE, 2000b)).
- Risk value: The risk tries to estimate monetary values for pain, grief and suffering of an average transport accident victim (injuries and fatalities). The use of only material accident costs would seriously underestimate the true value people will invest in safety. The most common method to assess the risk value is the contingent valuation method (CVM). An extensive discussion on the risk value and different methodological approaches for its quantification it could be found e.g. in High Level Group, 1999c; INFRAS/IWW, 2000/2004a; UNITE, 2001; UNITE, 2000b+d.

B Marginal accident costs

The basic principle of the external marginal accident cost is straightforward. The magnitude of the costs depends on the accident risk, the risk elasticity, the external element of the costs and the valuation of accidents (High Level Group, 1999c). Marginal costs are hereby defined as the derivation of total costs with respect to traffic volume. When a vehicle enters into the traffic flow the user exposes himself to the average accident risk in that transport mode. At the same time he may increase or decrease the accident the risk for all other users of the same mode. Finally, his entrance exposes users of other transport modes with an accident risk; this risk may also increase, decrease or stay constant. When economic values are assigned to these three consequences they express the marginal accident cost. Again, the question with respect to the risk value arises. In UNITE (UNITE, 2000d) the assumption is made that the user internalises in his decision the risk he exposes himself to, valued as his willingness-to-pay for safety.

The remaining cost, the external marginal accident cost, then consists of three components (UNITE, 2000d):

1. System externalities - the expected accident cost to the rest of the society when the user exposes himself to risk by entering into the traffic flow- mainly medical and hospital costs.
2. Traffic volume externalities - the willingness- to-pay of the household, relatives and friends and the rest of society related to the increase or decrease in the accident risk for all other users of the same mode; and finally.
3. Traffic category externalities - the willingness-to-pay of the household, relatives and friends and the rest of society related to the changed accident risk in other modes of transport.

GRACE, 2006b identified 3 different approaches to estimate marginal accident costs:

1. UNITE Methodology: critical element: Value of Statistical Life (VSL), proportion of internal costs, risk and risk elasticity.
2. Insurance externality: the relationship between the traffic flow and the insurance premium is estimated based on aggregate data. The underlying precondition is that the insurance covers all cost. The average driver then pays the average accident cost either in the form of an insurance premium or by bearing the accident risk. An additional distance driven by a driver will increase the insurance premium by a small amount. However, as all users are affected, the externality will be substantial. The method is most suitable for non-fatal accidents where VSL does not play such a dominant role.
3. CGE (computable general equilibrium): CGE would be able to cover also the effect of risk avoiding behaviour and could include secondary income effects through the economic costs of accidents. However, this approach is dependent on the same detailed information on elasticities, etc. as the first approach. If behaviour adjustments are included also this could be covered but the underlying knowledge on behaviour adaptation has to come from other sources.

Most of empirical work suggests that the risk decreases with traffic volume (the risk elasticity $E<0$). This highlights one of the problems of marginal accident cost calculation: risk avoiding behaviour. GRACE, 2006b discusses different problems regarding marginal cost calculations extensively. The critical questions concern risk changes when additional vehicles enter the traffic system. GRACE, 2006b summarizes the discussion as follows: It is well known that when the traffic volume increases on a road the speed goes down and the average travel time increases. But what about the accident risk? As the number of vehicles increases the number of accidents will most probably increase; we have not seen any evidence on the opposite effect. However, exactly how the number of accidents increases is important; will the number of accidents increase in proportion to the increase in traffic volume, or will the increase be progressive or degressive? If the number of accidents increases in proportion to the traffic volume the risk, i.e. the number of accidents per vehicle or vehicle kilometre, will be constant; the risk elasticity (E) will take the value nil. If the increase is degressive the accident risk

will decline and the elasticity will be negative. This means that an additional user reduces the risk for an accident for all other users. Finally, if the number of accidents increases progressively the risk will increase. An additional vehicle will impose an increased threat to all other vehicles and the external effect will be larger, the elasticity will be positive.
As the number of vehicles increases the number of possible interactions increases with the square. This suggests that the risk should increase with traffic volume. Dickerson, 2000 find that the accident elasticity varies significantly with the traffic flow. They argue that the accident externality is close to zero for low to moderate traffic flows, while it increases substantially at high traffic flows. This is also found by Fridstrøm, 1995. Winslott, 2005 concludes also from other literature that the accident risk involving only motor vehicles on urban-road links is independent of the traffic flow. At intersections the evidence is increasing accident risk. However, she also concludes that the estimates on rural roads show a great variation. Vitaliano, 1991 show in their estimation that the relationship between accidents and flows is nearly proportional and thus the risk elasticity is close to zero.

In an overview of six international studies, Chambron, 2000 finds a less than proportional increase in injury and fatal accidents. This has also been found by Hauer, 1997 and a majority of the results review in Ardekani, 1997. Edlin/Karaka-Mandic, 2003 studied the effect of traffic density on insurance premiums as well as on fatalities accident only. He found that fatalities decrease with traffic density in low density states but increases in high density state. He found the same pattern for insurance premiums. Ozbay, 2001 estimated the full marginal costs of highway transportation in New Jersey. From these estimates elasticites can be derived. Property damage and injury accidents increase with traffic volume in urban areas while fatality accidents decline. On freeway and expressway also property damage and injury accidents decline with traffic volume while they increase on interstate roads with increased traffic volume.
Winslott, 2005 estimates the relationship between accident and traffic flow on 83 Swedish road sections with information on hourly traffic flow. When the traffic is treated as homogenous (i.e. cars and lorries added together) the result is a decreasing accident risk, i.e. a negative elasticity. However, when cars are studied separately the result suggests that the accident rate is constant or increases. However, the result with respect to lorries is reversed, indicating a decreasing number of accidents as the number of lorries increases. This is also the result from the study in UNITE (UNITE, 2002c).

Recapitulating GRACE, 2006b concludes that there is still no consensus on the risk elasticity and thus on marginal external accident costs. Most results of the case studies carried out in UNITE suggest that the risk decreases with traffic volume, although as the number of vehicles increase on a specific road section the number of possible interactions increases with the square. The results with respect to marginal accident costs of different case studies in UNITE differ widely (UNITE, 2002c). Due to the low or even negative risk elasticities marginal costs are very low. It has to be borne in mind that within UNITE it was assumed that the user is aware of his own risk and related costs (risk value) of being a victim (a large part of total costs) are already internalised.

C Valuation of existing knowledge

Due to the different evidence and specifications (network, mode, insurance system, and methodological approaches), a generalisation and transfer of external accident costs is difficult. We base our recommendations on the case studies carried out in UNITE (UNITE, 2002d), due to the following reasons:

- UNITE and GRACE are the most important studies carried out at European level.
- The studies are based on a differentiated bottom-up approach using the recommended input values.
- The comparison of different studies shows that the UNITE case study applied for roads in Switzerland is most representative and most differentiated. Further on it fits into the range of study results of different bottom-up and top-down approaches.

Average(d) representative values for road transport can be taken from the UNITE Case Study 8a Marginal External Accident Costs in Switzerland (UNITE, 2002d). This case study provides values for Switzerland 1998 with a high differentiation with respect to network type (motorways, inside settlement areas, outside settlement areas) and vehicle types. For the central estimate the assumption was made that the risk value of a non-responsible victim is considered to be external. Although the traffic relation might be different, the figures are transferable to other countries by considering the specific differentiation of input values.

C.3 Input values and data sources

A Accident figures

Starting point of external accident cost calculation is statistical data on accidents for road, rail, air and waterway transport. The accident definition used in the different countries is most often in line with the EUNET definition (ITS, 1998):

- Fatality: death within 30 days for causes arising out of the accident.
- Serious injury: casualties who require hospital treatment and have lasting injuries, but who do not die within the recording period for a fatality.
- Slight injury: casualties whose injuries do not require hospital treatment or, if they do, the effect of the injury quickly subsides.
- Damage-only accident: accident without casualties.

Some countries use only fatality and injury definitions while e.g. Finland and Switzerland have a more advanced definition which includes (permanent) invalidity as a special case of severe injuries.

Road transport

There are different international databases providing statistical information on accidents for different countries which can be used e.g. CARE - Community database on Accidents on the Roads in Europe (EU)[31] or IRTAD - International Road Traffic and Accident Database (OECD)[32]. For many countries more advanced and more differentiated accident data is available from national statistical data (e.g. Germany (DESTATIS) provides data which gives information on the guilty part (causer) of a road accident and allows therefore highly differentiated cost allocation).

However, underreporting of road accidents is a well known problem in official accident statistics. Therefore the official figures for accidents underestimate the true number of accidents. We believe that unreported accidents should be included in careful evaluations because the true number of injury accidents may easily be the double of what official statistics show. While there is considerable literature on unreported road accidents, to our knowledge there is almost no literature on unreported accidents for other transport modes.

In road traffic a correction factor for unreported accidents (= all accidents/ reported accidents) should be applied. The number of reported accidents has to be increased by this factor. Correction factors for road transport are likely to be different in different countries. Whenever national estimates for correction factors are available, we should therefore use these national factors. However, such factors are only available for 6 countries (Sweden, Denmark, Norway, Switzerland, Germany and UK). For all other countries the average value derived from the results from these 6 countries have to be used. Cautious estimates of the average correction factors for unreported accidents are given in Table 67 (HEATCO, 2005).

Table 67 Recommendation for European average correction factors for unreported road accidents. The correction factor given for fatalities of 1.02 should be applied in all countries alike, since here the problem is not underreporting, but that some accidents victims die only after the first 30 days after the accident

	Fatality	Serious injury	Slight injury	Average injury	Damage only
Average	1.02	1.50	3.00	2.25	6.00
Car	1.02	1.25	2.00	1.63	3.50
Motorbike/moped	1.02	1.55	3.20	2.38	6.50
Bicycle	1.02	2.75	8.00	5.38	18.50
Pedestrian	1.02	1.35	2.40	1.88	4.50

Source: HEATCO, 2005.

31 http://europa.eu.int/comm/transport/care/index_en.htm.

32 http://www.bast.de/htdocs/fachthemen/irtad/.

Rail

Rail accident data could be found in national statistical databases or in the UIC railways statistic which covers all railway accidents of its members differentiated by accident type and fatality/injury. The HEATCO project states that unreported accidents can be neglected (HEATCO, 2005). Rail traffic accidents are hard to hide because they are often accompanied by (severe) delays of the concerned train and of other trains and because even single accidents are not only observed by only one (car or train) driver but by several people (passengers or rail company workers).

Since accidents in rail transport are not very frequent, the calculation of accident costs should be based on an average value over several years,. INFRAS/IWW, 2000/2004a use a seven-year-average, the UNITE pilot accounts use a five-year-average (UNITE, 2000b).

Although official accident statistics sometimes also include workplace accidents and suicides, casualties of these accidents should not be considered because there seems to be no argument that pricing instruments could prevent these kind of accidents.

Air and Water transport

Again, an average of several years for casualties from accidents should be used because accidents are not very frequent in these modes. Again, work place accidents should not be considered there.

B Valuation of accidents

The valuation of an accident can be divided into direct economic costs, indirect economic costs and a value of safety per se. The direct cost is observable as expenditure today or in the future. This includes medical and rehabilitation cost, legal cost, emergency services and property damage cost. The indirect cost is the lost production capacity to the economy that results from premature death or reduced working capability due to the accident (HEATCO, 2006a).

The following method is used to estimate the direct and indirect economic accident cost by cost component:

- **Medical and rehabilitation cost:** The major direct cost of accidents is medical and rehabilitation costs. The cost consists both of the cost the year of the accident and future cost over the remaining lifetime for some injury types. The future cost is expressed as the present value over the expected lifetime of the patient, taken the annual development in hospital efficiency into account.
- **Administration, legal court and emergency service cost:** The administrative cost of an accident consists of the cost for police, the court, private crash investigations, the emergency service and administrative costs of insurances.
- **Material damages**: compared to the values for casualties, material damages are of minor importance. We assume that data on costs is available in different countries and that consistency in valuation is less of a problem for material damages and recommend using national values.
- **Production losses:** The indirect economic cost of accidents consists of the value to society of goods and services that could have been produced by the

person, if the accident had not occurred. The (marginal) value of a person's production is assumed to be equal to the gross labour cost, wage and additional labour cost, paid by his employer. The losses of one year's accident will continue over time up to the retirement age of the youngest victim. The value of the lost production will grow with a growing economy over time. Three types of production losses can be found:

- Due to premature death.
- Due to reduced working capacity. and
- Due to days of illness.

– **Risk value, Value of safety**: When discussing the value of safety, it is important to note that not the (monetary) value of a life per se is assessed, but the value of a very small change in the risk of dying or getting injured in an accident.

  Two basic methods can be used to estimate willingness-to-pay (WTP), revealed preference or stated preference. The former is based on actual market transactions by the individuals. The most frequent technique used to elicit the value of safety per se is wage-risk studies which estimate the wage premium associated with the fatality risk at work (see Viscusi, 2003). The main disadvantage with revealed preference studies is the difficulty to find a distinctive traffic safety product on the market. However, some studies have derived VSL based on data from the car market (e.g. Andersson, 2005). In its place, stated preference methods have been the preferred method to estimate a value of traffic safety per se. A hypothetical market situation is created in which people are asked to value.

Factors that affect the risk value (Bickel et al., 2006)

The VSL varies with a number of characteristics which would imply that it is not possible to define one single European VSL today. The value should vary with population (or sample) characteristics - age and health status, sex, education and income but also possibly culture differences and religion - or type of safety projects considered - initial risk level, risk reduction, public or private measures, dread effect, level of control etc. The most important factor to consider when transferring values between countries is probably the income. In UNITE it was argued that income elasticity within studies can be around 0.3 (e.g. Persson, 2000), but that income elasticities between countries tend to be higher reflecting culture and social differences. Miller, 2000 estimated an 'income elasticity' between studies and countries of around 0.8 and UNITE recommended adjusting the value linearly with GDP/Capita, which implies an elasticity of 1.0. Viscusi, 2003 made surveys of mainly wage-risk studies and suggested income elasticity between 0.5 and 0.6.

We follow the UNITE recommendation of using an income elasticity of 1.0 when transferring values between countries.

ECMT, 2000 suggests that the value for severe injuries is 13% and for slight injuries 1% of the VSL of fatalities. In UNITE as well as in INFRAS/IWW, 2000/2004a similar values have been used. The analysis of existing practice in the EU countries as reported in HEATCO, 2005 suggests that on average this recommendation seems to be reasonable in absence of more accurate national information.

The HEATCO project suggests the following values for the VSL/Risk value as well as for other direct and indirect economic costs (medical cost, net production losses, administrative costs, etc.), for more Details see HEATCO, 2006a.

Table 68 Estimated values for casualties avoided (€2002, factor prices)

	Value of safety per se			Direct and indirect economic costs			Total		
Country	Fatality**	Severe injury	Slight injury	Fatality	Severe injury	Slight injury	Fatality	Severe injury	Slight injury
Austria	1,600,000	208,000	16,000	160,000	32,300	3,000	1,760,000	240,300	19,000
Belgium	1,490,000	194,000	14,900	149,000	55,000	1,100	1,639,000	249,000	16,000
Cyprus	640,000	83,000	6,400	64,000	9,900	400	704,000	92,900	6,800
Czech Republic	450,000	59,000	4,500	45,000	8,100	300	495,000	67,100	4,800
Denmark	2,000,000	260,000	20,000	200,000	12,300	1,300	2,200,000	272,300	21,300
Estonia	320,000	41,000	3,200	32,000	5,500	200	352,000	46,500	3,400
Finland	1,580,000	205,000	15,800	158,000	25,600	1,500	1,738,000	230,600	17,300
France	1,470,000	191,000	14,700	147,000	34,800	2,300	1,617,000	225,800	17,000
Germany	1,510,000	196,000	15,100	151,000	33,400	3,500	1,661,000	229,400	18,600
Greece	760,000	99,000	7,600	76,000	10,500	800	836,000	109,500	8,400
Hungary	400,000	52,000	4,000	40,000	7,000	300	440,000	59,000	4,300
Ireland	1,940,000	252,000	19,400	194,000	18,100	1,300	2,134,000	270,100	20,700
Italy	1,300,000	169,000	13,000	130,000	14,700	1,100	1,430,000	183,700	14,100
Latvia	250,000	32,000	2,500	25,000	4,700	200	275,000	36,700	2,700
Lithuania	250,000	33,000	2,500	25,000	5,000	200	275,000	38,000	2,700
Luxembourg	2,120,000	276,000	21,200	212,000	87,700	700	2,332,000	363,700	21,900
Malta	910,000	119,000	9,100	91,000	8,800	400	1,001,000	127,800	9,500
Netherlands	1,620,000	211,000	16,200	162,000	25,600	2,800	1,782,000	236,600	19,000
Norway	2,630,000	342,000	26,300	263,000	64,000	2,800	2,893,000	406,000	29,100
Poland	310,000	41,000	3,100	31,000	5,500	200	341,000	46,500	3,300
Portugal	730,000	95,000	7,300	73,000	12,400	100	803,000	107,400	7,400
Slovakia	280,000	36,000	2,800	28,000	6,100	200	308,000	42,100	3,000
Slovenia	690,000	90,000	6,900	69,000	9,000	400	759,000	99,000	7,300
Spain	1,020,000	132,000	10,200	102,000	6,900	300	1,122,000	138,900	10,500
Sweden	1,700,000	220,000	17,000	170,000	53,300	2,700	1,870,000	273,300	19,700
Switzerland	2,340,000	305,000	23,400	234,000	48,800	3,700	2,574,000	353,800	27,100
United Kingdom	1,650,000	215,000	16,500	165,000	20,100	2,100	1,815,000	235,100	18,600

Notes: Value of safety per se based on UNITE (see Nellthorp et al., 2001): fatality €1.50 million (market price 1998 – €1.25 million factor costs 2002); severe/slight injury 0.13/0.01 of fatality; Direct and indirect economic costs: fatality 0.10 of value of safety per se; severe and slight injury based on European Commission (1994). * no country specific value available in European Commission (1994), therefore estimated from comparable countries. ** Benefit transfer from EU-value of €1.25 million based on GDP per capita ratios (income elasticity of 1.0)

Source: HEATCO, 2006a.

C.4 Output values

Overview of differentiation of unit costs and traffic situations

Accident costs can be either defined as costs per accident, casualty, victim or causer or defined as cost per vehicle km or passenger km.

The main parameters determining accident costs are (UNITE D15).

- Accident risk (traffic volume, composition of traffic, speed of vehicles, road conditions, weather, time of day, consumption of alcohol, safety regulation).
- Risk elasticity.
- Proportion of cost already born by the user (especially risk value: internal or external).

Table 69 gives an overview on the scope of differentiation of average and marginal external accident cost values:

Table 69 Differentiation of external accident costs

Differentiation of unit costs				
Mode	**Indicator**	**Differentiation**		**Sources**
		Vehicle categories	**Infrastructure**	
Road	€/vkm €/pkm/tkm	Passenger car Motorcycle Van Bus HGV (different weight classes)	All roads Urban Interurban Motorway	UNITE D9 INFRAS, 2004
Rail	€/train-km €/passage (crossings)	Passenger Passenger high speed Train Freight	Rail (on track) At level crossings (barriers, Open crossing, Unprotected)	UNITE D9 INFRAS, 2004
Air transport	€/flight-km €/LTO €/aircraft movement	Passenger Freight Short-haul Medium-haul Long-haul	Airport Route (cruise)	PETS INFRAS, 2004
Inland waterways, sea shipping	€/ship-km €/tkm €/TEU-km	Freight vessels Poss. diff.: Bulk Container Tanker	Ports Fairway Open sea Inland waterways	UNITE D9, GRACE

Comparison of existing values: average costs

Table 70 shows average accident costs in €/1,000 passenger and tonne-kilometres based on INFRAS/IWW, 2004a.

Table 70 Average accident costs 2000

	Average costs													
	Road				**Rail**	**Aviation**	**Over all**	**Road**			**Rail**	**Aviation**	**Water-borne**	
	Passenger cars Euro/(1,000 pkm*a)	Busses and coaches Euro/(1,000 pkm*a)	Motorcycles Euro/(1,000 pkm*a)	Total road passenger Euro/(1,000 pkm*a)	Passenger transport Euro/(1,000 pkm*a)	Passenger transport Euro(1,000 pkm*a)	**Passenger transport** Euro/(1,000 pkm*a	LDV Euro/(1,000 tkm*a)	HDV Euro/(1,000 tkm*a)	Total road Freight Euro/(1,000 tkm*a)	Freight transport Euro/(1,000 tkm*a)	Freight transport Euro/(1,000 tkm*a)	Freight transport Euro/(1,000 tkm*a)	**Freight transport** Euro/(1,000 tkm*a)
Austria	32.9	1.9	197.5	35.3	1.1	0.4	27.5	35.4	2.8	3.1	0.0	0.0	0.0	2.8
Belgium	61.8	1.8	240.6	57.8	0.9	0.4	34.9	42.8	6.3	9.0	0.0	0.0	0.0	7.5
Denmark	25.5	1.9	191.8	22.3	0.3	0.4	15.8	30.4	3.0	4.1	0.0	0.0	0.0	3.9
Finland	14.7	1.3	83.3	13.7	1.5	0.4	10.7	13.6	1.9	3.1	0.0	0.0	0.0	2.2
France	29.0	1.7	217.0	28.3	0.4	0.4	19.3	35.3	6.4	12.2	0.0	0.0	0.0	10.2
Germany	40.4	2.6	224.1	40.4	1.1	0.4	29.2	40.3	5.8	7.3	0.0	0.0	0.0	5.9
Greece	17.6	0.7	127.3	24.7	1.6	0.2	17.5	20.7	2.5	4.8	0.0	0.0	0.0	4.8
Ireland	44.3	4.7	251.6	42.6	0.8	0.5	24.7	42.1	4.7	6.3	0.0	0.0	0.0	6.2
Italy	26.5	2.3	171.8	34.6	0.5	0.4	27.8	30.7	4.0	6.0	0.0	0.0	0.0	5.7
Luxemb'g	65.7	7.2	331.7	64.8	3.0	0.8	33.0	52.9	7.3	8.5	0.0	0.0	0.0	5.4
Netherland	38.3	2.2	253.0	39.2	0.1	0.4	19.1	43.4	4.4	4.4	0.0	0.0	0.0	3.4
Norway	22.9	3.3	171.0	23.4	3.7	0.5	16.2	74.4	3.2	7.2	0.0	0.0	0.0	6.0
Portugal	24.1	2.8	210.5	32.6	4.6	0.3	23.5	37.3	7.1	9.6	0.0	0.0	0.0	9.3
Spain	20.2	1.7	204.2	21.4	0.2	0.3	15.1	34.0	5.1	11.2	0.0	0.0	0.0	10.8
Sweden	17.4	2.4	112.4	17.3	0.3	0.4	12.9	19.3	2.5	4.3	0.0	0.0	0.0	3.1
Switzerland	30.2	2.3	201.8	32.2	1.2	0.4	17.5	88.5	5.5	10.8	0.0	0.0	0.0	6.2
United Kingdom	34.3	5.4	217.6	33.6	0.8	0.4	19.9	40.0	3.9	7.3	0.0	0.0	0.0	6.6
	30.9	**2.4**	**188.6**	**32.4**	**0.8**	**0.4**	**22.3**	**35.0**	**4.8**	**7.6**	0.0	0.0	0.0	**6.5**

Source: INFRAS/IWW, 2004.

Average costs depend mostly on accident rates of different countries as well as on income levels which influence the most important cost components (VSL). Therefore e.g. Greece with higher accident rates per vehicle-km shows average accident costs in the same order of magnitude like the Nordic countries Finland, Sweden and Norway with significantly lower accident rates.

Selected results of the UNITE pilot accounts are presented in the Table 71.

Table 71 Average accident costs 1998

		Road (€/vehicle-km)					Rail (€/train-km)		Air transport (€/flight-km)		Inland Waterway
	Costs	Passenger car	Motorcycles	Busses	LGV	HGV	Passenger	Freight	Passenger	Freight	Freight
Germany	Internal + external	0.1295	0.1295	0.111	0.0282	0.0228	0.651	0.498	0.4507	0.4507	0.515
Switzer-land	External	0.015	0.124	0.072	0.013	0.014	0.02	0.02	18.84		
	Internal	0.065	0.739	0.353	0.051	0.053	0.17	0.17	199.51		
	Total	0.080	0.863	0.425	0.064	0.067	0.190	0.190	218.35	0.000	
UK	External	0.002	0.054	0.0009	0.0007	0.0056	0.058	0.058	3	3	
	Risk value	0.025	0.5633	0.0089	0.0073	0.0577	0.609	0.609	30	30	
	Total	0.027	0.617	0.010	0.008	0.063	0.667	0.667	33	33.000	

Source: UNITE Pilot accounts for Germany, Switzerland and UK.

Average external accident costs of the UNITE case studies are significantly lower than INFRAS/IWW due to the fact that the risk value is assumed to be internal.

In CE Delft, 2004 accident costs for the Netherlands are presented which are again for e.g. passenger cars in a comparable order of magnitude like the results of INFRAS/IWW, 2004a.

Table 72 Average accident costs 2003 in the Netherlands

Vehicle category	Fatalities				Injuries				Value (€ct/v-km)	
	Urban	Rural			Urban	Rural			Urban	Rural
		Total	Of which MRN8	Of which SRN8		Total	Of which MRN	Of which SRN		
Passenger transport										
Car	8	5	3	8	160	45	27	64	5.0	2.0
Bus	46	34	20	46	311	105	77	128	11.9	6.9
Train	213				1.318				67.8	
Motorcycle	11	24	14	120	136	191	120	242	5.0	8.5
Moped, scooter	13	101	-	101	354	1.296	-	1.296	10.4	47.4
Freight transport										
LGV	4	7	3	10	55	66	47	78	1.9	2.8
HGV, sing. unit	42	18	9	43	187	79	50	164	11.6	4.9
HGV, tr/tr	40	16	7	56	150	53	37	130	10.5	3.9
Train	213				1.318				67.8	
Inland shipping	5				147				4.3	

* MRN/SRN: Main and Secondary Road Network, distinguished to provide additional information, but not used in the calculations.

In Switzerland (OSD 2002) a study on social and external accident costs using a highly differentiated accident data base produced the following results:

Table 73 Average accident costs 1998 in Switzerland (in prices 1998)

	Transport system external	Transport user external
	€ct/vkm	€ct/vkm
Passenger cars	1.0	3.1
Motorbikes	6.6	11.6
Busses (private)	5.5	49.5
Busses Public Transport	2.3	15.8
LGV	0.9	3.3
HGV	1.2	4.6

The study distinguished external costs which are transport system external (borne by the general public) and costs which are transport user external (borne by the innocent accident victim and the public). The latter view correspondents to the central value proposed below in the marginal cost chapter.

Comparison of existing values: marginal costs

Marginal external accident costs are presented in INFRAS/IWW, 2004a as well as in different UNITE case studies. Differentiated results are presented in the tables below.

Table 74 Marginal accident costs 2000 in €/1,000 vkm

Range of marginal accident costs for medium traffic flows € per 1000 vehicle kilometre																		
	Motorways						Inter-urban Roads						Urban Roads					
	Cars			HDV			Cars			HDV			Cars			HDV		
	low	mean	hgh	low	mean	high	low	mean	high	low	mean	high	low	mean	high	low	mean	high
Austria	14.2	27.3	34.1	8.7	16.6	20.7	36.7	41.9	51.6	22.3	25.5	31.4	51.8	53.5	55.1	31.6	32.5	33.5
Belgium	11.3	21.7	27.1	7.5	14.4	18.0	60.3	69.0	84.9	39.1	44.7	55.0	122.6	126.4	130.2	69.0	71.1	73.3
Denmark	6.3	12.1	15.1	4.0	7.6	9.5	35.8	40.9	50.4	23.1	26.4	32.4	89.5	92.3	95.1	52.3	53.9	55.6
Finland	5.0	9.5	11.9	3.4	6.5	8.1	28.7	32.9	40.4	19.5	22.3	27.4	9.5	9.8	10.1	6.5	6.7	6.9
France	7.5	14.5	18.0	5.4	10.5	13.1	46.0	52.6	64.8	32.9	37.6	46.3	62.0	36.9	65.9	38.4	39.6	40.8
Germany	7.1	13.6	17.0	4.5	8.6	10.7	48.9	55.9	68.8	30.6	35.0	43.0	122.2	126.0	129.9	65.4	67.5	69.5
Ireland Rep.	11.2	21.6	26.9	8.8	16.9	21.1	19.5	22.3	27.5	15.3	17.5	21.5	60.2	62.1	64.0	47.2	48.7	50.1
Netherlands	6.2	12.0	14.9	3.9	7.5	9.4	55.9	63.8	78.6	35.8	41.0	50.4	151.9	156.6	161.3	85.2	87.9	90.5
Sweden	3.9	7.6	9.5	2.5	4.9	6.1	27.4	31.3	38.5	17.5	20.0	24.6	19.5	20.1	20.7	12.5	12.9	13.3
Switzerland	5.1	9.8	12.2	3.1	6.0	7.5	52.3	59.8	73.6	32.3	36.9	45.5	59.3	61.2	63.0	36.6	37.8	38.9
UK	7.7	14.9	18.6	4.5	8.6	10.7	46.6	53.2	65.5	26.9	30.8	37.9	53.4	55.0	56.7	30.9	31.8	32.8

Source: INFRAS/IWW, 2004a.

The UNITE case studies on marginal accident costs show the following results.

Table 75 Marginal accident costs 1998

(1) Case Study	(2) Mode	(3) Unit	(4) Risk (Accident per million unit)	(5) Cost per accident (k€)	(6) Internal part (%)	(7) Elasticity	(8) Average Cost (€ per unit)	(9) Marginal external cost (€ per unit)
A	**Switzerland**							
	All road	Vehicle km	1.270	-	0.68[C]	-0.54	0.025	0.012
	Motorway	=	0.201	-		-0.50	0.005	0.002
	Other	=	1.184	-		-0.62	0.030	0.014
	Urban	=	2.362	-		-0.25	0.099	0.048
	Railways pass	Pass. km	0.0017	-	0	-	(0.04/0.30)	-
	Freight	Tonne km	0.0006	-	0	-		
B	**Stockholm-Lisbon** [E)]		[D)]					
	Sweden	Vehicle km	8.4	-	0.76	-	-	-
	Lisbon	=	38.1	-	0.65	-	-	-
	Urban Sweden	=	5.9	-	0.59	-	-	-
C	**Railways - Sweden**							
	All Level crossings	Passage	0.271[B)]	971.0	0[A)]	-0.87	0.26	0.034 [B)]
	Barriers	=	0.225	=	=	-0.72	0.22	0.062
	Open cross.	=	0.725	=	=	-0.85	0.70	0.108
	Unprotected	=	0.085	=	=	-0.92	0.066	0.007
	HGV							[F)]
D	Sweden average >12t	Vehicle km	0.869	58.3	0.09	-0.76	-	0.0084
	12t – 14.9t (2)	=	1.002	36.2	0.15	-0.90	-	(-0.00081)
	15t – 18.9 t (3)	=	0.896	77.0	0.07	-0.86	-	0.0062
	19t – 22.9 t (4)	=	0.724	45.9	0.09	-0.71	-	0.0074
	23t – 26.9t (5)	=	0.977	55.0	0.12	-0.74	-	0.0081
	27t – 30.9t (6)	=	0.914	57.6	0.07	-0.61	-	0.016

(1) Case Study	(2) Mode	(3) Unit	(4) Risk (Accident per million unit)	(5) Cost per accident (k€)	(6) Internal part (%)	(7) Elasticity	(8) Average Cost (€ per unit)	(9) Marginal external cost (€ per unit)
	Above 31 t (7)	=	1.030	99.3	0.03	-0.74	-	0.032
E	**Maritime**							
	Swedish ship on Swedish water	Registered ships	0.026	n.a.	n.a.	n.a.	-	73 – 10 000 annually
	Inland waterway							
F	Rhine	Ship tonne km	0.273	73.9	0.91	*0*	0.020	0.0019
	Rhine	Ship movement	0.0022	=	=	=	162	16

Source: UNITE, 2002c.
A) Only personal injuries in road/rail level accidents were included.
B) Personal injury accident.
C) Responsible injured/All injured.
D) Fatality risk.
E) For passenger car.
F) Model 3.

In CE Delft, 2003 results of different European studies on marginal external accidents are presented (values in €/vkm).

Table 76 Marginal accident costs 1998/2000 in €vt/vkm for the Netherlands

Passenger car rural

Cost category	INFRAS		ECMT	CE Delft	TRENEN	UNITE Low	UNITE High
Technology	Euro1		Euro3	Euro1	Euro2	Euro2	Euro2
Location	Rural	Motorway/densely pop/suburban	Rural	Outside built-up area	Tiel drive		
1 Accidents	7.2	1.3	**3.2	1.5	***4.6	****0.3	****1.6

Passenger car urban

Cost category	INFRAS	ECMT	CE Delft	TRENEN Amsterdam	UNITE Low	UNITE High
Technology	Euro1	Euro3	Euro1	Euro2	Euro2	Euro2
Location	Urban	Urban	Within built-up area	Amsterdam	Various	Various
1 Accidents	5.9	**3.2	2.7	***4.6	****4.2	****4.2

* EU average values.
** Average values rural/urban.
*** Belgium interregional.
**** In the variant in which the accident risk of the causer of the accident is assumed internalised (i.e. victim risks are not).

Light HGC rural

Cost category	INFRAS		ECMT	CE Delft	UNITE low	UNITE high
Size (in tonnes GVW)	3.5 – 7.5		Avg. van/lorry	3.5 – 12	Various	Up to 42
Load (t)	1.9		3	1.6		
Technology	Euro0		Euro3	Euro2	Euro2	Euro2
Location	Rural	Motorway/ densely pop.		Outside built-up areas	Various	Various
1 Accidents	2.8	0.6	**4.0	3.8	0.3	2.7

* EU average values.

** Average values rural/urban.

Light HGV urban

Cost category	INFRAS	ECMT	CE Delft	UNITE low	UNITE high
Size (in tonnes GVW)	3.5 – 7.5	Avg. van/lorry	3.5 – 12	Various	Various
Load (tonnes)	1.9	3	1.6		
Technology	Euro1	Euro0	Euro0	Euro2	Euro2
Location	Urban	Urban	Within built-up areas	Urban	Urban
1 Accidents	3.4	**4.0	10.4	0.6	10.7

* EU average values.

** Average values rural/urban.

Heavy HGV rural

Cost category	INFRAS		ECMT	CE Delft	TRENEN Belgium interregional	UNITE low	UNITE high
Size (tonnes GVW)	32 – 40		Avg. lorry	Articulated	Articulated	Up to 42	Up to 42
Load (tonnes)	15		6	12	11.3		
Technology	Euro1		Euro0	Euro0	Euro2	Euro2	Euro2
Location	Rural/ extra-urban	Motorway/ Densely pop	Rural	Within built-up areas		Various extra-urban	Various extra-urban
1. Accidents	2.8	0.6	**4.0	2.1	5.4	0.3	3.2

* EU average values.

** Average values rural/urban.

Heavy HGV urban

Cost category	INFRAS	ECMT	CE Delft	UNITE low	UNITE high
Size (tonnes GVW)	32 – 40	Avg. truck		Up to 42	Up to 42
Load (tonnes)	15	6	12		
Technology	Euro1	Euro0	Euro0	Euro2	Euro2
Location	Urban		Inside built-up areas	Diverse urban	Diverse urban
1. Accidents	3.4	**4.0	7.8	3.2	10.7

* EU average values.

** Average values rural/urban.

Passenger trains

Cost category	INFRAS	CE Delft	ECMT	INFRAS/ IWW Ranges	CE Delft	UNITE low	UNITE high
Location	EU	NL	EU	EU	NL		
Running on…	Electricity	Electricity	87%el., 12%D	Diesel	Diesel	Electric	Electric
No of pass. Carried	130	130	126	130	130		
1. Accidents	0 - 25	31	25	0 - 25	31	Small	Small

Freight trains

Cost category	INFRAS ranges	CE Delft	EMCT	INFRAS/ IWW ranges	CE Delft	UNITE low	UNITE high
Location	EU	NL	EU	EU	NL		
Running on…	Electricity	Electricity	76%el.,24%D	Diesel	Diesel	Electric	Electric
Tonnes load	285		323	285			
1. Accidents	0	19	25	0	19	Small	Small

Summary and comparison of existing values:

Table 77 gives an overview on marginal accident costs of passenger cars based on different studies:

Table 77 Overview marginal (average) accident costs for passenger cars in €/vkm

Study	UNITE	INFRAS/ IWW	CE Delft	CE Delft	ECMT	PETS 2000	ITS – UK study	SIKA2000	UNITE
	Urban case study Stockholm/ Lisbon	External costs of transport	The price of transport	Efficient prices for transport	Efficient transport for Europe	Pricing European transport systems	Surface transport costs and charges – Great Britain 1998	External costs of transport for Sweden	Case study Switzerland
Source	UNITE, 2002c	INFRAS, 2004	CE Delft, 2004	CE Delft, 1999		PETS, 2000	ITS, 2001		UNITE, 2002c
Definitions	Marginal external costs	Marginal external accident costs for medium traffic flows (range for diff. countries)	Average external costs	Marginal costs (NL)		Marginal cost case studies	Marginal Costs UK	Marginal costs for Sweden	Marginal external costs risk of causers internalised for Switzerland
Base year	1998	2000	2002	1998	1998	1998	1998	1998	1998
Unit	€/vkm	€/vkm	€/vkm	€vkm	€/vkm	€/vkm	€/vkm	€/vkm	€/vkm
	Passenger cars	Passenger cars	Passenger cars	Passenger cars	Passenger cars	Passenger cars	Passenger cars	Passenger cars	Passenger cars
Urban	0.010 – 0.084	0.020 – 0.156	0.050	0.027		Lisbon: 0.038 – 0.054		0.0176	0.048
Interurban	-	0.027 – 0.084	0.020	0.015				0.0097	0.016
Motorways	-	0.008 – 0.027	-	-					0.003
All roads	-	-	-	-	0.032	Finland: 0.0087 – 0.0277	0.012 – 0.020		0.012

Source: different studies.

The range of marginal accident costs on urban roads varies between 1 and 15.6 €ct/vkm. Average costs vary within the study considered between 2 and 15.6 €ct/vkm. Marginal costs on interurban roads and Motorways are significantly lower. The value proposed for the modelling step within this project is in the range of other European studies on marginal accident costs (however, the values presented in Table 77 are original values from the sources examined and therefore not adjusted to a similar base year or to average European values).
The ranges found in literature for Heavy Goods Vehicles are considerable wider. The ranges of different UNITE Case Studies vary for urban traffic situations between 0.6 and 10.7 €ct/vkm which reflects more or less the ranges found in other studies. For interurban roads and motorways on which the majority of road freight transport is circulating marginal accident costs are considerably lower (esp. on motorways).

Table 78 Overview marginal accident costs HGC in €/vkm

Study	UNITE	UNITE	INFRAS/ IWW	CE Delft	CE Delft	ECMT	PETS 2000	ITS – UK study	SIKA 2000	UNITE
	Case study Stockholm/Lisbon	HGV Case study Sweden	External costs of transport	The price of transport	Efficient prices for transport	Efficient transport for Europe	Pricing European transport systems	Surface transport costs and charges – Great Britain 1998	External costs of transport for Sweden	Case study Switzerland
Source	UNITE,2002c	UNITE, 2002c	INFRAS/ IWW, 2004	CE Delft, 2004	CE Delft, 1999	ECMT, 1998	PETS, 2000	ITS, 2001		UNITE, 2002c
Definitions	Marginal external costs	Marginal external costs (range for diff.weight classes)	Marginal external accident costs for medium traffic flows (range for diff. countries)	Average external costs	Marginal costs (NL)	Marginal costs (BJ average)	Marginal cost case studies	Marginal costs UK	Marginal costs for Sweden	Marginal external costs risk of causers internalised for Switzer-land
Base year	1998	1998	2000	2002	1998	1998	Not specified	1998	1998	1998
Unit	€/vkm	€/vkm	€/vkm	€/vkm	€/vkm	€./vkm	€/vkm	€/vkm	€/vkm	€/vkm
	HGV	HGV	HGV	HGV	HGV	HGV	HGV	HGV	0.043	0.107
Urban	0.038 – 0.058	0.006 – 0.032 (0.0084 central estimate)	0.007 – 0.098	0.105	0.078	-	Lisbon: 0.085 – 0.093		0.025	0.027
Interurban	-	-	0.018 – 0.045	0.039	0.021	-				0.003
Motor-ways	-	-	0.005 – 0.017	-	-	-	Transal pine: 0.011 – 0.023 European Average: 0.011 – 0.021			0.018
All roads	-	-	-	-	-	0.040	Finland: 0.079 – 0.091	0.015 – 0.029		

Source: different studies.

For rail transport only few studies on marginal (and average) accident costs exist. The following table shows the ranges found in recent literature for passenger and freight transport:

Table 79 Overview marginal accident costs in rail passenger transport in €/train-km

Study	UNITE	CE Delft	INFRAS/ IWW	CE Delft	ECMT	PETS 2000
	Case study Switzerland	The price of transport	External costs of transport	Efficient prices for transport	Efficient transport for Europe	Pricing European transport systems
Source	UNITE, 2002c	CE Delft, 2004	UNITE, 2002c	CE Delft,1999	ECMT, 1998	PETS, 2000
Definitions	Average external costs, risk of causers internalised	Average external costs	Average costs (European average value)	Marginal costs (NL)	Marginal costs (BJ average)	Marginal costs(for selected corridors), including internal parts
Base year	1998	2002	2000	1998	1998	1998
Unit	€/train-km	€/train-km	€/train-km	€/train-km	€/trian-km	€/train-km
	Rail passenger	Rail passenger	Rail Passenger	Rail passenger	Rail passenger	Rail passenger
Total	0.30	0.67	0.08	0.31	0.25	0.014 – 0.112 Optimal charges 0.5 (peak) – 2.15 (off-peak)

Source: different studies.

Only few studies show different values for passenger and freight transport.

Table 80 Overview marginal accident costs in rail freight transport in €/train-km

Study	UNITE	CE Delft	CE Delft	ECMT	PETS 2000
	Case study Switzerland	The price of transport	Efficient prices for transport	Efficient transport for Europe	Pricing European transport systems
Source	UNITE, 2002c	CE Delft, 2004	CE Delft, 1999	ECMT, 1998	PETS, 2000
Definitions	Marginal external costs, risk of causers internalised	Average external costs	Marginal costs (NL)	Marginal costs (EU average)	Marginal costs(for selected corridors) including internal parts
Base year	1998	2002	1998	1998	1998
Unit	€/train-km	€/train-km	€/train-km	€/train-km	€/train-km
	Rail freight	Rail freight	Rail passenger	Rail freight	Rail freight
Total	0.3	0.67	0.19	0.25	0.046 – 0.092

Source: different studies.

Marginal accident costs for rail transport vary between 8 and 67 €ct/train-km. Due to the fact that rail accidents are relatively rare, the values rather represent average than marginal costs.

D Air pollution costs

D.1 Overview of studies

Table 81 presents the most important studies on external air pollution costs covering at least one of the impact categories of transport related air pollution.

Table 81 Overview: studies on external air pollution costs

STUDIES ON EXTERNAL AIR POLLUTION COSTS OVERVIEW						
Author, Title, Year of Publication	**Base year(s) of results**	**Countries covered**	**Cost categories covered**	**Transport modes covered**	**Method used**	**Outputs, Result differentiation**
EU Projects and Programs						
High Level Group on transport Infrastructure charging, 1999a	Only Methodology	European Union	Air pollution costs: health costs, crop losses, material damages	Road, rail	Method proposed: Impact-Pathway Approach (ExternE)	Marginal costs, cost rates
UNITE (Unification of accounts and marginal costs for transport efficiency), 2003 Project coordinator: ITS, Leeds	1998, (1996, 2005)	EU-15, Hungary, Estonia, Switzerland		Road, rail, urban public transport, air, water	Impact-Pathway Approach (ExternE)	Total, average for all countries considered, marginal costs for specific countries (case studies)
RECORDIT (Real cost reduction of door-to-door intermodal transport), 2001 Project coordinator: ISIS, Rome	1998	3 selected European corridors	Air pollution costs: health costs, crop losses, material damages	Intermodal freight transport: road, rail, ship	Impact-Pathway Approach (ExternE)	Total and average costs, sector results
GRACE (Generalisation of research on accounts and cost estimation), ongoing Project coordinator: ITS, Leeds	2005 ongoing	EU-25	Infrastructure, accident, environment, congestion	Road, rail, air, water	Dep. on case study: Impact-Pathway and Top-Down Approach	Average and marginal costs
ExternE (Externalities of Energy), 1999 Project coordinator: IER, Stuttgart and updates	1995	EU-15, Norway, some NMS (e.g. Poland)	Air pollution costs: health costs, crop losses, material damages	External costs of energy	Impact-Pathway Approach	Methodology and selected results for energy systems (not for transport)

STUDIES ON EXTERNAL AIR POLLUTION COSTS OVERVIEW						
Author, Title, Year of Publication	**Base year(s) of results**	**Countries covered**	**Cost categories covered**	**Transport modes covered**	**Method used**	**Outputs, Result differentiation**
New Ext: ExternE (Externalities of Energy) Methodology Update 2005 Project coordinator: IER, Stuttgart	2004/5	EU	Air pollution costs: health costs, crop losses, material damages	External costs of energy	Impact-Pathway Approach	Methodological update, revised cost indicators, WTP- and shadow prices and dose-response functions
CAFE CBA	2000/2010/ 2020	European Union	Air pollution	-	Impact-Pathway Approach (ExternE)	Air pollution cost (cost-benefit analysis), no differentiation between urban + rural
HEATCO	2002	EU-25	Air pollution (health costs, crop losses, material damages)	External costs of transport and electricity generation	Impact Pathway Approach	Air pollution costs (cost benefit analysis), differentiation between urban + rural
TREMOVE	2000/ 2020	EU-25	Most relevant external costs, values used from CAFE CBA	All modes	Policy assessment tool	0
Other studies with a European Scope						
INFRAS/IWW, External costs of transport, 2000	1995 Estimate for 2010	EU-15, Norway, Switzerland	Air pollution costs: health costs, crop losses, building damages	Road, rail, air, water (inland water transport)	Top-down approach based on WHO 1999	Method and results: Total and average costs, marginal costs
INFRAS/IWW, External costs of transport – update study, 2004a	2000	EU-15, Norway, Switzerland	Air pollution costs: health costs, crop losses, building damages	Road, rail, air, water (inland water transport)	Top-down approach based on WHO 1999	Results: Total and average costs, marginal costs
NewExt, Environmental costs of transport, 2001	1995-1998 (dependent on the country)	Belgium, Finland, France, Germany, Greece, the Netherlands, United Kingdom	Air pollution costs: health costs, crop losses, material damages	Road, rail, air, inland shipping	Impact-Pathway Approach (ExternE)	Method and results: Marginal costs, total and average costs, cost rates
OECD/INFRAS/ Herry) External costs of transport in Central and Eastern Europe, 2003	1995 (2010)	Eastern Europe	Air pollution costs: health costs, crop losses, building damages	Road, rail, air, water	Top-down approach based on WHO 1999	Results: total and average costs

STUDIES ON EXTERNAL AIR POLLUTION COSTS OVERVIEW						
Author, Title, Year of Publication	**Base year(s) of results**	**Countries covered**	**Cost categories covered**	**Transport modes covered**	**Method used**	**Outputs, Result differentiation**
CE Delft / ECORYS, Marginal costs of Infrastructure use - towards a simplified approach, 2004	Unit cost rates for 2002	EU-15	Air pollution costs: health costs, crop losses, material damages	Road, rail, aviation	Impact-Pathway Approach (ExternE),	Method: marginal costs, unit costs for EU 15 countries (€/t pollutant)
TRL, A Study on the cost of transport in the European Union in order to estimate and assess the marginal costs of the use of transport, 2001	Literature survey for the years 1995-2000	EU-15, UK, SE	Air pollution costs: health costs, crop losses, material damages (partyl not specified)	Road, rail, aviation, inland waterways, maritme	Literature survey of different studies	Marginal costs, average European or country specific unit cost rates (€/vkm)
Country specific studies						
UBA 2006: Economic valuation of environmental damages – method convention for estimating environmental costs.	2005	EU	Air pollution costs: health costs, crop losses, building damages	Road, rail (energy)	Impact-Pathway Approach (ExternE)	Average costs
CE Delft, The price of transport - overview of the social costs of transport, 2004 (update of the 1999 study)	2002	The Netherlands	Air pollution costs	Road, rail, air, water (inland shipping)	Impact-Pathway Approach (ExternE)	Method and results: total costs, variable social costs
ITS, Surface transport costs and charges – Great Britain 1998, 2001	1998	United Kingdom	Air pollution: differentiation acc. to ExternE	Road, rail	Impact-Pathway Approach (ExternE)	Method and results : marginal and average costs
OSD (Federal Office for Spatial Development), Transport related external health costs, 2004	2000	Switzerland	Air pollution: health costs	Road, rail	Top-down approach	Total and average costs
Hvid, External costs of transport, 2004	2000	Denmark	Air pollution: differentiation acc. to ExternE	Road, rail	Impact-Pathway Approach (ExternE)	marginal costs (per vkm/per kg pollutant)

STUDIES ON EXTERNAL AIR POLLUTION COSTS OVERVIEW						
Author, Title, Year of Publication	**Base year(s) of results**	**Countries covered**	**Cost categories covered**	**Transport modes covered**	**Method used**	**Outputs, Result differentiation**
OSD (Federal Office for Spatial Development), Transport related building damages, update of external costs, 2004	2000	Switzerland	Air pollution: building damages, facadescleanin g costs	Road, rail	Top-down approach, three calculation approaches (GIS based)	Total and average costs
INFRAS 2007: External costs of transport in Germany	2005	Germany	Air pollution (health costs, crop losses, material damages)	Road, rail, inland waterways, aviation	Impact-Pathway Approach (ExternE)	Total and average costs for different vehicle categories
WHO 1999: Health costs due to Road Traffic-related Air Pollution	1996	Austria, France, Switzerland	Air pollution costs: health costs	Road	Top-Approach based on ambient concentration of particulate matter and estimation of transport related shares of PM10 to overall concentrations	Total costs for Austria, France and Switzerland
Boiteux Report 2001: Transports : choix des investissements et coût des nuisances	2000	France	Air pollution costs: health costs	Road, rail	Top-down approach/ Bottom-up approach	Average (marginal) costs for France
Ministero delle INFRAStrutture 2006: Model applications for the estimation of external costs	2005	Italy	Air pollution: health costs (different unit cost rates, some with crop losses and material damages	Road, rail	Top-down approach/ Bottom-up approach	Average (marginal) costs for Italy, Unit cost rates

Discussion of the studies available

In general almost all studies on external costs cover external health costs as one of the most important cost categories. However, the scope of transport related air pollution costs varies between studies. Some studies also cover damages to buildings and materials as well as crop losses in the agricultural sector. Damages to forests and ecosystems are also subject to some studies, but dose-response functions in this field are poor and very case sensitive.

Two major approaches are applied in all studies available on external air pollution costs. Most studies with a European scope apply the Impact Pathway Approach (IPA) developed and enhanced within the ExternE and NewExt project. In contrast, INFRAS studies applying a top-down methodology developed within the trilateral WHO study in order to estimate health costs of road transport.

National studies can be found with both, bottom-up and top-down approaches.

Scientific accuracy

Most of the studies examined are scientific accurate. However, some studies cover more than one external cost category. As a consequence the level of detail as well as the applied methodology is sometimes less developed and detailed in these overview studies compared to air pollution specific studies (e.g. INFRAS study).

The different studies using the bottom-up ExternE approach are scientifically in general accurate. The ExternE Methodology was updated several times, the latest update (NewExt) takes into account recent results for dose-response functions as well as new empirical based values for VSL and VOLY. CAFE CBA also using the Impact Pathway Approach has focused especially on up-to-date dose response functions based on WHO recommendations. Results of CAFE CBA have been subject to a peer review process. With respect to local effects of air pollution most ExternE based studies use a simplified approach (e.g. UNITE, HEATCO) when transferring results of a detailed local model for a specific country (e.g. Germany) to other countries considering population density, national emission factors and purchasing power parities.

From the top-down approaches the Swiss study on external air pollution costs on behalf of Swiss Federal Office for Spatial Development (OSD, 2004a) applies a very advanced approach and improves a methodology developed in the trilateral WHO study for Switzerland, Austria and France. Population's exposure to PM_{10} is modelled with a combined top-down and bottom-up approach (total exposure calculated with an exposure model, contribution of different polluters estimated with a bottom-up emission model similar to the ExternE approach). In addition the Swiss study on air pollution related building damages is based on an empirical model.

Quality of data basis

The quality of the data basis of the different studies is difficult to judge since the data base is not always described in detail. In general the data base of all studies focussing on air pollution costs can be considered as good. Bottom-up models have high requirements with respect to emission data, meteorological data and receptor density data. ExternE, HEATCO and CAFE CBA using dispersion models which requires not only transport emittent information but also emissions from all other sources. The classification of the quality of input data to the models is difficult but considered to be sound.

Completeness

With respect to different air pollution cost categories ExternE based studies consider damages to human health, damages to buildings as well as damages to crops/crop losses (HEATCO, ExernE). Some studies (NewExt) also try to calculate and define shadow cost factors for impacts on ecosystems and biodiversity. CAFE CBA considers in the current version (2005) damages to human health and crop losses, neglecting building damages. Due to the fact that human health impacts are the by far most important air pollution related damages, the omission of building damages in CAFE CBA seems to be justifiable.

Transferability

Transferability of results is naturally high for studies with a European wide scope presenting already detailed and differentiated data for the countries concerned. Transferability of single country studies to other countries or other points in time depend on information of the countries considered which allow a data transfer (beneath economic indicators also emission factors, traffic and population density, etc.). CAFE CBA and HEATCO present values for 25-27 countries.

Practical application

Practical application of study results is particularly easy in case external unit cost rates are expressed per kg of pollutant. An adjustment of values expressed per vehicle or train-km is more difficult since information on the specific characteristic of the vehicle unit costs are calculated for is necessary in order to transfer values to other vehicles or modes. Values from CAFE CBA and HEATCO are both easily applicable for different vehicle categories and transport modes. HEATCO has the particular advantage that differentiated values are available for metropolitan and urban areas as well as for rural areas. In CAFE CBA a so-called 'city delta' is currently developed for particulate matter.

Potential for aggregation

Studies covering more than one country and presenting results per mass unit of pollutant are preferable in order to derive general countrywide values than very specific studies focussing on one transport mode and one specific network type for instance. Again, HEATCO as well as CAFE CBA presenting values which can directly be used for all European countries and specific transport modes without any need of transferring or aggregate values from other studies.

Conclusion

Studies conducted on a European level covering all EU25/27 countries and which are based on costs per ton of pollutant are recommended in order to derive unit values. Results of CAFE CBA and HEATCO are both, well based concerning methodology and data basis as well as easily transferable to other countries and different transport modes. Other country specific or mode specific studies are suited for very specific questions however a value transfer or value generalisation is limited.

D.2 Main methodological approaches

Whereas earlier studies mainly focus on a top-down approach, starting from ambient air pollutant concentrations and estimations on the contribution of different pollutant sources, recent studies are mostly based on the ExternE model. The EU funded ExternE model uses a bottom-up approach in order to quantify external air pollution costs. This so-called Impact Pathway Approach is becoming more and more the standard approach for external air pollution cost estimations.

Both models differ mainly in the way the transport related pollutant concentration is modelled. When it comes to impact calculation and valuation, similar approaches are used. The valuation of the physical impacts (e.g. additional cases of asthma, premature death due to ambient concentration of particulates) is varying due to different health systems and valuation of immaterial costs.

A Health costs

- Impact Pathway Approach (IPA): Approach developed in the ExternE project, tracing the passage of a pollutant where it is emitted to the affected receptor (population, crops, forests, buildings, etc.). Dose-response functions are used to quantify pollutant related impacts which are then valuated with cost rates (approach used in e.g. ExternE, UNITE).
- Top-down approach: Approach used in the WHO, 1999 study as well as in the Swiss studies on health costs (OSD, 2004a). With a GIS based approach population's exposure to airborne pollutants (PM_{10}) is calculated. Based on this, additional cases of illness and death caused by air pollution are calculated and valuated with specific cost rates. Using emission-exposure models (similar to those of the IPA) the contribution of different pollutants to total ambient concentration and thus population's exposure is calculated. This enables the allocation of overall health costs to different categories (transport and non-transport).

B Building/material damages:

- Impact Pathway Approach: Methodology similar to the approach used for the estimation of health costs. Dose-response functions for different materials (stone, steel, paint coatings) are used to estimate a critical surface recession. Additional dose-response functions for surface soiling are used. The valuation of damages is made using repair cost rates per m^2 differentiated according to surface material.
- Top-down approach/Empirical approaches (Swiss approach): The Top-Down approach was applied within the Swiss study on external building damages (OSD, 2004b). In a GIS based ambient air pollutant concentration model and using a random sample of buildings, higher renovation frequencies and reduced lifespan of building facades can be determined for those locations which are exposed to high traffic related air pollutant concentrations. The economic valuation is made with the help of a repair cost approach.
  In addition, facade soiling was accounted for using higher window cleaning frequencies at locations which are exposed to high traffic volumes. The

valuation of higher cleaning frequencies was made with the help of cost rates based on expert interviews.

C Crop losses

- Impact Pathway Approach: Within the ExternE Model also Crop losses can be calculated using specific dose-response-functions for different pollutants and valuing the losses of agricultural products with market prices.
- Top-down approach: Top-down approach similar to health costs calculations used in OSD, 2006. Reduced agricultural productivity on locations with high ambient concentration of air pollutants and valuation with market prices.

Main differences between Bottom-up and Top-down approaches

The differences between both approaches are mainly due to the following reasons.

- Different methodology for the estimation of population exposure to air pollutants:
  The general difference between bottom-up and top-down approaches is the quantification of populations exposure to air pollutant. Top-down models use generally exposition models based on ambient air quality measurements. Bottom-up models trace a pollutant from source to the final receptor. In OSD, 2004a a differentiated discussion of differences between the two approaches regarding the dispersion modelling shows that the ExternE model (EcoSense) with general European wide model parameters may lead to some deviations compared to local or national dispersion models[33].
- Different dose-response functions: the selection of epidemiological studies in order to derive dose-response functions for health effects of air pollutants effects the results considerably. This leads to differences in results even in studies which uses the same dispersion model (e.g. HEATCO and CAFE CBA).
- Different valuation of air pollution effects on human health, crops and buildings and materials: Finally the valuation of different effects of air pollution leads to deviation in total and average costs. Ealier studies used VSL approaches where as recent studies (HEATCO, CAFE CBA) favour a VLYL approach.

Data requirements:

Depending on the level of the analysis undertaken, and on the typology of the modelling tool, data requirements can vary considerably:

- **Transport flows**: data required range from O/D data relevant to specific route(s), or corridor(s), to data at the aggregated level for the geographic unit considered (a country, a region, etc.) Disaggregation by vehicle technology and occupancy rates (load factors for freight) are systematically needed.
- **Emissions**: emission factors (by technology) for all vehicle, train, plane or ship technologies are needed including the emission factors for the main up-

[33] The analysis in OSD, 2004a came to the conclusion that the EcoSense model underestimates the exposition at least for Switzerland due to the fact that higher wind speeds than actually observed in Switzerland are used in the European model. Wind speed is in a Gaussian dispersion model inversely proportional to exposition. A Gaussian dispersion model is used in the Swiss Top-down study in order to quantify the contribution of the transport sector to overall air pollution.

and downstream processes. For modelling the chemical transformation of the pollutants in the atmosphere, emission data bases covering all emission sources are needed for the different spatial scales.

- **Concentrations and impacts**: in addition to transport flows and emissions, data requirements cover two main areas: i) receptor data (geographical co-ordinates, population density, other geo-morphological information, such as built environment pattern for urban situations, building surfaces, etc.), ii) meteorological data (mainly wind speed and direction). Impacts are derived from the application of exposure- or dose-response functions, whose knowledge is therefore a prerequisite.
- ***Monetary valuation***, finally, requires the availability of WTP/WTA, damage costs and restoration/reparation cost data.

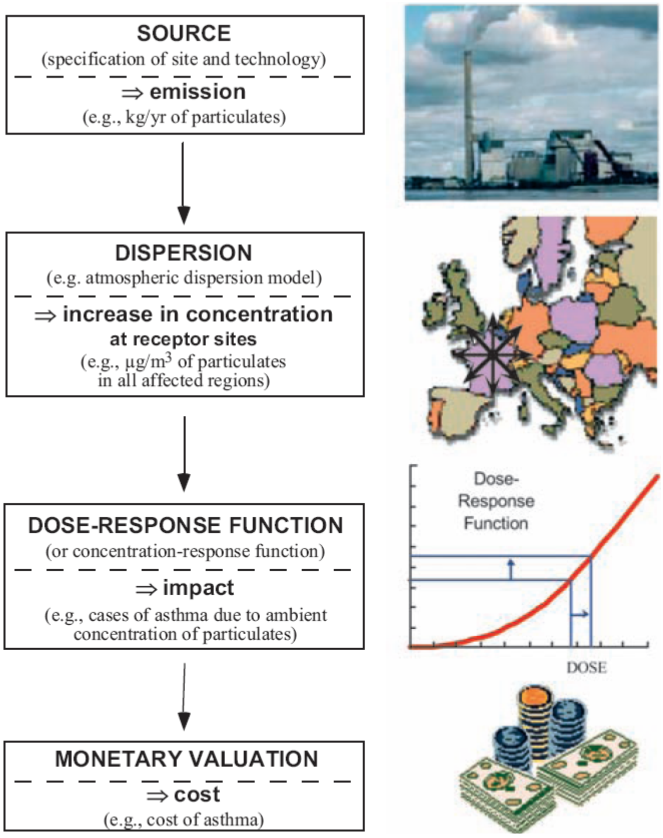
Data sources

- Transport flows: transport data from transport models, differentiated by type of vehicle, emissions standards, load factors, average speed etc. Respective data is also needed for all transport modes.
- Emissions: emission database (TRENDS, TREMOVE, Handbook Emission Factors, etc.), in order to apply the IPA properly also emissions of sources other than transport is necessary in order to model atmospheric dispersion and chemistry from different polluters.
- Concentrations/Impacts: dose-response functions (recently updated in NewExt, 2004/2005).
- Monetary valuation: different recently updated sources on damage costs, WTP for risk reduction, etc.

Data requirements for the complete IPA are rather challenging. Not only geo referenced data on transport related emissions is necessary but also emissions from non-transport sources have to be accounted for in order to comply with the non-linear dose-response functions. This has not only to be done for one specific country or regional entity but also for additional countries to cover the effects of long range transport of pollutants and effects of atmospheric chemistry with pollutants from different sources.

Main steps and outputs

Figure 24 The 4 Steps of the impact pathway. Source: ExternE (2005)



Step 1: **Emission:** specification of the relevant technologies and pollutants, e.g. kg of oxides of nitrogen (NO_x) per GWh emitted by a power plant at a specific site).

Step 2: **Dispersion**: calculation of increased pollutant concentrations in all affected regions, e.g. incremental concentration of ozone, using models of atmospheric dispersion and chemistry for ozone formation due to NO_x (this step is also called environmental fate analysis, especially when it involves more complex pathways that pass through the food chain).

Step 3: **Impact:** calculation of the dose from the increased concentration, followed by calculation of impacts (damage in physical units) from this dose, using a dose-response function, e.g. cases of asthma due to this increase in ozone.

Table 82 shows as an example the major impacts of air pollution on human health.

Table 82 Air pollutants and their effects on health

Primary Pollutants	Secondary Pollutant	Impacts
Particles (PM_{10}, $PM_{2,5}$, black smoke)		Mortality Cardio-pulmonary morbidity (cerebrovascular hospital admissions, congestive heart failure, chronic bronchitis, chronic cough in children, lower respiratory symptoms, cough in asthmatics)
SO_2		Mortality Cardio-pulmonary morbidity (hospitalization, consultation of doctor, asthma, sick leave, restricted activity)
SO_2	Sulphates	Like particles?
NO_x		Morbidity?
NO_x	Nitrates	Like particles?
NO_x+VOC	Ozone	Mortality Morbidity (respiratory hospital admissions, restricted activity days, asthma attacks, symptom days)
CO		Mortality (congestive heart failure) Morbidity (cardio-vascular)
PAH Diesel soot, benzene, 1,3-butadiene, dioxins		Cancers
As, Cd, Cr-VI, Ni		Cancers Other morbidity
Hg, Pb		Morbidity (neurotoxic)

Source: ExternE, Methodology Update 2005.

Step 4: Cost: economic valuation of these impacts, e.g. multiplication by the cost of a case of asthma. Table 83 shows cost values for impacts on health, crop losses and building surfaces/materials (see following chapter 'Input values').

D.3 Input values

Dose response functions

Table 83 Concentration-response functions for human health impacts due to air pollution according to the most currenct recommendations of the ExternE team (Watkiss, 2005). The exposure response slope, F_{er} has units of (cases/(year * person * µg/m^3)) for morbidity and chronic mortality, and (%change in annual mortality rate/(µg/m^3)) for acute mortality, PM_{10} given as annual mean concentrations, O_3 as seasonal 6-h-average concentration

Health Effect	Pollutant	Concentration-Responce-Factor	Risk Group
Acute mortality – Years of life lost due to acute exposure	O_3	0.03%	All
Chronic mortality / Years of life lost (YOLL) due to chronic exposure	PM_{10}	4.00E-04	All
New cases of chronic bronchitis	PM_{10}	2.65E-05	Age > 27
Respiratory hospital admissions	O_3	1.25E-05	Age > 65
	PM_{10}	7.03E-03	All
Attributable emergency cardic hospital admissions	PM_{10}	4.34E-03	All
Restricted activity days	PM_{10}	5.41E-02	Age 15 to 64
Minor restricted activity days	O_3	1.15E-02	Age 18 to 64
Cough days	O_3	9.30E-02	Age 5 to 14
Symptom days (lower respiratory symptoms including cough	PM_{10}	1.30E-01	Age > 18 with chronic respiratory symptoms
Days of Lower respiratory symptoms, including cough, in children in the general population, i.e. extra symptoms days	PM_{10}	1.86E-01	Age 5 to 14
Days of bronchodilator usage	O_3 PM_{10} PM_{10}	7.30E-02 9.12E-02 1.80E-02	Age > 20 with asthma Age > 20 with asthma Age 5 to 14 with asthma

Economic valuation

Economic valuation of these impacts is done by the multiplication with the costs of an additional case of asthma. Table 84 shows cost values for impacts on health, crop losses and building surfaces/materials:

Table 84 Monetary values (European average) used for economic valuation (€2002 factor costs)

Impact	**$€_{2002}$ per unit**
Human health, effects in respective units	
Acute mortality – Tears of life lost due to acute exposure	60,500
Chronic mortality – Years of life lost (YOLL) due to chronic exposure	40,300
New cases of chronic bronchitis	153,000
Hospital admissions (respiratory and attributable emergency cardiac)	1,900
Restricted activity days	76
Minor restricted activity days: cough days: symptom days (lower respiratory symptoms including cough): days of lower respiratory symptoms (excluding cough): days of lower respiratory symptoms, including cough, in children in the general population, i.e. extra symptoms days	31
Days of bronchodilator usage	1.0
Crops, yield loss in decitonnes	
Barley – yield loss	6.3
Oats – yield loss	6.6
Potato – yield loss	9.6
Rice – yield loss	254.9
Rye – yield loss	18.3
Sugar beet – yield loss	6.6
Sunflower seed – yield loss	25.8
Tobacco – yield loss	3,414
Wheat – yield loss	11.3
Fertiliser	53
Lime	1.8
Material, maintenance area in m^2	
	Country specific
Galvanised steel	(14 – 45)
Limestone	299
Mortar	33
Natural stone	299
Paint	13
Rendering	33
Sandstone	299
Zinc	27

Source: HEATCO D5 Annex D (HEATCO, 2006a).

Table 85 Values for use in CAFE CBA: Effects of chronic exposure on mortality

	VSL (€)	VOLY (€)	Derived from:
Median (NewExt)	980,000	52,000	Median value
Mean (NewExt)	2,000,000	120,000	Mean value

D.4 Output values

Air pollution costs can either be expressed in monetary units per tonne of pollutant or in monetary units per transport performance (vehicle-km, passenger/ton-km, LTO, aircraft- or ship-km).
Normally all approaches for air pollution costs will result in €/ton of pollutant. Average or marginal costs are derived values using specific emission factors for different kind of vehicles.

Costs in € per tonne of pollutant

The following tables give an overview on existing values of unit cost rates per unit of emission of a pollutant from different studies. Two recent studies (HEATCO, 2006a and CAFE, 2005a) provide detailed data per tonne of pollutant:

HEATCO

Table 86 Air pollution costs in €/tonne of pollutant for road, rail, waterways

	Factor costs in €, 2000 prices, Unit: €2000/ t of pollutant								
Pollutant	NO_x	NVMCC	SO_2	$PM_{2,5}$ (exhaust)			PM_{10} (non-exhaust)		
Local environment				Urban metropolitan	Urban*	Outside built – area	Urban metropolitan	Urban*	Outside built-up areas
Austria	4,200	600	3,800	415,400	134,300	69,600	166,200	53,700	27,800
Belgium	2,600	1,100	5,200	422,200	136,200	91,100	168,900	54,500	36,500
Bulgary	900	100	800	43,000	13,800	11,000	17,200	5,500	4,400
Cyprus	500	1,000	500	243,700	78,700	20,600	97,500	31,500	8,200
Czech Republic	3,000	1,000	3,800	252,600	81,400	62,700	101,000	32,600	25,100
Denmark	1,700	800	1,800	386,800	124,700	45,500	154,700	49,900	18,200
Estonia	1,200	400	1,000	133,400	43,400	22,500	53,400	17,300	9,000
Finland	800	200	600	337,100	108,600	28,100	134,800	43,400	11,200
France	4,400	800	4,100	392,200	126,300	78,400	156,900	50,500	31,400
Germany	3,000	1,100	4,300	384,500	124,000	75,000	153,800	49,600	30,000
Greece	2,000	600	1,300	248,700	80,100	35,000	99,500	32,100	14,000
Hungary	4,400	700	3,600	203,800	65,600	52,300	81,500	26,200	20,900
Ireland	1,800	400	1,400	391,000	126,200	40,900	156,400	50,500	16,400
Italy	3,000	1,500	3,300	371,600	120,100	67,600	148,600	48,000	27,100
Latvia	1,500	400	1,200	115,700	37,200	21,500	46,300	14,900	8,600
Lithuania	2,300	400	1,600	143,100	46,500	28,600	57,200	18,600	11,400
Luxemburg	4,400	1,300	4,500	671,500	216,200	95,700	268,600	86,500	38,300
Malta	500	1,100	500	245,400	78,700	20,400	98,200	31,500	8,200
Netherlands	2,500	1,000	4,800	422,500	136,400	82,600	169,000	54,500	33,000
Norway	1,100	300	900	309,600	99,600	30,100	123,800	39,900	12,000
Poland	2,800	700	3,200	174,500	56,000	52,400	69,800	22,400	20,900
Portugal	2,700	1,000	1,800	259,500	83,600	38,500	103,800	33,500	15,400
Romania	600	100	500	29,200	9,400	7,500	11,700	3,800	3,000
Slovakia	4,500	1,100	3,700	194,200	62,100	52,400	77,700	24,900	21,000
Slovenia	4,100	700	3,800	262,900	84,500	54,500	105,200	33,800	21,800
Spain	2,500	500	2,000	299,600	96,400	41,200	119,900	38,600	16,500
Sweden	1,200	300	1,000	352,600	113,400	34,300	141,000	45,400	13,700
Switzerland	4,400	600	3,800	444,800	143,100	73,500	177,900	57,200	29,400
UK	1,500	700	2,800	389,100	125,300	60.700	155,700	50,100	24,300

Source: HEATCO, values adjusted to € 2,000 values using GDP/cap. PPP development.
*UBA transferred to HEATCO, personal communication with P. Bickel April 5, 2007.

The approach can be used for all modes. For rail transport, the emission factors due to abrasion are very sensitive. Table 87 presents the cost factors for emissions from electricity generation:

Table 87 Air pollution costs in €/tonne of pollutant for electricity generation

	Factor costs in €, 2000 prices, Unit: € 2000/t of pollutant				
Pollutant	NO_x	NVMCC	SO_2	PM_{10}	PM_{10}
Local environment					
Austria	4,200	600	4,100	14,500	11,600
Belgium	2,600	1,100	5,500	16,300	13,400
Bulgary	900	100	800	1,700	1,300
Cyprus	500	1,000	400	3,700	1,900
Czech Republic	2,700	1.000	3,900	9,400	8,400
Denmark	1,800	800	2,000	7,700	4,800
Estonia	1,200	400	1,000	3,300	2,500
Finland	800	200	700	5,600	2,800
France	4,600	800	4,200	13,400	10,500
Germany	2,700	1,100	4,100	11,500	8,700
Greece	2,100	600	1,100	4,600	2,800
Hungary	4,500	700	3,800	8,000	6,200
Ireland	1,600	400	1,400	6,200	3,600
Italy	2,900	1,500	1,600	9,500	6,700
Latvia	1,500	400	1,200	2,500	1,700
Lithuania	2,300	400	1,700	3,600	2,700
Luxemburg	4,300	1,300	4,800	14,700	11,000
Malta	500	1,100	400	4,100	2,000
Netherlands	2,500	1,000	5,300	16,300	13,400
Norway	900	300	900	5,000	2,500
Poland	2,800	700	3,500	8,300	7,300
Portugal	2,400	1,000	1,600	6,700	4,800
Romania	1,900	300	1,600	3,300	2,600
Slovakia	4,500	1,100	3,900	7,800	6,800
Slovenia	4,100	700	3,900	7,500	5,600
Spain	2,200	500	1,800	5,600	3,700
Sweden	1,000	300	1,000	5,700	2,900
Switzerland	4,400	600	4,100	15,500	11,600
United Kingdom	1,300	700	2,800	12,300	9,500

Source: HEATCO, values adjusted to € 2,000 values using GDP/cap. PPP development.

CAFE CBA:

In CAFE CBA total damages from each of the pollutants considered are given for 4 combinations of sensitivity: The low end is calculated on the following basis:

- Inclusion of core health functions and crop functions.
- Use of the median estimate of VOLY from the NewExt study for mortality impacts of $PM_{2.5}$ and ozone.
- Use of the 35 ppb cut-point for quantification of ozone health impacts.

The upper end is calculated on the following basis:

- Inclusion of core and sensitivity health functions and crop functions.
- Use of the mean estimate of VSL from the NewExt study for mortality impacts of $PM_{2.5}$ and the mean estimate of VOLY for mortality impacts of ozone.
- Use of no cut-point for quantification of ozone health impacts.

The change in magnitude of damages for the central scenarios is largely a reflection of the unit values used for mortality valuation. It is notable that there is not clear separation of the results based on the VSL and VOLY approaches – although VOLY gives generally lower results than VSL, the result based on mean VOLY is greater than the one based on median VSL.

The results show very large variations in damage per tonne emission between countries. Generally, the highest damages are found from emissions in central Europe and the lowest from 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 (CAFE, 2005a).

The following tables show the unit costs per tonne of Pollutant for the most important pollutants $PM_{2.5}$ and NO_x.

Results of CAFE CBA represent an average of damages between rural and urban emissions. Specific analysis of NH_3, SO_2 and VOCs comparing the effects of urban and rural release would make little difference to the results, given that the effects of these pollutants are mediated here through formation of secondary aerosols and ozone whose formation in the atmosphere requires time. For NO_x, little difference is expected for impacts via secondary aerosol exposure, though impacts from ozone exposure would be likely to vary significantly between urban and rural sites. However, given that ozone damages are found here to be small compared to PM effects, this too should have little effect on the results. The one pollutant for which site of release is likely to be significant is (primary) $PM_{2.5}$. The results for $PM_{2.5}$ cannot be considered to represent either the urban or the rural position, but something in-between (CAFE, 2005a).

Table 88 Air pollution costs in €/tonne of $PM_{2,5}$

$PM_{2.5}$				
Marginal $PM_{2,5}$ damage (€) per tonne emission for 2010, with three sets of sensitivity analysis				
PM morality	VOLY – median	VSL – median	VOLY – mean	VSL – mean
O_3 morality	VOLY – median	VOLY – median	VOLY – mean	VOLY – mean
Health core?	Yes	Yes	Yes	Yes
Health sensitivity?	No	No	Yes	Yes
Crops	Yes	Yes	Yes	Yes
O_3 / health metric	SOMO 35	SOMO 35	SOMO0	SOMO0
Austria	37,000	56,000	72,000	110,000
Belgium	61,000	94,000	120,000	180,000
Cyprus	-	-	-	-
Czech Republic	32,000	49,000	62,000	91,000
Denmark	16,000	25,000	33,000	48,000
Estonia	4,200	6,500	8,300	12,000
Finland	5,400	8,300	11,000	16,000
France	44,000	68,000	87,000	130,000
Germany	48,000	74,000	95,000	140,000
Greece	8,600	13,000	17,000	25,000
Hungary	25,000	39,000	50,000	72,000
Ireland	15,000	22,000	29,000	42,000
Italy	34,000	52,000	66,000	97,000
Latvia	8,800	14,000	17,000	25,000
Lithuania	8,400	13,000	17,000	24,000
Luxembourg	41,000	63,000	81,000	120,000
Malta	9,300	14,000	18,000	27,000
Netherlands	63,000	96,000	120,000	180,000
Poland	29,000	44,000	57,000	83,000
Portugal	22,000	34,000	44,000	64,000
Slovakia	20,000	31,000	40,000	58,000
Slovenia	22,000	34,000	44,000	64,000
Spain	19,000	29,000	37,000	54,000
Sweden	12,000	18,000	23,000	34,000
United Kingdom	37,000	57,000	73,000	110,000
Baltic Sea	12,000	19,000	24,000	35,000
Mediterranean Sea	5,600	8,700	11,000	16,000
North East Atlantic	4,800	7,400	9,400	14,000
North Sea	28,000	42,000	54,000	80,000

Source: CAFE CBA (CAFE, 2005a).

Table 89 Air pollution costs in €/tonne of NO_x

NO_x				
Marginal NO_x, damage (€) per tonne emission for 2010, with three sets of sensitivity analysis				
PM mortality	VOLY – median	VSL – median	VOLY - mean	VSL – mean
O_3 mortality	VOLY – median	VOLY – median	VOLY – mean	VOLY – mean
Health core?	Yes	Yes	Yes	Yes
Health sensitivity?	No	No	Yes	Yes
Crops	Yes	Yes	Yes	Yes
O_3/health metric	SOMO35	SOMO35	SOMO0	SOMO0
Austria	8,700	13,100	16,000	24,000
Belgium	5,200	8,200	9,100	14,000
Cyprus	-	-	-	-
Czech Republic	7,300	11,000	13,700	20,000
Denmark	4,400	6,700	8,300	12,100
Estonia	810	1,100	1,600	2,200
Finland	750	1,100	1,500	2,000
France	7,700	12,000	14,000	21,000
Germany	9,600	15,000	18,000	26,000
Greece	840	1,100	1,400	1,900
Hungary	5,400	8,100	10,000	15,000
Ireland	3,800	5,600	7,500	11,000
Italy	5,700	8,600	11,000	16,000
Latvia	1,400	1,900	2,700	3,700
Lithuania	1,800	2,700	3,700	5,000
Luxembourg	8,700	13,000	16,000	24,000
Malta	670	930	1,300	1,700
Netherlands	6,600	10,000	12,000	18,000
Poland	3,900	5,800	7,100	10,000
Portugal	1,300	1,900	2,200	3,200
Slovakia	5,200	7,800	9,700	14,000
Slovenia	6,700	10,000	13,000	18,000
Spain	2,600	3,800	5,200	7,200
Sweden	2,200	3,200	4,100	5,900
United Kingdom	3,900	6,000	6,700	10,000
Baltic Sea	2,600	4,000	4,900	7,200
Mediterranean Sea	530	760	990	1,400
North East Atlantic	1,600	2,400	3,500	4,800
North Sea	5,100	7,900	9,500	14,000

Source: CAFE CBA (CAFE, 2005a).

Values in CAFE CBA are significantly lower for $PM_{2.5}$ than HEATCO, whereas values for NO_x, VOC and SO_2 are higher. The most important reason for this results is discussed above (valuation of secondary particles).

Within the UNITE project several case studies mainly for urban areas have been carried out. Table 90 presents the results for 4 urban case studies.

Table 90 Unit costs in €/tonne of $PM_{2.5}$

Location	Population density (inh./km)	Costs due to damages on the local scale in €/tonne of $PM_{2,5}$	Costs due to damages on the regional scale in €/tonne of $PM_{2,5}$
Helsinki	2,800	95,000	2,800
Stuttgart	2,800	200,000	26,800
Berlin	3,800	90,000	17,500
Florence [a]	*4,100*	*50,000*[a b]	*n.a.*

[a] Restricted comparability to other results, because estimate in based on a different methodological approach.

[b] €/t PM_{10}; n.a. = not available.

Source: UNITE D11 (UNITE, 2003b).

The values presented in Table 90 show the ranges of damage cost rates for different case studies carried out in the UNITE project. The case studies from Berlin and Stuttgart show clearly that irrespective of the size of city damage cost rates vary considerably. Although Berlin is considered to be a metropolitan city damage cost rates are lower basically due to different meteorological conditions (higher wind speeds) and a different topography (Stuttgart is situated in a basin with little air exchange and thus an accumulation of pollutants where as Berlin is located in a flat area). In principle the quantification of marginal air pollution costs would require detailed analysis for every geographical entity considering the specific characteristics with respect to emissions, meteorological conditions, topographical location, exposition and receptor density. In order to estimate marginal costs for countries this cannot be done in such a differentiated way. Therefore the use of more general values like in HEATCO or CAFE CBA is recommended as a practical and efficient solution.

Up-to-date unit costs per tonne of pollutant are available for Germany, these values have been used for an update study on external air pollution costs for Germany (INFRAS, 2007). They are based on the IPA/ExternE approach and differentiated by type of road network and vehicle category:

Table 91 Unit costs in €/tonne of $PM_{2.5}$/PM_{10}

	Local (Faktorkosten €2002, DE)								
€ per t PM2.5 exhaust		Car		Bus		LDV		HDV	All vehicles
Autobahn		33,400		23,900		32,500		25,500	27,900
Ausserortsstrassen		25,900		22,500		23,500		21,200	22,500
Innerortsstrassen		116,300		116,300		116,300		116,300	116,300
	Quelle: local damages Germany_updated.xls/damages								
€ per t PM_{10} non-exhaust	Car		Bus		LDV		HDV		All vehicles
Autobahn		13,360		9,560		13,000		10,200	11,160
Ausserortsstrassen		10,360		9,000		9,400		8,480	9,000
Innerortsstrassen		46,520		46,520		46,520		46,520	46,520

Source: local damages Germany_updated.xls/damages (ExternE, internal Excel-Document)/ (INFRAS, 2007).

The values presented above are in the same order of magnitude than unit cost rates calculated in UNITE for Berlin or HEATCO values for Germany for the urban road network. We consider them as good proxy for average marginal air pollution costs for Germany.

Costs in € per vehicle-km

Many studies on external costs of transport present marginal external air pollution costs in € per vehicle-km. Where as some studies estimate these values directly based on a top-down or bottom-up approach other studies apply unit cost rates on emission factors (esp. bottom-up approaches). In top-down approaches allocation of total costs to single vehicle categories is calculated based on the contribution of single vehicle categories to overall transport related emissions.

Table 92 gives an overview on marginal costs per vehicle km which were calculated within different marginal cost case studies of the UNITE project including cost estimates from other studies.

Table 92 Comparison of air pollution MC in the road sector in € 1998/vkm

Costs drivers		**Cost estimates**		**Methodological Approaches**
Type of road	Vehicle type and emission standards	UNITE	Other studies	
Urban	Car Petrol EURO-2	0.0012 [2] 0.0025 [3] 0.0015 [4]	0.0004-0.0148 [1]	IPA
	Car Diesel EURO-2	0.0145 [3] 0.0073 [4] 0.0026 [5]	0.0036-0.0604 [5]	IPA
	Heavy Goods vehicles	0.1752 [3] 0.1019 [4] 0.0469 [5]	0.4338-0.5199 [6]	IPA
Inter-urban	Car Petrol EURO-2	0.0011-0.0037 [7]	0.0010-0.0021 [8]	IPA
	Heavy Goods vehicles	0.0209-0.0746 [7]	0.0323-0.1606 [9] 0.0180-0.0770 [17]	IPA

1 ExternE range (Brussels, Helsinki, Stuttgart, Athens, Groningen, Amsterdam, London).
2 Helsinki.
3 Stuttgart.
4 Berlin.
5 Florence, only local scale pollutant (CO, Benzene, PM_{10}). IPA methodology integrated with regression analysis instead of dispersion models.
6 INFRAS/IWW (2000). European averages.
7 Range among Basel-Karlsruhe, Milano-Chiasso, Bologna-Brennero, Strasburg-Neubrandenburg case studies.
8 ExternE range (Brussels, Helsinki, Stuttgart, Athens, Groningen, Amsterdam, London.
9 INFRAS/IWW (2000). European averages.
10 RECORDIT case study (2001).
Source: UNITE, 2003b (D11).

In general petrol driven cars have lower costs than diesel driven cars and Heavy Goods vehicles higher costs than passenger cars. Marginal costs in urban areas are considerably higher due to the higher receptor density compared to interurban or rural regions.

A Rail Transport

In rail transport marginal air pollution costs vary considerably as the results of different case studies in the UNITE project depicts.

Table 93 Rail environmental marginal external costs (€/trian-km) 1998

		Air pollution	Global warming	Noise pollution	
				Day	Night
Interurban Case studies [1]	Freight train	0.148-0.32	0.0015-0.21 [2]	0.00-0.22	0.0059-0.16
	Passenger train [3]	0.16-0.418	0.004-0.17 [2]	0.0004-0.06	0.0003-0.41
Urban Case studies	Passenger train [4]	0.025-0.05	0.002-0.04	0.025-0.03	

[1] Results come from the Italian and German case studies.
[2] There was huge variance between the case studies with German results much higher.
[3] Results vary by train type; costs higher for high speed trains.
[4] Results come from the German case study.
Source: UNITE, 2003b (D11).

The main cost drivers of marginal air pollution costs for rail transport is the type of engine (Diesel or electrically driven) as well as the location of the emission (urban/interurban). In general freight trains have much higher marginal costs due to higher train weights, thus higher exhaust emissions in case of Diesel trains or higher emissions of electricity generation in case of electrically driven trains. In general electricity traction has much lower costs due to the fact that only particles from abrasion or re-suspension are emitted on the track and power plants have more efficient flue gas cleaning installations than Diesel engines.

B Air Transport

There are only a few studies on marginal air pollution cost calculations for air transport (UNITE D11, RECORDIT, 2005). The table below shows marginal costs for a short haul flight from Berlin to London Heathrow. Normally only LTO cycle emissions are accounted for the cost calculation.

Table 94 Marginal costs due to airborne emissions of a Boeing 737-400 in €

		Air pollution			Global warming			Total
		Direct emissions	Fuel production	Total	Direct emissions	Fuel production	Total	
Berlin Tegel	LTO-cycle	42.18	8.56	50.74	44.74	5.68	50.42	101.16
	Departure	28.29	4.64	32.93	24.26	3.08	27.35	60.28
London Heathrow	LTO-cycle	37.86	6.01	43.87	48.57	6.17	54.74	98.62
	Arrival	13.21	2.77	15.98	22.35	2.84	25.19	41.17
Flight Berlin-London	Cruise	[1]	33.47	33.47	175.000 [2]	22.22	197.22	230.70
	Total [3]	41.51	40.88	82.39	221.61	28.14	249.75	332.15

[1] Costs due to direct air pollution emissions not included.
[2] Possible order of magnitude for global warming effects due to high altitude nitrogen emission: ca. EUR 3000.
[3] Consisting of departure at Tegel, cruise, and arrival at Heathrow.
Source: UNITE, 2003b (D11).

C Summary UNITE results:

Table 95 presents the ranges of different UNITE case studies for road and rail transport as well as for inland waterways and maritime shipping. The case studies conducted within UNITE are the so far most comprehensive studies on marginal air pollution costs for different means of transport, In the ongoing GRACE project additional case studies have been carried out, first results are presented in the overview tables at the end of this chapter.

Table 95 Overview on marginal air pollutions costs of different UNITE case studies

Type of transport	Recommended method and key functions	Range of values from the case studies cent/vkm
Road transport	**Method: Impact Pathway Approach:** - Emission calculation - Dispersion & chemical conversion modelling - Calculation of physical impacts - Monetary valuation of physical impacts **Functions:** - Exposure response functions - Dispersion models	***Urban (interurban) passenger car*** Petrol: 0.12-0.25 (0.11-0.37) Diesel: 0.26-1.45 (0.26-1.91) ***Urban (interurban) HGV*** Euro2: 4.69-17.52 (2.09-7.46)
Rail transport		***Interurban passenger train*** High speed: 41.756 Intercity: 25.41-31.65 Local: 16.23-23.261 ***Urban passenger train*** 0.025-0.05 ***Freight train*** 14.758-32.03 cent/train-km
IWW		1.2-1.8 cent-TEUkm
Maritime shipping		***Passenger ferry at open sea (at berth)*** Direct:12.959 €/vkm (1.524-1.589 €/visit) Fuel chain: 1.38 cent/vkm (15 cent/visit of 8.5 hrs)

Source: UNITE, 2003b (D11).

D Results of INFRAS/IWW 2004a

Table 96 presents the results for the most important vehicle categories, technologies and traffic situations. The results are based on average cost calculations using differentiated emission factors for PM_{10}.

Table 96 Average marginal air pollution costs of transport in the EU17 countries

Vehicle category	Technology	Emission factors g/vkm	Marginal costs €/1000 vkm	Marginal costs €/1000 pkm/tkm
Passenger car urban	Gasoline	0.045	9.54	5.72
	Diesel	0.350	74.74	44.86
Passenger car interurban	Gasoline	0.045	9.54	5.80
	Diesel	0.141	30.12	18.32
Two-wheelers	Gasoline	0.017	3.59	3.21
Buses	Diesel	1.361	310.76	17.74
Coaches	Diesel	0.966	220.64	11.65
HDV	Diesel	1.084	227.29	33.50
LDV	Gasoline	0.059	11.36	15.14
	Diesel	0.394	75.62	100.82
Train passenger	-	6.00	696.00	5.1
Train Freight	-	21.40	2437.00	7.4
Air passenger	-	-	24.0	0.2
Air freight	-	-	-	1.8
Waterborne transport	-	-	-	8.8

Source: INFRAS, 2004.

E Summary and comparison of existing values

The following tables provide an overview of the studies analysed and present the ranges of results for unit costs for different transport modes, traffic situations and regional networks:

The first section of Table 97 shows marginal air pollution costs for passenger cars differentiated by network, EURO norms and fuel types of different recent studies with an European scope. The second part of the table covers recent studies on marginal costs for specific countries as well as the ranges of values recommended as best practice values based on CAFE CBA and HEATCO (Details see Table 15, p. 57).

Table 97 Marginal air pollution costs road passenger car transport

Results of studies with an European Scope

Study		UNITE	UNITE	UNITE	UNITE	GRACE	INFRAS	ExternE
		Environmental marginal cost case studie	Environmental marginal cost case studie	Environmental marginal cost case studie	Environmental marginal cost case studie	Marginal cost case studies for road and rail transport	External costs of transport in Western	Environmental external costs of transport
Source		UNITE, 2003b	UNITE, 2003b	UNITE, 2003b	UNITE, 2003b	GRACE, 2006a	INFRAS, 2004	Friedrich and Bickel, 2001
Definitions		Marginal costs, health, crops + material damages	Marginal costs, health, crops + material damages	Marginal costs, health, crops + material damages	Marginal costs, health, crops + material damages	Marginal costs, health, crops + material damages (vehicle use)	Marginal costs, health, crops + material damages	Marginal costs, health, crops + material damages
Country/Region		Finland/Helsinki	Germany Stuttgart (urban) Basel-Karlsruhe (interurban)	Germany, Berlin (urban), Strasburg-Neubrandenburg (interurban)	Italy, Florence (urban), diff. interurban	Urban case studies: Athens, Berlin, Copenhagen, Prague (highest values for Athens, lowest values for Pargue/Copenhagen)	EU15	Belguim, Finland, Germany, Greece, Netherlands, UK
Base year		1998	1998	1998	1998	2000 (not specified)	2000	1999 (not specified)
Unite		€ct/vkm	€ct/vkm	€ct/vkm	€ct/vkm	€ct/vkm	€ct/vkm	€ct/vkm
Vehicle		Passenger cars	Passenger cars	Passenger cars	Passenger cars	Passenger cars	Passenger cars	Passenger cars
Metropolitan	EURO2							
	EURO3							
Urban	EURO2	0.123	Petrol 0.25 Diesel 1.45	Petrol 0.15 Diesel 0.73	Petrol 0.87	Petrol 0.61-1.81 Diesel 1.49-4.75	Petrol 0.95 Diesel 7.47	Petrol – Diesel BE 0.77-3.26 FI 0.26-0.96 DE 0.39-1.29 GR 1.48-6.47 UK 1.04- 4.41 NL 0.49-2.42
	EURO3 [4]	0.095	(EURO4) Petrol 0.14 Diesel 0.37	(EURO4) Petrol 0.08 Diesel 0.20		(EURO4) Petrol 0.46-1.63 Diesel 0.77-2.54 Hybrid 0.57-1.75		
Interurban	EURO2		Petrol 0.37 Diesel 0.63	Petrol 0.12 Diesel 0.30	Petrol 0.55-0.67 Diesel 1.09-2.27		Petrol 0.95 Diesel 3.59	Petrol – Diesel BE 0.18-0.41 DE 0.09-0.21 GR 0.21-0.43 UK 0.10-0.26 NL 0.11-0.36
	EURO3		(EURO4) Petrol 0.15 Diesel 0.24	(EURO4) Petrol 0.04 Diesel 0.11				
Motorways	EURO2							
	EURO3							
All roads	EURO2							
	EURO3							

Country specific studies and recommended values (right column)

Study		DETR	Boiteux-Report	COWI	OSD	OSD	Schmid	INFRAS	CAFE CBA/HEATCO
		Surface transport costs & charges	Infrastructure investments and costs of external effects	Marginal external costs for Denmark	Transport related external health costs	Transport related building damages	Externe kosten des Verkehrs	External costs of transport in Germany	Air pollution costs
Source		ITS, 2001	Bioteux, 2001	COWI, 2004b	OSD, 2004a	OSD, 2004b	Schmid, 2005	INFRAS, 2007	Bickel et al., 2006/CAFÉ, 2005
Definitions		Marginal costs, health, crops, material damages	Average (marginal) costs, health	Marginal costs, only health costs	Average costs, health	Average costs, building damages	Marginal costs, health, crops, material damages	Marginal costs, health, crops, material damages	Marginal costs, health, crops, material damages
Country, region		UK	France	Denmark	Switzerland	Switzerland	Germany: Berlin/Stuttgart (urban), Basel-Karlsruhe (motorway), Strassburg/ Neubrandenberg (interurban)	Germany	Exemplary values for Germany, Ranges: different car sizes, different damage costs rates
Base year		1998	2000	2002	2000	2000	2000	2005	2000
Unit		€/vkm	€/vkm	€/vkm	€/vkm	€/vkm	€/vkm	€/vkm	€/vkm
Vehicle		Passenger cars	Passenger cars	Passenger cars	Passenger transport (cars, MC, busses)	Passenger cars	Passenger cars	Passenger cars	Passenger cars
Metropolitan	EURO2		Average value for France: 2.9						Petrol 0.9-1.4 Diesel 3.2-4.9
	EURO3								
Urban	EURO2		Average value for France: 1.0	Petrol 0.1-3.9 Diesel 0.1-3.1			Petrol 0.19-0.32 Diesel 0.93-1.84		Petrol 0.4-0.8 Diesel 1.5-3.0
	EURO3 [4]			Petrol 0.1-3.9 Diesel 0.1-3			EURO4 Petrol 0.10-0.18 Diesel 0.25-0.47		Petrol 0.3-0.6 Diesel 1.1-2.3
Interurban	EURO2		Average value for France: 0.1	Petrol 0.1-3.2 Diesel 0.1-2.7			Petrol 0.15 Diesel 0.38		Petrol 0.1-0.5 Diesel 0.9-2.0
	EURO3			Petrol 0.1-3.2 Diesel 0.1-2.7			(EURO4) Petrol 0.05 Diesel 0.14		Petrol 0.1-0.3 Diesel 0.7-1.6
Motorways	EURO2						Petrol 0.47 Diesel 0.8		Petrol 0.3-0.8 Diesel 1.2-2.7
	EURO3						(EURO4) Petrol 0.19 Diesel 0.30		Petrol 0.2-0.5 Diesel 0.9-2.1
All roads	EURO2	Average values for UK 0.27-1.3	Average value for France: 0.9		Average value for Switzerland 1.08	Average value for Switzerland 0.14		Average value for Germany 0.58	
	EURO3								

The ranges derived from the recommended unit cost rates in €/ton of pollutant from CAFE CBA and UNITE match largely with recent case studies on marginal air pollution costs on a European level as well as with country specific studies.

Table 98 presents results for Heavy Goods vehicles (HGV) with a similar differentiation like the results for passenger cars:

Table 98 Marginal air pollution costs for HGV. Overview of cost factors in €ct/vkm for different European and country specific studies

Results of studies with an European scope

Study	EURO	UNITE	UNITE	UNITE	UNITE	GRACE	INFRAS
		Environmental marginal cost case study	Environmental marginal cost case study	Environmental marginal cost case study	Environmental marginal cost case study	Marginal cost case studies for road and rail transport	External costs of transport in Western
Source		UNITE, 2003b	UNITE, 2003b	UNITE, 2003b	UNITE, 2003b	GRACE, 2006a	INFRAS, 2004
Definitions		Marginal costs, health, crops, material damages	Marginal costs, health, crops, material damages	Marginal costs, health, crops, material damages	Marginal costs, health, crops, material damages	Marginal costs, health, crops, material damages (vehicle use)	Marginal costs, health, crops, material damages
Country/Region		Finland	Germany Stuttgart (urban), Basel-Karlsruhe (interurban)	Germany, Berlin (urban), Strasburg-Neubrandenburg (interurban)	Italy, Florence, (urban), diff. interurban	Urban case studies: Athens, Berlin, Copenhagen, Prague (highest value for Athens, lowest values for Prague/Copenhagen), values include cliimate change costs)	EU15
Base year		1998	1998	1998	1998	2000 (not specified)	2000
Unit		€/vkm	€/vkm	€/vkm	€/vkm	€/vkm	€/vkm
Vehicle		HGV (42t)	HGV	HGV	HGV	HGV	HGV
Metropolitan	EURO2						
	EURO3						
Urban	EURO2		17.52	10.19		8.58-26.01	
	EURO3 (4)					(EURO4) 5.92-17.81	
Interurban	EURO2	2.09	6.91	4.99	7.2-8.8		
	EURO3	1.41					
Motorways	EURO2						
	EURO3						
All roads	EURO2						22.7
	EURO3						

Continued (next page)

Country specific studies and recommended values (right column)

Study	EURO	DETR	Boiteux	COWI	OSD	OSD	Schmid	INFRAS	CAFÉ CBA/HEATCO
		Surface transport costs & charges		Marginal external costs for Denmark	Transport related external health costs	Transport related building damages	Externe kosten des verkehrs	External costs of transport in Germany	Air pollution costs
Source		ITS, 2001	Boiteux, 2001	COWI, 2004b	OSD, 2004a	OSD, 2004b	Schmid, 2005	INFRAS, 2007	Bickel et al., 2006/CAFÉ, 2005
Definitions		Marginal costs, health, crops + material damages		Marginal costs, only health costs	Average costs	Average costs, building damages	Marginal costs, health, crops + material damages	Marginal costs, health, crops + material damages	Marginal costs, health, crops + material damages
Country/Region		UK	France	Denmark	Switzerland	Switzerland	Germany: Berlin-Stuttgart (urban), Basel-Karlsruhe (motorway), Strassburg-Nuebrandenburg (interurban)	Germany	Exemplary values for Germany, Ranges: different truck types different damage cost rates
Base year		1998	2000	2002	2000	2000	2000	2005	2000
Unit		€ct/vkm	€ct/vkm	€ct/vkm	€ct/vkm	€ct/vkm	€ct/vkm	€ct/vkm	€ct/vkm
Vehicle		HGV	HGV	HGV	Freight transport (LDV, HGV)	HGV	HGV	HGV	HGV
Metropolitan	EURO2		Average value for France: 28.2						30.7-65.5
	EURO3								32.6-59.7
Urban	EURO2		Average value for France: 9.9	0.4-12.2			12.94-22.25		19.1-51.2
	EURO3 (4)			0.4-12.2					17.8-43.5
Interurban	EURO2		Average value for France: 0.6	0.3-9.3			6.34		10.1-29.4
	EURO3			0.3-9.2					8.3-23.9
Motorways	EURO2						8.78		9.2-26.4
	EURO3								6.7-18.7
All roads	EURO2	HGV/rigid 2.44-12.21 HGV/artic 2.08-11.28	Average value for France: 6.2		Average value for Switzerland: 6.48	2.11		Average values for Germany: 4.63	
	EURO3					1.93			

The marginal costs recommended in chapter 3 for HGV are slightly higher than UNITE and GRACE results. The main reason for this might be the different treatment of secondary particles within CAFE CBA which leads to higher unit cost rates for NO_x and SO_2 in CAFE CBA compared to the ExternE based case studies of UNITE and GRACE. Besides, the values suggested (right column of

2nd part of the table) are in a same order of magnitude than the ranges observed in up-to-date studies.

Marginal air pollution costs for rail transport show greater variations than those of road transport.

Table 99 Marginal air pollution costs rail transport. Overview of cost factors in €ct/vkm for different European and country specific studies

Results of studies with an European scope

Study	EURO	UNITE	UNITE	UNITE	UNITE	GRACE	INFRAS	ExternE
		Environmental marginal cost case study	Environmental marginal cost case study	Environmental marginal cost case study	Environmental marginal cost case study	Marginal cost case studies for road and rail transport	External costs of transport in Western	Environmental external cost of transport
Source		UNITE, 2003b	UNITE, 2003b	UNITE, 2003b	UNITE, 2003b	GRACE, 2006a	INFRAS, 2004	Friedrich and Bickel, 2001
Definitions		Marginal costs, health, crops + material damages	Marginal costs, health, crops + material damages	Marginal costs, health, crops + material damages	Marginal costs, health, crops + material damages	Marginal costs, health, crops + material damages (vehicle use)	Marginal costs, health, crops + material damages	Marginal costs, health, crops + material damages
Country/ Region		Finland/Helsinki	Germany Stuttgart (urban) Basel-Karlsruhe (interurban)	Germany, Berlin (urban), Strasburg-Nuebrandenburg (interurban)	Italy, Florence (urban), diff. interurban	Urban case studies: Athens, Berlin, Copenhagen, Prague (highest value for Athens, lowest values for Prague/ Copenhagen)	EU15	Belgium, Finland, Germany, Greece, Netherlands, UK
Base year		1998	1998	1998	1998	2000 (not specified)	2000	1999 (not specified)
Rail			€ct/train-km	€ct/train-km	€ct/train-km	€ct/train-km	€ct/train-km	€ct/train-km
Urban	Light rail		2.51	5.24 (tram) – 11.22 (underground)		Tram 9.4-15.4 Metro 9.2-13.0 Light rail 15.5-21.9		DE Electr. S-bahn 16.2 DE Electr. Light rail 0.8 DE Electr. Tram 0.4 FI Electr. Tram 0.05 NL Electr. Metro 2 NL Electr. Tram 1.6
Interurban	Passenger train		25.41	16.23	Local/high speed train 23.26-41.76		69.6	DE Electr. 9.5-17 NL Electr. 2-4.8 DE Diesel 60-135 UK Diesel 155-320
Interurban	Freight train		32.03	21.87	14.76-18.33		243.7	DE Electr. 16.5 NL Electr. 12.8 DE Diesel 80 NL Diesel 170-385 UK Diesel 120

Country specific studies and recommended values (right column)

Study	EURO	DETR	Boiteux-Report	COWI	OSD	OSD	Schmid	INFRAS	CAFE CBA/HEATCO
		Surface transport costs & charges	Infrastructure investments and costs of external effects	Marginal external costs for Denmark	Transport related external health costs	Transport related building damages	Externe kosten des verkehrs	External costs of transport in Germany	Air pollution costs
Source		ITS, 2001	Boiteux, 2001	COWI, 2004b	OSD, 2004a	OSD, 2004b	Schmid, 2005	INFRAS, 2007	Bickel et al., 2006/CAFÉ, 2005
Definitions		Marginal costs, health, crops + material damages	Average (marginal) costs, health	Marginal costs, only health costs	Average costs, health	Average costs, building damages	Marginal costs, health, crops + material damages	Marginal costs, health, crops + material damages	Marginal costs, health, crops + material damages
Country/ Region		UK	France	Denmark	Switzerland	Switzerland	Germany, Berlin/ Stuttgart (urban), Basel-Karlsruhe (motorway), Strassburg-Neubrandenburg (interurban)	Germany	Exemplary values for Germany Ranges: different car sizes, different damage cost rates
Base year		1998	2000	2002	2000	2000	2000	2005	2000
Rail		€ct/tain-km	€ct/tain-km	€ct/tain-km	€ct/tain-km	€ct/tain-km	€ct/tain-km	€ct/tain-km	€ct/tain-km
Urban	Light rail	Intercity 41.3-279 Regional 6.1-53.2 London 9.9-113.9	Urban passenger (Diesel): 57-164	Diesel 20-303				Average value for Germany 25.2	
Interurban	Passenger train		Interurban passenger (Diesel) 3.8	Electr. 4-45 Diesel 10-103	Passenger transport 20.93	Passenger transport 2.7	Regional train Electr. 13.44 Diesel 208.32 ICE 20.28		Electr. 9.7-25.6 Diesel 98.6-221.4
Interurban	Freight train	24.5-177.6	Interurban freight (Diesel) 10.5	Electr. 5.54 Diesel 25-246	Freight transport 110.93	Freight transport 16.5	Electr. 22.5	Average value for Germany 81.1	Electr. 22.7-62.7 Diesel 332.6-746.4

Marginal costs for rail transport are higher for Diesel traction than for electric traction. In addition emissions of electricity have been accounted for. The recommended values are within the ranges of other studies, for Diesel freight trains rather on the upper limit of observed values.

Table 100 Marginal air pollution costs air transport. Overview of cost factors in €/LTO for different European and country specific studies

Study	UNITE	GRACE	ExternE	Schmid
	Environmental marginal cost case study	Marginal cost case studies for air transport	Environmental external costs of transport	Externe kosten des verkehrs
Source	UNITE, 2003b	GRACE, 2006a	Friedrich and Bickel, 2001	Schmid, 2005
Definitions	Marginal costs, health, crops + material damages	Marginal costs, health, crops + material damages	Marginal costs, health, crops + material damages	Marginal costs, health, crops + material damages
Year	1998	2000	1999	2000
	€/LTO	€/LTO	€/LTO	€/LTO
Air transport	Berlin B737 42.2 London B737 37.9	Frankfurt A319 22 A320 32 A340 117 B737 31 B747-400 153 EMB145 8	Berlin B737 30.5 London LHR B737 59.9 London LHR B747 431.5 London LHR B777 168.6	Frankfurt A319 22 A320 32 A340 117 B737 31 B747-400 153 EMB145 8

Values for air transport vary proportional to aircraft size and location. Short-haul flights cause marginal costs between 20 and 60 €/LTO whereas long-haul flights vary between 150 and 430 €/LTO. All case studies include only LTO emissions. Emissions of the cruise phase are normally not included. The contribute to regional damages and are difficult to model within the Impact Pathway Approach.

There are very few marginal cost case studies for inland waterway transport which are difficult to compare due to different locations and ship sizes.

F Conclusions and Recommendations.

The analysis of the marginal air pollution costs, found in up-to-date and state of the art literature, shows that there is a clear convergence of results of studies applying the Impact Pathway Approach (ExternE). However, due to the fact that local impacts of air pollutants vary considerably with respect to meteorological and topographical conditions and receptor density there are still considerable ranges of results for comparable vehicle categories.

The comparison between values found in specific case studies of UNITE or GRACE and the values calculated based on the recommended unit cost rates in €/ton of pollutant of CAFE CBA and HEATCO (for $PM_{2.5}/PM_{10}$) shows on the other hand, that these bottom-up calculated marginal cost rates are for most cases in a comparable magnitude.

CAFE CBA and HEATCO marginal damage cost rates (as presented in Table 13 and Table 14, p. 54 onwards) are available for all European countries and based on state-of-the-art methodology. In order to ensure transferability and a straightforward application to different transport means, emission factors, traffic situations and regional settings these damage cost rates are considered to be the best practice values in order to estimate marginal air pollution costs.

E Noise costs

E.1 Overview of existing studies

Table 101 gives an overview on noise covering studies which have been reviewed for this report.

Table 101 Overview of existing studies

Study	Base year(s) of results	Countries covered	Cost categories covered[a]	Transport modes covered	Method used	Outputs, results differentiation
EU projects and programmes						
UNITE 2003	1998	EU-15, H, CZ	1, 2, 3,	Road, rail, aviation	Bottom-up	Marginal costs, average costs
High Level Group on Infrastructure charging 1999a	Method and unit costs only	Selected EU	1, 2, 3,	All	Bottom-up	No calculations, only rough methodological recommendations Marginal costs
PETS 2000	2010	A, B, F, FIN, NO, P, SE, CH, UK	1	Road, rail, aviation	Bottom-up	Marginal costs
RECORDIT 2001	1998	A, CH, CR, H, PL, D, F, I, NL, UK, DK, GR, ES, SE, SK, SI	1, 2, 3,	Road (freight), rail (freight)	Bottom-up	Marginal costs
HEATCO 2006a	2002	EU-25	1, 2, 3,	Road, rail	Bottom-up	Total costs
GRACE 2005	2005 ongoing	EU	-	All	Bottom-up	No new calculations
TRL 2001	1998	EU	1, 2, 3,	Road, rail, aviation	Bottom-up	Marginal costs
Other studies with a European scope						
External costs of transport (INFRAS/ IWW, 2000/2004)	1995 2000	EU-15, N, CH	1, 2, (3)[b]	Road, rail, aviation	Top-down	Total and average costs, marginal costs
External Costs of Noise (INFRAS/IWW 2003)	2010	EU	1,3	Rail	Bottom-up	Marginal costs
External costs of transport in Eastern Europe (OECD/ INFRAS/Herry, 2003)	1995	BG, CR, CZ, H, PL, RO, SI, SK	1, 2, 3,	Road, rail, aviation	Top-down	Total and average costs

Study	Base year(s) of results	Countries covered	Cost categories covered[a]	Transport modes covered	Method used	Outputs, results differentiation
Marginal costs of Infrastructure use – towards a simplied approach (CE, 2004a)	Method only	-	-	Road, rail, aviation	-	No calculations, critical assessment of other studies to noise costs Marginal costs
External and Infrastructure costs of road and rail traffic (CE Delft, 2003)	-	-	-	Road, rail	-	No calculations, critical assessment of other studies to noise costs Marginal costs
External costs of aviation (CE Delft, 2002)	1999	EU	1, 2, 3, 4,	Aviation	Literature review	Marginal and average costs
Efficient transport for Europe – policies for the internalisation of external costs (ECMT, 1998)	1991	EU-15, N, CH	1	Road, rail	Top-down	Average costs
Determination and application of environmental costs at different sized airports (Ly & Morrell, 2006)	2001	UK, NL	1	Aviation	Top-down	Total and average costs
Country specific studies						
The price of transport (CE Delft, 2004b)	2002	NL	1, 2	Road, rail	Top-down	Total and average costs
Surface transport costs & charges (ITS, 2001)	1998	UK	1	Road, rail	Bottom-up	Marginal costs
Marginal costs of traffic noise (Kristensen et al., 2004)	2000	DK	1, 2, 3	Road	Bottom-up	Marginal costs
External costs of transport - 2nd report (COWI, 2004a)	2000	DK	1, 2, 3,	Road, rail	Bottom-up	Marginal
External costs of transport – 3rd report (COWI, 2004b)	2000	DK	1, 2, 3,	Road, rail	Top-down	Total

Study	Base year(s) of results	Countries covered	Cost categories covered[a]	Transport modes covered	Method used	Outputs, results differentiation
Economic valuation of environmental damages – method convention for estimating environmental costs (UBA, 2006)	2006	D	1, 2, 3,	All		Only input values
Economic measures for the reduction of the environmental impact of air transport (Öko Institut & DIW, 2004)	2000	D	1	Aviation	Bottom-up	Marginal
Monetisation of the health impact due to traffic noise (SAEFL, 2003)	1995	CH	1	Road	Bottum-up	Marginal
Noise Charges in railway Infrastructure. A pricing schedule based on the marginal cost principle (Andersson & Ögren (2007)	2000	SE	1, 2, 3	Rail	Bottom-up	Marginal

[a] 1) disutility due to transport noise, 2) medical costs, 3) risk value, 4) Land use costs.
[b] Only INFRAS/IWW (2004a) includes risk values.

Discussion of the existing studies

We will briefly evaluate the various studies in Table 101 in general considering the following criteria: scientific accuracy, quality of data basis, completeness, transferability, practical application, potential for aggregation. Based on this evaluation we will choose which studies we will take into account in the review in the next sections.

Scientific accuracy

Two major approaches are applied in the studies available on noise costs: top-down and bottom-up. The results of both studies differ. The top-down method produces average cost estimates, while marginal cost estimates are found by the bottom-up approach. From a scientific point of view, marginal cost estimates are preferred above average cost estimates for internalisation strategies. However, due to the big impact of local factors (initial noise levels, traffic levels, etc.) on marginal noise costs it will be questionable whether internalisation strategies based on marginal costs are feasible. Thus, for practical reasons (see below) noise cost estimates based on a top-down method may be preferred in some cases.

There are important differences in the scientific accuracy of the way different studies estimate the health costs of traffic noise. Some studies use rather rough estimation methods. For example, INFRAS/IWW, 2000 take 50% of the WTP to reduce noise annoyance as a proxy for the health costs due to traffic noise. On the other hand, some studies use a rather refined method to estimate the health costs of transport noise. These studies use dose-response functions and value the endpoints with the help of specific unit values. This method is among others used by UNITE, 2003 and RECORDIT, 2001.

Quality of data basis

The quality of data basis especially is a problem with top-down studies, due to a lack of reliable data about people exposed to traffic noise. For example, INFRAS/IWW, 2000 have to use a very rough procedure to estimate the number of people exposed to different noise levels in Eastern Europe, since no detailed numbers are available. Also other studies (e.g. INFRAS, 2004; UNITE, 2003; etc.) do not have empirical data for all countries, transport modes and noise exposure levels, and therefore techniques of data extrapolation have been used to estimate the lacking numbers. Due to Directive 2002/49/EC on environmental noise, which requires Member States to report harmonized data on exposure to transport noise, the lack of exposure figures will decline in the future (European Commission, 2002b). In general, bottom-up studies make use of cases for which more detailed data is available.

Completeness

The costs of disutility due to transport noise are taken into account by almost all studies. Since the WTP values on which these costs are based do not include long-term health impacts (increased blood pressure, cardiovascular diseases, etc), these impacts should be taken into account separately (HEATCO, 2006a). However, not all studies follow this procedure. PETS, 2000; ECMT, 1998; Ly, 2006; ITS, 2001; Öko Institut, 2004 and SAEFL, 2003 only estimates the costs of disutility due to transport noise. Other studies (e.g. CE Delft, 2004; INFRAS/IWW, 2000 and 2003) only take health costs partly into account. Different studies have shown that quantifiable health effects are of minor importance compared to the WTP for reducing annoyance (see e.g. HEATCO, 2006a). Thus, differences in completeness will probably not have a big impact on the end results.

Transferability

The (marginal) costs of traffic noise are highly dependent on local factors, such as population density, specific topographical conditions, speed and level of traffic, etc. In addition, also the transport mode and time of day have an important impact on the level of noise costs. All these factors are best taken into account when is chosen for a bottom-up approach. However, due to this location specific character of the costs estimates, it will be hard to transfer these data to other cases. Studies using a top-down approach present average cost figures, mostly with a national scale, which are better able to transfer to other countries.

However, also the transfer of these figures should be performed with care. For example, the average noise costs for the Netherlands and Sweden will differ heavily.

Practical application

Study results can be applied more easily in case differentiated values are available for various transport modes, areas and time of day. Differentiation to transport modes is applied in almost all studies. Except for SAEFL, 2003 all studies using a bottom-up approach estimate figures for road and rail for different types of areas (urban, rural, etc.). In addition, also CE Delft, 2004b makes a distinction between urban and rural values. Time of the day is only taken into account by a few studies, namely INFRAS/IWW, 2004a; UNITE, 2003 and SAEFL, 2003.

Potential for aggregation

Studies covering more than one country are preferable in order to derive general countrywide values than very specific studies focussing on one transport mode and one specific network type for instance. Most European-wide top-down studies do present these kind of results. Also some bottom-up studies (HEATCO, 2006a; INFRAS, 2004) present cost estimates which can rather easily be used for all European countries.

Conclusion

The different estimation methods used by the various studies do all have their own advantages. The bottom-up approaches are preferred from a theoretical point of view, because this method takes location-specific factors into account. Top-down approaches on the other hand are preferred from criteria such as transferability and potential for aggregation. Since no definitive choice can be made between top-down and bottom-up studies, we will take both type of studies into account in the next sections.

To reflect the importance of local factors on the level of noise costs and to include all countries and transport modes, we will take a broad range of studies into account in the next sections. More specifically, we will review the following studies more thoroughly.

- UNITE, 2003.
- RECORDIT, 2001.
- HEATCO, 2006a+b.
- TRL, 2001.
- INFRAS/IWW, 2003.
- INFRAS/IWW, 2000/2004.
- CE Delft, 2002.
- CE Delft, 2004b.
- ECMT, 1998.
- Ly, 2006.
- ITS, 2001.
- Kristensen et al., 2004.
- COWI, 2004a.

- UBA, 2006.
- Öko-institut, 2004.
- SAEFL, 2003.

In addition, we will discuss the results from some specific scientific and policy documents, if they provide some additional opinions. However, the discussion of these documents is only meant to increase the understanding of the main studies, and therefore we will not discuss these documents in detail.

E.2 General approaches

In general, two different approaches to estimate noise costs can be distinguished: a top-down approach and a bottom-up approach.

Top-down approach
The starting point in this approach forms the macro-level, for example a country. On this level total noise costs are determined. Most of the times this is established by estimating the number of people who are exposed to traffic noise, and multiplying this number by an average WTP-value to noise reduction. In addition, sometimes the number of people exposed to traffic noise is also multiplied by average values for health costs. To improve the estimation of total noise costs, various noise classes (e.g. classes of 5 dB) are distinguished, all with their own estimation of the number of exposed people and WTP and health costs figures. Next, total noise costs should be allocated to individual vehicles, based on the shares of these vehicles in total noise emissions. Vehicle mileage is often used to estimate the share of different transport modes in total noise emissions. Sometimes, weighting factors are applied to correct for differences between modes in noise emissions per kilometre. This approach results in average noise costs.

Bottom-up approach
The bottom-up approach is developed in the ExternE-project and is generally called the 'Impact Pathway Approach'. The starting point of this approach is the micro level, i.e. the traffic flow on a particular route. Two scenario's are calculated: a reference scenario reflecting the present scenario with traffic volume, speed distribution, vehicle technologies, etc., and a marginal scenario which is based on the reference scenario, but includes one additional vehicle. The difference in damage costs of both scenario's represents the marginal external noise costs of that vehicle.

In general, this approach consists of five steps:
- *Step 1: Estimate the emissions per vehicle (in dB(A)) for both scenario's;* In addition, also the propagation of sound should be modelled. The level of sound received by the receptor is subject to geometrical spreading, atmospheric attenuation, ground attenuation, screening attenuation, reflection and meteorological conditions.

- *Step 2: Determine the type of impact of different levels of noise to human health, annoyance, etc;* These impacts can be measured with 'dose-response' relationships.
- *Step 3: Estimate the number of persons exposed to various ambient noise levels over time;* In addition to noise propagation, the exposure of the population depends basically on the geographical settlement patterns and forms of urbanisation. Also site-specific characteristics have to be taken into account, like for example sound insulation.
- *Step 4: Establish the relationship between exposure to noise and the various health and welfare effects; and predict the physical effects of the emissions on the basis of these relationships.*
- *Step 5: Calculate the monetary value of effect on health and other welfare effects;* Assuming that the appropriate impact is identified, its monetary value should be appraised by using market prices or valuation methods such as hedonic pricing and contingent valuation.

The procedure of calculating marginal noise costs requires a considerable input of data and time. Hence it is impossible to carry out a detailed assessment for all route segments throughout Europe. Instead, results of selected case studies should be generalised.

Top-down vs. bottom-up approach

The results of top-down and bottom-up approaches are different. A top-down approach results in average noise costs, while a bottom-up approach provides marginal noise costs. From a theoretical point of view the bottom-up approach is superior, taking into account local factors which directly influence the size of marginal noise costs (e.g. traffic density, traffic mix, etc.). These factors cannot be taken into account by a top-down approach, as a consequence of which average costs instead of marginal costs can be estimated. However, it can be questioned whether pure marginal costs are useful for internalisation strategies. Due to the logarithmic nature of noise, adding an extra vehicle to traffic flows which are already dense will result in almost no increase in the existing noise levels. On the other hand, a vehicle on a quiet rural road will cause high marginal costs. Due to this complicated relationship between local factors (e.g. traffic density, time of the day) and the marginal noise costs using pure marginal costs in internalisation strategies is hardly possible. In addition, it will be hard to generalise the results of marginal costs studies for some case studies to all route segments throughout Europe. In comparison to a top-down method, this requires a lot more data and time.

Critical aspects and uncertainties

Both the top-down and bottom-up approach are characterized by certain critical aspects determining uncertainties in the valuation of transport noise.

The threshold chosen

The impact of the threshold above which noise is considered a nuisance on noise costs is substantial. ECMT, 1998 shows that changing the threshold from 50 dB(A) to 55 dB(A) reduces the average results for cars by almost 50%. In 1995 the WHO introduced a threshold of 55 dB(A) below which few people are seriously annoyed (WHO, 1999). This threshold is also recommended by the European Commission, 2002a. The thresholds for other health effects (such as cardiovascular diseases) are higher than 55 dB(A) (WHO, 1999). Some studies use the recommended thresholds of the WHO, while other studies use thresholds which differ from the recommended values. Finally, thresholds for rail noise are often set 5 dB(A) higher than those for road traffic, since noise generated by rail traffic causes less nuisance than road traffic noise as it is at lower frequencies and is less continuous.

The valuation method applied

Different methods can be applied to value the effects of transport noise. In some cases market prices can be used (cost of illness). However, for nuisance effects no market prices do exist, and WTP-values to avoid disturbances due to traffic noise should be used. In general, two relevant methods can be distinguished: hedonic pricing and contingent valuation. Both methods can be regarded as acceptable methods to be used for valuing traffic noise. However, the European Commission, 2002a emphasized that each methodology needs to be followed rigorously in order to attain meaningful and policy relevant results.

The hedonic pricing method examines variations in housing prices. These prices will vary with house size, amenities or proximity to the shops. In addition, environmental characteristics, such as noise, may influence the price. The association between traffic noise and housing prices can be expressed in the Noise Depreciation Sensitivity Index (NDSI), which gives the average percentage change in property prices per decibel. Based on the NDSI a monetary value for traffic noise can be estimated. The contingent valuation method, on the other hand, involves directly asking people, in a survey, how much they would be willing to pay to avoid some health effects of noise.

The main strength of the hedonic pricing method is that it is based on real market behaviour of people. General weaknesses are that the results of hedonic pricing methods, in terms of NDSI, are very sensitive for modelling decisions (e.g. the functional form used, estimation procedures, etc.) and conditions in the local housing market (e.g. competition in the housing market, transaction costs, etc.) (Navrud, 2002). Additionally, noise may be correlated with other environmental effects (e.g. air pollution) which may also affect the housing prices (Bjorner et al., 2003). The variations in housing prices may also include other negative impacts of traffic than just noise, and hence the hedonic pricing method overestimate the value of traffic noise. Finally, the hedonic pricing method assumes that both buyers and sellers have perfect information of the dwelling (including noise characteristics). However, this assumption will often be unrealistic and may result in biased estimates.

An advantage of using contingent valuation methods to estimate noise costs is that the value is measured directly, and is not subject to a number of modelling decisions (Bjorner et al., 2003). Among other things this means that SP values are more robust to benefit transfer (Navrud, 2002). If the survey is well specified, it will also be possible to isolate the effect of noise from other environmental effects. The main disadvantage of contingent valuation methods is its hypothetical nature, which may lead to biased results.

Finally, the costs of fatalities due to traffic noise can be valued in various ways. In general, two approaches are applied; in the first approach the increased mortality due to traffic noise is estimated and valued with the risk value, which is among other factors, based on the value of a statistical life. The latter is often gathered from literature for valuing victims of traffic accidents. This method is criticised, because victims of traffic accidents are much younger than victims of heart infarctions. In the second approach the 'years of life lost' (YOLL) are evaluated using a 'value of a life year lost' (VLYL). This method can be criticised due to ethical reasons, because it claims that the lives of elderly persons are 'less worth' than those of younger citizens.

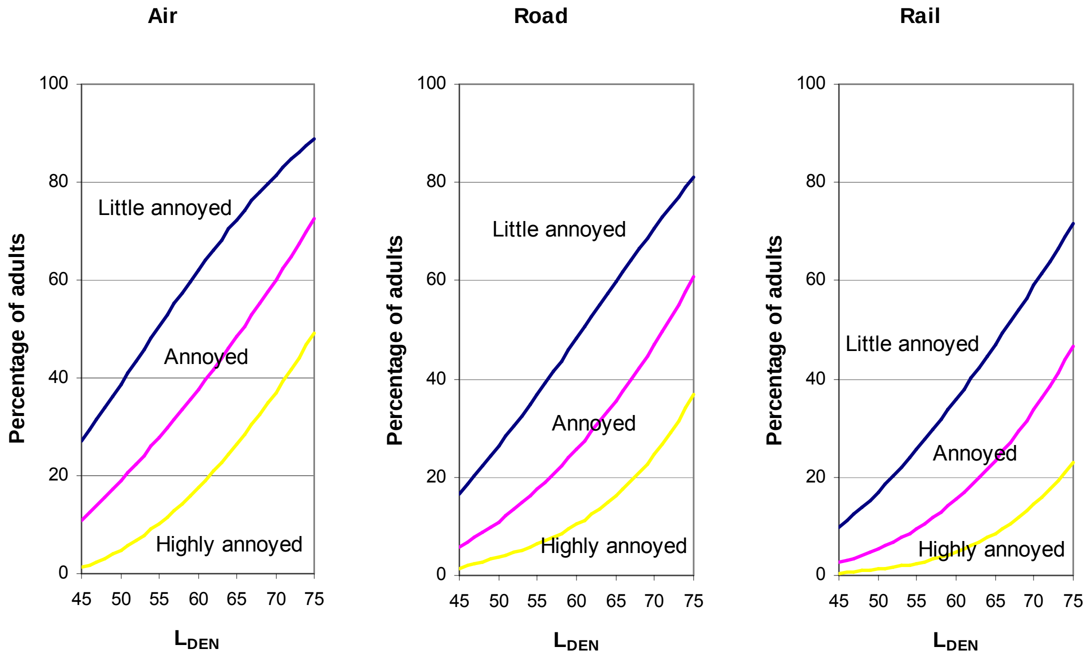
The effects included

Studies differ with respect to the effects of noise that are taken into account. Some studies only include the costs caused by annoyance, while other studies take also medical costs, costs of fatalities, and costs of production losses into account.

The transport mode assessed

The costs of transport noise depends on the source of the noise (European Commission, 2002b; Miedema and Oudshorn, 2001). As can be seen in Figure 25, the annoyance people report due to transport noise vary between different transport modes. Noise caused by an airplane is perceived as more annoying compared to the same noise level caused by road traffic. Transport modes also differ in the way their noise influence sleep disturbances (Miedama, 2002). These differences between transport modes are recommended to be taken into account (European Commission, 2002a; WG HSEA, 2003), e.g. by providing rail noise a 5 dB(A) bonus or by using mode-specific annoyance-exposure functions (ExternE, 2005).

Figure 25 Percentage of adult population feeling little annoyed, annoyed and highly annoyed as a function of noise levels



Source: European Commission, 2002b.

E.3 Input values

Disutility due to traffic noise

The disutility due to traffic noise can be estimated by measuring the WTP to avoid traffic noise. Most studies have done this by using a hedonic pricing method (see Table 102).

Table 102 Comparison of mean WTP-values per person per year, all estimated by the hedonic pricing method

Study	Mean WTP per person per year
UNITE, 2003	NSDI = 0,9 per dB
RECORDIT, 2001	NSDI = 0,9 per dB
TRL, 2005	NSDI = 0,61 per dB
INFRAS/IWW, 2004a	0.11% per capita income
OECD/INFRAS/Herry, 2003	0.11 % per capita income
ECMT, 1998	0.09% per capita income
CE Delft, 2004b	0.11% per capita income
ITS, 2001	NSDI = 0,2 - 0,67 per dB
Hvid, 2004	1.20% – 1.64% of real estate price per dB
Kristensen et al., 2004	1.20% – 1.64% of real estate price per dB
SAEFL, 2003	1% of real estate price per dB

Since some studies present the WTP-values as NSDI, and other studies as a percentage of per capita income, a comparison of all values is difficult. A first look, however, makes clear that most studies present WTP figures which are quite comparable. These values are both in line with the recommendations of

Navrud (2002) to use a range of 2–32 Euro per household per year and the findings of ExternE (2005). Based on the research of Navrud, the Working group on Health and Socio-economic Aspects recommends to use for road transport € 25 per dB(Lden) per household per year (WG HSEA, 2003). The validity range of this value is between 50/55 Lden and 70/75 Lden. Since the impact of air traffic noise is more severe at the same noise level, this value has to be adapted for air traffic noise. Therefore Öko Institut, 2004 use an adaptation factor of 1,55, which is based on the ratio between road noise and aircraft noise arising from the nuisance curves (see Miedema and Oudshorn, 2001). In this way a value of € 39 per dB per household per year is found.

HEATCO, 2006c use the contingent valuation method to estimate WTP values for five different annoyance levels. The results are presented in Table 103.

Table 103 Mean WTP per person per year to eliminate road/rail noise annoyance at 5 different noise annoyance levels

Annoyance level	**Mean WTP per person per year (€$_{2005}$)**	
	Road	**Rail**
Not annoyed	8.12	15.08
Slightly annoyed	37.08	38.20
Moderately annoyed	84.93	59.17
Very annoyed	84.30	49.58
Extremely annoyed	80.51	68.28
Urban – rural		
Urban – all annoyance levels	48.21	46.35
Rural – all annoyance levels	48.80	32.01

Note: For road the WTP values presented are mean values for 6 European countries (Germany, Hungary, Norway, Spain, Sweden and UK). For rail, the values are mean values for 5 European countries (Sweden was excluded).

The WTP increase with increased annoyance level when moving from ‘not annoyed’ to ‘moderately annoyed’. However, for the three highest annoyance levels no clear pattern for WTP exist. For road the WTP figures stay constant for these annoyance levels, while for rail the WTP first drop, but then increase again. This inconvenient pattern could be explained by the fact that people with lower income, and thus lower ability to pay, often live in areas with high traffic noise levels, since the houses in these areas are cheaper. The results in Table 103 also shows that rail noise annoyance is valued lower than road noise, supporting the 5 dB bonus for rail which is often used in valuation studies.

Navrud, 2002 states that economic values for noise are preferably based on WTP values derived for different annoyance levels based on SP methods. This eliminates the need for many strict and unrealistic assumptions needed to construct and transfer the costs per decibel from SP or RP data. However, there are currently few studies reporting economic values per annoyed person per year. HEATCO, 2006c compares their own results with two other studies presenting economic values for different annoyance levels, identifying large differences between the various studies. So, it is unclear how reliable the values presented by HEATCO are. For that reason, we recommend to use the economic values per decibel. More specific, a mean WTP per year of 0.09% – 0,11% of per capita income, which is in line with the range of WTP-values recommended by Navrud, 2002 and WG HSEA, 2003.

Health costs

The health costs due to traffic noise consist of two aspects: medical costs and costs of premature deaths. In most studies these two types of costs are distinguished, except for OECD/INFRAS/Herry, 2003 which estimate the total health costs by assuming that these costs are equal to 50% of the WTP to reduce noise annoyance.

To value the costs due to mortality some studies (e.g. INFRAS, 2004) estimate the increased mortality due to health risk and value each fatality with the Risk value, which is among other factors based on the value of a statistical life (VOSL). Other studies (e.g. UNITE, 2003) evaluates only the 'years of life lost' (YOLL) using a 'value of a life year lost' (VLYL). In Table 104 the VOSL, YOLL and VLYL values used in the various studies are presented.

Table 104 Overview of value of statistical life, Years of Life Lost, Value of a Life Year Lost used in various studies ($€_{2000}$)

	Value of a statistical life (€)	Years of life lost due to a heart attack caused by traffic noise	Value of a life year lost (€ per year)
UNITE, 2003		7	74,500
RECORDIT, 2001		7	74,500
HEATCO, 2005		7	40,300
TRL, 2001	1,500,000		
INFRAS/IWW, 2004a	1,500,000		
High Level Group, 1999a	3,100,000		84,000
UBA, 2006			50,000

Note: Corrected for GDP per capita development by CE Delft (GDP per capita in PPP consumer price index from http://epp.eurostat.ec.europa.eu).

Based on the values from the various studies we recommend to use a value of 50,000 - 75,000 Euro for a life of year lost, which corresponds to the most recent research by UBA, 2006 and NewExt (NewExt 2004 and ExternE, 2005). The values in UNITE and RECORDIT are based on the latter studies. These values correspond to a VSL of ca. 1 million €.

The way the medical costs are estimated differ widely between different studies. Some studies use rather rough estimation methods, like for example INFRAS/IWW, 2004a which estimate the medical cost due to traffic noise to be equal to 8% of total economic costs of heart illness. In other studies, like CE Delft, 2004b, only total medical costs due to traffic noise are presented. However, there are also some studies which provide a detailed overview of the monetary values for health impacts due to traffic noise. As can be seen in Table 105 the results presented by these studies are almost the same.

Table 105 Monetary values of impacts due to noise (€2000)

	UNITE, 2003	RECORDIT, 2001	UBA, 2006
Myocardial infarction (non-fatal, 8 days in hospital, 24 days at home)			
Medical costs	4,700	4,700	4,960
Absentee costs	2,800	2,800	2,816
WTP	15,000	15,000	-
Total per case	**22,500**	**22,500**	**7,780**
Angina Pectoris (severe, non-fatal, 5 days in hospital, 15 days at home)			
Medical costs	2,950	2,950	3,100
Absentee costs	1,750	1,750	1,760
WTP	9,400	9,400	-
Total per case	**14,100**	**14,100**	**4,860**
Hypertension (hospital treatment, 6 days in hospital, 12 days at home)			
Medical costs	1,800	1,800	1,920
Absentee costs	1,575	1,575	1,580
WTP	550	550	-
Total per case	**3,925**	**3,925**	**3,500**
Medical costs due to sleep disturbances (per year)	200	200	-

Note: Corrected for GDP per capita development by CE Delft (GDP per capita in PPP consumer price index from http://epp.eurostat.ec.europa.eu).

E.4 Output values

Average costs

In Table 106 ranges of the average road and rail noise costs resulting from all studies using a top-down approach are given.

Table 106 Ranges[a] of average costs from studies using a top-down approach for road and rail traffic (€2000)

Study	**Year**	**Road (pass car)[b]**	**Road (HGV)[c]**	**Rail (pass)[b]**	**Rail (freight)[c]**
ECMT (1998)	1991	2.21 – 14.02	3.04 – 32.63	0.92 – 19.26	1.12 – 63.99
UNITE (2003)[d]	1998	1 - 4	3- 21	0,2 - 14	0,2 – 7
INFRAS/IWW (2004a)	2000	5.2	4.9 – 32.4	3.9	3.2
OECD/INFRAS /Herry (2003)	1995	0.5 – 1.5	1.2– 3.1	0.7 – 6.3	0.3 – 1.44
CE Delft (2004b)[d]	2000	1 - 6	1 - 52	1 - 13	2 – 20

Note: Corrected for GDP per capita development by CE Delft (GDP per capita in PPP consumer price index from http://epp.eurostat.ec.europa.eu).

a The upper and lower bound of the ranges from ECMT, 1998, UNITE, 2003, and OECD/INFRAS/Herry, 2003 are based on the values for the countries with the highest and lowest average costs respectively. In CE Delft, 2004b the upper and lower bound are the costs for urban and rural areas.

b €/1,000 pkm.

c €/1,000 tkm.

d The average costs in CE Delft, 2004 and UNITE, 2003 are presented in € per 1,000 vehicle kilometres. However, this way of presentation prevents comparison of these results with the results of the other studies. For that reason, the results of CE Delft, 2004 and UNITE, 2003 are converted in € per 1,000 pkm or tkm. For this conversion the following assumptions were made: average seat occupancy of passenger cars is 1.8, the average load factor of trucks is 2,8 ton, the average occupancy of passenger trains is 126 passengers, and the average load factor of freight trains is equal to 323 ton (ECMT, 1998).

The average costs resulting from ECMT, 1998; UNITE, 2003; INFRAS/IWW, 2004a and CE Delft, 2004b are in the same range. Differences between these studies are caused by differences in input values (see section E.3), effects included, thresholds chosen and the way costs are allocated to different modes (a more elaborated discussion of the differences between studies will follow later on in this section). The average costs from OECD/INFRAS/Herry, 2003 are much lower, because this report studies noise costs in Eastern European countries. Since GDP in these countries are lower than in Western European countries, the WTP to reduce noise annoyance will also be lower and consequently the average noise costs estimated will be lower.

The results of the various studies with regard to average noise costs of air traffic are presented in Table 107.

Table 107 Ranges of average costs from studies using a top-down approach for air traffic (€$_{2000}$)

Study	Noise costs per LTO (€)
UNITE, 2003[a]	12 - 187
INFRAS/IWW, 2004a	383
OECD/INFRAS/Herry, 2003[a]	69 - 400
CE Delft, 2002[b]	300 - 600
Ly & Morrell, 2006[c]	16 - 774

Note: Corrected for GDP per capita development by CE Delft (GDP per capita in PPP consumer price index from http://epp.eurostat.ec.europa.eu).

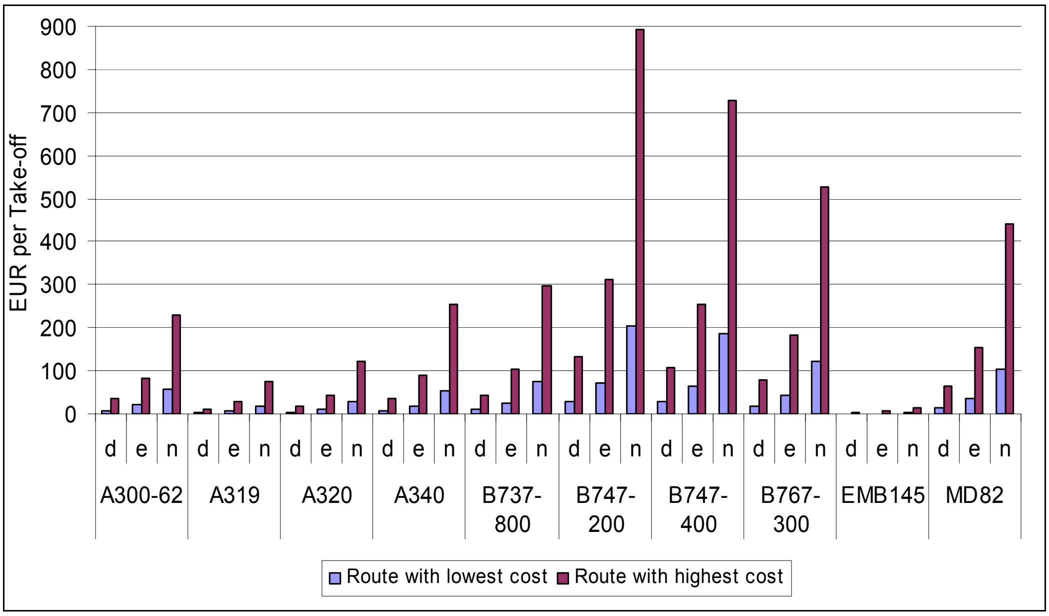
a The upper and lower bound of the ranges from UNITE, 2003 and OECD/INFRAS/Herry, 2003 are based on the values for the countries with the highest and lowest average costs respectively.

b The lower bound of the costs estimate in CE Delft, 2002 is based on a 100 seater with 1999 state-of-the-art technology, while the upper bound is based on a 200 seater also with 1999 state-of-the-art technology.

c Ly & Morrel, 2006 compare the noise costs per LTO for 5 airports in the UK and the Netherlands. They distinguish 7 different types of aircraft. The values presented here are the values for the airports with the highest and lowest weighted averages.

The average costs of air traffic noise vary widely between the various studies. First, this is caused by the different countries/airports that are included. The average costs are heavily dependent on the number of people affected by the noise of airplanes. Since there are large differences with regard to population densities around the various airport, location of noise emission is an important cost driver. Ly, 2006, for example, show that the average noise costs at the airport of Maastricht are significantly higher than at Gatwick (€ 111 per LTO against € 25 per LTO), which is mainly explained by differences in the number of people exposed to aircraft noise (Maastricht: ca. 13,000 people; Gatwick: ca. 2,000 people) Second, differences between studies can also be explained by differences in aircraft type and technology, which both heavily impacts the average costs of aviation noise. For example, Ly (2006) show that the average noise costs at London Heathrow vary between € 28 and € 2,194 depending on the aircraft type. The influence of aircraft type on the noise costs is also illustrated in Figure 26. Also the impact of time of the day on noise costs is shown in Figure 26.

Figure 26 Range of cost per take-off at Frankfurt airport for day (d), evening (e) and night (n) time



Source: GRACE (2006).

Marginal costs

The marginal costs resulting from studies applying a bottom-up approach are presented in Table 108.

Table 108 Marginal noise costs from studies using a bottom-up approach (€2000 per 1000 vkm)

Area	Time	Traffic / road type	Road (pass. Car)	Road (HGV)	Rail (pass.)	Rail (freight)
INFRAS/IWW (2004a)[a]						
Rural	Day	Thin	0.14	1.27	28.8	30.3
		Dense	0.06	0.58	17.4	18.4
	Night	Thin	0.25	2.31	52.4	55.2
		Dense	0.12	1.06	31.8	33.5
Suburban	Day	Thin	1.19	10.99	198.9	209.5
		Dense	0.43	3.94	121.2	127.7
	Night	Thin	2.18	20.01	362.2	381.5
		Dense	0.78	7.18	220.7	232.5
Urban	Day	Thin	18.49	170.11	0	424.8
		Dense	7.63	70.16	274.8	322.5
	Night	Thin	33.68	309.82	821.2	963.8
		Dense	13.89	127.79	500.4	587.4
INFRAS/IWW (2003)						
Rural	Day	Thin			25.7	50.0
		Dense			13.0	25.8
	Night	Thin			42.9	84.5
		Dense			42.9	84.5
Suburban	Day	Thin			206.1	400.6
		Dense			104.3	206.8
	Night	Thin			344.0	677.1
		Dense			344.0	677.1

Area	Time	Traffic / road type	Road (pass. Car)	Road (HGV)	Rail (pass.)	Rail (freight)
Hvid (2004)						
Urban					40,3 – 53,6	94,0
Rural						
Kristensen et al. (2004) / Hvid (2004)						
Central Copenhagen			103.4	665.8		
> 100,000 inhabitants			41.6	201.3		
20,000 – 100,000 inhabitants			26.9	110.1		
5,000 – 20,000 inhabitants			16.1	92.6		
1,000 – 5,000 inhabitants			17.5	95.3		
200 – 1,000 inhabitants			6.7	51.0		
Recordit (2001)						
Urban				159.9 – 545.4		
Non-urban				3.3 – 13.9		
	Night					55.9 – 312.5
ITS (2001)						
Central London		Motorway		0.88	1.82 – 6.06	
		Trunk & principal		0.66		
		Other		0.88		
Outer London		Motorway		0.43	1.31 – 4.34	
		Trunk & principal		0.43		
		Other		0.43		
Rural		Motorway		0.00	0.63 – 2.09	
		Trunk & principal		0.00		
		Other		0.22		
UNITE (2003)						
Helsinki urban			2.20 – 5.29	15.8 – 38.5		
Stuttgart urban[b]	Day		20	255		
	night		40	767		
Berlin urban[b]	Day		4	78		
			15	215		
Strasburg to Neubrandenburg [b]	Day		1	30		
	Night		2	50		
Basel – Karlsruhe[b]	Day				55	220
	Night				449	154
Strassburg - Neubrandenburg[b]	Day				20	40
Milano-Chiasso	Day		0.1	0.9	14.0	131.7
	Night		0.4	3.5	40.9	99.8
Bologna – Brennero	Day		0.01	0.06	0.4	3.0
	Night		0.02	0.21	0.3	5.9

Area	Time	Traffic / road type	Road (pass. Car)	Road (HGV)	Rail (pass.)	Rail (freight)
SAEFL (2003)						
Switzerland	Day		3.4 – 20.5	34.4 – 206.3		
Switzerland	Night		73.6 – 443.3	723.8 – 4,342.9		
Andersson & Ögren (2007)						
Lerum (Sweden)	Day				43	260
Lerum (Sweden)	Evening				140	810
Lerum (Sweden)	Night				430	2500

Note: Corrected for GDP per capita development by CE Delft (GDP per capita in PPP consumer price index from http://epp.eurostat.ec.europa.eu).
[a] The marginal noise costs for passenger trains are for inter-regional trains.
[b] Estimations based on UNITE, 2003.

The main conclusion of Table 108 is that marginal noise costs are highly dependent on local factors. INFRAS/IWW, 2004a shows that marginal noise costs can differ more than a factor 100 depending on the area where the noise is emitted. The impact of time of the day and the traffic situation on marginal noise costs are also proven by the result in Table 108 (see e.g. UNITE, 2003; INFRAS/IWW, 2003). Due to the dependence of marginal noise costs on local factors substantial ranges exist for the estimates of marginal noise costs. The impact of local factors on marginal noise costs explains also the main part of the differences in the results found by the various studies.

HEATCO, 2006a present noise costs per person per dB per year. In Table 109 we give an indication of the costs presented by HEATCO for Germany.

Table 109 Noise costs for Germany per person exposed per year (in $€_{2002}$)

Lden (dB(A))	Road	Rail	Aviation
≥ 51	9	0	14
≥ 52	18	0	27
≥ 53	26	0	41
≥ 54	35	0	54
≥ 55	44	0	68
≥ 56	53	9	82
≥ 57	61	18	95
≥ 58	70	26	109
≥ 59	79	35	122
≥ 60	88	44	136
≥ 61	96	53	149
≥ 62	105	61	163
≥ 63	114	70	177
≥ 64	123	79	190
≥ 65	132	88	204
≥ 66	140	96	217
≥ 67	149	105	231
≥ 68	158	114	245

Lden (dB(A))	Road	Rail	Aviation
≥ 69	167	123	258
≥ 70	175	132	272
≥ 71	233	189	334
≥ 72	247	204	354
≥ 73	262	218	373
≥ 74	277	233	393
≥ 75	291	248	412
≥ 76	306	262	432
≥ 77	321	277	451
≥ 78	335	292	471
≥ 79	350	306	490
≥ 80	365	321	509
≥ 81	379	336	529

The marginal noise costs of aviation estimated by the different studies are shown in Table 110. All these estimates are presented in € per LTO event.

Table 110 Marginal noise costs of aviation per LTO (€$_{2000}$)

		40 seater	100 seater	200 seater	400 seater
CE Delft, 2002	Fleet average technology	180	300	600	1,200
	State-of-the-art technology	90	150	300	600
UNITE, 2003		61			
TRL, 2001		0.17 – 12.1			
Öko-Institut/DIW, 2004[a]		0,2 – 934			

a The wide range in marginal costs presented by Öko-Institut/DIW, 2004 can be explained by differences in aircraft type and time of the day.

Note: Corrected for inflation by CE Delft.

Again, differences between aircraft type and technology (illustrated by the results of CE Delft, 2002) and population density around airports (in contrast to the airport analysed in CE Delft, 2002 the airports considered in TRL, 2001 are situated in sparsely populated areas) are main causes of the large differences between the results found by the various studies. Öko-Institut/DIW, 2004 show also the important impact time of day has on the marginal noise costs. The marginal noise costs at night can be a factor 8 higher than at day.

Differences between the results of the various studies

Next to the differences in input values (see section E.3), the following general differences between the various studies can be distinguished.

Effects included

Table 101 shows that not all studies include the same effects. In all studies the impact of noise on annoyance is taken into account, but not all studies include health costs (e.g. ECMT, 1998; ITS, 2001).

Thresholds

As was mentioned, the threshold above which noise is considered a nuisance has a substantial impact on the level of marginal noise costs. Most studies use a threshold of 55 dB(A) for road traffic and 50 dB(A) for rail. Exceptions are ECMT, 1998 and Andersson & Ögren, 2007 which both use a threshold of 50 dB(A) for both road and rail traffic. Also TRL, 2001 and INFRAS (marginal costs) choose other thresholds.

Some studies use different thresholds than those for noise annoyance for health effects of transport noise. For example, in UNITE, 2003 the threshold for health effects other than sleep disturbance are set on 70 dB. The thresholds for sleep disturbance on the other hand are set on 43,2 and 40 dB for road and rail traffic respectively. Also INFRAS/IWW, 2004a and CE Delft, 2004b are using other (higher) thresholds for health effects than for annoyance.

Allocation of noise costs to different modes

Studies using a top-down approach first estimate total noise costs and subsequently allocate these costs to different modes. This allocation should be based on some characteristic of the modes that is the main cost driver. All studies choose total vehicle kilometres by a mode as an allocation factor. However, a truck emitted more noise in one kilometre than a passenger car. For that reason, most studies use a weighting factor to compensate for the differences in noise emissions of the modes. Unfortunately, an internationally agreed set of weights is lacking. Therefore, INFRAS/IWW, 2004a decided not to use weights at all. Other studies do use weights, but there are large differences between them. For example, ECMT, 1998 use a weighting of 10:10:1 for the relative noise nuisance from HGV's, buses and cars, while OECD/INFRAS/Herry, 2003 uses a weighting of respectively 2,5:3:1.

Most studies do also use weighting factors to allocate rail noise costs to freight and passenger trains. It is assumed that freight trains create four times more noise than passenger trains.

Base year

The year for which the calculations of noise costs are done differ between studies. The base year influences some cost drivers, like the existing traffic flows, the vehicle technology, etc.

Models

Both top-down and bottom-up approaches make use of models to estimate noise costs of traffic. In top-down approaches models are used to estimate the number of people affected by traffic noise. Bottom-up approaches also use models to estimate the noise emissions of vehicles and the propagation of noise. Due to differences in the models used by the various studies, differences in the estimates of noise costs will arise.

Recommended values

As was mentioned before, noise costs are highly dependent on local factors (population density, traffic flow) and timing (day, evening, night). In contrast to average costs, these factors are taken into account if marginal costs are estimated. For this reason, marginal noise costs are from a theoretical point of view preferred above average costs. However, the dependence of marginal noise costs on local factors makes it hard to generalise the results of marginal costs studies for some case studies to all route segments throughout Europe. For the same reason, using marginal costs in internalisation strategies is very complicated.

INFRAS/IWW, 2004a and INFRAS/IWW, 2003 estimate marginal noise costs for particular scenarios of traffic situations and settlement structures. These scenarios take different levels for decisive characteristics into account:

- Two - three types of land use: rural, suburban, urban (only INFRAS/IWW, 2004a).
- Two time periods: day, night.
- Two traffic conditions: relaxed, dense.

The costs estimates resulting from this estimation method can be regarded as averaged costs for some specific situations, instead of pure marginal costs. The scenarios were developed in such a way that the results could be regarded as EU average values, as a consequence of which these results could be generalized to all route segments in Europe. In addition, contrary to the average cost estimates presented in Table 106 the results from these studies could be differentiated to types of settlement structures. Finally, the results from INFRAS/IWW, 2004a and INFRAS/IWW, 2003a are in general in line with the cost estimates of most other studies. For example, the values provided by UNITE, 2003 and RECORDIT, 2001 are almost all in the same range. Also Kristensen et al., 2004 present comparable figures for Copenhagen, with the exception of the estimates for central Copenhagen. The night-time values found by SAEFL, 2003 for road traffic in Switzerland do not fall in the range of INFRAS/IWW, 2004a, but we can consider these values as outliers. The relatively high night-time values found by Andersson & Ögren, 2007 for rail are probably the consequence of the distinction the authors made between evening and night-time values; this distinction is not made by other studies.

Based on the reasons above we recommend for road traffic to use the noise costs estimates from INFRAS/IWW, 2004a. For rail, we recommend to use the values presented by INFRAS/IWW, 2003. The approach to estimate marginal noise costs of rail traffic used in this study is more sophisticated than the approach applied in INFRAS/IWW, 2004a. First, in INFRAS/IWW, 2003 the STAIRRS[34] noise model is used, which is constructed on the basis of several national noise models of the Netherlands, Germany, Switzerland and France. The parameters of this model are estimated for all different characteristics (e.g.

[34] Strategies and Tools to Assess and Implement Noise Reducing Measures for Railway Systems. The aim of this EU research program was to estimate noise impacts for different noise scenarios (esp. considering different rolling stock specifications, wagon brake specifications, track side measures and different traffic situations).

train classes) which are included in the national models. In contrast, INFRAS/IWW, 2004a makes use of the German noise model. Further, the determination of marginal costs in INFRAS/IWW, 2003 is more realistic than in INFRAS/IWW, 2004a. In INFRAS/IWW, 2004a marginal costs were defined as the additional effect caused within a single class of trains. All other trains passing the same track are regarded as background noise generators only. In contrast, INFRAS/IWW, 2003 calculates the effect on the total noise emission coming from the railway line. This approach is closer to reality. Finally, there is large consensus in the studies reviewed that noise costs of freight trains exceed those of passenger trains. This pattern can be found in the results from INFRAS/IWW, 2003, but not in those from INFRAS/IWW, 2004a.

There is one problem with the results from INFRAS/IWW, 2003; they do not include values for urban areas. To estimate these values we use the ratio between the marginal rail noise costs in interurban and urban areas from INFRAS/IWW, 2004a and apply this ratio on the interurban values from INFRAS/IWW, 2003.

In Table 111 the recommended values for road and rail traffic are presented. The values are differentiated into three types of settlement structure - urban, suburban and rural – and two time periods: day and night.

Table 111 Unit values for marginal noise costs for different network types in (€ct/vkm) for road and rail traffic, Central values in bold, ranges in brackets

	Time of day	Urban	Suburban	Rural
Car	Day	**0.76** (0.76 – 1.85)	**0.12** (0.04 – 0.12)	**0.01** (0.01 – 0.014)
	Night	**1.39** (1.39 – 3.37)	**0.22** (0.08 – 0.22)	**0.03** 0.01 – 0.03
MC	Day	**1.53** (1.53 – 3.70)	**0.24** (0.09 – 0.24)	**0.03** (0.01 – 0.03)
	Night	**2.78** (2.78 – 6.74)	**0.44** (0.16 – 0.44)	**0.05** (0.02 – 0.05)
Bus	Day	**3.81** (3.81 – 9.25)	**0.59** (0.21 – 0.59)	**0.07** (0.03 – 0.07)
	Night	**6.95** (6.95 – 16.84)	**1.10** (0.39 – 1.10)	**0.13** (0.06 – 0.13)
LGV	Day	**3.81** (3.81 – 9.25)	**0.59** (0.21 – 0.59)	**0.07** (0.03 – 0.07)
	Night	**6.95** (6.95 – 16.84)	**1.10** (0.39 – 1.10)	**0.13** (0.06 - 0.13)
HGV	Day	**7.01** (7.01 – 17.00)	**1.10** 0.39 – 1.10	**0.13** (0.06 – 0.13)
	Night	**12.78** (12.78-30.98)	**2.00** 0.72 – 2.00	**0.23** (0.11 – 0.23)
Passenger train	Day	**23.65** (23.65 – 46.73)	**20.61** 10.43 – 20.61	**2.57** (1.30 – 2.57)
	Night	**77.99**	**34.40**	**4.29**
Freight train	Day	**41.93** (41.93 – 101.17)	**40.06** 20.68 – 40.06	**5.00** (2.58 – 5.00)
	Night	**171.06**	**67.71**	**8.45**

Note: The lower limit of the bandwidth is based on dense traffic situations, while the upper limit is based on thin traffic situations. Central values (in bold) chosen based on the predominant traffic situation.

The noise costs of air traffic depend heavily on local factors (e.g. population density around airports), aircraft type and technology, and time of the day. Currently no study presents an overview of marginal noise costs from aviation taking all these factors into account. For that reason we only differentiate to time of the day, based on the results from Öko-institut, 2004. The range found in this study includes most of the values found in other studies. In Table 112 we distinguish noise costs at day, in the evening and at night. The wide ranges especially indicate the big impact technology has on marginal noise costs.

Table 112 Recommended values for marginal aviation noise costs ($€_{2000}$ per LTO)

Day	Evening	Night
0.2 – 113.6	0.4 – 304.0	1.4 – 934.0

The most important explanation for the wide ranges in the table is aircraft type. For example, the night-time noise costs differ a factor 700 between the most and less quiet aircraft type.

F Climate change costs

F.1 Introduction

Climate change or global warming impacts of transport are mainly caused by emissions of the greenhouse gases carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). To a smaller extent emission of refrigerants (hydrofluorocarbons) from Mobile Air Conditioners (MAC) also contribute to global warming. In the case of aviation also other aircraft emissions (water vapour, sulphate, soot aerosols and nitrous oxides) at high altitude have an impact on global warming.

F.2 Climate change impacts

Climate change impacts have a special position in external cost assessment as:

- Climate change is a global issue so that the impact of emissions is not dependent on the location of emissions.
- Greenhouse gases, especially CO_2, have a long lifetime in the atmosphere so that present emissions contribute to impacts in the distant future.
- Especially the long-term impacts of continued emissions of greenhouse gases are difficult to predict but potentially catastrophic.

The general approach for quantifying total external costs due to climate change impacts for the transport sector is to:

1 Assess total vehicle kilometres by vehicles of different categories for an area, region or country.
2 Multiplication of vehicle kilometres by emission factors (in g/km) for the various greenhouse gases.
3 Adding various greenhouse gas emissions to a total CO_2 equivalent greenhouse gas emission using Global Warming Potentials[35] [36].
4 Multiplication of the total tonnes of CO_2 equivalent greenhouse gas emission by an external cost factor expressed in €/tonne CO_2 equivalent to estimate total external costs related to global warming.

For aviation a slightly different approach is required to add the global warming impacts of other emissions at high altitudes.

In some studies the external cost factor is time-dependent so that impacts of emission in different years have to be calculated separately.

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[35] For CH_4 the GWP = 23, for N_2O GWP = 296. For refrigerants GWP-values are much higher, e.g. GWP = 120 for HFC-134a and GWP = 8'500 for CFC-12 (now banned but used in older MAC systems).

[36] This step is formally not correct. (Watkiss, 2005b) calculates separate costs for CO_2 and CH_4, and the ratio between these two is not the GWP and is not constant over time (see section 2.3.1).

F.3 Main research question

In the above sketched general approach the steps 1 to 3 are trivial for all modes except aviation. Vehicle kilometres can be derived from transport statistics (in case of historic data) or from modelling exercises (in case of future projections or evaluation of policy measures or new projects) transport. CO_2 emission factors are available from models such as COPERT[37] or the German Handbuch Emissionsfaktoren (HBEFA)[38].

The main research question for internalising external costs of global warming therefore concerns the determination of the external cost factor(s) for CO_2 (and other greenhouse gases).

Besides that, it may be useful to take a closer look at the methodology to be used for valuation of the climate impacts of emissions from aircraft at high altitudes.

After that, determination of external costs per vehicle kilometre or total external costs per country becomes a straightforward calculation exercise in the case of climate change impacts, provided that the necessary transport data and emission factors are available.

F.4 Note on units

In literature the (damage or avoidance) costs of carbon dioxide are expressed in $, £ or € per tonne of carbon (C) or per tonne of carbon dioxide (CO_2). Costs per tonne C translate into costs per tonne CO_2 by dividing by a factor 44/12 = 3.667. If not specified otherwise the costs per tonne values cited in this report are always per tonne of CO_2.

For translations between currency units it has to be known for which year costs are calculated. For the 2005 situation the translation factors are 1.45 €/£ and 0.81 €/$. In 2000 these factors were 1.64 €/£ and 1.09 €/$. When comparing results from different studies at a glance care should be taken of these different units.

F.5 Overview of studies available

A large amount of literature is available on the issue of external costs of greenhouse gas emissions. For this report the following studies have been reviewed:

- *Environmental External Costs of Transport*, (Friedrich and Bickel, 2001).
- *Surface Transport Cost and Charges, Great Britain 1998*, (ITS, 2001).
- *External costs of transport: Accident, environmental and congestion costs in Western Europe*, (INFRAS/IWW, 2000).
- *Real Cost Reduction of Door-to-Door Intermodal Transport (RECORDIT),* (RECORDIT, 2000), (RECORDIT, 2001).

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37 http://lat.eng.auth.gr/copert/.

38 http://www.hbefa.net/.

- *A study on the costs of transport in the European Union in order to estimate and assess the marginal costs of the use of transport*, (TRL, 2001a), (TRL, 2001b), (TRL, 2001c).
- *External Costs of Aviation*, (CE Delft, 2002).
- *UNIfication of accounts and marginal costs for Transport Efficiency (UNITE)*, (UNITE, 2003a), (UNITE, 2003b).
- *External Costs of Transport, Update Study*, (INFRAS, 2004).
- *ExternE,* (ExternE, 1997), (ExternE, 1998), (ExternE, 1999a), (ExternE, 1999b), (ExternE, 2005).
- *Developing Harmonised European Approaches for Transport Costing and Project Assessment, Deliverable 2: State-of-the-art in project assessment*, (HEATCO, 2005) and (HEATCO, 2006).
- *The Social Cost of Carbon (SCC) Review*, (Watkiss, 2005a), (Watkiss, 2005b).
- *The Social Cost of Carbon: A Closer Look at Uncertainty*, (SEI (Downing, 2005)).
- *The marginal damage costs of carbon dioxide emissions: an assessment of the uncertainties*, (Tol, 2005).
- *Externe Kosten de Stromerzeugung aus erneuerbaren Energien im Vergleich zur Stromerzeugung aus fossilen Energieträgern*, (DLR, 2006).
- *The Economics of Climate Change, The Stern Review*, (Stern, 2006).
- *Limiting Global Climate Change to 2 degrees Celsius, The way ahead for 2020 and beyond*, Impact Assessment, SEC (2007) 8.

The most relevant and recent studies from the list above are summarized and discussed in section F.7.

F.6 Main methodological approaches for valuation of climate change impacts

To be consistent with the valuation of other external costs of transport the climate impacts should be monetised on the basis of an assessment of damage costs. Due to the inherent uncertainties in the assessment of damage related to global warming, many studies however have adopted an alternative approach using external costs based on the marginal avoidance costs for reaching a given reduction target. Both approaches are discussed below.

Damage costs

The damage cost approach uses detailed modelling to assess the physical impacts of climate change and combines these with estimations of the economic impacts resulting from these physical impacts (see e.g. Watkiss, 2005b). The costs of sea level rise could e.g. be expressed as the capital cost of protection and the economic value of land and structures lost in the absence of protection. Agricultural impact can be expressed as costs or benefits to producers and consumers, and changes in water runoff might be expressed in new flood damage estimates.

Using a monetary metric to express non-market impacts, such as effects on ecosystems or human health, is more difficult and requires dedicated methodologies. There is a broad and established literature on valuation theory and its application, including studies on the monetary value of increased mortality risk, ecosystems, quality of life, etc. However, economic valuation, especially in the area of climate change, is often controversial. First of all there is a general lack of knowledge about the physical impacts caused by global warming. Some impacts are rather certain and proven by detailed modelling, while other possible impacts, such as extended flooding, hurricanes with higher energy density or more dramatic non-linear effects such as a slowing down or even stop of the gulf stream, are often not taken into account due to lack of information on the relationship between global warming and these effects. Secondary impacts such as socially contingent damages (e.g. regional conflicts) are even more difficult to assess.

Available damage cost estimations of greenhouse gas emissions vary by orders of magnitude due to special theoretical valuation problems related to equity, irreversibility and uncertainty. Concerning equity both intergenerational and intra-generational equity must be considered. Besides the assessment of physical impacts and the question of which impacts are included in the assessment, key issues determining differences between studies are:

- Discount rate used.
- Approach to weighting impacts in different regions (called equity weighting).
- Time horizon.

An advantage of using the damage costs approach is that no sustainability criteria are necessary (see section 6.5.7 on avoidance costs).

A recent detailed assessment of damage costs is carried out by the Social Cost of Carbon project[39] carried out by AEA Technology and the Stockholm Environment Institute on behalf of Defra, UK. The term Social Cost of Carbon (SCC) is used to denote damage cost as opposed to Marginal Avoidance Costs (MAC). The study reviews a large number of existing studies on damage cost estimates and compares these to own modelling results[40]. Some interesting results are presented below (Table 113 and Table 114).

According to (Watkiss, 2005b) the Social Cost of Carbon increase over time. This is caused by:

- The long but finite lifetime of carbon in the atmosphere.
- Decreasing discount rates (STPR[41]) for future emissions due to uncertainties about the future economic development.
- Non-linearity in the impacts of CO_2 emissions.

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39 http://socialcostofcarbon.aeat.com/index.htm.

40 Using the PAGE and FUND models for damage costs and the MARKAL model for estimating avoidance costs.

41 STPR or Social Rate of Time Preference = PRTP + μ * g, with PRTP the Pure Rate of Time Preference, g the annual growth in per capita consumption and μ the elasticity of the marginal utility of consumption.

Table 113 Example of the evolution of damage costs of CO_2 over time (PAGE results for SCC value over time (in £). Values presented for year of emission

	SCC in year of emission (£/tC)		
	5%	**Mean**	95%
2001	9	**46**	130
2010	12	**61**	159
2020	14	**77**	215
2040	27	**127**	324
2060	34	**187**	513

Based on the A2 scenarios, with PPP exchange rates, Green book SRTP, an equity weight parameter of 1. The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effect.

Source: Watkiss, 2005b.

Note: With a conversion factor of 1.45 €/£ damage costs of 1 £ per tonne carbon (£/tonneC) are equivalent to 0.4 € per tonne CO_2 (€/tonneCO_2).

Interestingly the Social Costs of methane emissions do not scale with GWP (23 for CH_4). The initial costs per tonne CH_4, when expressed per ton of CO_2 equivalents[42], are lower than the value of a ton of CO_2, but the costs of CH_4 grow faster with time than the SCC values for CO_2 as stated above. The latter is caused by the shorter lifetime of methane in the atmosphere.

The above presented serve as illustration of methodological aspects. A more detailed summary and discussion of results from various studies is presented in section F.7.

Table 114 Example of the evolution of damage costs of CH_4 over time

	SC in year of emission (£/tC)		
	5%	mean	95%
2001	41	194	530
2010	75	317	842
2020	102	458	1,220
2040	196	920	2,487
2060	302	1,744	5,059

Based on the A2 scenarios, with PPP exchange rates, Green book SRTP, an equity weight parameter of 1. The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects.

Source: Watkiss, 2005b.

Avoidance costs/mitigation costs

An alternative approach which avoids the uncertainties associated with assessing damage costs of climate control is to assess the costs of avoiding CO_2 emissions. These are often referred to as avoidance costs, abatement costs or mitigation costs.

[42] If the costs of CH_4 and CO_2 would scale with GWP the following equation would be valid: 194 £/tonneCH_4 = 194/32 £/tonneCO_2 = 8.4/(12/44) £/tonneC = 31 £/tonneC.

The method is based on a cost-effectiveness analysis that determines the least-cost option to achieve a required level of greenhouse gas emission reduction, e.g. related to a policy target. Using a cost curve approach or other modelling methodologies the costs of reaching the specified target are calculated. The target can be specified at different system levels, e.g. at a national, EU or worldwide level and may be defined for the transport sector only or for all sectors together.

According to (Watkiss, 2005b), (RECORDIT, 2000) and other studies the avoidance costs approach is not a first-best-solution from the perspective of welfare economics, but can be considered theoretically correct under the assumption that the selected reduction target represents people's preferences appropriately. Under that assumption the marginal avoidance costs associated with the reduction target can be interpreted as a 'willingness-to-pay' value. For this reason the avoidance cost approach should only be used in combination with reduction targets that are laid down in existing and binding policies or legislation. For CO_2 emissions this generally comes down to targets fixed in the context of the Kyoto-protocol. Long term goals such as the 50% target expressed by IPCC, or ambitions expressed in national or EU policy documents do not qualify as socially desired. The recent European proposal for a strategy to reduce CO_2 emissions to 20 or 30% below the 1990 level obviously does provide a new frame of reference for assessing avoidance costs (see SEC (2007) 8).

If in the course of time reduction targets for CO_2 are tightened in one or more steps the valuation of the costs of CO_2 in €/tonne will increase in accordance with the (generally supra-linear) increase in marginal avoidance costs for reaching future targets. Internalisation of these higher external cost in the costs of transport will thus stimulate the implementation of CO_2 reduction measures with increasingly higher avoidance costs. In that sense the use of the avoidance cost approach fits the dynamics of the transition towards a more sustainable transport system that is intended to be stimulated by the internalization of external costs. In the first stages it suffices to promote the implementation of relatively inexpensive measures, while in later stages stronger price incentives are necessary to foster the application of more expensive measures.

A more detailed summary and discussion of results from various studies is presented in section F.7.

Valuation of the climate change impacts of aircraft emissions

Besides the emissions of CO_2 also other substances emitted by aircraft at high altitudes have an impact on global warming through radiative forcing. The main emission components are water vapour (e.g. contrail formation), sulphate, soot aerosols and nitrous oxides. The non CO_2 related impacts on climate change are partly heating effects, partly cooling effects, such as atmospheric chemical reactions on the basis of NO_x which increase ozone concentrations in the atmosphere (heating) and which convert methane (cooling), soot emissions from aircraft engines (heating), sulphur aerosols (cooling), and formation of condensation trails (cooling in daytime and heating at night) and possibly cirrus clouds. IPCC estimates the total climate change impact of aviation (excluding the effect through formation of cirrus clouds) to be 2 to 4 times higher than the impact of CO_2 emissions alone. More recent studies indicate in the direction of a factor of 2.

Critical aspects and uncertainties

Critical aspects determining uncertainties in valuation studies based on damage costs are:

- Assessment of the physical impacts of climate change and selection of the impacts included in the analysis.
- Assessment of the economic impacts resulting from the estimated physical impacts and selection of the impacts valued in the analysis.
- The discount rate used.
- The approach to weighting impacts in different regions (called equity weighting).
- The time horizon used.

Critical aspects determining the accuracy of avoidance cost estimates are:

- Assessment of the future costs of technical and non-technical options is various sectors to reduce greenhouse gas emissions.
- Assumptions on the energy costs used in the assessment of avoidance costs for the technical and non-technical options.
- Estimation of the greenhouse gas reduction potential of technical and non-technical options.

Concerning assessment of future costs it is known that ex-ante assessments generally tend to overestimate costs. A recent comparison between ex-ante and ex-post assessments of environmental technologies and policies (IVM, 2006) has shown that the difference between estimated costs and the real costs for application of environmental measures may be as high as a factor of 2 to 6. Unfortunately the reasons for this overestimation seem to differ from case to case. In all cases, however, it seems clear that in general not sufficient information is available to adequately assess the possible impacts of innovation, learning effects and economies of scale on the development over time of costs and performance of new technologies.

Valuation of existing knowledge

In the area of damage cost assessment the Social Cost of Carbon project (Watkiss, 2005a and 2005b), (Tol, 2005), and (SEI (Downing, 2005)) appear to be the most up-to-date and comprehensive studies. Other important recent sources are (ExterneE, 2005), (DLR, 2006) and (Stern, 2006). From a historic point of view earlier ExternE reports are also important and will be briefly reviewed.

Stern (2006) has recently assessed that the costs of avoiding CO_2 emissions are lower than the long-term costs resulting from global warming impacts. Due its high public and political impact this report also deserves reviewing. Another important recent study is the European Commission's Impact Assessment reported in SEC (2007) 8.

F.7 Assessment of existing studies

In the sections below the main results and underlying methodologies of a number of studies are summarized. Studies are grouped according to the approach being based on assessment of damage costs or assessment of avoidance costs.

Studies assessing external costs based on damage costs

ExternE

Reports: (ExternE, 1997), (ExternE, 1998), (ExternE, 1999a), (ExternE, 1999b), (ExternE, 2005)

Various reports from the ExternE project describe methodological aspects and results of damage cost assessments for climate change. Below some of these reports are cited. Results in ExternE are largely based on calculations with the FUND model. Results appear to change over time in function of changing insights and differences regarding the climate change impacts and associated damage costs taken into account.

(ExternE, 1997) presents the following 'preliminary' results (Table 115) on damage costs of CO_2. The 170 \$/tonne C value corresponds to around 50 €/tonneCO_2.

Table 115 Results taken from ExternE, 1997 (Global warming damages due to CO_2 based on different damage factors)

Vehicle[3]	IPCC range (5 – 125 \$/t C) (0 – 30 ECU/t CO_2)	ExternE preliminary[2] (170 \$/t C) (41 ECU/t CO_2)
mECU/pkm		
Petrol car	0.1 – 3.7	5.1
Diesel car	0.1 – 2.9	3.9
Bus	0.06 – 1.9	2.6
Intercity train	0.1 – 2.9	4.0
mECU/tkm		
Heavy goods vehicle	0.1 – 4.3	5.9
Goods train (electric)	0.1 – 4.0	5.5

1 Estimates based on emission factors of German case studies.
2 Preliminary results from the FUND Model, 'base case' assumptions, discount rate of 1%.
Source: ExternE, 1997.

Similar results are found in (ExternE, 1998) based on the use of two different models (FUND and Open Framework) and two different discount rates (1 and 3%):

Table 116 Results taken from ExternE, 1998

Greenhouse Gas	Damage Unit	Marginal Damage from Model			
		FUND		Open Framework	
		1%	3%	1%	3%
Carbon Dioxide, CO_2	ECU/tC	170	70	160	74
	ECU/tCO_2	46	19	44	20
Methane, CH_4	ECU/tCH_4	530	350	400	380
Nitrous Oxide, N_2O	ECU/tN_2O	17,000	6,400	26,000	11,000

Source: FUND v1.6 and Open Framework v2.2.
Basis: IPCC IS92a scenario.
Equily weighted.
No socially contingent effects.
Emissions in 1995-2005.
Time horizon of damages 2100.
Source: ExternE, 1998.

(TRL, 2001a) quotes the following results from (ExternE, 1999b) as presented in Table 117. The central estimate of 2.4 €/tonne is much lower than the values from previous reports as quoted above.

Table 117 Results taken from TRL, 2001a quoting, ExternE, 1999b

	Minimum b	Low c	Central estimate	High	Maximum
CO_2 (EURO/t)	0.1	1.4	2.4	4.1	16.4
N_2O (EURO/t)	24.3	440.2	748.3	1,272.1	5,242.1
CH_4 (EURO/t)	1.9	28.2	44.9	71.5	257.0
N (EURO/kg)	-5.5	198.2	337.0	527.9	1,270.2
S (EURO/kg)	-35.8	-16.6	-9.8	-5.8	0.0

Source: ExternE, Joule III, 1998-1999, p. 150.

The DG-Research website[43] contains the following quote of recent ExternE-results: 'For instance, based on the Kyoto Protocol targets, costs of between €5-22 per tonne of emitted CO_2 - with a central value of €19 per tonne of CO_2 - have been determined for the period 2008-2012.

Table 118 and Table 119 are taken from (ExternE, 2005). The first one shows results of calculations with the FUND model, which are stated to be in line with (Tol, 2005). The 'simple summation' value at 1% discount rate of 25 $/tonneC corresponds to some 5.5 €/tonne CO_2, while the 'equity weighting' value of 94 $/tonneC translates into 21 €/tonne CO_2.

[43] http://ec.europa.eu/research/headlines/news/article_05_10_21_en.html.

Table 118 Results taken from Externe, 2005 (Marginal damage costs of climate change ($/t C) with and without a thermohaline circulation collapse (THC), for three alternative discount rates (o,1 and 3 per cent pure rate of time preference), for simple summation (SS) and equity weighing (EW)

Discount rate	0% SS	EW	1% SS	EW	3% SS	EW
No THC	79.0	170.0	25.2	94.1	5.1	45.1
THC	75.6	167.8	24.4	93.6	5.0	45.0

Source: ExternE, 2005.

According to (ExternE, 2005) the most comprehensive review of marginal damage costs of carbon dioxide to date is given in (Tol, 2005)[44]. Key findings are given in Table 119. The median is considered the best measure of central tendency. Depending on the pure rate of time preference (PRTP) used, the marginal damage costs are either 7 $/tonneC (= 2 €$_{2000}$/tonne CO_2) or 33 $/tonne (9 €$_{2000}$/tonne CO_2).

Table 119 Results taken from ExterneE, 2005 (The marginal costs of carbon dioxide emissions ($/tC)

	Mode	Mean	5%	10%	Median	90%	95%
All	1.5	93	-10	-2	14	165	350
PRTP=3% only	1.5	16	-6	-2	7	35	62
PRTP=1% only	4.7	51	-14	-2	33	125	165
PRTP≤ 0% only	6.9	261	-24	-2	39	755	1,610

Source: ExternE, 2005.

The 9 €/tonne value, based on a discount range of 1%, is stated as the final result of (ExternE, 2005) on the issue of climate change costs. The report also states that this is a conservative estimate in the sense that only damage is included that can be estimated with a reasonable certainty. Impacts such as extended floods and more frequent hurricanes with higher energy density are not taken into account as there is not enough information about the possible relationship between global warming and these impacts.

To account for the precautionary principle (ExternE, 2005) proposes to use an **avoidance cost approach** for the central value. For reaching the Kyoto targets these are estimated between 5 and 20 €/tonne. A central value of 19 €/tonne is proposed. For reaching the EU indicative target of limiting global warming to 2ºC above pre-industrial temperatures marginal abatement costs are estimated to be as high as 95 €/tonne.

The Social Cost of Carbon
Reports: (Watkiss, 2005a), (Watkiss, 2005b).

(Watkiss, 2005b) presents a comprehensive review of existing estimates of damage costs related to global warming. The study focuses on the economic costs to society from climate change actually occurring, known as the Social Cost of Carbon (SCC). According to (Watkiss, 2005b) the SCC is usually estimated as

[44] Summarised in more detail further on in this section.

the net present value of climate change impacts over the next 100 years (or longer) of one additional tonne of carbon emitted to the atmosphere today. It is the marginal global damage costs of carbon emissions.

(Watkiss, 2005b) recognises a general trend towards the use of marginal abatement cost estimates as external costs of carbon emissions in project and policy appraisal, rather than a marginal damage cost estimate represented by the SCC. The UK government appears unique in its widespread adoption and implementation of a SCC estimate in policy assessment.

From the literature study survey (Watkiss, 2005b) concludes that very few studies cover any non-market damages, or the risk of potential extreme weather (floods, storms, etc.). None cover socially contingent effects, or the potential for longer-term effects and catastrophic events. Therefore the uncertainty in the SCC value concerns not only the 'true' value of impacts that are covered by the models, but also uncertainty about impacts that have not yet been quantified and valued. It indicates that values in the literature are a sub-total of the full SCC, although it is difficult to know by how much.

The SCC project concludes that estimates of the social cost of carbon span at least three orders of magnitude, from about zero to more than 1,000 £/tC, reflecting uncertainties in climate change and its impacts, coverage of sectors and extremes, and choices of decision variables. Moreover, the models do not fully capture the full risk matrix (and the full SCC). It is concluded that it is not possible to provide an illustrative central, or an upper benchmark of the SCC for global policy contexts, though the risk of higher values for the social cost of carbon is significant. The modelling study did, however, provide a lower benchmark of 35 £/tC (≈ 14 €/tonne CO_2) as reasonable figure for a global decision context committed to reducing the threat of dangerous climate change and includes a modest level of aversion to extreme risks, relatively low discount rates and equity weighting.

(Watkiss, 2005b) suggests that a pragmatic way forward to the choice of external cost factors for use in (day-to-day) appraisal is to examine the marginal abatement cost curve towards the existing 2050 target, and to compare this against the SCC estimates over time. This approach is considered to have some theoretical basis. If the MAC and SCC values are derived based upon the same set of underlying assumptions, then any divergence between these two values reflects a divergence from the optimal level of carbon emissions. The optimal carbon price is simply a weighted average of the MAC and SCC values, depending on the respective elasticities of the two curves.

Table 120 Results taken from Watkiss, 2005b

	SCC Estimates/Year of Emission						
£/tC	2000	2010	2020	2030	2040	2050	2060
Existing SCC central	70	80	90	100	110	120	130
Tol Lit. Rev mean Tol Lit. Rev 5% Tol Lit. Rev 95%	80/111/43 -9/-10/-8 300/550/210						
FUND Mean 1% FUND 5% FUND 95%	65 -53 309	75 -46 378	85 -46 482	95 -41 458	97 -47 498	129 -40 575	
PAGE CC Mean PAGE 5% PAGE 95%	45 9 130	61 12 159	77 14 215	102 20 270	127 27 324	157 30 418	187 34 213
	Energy White Paper MAC estimates/Year of Emission						
EWP MAC central Low MAC High MAC				0 93 143	13 193 229	242 351 538	

The mean value from the literature review of Tol, 2005 contains information from 28 published studies. Note values for FUND and PAGE are based on declining discount scheme in the Green Book and assume equity weighting. The FUND model results exclude some bounded risks, and exclude major climatic system events but exclude any socially contingent effects. The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects. The MAC estimates are based on the MARKAL model estimates (the Low Carbon Futures work).
Source: Watkiss, 2005b.

In the Table 121 the lower values are based on SCC (damage costs), while the upper values are derived from a comparison of SCC values and MAC curves (avoidance costs).

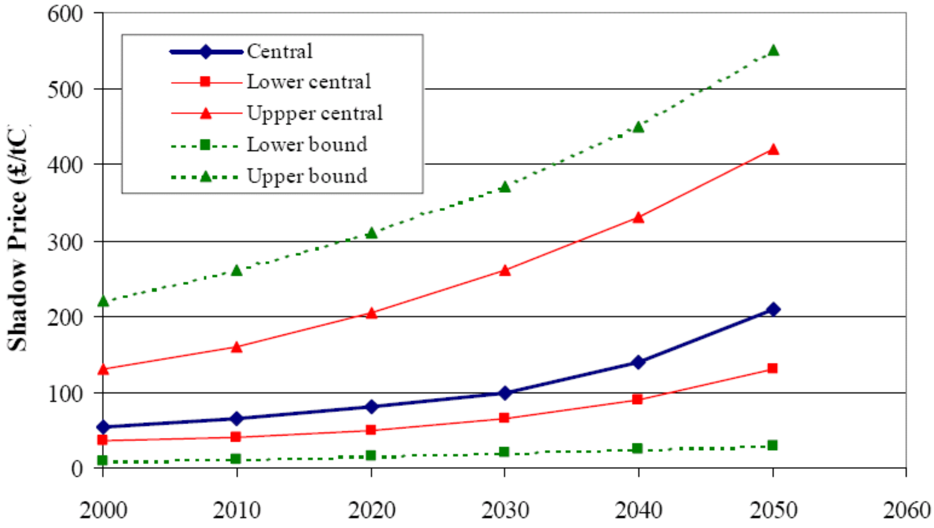
Table 121 Results taken from Watkiss, 2005b expressed in £/tonne C[45] (Example Shadow Price Values from the study, consistent with study Recommendations)

Year of emission	Central guidance	Lower central estimate	Upper central estimate	Lower bound	Upper bound
2000	55	35	130	10	220
2010	65	40	160	12	260
2020	80	50	205	15	310
2030	100	65	260	20	370
2040	140	90	330	25	450
2050	210	130	420	30	550

Source: Watkiss, 2005b.

45 Translation to €/tonne CO_2 is provided in section F.4.

Figure 27	Results taken from Watkiss, 2005b



Example Shadow Price Estimates (£/tC), consistent with study recommendations

Notes:
The FUND model results exclude some bounded risks, and exclude major climatic system events and socially contingent effects. The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects. The consideration of the SCC as part of these numbers is dependent on the assumed low discount rates (specifically declining discount rates), and includes equity weighting from a global policy perspective. The issue of equity weighting is the subject of continued debate, both in relation to the approach, and the consistency with other policy areas. At the present time, we have not recommended adjustments between the SCC and the MAC.
The consideration of the MAC is based primarily on the full range from the Government analysis (the White Paper analysis), though we also benchmark these values against the wider literature. We highlight the current debate on the accuracy of these values and the need for further modelling work.
The SCC from PAGE and FUND are global estimates (i.e. global social costs). The MAC in terms of the 60% UK target is in relation to UK marginal abatement costs, though these values have also been compared against the wider literature.
Succesfull mitigation policy will reduce the SCC estimates, as progress is made towards the 2050 target, and some of the major effects from climate change are avoided (i.e. we move below a threshold of effects for some impacts). Therefore in looking at long-term policies, further work is needed to look at the potential effect of different policies on the SCC over time.

In the Table 122 all values are based on SCC (damage costs) only.

Table 122 Results taken from Watkiss, 2005b expressed in £/tonne per C[46] (Example SCC Values from the study. Note these should only be used as part of a wider framework that considers additional effects of non-quantifiable impacts across the full risk matrix (including major change)

Year of emission	Central guidance	Lower central estimate	Upper central estimate
2000	56	35	220
2010	68	43	270
2020	81	51	350
2030	99	62	365
2040	112	71	410
2050	143	90	500

The use of these SCC values for CBA of future climate change policy objectives and measures should be consistent with recommendation 1 above, i.e. undertaken within a wider framework that considers all the impacts of climate change, using disaggregated information, considering uncertainty, and ensuring that additional effects of non-quantifiable impacts in the full risk matrix (including risk of major change) are included.

The uncertainties in the valuation of climate change damage costs are illustrated in the Table 123.

Table 123 Uncertainties in the valuation of the external costs of climate change

	Uncertainty in Valuation →			
Uncertainty in Predicting Climate Change ↓		Market	Non Market	(Socially Contingent)
	Projection (e,g, sea level Rise)	Coastal protection Loss of dryland Energy (heating/cooling)	Heat stress Loss of wetland	Regional costs Investment
	Bounded Risks (e.g. droughts, floods, storms)	Agriculture Water Variability (drought, flood, storms)	Ecosystem change Biodiversity Loss of life Secondary social effects	Comparative advantage & market structures
	System change & surprises (e.g. major events)	Above, plus Significant loss of land and resources Non- marginal effects	Higher order social effects Regional collapse Irreversible losses	Regional collapse

Source: Watkiss, 2005b.

[46] Translation to €/tonne CO_2 is provided in section F.4.

Tol 2005

Reports: (Tol, 2005).

In (Tol, 2005) a total of 103 estimates of marginal damage costs of carbon dioxide emissions has been gathered from 28 published studies and analyses to derive a probability density function. All studies combined the mode value is 2 \$/tonneC (0.5 \$/tonneCO_2), the median 14 \$/tonneC (3.8 \$/tonneCO_2), the mean 93 \$/tonneC (25 \$/tonneCO_2) and the 95 percentile 350 \$/tonneC (95 \$/tonneCO_2).

For selections of the studies and scenario results according to various criteria (among other discount rate and equity weighting) yields different results, with the main conclusion as stated by (Tol, 2005) that studies with better methodologies tend to lead to lower estimates of the damage costs. An overview is given in the Figure 28. Note that results are per tonne of carbon.

Figure 28 Graph taken from Tol, 2005

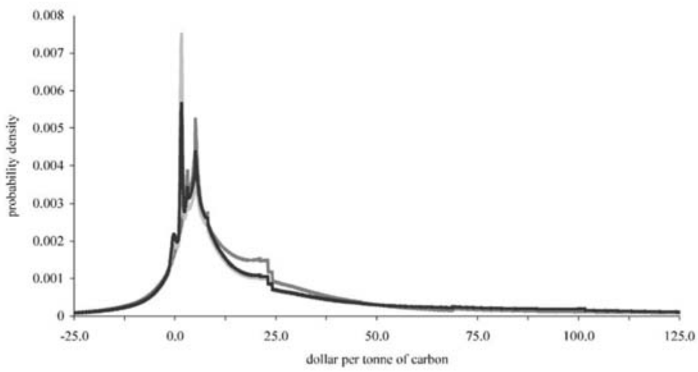


Fig. 2. The composite probability density function of the marginal costs of carbon dioxide using author weights (light gray), quality weights (black), and quality weights including peer-reviewed studies only (dark gray).

Source: Tol, 2005.

Table 124 Results taken from Tol, 2005

	Mode	Mean	5%	10%	Median	90%	95%
Base	1.5	93	-10	-2	14	165	350
Author-weights	1.5	129	-11	-2	16	220	635
Peer-reviewed only	5.0	50	-9	-2	14	125	245
CoV = 0.5	5.0	92	-1	2	17	160	345
CoV = 1.5	1.5	94	-25	-8	14	170	375
No equity weights	1.5	90	-8	-2	10	119	300
Equity weights	-0.5	101	-20	-2	54	250	395
PRTP = 3% only	1.5	16	-6	-2	7	35	62
PRTP = 1% only	4.7	51	-14	-2	33	125	165
PRTP ≤ 0% only	6.9	261	-24	-2	39	755	1,610

Source: Tol, 2005.

Overall the conclusion from (Tol, 2005) is that, although climate change impacts may indeed be very uncertain, it is unlikely that the marginal damage costs of carbon dioxide emissions exceed 50 $/tonneC (= 14 $/tonne CO_2 ≈ 12 €/tonne CO_2) and that they are likely to be substantially smaller than that.

(Watkiss, 2005b) states that the SCC value increases over time. It is not clear how the conclusion from (Tol, 2005) should be interpreted in relation to that. Overall it is unclear whether the statistical approach used by (Tol, 2005) is a valid means of assessing and comparing the results of different studies.

DLR-study
Reports: (DLR, 2006).

In (DLR, 2006) results of (SEI, (Downing, 2005)) have been analysed and used for the determination of a central estimate of 70€/t CO_2. For sensitivity analyses a lower limit of 15 €/t CO_2 is proposed. According to (DLR, 2006) most studies agree that the damage costs of climate change are very likely to be above this value. As upper limit (DLR, 2006) proposes a value of 280 €/t CO_2 which is determined from calculations by (SEI, (Downing, 2005)) using the same damage cost modelling as the central value but with a discount rate of PRTP = 0%. This value can only be seen as a rough estimate of the upper value of the damage costs as the modelling underlying (SEI, (Downing, 2005)) certainly does not include all possible effects and impacts[47].

The STERN Review
Reports: (Stern, 2006).

(Stern, 2006) assesses both the costs of climate change impacts and the costs of mitigation, and is included here not so much for its scientific merits as for its recent political impact.

(Stern, 2006) states that the damage costs of climate change are significantly higher than estimated by many earlier studies, for a number of reasons, among which:
- These studies excluded the most uncertain but potentially most dramatic impacts.
- Most studies assumed a temperature increase of 2 – 3ºC, while recent insights show that for the BAU case increases of 5 – 6ºC are a serious possibility.

[47] On the other hand this value is likely to exceed the avoidance costs associated with reaching the long term reduction targets that are required to stabilise global average temperature increase at an acceptable level (e.g. 2ºC). These avoidance costs are found to be in the order of 150 €/t CO_2.

The analysis in (Stern, 2006) appears largely based on modelling with the PAGE2002 model. In the calculations also a sensitivity analysis with respect to discount rates and assumptions on equity-weighting has been carried out.

Overall costs of climate impacts are assessed to reach 5 to 20% of the per capita consumption in the BAU scenario for now and forever. The mitigation costs associated with limiting the CO_2 concentration in the atmosphere to 500-550 ppm are assessed to be around 1% GDP around 2050. By that year worldwide CO_2 emissions would then be around 25% of the current level.

For the BAU scenario (Stern, 2006) states that ‘preliminary analysis’ of the model results points to a value of the Social Costs of Carbon (= damage costs) around 85 \$/tonneCO_2 (≈ 71 €/tonne). For stabilisation at 550 resp. 450 ppm the Social Costs of Carbon would equal around 30 resp. 25 \$/tonne (25 resp. 21 €/tonne), around one third of the level reached in the BAU scenario. The model is stated to be different from its predecessors in the sense that it incorporates both explicit modelling of the role of risk, and makes some allowance for catastrophe risk and non-market costs, albeit in an oversimplified way. (Stern, 2006) stresses that it is important to take these aspects into account and that it leads to SCC values significantly above the 29 \$/tonne value from (Tol, 2005) (also quoted in (Watkiss, 2005)) and the 13 \$/tonne given in (Watkiss, 2005).

A problem with the Stern Review is that it provides a lot of explanatory text but hardly any concrete data on the results. This is especially the case for the SCC data. Most cost impact are expressed in % of GDP or of consumption per capita. The figures on costs per tonne are only briefly mentioned and are called preliminary. No detailed results on cost curves are presented, not for damage costs and not for abatement costs.

Studies assessing external costs based on avoidance costs

RECORDIT
Reports: (RECORDIT 2000), (RECORDIT 2001).

In chapter 16 of (RECORDIT 2000) an elaborate discussion is presented on how to deal with climate change in a modern cost-benefit analysis.

- Damage cost estimations of greenhouse gas emissions vary by orders of magnitude due to special theoretical valuation problems related to equity, irreversibility and uncertainty.
- An advantage of damage costs, however, is that no sustainability criteria are necessary.
- Concerning equity both intergenerational and intragenerational equity must be considered.
    - For intergenerational equity time-variant discounting has been introduced using a standard discount rate of 3% for short term impacts, 0% for long term impacts which rise with income and a discount rate of 1% for other long term impacts;

- For intragenerational equity damages are weighted by the inverse of the income for each single country, so that damages and deaths in developed countries do not count more than in developing countries.

– A unique feature of global warming is its high level of irreversibility due to long lifetime of emissions in the atmosphere.

In RECORDIT the avoidance cost approach is used with avoidance costs of 37 €/tonne based on a cost effectiveness analysis for reaching the 5.2% reduction target for OECD under the Kyoto-protocol, which corresponds to an 8% reduction target for the EU. The cost figure is taken from (INFRAS/IWW, 2000). For the long term IPCC target of 50% the cost figure would be 135 €/tonne. On the other hand (INFRAS/IWW, 2000) also presents damage costs for which the estimate ranges from 0,05 to 200 €/tonne.

UNITE
Reports: (UNITE, 2003a) (UNITE, 2003b).

For global warming the method of calculating costs of CO_2 emissions as used in (UNITE, 2003a) and (UNITE, 2003b) consists of assessing the amount of CO_2 emitted by different transport modes and multiplying the amount of CO_2 by a constant cost factor that is independent of the location of the emissions. (UNITE 2003a) is not explicit about the method used to assess costs of other greenhouse impacts of aircraft (e.g. high altitude NO_x emissions).

The cost factor is based on the avoidance cost approach. Based on an external assessment (Capros and Mantzos, 2000) that assesses the costs for reaching the Kyoto targets for the EU at 5 €/tonne in the case of a full trade flexibility scheme and 38 €/tonne without trading with countries outside the EU, a middle value of 20 €/tonne is chosen for the UNITE project.

INFRAS
Reports: (INFRAS/IWW, 2004).

INFRAS, 2004 uses the avoidance cost approach. INFRAS, 2004 uses an external cost factor of 140 €/tonne as upper value for long term objectives (Scenario High), and a lower value of 20 €/tonne (Scenario Low) for short term targets as defined in the Kyoto Protocol.

Table 125 Results taken from INFRAS, 2004

Scenario and bandwidths used in this study	
Scenario	**Avoidance costs**
Lower boundary: International approach to meet Kyoto targets	20 € per tonne CO_2
Upper boundary: National transport approach to reach long term cut of CO_2 emission by 50% (2030)	140 € per tonne CO_2

Source: INFRAS/IWW, 2004.

HEATCO
Reports: (HEATCO, 2005), (HEATCO, 2006a).

HEATCO compares CBA-approaches in EU25 countries. Not all countries include global warming in their CBA methodology. Table 126 lists the monetization method and the CO_2 costs used in different countries. Analysis of these numbers reveals no correlation with e.g. GDP or other relevant indicators.

Table 126 Results taken from HEATCO, 2005

	Country	Monetisation Method	Road	Rail	General	Unit
North/West	Austria	Avoidance costs- based on literature	---	---	7.80	€/t
	Denmark	Official stated 'cut off' price	23.50	17.30	---	€/t
	Finland	Damage costs (all modes)	---	---	23.20	€/t
	France	Avoidance costs for reaching Kyoto targets in France	---	---	84.60	€/t
	Germany	Avoidance costs for reducing German CO_2 emissions in the year 2050 by 80% compared to 1987	---	---	194.80	€/t
	Netherlands	Avoidance costs for EU15 emission stabilisation at 1990 levels	---	---	46.30	€/t
	Sweden	Avoidance costs – transport sector specific reduction target	---	---	108.90	€/t
	Switzerland	Avoidance costs – Kyoto targets	---	---	54.20	€/t
South	Portugal	Value used in the Extension of the Lisbon Metro Assessment	---	---	35.70	€/t

Source: HEATCO, 2005.

HEATCO, 2005 suggests to use a range of CO_2 cost factors for the external costs assessment because of the uncertainties related to:
- The high level of uncertainty in estimating damage costs.
- The undecided debate on the appropriateness of using avoidance costs instead of damage costs.
- The variation of avoidance costs with the target set, and the uncertainty about the public acceptance of ambitious future targets.

As a central value HEATCO uses 20 €/tonne, based on the estimate by (Capros and Mantzos, 2000) of the cost for reaching the 2010 Kyoto target in the EU. (Capros and Mantzos, 2000) assesses the costs for reaching the Kyoto targets for the EU at 5 €/tonne in the case of a full trade flexibility scheme and 38 €/tonne without trading with countries outside the EU.

HEATCO, 2006a also mentions that recent work (e.g. (Watkiss, 2005)) confirms the assumption that future emission years will have stronger total impacts than present emissions. Subsequently it is proposed to increase CO_2 cost factors as a function of time. The result is given in the Table 127.

Table 127 Results taken from HEATCO, 2006

	Central guidance	For sensitivity analysis	
Year of emission		**Lower central estimate**	**Upper central estimate**
2000 – 2009	22	14	51
2010 – 2019	26	16	63
2020 – 2029	32	20	81
2030 – 2039	40	26	103
2040 – 2049	55	36	131
2050	83	51	166

Notes: Values are for year of emission and were derived combining damage cost and marginal abatement cost estimates. The damage cost estimates are based on declining discount rates and include equity weighting. Some major climatic system events as well as socially contingent effects are excluded. For details see Watkiss, 2005b.

Source: HEATCO, 2006.

The recommended calculation procedure is as follows:

Step 1: Quantification of change in greenhouse gas emissions (CO_2, CH_4, N_2O and others if data are available) due to a project measured in tones.

Step 2: Classification of emissions according to height of emission sources (ground level – high altitude aircraft). Calculation of CO_2 equivalents of ground level emissions; multiplication of high altitude aircraft CO_2 emissions with a factor 2 (to consider global warming impact of other emission components).

Step 3: Multiplication of the CO_2 equivalents with the cost factor for year of emission.

Step 4: Reporting of emissions and costs.

ExternE

Reports: (ExternE. 2005).

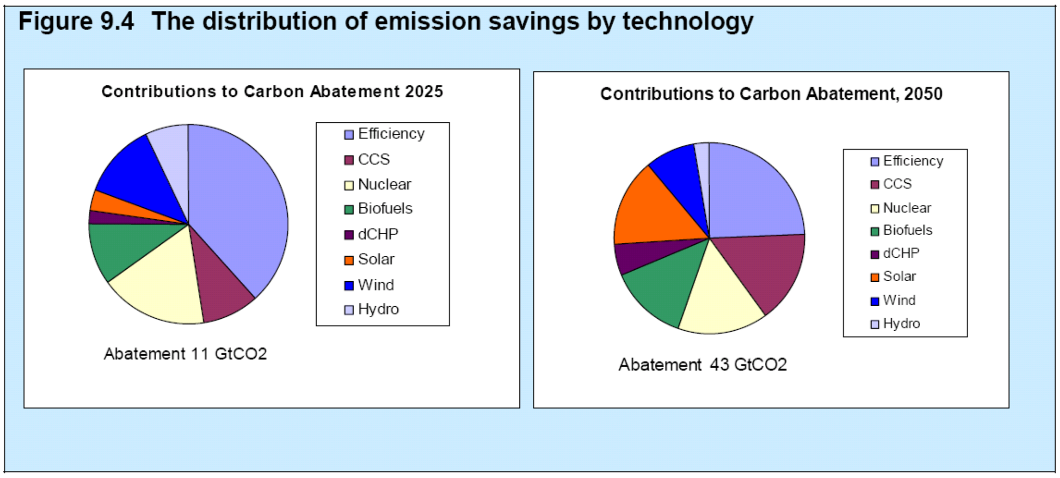
As mentioned already, to account for the precautionary principle (ExternE, 2005) proposes to use an avoidance cost approach for the central value. For reaching the Kyoto targets these are estimated between 5 and 20 €/tonne. A central value of 19 €/tonne is proposed. For reaching the EU indicative target of limiting global warming to 2ºC above pre-industrial temperatures marginal abatement costs are estimated to be as high as 95 €/tonne.

The STERN Review
Reports: (Stern, 2006).

Stern, 2006 assesses both the costs of climate change impacts and the costs of mitigation. Damage costs have been reviewed above.

The graphs below indicate how according to Stern, 2006 various technologies contribute to meeting abatement goals in 2025 and 2050.

Figure 29 Results taken from Stern, 2006

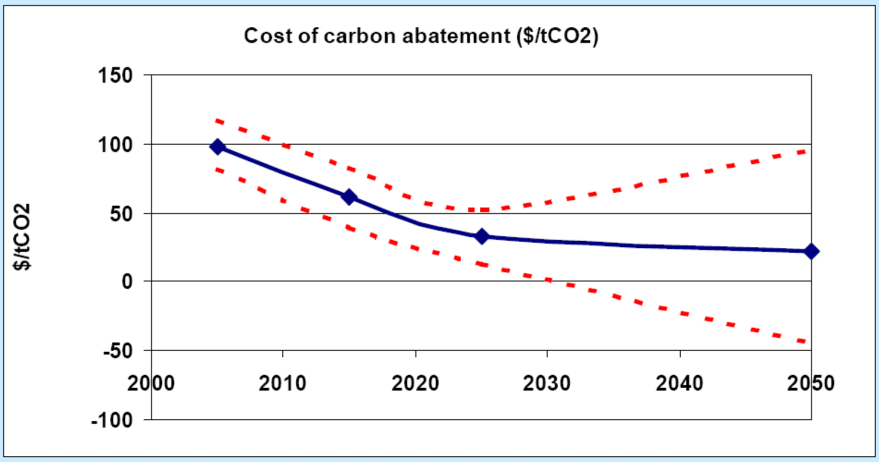


Source: Stern, 2006.

Figure 30 shows the estimate for the average CO_2 abatement costs. it should be noted here that in general the marginal abatement costs are expected to increase with tightening of the reduction targets over time, in which case the average costs should also increase over time. Stern, 2006, however, assumes that due to economies of scale and learning effects the average costs will decrease over time.

Figure 30 Results taken from Stern, 2006

Figure 9.5 Average cost of reducing fossil fuel emissions to 18 $GtCO_2$ in 2050*



*The red lines give uncertainty bounds around the central estimate. These have been calculated using Monte Carlo analysis. For each technology, the full range of possible costs (typically ± 30% for new technologies, ±20% for established ones) is specified. Similarly, future oil prices are specified as probability distributions ranging from $20 to over $80 per barrel, as are gas prices (£2-6/GJ), coal prices and future energy demands (to allow for the uncertain rate of uptake of energy efficiency). This produces a probability distribution that is the basis for the ranges given.

Source: Stern, 2006.

Table 128 Results taken from Stern, 2006 (Annual costs of reducing fossil fuel emissions to 18 $GtCO_2$ in 2050)

	2015	2025	2050
Average costs of abatement, $/t CO_2	61	33	22
Emissions Abated $GrCO_2$ (relative to emissions in BAU)	2.2	10.7	42.6
Total cost of abatement, $ billion per year	134	349	930

Source: Stern, 2006.

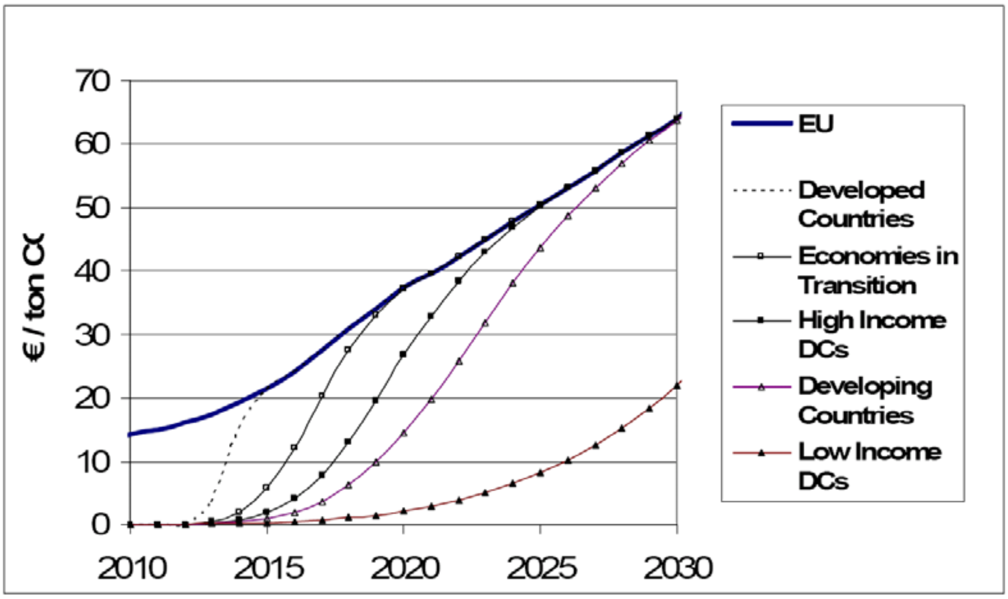
Stern, 2006 states that for a path leading to stabilisation at 450 ppm ‘most models’ show carbon prices to start off low and rise to 360 $/tonne +/- 150% by 2030, and are in the range of 180 – 900 $/tonne by 2050. It is not clear whether these are models used for the calculations in (Stern, 2006) or whether these are quotes of results from other studies.

SEC (2007) 8

In SEC (2007) 8 an Impact Assessment is presented of a proposed EU strategy to reduce the global climate change to 2ºC compared to pre-industrial levels. Using the POLES and GEM E3 models the costs are calculated for a scenario in which global greenhouse gas emissions are reduced to 25% below the 1990 level in 2050. In the baseline scenario global greenhouse gas emissions are projected to increase by 86% in 2050 compared to 1990.

Carbon prices resulting from CO_2 emissions trading in the policy scenario for different regions and over time are presented in Figure 31. These carbon prices more or less represent the development of the avoidance costs in the least cost path towards the 2050 target. Carbon prices can be seen to gradually increase from 15 €/tonne in 2010 to 65 €/tonne CO_2 in 2030. Unfortunately SEC (2007) 8 does not show costs beyond 2030, but from the trend in Figure 31 these may be expected to increase linearly to around 120 €/tonne CO_2 in 2050.

Figure 31 Carbon prices in €/tonne CO_2 resulting from CO_2 emissions trading for different regions and over time calculated using the POLES model for a scenario in which global greenhouse gas emissions are reduced to 25% below the 1990 level in 2050 (Figure 14 from (SEC(2007)8)



F.8 Output values/Unit cost rates

General considerations

Generally, damage costs are preferred as a basis for internalising external costs. An important problem with damage costs, however, is that they tend to be an underestimate as not all possible damages can be included. The amount of underestimation is difficult to judge. Avoidance costs have their own uncertainties but these are more related to the accuracy with which one can calculate the cost of abatement options that are included in the modelling/cost curve. At the same time also avoidance costs tend to be an underestimate of the long term costs of climate change. Avoidance costs have to be related to politically accepted reduction targets, which tend to be a step towards solving the problem, rather than the full reduction required to solve the problem. However, when long-term emission reduction targets have been agreed, avoidance costs are to be preferred.

The large divergence in cost estimates both for damage costs and for avoidance costs, make it difficult to propose unit values. Instead of using single values we will therefore propose bandwidths. The values proposed below should furthermore be seen as pragmatic choices based on present-day understanding of the issue. Further in-depth research (rather than meta-analyses) is highly recommended.

Overview of results from various studies

The recommended values from the various studies discussed in section F.7 are summarised in Table 129 and Figure 32 for damage costs and in Table 130 and Figure 33 for avoidance costs.

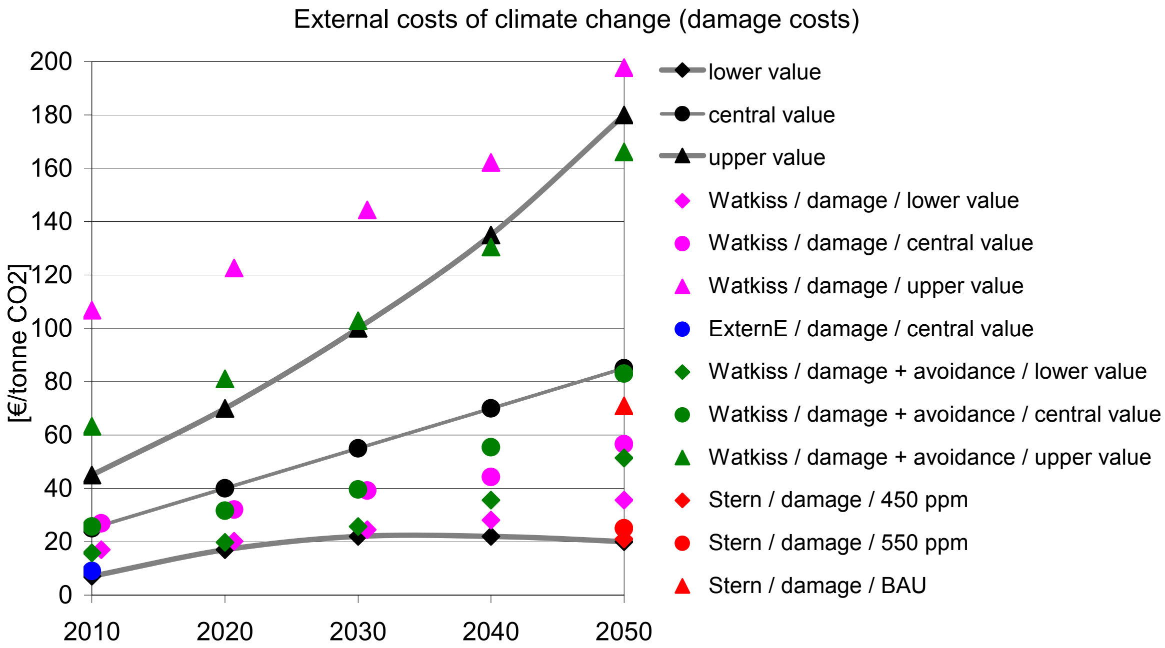
From these tables and graphs the following conclusions can be drawn:

- The spread in estimates for short term external costs between different studies is smaller for avoidance costs than for damage costs.
- Central values for the long term (i.e. 2050) damage and avoidance cost as calculated by recent studies tend to be in the same range: 50 – 100 €/tonne CO_2. The claim by Stern, 2006 that damage costs are higher than avoidance costs, which also appears the underlying assumption for the EU strategy aimed at stabilizing global warming at 2ºC above pre-industrial levels, can be neither confirmed nor rejected on the basis of these recent estimates.
- Both damage costs and avoidance costs are expected to increase over time (with Stern, 2006 as an exception).

Table 129 Overview of the damage costs of climate change (in €/tonne CO_2) as estimated by various studies

		Damage costs (€/tone CO_2)			
Source	Year of application	Min	Central	Max	Comments
ExternE, 2005	2010		9		
Watkiss, 2005b	2000 2010 2020 2030 2040 2050	14 17 20 25 28 36	22 27 32 39 44 57	87 107 138 144 162 198	Results based on damage costs only
Watkiss, 2005b	2000 2010 2020 2030 2040 2050	14 16 20 26 36 51	22 26 32 40 55 83	51 63 81 103 131 166	Results based on comparison of damage and avoidance costs
Tol, 2005		-4	11	53	Based on studies with PRTP = 1%
Stern, 2006	2050 2050 2050		71 25 21		Business-as-usual scenario Stabilisation at 550 ppm Stabilisation at 450 ppm
DLR, 2006		15	70	280	Based on Downing, 2005

Figure 32 Overview of the damage costs of climate change (in €/tonne CO_2) as estimated by various studies (see Table 129)

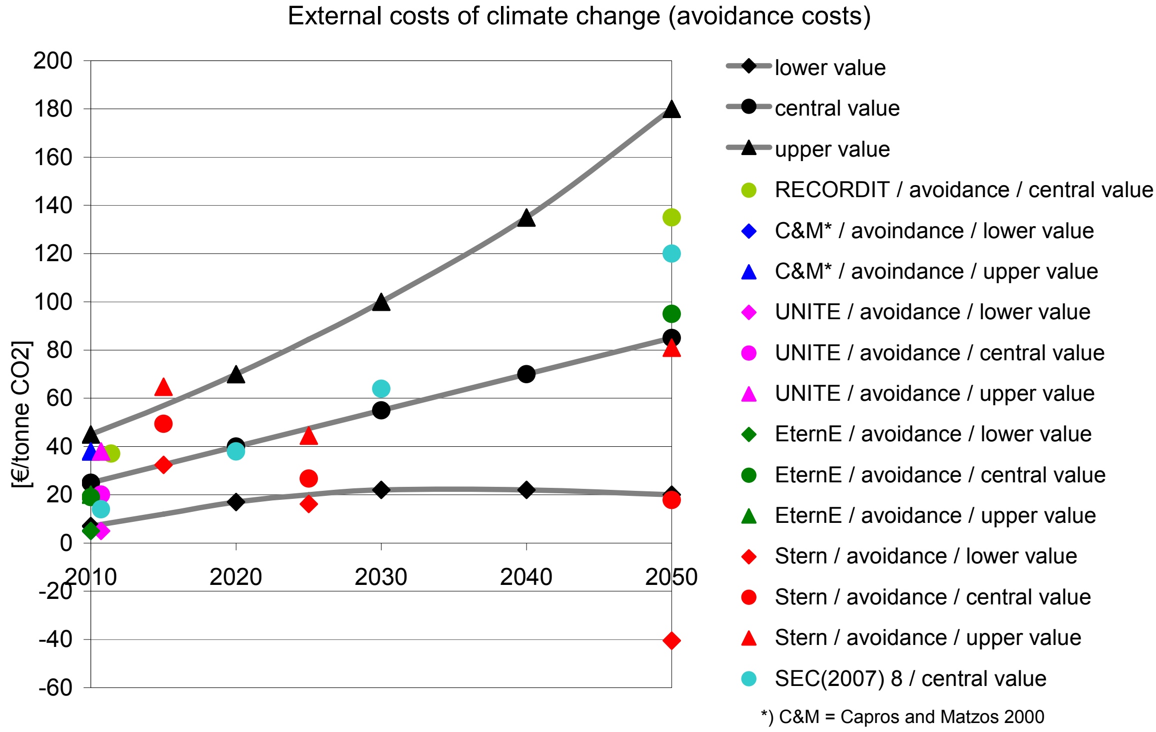


Note: The black markers and grey lines correspond to the recommended values as indicated in Table 131 and Figure 34.

Table 130 Overview of the CO_2 avoidance costs (in €/tonne CO_2) as estimated by various studies

		Avoidance costs (€/tone CO_2)			
Source	Year of application	Min	Central	Max	Reference for avoidance costs
RECORDIT, 2000/1	2010 2050		37 135		Kyoto target Long term IPCC 50% reduction target
Capros and Mantzos, 2000	2010	5		38	Kyoto target: lower value based on trading with countries outside EU, upper value on situation without trading outside EU
UNITE, 2003	2010	5	20	38	Based on Capros and Mantzos, 2000
INFRAS, 2004	2010 2050		20 140		Kyoto target Long term IPCC 50% reduction target
ExternE, 2005	2010 2050	5	19 95	20	Kyoto target Stabilisation at 2°C temperature increase
Stern, 2006	2015 2025 2050	32 16 -41	49 27 18	65 45 81	Average abatement costs
SEC, (2007)8	2010 2020 2030 2050		14 38 64 120		Stabilisation at 2°C temperature increase Lineair extrapolation based on 2020-2030 data

Figure 33 Overview of the CO_2 avoidance costs (in €/tonne CO_2) as estimated by various studies (see Table 130)



Note: The black markers and grey lines correspond to the recommended values as indicated in Table 131 and Figure 34.

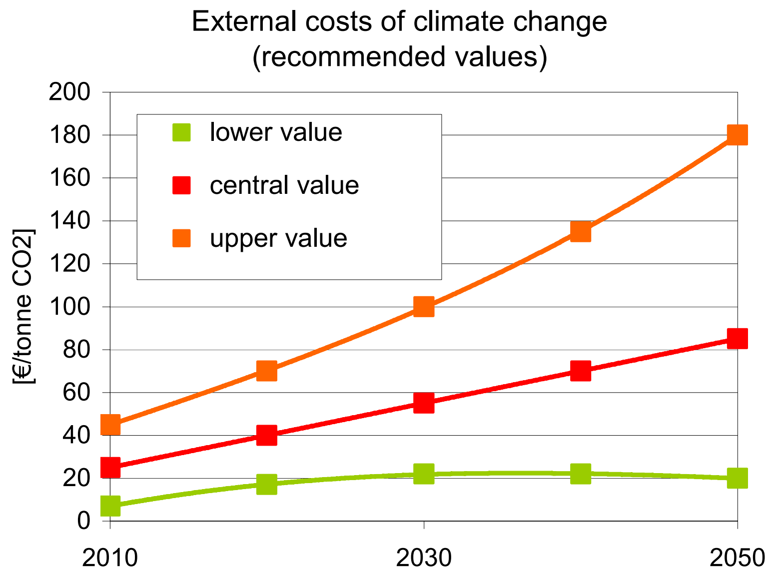
Recommended values

Based on the data in Table 129 and Table 130 recommended values are derived which are presented in Table 131 and in Figure 36. Recommended values are specified for different years of application.

Table 131 Recommended values for the external costs of climate change (in €/tonne CO_2), expressed as single values for a central estimate and lower and upper values

	Central values (€/tonne CO_2)		
Year of application	Lower value	Central value	Upper value
2010	7	25	45
2020	17	40	70
2030	22	55	100
2040	22	70	135
2050	20	85	180

Figure 34 Recommended values for the external costs of climate change (in €/tonne CO_2), expressed as single values for a central estimate and lower and upper values



The recommended values have been chosen on the basis of the following considerations:

- For the **short term** (2010 and 2020) the recommended values are based on the bandwidth of studies based on avoidance costs (see Figure 33). The central values for the short term are in line with the values used in SEC (2007) 8. The reasons for using values based on avoidance costs for 2010 and 2020 are the following:
  - For the 2010-2020 there are policy goals available to which avoidance costs can be related.
    - o For 2010 the targets set under the Kyoto-protocol are leading.
    - o Recently the European Commission and various Member States have announced ambitious and emission reduction goals for 2020 (20 to 30% reduction compared to 1990). The European Commission's target has been adopted by the European Council of March 2007. Reaching these post Kyoto targets will involve significantly higher abatement costs than the 20 €/tonne CO_2 value associated with the Kyoto target.
  - The uncertainty range for avoidance costs is smaller than for damage costs. This makes the use of avoidance costs more acceptable from a political and practical point of view. The short term values are most relevant to internalisation policies to be developed by the European Commission or by EU member states.
- The central value for 2010 is chosen somewhat higher than the 2010 value form SEC(2007) 8, to reflect the fact that for the transport sector measures are taken by the European Union which have higher avoidance costs than the measures taken in other sectors:

- One example is the EU Biofuels Directive, aiming at a share of 5.75% biofuels in the energy use of transport in 2010, and the recent proposal to oblige fuel producers to reduce well-to-wheel greenhouse gas emissions from fuels with 1% p.a. between 2011 and 2020[48]. The first generation biofuels, that will be used to meet the target of the Directive, have CO_2 avoidance costs of several hundred € per tonne CO_2. For the 2nd generation biofuels avoidance costs will be lower but may still amount 50 to 100 €/t CO_2.
- A second example is the proposed EU policy to reduce CO_2 emissions from new passenger cars to 130 g/km in 2012[49]. CO_2 abatement costs of various technical measures available to improve fuel efficiency of passenger cars involve abatement costs of the order of 50 to 150 €/t CO_2 (although strongly dependent on the method of evaluation, (see e.g. TNO, 2006; ZEW, 2006 and SEC (2007) 60[50]).

Apparently in the decision process underlying these policies CO_2 emissions or other impacts from the transport sector have a 'value' that is higher than the current external cost value for CO_2 based on either abatement costs for meeting Kyoto targets or marginal damage costs of present-day emissions. This can be seen as a 'stated preference' within the European Union motivating the use of higher external cost factors for greenhouse gas emissions for internalising external costs of the transport sector. It should be noted here, however, that the motivation for policies such as the Biofuels Directive may also include subsidies to emerging technologies and energy security considerations next to social costs of CO_2 emissions.

– As the external cost factors recommended in this report are intended for the purpose of internalisation of external costs in the transport sector, it seems reasonable to use external cost factors for greenhouse gas emissions that take account the avoidance costs associated with existing policies for the transport sector.

– For the **longer term** (2030 to 2050) the recommended values are based on damage costs (see Figure 32). This is done for the following reasons:
  - From the perspective of consistency with external cost valuations of other environmental impacts the concept of damage costs is preferred over the use of avoidance costs. Also in the field of environmental cost-benefit analysis, in which external costs are used to derive a monetary value for the benefits of assessed policies or investment, a tendency is observed to move from avoidance costs to damage costs.
  - For the long term no agreed policy goals are available yet for which avoidance costs can be assessed.
  - As indicated in the review presented above, various recent studies have made meaningful attempts to determine external cost values based on damage costs. Despite the uncertainty still involved in this approach, the

48 COM (2007) 18.
49 COM (2007) 19.
50 SEC (2007) 60: Results of the review of the Community Strategy to reduce CO_2 emissions from passenger cars and light-commercial vehicles, Impact Assessment, Commission Staff Working Document, February 2007.

results of these studies appear useful for valuation of external costs of future greenhouse gas emissions.

- Improved insights in the impacts of global warming (as modelled e.g. in FUND or PAGE) indicate that the damage costs associated with global warming are higher than previously assessed (see e.g. Watkiss, 2005a and 2005b and Stern, 2006), especially in the light of possible non-linear, dramatic effects that may occur in the longer term. In recent literature therefore a trend towards higher damage cost values can be observed.
- Marginal damage costs depend on the assumed scenario describing the global emissions of greenhouse gases and increase over time in scenarios with growing emissions. For short term greenhouse gas policies one should use the present day marginal damage costs. For policies involving investments that determine CO_2 emissions for a longer period it makes sense to use an external cost factor for CO_2 that is related to the costs of future CO_2 emissions. This value will be higher than the value for present-day emissions, although the level will depend on the amount of CO_2 emission reduction measures that are taken worldwide. As no worldwide long term targets and policies have been agreed yet, and as various developing economies are expected to increase their CO_2 emissions significantly over the next decades it seems wise to use damage cost values related to business-as-usual projections rather than to scenarios in which drastic global greenhouse gas emission reductions are assumed.

It should be highlighted here that CO_2 reduction targets vary from country to country and that also the translation of national targets to targets per sector may be different between countries. Furthermore also CO_2 avoidance costs may differ from country to country. As such external costs defined on the basis of avoidance costs could be made country specific. The values presented in this Handbook should be seen as a guideline at the European level for external costs associated with climate change.

F.9 Value transfer procedure

Calculation of cost per vehicle-km per traffic situation and vehicle type is in principle a trivial multiplication of emissions per vehicle-km and the cost factor for the specific emission type. External costs can also be expressed per unit of fuel used. This is worked out in detail in the main report.

To give some feeling of the overall impact of internalising climate change costs the example for passenger cars can be analysed. For a present day passenger car with a typical real world CO_2 emission of e.g. 200 g/km the central value of 20 €/tonne CO_2 translates into 0,004 €/km. For a passenger car in 2030 with a typical real world CO_2 emission of e.g. 120 g/km the central value of 55 €/tonne CO_2 translates into 0,007 €/km. These amounts are fairly insignificant compared to the overall cost of ownership per vehicle kilometre.

The method by which general values can be translated to values per country is in essence also trivial for the case of global warming. It only involves estimating the total vehicle-km per traffic situation and vehicle type and multiplying these numbers with the cost per vehicle-km per traffic situation and vehicle type as mentioned above. This is also worked out in detail in the main report.

F.10 Valuation of the climate change impacts of aircraft emissions

Besides the emissions of CO_2 also other substances emitted by aircraft at high altitudes have an impact on global warming through radiative forcing. The main emission components are water vapour (e.g. contrail formation), sulphate, soot aerosols and nitrous oxides. The non CO_2 related impacts on climate change are partly heating effects, partly cooling effects, such as atmospheric chemical reactions on the basis of NO_x which increase ozone concentrations in the atmosphere (heating) and which convert methane (cooling), soot emissions from aircraft engines (heating), sulphur aerosols (cooling), and formation of condensation trails (cooling in daytime and heating at night) and possibly cirrus clouds.

Review of various studies
IPCC, 1999 estimates the total climate change impact of aviation (excluding the effect through formation of cirrus clouds) to be 2 to 4 times higher than the impact of CO_2 emissions alone.

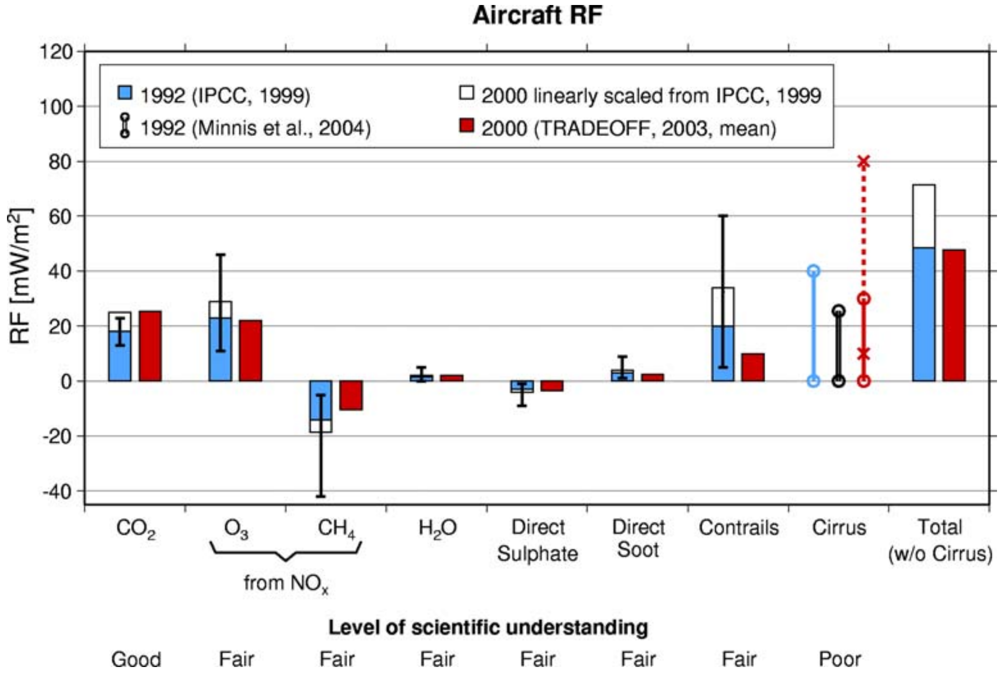
TRL, 2001c presents a case study for aviation. The methodology comes down to estimating total emissions of aircraft (in the case study for a return trip to a specific destination) and multiplying these with external cost factors. For CO_2 and NO_x marginal damage costs from DETR, 2000 are used which come down to 33 – 133 €/tonne C (central estimate 86 €/tonneC) for the case of CO_2 and 3900 €/tonne for NO_x. TRL, 2001c does not explicitly mention how the damage costs of NO_x take account of the various radiative forcing mechanisms involved.

For estimating the impacts of radiative forcing due to aircraft emissions at high altitudes in INFRAS, 2004 a factor of 2.5 is used to translate pure CO_2 related radiative forcing into the combined radiative forcing of CO_2 and other aircraft emissions.

According to Sausen, 2005 the total radiative forcing of aviation is about a factor of 2 times the radiative forcing associated with the CO_2 emissions from aircraft (see Figure 35).

HEATCO, 2006 mentions the impact of other aircraft emissions (water vapour, sulphate, soot aerosols and nitrous oxides) at high altitude on global warming and proposes to multiply the CO_2 emissions from aircraft by a factor of 2 to account for these effects based on the assessment by IPCC of the total climate change impact compared to the direct CO_2 impact.

Figure 35 CO_2 and non-CO_2 related climate impacts of aviation



Source: Sausen, 2005.

CE Delft-study on External Costs of Aviation

For the valuation of climatic impacts from aviation, both the damage cost and prevention cost approach is used in CE Delft, 2002, leading to a middle estimate of 30 € per tonne of CO_2 equivalent, with sensitivities of 10 and 50 € per tonne. As contrails have a relatively large climatic impact and their formation can quite accurately be predicted, the climatic impact is differentiated for situations with and without contrail formation. For this analysis the most important assumption is that contrails are formed during 10% of flight kilometres.

For aircraft flying at distances up to a few hundred kilometres, external costs related to LTO emissions are dominant, especially noise costs. For flights over about 1,000 km, external costs of climatic impacts exceed those of LTO impacts, also in case no contrails are formed. New technology has more impact on LTO related costs than on costs related to climatic impact. Contrail formation has a large influence on the climatic impact of aircraft, and thus on external costs related to this climatic impact. Based on a number of assumptions, a middle estimate is that the climatic impact of a contrail-causing aircraft km is, on average, about eight times as high as an aircraft km that does not lead to persistent contrails.

Contrails and other non-CO_2 climate impacts

According to an IPCC middle estimate, in 1992 the full climatic impact of aviation emissions was 2.7 times greater than that of CO_2 alone. Contrail formation and NO_x emissions are the most important environmental impacts besides CO_2 emissions.

Specific attention has been given to contrail formation in this study. This is for two reasons: its substantial contribution to the overall radiative forcing due to aviation, and the specific and fairly well predictable operational circumstances under which contrails arise. It has been assumed in this study that contrails are, on average, formed during 10% of flight kilometres. It is furthermore assumed that contrail formation is not correlated with any other environmental impact of aviation. Finally, the possible additional impact of cirrus cloud formation from persistent contrails has not been addressed.

Under these assumptions, CE Delft, 2002 has differentiated between the climatic impact of average flights that do, and do not, cause contrails (Table 132).

Table 132 presents the global average perturbation of radiative balance, in W/m2, differentiated for situation with and without contrails, under assumptions stated below the table, based on 1992 data and 1999 IPCC report.

Table 132 Global average perturbation of radiative balance, in W/m2, differentiated for situation with and without contrails

Perturbation due to	Average situation (with assumed 10 % probability of contrails for each km flown)	Situation without contrails (about 90% of flight time)	Situations with contrails (about 10 % of flight time)
CO_2	+0.018	+0.0162	+0.0018
Contrails	+0.02	0	+0.02
Other (NO_x, H_2O, sulphur, soot)	+0.011	+0.0099	+0.0011
Total	+0.049	+0.026	+0.023
Per flights km (picoW/m^2)	+2.4	+1.4	+11

Source: CE Delft, 2002.

As the Table 132, under the stated assumptions the total average climatic impact of a contrail-inducing flight kilometre is about eight (8) times the total average impact of a flight kilometre without contrails (11 vs. 1.4). For an average contrail-inducing flight kilometre, the climatic impact of the contrail alone is about eleven (11) times that of CO_2 alone (0.02 vs. 0.0018).

An advantage of the differentiation made is that the 'average' climatic impact of flights, as presented in the first column of the table above, is in practice never achieved and therefore always 'wrong'. The differentiated figures in the second and third columns provide insight into the additional impact of contrails, and probably come closer to real-world situations.

The climatic impact of NO_x emissions arises from two entirely different processes: net production of tropospheric ozone and net loss of methane. Each mechanism has a different chemical background and occurs under different circumstances. Although, strictly speaking, the two mechanisms should be valued separately, for reasons of simplicity we have opted here to work with a global average net result.

Subsequently, non-LTO NO_x emissions have been valued at € 1.2, 3.6 and 6.0 per kg, as low middle and high variants. With these values one W/m^2 of radiative forcing due to NO_x emissions is valued identically to one W/m^2 forcing due to CO_2 emissions.

The climatic impacts of sulphur and soot aerosol emissions have not been financially valued in CE Delft, 2002 because at a global level the two effects are assumed to cancel.

Recommended values for aircraft

Based on the above it is proposed to use the external cost figures from section F.9 multiplied by a factor of 2 to account for non-CO_2 related impacts. This value can then be multiplied by the total CO_2 emissions of an aircraft to arrive at the total climate change costs of this aircraft.

G Other external costs

G.1 Overview of existing studies

Table 133 gives an overview on the studies available covering other external cost categories such as costs for nature and landscape (N & L), soil and water pollution, additional cost in urban areas and costs of up- and downstream processes.

Table 133 Overview on studies quantifying other external cost categories. Studies with own methodologies are highlighted

STUDIES QUANTIFYING 'OTHER EXTERNAL COST CATEGORIES'						
Author, Title, Year of Publication	**Base year of results**	**Transport modes covered**	**Cost categories covered**	**Output, Results: Cost type**	**Method used**	**Countries covered**
UNITE, 2003: Unification of accounts and marginal costs for transport efficiency	1998	Road, rail, air, inland waterways	Nature & landscape, soil & water	Total and average costs	INFRAS/ IWW 2000 methodology.	EU15, CH, H
High Level Group on Infrastructure charging 1999a: Calculating transport environmental costs	-	All	Water (and soil)	Total costs	No calculations, only rough methodology recommendation	-
CAPRI, 2001: Concerted Action on Transport Pricing Research Integration	1990	Road	Water	Total costs	No own calculations, only citation of existing studies	European Union
ExternE, 1999, New ExternE, 2004/5: Externalities of Energy, Methodology 2005 Update	1995, 2004	External costs of energy (not transport)	N & L, soil, water: impact of air pollutants on ecosystems and biodiversity; up-& downstr.	Total and average costs, New Ext: cost indicators, shadow prices	Own methodology	EU15, N
NEEDS, 2005, New energy externalities development for sustainability	-	External costs of energy (not transport)	N & L: biodiversity losses due to land use change & airborne emissions	Total costs	Own methodology	? (Results of study not yet available)

STUDIES QUANTIFYING 'OTHER EXTERNAL COST CATEGORIES'						
Author, Title, Year of Publication	**Base year of results**	**Transport modes covered**	**Cost categories covered**	**Output, Results: Cost type**	**Method used**	**Countries covered**
INRAS 2000/ 2004: External costs of transport	2000, 1995	Road, rail, air, water	N & L, soil & water, urban areas, up-/ downstr.	Total and average costs, marginal costs	Own methodology	EU15, N, CH
Friedrich and Bickel, 2001: Environmental external costs of transport	1995-1998	Road, rail, air, water (inland shipping)	Up-/ downstream; N & L, soil & water: impact of air pollut.	Total and average costs, marginal costs	Methodology analogue to ExternE	B, FI, F, D, G, NL, UK
OECD/INFRAS/Herry, 2003: External costs of transport in Central and Eastern Europe	1995	Road, rail, air, water	Nature & landscape, soil & water	Total and average costs	INFRAS/ IWW 2000 methodology	CEI countries
TRL, 2001: A study on the cost of transport in the European Union in order to estimate and assess the marginal costs of the use of transport	1998	Road, air transport	Up-/down: vehicle & fuel prod. and Infrastructur e use.	Marginal damage costs	ExternE methodology and costs rates from INFRAS/ IWW 2000	B, FI, D, G, NL, UK
OSD, 2003-2006: External costs of road and rail transport in Switzerland.	2000	Road, rail	N & L, soil & water, urban areas, up-/ downstr.	Total and average costs	Own methodology (N & L, soil, urban areas)	CH
Mathieu, 2002: Environmental costs of transport in France in 2001.	2001	Road, rail, air, water	Nature & landscape, soil & water, urban areas, up-/ downstr.	Total and average costs	INFRAS/ IWW 2000 methodology	F
UBA, 2006: Economic valuation of environmental damages – method convention for estimating environmental costs.	-	All	N & L: land use, separation effects of transport infrastruc-ture	Total costs	No calculations, only rough methodology recommenda tions	D
LEBER/INFRAS, 2006: External costs of transport in the Basque Country	2004	Road, rail	Nature & landscape, soil & water, urban areas, up-/ downstr.	Total and average costs	INFRAS/ IWW 2000 and OSD 2006 (soil, urban areas) methodology	Basque Country

Valuation of existing knowledge

Until now, there is not much knowledge about the described external costs categories. Only very few studies have calculated costs of those categories. More research is needed above all in the field of more and better dose-response functions. This holds particularly true for the effects on natural ecosystems (nature and landscape, soil and water).

G.2 Costs for nature and landscape

General approaches

- Repair cost approach for ground sealing and other impacts on ecosystems (disturbance of animals and their biotopes by noise or barrier effects, visual disturbance, etc.) (INFRAS/IWW, 2000/4).
- Standard price approach for quantifying the negative effects of airborne emissions on ecosystems and biodiversity (through acidification and eutrophication) (ExternE, 1999; NewExt, 2004).
- Two-stage approach for quantifying biodiversity losses: a. repair costs for reduced species diversity due to *land use change* and b. repair costs for negative effects of *airborne emissions* on ecosystems and biodiversity (through acidification and eutrophication) (NEEDS, 2005a).
- Two-stage approach for habitat loss and fragmentation: a. compensation costs for *habitat loss* due to transport Infrastructure (creating compensatory ecosystem) and b. compensation cost approach for *habitat fragmentation*. (OSD, 2003).

The costs for nature and landscape due to airborne pollutants (e.g. through acidification and eutrophication) do not belong to the cost category 'nature and landscape' but are covered within the cost category 'air pollution'.

Main methodology and possible alternatives

Main methodology: Two-stage approach: a. compensation costs for habitat loss due to transport Infrastructure (creating compensatory ecosystem) and b. compensation cost approach for habitat fragmentation (OSD, 2003).

Habitat loss and habitat fragmentation lead to a decrease in the number of species in an ecosystem (i.e. reduced biodiversity). The two cost elements are calculated as follows:

- **Habitat loss:** The first step is the calculation of the size of all ecosystems (habitats) lost due to transport Infrastructure since 1950 (reference state). The analysis is based on the interpretation of 3-dimensional air photographs of sample areas along transport Infrastructure. The areas are differentiated by ecosystem type and region. Then, these areas of lost ecosystems are valuated with the specific costs for creating compensatory ecosystem areas of the same quality at another place (not repair costs but compensation costs).
- **Habitat fragmentation:** The first step is the calculation of the number of fragmentations along transport Infrastructures, based on the interpretation of 3-dimensional air photographs of sample areas. The fragmentations are differentiated by the type of animals affected and the type of transport Infrastructure. Then, the costs are calculated with cost factors for remedying

the habitat fragmentations by building adequate Infrastructures (e.g. wildlife overpass).

Alternative methodology: Repair cost approach for ground sealing and other impacts on ecosystems (INFRAS/IWW, 2000/2004, NEEDS, 2005a).
If no detailed data about lost and fragmented habitats are available, the costs of ground sealing and other impacts (disturbance of animals and their biotopes by noise or barrier effects, visual disturbance) can be calculated on the basis of transport Infrastructure length: First, the sealed area and the additional impaired area along transport Infrastructure are quantified. Then, the affected area is multiplied by repair cost factors for a) ground sealing (unsealing costs plus restoration costs of target biotopes for converting a low quality habitat into a high quality habitat) and b) other impacts (barrier and visual effects: repair costs).

Input values

Data requirements, main methodology:

- Habitat loss: area of lost habitats due to transport Infrastructure since 1950, differentiated by habitat type.
- Habitat loss: specific cost factor for creating compensatory ecosystem areas (compensatory costs), differentiated by habitat type (see table below).
- Habitat fragmentation: number of habitat fragmentations along transport Infrastructures (for different groups of animals).
- Habitat fragmentation: specific cost factors for remedying the habitat fragmentations by building adequate Infrastructures (see Table 134).

Table 134 Habitat loss: compensatory costs for different ecosystems in € per square metre and year. Cost rates for Switzerland, in $Euro_{2000}$

	Costs rates in EUR/(m^2*a)		
Ecosystem type	*Minimum*	*Medium*	*Maximum*
Standing water body	1.23	1.75	2.28
River narrow	0.95	1.18	1.40
River broad	0.48	0.59	0.70
Moor	1.35	2.00	2.66
Reed	0.79	0.98	1.22
Fen	1.59	2.87	4.17
Grassland, meadow	0.64	0.92	1.18
Acre, fallow land	0.12	0.20	0.29
Rock	0.51	0.58	0.66
Hedge	1.17	1.42	1.67
Tree avenue	0.11	0.12	0.14
Alluvial forest	0.94	1.22	1.50
Forest (deciduous, coniferous, mixed)	0.64	0.87	1.09

Source: OSD, 2003 (data for year 2000).

Table 135 Habitat fragmentation: specific cost factors for different Infrastructure types to remedy habitat fragmentation. Cost factors for Switzerland

	Costs factors (in EUR/a), medium values					
Infrastructure type	Motorway	1st class road	2nd class road	3rd class road	Rail single-lane	Rail multi-lane
Wildlife overpass	65,922	27,922	22,915			18,165
Wildlife underpass	135,760	57,706	47,500			71,763
Stream passage for wildlife	150,395	63,932	52,635			71,763
Passage for stream animals	7,382	4,493	4,493	3,017	4,493	4,493
Small animal passage	3,723	2,247	2,247			2,247

Source: OSD, 2003 (Data for year 2000).

Data requirements, alternative methodology:

- Transport Infrastructure length, differentiated by transport mode and Infrastructure class (rail: single track vs. double track; road: motorway vs. national roads vs. regional roads vs. smaller roads; water: length of artificial channels; air: sealed area of airports).
- Width of transport Infrastructure: sealed width and additional impaired width (see Table 136).
- Cost factors for ground sealing: unsealing costs (repair costs) plus restoration costs of target biotopes (compensation costs) (see Table 136).
- Repair cost factor for other impacts (barrier and visual effects, etc.) (Table 136).

Table 136 Sealed and additional impaired area: width of transport Infrastructure. Data for Germany

		Sealed area (width in m)	Additional impaired area (width in m)
Road	Motorways	35	15
	1st class / national roads	12	8
	2nd class / regional roads	9	5
	3rd class roads	5	5
Rail	Single track	7	5
	Multi track	13	5
		Sealed area (km^2/airport)	Additional impaired area (km^2/airport)
Air	National airports	3	0.32
	Regional airports	0.8	0.08
		Sealed area (width in m)	Renaturarion area (width in m)
Water	Channels (artificial waterways)	10	40

Source: INFRAS, 2004.

Table 137 Sealed and additional impaired area: specific cost factors for Germany

		Sealed area: repair & compensation costs (in EUR/m^2)	Add. Impaired area: repair & compensation costs (in EUR/m^2)
Road, rail and air transport		67.2	38.7
	Unsealing costs (in EUR/m^2)	Compensation costs (in EUR/m)	Renaturation costs of banks (in EUR/m)
Water	28.5	438.5	398.6

Source: INFRAS, 2004 (data for year 2000).

* The total cost factor for sealed area consists of unsealing costs (29 EUR/m_2), compensation & restoration costs (11 EUR/m^2), repair costs for other effects such as barrier and visual effects, etc. (27 EUR/m^2).

Data sources

- Detailed maps, 3-dimensional air photographs, etc.
- National statistics about transport Infrastructure length.
- Specific cost factors: OSD, 2003; NEEDS, 2005a.

Sensitivity analysis

- Variation of the cost factors.
- Variation of the reference state (instead of 1950 another point of time).

Output values

The cost factors for Switzerland (OSD, 2003) are most elaborated. However, the average cost factors shown in the first table below have to be adapted to other countries if no national or local estimates are available by taking into account a value transfer procedure looking at the costs of repair measures in the respective countries. It is obvious that the cost structure refers at least partially to the specific local situation in Switzerland (topography, alpine ecosystems, etc.) and transferability is limited, however, if no other national studies are available at least a rough estimation might be possible. In the second table below, the cost factors from the alternative methodology (INFRAS/IWW, 2004a) are also shown.

Table 138 Habitat fragmentation and habitat loss (main methodology): average costs per km Infrastructure for road and rail transport in Switzerland

	Average costs (in EUR/(km*a))		
Transport mode	*Habitat loss*	*Habitat fragmentation*	*Total*
Road total	3,591	7,101	10,691
Motorways	18,639	91,643	110,282
1st class / national roads	3,222	12,642	15,864
2nd class / regional roads	4,191	2,715	6,906
3rd class roads	2,249	1,606	3,855
Railway total	5,955	10,186	16,141
Railway single track	3,286	5,620	8,906
Railway multi track	13,513	23,115	36,628

Source: OSD, 2003 (data for year 2000).

Table 139 Costs for nature and landscape (alternative methodology): average costs per km Infrastructure for road, rail and water transport in Europe (data for EU-15 plus CH and N)

Transport mode	*Average costs (in EUR/(km*a))*
Road total	4,056
Motorways	49,121
1st class / national roads	5,480
2nd class / regional roads	4,002
3rd class roads	3,125
Railway total	1,671
Railway single track	1,303
Railway multi track	2,094

Source: INFRAS/IWW 2004a (data for year 2000).

G.3 Costs for soil and water pollution

General approaches

- Repair cost approach for polluted areas (soil and water pollution) along transport Infrastructure (dependent on the Infrastructure length). (INFRAS/IWW, 2000/2004a).
- Repair cost approach for the soil and water pollution by heavy metals, organic pollutants (e.g. polycyclic aromatic hydrocarbons, PAH), de-icing salt, herbicides and other agents along transport Infrastructure (dependent on the amount of emissions and the critical concentrations) (OSD, 2006).
- Damage costs approach: health costs for human beings due to the emission of toxic heavy metals into soil, water and air (ExternE, 1999; NewExt, 2004).

Main methodology and possible alternatives

Main methodology: Repair cost approach for the soil and water pollution by heavy metals, organic pollutants (e.g. polycyclic aromatic hydrocarbons, PAH), de-icing salt, herbicides and other agents along transport Infrastructure (dependent on the amount of emissions and the critical concentrations). (OSD, 2006; High Level Group, 1999a).

The calculation is based on the amount of heavy metals (lead, cadmium, zinc copper, etc.) PAH, de-icing salt, herbicides, etc. emitted by transport vehicles (through combustion, abrasion of tyres, brakes, road surface, tracks, overhead contact wires and through treatment of transport Infrastructure with salt, herbicides, etc.). On the basis of the amount of emissions and the critical soil or water concentration of these pollutants, it can be calculated which volume of soil or water would be polluted up to the critical concentration. To quantify the cost of this pollution, the volume is multiplied by a repair cost factor for the disposal and replacement of the polluted soil or the treatment/cleaning of the polluted water.

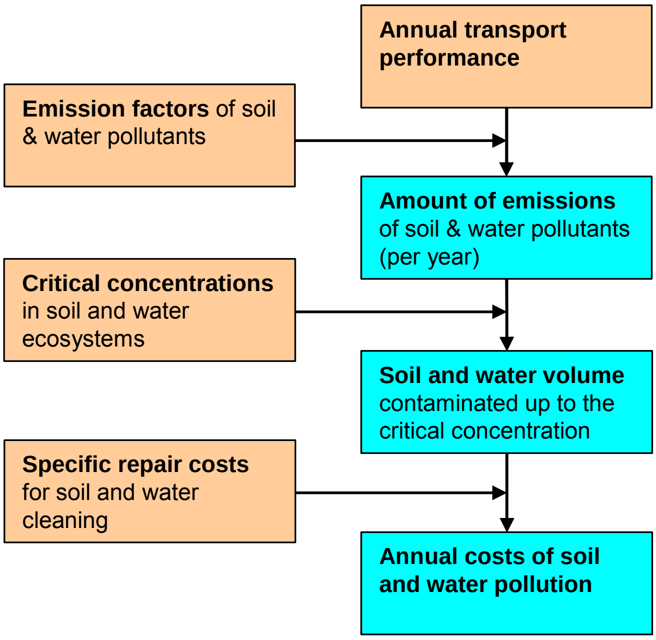
Alternative methodology 1: Repair cost approach for polluted areas (soil and water pollution) along transport Infrastructure (dependent on the Infrastructure length) (INFRAS/IWW, 2000/2004a).

The calculation is analogue to the INFRAS methodology for the costs for nature and landscape. The calculation is based on the length of the transport Infrastructure: First, the affected area/soil volume along transport Infrastructure is quantified. Then, this area is multiplied by the cost factors of repair measures for cleaning and replacing polluted soil and water (repair cost approach).

Alternative methodology 2: Damage costs approach: health costs for human beings due to the emission of toxic heavy metals into soil, water and air. (ExternE, 1999; NewExt, 2004).

In this approach, the costs for soil and water pollution cover the costs of human health effects (higher risk of certain diseases) due to the emission of toxic heavy metals (lead, chromium, cadmium, mercury, nickel, arsenic). The costs are quantified by using specific health cost factors for diseases caused by the exposure to those toxic agents. Environmental damages caused by heavy metals or other toxic substances are not quantified, however.

Figure 36 Main steps and outputs (main methodology)



The red boxes represent input data, the blue boxes represent output data.

Input values

Data requirements, main methodology:

- Emission of soil pollutants (heavy metals, organic pollutants such as PAH): can be calculated, if emission factors and transport performance are known.
- Emission of water pollutants (de-icing agents, herbicides, etc.): can be calculated, if emission factors and transport performance are known.
- Critical concentration of these pollutants in soil and water ecosystems (see Table 140).
- Specific repair costs for the disposal and replacement of the polluted soil (see Table 141).
- Specific repair costs for cleaning the polluted water.

Table 140 Critical concentration of soil pollutants according to Swiss environmental legislation

	Critical soil concentration (in g/m^3)
Cadmium	2
Zinc	300
Lead	200
Copper	150
PAH	20

Source: OSD, 2006.

Table 141 Repair costs for the disposal and replacement of the polluted soil

Data source, country	*Specific repair costs (in EUR/m^3)*
OSD, 2006, Switzerland	58
UNITE, 2000c, EU	36

Source: OSD, 2006 (data for 2004), UNITE 2000c (data for 1998).

Data requirements, alternative methodology 1:

- Transport Infrastructure length, differentiated by transport mode and Infrastructure class (rail: single track vs. double track; road: motorway vs. national roads vs. regional roads vs. smaller roads; water: length of artificial channels; air: sealed area of airports).
- Width of transport Infrastructure which is impaired by soil and water pollution (see Table 136).
- Repair cost factor for cleaning and replacing polluted soil and water (see above).

Data requirements, alternative methodology 2:

- Emission of toxic heavy metals.
- Specific health costs for diseases caused by these toxic agents.

Data sources

- Critical concentrations: regulations in national or international law or recommendations from international organisations (e.g. United Nations Economic Commission for Europe UNECE conventions and protocols).
- Emission factors: emission factor Handbooks, life cycle inventories for transport, etc.
- Specific cost factors: INFRAS/IWW, 2000/2004a; OSD, 2006; national repair cost factors for soil and water cleaning.

Sensitivity analysis

- Variation of the emission factors.
- Variation of the critical concentrations.
- Variation of the cost factors.

Output values

Table 142 presents unit costs in €ct/vkm based on the results of a Swiss study (Base year 2004). For value transfer to other countries basically an adaptation of the repair cost rates is necessary (GDP/cap. PPP). A value transfer to other countries is sensitive to national and local specifications and should only be undertaken if no national studies are available. The respective results represent then rough estimates.

Table 142 Soil and water pollution: unit costs for road and rail transport in Switzerland

	Transport mean	*Unit costs, in €ct/vkm*
Road	Passenger cars	0.06
	Busses (public transport)	1.07
	Coaches	1.05
	Motorcycles	0.04
	Vans	0.17
	Heavy duty vehicles	1.05
Rail	Rail total	0.43
	Rail passenger	0.29
	Rail freight	1.02

Source: OSD, 2006 (data for the year 2004).

G.4 Additional costs in urban areas

General approach: main methodology and possible alternatives

Main methodology: Two-stage approach with two cost categories: a. damage costs due to separation effects of transport Infrastructure in urban areas (waiting time for pedestrians) and b. compensation cost approach for scarcity problems due to transport Infrastructure (construction of bicycle lanes) (INFRAS/IWW, 2000/2004a; OSD, 2006) .

The two cost aspects in urban areas are calculated as follows:

- **Separation effects:** The calculation of the damage costs for pedestrians is based on the time lost by pedestrians for crossing transport Infrastructure in urban areas. This lost time is calculated on the basis of the following components: transport Infrastructure length in urban areas, average number of affected people (per Infrastructure length), average number of crossings per person and day, average time lost per crossing. To get the total costs, the time lost is multiplied by a time cost factor for pedestrians.
- **Scarcity problems (e.g. costs for bicycle lanes)[51]:** The calculation is based on the cost of the bicycle lanes that have to be built because of scarcity problems on roads. To quantify these costs the length of urban road Infrastructure where bicycle lanes are needed are multiplied with a specific cost factor for the construction of bicycle lanes. These costs are however only then relevant if bicycle lanes really will be constructed as a result of increased traffic.

All existing studies only calculate the additional costs in urban areas for road and rail transport.

Alternative methodology: If no detailed data about the Infrastructure length (and types) in urban areas is known, the calculation can alternatively been done with a simpler methodology. In this approach, the total number of affected people in urban areas (inhabitants and commuters) is multiplied by specific cost factors per person and year (INFRAS/IWW, 2000/2004a).

[51] It has to be noted that this scarcity effect can only serve as a proxy for external scarcity costs for non motorised transport in urban areas. It might be more efficient to use this argument for transport planning instead of pricing. Some regions are however earmarking road taxes to finance bicycle lanes.

- **Separation effects:** The calculation is done by multiplying the total number of affected people in urban areas with a damage cost factor from literature or from an exemplary city (time costs per person and year).
- **Scarcity problems (e.g. costs for bicycle lanes):** The calculation is done by multiplying the total number of affected people in urban areas with a cost factor from literature or from an exemplary city (bicycle lane costs per person and year). These costs are however only then relevant if bicycle lanes really will be constructed as a result of increased traffic.

Input values

Data requirements, main methodology:

- Separation effects:
  - Transport Infrastructure length in urban areas (differentiated by Infrastructure class).
  - Average number of affected people per Infrastructure length.
  - Average number of crossings per person and day (differentiated by Infrastructure type).
  - Average time lost per crossing (differentiated by Infrastructure type).
  - Time cost factor for pedestrians.
- Scarcity problems:
  - Length of urban road Infrastructure where bicycle lanes are needed.
  - Specific cost factor for the construction of bicycle lanes.

Table 143 Separation effects: input values and cost factors for road and rail Infrastructure in urban areas. Data for Switzerland

	Road			**Rail**
	Type A: regional / communal road	Type B: main street, 2 or max. 3 lanes	Type C: city motorway (4 lanes or more)	
Average number of crossings per day and person Average time lost per crossing (in s)	3 10	2 45	1.5 260	1.5 260
Time costs factor for pedestrians (road and rail)	6.5	EUR/hour		

Source: OSD, 2006 (data for year 2004).

Table 144 Scarcity problems: specific cost factors for the construction of bicycle lanes in urban areas. Data for Switzerland

Cost rates for bicycle lanes	*Cost rates*
Bicycle lane: painted lane on the road track	1,900 EUR/(km*a)
Bicycle lane: separate track	24,100 EUR/(km*a)

Source: OSD, 2006 (data for year 2004).

Data requirements, alternative methodology:

- Total number of affected people (e.g. inhabitants of all cities with more than 50,000 inhabitants).
- Separation effects: specific time costs per person and year for separation effects (from literature or from an exemplary city).
- Scarcity problems: specific costs per person and year for the construction of bicycle lanes (from literature or from an exemplary city).

Table 145 Alternative methodology: specific cost factors per person (city inhabitant) in urban areas. Data for EU-15 plus CH and N

	*Specific costs per person (city inhabitants) and year, in EUR (person*a)*	
	Road	Rail
Separation costs	35.2	12.0
Scarcity problems	8.4	-

Data sources

- National or city statistics: Infrastructure length in urban areas (per Infrastructure type); number of inhabitants in urban areas; if possible, number of commuters into urban areas; share of roads where bicycle lanes have already been built.
- Existing studies (INFRAS/IWW, 2000/2004a; OSD, 2006) for specific data such as: number of crossings per persons and day, average time lost per crossing.
- Time cost factor for pedestrians: national studies about the value of travel time or data from existing studies (INFRAS/IWW, 2000/2004a; OSD, 2006).
- Cost factors for the construction of bicycle lanes: national or urban road accounts or specific cost factors from existing studies (INFRAS/IWW, 2000/2004a; OSD, 2006).

Sensitivity analysis

- Variation of the Infrastructure length.
- Variation of the average number of crossings per day and the time lost per crossing.
- Variation of the cost factors.

Output values

Table 146 Additional costs in urban areas: unit costs for road and rail transport in Europe (EU15 plus CH and NO, European average results)

	Transport mean	*Unit costs, in €ct/vkm*
Road	Passenger cars	0.26
	Busses and coaches	0.66
	Motorcycles	0.11
	Vans	0.37
	Heavy duty vehicles	0.77
Rail	Rail total	16.83
	Rail passenger	16.50
	Rail freight	17.93

Source: INFRAS/IWW 2004a (data for year 2000).

G.5 Costs of up- and downstream processes

General approach: main methodology and possible alternatives

Generally speaking, the costs of up- and downstream processes are calculated the same way as the direct external cost categories of transport operating. However, the calculations are not based on the emissions/environmental effects of transport operating, but on all other emissions in up- and downstream processes of transport (life cycle emissions): energy production, vehicle and Infrastructure production, maintenance and disposal.

For calculating the costs of up- and downstream processes it must first be defined what kind of cost categories (effects) should be covered. The most important cost categories to be covered are the climate change costs and the air pollution costs (health costs, crop losses) of up- and downstream processes. Another effect could be the costs due to nuclear power risks, above all in countries where nuclear power plants are an important factor in power generation (see the discussion in section 3.6.4, p. 92 on attempts in Germany to quantify nuclear power risks).

In principle, the calculation of the costs of upstream and downstream processes is the same for the different cost categories: the total emissions of up- and downstream processes (e.g. CO_2, PM_{10}, NO_x, SO_2, etc.) are multiplied with specific cost factors of the corresponding cost category (shadow price: costs per emitted amount of a pollutant).

The main difference between the existing studies is the different kind 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).

Input values

Data requirements:

- Total emissions of up- and downstream processes (e.g. emission of CO_2, PM_{10}, NO_x, SO_2, etc.). The type of pollutants for which emission data are needed is dependent 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).
- Shadow prices of the corresponding cost categories: costs per emitted amount of a pollutant (see corresponding chapters above: 'air pollution costs' and 'climate change costs').

Data sources

- Emission data: emission factors for up- and downstream processes from life cycle inventories for transport (national or international), e.g. Ecoinvent 2004, INFRAS 1995.
- Shadow prices: see data in the chapters above about the corresponding cost categories: above all chapters on air pollution costs and on climate change costs. Specific cost factors can also be taken from existing studies.

Sensitivity analysis

- Variation of the life cycle emission factors.
- Variation of the shadow prices.

Output values

Output values for the well-to-tank emissions (also referred to as 'precombustion') comprise emissions and its related air pollution and climate change costs of the fuel chain as well as of electricity generation for railways. Values for road, rail, inland waterway and air transport are presented in Chapter 3.6.4 (p. 92) for each mode based on TREMOVE model results.

Costs for Infrastructure and vehicle production, maintenance and disposal

This part of external air pollution and climate change costs is not directly Infrastructure use related. Different studies like INFRAS/IWW, 2004a show that the share of these costs is for road transport between 30-40% of total external costs of up- and downstream processes, for rail transport the share is highly dependent of the electricity generation mix (higher 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%.

Table 147 presents the results of total up- and downstream processes (incl. precombustion, vehicle- and Infrastructure-production) from INFRAS/IWW, 2004a.

Table 147 Up- and downstream unit costs for Europe (EU15 plus CH and N). Data include costs of up- and downstream emissions of CO_2 and PM_{10}, plus the costs of nuclear power risks for upstream electricity production

		Unit costs per vkm, pkm, tkm		
	Transport mean	Unit costs in €ct/vkm	Unit costs in €ct/pkm	Unit costs in €ct/tkm
Road	Passenger cars	0.87	0.52	
	Busses and coaches	7.02	0.36	
	Motorcycles	0.33	0.30	
	Vans	1.66		2.24
	Heavy duty vehicles	4.99		0.74
Rail	Rail total	52.29		
	Rail passenger	44.17	0.34	
	Rail freight	79.76		0.24
Aviation	Aviation total	15.41		
	Aviation passenger		0.10	
	Aviation freight			0.74
Waterborne	Water freight	212.62		0.33

Source: INFRAS/IWW, 2004a (data for year 2000).

An overview on bandwidths and the importance of the different aspects of up- and downstream processes can be obtained from the TRL study which uses data from the ExternE project (TRL, 2001a). It includes vehicle production, fuel production and Infrastructure and shows that values differ for different countries (electricity production), fuel types, technologies and locations (rural/urban, type of road).

Table 148 Up- and downstream unit costs for passenger transport in Europe including cost of air pollution and climate change (TRL, 2001a). Damage costs are depicted in Euro/1,000vkm. Low values for fuel production refer to cars running on compressed natural gas

	Up- and downstream processes (base year 1998)		
€ct/vkm	**Vehicle production**	**Fuel production**	**Infrastructure**
Car	0.27-0.48	0.04-0.26	0.29-0.53
Coach	1.1-4.0	0.05-2.0	0.05-2.0
Urban bus	1.1-1.95	0.30-0.78	0.5-0.9
Train	1.5	0	1.5

The output values in the tables above (data from INFRAS/IWW, 2004a and TRL, 2001a) are significantly higher than in the table below (from OSD, 2006), since the data cover the costs of up- and downstream emissions of CO_2 and PM_{10} as well as the costs of nuclear power risks for upstream electricity production. The data below only include the costs of up- and downstream CO_2 emissions.

Table 149 Up- and downstream unit costs for Switzerland. Data only include the costs of up- and downstream CO_2 emissions

		Unit costs per vkm, pkm, tkm		
		Unit costs in €ct/vkm	*Unit costs in €ct/pkm*	*Unit costs in €ct/tkm*
Road	Passenger cars	0.22	0.14	
	Busses	0.85	0.07	
	Coaches	0.72	0.04	
	Motorcycles	0.14	0.12	
	Vans	0.32		0.81
	Heavy duty vehicles	0.92		0.16
Rail	Rail total	7.83		
	Rail passenger	5.59	0.06	
	Rail freight	17.89		0.05

Source: OSD, 2006 (data 2004).

The study by Schmid, 2005 only includes up-and downstream processes for vehicle and fuel production but not for the provision of Infrastructure. On the other hand, it includes a wide range of air pollutants (CO, PM_{10}, SO_2, No_x, NMVOC), so that its values lie between the values of INFRAS, 2004 and OSD, 2006. For passenger cars, the costs of up-and downstream processes are between 0.45 €ct/vkm (diesel, Euro4) and 0.71 €ct/vkm (petrol, Euro1) (Schmid 2005, p. 87).

The analysis of the different studies makes clear that it is important to carefully consider the cost drivers included in the studies before comparing results. Studies differ both on the inclusion of cost factors (vehicle production, fuel production and Infrastructure) and the inclusion of greenhouse gases, air pollutants and nuclear power risks.

G.6 External costs in sensitive areas

Definitions and indicators

The Eurovignette Directive (1999/62/EC and 2006/38/EC) allows for the possibility to apply mark-ups to tolls in the case of roads in sensitive areas, in particular in mountain regions (Alps, Pyrenees, etc.) for cross-financing the investment costs of other transport Infrastructures of a high EU interest in the same corridor and transport zone. However, there exists no clear EU-wide definition of sensitive areas so far. The recently launched and ongoing EU research project ASSET (Efficient transport and environmentally sensitive areas) aims at developing an EU-wide framework of definitions and assessment methods for transport sensitive areas (TSAs), surveying European TSAs and review existing policies affecting them and finally will produce common policy guidelines for the treatment of TSAs in developing transport systems. A specific case study of GRACE (GRACE, 2006c) dealt with external environmental, accident and other costs in sensitive alpine areas.

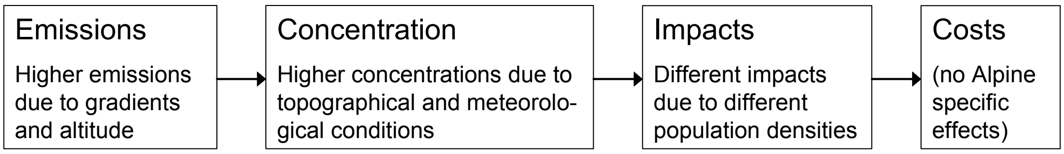
Sensitive areas there are defined as areas:

- Where damages are higher.
  - Because of higher environmental pressures.
  - And/or because of more damaging effects of the same pressure level.
- And possibly where unique natural resources or cultural heritages are in danger.

The GRACE case study is focussing on cost differentials between an Alpine area and a flat, ‘insensitive’ area for road and rail transport and the reasons behind. The method is based on the impact pathway approach. For each step in the pathway a comparison is made between a Alpine area and a flat area is made. The factors for each step are added together to suggest a total cost difference between the Alpine and the flat area. The impact pathway steps considered is Emissions, Concentration and Impacts.

Figure 37 gives an exemplary overview on the methodology applied to derive cost factors for sensitive areas for health costs.

Figure 37 Impact pathway approach for health costs due to air pollution: Effects and Alpine specific characteristics



Source: GRACE, 2006.

Basically different costs for sensitive areas arise from the following effects:

- Generally higher emissions (air pollutants and noise) due to:
  - Gradients (air pollutants and noise).
  - Higher altitudes (air pollutants).
- Higher concentrations of air pollutants due to:
  - Topographical conditions.
  - Meteorological conditions.
- Higher noise exposition due to temperature inversions and reflections.
- Slightly higher accident rates in alpine areas due to longer braking distances on descending roads.
- Different impacts of air pollution and noise exposure due to different population densities.

As the main result in GRACE, 2006c factors were derived between the costs in Alpine and flat areas – differentiated for passenger and goods transport and for different indicators (air pollution, noise, accidents).

Air pollution

The focus lies on those pollutants which cause local damages. Pollutants which are formed at considerable distances from the emission source (e.g. nitrate aerosols from NO_x) or are transported over large distances are important to consider when analysing the full costs of air pollution, but not when additional costs of traffic through mountain areas have to be quantified. The only pollutant with local effects is PM_{10}. The effects of primary PM_{10} (with local effects) and secondary PM_{10} (with regional effects) has, however, to be disentangled. It follows that the costs per vkm or trainkm for crop losses and forest damages are equal in flat and Alpine areas, since these effects are caused by regional pollutants. The factors derived in GRACE, 2006c apply to the health costs and damages to buildings which are caused locally.

Table 150 present the results for air pollution for road and rail transport.

Table 150 Results for local air pollution for road and rail transport

Road transport

Impact pathway	Cost driver	Factor Alpine/flat	Description in brief/source
Emissions	Gradients	1.06 (1.02-2.28)	More pronounced for cars than for HGV's (own calculation based on UBA and BUWAL 2004)
	Altitude	1.35 (1.10-1.60)	Higher emissions due to 1000m higher above sea level (BUWAL, 1995; EMPA, 2002)
Concentration	Topographical and meteorological conditions	4.22 (2.50-6.25)	Mainly due to inversions (case study, see text, Swiss data)
Impacts	Population density	0.87	Population density in permanent settlement area (own calculation based on data from the Gotthard motorway)
Total		5.25 (2.44-19.8)	5.35 (2.5-19.8) for cars and 5.15 (2.4-11.3) for HGV's

Rail transport

Impacts pathway	Cost driver	Factor Alpine/flat	Description in brief/source
Emissions		1	No difference (see text)
Concentration	Topographical and meteorological conditions	4.22 (2.50-6.25)	Mainly due to inversions (case study, see text, Swiss data)
Impacts	Population density	0.83	Population density in permanent settlement area (own calculation based on data from the Gotthard rail line)
Total		3.5 (2.08-5.19)	

Source: GRACE, 2006c.

The overall factor for locally emitted pollutants of road transport turns out to be about 5.25 (see Table 150). For cars the factor is slightly higher (5.35) than for HGVs (5.15). For rail transport the overall factor of 3.5 is smaller (sensitivity interval 2.1 – 5.2). The reason is that the higher emissions due to the gradients are not emitted along the rail track, but at the location of electricity production.

For air pollution only primary PM_{10} causes local effects, while secondary PM_{10} is a regional pollutant. Therefore the damages caused by PM_{10} have to be split up into locally and regionally caused parts. The factor derived above is only valid for the local effects. Therefore the total factor for total air pollution from road is only 2.1, since the factor of 5.25 for local air pollutants is reduced by the regional pollutants with a factor of 1 (for rail the reduction is much smaller (from 3.5 to 3.3), since most damages are caused by local pollutants).

Noise

For road noise higher motor noise emissions are caused by gradients. For rail noise emissions seem not to be higher than in flat areas due to the fact that railway noise is mainly caused by the moving rolling stock rather than from engine noise. Furthermore, noise propagation conditions are better in mountain valleys than in flat areas due to temperature inversion and amphitheatre effects and reflections. Due to these effects a much larger distance from the road or from the rail track is necessary to reduce noise to a certain level along mountainsides than in a flat area.

The Table 151 gives an overview on the results found in GRACE.

Table 151 Results for noise road and rail transport

Road transport

Impact pathway	Cost driver	Factor Alpine/flat	Description in brief/source
Emissions	Gradients	1	No quantification available
Concentration/Noise level	Topographical and meteorological condition	5 (2.5-12.5)	Higher noise propagation due to inversions, the amphitheatre effect and reflections (case study, see text)
Impacts	Population density	0.83	Population density in permanent settlement area (own calculation based on data from the Gotthard rail line)
Total		4.15 (2.1-10.4)	

Rail transport

Impact pathway	Cost driver	Factor Alpine/flat	Description/source
Emissions	Gradients	1	No quantification available
Concentration/Noise level	Topographical and meteorological conditions	5 (2.5-12.5)	Higher noise propagation due to inversions, the amphitheatre effect and reflections (case study, see text)
Impacts	Population density	0.83	Population density in permanent settlement area (own calculation based on data from the Gotthard rail line)
Total		4.15 (2.1 – 10.4)	

Source: GRACE, 2006c.

Due to the lower population density in Alpine areas and the higher emissions, the final result for road noise is also a factor of 5 (2.3 – 19.8). For rail the results are similar; noise propagation conditions are identical, the population density along the Gotthard rail line is slightly lower than along the Gotthard motorway, but emissions seem not to be higher in Alpine areas. Thus the factor for rail is 4.2.

An additional reference for external costs in sensitive regions can be obtained from the case study calculations of the RECORDIT project. For the calculation of noise, the case studies use the general bottom-up methodology of RECORDIT for calculation of road and rail noise costs including ressource costs, opportunity costs and disutility. While the 'Cost of illness' measure is used for the first two categories, the third category is based on willingness-to-pay/accept to avoid/ compensate for the loss of welfare (RECORDIT, 2001). Within the case study, GIS data is used for assessing population density which differs considerably within the different case studies. For road transport, the external noise costs for three different case studies have been calculated representing low, medium and high population densities (Table 152).

For rail, nine case studies have been calculated including different population densities. Next to the population density, the length of the trains and loading factors are cost-driving factors which lead to differences in external costs. Table 152 gives an overview on four case studies.

Table 152 Marginal external costs for different population densities

Transport mode	Case study	Population density	Time	Cost per vkm (Road) Cost per tkm (Rail)
Road	Basel-Venlo	Medium	Night	1.29 €ct/vkm
	Bergamo-Chiasso	Low	Night	0.48 €ct/vkm
	Stuttgart (urban)	High	Night	85 €ct/vkm
			Day	26 €ct/vkm
			Average	43 €ct/vkm
Rail	Basel-Karlsruhe	Medium	Average	31.3 €ct/tkm
	Brenner-Kufstein	Low	Average	14.5 €ct/tkm
	London	High	Average	99.9 €ct/tkm

Source: RECORDIT, 2001.

Unlike the results of GRACE, 2006c, the RECORDIT calculations show lower marginal costs in sensitive regions as only the population density is considered. As the study by GRACE, 2006c does not explicitly illustrate the effect of lower population density but only shows the overall values (including effects that adjust external costs upwards and downwards), the results of RECORDIT can be seen as a supplementation to the results of GRACE, 2006c.

Other effects

The GRACE project also presents some pilot calculations regarding further effects. However, all additional effects are difficult to quantify in monetary values and from a marginal cost point-of-view rather irrelevant. The following effects have been analysed (Details in GRACE, 2006c):

- **Visual intrusion**: Visual intrusion is more severe in Alpine areas where the traffic routes can be seen from much farther away (from the mountain flanks) than in a flat area. However, visual intrusion is rather irrelevant for the marginal costs, but a relevant alpine-specific cost factor (average costs). The total factor for average costs (per vkm or train-km) is about 10.7 for road (sensitivity interval 4.8 – 22.5) and about 5.3 for rail (2.4 – 11.1).
- **Recreational value of mountain areas / tourism**: tourism is about 10 times more important in the Alps than in a flat area and can account for more than 25% of the local GDP. Large traffic routes deteriorate recreational qualities. Thus, while major traffic routes have little influence on tourism in flat areas, they can considerably weaken the local economy in Alpine areas. However, it must be noted that these effects depend mainly on whether or not there is an Infrastructure, not on how many vehicles are driving on it. Hence, if one could monetize these costs (which is not possible so far), we would derive average costs, while marginal costs are virtually zero.
- **Further environmental effects**: reduced carrying capacity of alpine ecosystems with respect to pollutants, damages to protective forests, pollution of rivers and lakes, etc. However, most of these effects are caused by regional and/or global pollutants and hence cannot be attributed the local traffic itself.

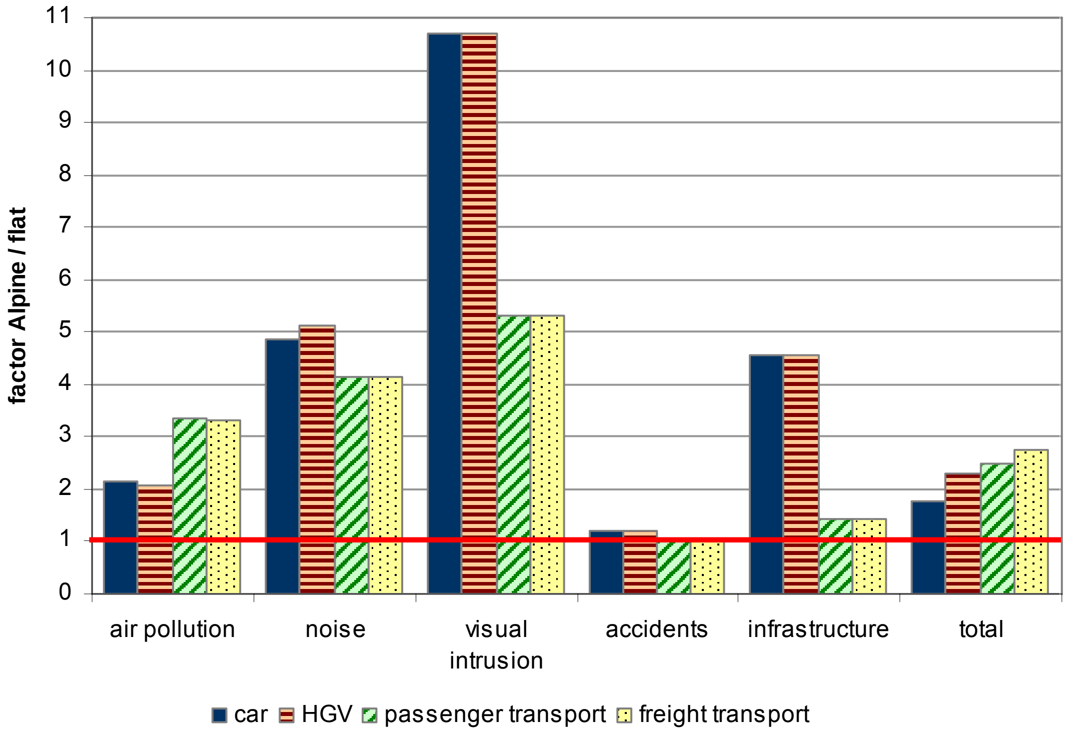
Accidents

Accidents in tunnels and on bridges can have more serious consequences than accidents on a ‘normal’ traffic route. Moreover, on descending slopes the braking distance is larger. However no evaluations on accident rates for Alpine and flat areas exist. Therefore the GRACE case study (GRACE, 2006c) evaluated detailed accident data from the Swiss motorways to fill this gap. In a comparison between the Gotthard motorway and the main motorway in the flat area of Switzerland the causality rate (casualties per vkm) on motorways was 1.22 times higher in the Alpine area. In contrast, it was assumed that rail accidents are identical in Alpine and flat areas, because the external accident costs of rail freight transport are almost negligible. Hence, no evidence could be found that the costs are higher in an Alpine environment.

Synthesis

Figure 38 summarizes all the results for the factors between Alpine and flat areas (reduced factors for total instead of local air pollution are used). For road transport the highest factor of more than 10 is observed for visual intrusion. For noise and Infrastructure costs a factor of 5 is estimated. Effects of local air pollution are also in that magnitude. But due to the regional air pollutants the factor is about halved to 2.1. The factor for accidents of 1.2 is again about half of this.

Figure 38 Factors Alpine/flat for the different effects for road (car and HGV) and rail transport (passenger and freight transport)



Source: GRACE, 2006.

The overall factor for road traffic is around 2 (weighted by the costs per vkm), the factor for rail transport is slightly higher with about 2.5. The main reason for that are the higher particle emissions of trains while braking in slopes.

Valuation of the existing studies

The main study cited here (GRACE, 2006c within the GRACE project) is the only available study including the full range of cost-driving factors in sensitive regions. It includes differences in meteorological conditions, topographical differences as well as accident costs and costs of visual intrusion.

The RECORDIT project analyses external noise costs for different transmodal case studies for different transport corridors (RECORDIT, 2001). Although it includes the differences in population densities for the calculation of external costs on different stretches of the transmodal solutions, it does not include a further differentiation between sensitive areas and flat areas as illustrated by GRACE, 2006c. Thus, the results of RECORDIT relating to sensitive areas go into a different direction than results by GRACE as they only include the cost-reducing factors (population density) but not the cost-driving factors (higher air emissions and concentrations in sensitive areas).

The values presented above only refer to increased costs in alpine areas compared to flat areas and cannot be transferred to other transport sensitive areas.

G.7 Costs of energy dependence

Another category of external costs of transport is the costs related to (oil) energy dependence. The strong dependency of an economy on a certain energy resource (such as oil) can lead to considerable economic costs. Economic costs not only occur after oil price shocks, but also because of higher oil prices due to a world oil supply that is controlled by a small number of countries. Until now, only few studies have investigated these costs. The study of Greene and Ahmad, 2005 has investigated the costs of U.S. oil dependence. This study is an update study of two older studies from Greene and Tishchishyna, 2000 and Greene and Leiby, 1993. In addition, a study by Parry and Darmstadter, 2003 gives a second assessment of the costs of oil dependency.

According to the study of Greene and Ahmad, 2005 oil consuming economies include three types of economic costs, when monopoly power is used to raise the price of oil above competitive market levels. The costs of oil dependence are therefore mainly a consequence of market failure. The three cost categories are:

1 Costs due to transfer of wealth.
2 Potential GDP losses: reduction of the maximum output an economy is capable of producing due to the increased economic scarcity of oil.
3 Macroeconomic adjustment costs: costs of adjusting to sudden, large price changes.

Parry and Darmstadter, 2003 also take account of the fact that not only the oil producing nations have monopoly power but that the U.S. as largest oil importer partly needs to be seen as monopsony. This aspect can partly compensate the effect of oil dependency so that external costs are lower than in studies which do not take account of this aspect.

The costs in the first category of Greene and Ahmad, 2005 represent a transfer of wealth from oil consumers to oil producers. This wealth transfer is a consequence, when oil suppliers use market power to raise oil prices above competitive market levels. However, the transfer of wealth is not a loss to the global economy, but only to the economy of nations with a net import rate of oil. Oil exporting countries, on the other side, profit from this transfer of wealth. Therefore, this first cost category is only relevant when having a look on the external costs of transport for a national or regional economy.

The second category represents costs of a potential GDP loss due to the raise of the oil price above the competitive market level. When the oil price is raised above the competitive market level, the higher price signals the economy that oil is scarcer. In an economy where oil is scarcer, the ability of economies to produce output is decreased. This economy-wide loss of ability to produce output is called a loss of potential GDP. The loss of potential GDP can be measured by summing the losses of producers' and consumers' surplus caused by higher oil prices throughout the whole economy.

The macroeconomic adjustment costs (third cost category) arise when a sudden price shock brings the economy out of equilibrium, wages and prices are not able to adjust rapidly enough and underemployment of labour and capital results.

The methodology how to quantify these three cost categories is not described in detail here. For more information, please refer to Greene and Ahmad, 2005.

The dynamics over time of the three cost categories differs. The transfer of wealth (1st category) and the macroeconomic adjustment costs (3rd category) respond immediately after a sudden raise of the oil price (e.g. after the oil shock in 1974 and the sudden price rise in 1979/80). The potential GDP loss (2nd cost category), however, responds much more slowly to such price changes because it is a function of the whole economy (indirect effect).

Greene and Ahmad, 2005 quantified the total costs of oil dependence to the U.S. economy between 1990 and 2005. According to their calculations, the total costs over this period were 3.6 trillion USD (= 3,600,000 million USD) in constant prices (2,000 dollars). Adjusted to present values, the costs even amount to 8 trillion USD. The three cost components of oil dependence costs are about equal in size, which means that each of the three components makes up around a third of the total costs.

Greene and Ahmad, 2005 also calculated the costs for only one year. According to their forecast, the total costs of oil dependence in 2005 amounted to over 200 billion USD (= 200,000 million USD). If this figure is divided by the total amount of oil (crude oil and petroleum) consumed in the United States in 2005 (7,593 million barrels), the average costs of oil dependence are 26.3 USD per barrel or 0.166 USD per litre of oil. Assuming an average fuel consumption of 10 litre per 100 km of a passenger car in the U.S., the average costs of oil dependence are around 1.7 $cts per vehicle-km (i.e. around 1-1.5 €ct per vehicle-km). A new study by Leiby, 2007 attributes the costs of the U.S. military presence in the

Middle East to the enhancement of oil security which leads to higher external costs than any other study (Table 153).

In addition to the study of Greene and Ahmad, 2005 there is a number of other studies that have investigated the costs of energy dependency or the costs of security of energy supply. Mainly, three methods to determine the costs of energy dependency can be differentiated, using three different reference points for comparison with the current level of oil imports and consumption: 1. competitive market prices, hypothetical perfectly competitive market conditions; 2. optimal levels of imports given market imperfections; 3. a marginal change in imports from the current level.
Most of the studies on the costs of energy dependence are U.S. studies on the costs of US oil imports (Leiby, 1997; NRC, 2002; Parry and Darmstadter, 2003; Leiby, 2007). The two major costs mentioned are economic losses as a result of oil prices above a competitive market level (due to market power of the oil suppliers) and costs of oil supply disruptions. For Europe, there has been found only one study from Joode et al., 2004, which investigates the cost and benefits for certain policies to enhance security of energy supply.
The results from the mentioned U.S. studies for the energy dependency costs range from 3.6 UDS per barrel (Leiby, 1997) to 5 USD/barrel (NRC, 2002; Parry and Darmstadter, 2003) to 13.6 USD per barrel in the latest study of Leiby, 2007.

Table 153 Marginal external costs of oil dependency from different studies in €/l mineral oil

Study	**Baseyear for calculation**	**USD/barrel**	**€ct/l mineral oil****	**Specific aspects considered**
Leiby, 1997	1993	0.23-9.91	0.17€ct/l – 7.2€ct/l	Different scenarios from ‘zero probability of net disruption’ to ‘Monopsony of US and monopoly of OPEC’
NRC 2002	Assumption: 1999*	5	3.35€ct/l	
Parry and Darmstadter, 2004	Based on NRC 2002	5	3.35€ct/l	Includes aspect of monopsony
Leiby 2007	2004	13.6	10.63€ct/l	Includes costs of enhancing oil security (strategic oil reserves, military presence in Middle East)

Notes: * The NRC 2002 study is an update of earlier work, the base year does not become clear.
** Values are transformed with the relevant annual exchange rate according to the Swiss National Bank.

Results on the external costs of energy dependence are at the moment only available for the U.S., as especially oil security is a more political issue in the U.S. than in Europe. Due to different economic structures and energy mixes, the U.S. values cannot directly be transferred into European values but need to be seen as indicative values only.

A Best Practice approach for Europe is not yet available and would need to include information on the degree of oil dependency of the relevant country, its energy intensity, the importance of energy intensive industries as well as the market position of the country or the European Union as a whole as market force on the demand side. One should take care when trying to assess the EU costs to take account of:

1 The risk premium already in the crude oil price.
2 That the US estimates may include the related defence costs which are far lower for the EU.

H Glossary and Abbreviations

Accident rate	Accident rates describe the probability of an accident per 1,000 vehicle kilometres.
Average costs	Total costs in a period, divided by the quantity (output) produced/consumed in that period. Long term average costs include a share of fixed costs (e.g. costs associated with expansion of existing infrastructure).
Barrier effect	Separation of adjacent areas due to road or rail Infrastructure investments; negative impact on human beings (e.g. recreation), or on flora and fauna (e.g. constriction of habitat).
Contingent valuation Method	Valuation technique which asks people directly how much they are willing to pay/to accept for improving/deteriorating environmental quality. Method is based on the -> stated preference approach; it is the only method that allows the estimation of -> existence value. The values obtained are compared with other opportunities, in order to make visible a budget restriction.
Cost-effectiveness	Seeks to minimise the costs of achieving a given (e.g. environmental) objective/target. This principle is a ‘second-best’ efficiency criterion, often used when a full cost-benefit analysis is not feasible.
CO_2	Carbon dioxide is a major greenhouse gas i.e. it contributes to the climate change.
Decibel	(dB(A)) Decibel (dB) is a measure for the intensity of sound energy. According to the characteristic of human ears the relationship between sound energy and dB is logarithmic. Several filters have been defined to achieve a better adaptation of dB measurements and the loudness impression of human beings. The most commonly used type of filter is the (A) filter.
Defensive expenditures	Valuation technique wherein a value for environmental quality is inferred from people’s (voluntary) expenditures aimed at improving their situation.
Dose-response-functions	Functions showing the connection between a specific concentration and its specific effects. They are especially used for the measurements of air pollution impacts. For example health: Impacts on mortality due to specific air pollution concentrations.

Efficiency	Refers to the efficient allocation of scarce resources. At the margin, resources should be used by the individual who is willing to pay the most for them (i.e. where marginal social cost equals marginal social benefit).
Elasticity	Proportional change in demand in response to a price increase or decrease (price elasticity); or reaction in total demand after an increase/decrease in income (income elasticity).
Environmental effectiveness	Effect on the environment that a given policy response generates. This criterion ignores the economic costs that may result from implementing the policy.
Existence value	Economic value which people attribute to something purely for its existence (no consumption is fore-seen); can only be estimated via the -> contingent valuation method.
Externality (external cost)	Economic cost not normally taken into account in markets and in the decisions made by market players.
Fixed cost	Cost which are not depending on the traffic volume (in the short run).
(Full) fuel cycle	Complete fuel cycle; comprising discovery, depletion (mining), processing, transport and use of an energy resource.
Free-flow situation	Traffic situation without congestion, used as a reference level. Usually an Off-Peak-Situation can be used for urban traffic.
GDP	(= Gross Domestic Product). The GDP is the sum of all goods and services produced within a country and a year. GDP per capita can be regarded as the relative economic power of a country per inhabitant.
HC/VOC	Hydrocarbons/Volatile Organic Compounds contribute to ozone formation. Some like benzene, butadiene and benzo-a-pyrene have been found to have impacts on public health.
HDV	Heavy duty vehicles (Road trucks) above 3,5 tonne gross weight.
Hedonic pricing	Valuation technique which infers a value for environmental quality from rent or property price differentials.
Human value (loss)	Value attributed to human life in excess of the average economic output produced by an individual (e.g. grief, pain, etc.). –> VSL

Internalisation	Incorporation of an externality into the market decision making process through pricing or regulatory intervention. In the narrow sense internalisation is implemented by charging the polluters with the damage costs of the pollution generated by them, the corresponding damage costs resp. according to the polluter pays principle.
LDV	Light duty vehicles (Vans up to 3,5 tonnes gross weight).
Life-cycle based approach	An approach, where up- and downstream processes of transport services are included (i.e. vehicle production and disposal, fuel cycles of the electricity production, etc.).
Marginal costs	Costs related to a small increment in demand (e.g. an extra vehicle-kilometre driven). Long-term marginal costs include the capacity expansion needed to service increased traffic demands.
MC	Motorcycle.
Mohring effect	Positive relationship between additional demand and quality of service in scheduled transport. Herbert Mohring has first shown the positive externality of additional demand in local bus services in the late 1960s.
NO_x	Nitrogen oxides, which are formed primarily by fuel combustion and contribute to the formation of acid rain. They also combine with hydrocarbons in the presence of sunlight to form ozone.
Opportunity costs	Costs which arise when a particular project restricts alternative uses of a scarce resource (e.g. land-use of Infrastructure prevents an alternative use, such as recreation). The size of an opportunity cost is the value of a resource in its most productive alternative use.
Option value	Value of keeping open the possibility of consuming a good/service at some time in the future.
PCU (=PCE)	(= Passenger Car Units / Passenger Car Equivalent) PCU is used in order to standardise vehicles in relation to a passenger car. Speed and lengths differentials are most common. Within this study they are used for the allocation of different costs (e.g. nature and landscape, urban effects, congestion).
pkm	Passenger kilometre
PM	Particulate matter. Fine particulate (PM_{10} or $PM_{2.5}$ with a diameter of less than 10 pm and 2.5 pm respectively) can contribute to the chronic and acute respiratory disease and premature mortality, as they are small enough to be inhaled into the lungs.

	Larger particles decrease visibility and increase fouling.
Polluter-pays-principle	Political/economic principle which stipulates that the user should pay the full social cost (including environmental costs) of his/her activity.
Precombustion	Production, storage and transportation of energy for its final use.
Prevention approach	Valuation technique for estimating externalities whereby the costs of preventing damage are used as a proxy for the cost of the damage itself for society.
Purchasing power parity	(= PPP) The purchasing power parity describes the amount of goods or services which can be bought in a particular country compared to a reference country. The PPP necessarily must be expressed relative to a particular currency.
Revealed preference	Valuation technique wherein consumers choices are revealed in the marketplace (e.g. by the purchase of a good).
Risk approach	Valuation technique for estimating externalities whereby external costs inferred from premia for risk factors (e.g. the cost of insurance, or of risk diversification).
Risk value	Monetary value for pain, grief and suffering of an average transport victim, mainly used for the estimation of accident fatalities.
Shadow Prices	Shadow price is the marginal opportunity cost of the use of a resource (i.e. the loss of benefits caused if this resource cannot be used the next best purpose).
Social costs	The sum total of internal and -> external costs.
Social cost benefit analysis	Systematic estimation of all costs and benefits of a project that are relevant to society. Includes both - technological externalities and - pecuniary externalities, as long as the latter are not merely redistribution of income.
SO_2	Sulphur dioxide contributes to the formation of sulphate aerosols and is the primary pollutant in the formation of acid rain. It can also cause respiratory system damage in humans.
Speed-flow function	A mathematical or graphical relationship between the flow on a particular road, and the speed of that traffic flow. As traffic flows increase, traffic speeds eventually fall.
Stated preference	Valuation technique wherein monetary estimates are derived from hypothetical statements by individuals about their preferences. The typical

	method used is a questionnaire approach (e.g. - contingent valuation method).
Technological Externality	External effect that is not actively or voluntarily processed through markets, which results in economic inefficiencies. This occurs when some firm or individual uses an asset without paying for it. Technically they occur where one productive activity changes the amount of output or welfare which can be produced by some other activity using any given amount of resources. Negative technological externalities reduce the amount of output or welfare which an economy can produce with any given allocation of inputs.
tkm	Tonne kilometre.
Traffic mode	Category of means of transport (road, rail, aviation, shipping, etc.).
Traffic volume	Measure for traffic activity which can be expressed in vehicle-kilometres, or in passenger/tonne kilometres.
UCPTE	(Union pour la coordination de la production et du transport de l'éléctricité) International mix of electricity production, varying slightly every year. The mix used for the forecast 2010 is based on: - 50% fossil fuels. - 15% hydro generation. - 35% nuclear generation.
Unit costs	Costs per unit of service or goods provided (e.g. traffic volume).
(User) charge	Charge imposed on the user of a good (e.g. road Infrastructure), often linked to the costs generated by his or her use.
Utility (Private)	Private benefit received by an individual due to his/her consumption of a good or service, or by the existence of that good/service.
Utility (Social)	The aggregate of private utilities in an economy.
Valuation	Process of estimating the economic value of a certain quantity of a transport good/service; generally expressed in monetary terms.
Value of a live year	(=VOLY) Approach applied esp. for the valuation of air pollution related health effects. The approach values lost live years and not premature deaths (see also VSL). The value of a live year can be derived from the VSL taking age, life expectancy and discount rates into account.
Value of statistical life	(=VSL) The value of statistical life is a methodology to find a monetary equivalent to a killed or injured human being. VSL is the opportunity costs of a saved human life.

Variable costs	(Fixed costs) Full costs can be subdivided into fixed costs and variable costs. Fixed costs remain constant with varying use of a transport system (e.g. supplier- or capital costs for road and rail networks or administrative costs). The expression 'fixed' in the way it is used in the Real Cost Scheme means 'fixed in the short run' (without consideration of new Infrastructure), as in the long run also Infrastructure supply costs vary with the traffic demand that is in the long run all costs can be made variable. Main relations of variable costs are kilometres driven or the amount of vehicles (e.g. crossing a specific section).
Vkm, Vehicle-kilometre	One kilometre travelled by a single vehicle.
Willingness to pay (= WTP)	The willingness (or ability) of people to pay for the abolishment, reduction or reception of a particular matter can be estimated by two ways: (1) by - stated preference surveys and by -> hedonic pricing methods.

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