JRC Scientific and Technical Reports

Maritime transport - Report 1

Review of the measurement of external costs of transportation in theory and practice

Authors A. Miola , V. Paccagnan, M. Turvani, V. Andreoni,
A. Massarutto, A. Perujo

EUR 23714 EN - 2008

EUROPEAN COMMISSION

Institute for Environment and Sustainability

The mission of the Institute for Environment and Sustainability is to provide scientific-technical support to the European Union's Policies for the protection and sustainable development of the European and global environment.

European Commission
Joint Research Centre
Institute for Environment and Sustainability

Contact information
Apollonia Miola
Address: Via Enrico Fermi TP441 Ispra (VA) Italy
E-mail: apollonia.miola@jrc.it
Tel.: +39 (0332)786729
Fax: +39 (0332)785236

http://ies.jrc.ec.europa.eu/
http://www.jrc.ec.europa.eu/

JRC 49328

EUR 23714 EN
ISBN 978-92-79 -11279-9
ISSN 1018-5593
DOI 10.2788/77724

Luxembourg: Office for Official Publications of the European Communities

Printed in Italy

Summary

In the last years public concerns regarding the environmental impacts of maritime transport have been increasing. This is due to the fact that, despite the better environmental performance of this mode of transport with respect to other modes, its overall impacts will be out weighted by the expected increase in the volume of ship movements. In order to define effective measures to internalise the external costs of maritime transport it is necessary to assess these costs and find adequate methodologies to evaluate them.Besides external costs estimation, it is important to understand the degree of internalization of such costs, so as to give some insights on how to apply policy instruments that should be informed by efficiency and equity principles.

For this reason a study that aims at defining a framework for estimation of maritime external costs have been developed. The study consists of two tasks: (1) review of the theory and practice of measurement of external costs in transport; (2) definition of a general methodology to estimate environmental costs for maritime transport.

This report carries out the first task, by summarising the state of the art in evaluation of transport externalities. Different transport modes have been considered through a comprehensive review of theoretical and empirical studies, by carrying out both EU funded research and national studies.

This work is organised as follows. In the first paragraph the different components of external costs, which are considered in evaluation studies, are defined. This will make possible to clarify the elements that should be considered when estimating external costs. In the following paragraph the approaches used to estimate external costs are described. Next, the economic literature regarding external cost estimation is reviewed, and the most relevant EU-funded projects are summarised. Then, the report describes whether and how national environmental agencies or other public entities are considering the issue of maritime external cost accounting. This report concludes by pointing out how the findings of this review can be transposed to the case of maritime transport.

Table of Contents

List of Tables

List of Figures

1. *The definition of external costs in transportation*

Definition

Generally speaking, external costs are defined as those costs which arise when the social or economic activities of one group of persons have an impact on another group and when that impact is not fully accounted, or compensated for, by the first group (Bickel and Friedrich, 2005). In the case of transport, these costs to society are generated by transport users that, without policy intervention, are not taken into account and borne by the transport users themselves (Maibach *et al*., 2007; Maddison *et al*., 1997; Mayeres *et al*., 1996; Button, 1990). For instance, in the case of transport these costs comprise the costs of air and noise pollution which the individual user will not take into account in deciding how many journeys to make.

In transport sector, external costs emerge because of scarce infrastructure (subjected to congestion patterns) and side-effects borne by other users (such as accidents and environmental impacts).

Before analysing in detail the approaches and methodologies developed to estimate external transport costs, it is necessary to clarify some preliminary methodological issues, such as the fact of considering marginal vs. average costs and the cost components that should be included in the estimation of external costs. In the following analysis we consider all these indexed, by specifying their best use in policy making definition.

Average vs. Marginal Costs

According to Sansom *et al*. (2000), in order to maximise economic efficiency charges for infrastructure uses should be defined according to marginal social costs. Generally speaking, marginal costs are costs related to a small increase in the demand (e.g. an extra vehicle km driven) and can be defined by considering the components defined in the following paragraph.

In transport sector, the distinction between short and long term marginal cost is important with respect to marginal (internal) infrastructure costs: whereas short-run marginal costs do not consider capacity increases and are related to the costs of additional traffic using the existing infrastructure, long-run marginal costs consider the capacity expansion needed to service increased traffic demands.

The distinction between short run and long run marginal costs is not relevant for the external cost components, such as accident and environmental costs. Since in this work we analyse external costs (marginal costs related to infrastructure will be only defined below) we generally refer to marginal external environmental costs, without specifying the time horizon considered.

Moreover, we do not take into account the effect of technological development on transport modes. In particular, we will not consider the well known rebound effect, i.e. the increase in demand which is caused by the introduction of more efficient technologies.

Another issue that should be considered in external cost estimation is the optimal level of disaggregation: generally speaking, since marginal costs are location and time period specific (especially congestion and environmental costs) it is necessary to have highly disaggregated data. Obviously, the level of disaggregation will be determined by data availability. This issue will be analysed in depth in the paragraph below.

Average costs are defined as the total costs divided by the good consumed (in case of transport the overall users for means of transport). The consideration of total and average costs is also fundamental in policy making, since average or total costs can be included in life cycle analyses of integrated transport systems or can be used to compare different alternative modes of transportation.

The choice between marginal or average costs depends on the purposes of the analysis. If the aim is to measure the full costs and compare them with the proportion of total costs that are borne by users, then the average cost is adequate. If the aim is to measure full social costs to identify the policy actions that would entail a more efficient use of transportation and mix of transport modes, then the marginal cost is appropriate.

Marginal Costs components

Marginal social costs (MSC) are expressed as 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.

The components of social marginal cost can be summarised by the following equation (Sansom *et al*., 2000):

(1) $$MSC = MINFR + MOPC + MECC + MEACC + MEEC$$

Where:

MINFR = Marginal infrastructure charge

MOPC = Marginal operating cost

MECC = Marginal external congestion cost

MEACC = Marginal external accident cost

MEEC = Marginal external environmental cost

For all transport modes, infrastructure costs are defined by considering capital (i.e. new investment and asset replacement) and operation costs (maintenance and administration). Operating costs are defined as all monetary costs paid by the operator for the provision of transport service and include: vehicle related costs, costs of personnel and administrative costs. These costs categories will not be analysed in this report. Our focus will be only on external cost components, described hereafter.

Costs of scarce infrastructure emerge because users mutually disturb each other and compete for limited transport system capacity (Maibach *et al*., 2007). They are identified with congestion costs (i.e. the welfare loss associated with the fact that the use by the transport infrastructure by one additional uses entails a cost on other uses that she does not take into account) and scarcity costs (i.e. the costs caused by the fact that infrastructure cannot be used because of overcrowding).

Depending on the mode of transport, type of users, infrastructure characteristics, local travel time and activity alternatives, excess demand can cause several effects, namely: (i) Travel time increases (this component is the most important for estimating congestion costs and is normally estimated through the Value of Time, VOT). The VOT estimate is normally inferred through stated preferences techniques (van Essen et al., 2007); (ii) vehicle provision and operating costs (especially for commercial transport); (iii) disamenities in crowded situations, (due to the increase of the time spent in travelling and uncomfortable conditions); (iv) Additional fuel costs entailed by crowded situations (stop-and-go conditions for road traffic and stacks for planes and ships); (v) reliability; (vi) scarcity of slots, for regulated access infrastructure; equivalent to the opportunity costs to service providers for the non-availability of desired departure or arrival times; (vii) positive externalities of improved or additional services enjoyed for passengers who already used the transport system before the improvement (the so called Mohring-effect).

According to the type of infrastructure facility, congestion effects can be separated into:

- Bottleneck congestion, which appears at road junctions, railway stations, ports and airports through queuing effects. Additional user costs are dependent on the capacity and load-dependent processing time of the facility.
- Flow congestion, intended as the exceeding of carrying capacities of links, which can easily be described by speed-flow diagrams or micro simulation models face the challenge of the partial dependency of vehicle speeds on each other.

Considering **accident costs**, they are related to the fact that transport users can be injured (or even die) following a car/flight or ship accident. However, external accident costs are those social costs related to traffic accidents which are not covered by risk oriented insurance premiums. Therefore the level of external costs does not only depend on the number and severity of accidents, but also on institutional factors (such as the existence of a compulsory insurance system), which affect the degree to which the party responsible for the accident is obliged and able to reimburse the victims.

The most important accident cost categories are material damages, administrative costs (for police and justice administration), medical costs (i.e. real expenses of health sector for accident), production losses (i.e. current and future loss of output) and the monetary values used as a proxy for pain, grief and suffering caused by accidents experienced by transport users (the so called risk value).

In case of mortality, this impact is monetised by using as reference the value of a statistical life (VSL, Viscusi, 1993; Viscusi and Aldy, 2003), defined as the rate at which people are prepared to trade off income to avoid the risk of a premature death. The marginal value of a reduction in the risk of dying is determined by inferring the WTP of individuals to avoid such an effect. The VSL is deemed appropriate for accidental death, whilst its use has been criticised for air pollution mortality, beause the total number of deaths attributable only to air pollution cannot be determined (Rabl, 2003) and pollution is a contributory, not a primary cause of death. For this reasons, it is deemed more adequate to refer to the loss of life expectancy (LE) for premature death following exposure to air pollution and monetise this impact through the use of the value of a life year (VOLY). Both the VSL and the VOLY are estimated through stated preferences methods (see below).

Air pollution costs includes the impacts of different air pollutants produced by vehicles, planes and ships in burning fuels or by producing the electricity necessary for rains. As a consequence, air pollution costs can be divided into health costs (deriving from pollution and noise), climate change, cost for nature and landscape and cost for soil and water pollution (such as biodiversity loss).

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.

The most important pollutants generated by transport activities 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 several impact categories.

First, health costs are entailed by the impacts on human health due to the aspiration of fine particles ($PM_{2.5}$/PM_{10}, other air pollutants). Exhaust emission particles are considered as the most important pollutant. In addition Ozone (O_3) has impacts on human health.

Second, building and material damages are also caused by air pollutants. Mainly two effects are of importance: (i) soiling of building surfaces/facades mainly through particles and dust; (ii) the degradation through corrosive processes due to acid air pollutants like NO_x and SO_2.

Third, crop losses in agriculture and damages forests and other ecosystems are produced by acid deposition, ozone exposition and SO_2.

Finally, Impacts on biodiversity and ecosystems (soil and water/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).

Considering **noise costs**, they are defined as the additional costs of noise caused by adding one vehicle to the existing traffic flow. 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.

Climate change costs have a high level of complexity due to the fact that they are long term and global in nature and that risk patterns are very difficult to anticipate. They must be considered for intergenerational equity reasons, since ignoring them will be equivalent to transfer to the next generation the burden of dealing with climate change. Since climate change effects materialise in the long run and the adjustment path is still unclear, climate change is analysed by considering two scenarios, one coincident with the status quo and one where climate change impacts occur. 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, see below, paragraph 3) is necessary.

Climate change or global warming impacts of transport are mainly caused by emissions of the greenhouse gases (GHG), such as carbon dioxide (CO2), nitrous oxide (N2O) and methane (CH4). To a smaller extent emissions of refrigerants (hydrofluoro-carbons) 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. The impacts of global warming causing external costs can be summarised as follows (Watkiss *et al*., 2005).

1. Sea level rise entails costs for additional protection, in order to avoid loss of dry land and wetland loss.
2. Crops changes in the cultivated area and yields are likely to occur. Agricultural impacts depend on regional changes in temperature and rainfall, as well as atmospheric carbon dioxide levels (and fertilisation).
3. 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.
4. 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.
5. 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. Water supply impacts depend on changes in rates of precipitation and evapo-transpiration and demand changes – including those driven by climate change.
6. 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.
7. 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).
8. Extreme weather events are also likely to increase, with heat waves, drought, floods, and potentially storms, tropical cyclones and even super-typhoons.

Finally, **other impacts**, which are not considered in EU funded studies, are the habitat fragmentation and quality losses caused by the construction of transport infrastructures (hubs, ports, etc.) and effects of traffic on soil, especially 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.

Table 1 – Specification of cost components 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.
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.

Source: Maibach *et al.*, 2007

Table 1 above summarised how the general impacts sketched above should be considered in the different transport modes. Congestion costs are more significant for road transport, especially in urban areas, whilst for scheduled transport it should be intended as excessive waiting time to use the slots. Accidents costs are treated similarly for all means of transport. Air pollution, noise and climate costs highly depend on the distance from polluting source and the exposed individuals and the density of concerned areas, together with the kind of fuel chosen. Nature and landscape impacts are relevant only for new transport networks.

Besides external costs estimation, it is important to understand the degree of internalisation of such costs, so as to give some insights on how to apply policy instruments. Table 2 specifies which part of the marginal social cost should be considered as the external part, by specifying how to treat different transport modes.

Table 2 – Degree of internalisation per cost component and mode of transport

Cost component	Social Costs	External part in general	External part road	External part road and air	External part water
Cost of scarce infrastructure	All costs for traffic users and society based on the difference between the current traffic situation and an optimal situation Time costs Costs of reduced reliability	Cost entailed by additional demand above a certain traffic volume	Difference between marginal and average costs Congestion costs	Difference between WTP for scarce slots and average airport/air control charges	Difference between marginal and average costs
Accident costs	All direct and indirect costs of an accident, e.g.: Material costs Medical costs Production losses Suffer and grief	Part of social costs which is not considered in own risk anticipation and not covered by insurance	Additional costs for the health sector WTP for fatality risk reduction	WTP for fatality risk reduction (depending on insurance systems)	WTP for fatality risk reduction
Environmental costs	All damages of environmental nuisances Health costs Material damages Biosphere damages Long term risk	All remaining costs	Total damage to society and nature	Total damage to society and nature	Total damage to society and nature

Source: van Essen *et al*. (2007)

The following table summarises whether the different costs components described above (by considering different transport modes) are treated in the EU funded projects considered in this review.

The measurement of external costs in transport constitutes the object of this study. In the following paragraphs we will analyse more in depth these cost components by considering estimation approaches adopted by different EU funded projects, the data used in estimation, the estimation results, together with the sources of uncertainty and discrepancies in results with comparison to other projects.

This review will consider all the modes of transport (road, train, airport, waterborne transport), different transport sectors (passengers, commercial, short and long distances) and different situations (rural, urban, peak and non peak hours, etc.). Each study will be analysed taking into account the estimation approach used and the results (i.e. total and per unit values for external costs, marginal and average cost estimates).

Table 3 - Overview of External Cost components considered in EU funded projects

EU project	Transport mode	Cost of scarce infrastucture	Accident costs	Air pollution – Human health	Air pollution – nature	Noise	Climate change	Nature and landscape
GRACE	Road	X	X	X	X	X		
	Train	X			X	X		
	airport	X		X			X	
	In-land nav	X		X			X	
	maritime	X	X	X			X	
UNITE	Road		X	X	X	X	X	
	Train		X					
	airport					X		
	In-land nav		X	X			X	
	maritime		X	X	X		X	
RECORDIT	Road	X	X	X		X		
	Train	X	X	X		X		
	airport							
	In-land nav	X	X	X		X		
	maritime							
SPECTRUM	Road			X		X		
(review)	Train			X		X		
	airport			X				
	In-land nav							
	maritime							
HEATCO	Road	X	X	X		X	X	
	Train	X		X		X		
	airport					X		
	In-land nav							
	maritime							
NEWEXT	Update IPA			X	X		X	

Source: Own elaboration.

2. *Approaches for estimating transport external costs*

In this paragraph we will recall each cost component introduced above and specify what are the approaches used to estimate the related external costs.

Generally speaking, two general approaches are adopted, i.e. the bottom-up and top-down one, both having advantages and pitfalls. For instance, the estimation of marginal costs is usually based on bottom-up approaches, which consider specific traffic conditions (by referring to case studies). In this approach, impacts of emissions to health, water and soil are monetised following the impact pathway approach. For example, in the case of road transport, the impact of a single vehicle will be determined by considering its technical characteristics together with local environmental data (so as to estimate its impact on the pollutant concentrations). Then, through adequate dose-response functions, the impact of the increase of concentrations due to the use of a single vehicle will be assessed. Finally, all the impacts of the single vehicle are summed up to derive the aggregate impact of that mode of transport. Uncertainties about impact estimates (and consequently on external cost valuation) derive from uncertainties related to the slope of the "dose-response" function and the contribution to ambient concentration of a given pollutant emission.

In order to get national averages of external cost, the estimation of average costs are based on top-down approaches using national data. For example, in the case of SO_x, the external cost of a mode of transport will be derived by considering the total concentration of this pollutant (for example at national level) and by determining which part of the total concentration is imputable to transport sector and to the specific transport mode considered.

It is important to note that each approach has advantages and weaknesses, so none of the two is superior to the other. In particular, the top-down approach is more suitable for deriving average costs. On the one hand, they are more representative on a general level and make possible to compare between modes of transport. 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 bottom-up is more appropriate when dealing with marginal cost valuation: they are more precise and accurate, with potential for differentiation. However, they are costly and difficult to aggregate to get average figures for transport clusters or national averages.

In practice a mixture of bottom-up and top-down approaches (with representative data) should be combined.

Let's now discuss more in depth how these approaches are applied to estimate each cost component introduced in the previous paragraph.

Cost of scarce infrastructure

For what concerns the cost of scarce infrastructure, 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). For this cost component, marginal cost estimates are deemed more appropriate than average cost estimates (Safirova and Gillingham, 2003). In fact, the latter do not take into account the externality each user engender on other users and, as a result, tend to underestimate the true cost of congestion. These authors also suggest avoiding defining congestion costs simply as the difference between actual traffic speeds and no-traffic speeds, since this would imply an overprovision of road space (it is nor realistic to bring all traffic to free-flow condition). For policy definition, marginal costs are definitively more appropriate. They should be valued according to real traffic conditions.

Formally, marginal external congestion costs at a given traffic volume Q can be computed as follows (Maibach *et al*., 2007):

(2) $$MEC_{cong}(Q) = \frac{VOT}{V(Q)} * \varepsilon$$

Where:

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

In order to get marginal external cost for scarce infrastructure, the inputs needed are value of time savings, speed-flow relationships and elasticity of demand to traffic conditions. Value of time savings is normally 50% to 150% above the free-flow time valuation (Maibach *et al*., 2007). Speed-flow functions describe how the average speed (s) is influenced by traffic flow, defined as the number of passenger car units per hour (Mayeres *et al*., 1996). They are normally computed from simulations with a network model. Elasticity of demand to traffic patterns can be computed through sophisticated models, which make possible to consider user reactions to a specific situation.

Usually the estimates are elaborated for different traffic networks (classified as metropolitan/urban/interurban, single/multiple lanes). The evidence for congestion costs on road transport is much more elaborated than for congestion and scarcity in scheduled transport. Nevertheless, the estimates vary considerably, depending on the type of infrastructure, the speed-flow characteristics and the input values such as the value of time (see below).

To conclude, we remind the data necessary to carry out these analyses, as summarised in Table 4 below (UNITE D2).

Table 4 - Data needed to estimate the costs of scarce infrastructure

Data	Specification
Cost values (for all modes of transport)	Cost value for travel, waiting time, crowding, search time, energy costs
Cost functions	Speed-flow relationships, speed-fuel relationships
Traffic data	Speed during congestion, least acceptable speed
Congestion data: road	For urban and interurban: length (km or vehicles), duration, number of lanes, traffic mix, causes Average daily inter-urban traffic, population in urban study areas
Congestion data: rail, air, waterborne	Distribution of arrival over time, connection times, delay probabilities, demand (passengers and goods for working days and weekends)

Accident costs

Regarding accident costs, there are many studies on total (social) accident costs (as defined above). Not many studies so far have however focussed on (marginal) external accident costs, defined according different traffic conditions. Even this cost component could be estimated following a top-down or bottom-up approach. In particular, the bottom-up approach (see UNITE and GRACE projects) aims at estimating marginal accident costs depending on traffic volumes. The magnitude of the costs depends on the risk elasticity (i.e. the correlation between traffic levels and accidents) and on the assumption of risk values (i.e. the Value of Statistical Life).

Formally, for all means of transport, one could consider

(3) TC = A(a+b+c) = rQ(a+b+c)

By indicating $E = \partial r / \partial Q \frac{Q}{R}$

(4) $$MC_j = \frac{\partial A}{\partial Q}(a+b+c) = r(E+1)(a+b+c)$$

(5) $$MC_j = MC - PMC_j$$

Where:

A = number of accidents

a, b, c = VSL per se, relatives and society, respectively

TC = total costs

r = A/Q, it is the risk to be involved in an accident

E = risk-elasticity

MC = mg acc costs

PMC = private marginal costs

A more sophisticated specification is provided in Jansson (1994). He writes total accident costs as follows:

(6) $$\sum_{i=1}^{6}\sum_{n=1}^{4}(a^n + b^n + c^n)\sum_{j=1}^{7} r_{ij}^n X_i$$

Where:

i = transport modes (car, bus, tram, metro, truck and non motorised transport)

n = severity of the accident (fatal, with serious injuries, with light injuries and with only material damages)

Xt = number of vehicle km travelled by transport mode i

r_{ij}^n = probability that an accident of severity n occurs between transport modes I and j in which i is the victim

a, b, and c are defined as above.

Given its detailed data requirements, we will not consider this specification in this review.

The top-down approach 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.

Data requirement for accident costs are summarised in table below (UNITE D2, p. 53).

Table 5 – Data needed to estimate accident costs

Data	Specification
Accident and casualties	Total n. of accidents in severity class, n. of non-reported accidents
Public bodies	Administrative costs (police, legal sector, health sector) average time per accident and sector
Insurance data	All payments from insurance (damages, legal costs, health, gratification), administrative costs of insurance
Economic data	Per capita consumption, employment rate, average replacement costs, WTP (risk value)
Traffic data	Delay situations due to accidents, normal traffic situation

Air pollution

Considering air pollution, a considerable amount of studies on methodology as well as studies on total, average and marginal air pollution costs is available. It is acknowledged that a bottom up approach is most suitable to deal with technology, site-specific parameters and variations of costs with time (Bickel et al., 2006d).

With reference to impacts on human health, the impact pathway approach (IPA) makes possible to estimate damage cost (expressed as unit cost per ton of air pollutant). It can be formally expressed as follows (Maddison *et al*., 1996):

(7) $\Delta H_{ij} = b_{ij} * POP * \Delta A_{jt}$

Where:

ΔH_{ij} = change in health impact;

j= a particular pollutant;

t = a particular fuel;

b_{ij} = slope of the “dose-response” function

POP = population exposed to pollutant j

ΔA_{jt} = ambient concentration pf the pollutant j attributable to fuel t

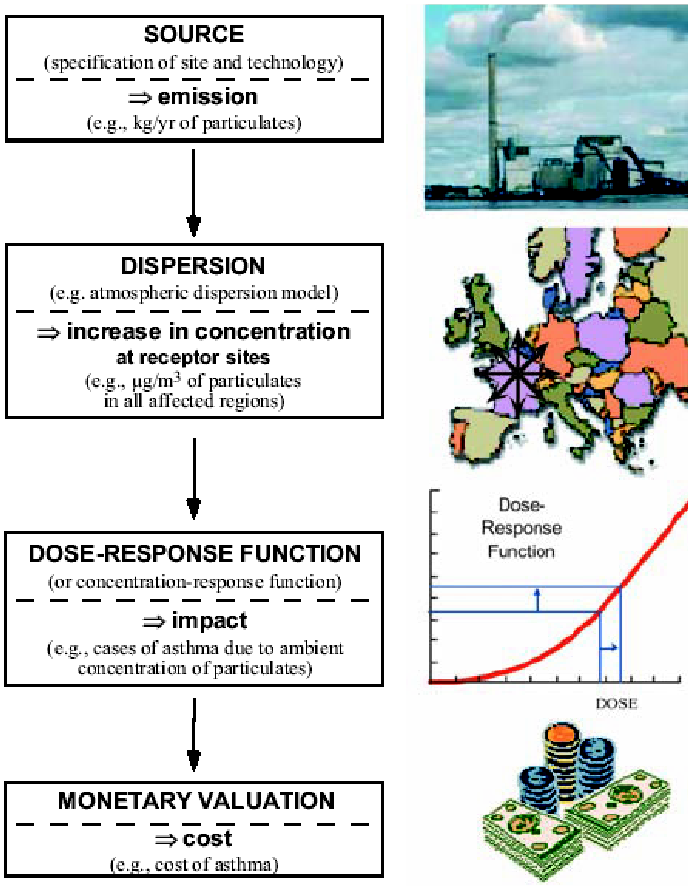
In order to get monetary estimates, it is assumed that these changes affect people utility. This welfare change is then monetised through stated preferences or revealed preferences techniques.

In fact, not all impacts have been monetised so far. Detailed analysis is available for the most important pollutants and impact categories (see below). It has to be noted that research focused on evaluating specific damages instead of general willingness to pay for an environmental improvement. This choice improves the reliability of available estimates.

The IPA has been updated by the ExternE project series. This approach is a bottom-up approach aiming at estimating marginal costs for different traffic situations. The principal steps if the analysis are (see Figure 1): (i) the specification of relevant technologies and pollutants; (ii) the calculation of the incremental concentrations of pollutants; (iii) the calculation of impacts (i.e. damage per physical units), estimated through epidemiologic dose-response models and (iv) economic valuation of these impacts (Bickel and Friedrich, 2005).

As a result, in this approach the pressure on the environment, the resulting burden, the response of receptor and monetary valuation are all modelled. In order to apply this procedure it is necessary to have available models for each stage.

Figure 1 – Steps of the impact pathway analysis with reference to air emissions



Source: ExternE Methodology 2005 Update

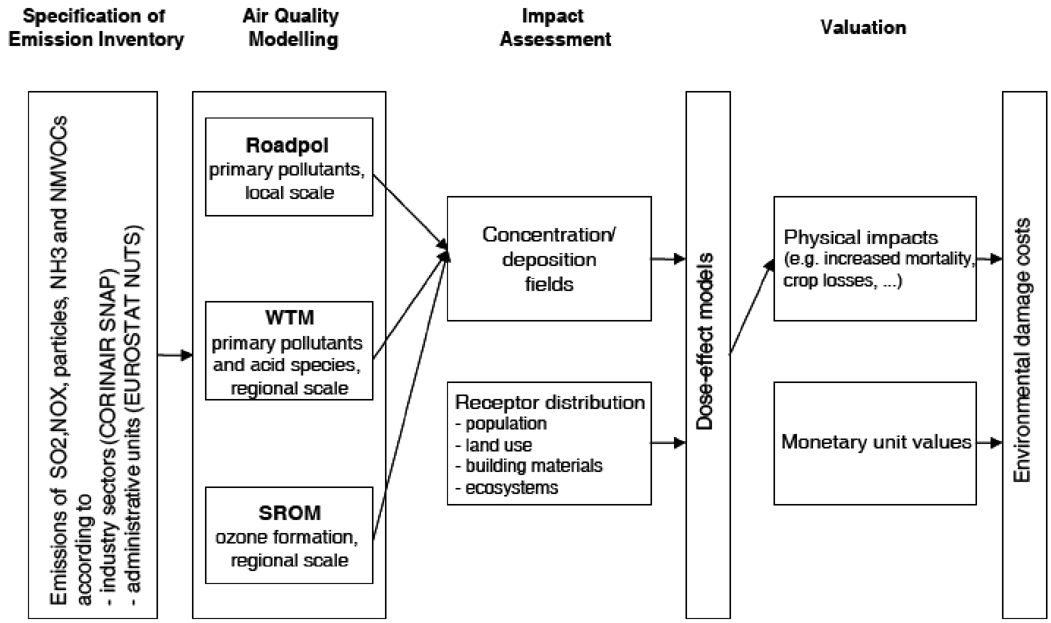
Let's analyse all these steps so as to clarify methodological issues. Step (i) is carried out through a review of existing studies. The analysis carried out above highlights the environmental burdens entailed by road transport.

Regarding step (ii) and (iii), the concentration of pollutants is calculated through specific software aid. In particular, the ExternE project series developed the EcoSense Transport software tool[1]. This is a computer model which supports the quantification of environmental impacts by following a detailed site-specific damage function approach, in which the causal relationships from the release of pollutants through their interactions with the environment to a physical measure of impact are modelled and valued monetarily.

The flowchart of the Ecosense Transport model is shown in figure below.

[1] http://externe.jrc.es/Method+EcoSense.htm

Figure 2 – Flowchart of the EcoSense Model



Source: Bickel et al. (2006d)

In the EcoSense Transport model, air quality and impact assessment models and input data are provided, so as to get a site-specific bottom-up impact analysis. For what concerns the models used, the software integrates three air quality models, (ROADPOL, Windrose Trajectory Model and Source-Receptor Ozone model)[2] to establish dose response functions.

For what concerns input data, the software uses:

- receptor data, i.e population data taken from the Eurostat Regio Database (base year 1996). Data are available on NUTS 3 level;
- emission data, i.e. emissions inventory for SO_2, NO_x, NH_3, NMVOC and particles. Data are taken from the European Monitoring and Evaluation Programme (EMEP) 1998 emission inventory, from CORINAIR 1994 and CORINAIR 1990 inventory.
- Meteorological data are taken from EMEP 1998.

It has to be noted that the input data are out-of-date and could be updated (e.g. the CORINAIR inventory is available for the year 1999). The following table summarises the data already available in the software.

[2] For a description of these models see Bickel et al. (2006d).

Table 6 - Environmental data available in the EcoSense database

Resolution		Source
Receptor distribution Population	administrative units, EMEP 50 grid	EUROSTAT REGIO Database, The Global Demography Project
Meteorological data		
Wind speed	EMEP 50 grid	European Monitoring and Evaluation Program (EMEP)
Wind direction	EMEP 50 grid	European Monitoring and Evaluation Program (EMEP)
Precipitation	EMEP 50 grid	European Monitoring and Evaluation Program (EMEP)
Emissions SO2, NOx, NH3, NMVOC, primary particles	administrative units, EMEP 50 grid	CORINAIR 1994/1990, EMEP 1998 TNO particulate matter inventory (Berdowski et al., 1997)

Source: Bickel et al. (2006)

The following table summarises the impacts for which dose-response functions are available.

Table 7 - Health and environmental effects for which exposure-response functions are established.

Impact category	**Pollutant**	**Effects included**
Public health – mortality	PM2.5 , PM10	Reduction in life expectancy due to acute and chronic effects
	O3	Reduction in life expectancy due to acute effects
Public health	PM2.5 , PM10	Respiratory hospital admissions
– morbidity	O3	(Minor) Restricted activity days
		Days of bronchodilator usage
		Days of lower respiratory symptoms
	PM2.5 , PM10 only	New cases of chronic bronchitis
		Cardiac hospital admissions
	O3 only	Cough days
Material damage	SO2, acid deposition	Ageing of galvanised steel, limestone, natural stone, mortar, sandstone, paint, rendering, zinc
Crops	SO2	Yield change for wheat, barley, rye, oats, potato, sugar beet
	O3	Yield loss for wheat, potato, rice, rye, oats, tobacco, barley
	Acid deposition	Increased need for liming
	N	Fertiliser effects

Source: Bickel et al. (2006)

The dose-response function (DRF) relates the quantity of a pollutant that affects a receptor to the physical impact of that receptor. The choice of DRF is crucial in applying the IPA. Bickel and Friedrich (2005) discussed the critical issues of dose-response function. The difficulty in deriving DRF lies in the fact that relatively high doses are needed to obtain observable responses (unless the sample is very large). Such doses are far in excess of typical exposure. Moreover, population are exposed to a mix of pollutants that tend to be highly correlated, so it is difficult to isolate the effect of one single pollutant.

The relationship between exposure and impacts can be described by several functional forms (linear, exponential, linear with a threshold). There is not evidence in support of one form or another. Dose response functions are available for the impacts on human health, building materials and crops, caused by a range of pollutants (CO, SO_2, NO_x, benzene, dioxins, As, Cd, Cr, Ni, and Pb).

Bickel and Friedrich (2005) report DRFs for chronic mortality (for both adults and children), morbidity (chronic bronchitis, chronic cardio-vascular disease, respiratory hospital admissions, restricted activities, asthma, lower and acute respiratory symptoms), cancer insurgence (for heavy metals and benzene).

Regarding step (iv), this is the point were research efforts have been concentrated in the last years.

In particular, the NewExt project aims at updating the IPA approach, by providing new evidence regarding already studied impacts or original research for impacts not previously considered. In particular, it is organised along four specific workpackages (WPs) aiming at providing:

- an improved methodology for the monetary valuation of mortality impacts from air pollution
- valuation of environmental impacts from air pollution
- a methodology for the assessment of effects from multi-media (air/water/soil) impact pathways
- a methodology and a related database for the assessment of major accidents in non-nuclear fuel chains

We now discuss methodological issues regarding the first WP. The second and the third ones will be reviewed on the following paragraphs. The forth WP will not be discussed in this report because not relevant for our research objectives.

Regarding the monetary valuation of increased mortality from air pollution, IER *et al*. (2004) stresses that the unit values used for the final estimation of environmental external costs have been derived in ExternE in previous literature. These authors (p. 9) claim that “values that currently exist are generally not believed to express accurately the willingness-to-pay (WTP) that individuals might express, e.g. for the introduction of new air quality regulation”.

In order to derive unit values for the incidence of premature death caused by air pollution in Europe, this WP undertook three surveys in UK, France and Italy. It adopted a survey instrument already employed in the USA, so as to get comparable unit values. In particular, the survey instrument aims at eliciting the WTP for mortality risk reductions to be incurred over 10 years and for reductions in the probability of dying between age 70 and 80.

Results are shown and discussed below.

Noise costs

Noise costs are quite complicate to calculate, due to the logarithmic nature of the relationship between noise and traffic volume. As a consequence, marginal noise costs are extremely sensitive to existing traffic flows or to existing noise. For instance, 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. Moreover, external noise costs appear to be higher at night that during the day. The number of the exposed people is also needed.

Even in the case of noise costs the IPA is applicable, by considering two scenarios: 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.

Regarding the top-down approach, it estimates the willingness to pay or the willingness to accept (i.e. the compensation required) for more silence and the health effects and multiplies these unit values with the national data on noise exposure for different noise classes. WTP is estimated mainly through Hedonic Pricing techniques, especially for noise of road traffic () and aircraft (Espey and Lopez, 2000; Cohen and Coughlin, 2007). Stated Preferences and Revealed Preferences could also be applied (and in fact the use of Stated Preferences Technique use is increasing). Navrud *et al*. (2006) review the studies that estimate noise external costs for different transport modes.

For what concerns EU funded project research, the UNITE project uses IPA approach to estimate noise external costs for road and rail transport. The HEATCO project applies Stated Preferences techniques to elicit WTP for road, rail and aircraft noise annoyance and the value of travel time savings (VTTS).

Similarly to other cost components, the bottom-up approach estimates marginal costs, whilst the top-down approach produces an average value.

The following table summarises the data needed for estimation of noise costs.

Table 8 – Data needed to estimate noise costs

Data	Specification
Transport data	NUTS III level for road transport, NUTS for roads, rail, inland, and maritime waterways, administrative units for air transport
Noise	Estimates of noise exposure
Nature and landscape	Description of infrastructure

Source: Lindberg et al. (2002)

Climate change costs

As underlined above, climate change costs are quite complicated to estimate, due to the complexity and uncertainty underlying the interactions between human and natural systems and the several effects that should be included in the analysis (see above). Even in this case two approaches are used:

- bottom up, i.e. damage cost approach, by modelling and monetise physical impacts;
- top-down, i.e. avoidance costs coincident with the least-cost option to achieve a required level of GHG reduction.

In particular, the damage cost approach follows the impact pathway approach. It assesses the physical impacts of climate change using modelling and combines these with estimations of the economic impacts resulting from these physical impacts (Watkiss, 2005). For example, the costs of sea level rise could 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.

An alternative approach consists in assessing the costs of avoiding CO_2 emissions. 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. 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.

In particular, in the NewExt project two approaches have been developed, both based on revealed preferences. The first estimates revealed preferences based on policy targets, i.e. the abatement costs necessary to implement the Kyoto Protocol.

It set policy targets (8% reduction of GHG emissions by 2008-2012 compared to 1990 emissions), whilst not indicating how the target should be achieved. A discussion of the results is provided in the next paragraph.

For our purposes, it has to be noted that transport specific marginal abatement costs may be better that European marginal abatement costs.

Despite the fact that the avoidance cost approach is considered more feasible, it has to be noted that the estimates are dependent upon political decisions, e.g. regarding the reduction target (short or long term) and the scope of reduction (transport or all sectors, national or international). As a consequence, different external cost factors per tonne of CO_2 should be considered depending on the time horizon and the assumed reduction target. For this reason, recent studies move away from avoidance cost methodologies and use instead damage cost approach, as we will show in the next paragraph.

In particular, the ExternE update methodology (Bickel and Friederich, 2005) and the NEEDS Integrated Project adopt the FUND[3] integrated assessment model to assess damage costs due to climate change. In this model, climate change impacts are dead-weight losses to the economy. As a result, climate change reduces long-term economic growth, although consumption is particularly affected in the short-term. Economic growth is also reduced by carbon dioxide abatement measures.

FUND consists of a set of exogenous scenarios and endogenous perturbations. The model distinguishes 16 major regions of the world[4]. The model runs from 1950 to 2300 in time steps of one year, by considering different scenarios, defined by the rates of population growth, economic growth, autonomous energy efficiency improvements as well as the rate of decarbonisation of the energy use (autonomous carbon efficiency improvements), and emissions of carbon dioxide from land use change, methane and nitrous oxide. In particular, the scenarios of economic and population growth are perturbed by the impact of climatic change. The scenarios are defined by the rates of population growth, economic growth, autonomous energy efficiency improvements as well as the rate of decarbonisation of the energy use (autonomous carbon efficiency improvements), and emissions of carbon dioxide from land use change, methane and nitrous oxide. Population decreases with increasing climate change related deaths that result from changes in heat stress, cold stress, malaria, and tropical cyclones. Heat and cold stress are assumed to have an effect only on the elderly.

The costs of methane and nitrous oxide emission reduction are based on the supply curve emission reductions calculated by EPA. The model calculates total emission reduction costs, expressed as a fraction of GDP, and attributes them to the regions. Finally, reduction cost curve are specified for methane and nitrous oxide, considering all regions and two specifications, quadratic and exponential (see Table 9 and 10 below).

A limit of this kind of analysis is that it does not consider a wide array of impacts, uncertainties are quite large. In the next paragraph we will compare the findings of the FUND model with those of other integrated assessment models.

[3] Climate Framework for Uncertanty, Negotiation and Distribution
[4] The United States of America, Canada, Western Europe, Japan and South Korea, Australia and New Zealand, Central and Eastern Europe, the former Soviet Union, the Middle East, Central America, South America, South Asia, Southeast Asia, China, North Africa, Sub-Saharan Africa, and Small Island States.

Table 9 – Parameters of the methane emission reduction cost curve (67% C.I. in brackets)

	Quadratic		Exponential - constant	Exponential - exponent	
USA	5.74E-04	(4.15E-04 7.90E-04)	5.43E-06 (4.44E-06 6.64E-06)	10.28 (9.66	10.90)
CAN	1.20E-03	(8.70E-04 1.64E-03)	7.69E-06 (6.30E-06 9.37E-06)	12.49 (11.75	13.23)
WEU	3.71E-04	(2.34E-04 5.80E-04)	1.82E-06 (1.37E-06 2.43E-06)	14.27 (13.10	15.45)
JPK	1.27E-04	(8.75E-05 1.84E-04)	4.19E-07 (3.32E-07 5.29E-07)	17.43 (16.23	18.63)
ANZ	4.12E-03	(3.03E-03 5.57E-03)	1.25E-05 (1.03E-05 1.51E-05)	18.18 (17.14	19.21)
EEU	3.90E-03	(2.81E-03 5.38E-03)	3.13E-05 (2.56E-05 3.83E-05)	11.17 (10.49	11.85)
FSU	8.87E-03	(7.49E-03 1.05E-02)	8.51E-05 (7.65E-05 9.46E-05)	10.21 (9.89	10.52)
MDE	6.32E-03	(4.86E-03 8.19E-03)	1.26E-05 (1.07E-05 1.49E-05)	22.38 (21.29	23.47)
CAM	3.65E-03	(2.87E-03 4.62E-03)	1.30E-05 (1.12E-05 1.51E-05)	16.77 (16.03	17.52)
SAM	2.75E-02	(1.81E-02 4.14E-02)	4.07E-06 (3.14E-06 5.27E-06)	82.24 (75.89	88.58)
SAS	3.16E-02	(2.43E-02 4.08E-02)	2.51E-05 (2.13E-05 2.95E-05)	35.45 (33.74	37.16)
SEA	1.43E-02	(1.06E-02 1.91E-02)	1.94E-05 (1.62E-05 2.33E-05)	27.15 (25.66	28.65)
CHI	1.26E-02	(9.50E-03 1.67E-02)	3.18E-05 (2.67E-05 3.80E-05)	19.93 (18.88	20.97)
MAF	1.43E-02	(1.06E-02 1.91E-02)	1.94E-05 (1.62E-05 2.33E-05)	27.15 (25.66	28.65)
SSA	1.43E-02	(1.06E-02 1.91E-02)	1.94E-05 (1.62E-05 2.33E-05)	27.15 (25.66	28.65)
SIS	1.43E-02	(1.06E-02 1.91E-02)	1.94E-05 (1.62E-05 2.33E-05)	27.15 (25.66	28.65)

Table 10 – Parameters of the nitrous oxide emission reduction cost curve (67% C.I. in brackets)

	Quadratic	Exponential - constant	Exponential - exponent	
USA	2.14E-05 (1.91E-05 2.39E-05)	1.36E-08 (1.29E-08 1.45E-08)	39.61 (38.56	40.65)
CAN	6.92E-05 (6.29E-05 7.60E-05)	1.62E-08 (1.54E-08 1.70E-08)	65.33 (63.88	66.78)
WEU	7.26E-06 (6.60E-06 7.98E-06)	1.97E-08 (1.88E-08 2.08E-08)	19.18 (18.75	19.60)
JPK	5.32E-07 (3.21E-07 8.57E-07)	9.54E-09 (7.38E-09 1.23E-08)	7.46 (6.60	8.33)
ANZ	2.08E-04 (1.89E-04 2.29E-04)	4.62E-09 (4.39E-09 4.86E-09)	212.40 (207.68	217.11)
EEU	9.39E-05 (8.89E-05 9.93E-05)	8.35E-08 (7.91E-08 8.83E-08)	33.53 (33.53	33.53)
FSU	1.05E-05 (1.00E-05 1.10E-05)	1.94E-08 (1.91E-08 1.98E-08)	23.25 (22.91	23.60)
MDE	1.05E-05 (1.00E-05 1.10E-05)	1.94E-08 (1.91E-08 1.98E-08)	23.25 (22.91	23.60)
CAM	2.35E-04 (2.19E-04 2.53E-04)	2.00E-08 (1.89E-08 2.13E-08)	108.39 (107.83	108.95)
SAM	1.05E-05 (1.00E-05 1.10E-05)	1.94E-08 (1.91E-08 1.98E-08)	23.25 (22.91	23.60)
SAS	5.64E-04 (5.29E-04 6.01E-04)	1.71E-07 (1.62E-07 1.80E-07)	57.44 (57.14	57.74)
SEA	2.55E-15 (2.16E-15 3.01E-15)	4.72E-18 (4.12E-18 5.40E-18)	23.25 (22.91	23.60)
CHI	2.16E-05 (2.02E-05 2.30E-05)	1.42E-07 (1.35E-07 1.50E-07)	12.32 (12.26	12.39)
MAF	1.05E-05 (1.00E-05 1.10E-05)	1.94E-08 (1.91E-08 1.98E-08)	23.25 (22.91	23.60)
SSA	1.05E-05 (1.00E-05 1.10E-05)	1.94E-08 (1.91E-08 1.98E-08)	23.25 (22.91	23.60)
SIS	1.05E-05 (1.00E-05 1.10E-05)	1.94E-08 (1.91E-08 1.98E-08)	23.25 (22.91	23.60)

The economic valuation of climate change impacts proves to be an extremely complicated matter. In the words of Stern's review: "Climate change presents a unique challenge for economics: it is the greatest and widest-ranging market failure ever seen. The economic analysis must therefore be global, deal with long time horizons, have the economics of risk and uncertainty at centre stage, and examine the possibility of major, non-marginal change".

We have extensively discussed the methodological issues and valuation techniques used to estimate such impacts. In this part we will focus on the estimation of damage costs of climate change and review the related literature. This choice is dictated by the fact that policies for the post-Kyoto scenarios are still under discussion and thus compliance costs will be dependent upon what level of environmental protection will be decided on the basis of international agreements.

In fact, the issues that should be carefully taken into account in the valuation of climate change impacts are the following:

- the variety of impacts that climate change entails. This point has already been analysed in D1 but will be expanded by reporting the findings of the Stern Review.
- the differences in climate change damages accounting. This paragraph will focus on this point.

Consideration of climate change impacts

The most up-to-date review of impacts of climate change is the one carried out in the Stern's Review (2006, see box below).

The Stern Review

This Review was commissioned by the Chancellor of the Exchequer as a contribution to assessing the evidence and building understanding of the economics of climate change. The Review first examines the evidence on the economic impacts of climate change itself, and explores the economics of stabilising greenhouse gases in the atmosphere. The second half of the Review considers the complex policy challenges involved in managing the transition to a low-carbon economy and in ensuring that societies can adapt to the consequences of climate change that can no longer be avoided. The analysis undertaken in the Review leads to the conclusion that the benefits of policy action considerably outweigh the costs.

The Review considers the economic costs of the impacts of climate change, and the costs and benefits of action to reduce the emissions of greenhouse gases (GHGs) that cause it, by using three different methodologies, i.e. by:

• Using disaggregated techniques: it considers the physical impacts of climate change on the economy, on human life and on the environment, and examines the resource costs of different technologies and strategies to reduce greenhouse gas emissions;

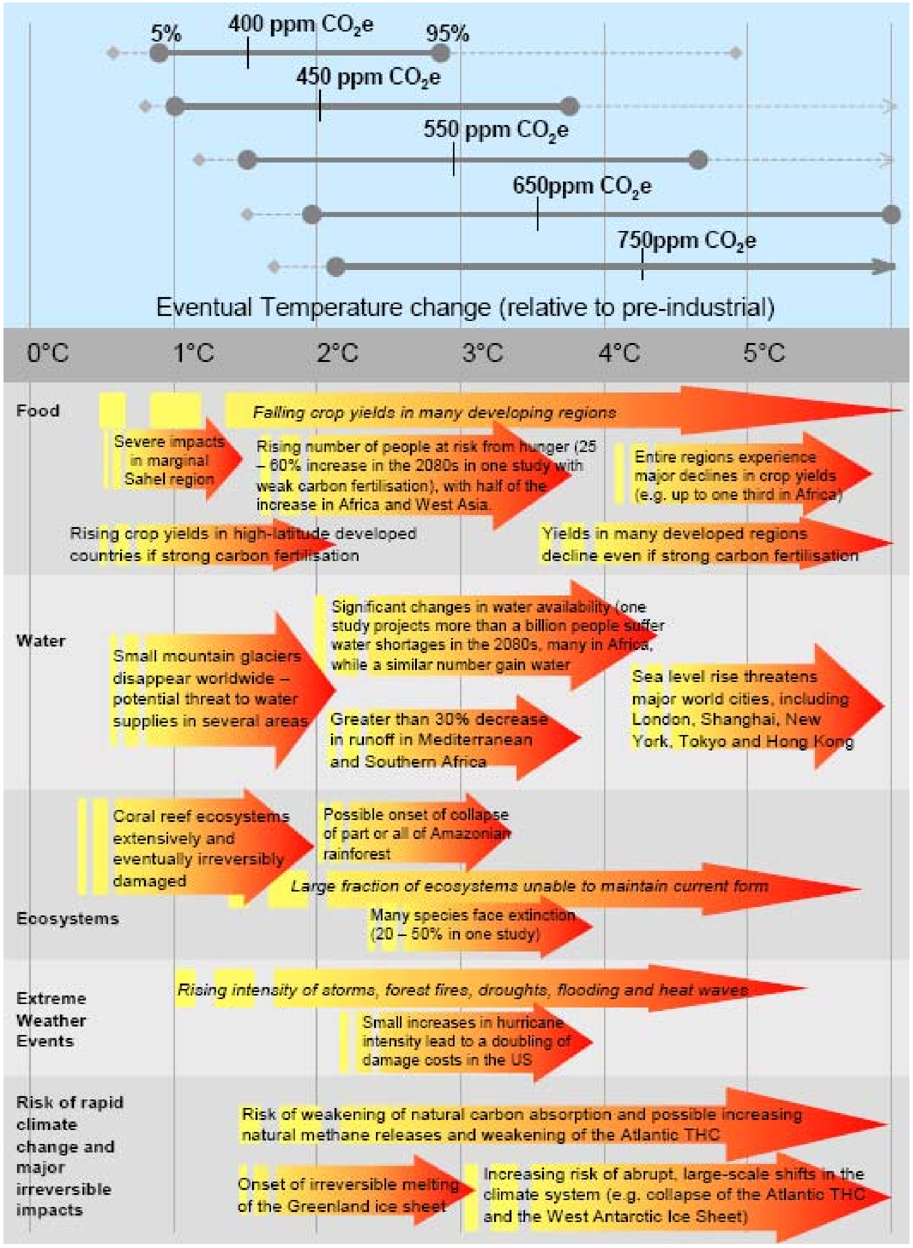
• Using economic models, including integrated assessment models that estimate the economic impacts of climate change, and macro-economic models that represent the costs and effects of the transition to low-carbon energy systems for the economy as a whole;

• Using comparisons of the current level and future trajectories of the 'social cost of carbon' (the cost of impacts associated with an additional unit of greenhouse gas emissions) with the marginal abatement cost (the costs associated with incremental reductions in units of emissions).

The study considers a wide range of impacts, from increased flood risk and declining crop yields to damages to ecosystems. These impacts are summarised in the Figure below. As the reader can see, their occurrence is dependent upon the projected increase of world temperature[5].

[5] The top panel shows the range of temperatures projected at stabilisation levels between 400ppm and 750ppm CO2e at equilibrium. The solid horizontal lines indicate the 5 - 95% range based on climate sensitivity estimates from the IPCC 2001 and a recent Hadley Centre ensemble study. The vertical line indicates the mean of the 50th percentile point. The dashed lines show the 5 - 95% range based on eleven recent studies (Stern Review, 2006).

Figure 3 – Impacts of climate change depending on the increase of temperature



Source: Stern Review (2006)

These impacts have been monetised by considering previous studies that employ various estimation techniques, from general equilibrium models to damage costs.

The assessment of these impacts leads to the following conclusions:

- the costs of extreme weather alone could reach 0.5 - 1% of world GDP per annum by 2050;
- water availability and crop yields in southern Europe are expected to decline by 20% with a 2°C increase in global temperatures.

By considering past work on IAM and climate change, the review concludes that earlier models were too optimistic about warming, since they considered an increase in world temperature of 2-3 °C. It emphases that existing models that include the risk of abrupt and large-scale climate change estimate an average 5-10% loss in global GDP, with poor countries suffering costs in excess of 10% of GDP. These models consider only impacts on local economies, and they do not take into account the so-called "non market" impacts, such as environment and human health. If these aspects are included in the analysis, then the total cost of climate change on will amount from 5% to 11% of global per-capita consumption.

Moreover, by considering that a disproportionate share of climate-change burden falls on poor regions of the world and that climate systems could be more sensitive to GHG emissions than previously thought, then the reduction in consumption per head would be wider. Analyses that take into account the full ranges of both impacts and possible outcomes suggest that BAU climate change will reduce welfare by an amount equivalent to a reduction in consumption per head of between 5 and 20%.

Alternatively, macro-economic models suggest that the costs for stabilising emissions at 500-550ppm CO2e are significant: central estimate is that stabilisation of GHG will cost, on average, around 1% of annual global GDP by 2050.

Finally, the report considers a third approach which compares the marginal costs of abatement with the social cost of carbon. Preliminary calculations adopting the approach to valuation taken in the Review suggest that the social cost of carbon today, if we remain on a BAU trajectory, is of the order of $85 per tonne of CO2 - higher than typical numbers in the literature, largely because we treat risk explicitly and incorporate recent evidence on the risks, but nevertheless well within the range of published estimates. This number is well above marginal abatement costs in many sectors.

Damage costs accounting in IAMs

In the previous paragraph we have emphasised that the damage costs of climate change can be calculated by using Integrated Assessment Models (IAMs). In fact, the estimate of these damages is dependent upon the choice of the model and the use of different models lead to quite different results. We consider FUND (Tol et al., 2004), MERGE (Manne et al., 1995) and RICE99 (Nordhaus and Boyer, 1999) models.

In fact FUND, MERGE and RICE99 estimate climate change damages in different manner. The MERGE model is calibrated by assuming that rich countries will spend 2% of GDP (1% for poor countries.) to avoid a 2.5°C temperature increase. In RICE models calculate for each region the WTP to avoid a 2.5 increase in temperature (in term of compliance costs)[6]. Finally, in the FUND model climate change damages are estimated by considering market and non market impacts, such as: agriculture, forestry, water resources, energy consumption, sea level rise, ecosystems, human health and respiratory and cardiovascular mortality.

Nature and landscape costs

Finally, nature and landscape costs can be estimated following two approaches: on the one side the damage cost approach (to estimate the health costs for human beings due to the emission of toxic heavy metals into soil, water and air) and on the other the remediation costs, necessary to dispose and replace the polluted soil. Examples of these approaches can be found in ExternE and UNITE, respectively for bottom-up and top-down approaches.

For instance, IER et al. (2004) value the impacts of SO_2, NO_x and NH_3 on acidification and eutrophication of ecosystems by referring to the abatement costs of emissions reductions. The assumption is that policy makers' WTP approximate the European society's WTP for the improvement of ecosystems. These authors note that abatement costs expressed as "€ per

[6] This WTP is estimated by calibrating an "impact index" equal to the fraction of annual output that subregion j would be willing to pay to avoid the consequences on sector i of a temperature increase of T° C.

ton pollutant", as provided by earlier studies, are not immediate applicable to the IPA (since the impacts entailed by this additional pollution are needed). In order to amend this limit, marginal impacts of SO_2, NO_x and NH_3 emissions are quantified in "hectares of ecosystems with exceedance of critical loads/year". These impacts are then monetised by inferring WTP per hectare of ecosystem protected against acidification and euthrophication (in €/ha*year). They do so by determining marginal cost curves for emission reductions, by considering the reference scenario (business as usual) vs. that defined by the implementation of the Protocol of Gothenburg on the Convention of Long-range Transboundary Air Pollution (1999) and the European Directive 2001/81/EC on National Emission Ceilings for some air pollutants. Compliance costs are taken from studies applying integrated assessment models (Amann *et al*., 1999). Instead of considering marginal costs of single measures, the average cost of a marginal policy package is taken instead.

NewExt project also assesses priority impact pathway for soil and water, and apply them to the emissions of toxic substances emitted by power plant. No example of a similar study for transport emissions has been undertaken so far.

Other impacts, such as the loss of land due to transport infrastructure, are not addressed in EU funded studies. The interest reader, for a discussion on this point, could refer to the work undertake under the COST initiative[7] and to Koomen *et al*. (2002) for a methodological issues.

The following table summarises the methodologies used by the EU-funded projects reviewed in this report.

Table 11 - Overview of approaches considered in EU funded projects

Transport mode	Cost of scarce infrastucture	Accident costs	Air pollution – Human health	Noise	Climate change
Road	Value of time lost because of congestion	Value of a statistical life	Impact pathway approach	Impact pathway approach/WTP estimated on SP or HP techniques	Abatement Costs/Damage costs
Train	Opportunity cost of a slot	VSL		Impact pathway approach/ WTP estimated on SP or HP techniques	Abatement Costs/Damage costs
Air transport	Value of time (calculated on the basis of delay)	VSL	Impact pathway approach	WTP estimated on SP or HP techniques	Abatement Costs/Damage costs
In-land nav and maritime	Value of the time (as a function of the value of the goods transported and the value of the time for the ship)		Impact pathway approach		Abatement Costs/Damage costs

[7] http://cordis.europa.eu/cost-transport/src/cost-341.htm

3. *A review of the literature regarding transport external costs*

The strong expansion of transport activities throughout Europe is an important source of congestion and pollution, as well as a cause of many accidents.

Economic analysis of external costs of the transport sector was developed following the interest in knowing the full social costs of transport activities, necessary to apply the optimal pricing policy. In a seminal paper, De Borger and Wouters (1998) develop a theoretical model to analyse how demand and supply affect the marginal social costs of transport services. They define the marginal external cost associated with an increase in passenger-kilometres travelled by private car in the peak period imposed on individual *h* as the change in the utility of that individual entailed by three effects: traffic speed for private and public transport in the corresponding period declines, extra pollution is generated, and accident risks increase (p. 169). They thus consider three of the different external cost components that will be considered in this report. Optimal pricing and supply rules are derived, both in the presence and in the absence of budgetary constraints. Proost *et al*., 2002, by applying the TRENEN model, determine optimal pricing. They found that prices needs to be raised most for peak urban passenger car transport. They also calculate external costs of six European cities, by considering congestion, accident and air pollution external costs.

Moreover, several studies focus on assessing whether the tax and fee payments by transport users equates government spending, in both ES and EU contexts (Delucchi, 2007; Lee, 1994; Dougher, 1995; Link, 2005; Gibbons and O'Mahony, 2002). The common finding of all these works is that generally taxes on all transport modes should be increased substantially, particularly in the morning and evening peak periods. Moreover, all of them point out that, in order to have the full social costs of transport activities, it is necessary to consider any non-monetary environmental externality.

Some studies (Johnstone and Karousakis, 1999; Rouwendal and Verhoef, 2006) focus on the implementation of pricing policies, by showing that the introduction of first best tax presents practical difficulties and that "second best" policies should be pursued, due to the economic distortions in related markets and/or inherent constraints on the pricing instrument itself call for the use of second-best taxes.

Recent research has enlarged the scope of analysis to consider the issues related to the choice between different transport modes and the effects of increased amount of transportation activities. For instance, Graham and Shaw (2008) claim that the rapid growth of low cost airlines leads to environmental unsustainable development patterns. Beuthe *et al*. (2002) claim that societal benefits can be obtained through the promotion and substitution of transportation modes with less negative effects. In their study, they outline the results of a simulation of the flows over the Belgian interurban network in 1995, and give estimates of the corresponding pollution, congestion, noise and accidents costs as well as of the road damages by trucks. Secondly, we present the simulated impacts of a simple Pigovian internalisation of these costs into the users' costs.

As a result, several works have been published on methodological aspects, regarding the cost components that have to be included in the assessment of external costs deriving from transport activities, the estimation approach to be applied and critical aspects regarding the application of such techniques. We will recall methodological issues later on in this note. The interested reader could refer, among others, to Delucchi (2004) and Lvovsky *et al*. (2000) for review works.

In fact, the economic literature regarding the externality assessment of transportation can be divided into two strands, an empirical one and a theoretical one. The empirical works are the majority, and were first developed starting from mid-90s. Nonetheless, even theoretical models have been developed in the last few years.

Peirson *et al*., (1995) first estimate marginal external costs for UK passenger transport.

In their book “The true cost of road transport”, Maddison et al. (1997) define, discuss and estimate several cost components of road transport external costs (air pollution, noise and accidents) for UK. They also compare the UK case with other national experiences, such as Sweden, North America and the Netherlands.

Mayeres *et al*., (1996) estimate the marginal external costs for different transport modes (cars, buses trams, metro, and trucks) in the Brussels area, by considering different cost components, such as congestion costs, accident costs, noise costs, the effects of air pollutants on health and vegetation and global warming. Congestion costs are estimated by considering an exponential congestion function, and by transferring monetary results regarding the value of time (VOT) obtained in previous studies. Marginal air pollution costs are estimated through a direct damage estimation approach, instead of using avoided costs approach (see below, for a discussion on methodology used). Impacts of local air pollution are estimated through dose response functions derived from the studies carried out in the ExternE project series. External noise costs are estimated through a hedonic market method.

Jakob *et al*. (2006) estimate the total costs of private and public transport in Auckland (NZ). They consider several cost components (accident costs, air pollution costs and climate change) that accounts for 77% of the total costs. They value accident costs by considering direct and indirect costs (medical costs, rehabilitation costs and legal costs), costs due to the loss of production (they first calculate the gross product loss, by multiplying the average income by the average loss of work time, and then subtract the consumption to get the net loss of production), humanitarian costs (suffering and pain, approximated through WTP) property damages due to car crashes. They also consider air pollution costs, by assessing health costs and damage to vegetation and buildings. They finally quantify climate change costs by adopting a shadow price of CO2 equal to NZ$ 25.

Forkenbrock D.J., (2001) estimates external costs for four representative types of freight trains. For each type of freight train, three general types of external costs are estimated, namely accidents (fatalities, injuries, and property damage); emissions (air pollution and greenhouse gases) and noise. This study transfers the estimates obtained in other studies.

Other studies consider single external cost components. Nijland *et al*. (2003) in carrying out a cost-benefit analysis of a number of (possible) noise abatement measures in the Netherlands, estimate external noise costs by applying two different methodologies (hedonic pricing and contingent valuation). Blaeij *et al*. (2003) review the literature on the value of a statistical life (VSL). They show that the magnitude of VSL estimates depends on the value assessment approach (particularly, stated versus revealed preference), and for contingent valuation studies also on the type of payment vehicle and elicitation format. Their conclusions are of interest for this work. They explain that VSL estimates cannot simply be averaged over studies and that the magnitude of VOSL is intrinsically linked to the initial level of the risk of being caught up in a fatal traffic accident and to the risk decline implied by the research set-up. Panis *et al*. (2004), by applying the ExternE approach and by considering data and models related to the future composition of the vehicle fleet and transportation demand, evaluate the impact of new policy proposals on air quality and aggregated (total) external costs by 2010.

Coming to the theoretical studies, Janik (2007) developed a model for calculating internal and external costs of intermodal and road freight transport network and apply it to simplified configurations of intermodal rail-truck and road networks in Europe. The external cost components considered in this study are air pollution, congestion, noise and traffic accidents. He gets that the average cost of road and intermodal transport depends on the door-to-door distance and that intermodal transport is competitive in the long distances.

In their review work, Sirikijpanichkul *et al*. (2006) label empirical research on assessment of external costs along geographical boundaries, in international (i.e. World Bank), European, US and Australian studies. The focus of this deliverable is in European research. References to the latter set of studies will be given in the last part of this report.

Some of the studies quoted above focus on estimation of marginal cost pricing, considered for allocative reasons, since only prices set equal to consider the external marginal cost could produce efficient outcome. In fact, considering average cost pricing could entail an overestimation of external costs (Safirova and Gillingham, 2003). Some other studies consider total costs, and then estimate average costs. Janic (2007) estimates average costs.

Regarding the comparability of results obtained in different studies, it has to be noted that the unit of measurement differs from study to study, and this makes comparisons among results more difficult. In some studies transport external costs are expressed as cost per vehicle km, whilst in other they are expressed as cost per hour.

Some of these studies consider only one cost components, whilst other studies consider more than one component. It has to be noted that, for those studies that consider more than one component, that health costs are the dominant one. There is a general agreement on the fact that the overall external cost components to be considered are the following: congestion costs, accident costs, air pollution costs (health and environmental) and climate change costs.

Regarding estimation methodologies, they obviously vary according to the cost component considered. Congestion costs are estimated by using traffic simulation models to understand the additional travel time incurred by congested traffic conditions. External accident costs are estimated by assessing the consequences of traffic accidents (mortality, sever injuries and other "non material" components) in relation to traffic conditions and by monetising these impacts through the value of the statistical life. External air pollution costs are often estimated following a bottom up approach, through dose-response functions which link local pollutants concentration with various set of impacts. Climate change costs are assessed either by considering avoidance costs or damage costs. All these approaches will be reviewed in the following paragraphs.

Uncertainties of results are dependent upon the quality of the data used, the emission-concentration relationships (for external air costs), the relationship between the number of accidents and the traffic flow and the value of the statistical life considered (for external accident costs). The empirical results are sensitive to the approach used to estimate them.

To sum up, the papers published in peer review journals mainly focused on land transport modes, like road and rail. Some of them focus on air transport (with particular emphasis to the noise component), whilst none deals with maritime transport. In this sense, this review work carried out in this task and the definition of a general methodology in the second task pave the way to new empirical evidence regarding a transport mode (the maritime one) which is not analysed in depth by the published literature.

4. *Summary of the EU-funded research on transport economics*

The Commission has financed numerous projects on transport economics. The aim of this paragraph is to briefly describe each of them, so as to sketch the state of the art of the EU funded research. For each one we will recall their objectives and give a brief description of the research work carried out, together with the specification of the deliverables of interest for this research work. In doing so, we will justify the exclusion of some of them from the review work described in the following part of this report. The website references of all these projects could be found after the references.

Recordit (REal COst Reduction of Door-to-door Intermodal Transport)

The Recordit project concerns intermodal transport. Nonetheless, interesting insights can be found for what concerns external costs account, since one of its aims is to define and validate a methodology for the calculation of the real (internal + external) costs of intermodal freight transport. In particular, after having developed a methodology (WP1 and WP2) for resource cost calculation in selected corridors, WP4 focuses on calculation of marginal external costs for selected corridors. It applies the bottom-up impact pathway approach developed in ExternE and considers the following impact categories will be addressed: impacts from airborne pollutants on human health, building materials, agricultural products and ecosystems, impacts from noise, climate change, severance effects, impacts on biodiversity, accident risks, congestion and slot scarcity. The following WPs are concerned with analysis of taxes and charging, assessment of imbalance, reduction of transport costs of intermodal options and policy recommendations.

SPECTRUM (Study of Policies regarding Economic instruments Complementing Transport Regulation and the Understanding of physical Measures)

The SPECTRUM project was funded by the EU as part of FP5. Its main objective is to develop a theoretically sound framework for defining combinations of economic instruments, regulatory and physical measures in reaching the broad aims set by transport and other relevant policies. The project outputs have been the following: 1. a theoretically framework for analysing the trade-off between objectives and identifying optimal combinations of instruments to achieve them (D10); 2. analysis and assessment of transport packages (providing quantified evidence on the use of economic and alternative instruments in managing urban or inter-urban capacity) and indication of practical impacts of using economic instruments alongside or instead of other types of instrument. (D2; D3; D4; D5; D6; D7) 3. generalisation of results, in form of information to target users and transferability of alternative transport management packages across the broader urban/inter-urban spectrum and their wider social impact (D11; D12) 4. Guidance and recommendations on the use of economic and other measures, including a conceptual tool to support decision makers in assessing the potential to use economic instruments (alongside or instead of other instruments) and what the likely impacts on the transport and other sectors may be.

HEATCO (Developing Harmonised European Approaches for Transport Costing and Project Assessment)

HEATCO's primary objective was the development of harmonised guidelines for project assessment on EU level. The project has been organised as follows. 1. Review and analysis of the current project assessment practice in the EU member states. 2. Comparison of existing practice in the assessment of the value of time and congestion, accident risk reduction, health impacts and nuisances from pollutant and noise emissions, and infrastructure costs with the theoretical and empirical evidence from the literature. 3. Harmonisation of guidelines through involvement of representatives from member countries, discussions and revision of different guideline versions. Contingent-valuation studies for valuing noise annoyance and travel time changes were carried out in Norway, the UK, Spain, Hungary, Germany and Sweden to explore differences from different geographical, cultural and traffic conditions.

Imprint (Implementing Pricing Reforms in Transport Networking)

IMPRINT-NET is a Sixth Framework Coordination Action project for the European Commission (2005-2008). It will provide a discussion platform for policy makers, transport operators, researchers and other stakeholders to exchange views on the implementation of new pricing regimes, cost calculation methods, derivation of tariffs to be levied and on successful approaches to overcome barriers and to affect attitudes and perceptions. This discussion platform takes the form of an annual conference. The Action foresees three annual conferences, the last being the Final Conference where the results of the entire project will be presented. The two conferences preceding the final one will provide room for discussion of the intermediate outcomes of the EGs, and will focus the first on the issue of Pricing and Financing, and the second on Transit and Peripheral countries.

The network has published a report on “Pricing for (sustainable) transport policies – A state of the art”. Since the project focuses on transport pricing, it will not be considered for the purposes of this report.

Revenue (The Use of Transport Pricing Revenues)

This research project has three goals: 1. to know what are current institutions and practice of transport revenue use, 2. to develop guidelines for a good revenue use in the presence of marginal social marginal cost pricing on the basis of sound economic theory, 3. to test the guidelines on a large set of case studies.

The structure of the project is as follows. WP1 sets the stage for the overall project, notably through the assessment of the range of policy issues addressed, the critical review of evidence provided by previous research, and the establishment of a common terminology of concepts. The economic principles of optimal revenue use are studied in WP2. The theoretical prescriptions to be developed will play a dual role: to help explain the failures of current practice, and to provide alternative (better) guidelines for revenue use. The case studies will cover different modes and countries. The main purpose of the case study work is to compare current practice of revenue use with the main theoretical guidelines. WP3 defines a common methodology for the case studies. WP4 concentrates on revenue use in inter urban cases, while WP5 analyses urban case studies. WP6 consolidates and summarises the findings of work packages 1-5. The policy conclusions will be used to prepare a guideline, which will be disseminated to all parties involved (policy makers, EU community, academic community, operators, pressure groups and lobbies).

Since it focuses on pricing and institutional issues, it will not be considered for the purposes of this report.

UNITE (UNIfication of accounts and marginal costs for Transport Efficiency)

The project objectives are the following: 1. to develop pilot transport accounts for all modes, for the EU15 and additional countries; 2. to provide a comprehensive set of marginal cost estimates relevant to transport contexts around Europe; 3.

deliver a framework for integration of accounts and marginal costs, consistent with public finance economics and the role of transport charging in the European economy.

The tasks of the projects are: 1. methodological development, 2. empirical estimation; 3. synthesis. To maximise exploitation, key European and National decision-makers will be integrated within the project from day 1, through an Advisory Board and a Research User Group.

In the first stage the overall UNITE methodology has been established and the accounts approach and marginal cost methodology was created. The second stage have been devote to the implementation of the accounts and marginal cost methodologies, in parallel with the elaboration of the integration of approaches work. This second phase also includes substantial methodological development for both the accounts and the marginal cost approaches. In the final stage the focus becomes the determination of future strategies for developing the three core aspects of the project, and the overall consolidation of the research results.

GRACE (Generalisation of research on accounts and cost estimation)

The objectives (and work tasks) of the GRACE project are: 1. to undertake new case study research to address gaps in the existing level of knowledge of marginal social costs in road and rail transport. 2. to undertake new case study research to address gaps in the existing level of knowledge of marginal social costs in air and water borne transport; 3. to develop and refine the methods of using transport accounts to monitor the implementation of transport pricing reform in an enlarged Europe; 4. to provide guidance on the effective trade off between pricing systems that give appropriate incentives by portraying variations in marginal social cost in time and space in detail and pricing systems that are easily understood and acted upon; 5. to provide clear guidance on the marginal social cost of the different modes of transport in specific circumstances and on simple and transparent methods for determining charges; 6. to refine the use of models to address the broad socio-economic impacts of pricing reform; 7. to draw clear conclusions and recommendations for policy and for research in the field of transport infrastructure costs and charges.

Trans-tool

TRANS-TOOLS aims to produce a European transport network model covering both passengers and freight, as well as intermodal transport, which overcomes the shortcomings of current European transport network models.

Since it deals more with logistic issues, it will not be considered for the purposes of this report.

Transtalk (Thematic Network on Policy and Project Evaluation Methodologies)

The objective of TRANS-TALK is to develop a framework for integration of current research on development of transport policy and project evaluation methodologies in different settings. This will be of major relevance for policy analysis and evaluation, hence by default also for decision-making processes. It will thus contribute to the further development of the Common Transport Policy.

In order to consider the European research on air pollution externalities, in this report we will recall the findings of projects not directly linked with transport activities but concerned with air pollution effects, such as ExternE, NewExt, Needs and the work carried out in the CAFE group.

Table 12 – The EU funded projects considered in this review

EU Funded Project	Date	Project's objective	WPs of interest
GRACE	2004-2007	To undertake new case study research to address gaps in the existing level of knowledge of marginal social costs in road and rail transport, in air and water borne transport To provide clear guidance on the marginal social cost of the different modes of transport in specific circumstances and on simple and transparent methods for determining charges	WP3 - Marginal cost case studies for road and rail transport WP4 - Marginal cost case studies for air and water transport
UNITE	2000-2003	To support policy-makers in the setting of charges for transport infrastructure use	D1 - Overall UNITE approach D2 – The accounting approach D3 – The Mg Cost approach D11 - Environmental Marginal Cost Case Studies D15 - Guidance on Adapting Marginal Cost Estimates
RECORDIT	2000-2001	To define and validate a methodology for the calculation of the real (internal + external) costs of intermodal freight transport To assess the existing charging and taxation systems, and to compare real costs to charges and taxes currently paid	WP4 - External cost calculation for selected corridors
SPECTRUM	2003-2005	To develop a theoretically sound framework for defining combinations of economic instruments, regulatory and physical measures in reaching the broad aims set by transport and other relevant policies	WP6 - Measurement and Treatment of High Level Impacts
HEATCO	March 2004 - May 2006	To develop a set of harmonised guidelines for project assessment and transport costing on the EU level in the areas	WP4 - Economic values for key impacts valued in the Stated Preference surveys
ExternE	Last update (2005)	To provide a framework for transforming impacts that are expressed in different units into a common unit – monetary values. To cover all relevant (i.e. not negligible) external effects	2005 Methodological Update
NEWEXT	January 2001 - June 2003	Update ExternE methodology	Methodological part
CAFE	Launched in 2001	To establish the capability to assess the costs and benefits of air pollution policies, and to conduct analysis on scenarios generated within the CAFE programme.	Methodological part (vol. 1)

5. *Estimation of external costs for different transport modes: results of European research*

After having discussed the methodological issues regarding the components of external costs of transport, in this paragraph the findings of the most important EU funded projects related to the transport sector (i.e. GRACE, UNITE, RECORDIT, SPECTRUM, HEATCO and NEWEXT) will be summarised. The review will consider all the modes of transport (road, train, airport, waterborne transport), different transport sectors (passengers, commercial, short and long distances) and different situations (rural, urban, peak and non peak hours, etc.). In the previous paragraph the estimation approaches used have been reviewed. Here we will focus on the results obtained.

In order to appreciate EU-funded project added value, we will distinguish original work from review research.

Cost of scarce infrastructure

Before analysing in detail the findings of EU funded projects for different transport modes, it is worthy to highlights the VOT estimates which are used by them.

Bickel *et al*. (2006c) estimate value of time savings for each EU Member State and Switzerland, by distinguishing working and non-working purposes (and among the latter (shopping and leisure), for different transport modes. These estimates have been derived from HEATCO meta-analysis for commercial goods traffic, which has been based on values for road and rail traffic only. Therefore, no values can be recommended by this research for other modes (inland waterway, maritime and air).

Table 13 - Estimated VTTS values – work (business) passenger trips and freight (€2002, factor prices)

Country	Business (per passenger per hour)			Per tonne of freight carried (per freight tonne per hour)	
	Air	Bus	Car, Train	Road	Rail
Austria	39.11	22.79	28.40	3.37	1.38
Belgium	37.79	22.03	27.44	3.29	1.35
Cyprus	29.04	16.92	21.08	2.73	1.12
Czech Republic	19.65	11.45	14.27	2.06	0.84
Denmark	43.43	25.31	31.54	3.63	1.49
Estonia	17.66	10.30	12.82	1.90	0.78
Finland	38.77	22.59	28.15	3.34	1.37
France	38.14	22.23	27.70	3.32	1.36
Germany	38.37	22.35	27.86	3.34	1.37
Greece	26.74	15.59	19.42	2.55	1.05
Hungary	18.62	10.85	13.52	1.99	0.82
Ireland	41.14	23.97	29.87	3.48	1.43
Italy	35.29	20.57	25.63	3.14	1.30
Latvia	16.15	9.41	11.73	1.78	0.73
Lithuania	15.95	9.29	11.58	1.76	0.72
Luxembourg	52.36	30.51	38.02	4.14	1.70
Malta	25.67	14.96	18.64	2.52	1.04
Netherlands	38.56	22.47	28.00	3.35	1.38
Poland	17.72	10.33	12.87	1.92	0.78
Portugal	26.63	15.52	19.34	2.58	1.06
Slovakia	17.02	9.92	12.36	1.86	0.77
Slovenia	25.88	15.08	18.80	2.51	1.03
Spain	30.77	17.93	22.34	2.84	1.17
Sweden	41.72	24.32	30.30	3.53	1.45
United Kingdom	39.97	23.29	29.02	3.42	1.40
EU (25 Countries)	**32.80**	**19.11**	**23.82**	**2.98**	**1.22**
Switzerland	45.41	26.47	32.97	3.75	1.54

Road

Original research have been carried out in the UNITE, RECORDIT and HEATCO projects. We report first their findings and then review the other EU projects.

In the UNITE project (Doll, 2002) congestion costs have been assessed by determining welfare-optimal congestion charges in road transport by computing the equilibrium of traffic demand and marginal social user costs of a single road link. By considering several case studies, it has been possible to check the variability of results face to cost drivers, such as variation of road type, variation of HGV-share and variation of demand elasticity. The following table summarises the results range considering these cost drivers. Standard conditions present a congestion cost of €0.15 (for car passengers) and € 0.35 (for HGV). From the data reported below, it is clear that congestion costs increase by 50% for HGV drivers in rural road (whilst almost no variation occurs for car passengers. Congestion costs also increase as the share of HGV increases. They decrease as demand elasticity increases.

Table 14 - Variations of congestion costs by cost driver

Cost driver	Congestion costs for passenger cars (€-ct. / km) 1)	Congestion costs for HGVs (€-ct. / km) *
Standard conditions: (2-lane motorway, HGV-share: 15%, Elasticity: -0.35)	15	35
Variation of road type: (4-lane motorway - 2-lane rural road)	15 - 16	33 - 48
Variation of HGV-share: (p = 10% - 30%)	15 - 15	32 - 72
Variation of demand elasticity: (Eta(P) = Eta(G) = -0.1 - -1)	26 - 10	61 - 20

Source: Doll (2002)
Note: * Current congestion costs before user reaction

Congestion costs have been estimated also in the RECORDIT project (Schmid et al., 2001: 38), by considering several member states and the travel time spent in different travel situations. In this study, the authors consider the VOT estimated in previous studies (UNITE) and transfer these values to local conditions by considering as a conversion factor the real per capita income at purchasing power exchange rates for each country. Monetary valuation of travel time (expressed in 1998 €per person hour) results higher in case of business and freight (going from 7.60€ for Poland to 25.68 for Switzerland and from 10.1€ for Croatia to 52.6 for Switzerland, for business and freight, respectively) with respect to the value get for commuting and leisure (going from 0.78€ for Croatia to 4.54 for Switzerland and from 1.18€ for Croatia to 6.81€ for Switzerland, for leisure and commuting, respectively).

Congestion costs are also evaluated by Navrud *et al*. (2006) in the HEATCO project (D4). In their original study, they ask respondent to assess their WTP to save 5 and 10 minutes for travelling to work (survey were administered in five countries). Pooled/averaged results for all countries, again using the results corrected for protest zero responses, give a mean WTP of €0.15 and €0.24 for 5 and 10 minutes travel time-savings, respectively. This corresponds to a value per hour of saved travel time going on a journey to work by car equal to €1.80 and €1.44, based on a 5 and 10 minutes time savings, respectively. These values are significantly lower then what is experienced in other surveys for valuing time and are probably explained by the use of a different methodological approach, rather than underlying changes in individual's preferences.

Regarding review works, Lindberg (2006), for the Grace D3, reports the estimates obtained in previous studies, by converting them in 2003 prices pence and expressing them in per car unit Km (by assuming that average car trip length is around 10.5 km).

Maibach *et al*. (2007) convert the values obtained by previous studies in $€_{2005}$/vkm. Their findings are summarised in Table 15 below. By looking at these estimates, the following generalisations can be drawn:

- some studies consider MSCP, whilst other consider MEC, with the latter being greater than the former. Estimates vary from to (for MSCP) and from to (for MEC)
- whilst the majority of these studies expresses these measures as €/vkm, some of them use €/trip.
- Only one study compares urban with rural situations areas, whilst the majority considers urban conditions.
- in urban areas the results vary considerably: to name just a few, MSCP estimates go from 0,05€ for Helsinki to 2.20€ for Northampton; MEC goes from 0.17€ to 4.92€,

- Some studies consider also peak and off-peak hours, with off-peak estimates being double with respect to peak estimates.

Marginal external costs are obtained by using speed-flow relationships or through Saturn[8]. In these studies the cost components considered are delay, accident, local air pollution, noise and climate change. As a result, they cannot be interpreted as estimates of the marginal costs of congestion.

Table 15 – Review of studies estimates of short run MEC

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	

[8] Saturn is a transport planning software developed at the Institute for Transport Studies, University of Leeds. http://www.saturnsoftware.co.uk/

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	

Source: Maibach et al., (2007)

Lindberg (2006) explains these variations by arguing that private marginal cost and social marginal costs increases faster as the traffic increases. A more detailed explanation of these differences could be found in Bonsall *et al*. (2006), who sketched the following hypothesis:

- The different results may reflect real differences in the nature and scale of the externalities. For instance, more the congestion, the severity of accident and the level of air emissions, more is the optimal charge needed. The level of the charge will depend upon the externality components considered.
- Network morphology and availability of modal alternatives. The different results may reflect real differences between the availability of capacity or alternative options in the different cities, as it is the case in dense road networks. This could explain the low estimates obtained in May and Milne's study (using SATURN models of Cambridge, York and Leeds), and Santos' one in eight UK cities. Factors which are particularly likely to influences the results include the degree of congestion, the availability and attractiveness of alternative modes, the drivers' tolerance of congestion, and the capacity of the network to absorb additional demand.
- Demand characteristics and behavioural response assumptions and parameters. The different results may reflect real differences between the demand pattern and assumed behavioural response in the different cities. The charge required will be lower, e.g., if there is much less demand off-peak. This could be the case for Santos (2004) and May, Liu and Shepherd (2001)'s studies.
- Specification of charging scheme. The different results reflect differences in the way that optimal charges have been defined. Charging sometimes relates only to congestion tolls (rather than covering other externalities), sometimes allows for the cost of implementation of the tolls (and sometimes not), and sometimes relates only to simple tolls - such as cordons (rather than tolls which vary in space and time).

- The different results reflect differences in modelling assumption, i.e. the way that the cities have been represented in the models, the way that behavioural responses have been modelled, and due to incomplete convergence in the modelling process or to the existence of multiple solutions

Rail

The only EU funded project that assesses rail congestion costs is GRACE (D3). The RECORDIT project does not consider them due to the fact that there is not an accepted methodology.

As stated above, the cost of scarce infrastructure, for railways, corresponds to the opportunity cost of a slot. There are several approaches to estimate such cost component:

- Nilsson (2002) suggests estimating this cost by using auction theory. In this manner, train operating companies could be asked to bid on the basis of what they are willing to pay for their most desired slot. By solving an optimisation problem the best available solution is found.
- NERA (1998) proposes to consider as cost of scarce infrastructure the long run marginal cost of incrementing the capacity. This approach is quite complicated to apply, since the long run marginal cost will depend upon the proposed expansion of capacity.
- Lindberg (2006) recommends considering the costs incurred when depriving another operator of the possibility of using the slot and oblige her to run the train at another time. Since this involves a shifting in departing time, the cost of scarce infrastructure in this approach could be estimated by considering the value of time. The basis of the approach taken here is that operators should be charged for the capacity they use in accordance with the social opportunity cost of that capacity. In order to implement this approach it is necessary first to measure the amount of capacity used by each train run, and then to estimate its opportunity cost.

Estimates of the cost of scarce infrastructure provided by Lindberg (2006) are reported in the last row of Table 16.

Table 16 - Summary of slot value (Full value for existing operator at peak=100)

	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: Lindberg (2006)

Ports

In the case of ports, congestion costs are defined by Jansson and Shneerson (1982, p. 52) as follows: “Congestion costs exist if the other short-run costs of port operations, per unit of throughput, are an increasing function of the actual capacity utilization. When actual demand exceeds capacity, extreme congestion costs arise, which we call queuing costs. When a port is said to be congested, it is commonly meant that ships are queuing, waiting to obtain a berth.”

Recent analyses have operationalised this definition. For instance, Blauwens, De Baere and Van de Voorde (2006), by taking into account that a port has several bottlenecks which could in turn generate several queues, propose to empirical estimate the total time that an average vessel spends in a port taking into account all bottlenecks and to model the time spent as a function of the traffic level (through regression analyses).

Bickel et al. (2006b) note that congestion is not an issue nowadays for ports, due to overcapacity of existing infrastructure with respect to the current demand. However, they note that this situation could change and introduce a simulation tool, by which calculating congestion costs in port by comparing the baseline situation (no congestion) with alternative scenarios (defined on the basis of the waiting time in ports). For instance, the additional marginal cost for a 2 hour- waiting time is estimated in 371€.

Accident costs

In this paragraph we will discuss two approaches to estimate the external marginal accident cost in principle consistent with the definitions discussed above: i) UNITE, and ii) Insurance externality. Let’s see them in detail.

To apply the first estimation approach, one needs to have information on the accident risk (r) and its relationship with traffic volume (the elasticity E), the cost per accident (a+b+c) and how this cost is allocated between user groups (θ). Unfortunately none of this information is easy to get. The UNITE approach estimates each element of the equation 4 above. The critical elements are the value of statistical life (VSL), the proportion of internal costs, the risk and the risk elasticity.

Regarding the VSL, a wide range of estimates are available, going from 200.000 $ to 30 ml US$ (Blaeij, 2003). The HEATCO project makes recommendations on methods to adopt when estimating VSL and provides figures for each European States (see Table 17). It also estimates the value of a severe and slight injury as a percentage of the fatality estimate, equal to 13% and 1% respectively. These values can be used as in equation 4 above. Direct and indirect economic costs have to be estimated separately and have to be split into internal and system external (c).

For what concerns risk elasticity, Lindberg (2006) after surveying the literature concludes that no single recommendation on the magnitude and the sign on the risk elasticity can be drawn. Surprisingly many studies find decreasing risk with increasing traffic volume. This could be a problem of the studies or due to behaviour effects. If we do not control for infrastructure quality, we may find that roads with higher expected traffic volume are designed with a higher traffic safety standard. In addition, road users may react to a perceived increased risk by driving more carefully and slower. This is an unobserved cost component that would increase the cost.

In the RECORDIT project, a risk elasticity of 0.25 is adopted.

Table 17 – Recommended estimates for VSL

Country	Fatality	Severe injury	Slight injury	Fatality	Severe injury	Slight injury
	(€2002, factor prices)			(€2002 PPP, factor prices)		
Austria	1,760,000	240,300	19,000	1,685,000	230,100	18,200
Belgium	1,639,000	249,000	16,000	1,603,000	243,200	15,700
Cyprus	704,000	92,900	6,800	798,000	105,500	7,700
Czech Republic	495,000	67,100	4,800	932,000	125,200	9,100
Denmark	2,200,000	272,300	21,300	1,672,000	206,900	16,200
Estonia	352,000	46,500	3,400	630,000	84,400	6,100
Finland	1,738,000	230,600	17,300	1,548,000	205,900	15,400
France	1,617,000	225,800	17,000	1,548,000	216,300	16,200
Germany	1,661,000	229,400	18,600	1,493,000	206,500	16,700
Greece	836,000	109,500	8,400	1,069,000	139,700	10,700
Hungary	440,000	59,000	4,300	808,000	108,400	7,900
Ireland	2,134,000	270,100	20,700	1,836,000	232,600	17,800
Italy	1,430,000	183,700	14,100	1,493,000	191,900	14,700
Latvia	275,000	36,700	2,700	534,000	72,300	5,200
Lithuania	275,000	38,000	2,700	575,000	78,500	5,700
Luxembourg	2,332,000	363,700	21,900	2,055,000	320,200	19,300
Malta	1,001,000	127,800	9,500	1,445,000	183,500	13,700
Netherlands	1,782,000	236,600	19,000	1,672,000	221,500	17,900
Norway	2,893,000	406,000	29,100	2,055,000	288,300	20,700
Poland	341,000	46,500	3,300	630,000	84,500	6,100
Portugal	803,000	107,400	7,400	1,055,000	141,000	9,700
Slovakia	308,000	42,100	3,000	699,000	96,400	6,900
Slovenia	759,000	99,000	7,300	1,028,000	133,500	9,800
Spain	1,122,000	138,900	10,500	1,302,000	161,800	12,200
Sweden	1,870,000	273,300	19,700	1,576,000	231,300	16,600
Switzerland	2,574,000	353,800	27,100	1,809,000	248,000	19,100
United Kingdom	1,815,000	235,100	18,600	1,617,000	208,900	16,600

Source: HEATCO

Lindberg (2002) carries out some case studies in order to estimate the marginal external accident cost, for different transport means. Due to the limited number of case considered, the author recognises that "result from this report is thus nothing more than an indication on the external marginal accident cost in European transport and a base for more studies" (p.1).

In particular, by considering the number of accidents per hour and transport volume per hour for 114 road sections in Switzerland, he finds that the external marginal costs turn out to be in the range between € 0.002 (motorway) and 0.048 (roads inside settlement area) per vkm. Moreover, by carrying out two other analyses in Sweden and Portugal, he concludes that differences in valuation could be explained by different purchasing power between countries and that the accident risk is very country specific.

For what concerns waterborne transport, he estimates external marginal costs by considering accident statistics and compensation paid, so as to derive an estimate of the external cost of an additional travel. He gets that for the Rhine case study external costs to amount to approximately € 16 per movement or 0.0019 € per ship tonne kilometre.

The table below summarises the findings of the UNITE D9 (Lindberg, 2002).

Table 18 – Marginal accident costs for different transport modes

(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
	Above 31 t (7)	=	1.030	99.3	0.03	-0.74	-	0.032
E	**Maritime**							
	Swedish ship on Swedish water	Registred ships	0.026	n.a.	n.a.	n.a.	-	73 – 10 000 anually
	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

In studies of the 'Insurance externality' the relationship between the traffic flow and the insurance premium are 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 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.

The results in Edlin (2003b) suggest that the insurance premium increases strongly in high density states with increased traffic. However, since these increases vary from 60$ (South Dakota) to $2,432 (California) generalisation to other contexts is not adviced.

Air pollution costs

For what concerns air pollution costs, all the projects reviewed consider the impact pathway approach. Bickel et al. (2006c) provide an overview of the cost factors for road transport to be applied at Member State level, for each of the pollutants recalled above (see Table below). These figures include human health, crop losses and material damage impacts.

Table 19 - Cost factors for road transport emissions* per tonne of pollutant emitted in €2002 PPP (factor prices).

Pollutant emitted	NOx	NMVOC	SO2	PM2.5	
Effective pollutant	**O3, Nitrates, Crops**	**O3**	**Sulphates, Acid deposition, Crops**	**primary PM2.5**	
Local environment				**urban**	**outside built-up areas**
Austria	4,300	600	3,900	430,000	72,000
Belgium	2,700	1,100	5,400	440,000	95,000
Cyprus**	500	1,100	500	260,000	22,000
Czech Republic	3,200	1,100	4,100	270,000	67,000
Denmark	1,800	800	1,900	400,000	47,000
Estonia	1,400	500	1,200	160,000	27,000
Finland	900	200	600	360,000	30,000
France	4,600	800	4,300	410,000	82,000
Germany	3,100	1,100	4,500	400,000	78,000
Greece	2,200	600	1,400	270,000	38,000
Hungary	5,000	800	4,100	230,000	59,000
Ireland	2,000	400	1,600	440,000	46,000
Italy	3,200	1,600	3,500	390,000	71,000
Latvia	1,800	500	1,400	140,000	26,000
Lithuania	2,600	500	1,800	160,000	32,000
Luxemburg	4,800	1,400	4,900	730,000	104,000
Malta (O3 estimated)	500	1,100	500	240,000	20,000
Netherlands	2,600	1,000	5,000	440,000	86,000
Poland	3,000	800	3,500	190,000	57,000
Portugal	2,800	1,000	1,900	270,000	40,000
Slovakia	4,600	1,100	3,800	200,000	54,000
Slovenia	4,400	700	4,000	280,000	58,000
Spain	2,700	500	2,100	320,000	44,000
Sweden	1,300	300	1,000	370,000	36,000
Switzerland	4,500	600	3,900	460,000	76,000
United Kingdom	1,600	700	2,900	410,000	64,000

Source: HEATCO

Lindberg (2002) provides monetary estimates for health effects. They are summarised in the following table.

Table 20 – Monetary values for health impacts (€ 2002 factor costs)

Impact	European average	
Year of life lost (chronic effects)	40,300	€ per YOLL
Year of life lost (acute effects)	60,500	€ per YOLL
Chronic bronchitis	153,000	€ per new case
Cerebrovascular hospital admission	1,900	€ per case
Respiratory hospital admission	3 610	€ per case
Congestive heart failure	2 730	€ per case
Restricted activity day,	76	€ per day
Minor restricted activities days, cough days, Symptom days	31	€ per day

Source: HEATCO (2006)

In recent research, Lindberg et al. (2006) value the external costs due to air pollution by considering four case studies (Berlin, Copenhagen, Athens and Prague).

The data used for estimation were meteorological data together with detailed population data (so as to calculate exposure functions). They take into account different vehicle categories. In particular, road vehicle types covered comprise passenger cars, light and heavy duty vehicles (LDV, and HDV respectively) with both petrol and diesel fuelled engine, except for HDV (diesel only). Vehicle emissions were modelled taking into account driving patterns and traffic situations common in city centres. In order to calculate the costs deriving from emissions, they follow the methodology sketched above, by multiplying the amount of CO2 equivalent emitted by a cost factor (taken from previous literature). In particular, they derive shadow prices by considering the estimates in Watkiss et al. (2005) and converting from £2000/t C to €2002 (factor prices). As a result, they recommend using a range of €14 to €51 (with a central value of €22 per tonne of CO2- equivalent emission in the period 2000 to 2009). All the elaborations have been carried out through the Ecosense transport software tool. Bickel (2002) calculate the external costs due to air pollution for different vehicles (see Table 21 below).

Table 21 - Damage costs due to air pollution from road vehicle exhaust emissions in €cent / vkm

		Car Petrol EURO2	Car Diesel EURO2	HGV Diesel EURO2
urban case studies	Helsinki	0.12	n.a.	n.a.
	Stuttgart	0.25	1.45	17.52
	Berlin	0.15	0.73	10.19
	Florence a)	0.01 a)	0.26 a)	4.69 a)
inter-urban case studies	Helsinki – Turku	n.a.	n.a.	2.09
	Basel – Karlsruhe	0.37	0.63	6.91
	Strasburg – Neubrandenburg (outside built-up areas)	0.12	0.26	3.89
	Strasburg – Neubrandenburg (within built-up areas)	0.11	0.38	7.46
	Milano – Chiasso	0.25 b)	1.91 b)	6.72 b)
	Bologna – Brennero	0.20 b)	0.73 b)	5.07 b)

They conclude that these estimates vary according to the following parameters:

- Emission factors, which are different according to the fuel used (e.g. petrol – diesel), the vehicle type (e.g. heavy diesel vehicles – diesel cars), the emission standard (e.g. EURO2 – EURO4), and driving pattern (speed, acceleration processes).

- The local environment close to the road (receptor density, meteorology, above all average wind speed).

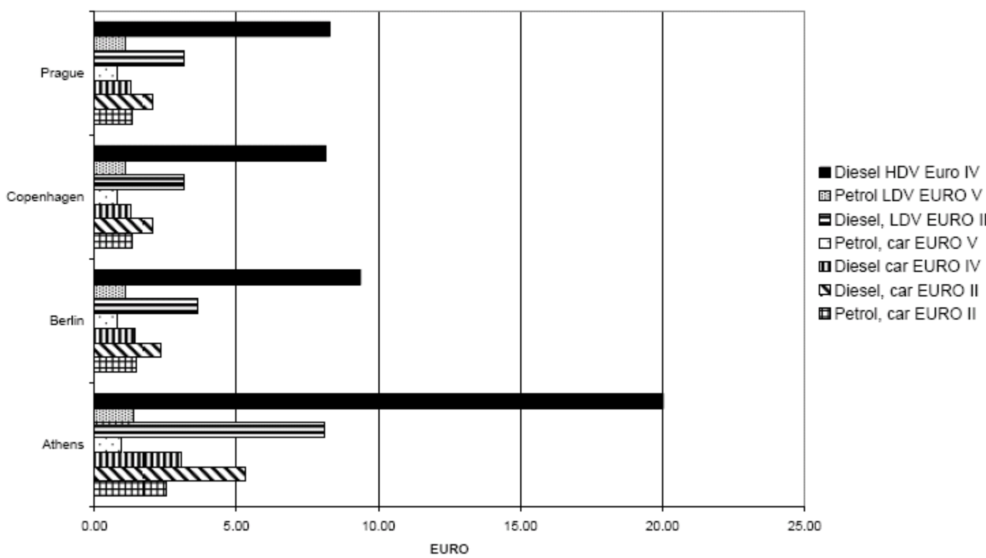
- The geographical location (determining the number of receptors affected by long-range pollutant dispersion and formation of secondary pollutants).

These estimates varies from 0.11 to 0.37 € (for car petrol) and from 2.09 to 17.52 (for HGV Diesel). Bickel et al. (2002) suggest being cautious in transferring these results in other contexts, since transfer would need a broader statistical basis for case studies. However, they clearly indicate some elements that can be generalised, such as the overall methodology (i.e. the impact pathway approach), the exposure response functions, the monetary values for health impacts (after having adjusted them by country).

They also note that "the relationships between pollutant emission and associated costs are in principle the same as for road transport". As a result, the emissions caused by other transport modes can be treated like emissions from road vehicles, taking into account the character of the route. For these modes however the main part of emissions will occur in extra-urban areas.

Bickel *et al*. (2006) replicate this analysis. The figure below summarises the results (marginal costs include vehicle use, up- and downstream processes and greenhouse gases). In all the cases considered, the diesel HDVs show higher marginal costs, ranging from 0.075 € (Copenhagen) to 0.20€ (Athens). At the contrary, petrol EuroV cars show the lowest estimates, below 0.01€ vkm. The factors that seem to be more relevant for these results are the wind speed and the population density. The high share of low wind speeds for the Athenian area together with a population density close to 20 000 hab/km_2 in some zones, leads to a pollutant exposure of the population which is about a factor of two higher compared to the other cities. Petrol cars cause lower cost per vehicle kilometre compared to diesel cars as they emit much less fine particles, leading to lower health impacts.

Figure 4 - Marginal costs due to airborne emissions in EUR /100 vkm



Source: Lindberg et al. (2006)

Lindberg *et al*. (2006) analyse also rail transport, by considering as relevant options tram, metro (underground train) and light train, all with electrical traction. The marginal cost of running and additional train was estimated considering two assumptions: 1) the necessary electricity is produced in coal-fired power plant and 2) the electricity is bought in European electricity market.

It can be noticed that the environmental costs associated with electric trains depends on the sources used to produce the electricity.

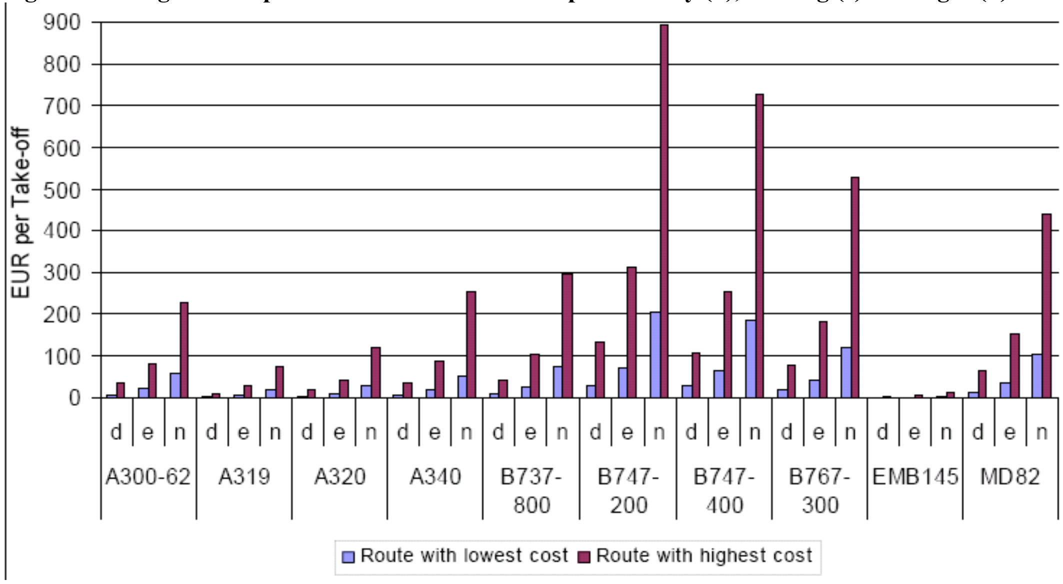
Table 22 - Marginal cost for urban passenger rail operation

City	Train type	Energy use per vehicle kWh/km	Cost factor Electricity production (EUR / kWh)	PM10 EUR/km	Total cost EUR/ 100 vkm	With UCTE Mix
Athens	Tram	3.81	0.0404	1.05	15.4	4.5
	Metro	3.22	0.0404	1.05	13.0	3.8
	Light Train	5.42	0.0404	1.05	21.9	6.4
Berlin	Tram	3.81	0.0293	0.34	11.2	4.5
	Metro	3.22	0.0293	0.34	9.4	3.8
	Light Train	5.42	0.0293	0.34	15.9	6.4
Copenhagen	Tram	3.81	0.0286	0.30	10.9	4.5
	Metro	3.22	0.0286	0.30	9.2	3.8
	Light Train	5.42	0.0286	0.30	15.5	6.4
Prague	Tram	2.92	0.0321	0.27	9.4	3.4
	Metro	2.89	0.0321	0.27	9.3	3.4
	Light Train	5.47	0.0321	0.27	17.6	6.5

Source: Lindberg et al. (2006)

Bickel *et al*. (2006b) provide estimates of the marginal external costs for Frankfurt airport, by considering different aircraft types and different day time. Estimates are obtained from Schmit *et al*. (2001). Results are shown in figure below. Costs due to air pollution amount – depending on aircraft type – to between 10 and 235 € per LTO cycle, greenhouse gas emissions add another 20 to 220 € per LTO cycle. Noise costs were quantified for different times of day: day time, evening and night time with the latter showing the highest cost. Quantified night time noise – depending on flight route – ranges from 4 – 16 € per take-off to 200 – 900 € per take-off. Costs for landing tend to be lower, but are in the same order of magnitude.

Figure 5 - Range of cost per take-off at Frankfurt airport for day (d), evening (e) and night (n) time



Source: Bickel *et al*. (2006b)

Global warming

Considering global warming, Tol (2005) contains the most comprehensive review of marginal costs of CO2. Bickel et al. (2005) suggest using the median as the best measure of central tendency. This amounts at $14/tC.

Similar figures have been uses by Bickel et al. (2002) (they use a cost factor for global warming equal to 20€). By using the impact pathway approach and considering as cost factor the costs necessary to implement the Kyoto protocol in Europe, they get the estimates for road vehicles shown in Table 23. Surprisingly, the less polluted vehicles are car diesel (0.31€ to 0.43€), followed by car petrol (from 0.34 € to 0.69€). Heavy vehicles remain the most impacting means of transport, with damage costs varying from 2€ to 3.28€.

Table 23 - Damage costs due to global warming from exhaust greenhouse gas emissions from road vehicles in €cent / vkm

		Car Petrol EURO2	Car Diesel EURO2	HGV Diesel EURO2
urban case studies	Helsinki	0.35	n.a.	n.a.
	Stuttgart	0.47	0.31	3.28
	Berlin	0.47	0.31	3.28
	Florence	0.69	0.43	2.00
inter-urban case studies	Helsinki – Turku	n.a.	n.a.	2.40
	Basel – Karlsruhe	0.37	0.32	2.18
	Strasburg – Neubrandenburg (outside built-up areas)	0.34	0.25	2.03
	Strasburg – Neubrandenburg (within built-up areas)	0.47	0.31	3.28
	Milano – Chiasso	0.36 a)	0.36 a)	2.16 a)
	Bologna – Brennero	0.36 a)	0.36 a)	2.16 a)

Source: Bickel et al. (2002)

As underlined above, the avoidance cost approach applied by Lindberg et al. (2002) is progressively being abandoned. We also report the shadow prices recommended by the HEATCO project to take into account future damage and abatement costs for GHG (see Table 24 below), which could arrive at €83/t, on the basis of the assumption that future emissions will have stronger total impacts than present emissions.

Table 24 - Shadow prices converted from ₤2000/t C to €2002 (factor prices) per tonne of CO2 equivalent emitted.

	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

Source: Watkiss *et al*. (2005b)

Noise

Models for assessing impacts from noise were provided in the projects UNITE (see Bickel et al., 2003) and RECORDIT (see Schmid *et al*., 2001).

As underlined above, first approaches to quantify costs due to noise were using general values per dB, which mostly were derived from hedonic pricing studies. Such studies established a relationship between rents or house prices and properties of the flat or house, one of which was the noise exposure.

De Kluizenaar *et al*. (2001, quoted in Lindberg et al., 2006 and Lindberg, 2002) reviewed the state of the art, reporting risks due to noise exposure in the living environment. They stress that noise can entail stress related health effects, psyco-social effects and sleep disturbances. Lindberg (2002) estimate the health costs deriving from noise and get the estimates shown in Table 25 below, by considering the medical costs paid by the health service, the costs in terms of productivity losses and other social and economic costs.

Table 25 – Monetary impacts due to noise (€ 1998)

Impact	**Finland**	**Germany**	**Italy**
Myocardial infarction (fatal, 7 YOLL)			
Total per case	**535 000**	**564 000**	**528 000**
Myocardial infarction (non-fatal, 8 days in hospital, 24 days at home) Medical costs	4 800	4 700	3 700
Absentee costs	2 900	3 500	2 700
WTP	15 400	16 300	12 900
Total per case	**23 100**	**24 500**	**19 400**
Angina pectoris (severe, non-fatal, 5 days in hospital, 15 days at home) Medical costs	3 000	2 900	2 300
Absentee costs	1 800	2 200	1 700
WTP	9 700	10 200	8 100
Total per case	**14 500**	**15 300**	**12 100**
Hypertension (hospital treatment, 6 days in hospital, 12 days at home) Medical costs	1 900	1 800	1 500
Absentee costs	1 600	2 000	1 500
WTP	600	600	600
Total per case	**4 100**	**4 400**	**3 500**
Medical costs due to sleep disturbance (per year) WTP (per year)	200 400	210 430	200 400
WTP for avoiding amenity losses (€/dB/person/year)	20	16	8
Source: Own calculations based on Metroeconomica (2001); country-specific valuation based on Nellthorp et al. (2001); for the derivation of the WTP for avoiding amenity losses see text			

Source: Lindberg (2002)

To enable the application of the exposure-response functions predicting annoyance reactions on the population level as recommended by European Commission (2002), the project HEATCO's carried out stated preference surveys in five European countries (see Navrud et al. 2006). Based on surveys in Germany, Hungary, Norway, Spain, Sweden and the UK, values for application in Europe were derived for the annoyance levels highly annoyed, annoyed and little annoyed. Results are summarised in the Table 26.

Table 26 - Annual willingness-to-pay by annoyance level for reducing annoyance (€ 2005)

Annoyance level	**Mean WTP per person per year (PPP-converted 2005-euro)**
Not annoyed	8.12
Slightly annoyed	37.08
Moderately annoyed	84.93
Very annoyed	84.30
Extremely annoyed	80.51
Urban-Rural	
Urban – all annoyance levels	48.21
Rural – all annoyance levels	48.80
Total number of observations (excluding protest zero responses)	2709

Source: Navrud et al. (2006)

One can see a clear pattern of increased WTP with increased annoyance level when moving from "not annoyed" to "slightly annoyed", and on to "moderately annoyed". However, the authors note that for the overall sample there is no significant difference in WTP between the three highest annoyance levels (i.e. moderately, very and extremely annoyed). A possible explanation could be found on the fact that people with lower income, and thus lower ability to pay, often live in areas with high road traffic noise levels, since the houses in these areas are cheaper. To conclude, Navrud et al (2006) suggest using the same value, i.e. 85 euros for the three highest noise annoyance levels. They also note that there is no significant difference in WTP to avoid noise annoyance in rural versus urban areas. Thus, the same values should be used when valuing reduced road noise annoyance in rural and urban areas.

The HEATCO project also considers the cost of rail noise annoyance. By following the same methodology used in the road case, they get the following estimates. They found that rail noise is valued lower that road noise. They detect the same income effect as in the road case (i.e. WTP increase until with increasing annoyance level up until "moderately annoyed". As a result, they suggest considering an estimate as shown in Table 27 for not and slightly annoyed, and the same value for the three highest annoyance level, i.e. 60 euro per person per year.

Table 27 - Annual willingness-to-pay by annoyance level for reducing annoyance (€2005)

Annoyance level	**Mean WTP per person per year (PPP-converted 2005-euro)**
Not annoyed	15.08
Slightly annoyed	38.20
Moderately annoyed	59.17
Very annoyed	49.58
Extremely annoyed	68.28
Urban-Rural	
Urban – all annoyance levels	46.35
Rural – all annoyance levels	32.01
Total number of observations (excluding protest zero reponses)	1519

Source: Navrud et al. (2006)

For what concerns aircraft noise annoyance, they found that WTP does not vary systematically with changes in annoyance level nor with whether it is an urban or rural locality (see Table 24 below).

Table 28 - Mean WTP per person per year to eliminate aircraft noise annoyance for each noise annoyance level, and separate for urban and rural locations in Hungary

Mean WTP	Noise annoyance level				
	Not annoyed	**Slightly**	**Moderately**	**Very**	**Extremely**
Rural	2.1	19.8	9.8	15.6	0
Urban	2.6	14.3	6.1	13.8	4.0

Source: Navrud *et al*. (2006)

The RECORDIT project estimates marginal external noise costs of heavy goods vehicles per vkm, by distinguishing the motorway and urban case. In the former case, these estimates go from 0.22 cent€ for (Croatia) to 1.13cent€ (Switzerland) for motorway, and from 10.50 cent€ (Croatia) to 54.63 cent€ (Switzerland) for urban.

The UNITE project also calculate noise costs from cars in urban areas (by considering the cases of Stuttgart, Berlin and Helsinki). In all the case considered, costs are increasing from day to night, reflecting the higher disturbance effect of noise during night time. Day-related estimates range from 0.2 €/vkm in Helsinki (day) to 1.5 € in Stuttgart. Night-related estimates go from 0.5€ in Helsinki to 4.5 € in Stuttgart. These variations can be explained by considering the background noise level and the population densities of the considered areas. Estimates are lower in low density areas and in conditions with a high traffic level.

Table 29 – Costs due to noise for road vehicles (€cent/vkm)

		Passenger car		**HGV**	
		daytime	**night time**	**daytime**	**night time**
urban case studies	Helsinki	0.22	0.53	n.a.	n.a.
	Stuttgart	1.50	4.50	25.75	78.25
	Berlin	0.47	1.45	7.67	23.33
	Florence	a)			
inter-urban case studies	Helsinki – Turku	n.a.	n.a.	1.58	3.86
	Basel – Karlsruhe	0.02	0.03	0.11	0.18
	Strasburg – Neubrandenburg (outside built-up areas)	0	0	0	0
	Strasburg – Neubrandenburg (within built-up areas)	0.12	0.19	3.04	5.06
	Milano – Chiasso	0.01	0.04	0.09	0.35
	Bologna – Brennero	0.001	0.002	0.006	0.02
a) marginal costs not given per vehicle kilometre, but per 1 dB(A) reduction					

Source: Lindberg (2002)

For the generalisation of these results the same considerations made above for air pollution hold. The HEATCO project provides the central values for noise exposure for all the Member States (Bickel et al., 2006c).

6. *The monetisation of external cost of transport in national experiences*

After having reported extensively the approaches and results of the EU funding research, in this section we describe the work carried out in national experiences, both at EU and extra-EU (i.e. USA, Canada and New Zealand) experiences.

Review of European National Studies

In the European context, several studies are available at Member State level. In particular, we will analyse here the analysis carried out by the United Kingdom, Norway and Sweden.

United Kingdom

Several studies exist for the UK case study (Piecyk and McKinnon, 2007; Sanson et al., 2001).

The first of those (Sanson et al., 2001) considers road and rail internal and external costs, by referring to infrastructure and operation costs, congestion, air pollution, noise and climate change.

The external cost categories are assessed as follows:

- the marginal external congestion cost is calculated by differentiating total time cost by traffic volume and subtracting the average cost (thus following the approach explained above);
- Air pollution impacts have been calculated using the ExternE methodology;
- Noise was assessed by considering the relationships between average noise and property prices;
- Climate change was evaluated by referring to the damage cost approach, by considering as low, central and high values £7.3/tonne of CO_2, £14.6 and £29 respectively.

The analysis shows that marginal (internal and external) costs of road transport range from 12.32£ to 17.05£ and are insufficient to cover them. The highest proportion of costs is covered by congestion costs (£9.71 - £ 11.16), followed by infrastructure and operation (£ 0.42 - £0.54) and air pollution (0.34-1.70). It can thus be concluded that external costs exceed internal costs.

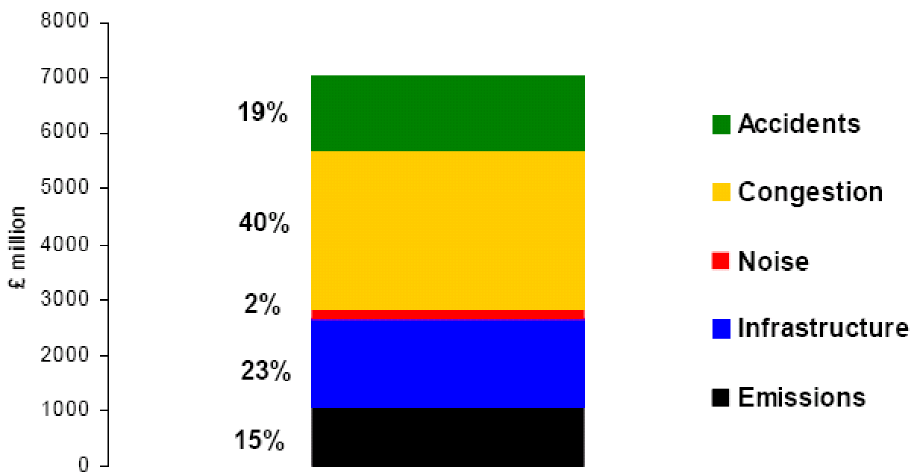
The Piecyk and McKinnon (2007)'s study assesses the degree to which the external costs of road freight transport in the UK are currently being internalised by taxation. The analysis focused on three types of cost: environmental costs (comprising climate change, air pollution, noise and accidents), congestion costs and infrastructure costs.

Current estimates of infrastructural, environmental and congestion costs have been obtained from official government sources and disaggregated by vehicle type and gross weight class.
Using mid-range estimates, the total infrastructural, environmental and congestion costs attributable to UK-registered heavy goods vehicles (HGVs) in 2006 were £7.1 billion for the base-case and £7.6 billion for the worst- case scenario.

The taxes paid by HGVs covered approximately two-thirds of these costs (in the base-case scenario). The proportion of the total cost internalised varied by vehicle class, with the lightest category of rigid vehicles covering only 55% of their allocated costs, but the heaviest rigid vehicles covering 79%. Overall, the analysis suggested that taxes on lorries would have to rise by around 50% to fully internalise infrastructural, environmental and congestion costs.

Overall, 40% of the total external costs is attributable to congestion, 23% to infrastructure, 19% to traffic accidents, 15% to air pollution and greenhouse gas emissions and only 2% to noise (Figure 4). As some gases, such as methane and carbon monoxide, contribute both to global warming and air pollution, it has not been possible to split the external costs associated with these emissions between climate change and reductions in air quality. An indication of the climate change component can be given by focusing on CO2 emissions from lorry exhausts as these have no effect on air quality. On this basis, climate change costs would represent around 8% of the total external costs of road freight transport in the UK.

Figure 6 – Breakdown of Total external costs of HGV in UK



Source: Piecyk and McKinnon (2007)

Norway

Here we consider the Eriksen (2000)'s work. The study was initiated by the Norwegian Ministry of Transport as part of their input to the National Transport Plan 2002 – 2011. This plan includes all transport modes and all infrastructure investment and other policy plans for this eight year period.

The present study aims to calculate the marginal external effects of transportation activities in Norway. The external effects included are:

- emissions to air
- noise
- accidents
- infrastructure wear

- congestion

The study refers to three estimation approaches, namely: stated preferences, damage costs and indirect valuation (by considering measures to protect the environment are often implemented by the state or local authorities).

Regarding emissions to air, the physical emissions to air from road traffic are calculated in the Norwegian ‘Road Emission Model’. The substances included in the valuation are:

- Sulphur dioxide (SO2)
- Nitrogen oxides (NOX)
- Volatile organic components (VOC and NMVOC)
- Particles with diameter less than 10 µm in diameter (PM10).

The study builds its unit cost estimates upon different sources, with preference for estimates on WTP studies, preferably combined with dose-response functions (damage cost analyses). For SO2 it considers an unpublished study by The Norwegian Pollution Control Administration (SFT).

Marginal cost of SO2-emission are by use of damage cost methods assessed to NOK2 50 - 90 (EUR 6 – 11) per kg in densely populated and NOK 8 – 25 (EUR 1 – 3) in sparsely populated areas. For NOX, VOC and particles (PM10) the ‘recommended’ values from a meta study from The Conference of European Transport Ministers (ECMT) under OECD (ECMT 1998) have been applied.

For particles (PM10) the same report finds an average value of 70 EURO (NOK 580) in densely populated areas and 0 in sparsely populated areas. A Norwegian study by Rosendahl (1999) indicates that the damage cost function is rapidly increasing by the concentration of particles in the air. As long as the concentration is not exceeding certain threshold values the damage is assumed to be zero.

Regarding global emissions, expert assessments of damage costs have lead to cost estimates in the interval NOK 125 to NOK 350 per tonne. It is however in our view difficult to overlook all consequences of future global warming. Therefore we have chosen to base our calculation on shadow costs.

For noise costs the study refers to literature findings. For *road transport* it applies a study by Sælensminde & Hammer (1994). The value is found to be NOK 1170 (EUR 145) per year for a noise reduction of 20%, among people that are bothered by noise, which represents a traffic reduction of 52,3%.

For *railway transport* a hedonic price approach is chosen. Vågnes & Strand (1996) made a survey for an area close to the railway passing through the eastern part of Oslo. They found that an average apartment increased its value by 10% when the distance to the railway track was doubled. For an average apartment this under certain conditions gives a value of NOK 1100 (EUR 137) per person for reducing railway noise to half its level.

Noise from *air traffic* is a nuisance to people living close to airports. Thune-Larsen (1995) found that the WTP among people bothered by noise is valued to NOK 1000 (EUR 125) per person for reducing the noise level by 50%. This represents a traffic reduction of 90%.

Also for congestion costs literature findings are recalled. Rekdal & Tretvik (1997) calculate the extra congestion cost over a 24-hour period to be NOK 0,94 (EUR 0.12) per vehicle km for the Oslo area. For the Trondheim area the congestion cost per km is calculated to be NOK 0,80 (EUR 0.10).

Regarding accident costs, even this study refers to costs of loss of human life and reduced health condition; the lost income and expenses due to accidents; and material costs. It considers a value of a statistical life to be NOK 17.7 millions.

Finally, the study considers also infrastructure costs. All infrastructure costs are split into fixed costs, transport-related costs and volume-related costs. The results are summarised in the following table.

Table 30 - Estimation methods and basic unit costs after type of external cost (Euro)

	per unit	*estimation method*	Big cities	Other built-up areas	Rural areas
			Local emissions		
SO_2	kg	WTP	8.75	8.75	2.12
NO_X	kg	meta-analysis	8.25	8.25	4.12
VOC	kg	meta-analysis	8.25	8.25	4.12
PM10	kg	WTP	212.5	25	0
			Global emissions		
CO_2 (and equivalents)	ton	shadow price	46.25	46.25	46.25
			Noise		
Road transport	20%*	WTP	146.25	146.25	0
Rail transport	50%*	hedonic price	137.50	137.50	0
Air transport	50%*	WTP	125.00	125.00	125.00
			Accidents		
Statistical death	case	WTP + mat **	2 150 000	2 150 000	2 150 000
Very serious injury	case	WTP + mat **	860 000	860 000	860 000
Serious injury	case	WTP + mat **	282 000	282 000	282 000
Light injury	case	WTP + mat **	24 000	24 000	24 000
			Congestion		
Passenger car unit	km	simulations	0.105	0	0

Source: Eriksen (2000)

Sweden

Two studies have been carried out by the Swedish Institute For Transport and Communications Analysis (SIKA) regarding external costs of transport, one in 2001 and the other in 2003, funded by the Swedish Government (SIKA, 2001; 2004).

The first report contains a survey of price-relevant marginal costs for the different modes of transport. There is also information on how marginal cost-related charges can be applied in practice. It considers wear and tear costs, congestion costs (by referring to previous studies), costs of air pollution and noise for all the transport modes. Unfortunately, only an executive summary is available in English, where the results are reported but not the methodology followed to obtain them.

We thus consider more in detail the 2004 report.

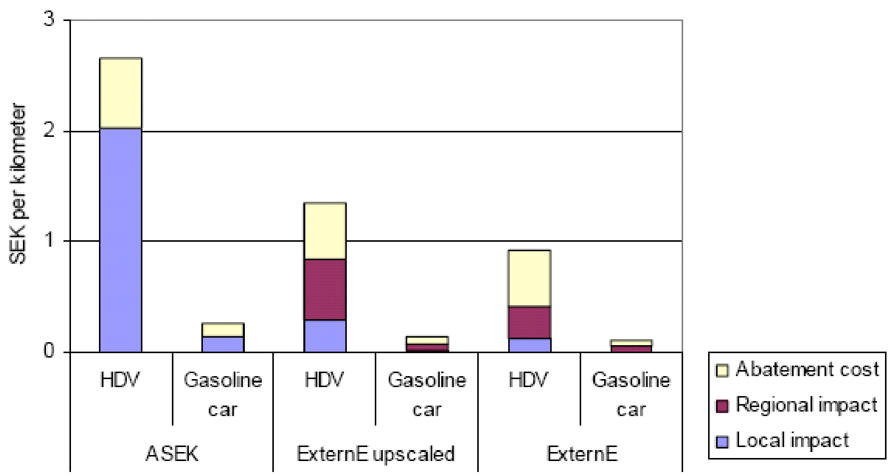
The report contains updated calculations of the marginal costs for different categories of transport and calculations of how these marginal costs relate to the variable traffic-related charges and taxes currently levied.

For what concerns road transport, regarding users costs, the National Road Administration has produced new calculations during the year for road traffic's wear and tear costs broken down by road category and type of vehicle. The marginal cost for an average lorry for roads with differing density of traffic varies from SEK 0.21 to 1.20 per vehicle kilometre. With reference to air pollution costs, work has continued in 2003 on clarifying the prerequisites for going over to the ExternE model for estimates of the emission costs of Swedish traffic. A study by Nerhagen and Johansson shows major differences in valuation of environment effects by different methods, in particular with regard to local effects. These will be considerably lower with ExternE than ASEK-values[9]. As shown in the following diagram, the local costs are about 10 times higher with ASEK estimates. The "higher" ExternE alternative is based on the higher so-called ER coefficient for the longterm effect on mortality of particle emissions that experts have considered as possibly being preferable.

In the case of sea transport, the emission cost is the predominant marginal cost item. The total marginal cost is around SEK 450 million during a year if the emission component is värderas using ExternE. This is to be compared with total charge revenue of SEK 1,130 million per year, i.e. charges are of the magnitude of 2.5 times the marginal costs. If, however, the emission costs are evaluated in accordance with ASEK, the aggregate marginal costs come to a considerably higher level, SEK 1,825 million and charge revenue accounts in this case only for approximately 60 per cent of the marginal cost.

In the case of air transport, the Civil Aviation Administration has accounted for marginal costs calculated for a flight example between Stockholm/Arlanda and Gothenburg/Landvetter (see table). This shows that there is especially great uncertainty concerning emission costs en route.

Figure 7 - Comparison between ASEK and ExternE, emission costs for traffic in built-up areas.



Source: Nerhagen och Johansson (2003)

9 In transport investment analysis in Sweden a common set of prices are used to value benefits and costs, the so-called ASEK values. These values are concerning particles are to a large extent based on the findings in the SHAPE Project (The Stockholm Study on Health Effects of Air Pollution and their Economic Consequences), a large research project undertaken in Stockholm that ended in 1999.
.

Table 31 - Estimated marginal cost for the example route Stockholm/Arlanda– Gothenburg/Landvetter.

Cost component	*SEK/flight*
Environmental impact except noise*	
Start and landing	147–776
En route	178–4 853
Health effects from flight en route	-
Noise	-
Airport services	
Plane-related	286
Passenger-related	476
Rubber removal	0–24
Air traffic management service (including external congestion and security/accidents)	0–140
Accidents incurred	-
Total	1 086–6 555

The type of aircraft in the calculations is a Boeing 737-600 with 123 seats and an assumed seat occupancy rate of 0.6.
*Emissions except carbon dioxide are evaluated in accordance with the ExternE method. ASEK-values would produce higher emission costs.

Source: Final report of the government commission in 2003 for the marginal social costs of air transport, Civil Aviation Authority, 2003 (quoted in SIKA, 2004).

Review of non-European National Studies

USA

For the USA no specific study regarding the externalities of transport is available. However, the USEPA has published a comprehensive review of air regulation compliance costs, which can be considered as a reference for air pollution external costs. This study is under a process of updating. The report (EPA, 1999) is organised along the six steps of the analysis, namely:

1. estimate air pollutant emissions in 1990, 2000, and 2010;
2. estimate the cost of emission reductions arising from the Clean Air Act Amendments;
3. model air quality based on emissions estimates;
4. quantify air quality related health and environmental effects;
5. estimate the economic value of cleaner air;
6. aggregate results and characterize uncertainties.

Regarding the economic valuation of cleaner air, the report considers both costs and benefits. The costs of the Clean Air Act Amendment provisions are based on an evaluation of the increases in expenditures incurred by various entities to meet the additional control requirements. These costs include operation and maintenance (O&M) expenditures, which includes research and development (R&D) and other similarly recurring expenditures, plus amortized capital costs (i.e., depreciation plus interest costs associated with the existing capital stock). Regarding benefits, models to estimate changes in air quality, human health effects, ecological effects have been used.

The study founds that the majority of the total monetized benefits, however, is attributable to changes in particulate matter concentrations and, more specifically, to the effect of these ambient air quality changes on avoidance of premature mortality.

The direct benefits of the air quality improvements the reduced incidence of a number of adverse human health effects, improvements in visibility, and avoided damage to agricultural crops following the amendments implementation have been estimated. The estimated annual economic value of these benefits in the year 2010 ranges from $26 to $270 billion, in 1990 dollars, with a central estimate of $110 billion. These estimates do not include a number of other potentially important effects which could not be readily quantified and monetized. These excluded effects include a wide range of ecosystem changes, air toxics-related human health effects, and a number of additional health effects associated with criteria pollutants.

The results are summarised in the table below.

Based on the findings of this study, the highest priority research needs are:

i. Improved emissions inventories and inventory management systems

ii. A more geographically comprehensive air quality monitoring network, particularly for fine particles and hazardous air pollutants

iii. Use of integrated air quality modelling tools based on an open, consistent model architecture

iv. Development of tools and data to assess the significance of wetland, aquatic, and terrestrial ecosystem changes associated with air pollution

v. Increased basic and targeted research on the health effects of air pollution, especially particulate matter

vi. Continued development of economic valuation methods and data, particularly valuation of changes in risks of premature mortality associated with air pollution

Table 32 - Summary Comparison of Benefits and Costs (Estimates in millions 1990$)

	Annual Estimates	
	2000	2010
Monetized Direct Costs:		
Low [a]		
Central	$19,000	$27,000
High [a]		
Monetized Direct Benefits:		
Low[b]	$16,000	$26,000
Central	$71,000	$110,000
High[b]	$160,000	$270,000
Net Benefits:		
Low	($3,000)	($1,000)
Central	$52,000	$83,000
High	$140,000	$240,000
Benefit/Cost Ratio:		
Low[c]	less than 1/1	less than 1/1
Central	4/1	4/1
High[c]	more than 8/1	more than 10/1

[a] The cost estimates for this analysis are based on assumptions about future changes in factors such as consumption patterns, input costs, and technological innovation. We recognize that these assumptions introduce significant uncertainty into the cost results; however the degree of uncertainty or bias associated with many of the key factors cannot be reliably quantified. Thus, we are unable to present specific low and high cost estimates.

[b] Low and high benefits estimates are based on primary results and correspond to 5th and 95th percentile results from statistical uncertainty analysis, incorporating uncertainties in physical effects and valuation steps of benefits analysis. Other significant sources of uncertainty not reflected include the value of unquantified or unmonetized benefits that are not captured in the primary estimates and uncertainties in emissions and air quality modeling.

[c] The low benefit/cost ratio reflects the ratio of the low benefits estimate to the central costs estimate, while the high ratio reflects the ratio of the high benefits estimate to the central costs estimate. Because we were unable to reliably quantify the uncertainty in cost estimates, we present the low estimate as "less than X," and the high estimate as "more than Y", where X and Y are the low and high benefit/cost ratios, respectively.

Canada

Canadian research has produced several reports on estimation of social and environmental costs of transport.

For instance, Zhang *et al*. (2005) examine five categories of externalities, i.e. congestion (and the value of time), accident costs; noise costs; costs of air pollution and the costs of greenhouse gas emissions.

In their 460 page report, they discuss methodological issues regarding all the cost components quoted above, and suggest recommended estimates of full costs of air pollution (in 2002 $C), see

Table 33 – Recommended estimates of Full Costs of Air Pollution (2002 $C)

Interurban passenger transport (per passenger-km)	
Private vehicle	0.00088
Aircraft	0.00008
Bus	0.00100
Train	0.00471
Ferry	0.01091
Urban passenger transport (per passenger-km)	
Private vehicle	0.00842
Urban transit	0.00331
Freight transport (per passenger-km)	
Truck	0.00503
Rail	0.00173
Marine	0.00074
Aircraft	0.00003

Source: Zhang *et al.* (2005)

The full cost of transport, considering different transport modes, has been assessed also in a three-year project that has been launched by Transport Canada at the beginning of 2004 with the support of provincial and territorial departments of transport[10]. For what concerns external costs estimation, reports have been published in 2007 regarding different external cost components[11].

Regarding climate change, by considering the shadow price of carbon (taken from price emerged from the European Trading Scheme), the total costs of climate change for Canada are estimated in almost $C 5,900 millions.

Total accident costs are estimated by carrying out a sensitivity analysis, by considering different VSL (see Table 33 below). In particular, the base case estimate is $ 4.05 million and for the sensitivity analysis a VSL of $ 3.05 million for the low scenario and a VSL of $ 5.05 million for the high scenario were used. Results are shown in Table 33 below.

Table 34 - Estimated Costs of Accidents by Mode in 2000 (million of 2000 $C)

	Base Scenario	Low estimates	High estimates
Road	$ 15,786.1	$ 12,418.3	$ 19,191.0
Rail	$ 295.9	$ 223.0	$ 368.7
Marine	$ 63.4	$ 47.8	$ 78.9
Air	$ 98.6	$ 74.3	$ 122.8
Total	$ 16,244.0	$ 12,763.4	$ 19,761.4

Source: Borer Blindenbacher and Karangwa (2007)

Annual noise costs are estimated in more than $C 260 millions Gillen (2007).

Concerning air pollution, total external costs are calculated (considering health and environmental impacts). Results are shown in Table 34 below.

[10] http://www.tc.gc.ca/pol/en/aca/fci/menu.htm
[11] http://www.tc.gc.ca/pol/en/aca/fci/transmodal/menu.htm

Table 35 - Air Pollution costs to Transport Canada Modes (Without Paved Road Dust) (000's 2000$)

Transport Canada Modes	**National Economic Value of Emissions from Transport Modes (000's 2000$)**	
	Total	**% of Total**
Freight Air Transport	$1,580	0.0%
Freight Heavy-duty diesel vehicle	$1,110,000	29.0%
Freight Heavy-duty gas vehicle	$87,200	2.0%
Freight Light-duty diesel truck	$7,100	0.0%
Freight Light-duty gas truck	$176,000	5.0%
Freight Marine Transport	$492,000	13.0%
Freight Rail Transport	$428,000	11.0%
Passenger Air Transport	$28,500	1.0%
Passenger Interurban diesel bus	$16,200	0.0%
Passenger Interurban gas bus	$220	0.0%
Passenger Light-duty diesel truck	$16,700	0.0%
Passenger Light-duty diesel vehicle	$10,500	0.0%
Passenger Light-duty gas truck	$446,000	11.0%
Passenger Light-duty gas vehicle	$917,000	24.0%
Passenger Marine Transport	$46,200	1.0%
Passenger Rail Transport	$15,300	0.0%
Passenger Urban and School Diesel Bus	$86,800	2.0%
Passenger Urban and School Gas Bus	$60	0.0%
All Transport Canada Modes	**$3,880,000**	**100.0%**

Source: Marbek Resource Consultants for Transport Canada (2007)

Australia

The Australian Bureau of Transport and Regional Economics (BTRE) published two reports on external costs of transportation, one related to health effects of air pollution and the other concerning urban congestion costs (BTRE, 2007; BTRE, 2005).

Regarding air pollution, BTRE study estimates that in 2000 motor vehicle-related ambient air pollution accounted for between 900 and 4500 morbidity cases—cardio-vascular and respiratory diseases and bronchitis—and between 900 and 2000 early deaths.

The economic cost of morbidity ranges from \$0.4 billion to \$1.2 billion, while the economic cost of mortality ranges from \$1.1 billion to \$2.6 billion. The value of a statistical life used was \$1.3 million—a discount of 30 per cent on the Bureau's costing of transport accident fatalities.

The study also adopts the Künzli *et al*. (2000) study's estimates of the long-term health impact of pollution, which is typically larger than the short-term or immediate impact. The estimates in the Künzli study are based on meta-analysis of cohort studies undertaken in the United States of America (United States).

Results are shown in Table 36 below.

Table 36 - Total economic costs of motor vehicle–related pollution (\$m) in Australian capital cities, 2000

Capital Cities	Mortality			Morbidity			Total		
	Base	Lower	Upper	Base	Lower	Upper	Base	Lower	Upper
Sydney	713	441	990	323	173	472	1,036	613	1,462
Melbourne	448	276	621	211	113	307	658	389	928
Brisbane	197	122	273	98	52	142	295	174	415
Adelaide	113	70	156	49	26	72	162	96	228
Perth	104	64	144	49	26	71	153	90	215
Hobart	8	5	11	3	2	5	11	7	16
Darwin	5	3	7	2	1	3	7	4	10
Canberra	8	5	12	-	-	-	8	5	12
All capital cities	1,596	986	0	735	394	1,072	2,330	1,380	3,286

Source: BTRE (2005)

Regarding congestion costs, the BTRE report (2007) adopts an aggregate modelling approach, i.e. it does not use detailed network models, but aims to roughly estimate the scale of a city's congestion situation using aggregate indicators of a city's overall average traffic conditions. There are no complete estimates of the cost of congestion (for Australian cities) using a network modelling approach.

The congestion costs included: (1) the extra travel time (e.g. above that for a vehicle travelling under less congested conditions); (2) extra travel time variability (where congestion can result in trip times becoming more uncertain—leading to travellers having to allow for an even greater amount of travel time than the average journey time, in order to avoid being late at their destination); (3) increased vehicle operating costs (primarily higher rates of fuel consumption), and (4) poorer air quality.

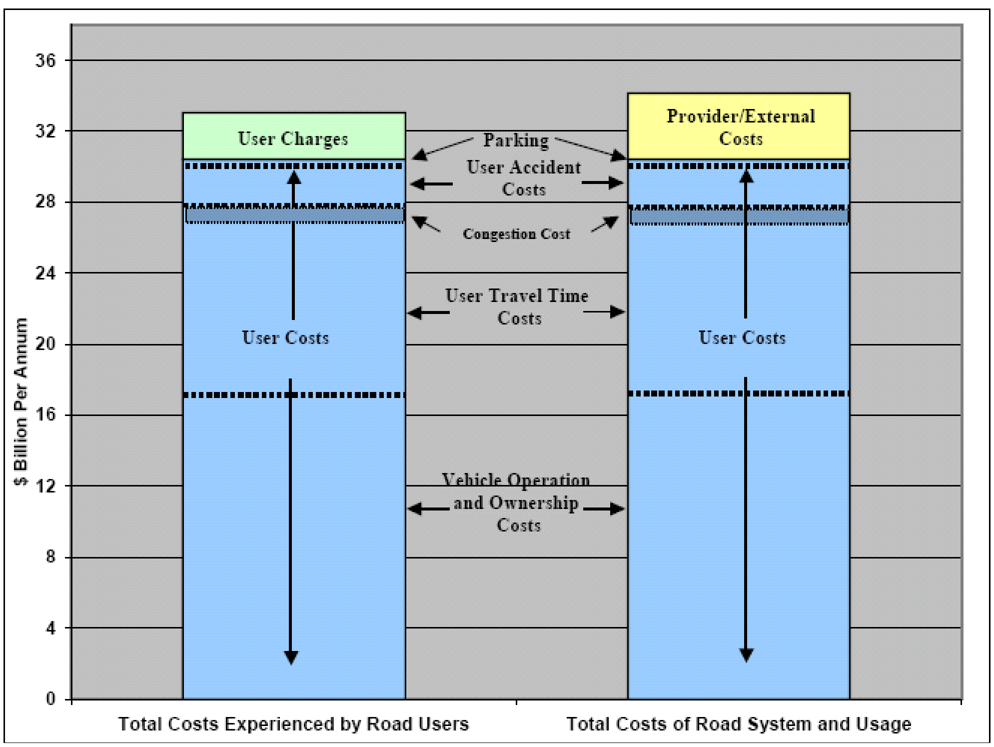
BTRE aggregate congestion estimates for this study give a total of about $9.4 billion for the 2005 social costs of congestion. This total figure considers approximately $3.5 billion in private time costs (losses from trip delay and travel time variability), $3.6 billion in business time costs (trip delay plus variability), $1.2 billion in extra vehicle operating costs, and $1.1 billion in extra air pollution damage costs. The national total is spread over the capital cities, with Sydney the highest (at about $3.5 billion), followed by Melbourne (with about $3.0 billion), Brisbane ($1.2 billion), Perth ($0.9 billion), Adelaide ($0.6 billion), Canberra ($0.11 billion), Hobart ($50 million) and Darwin ($18 million).

New Zealand

The *Surface Transport Costs and Charges Study* (STCC) is designed to provide baseline data on the costs and charges associated with the road and rail networks. In particular, regarding the cost side, it expressively considers both the cost of infrastructure and the external costs. It then compares the aggregate figures with the user charges to understand whether and to what extent road and rail users pay the total costs they contribute to rise.

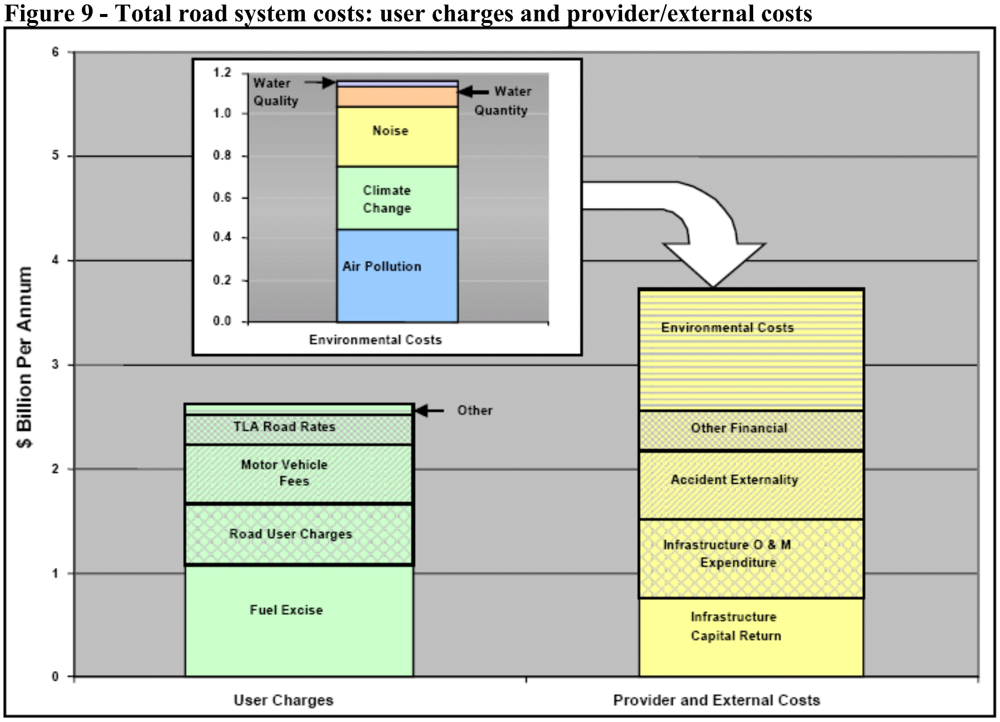
The analysis consist in a theoretical part, where the concepts of marginal and average costs, together with short run and long run mg costs are discussed. Then it carries out an empirical analysis, by appraising the total costs and marginal costs of road and rail transport modes in New Zealand. The break up of different cost categories and the comparison with user charges in the case of road transport are highlighted in the figures below.

Figure 8 - Total road system costs – Overview



Source: NZMOT (2005)

Figure 9 - Total road system costs: user charges and provider/external costs



Source: NZMOT (2005)

The main issues that have to receive attention by future research are all the environmental and distributional aspects, namely: (i) the costs of road traffic congestion; (ii) the viability of the rail sector; (iii) the costs of environmental impacts from road and rail, and (iv) the fairness of the road charging system.

The study considers all the environmental effects entailed by land transport, namely: local air pollution; water quality; water quantity (hydrology); noise and climate change (greenhouse gas - GHG).

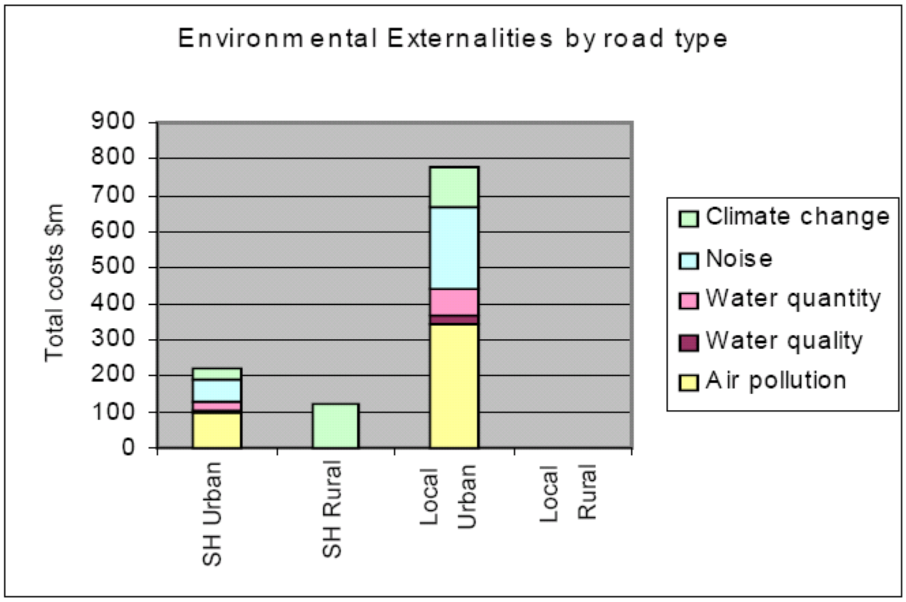
These external costs are assessed with the following approaches:

- for local air quality the report refers to the ExternE approach;
- for water quantity and quality a mitigation cost approach has been applied;
- for noise cost it refers to previous national studies;
- for climate change a $25 /tonne CO2 indicator is then applied, which is the government's cap for a carbon charge under the Kyoto Protocol.

Regarding environmental costs, land transport-related public health costs are generated almost entirely by road traffic, with particulate matter emissions from rail equal to less than 2% of road traffic emissions. However, the overall environmental externalities generated by rail are lower because the total level of rail activity in New Zealand is comparatively small (NZMOT, 2005).

The total cost analysis shows that the costs of environmental externalities of road traffic total $1.2 billion per annum. Approximately 85% of environmental externality costs relate to impacts in urban areas and include air quality, noise, and water quantity (runoff). Local air pollution is the most costly environmental externality and is estimate to cost $442 million per annum. Air pollution is of course, strongly linked to high traffic volumes and congestion. When allocated across vehicle types, heavy commercial vehicles account for 43% of local air pollution, cars account for 34%, light commercial vehicles account for 22% and buses account for only 1%.

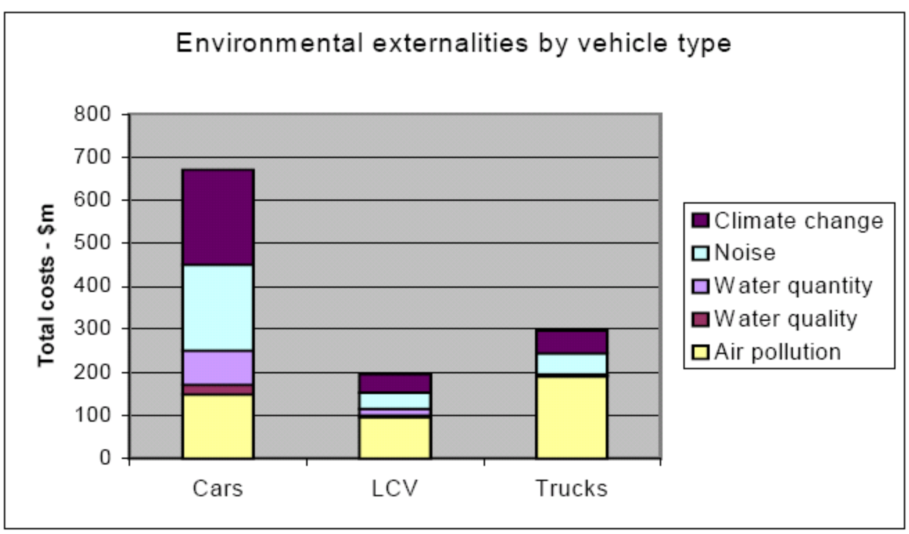
Figure 10 - Environmental externalities by road type



Source: NZMOT (2005)

Transport related greenhouse gas emissions (GHG) cost $317m per annum, and cars generate 70% of GHG emissions in New Zealand.

Figure 11 - Environmental externalities by vehicle



Source: NZMOT (2005)

7. Conclusions

In this report theory and practice in external cost estimation have been analysed. This review has considered all the modes of transport (road, train, airport, waterborne transport), different transport sectors (passengers, commercial, short and long distances) and different situations (rural, urban, peak and non peak hours, etc.). In the previous paragraph the estimation approaches used have been reviewed. We have emphasised the high variability of the point estimates get from different studies. Quinet (2004: 468) concludes that point estimates differ because of: the specifics of the situations; the type of cost taken into consideration; the types of external effect taken into account; the physical relationships; the hypotheses used by the modelling framework and the unit values.

In fact, some authors (Mayeres *et al*., 1996) question the suitability of cost estimates derive above for policy making purposes. They stress that marginal external costs are always computed for a given equilibrium and that this equilibrium changes due to the implementation of social cost pricing. They conclude that "what is needed is a marginal external cost function, rather than a point estimate of the external cost in the present equilibrium" (p. 111). In this respect, they suggest to express the external cost information as a function of the gram of pollutant.

Regarding maritime transport, the following issues deserve particular attention:

- external cost components that should be considered in empirical studies;
- applicability of methodologies adopted for other transport modes (and their robustness with respect to the sources of variability explained above);
- methodological aspects that should be adapted to maritime transport specificity and occurrence of local effects.

Empirical studies consider congestion, accident, environmental and climate change costs. With regards to maritime costs, it has to be noted that congestion costs are considered a negligible component, due to overcapacity of existing infrastructure with respect to the current demand. Regarding accident costs, the same considerations made for other transport modes hold. Consequences of ship accidents, like victims or severe injuries should be assessed similarly for other transport modes.

Marginal noise costs due to maritime shipping and inland waterway transport are assumed to be negligible, because most of the transport activities take place outside densely populated areas.

Environmental impacts regards both air and water pollution. Regarding air impacts, ship emissions on atmosphere comprises ozone and aerosol precursors (NO_x, CO, VOCs, SO_2, etc) and the emissions of greenhouse gases (CO_2). Effects of these pollutants are well known. SO_2 and NO_x can become converted into sulphate and nitrate particles. Exposure to fine particles is associated with increase mortality and morbidity. Shipping emissions contribute notably to the formation of ground-level ozone, especially in the Mediterranean region, with effects human health and crop yields. The deposition of sulphur and nitrogen contribute to exceedances of critical loads of acidity. Nitrogen oxides lead to eutrophication, which affects biodiversity both on land and coastal waters. Finally, emissions from ships contribute to climate change.

With respect to other transport modes, ship emissions let out 150-300 times more sulphur per ton-kilometre than a truck (with low sulphur content of diesel oil) and twice as much NO_x per ton-kilometre than a truck. In the case of ship emissions, the degree of exposure varies considerable with respect to land transport, and depends on ports distance from city centre.

With respect to other transport modes, ship transport has significant impacts on water, due to the effects of ballast water and the use of antifouling varnish. All these impacts will be analysed in depth in the next task.

Last but not least, maritime transport produce important impacts on soil, due to the high land use consumption entailed by location of harbours and due to sediment deposition.

Indeed the occurrence of these external effects varies according to the different activities entailed by maritime transport (namely cruising, manoeuvring, hotelling, tanker offloading and auxiliary generators).

For what concerns the applicability of methodologies adopted for other transport modes to maritime transport, we have already emphasised that congestion and noise costs should be left apart, since they are normally assumed to be negligible. For accident external costs the methodologies described above could be adopted.

It is clear that the analytical approach adopted to assess environmental costs (with particular reference to those relating to air emissions) and described above, in order to be applicable to maritime transport have to be adjusted to consider the following aspects:

- The existing literature on climate change external costs focus on shadow price of CO_2. However, in maritime transport other GHGs, such as NO_x, are relevant. As a consequence, a shadow price for NO_x needs to be defined;
- Health effects of ship emissions depend on exposure to pollutants. Of course this occurs only for activities at ports, whilst health effects of other activities (like cruising) could turn to be negligible to the absence of exposure. Dose response function should consider this aspect.

8 References

Amann M., Bertok I., Cofala J., Gyarfas F., Heye C., Klimont Z., Schöpp W. (1999), Integrated Assessment Modeling for the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone in Europe; Lucht & Energie 132, by IIASA, Austria, for Ministry of Housing, Spatial Planning and the Environment (VROM) of the Netherlands, Available at: http://www.iiasa.ac.at/~rains/dutch/dutch2.pdf

Axel Friedrich, Falk Heinen, Fatumata Kamakaté, Drew Kodjak, Air pollution and greenhouse gas emissions from ocean-going ships: impacts, mitigation options and opportunities for managing growth, International Council on Clean Transportation, March 2007, 102 p. Available at http://www.theicct.org/documents/MarineReport_Final_Web.pdf

Bailey D., G. Solomon, (2004), Pollution prevention at ports: clearing the air, *Environmental Impact Assessment Review*, 24 749–774.

Bahlke C., (2004), *Implementation of Agenda 21 in European Ports at the example of Lübeck-Travemünde*. Final report Research report UBA F+E-project: FKZ 201 96 105

Beuthe M., F. Degrandsart, J-F. Geerts, B. Jourquin, 2002, External costs of the Belgian interurban freight traffic: a network analysis of their internalisation *Transportation Research Part D: Transport and Environment*, *Volume 7, Issue 4*, *Pages 285-301*

Bickel P., Sandra Torras Ortiz, Ulrike Kummer (IER), 2006a, Case study 1.5 Air pollution and Greenhouse gases, Annex to Deliverable D 3, Marginal environmental cost case studies for road and rail transport. Funded by the Sixth Framework Program. IER, Universität Stuttgart, Stuttgart, September 2006

Bickel P, Jordans M, Martìn JC, Meersman H, Monteiro F, Pauwels T, Román C, Ruijgrok C, Sieber N, Socorro-Quevedo P, Van de Voorde E, Vanelslander T and A Voltes-Dorta, 2006b, "Marginal cost case studies for air and water transport", Deliverable 4 of GRACE (Generalisation of Research on Accounts and Cost Estimation), Funded by Sixth Framework Programme. ITS, University of Leeds, Leeds. October 2006

BTRE (2007), Health impacts of transport emissions in Australia: Economic costs. *Btre working paper 63*. Available at: http://www.bitre.gov.au/publications/94/Files/wp63.pdf

BTRE (2007), Estimating urban traffic and congestion cost trends for Australian cities. . *Btre working paper 71*. Available at: http://www.bitre.gov.au/publications/49/Files/wp71.pdf

Bickel P., Sandra Torras Ortiz, Ulrike Kummer (IER), Case study 1.5 Air pollution and Greenhouse gases, Annex to Deliverable D 3 – Marginal environmental cost case studies for road and rail transport. GRACE Funded by the Sixth Framework Program. IER, Universität Stuttgart, Stuttgart, September 2006

Bickel P., R. Friedrich, A. Burgess, P. Fagiani, A. Hunt, G. De Jong, J. Laird, C. Lieb, G. Lindberg, P. Mackie, S. Navrud, T. Odgaard, A. Ricci, J. Shires and L. Tavasszy, Deliverable 5. Proposal for Harmonised Guidelines. HEATCO (Developing Harmonised European Approaches for Transport Costing and Project Assessment

Bickel P., Friedrich R., (2005), *ExternE. Externalities of Energy. Methodology 2005 Update*. European Commission, Brussels.

Bonsall PA et al (2006) Understanding Variation in Estimates of Road Congestion Costs GRACE Deliverable 3, Annex 1.3b, University of Leeds

Borer Blindenbacher F. and E. Karangwa, 2007, *Estimating the Total Costs of Accidents*. Full-Cost Investigation Project Economic Analysis Directorate. Transport Canada. http://www.tc.gc.ca/pol/en/Report/FullCostInvestigation/Transmodal/t005/t005.pdf

Button, 1990, Environmental Externalities and Transport Policy. *Oxford Review of Economic Policy*. 6: 61-75.

CE Delft et al., 2006, Greenhouse Gas Emissions for Shipping and Implementation Guidance for the Marine Fuel Sulphur Directive, Report. December, 2006. http://ec.europa.eu/environment/air/pdf/transport/final_report.pdf

Cohen J.P. and C. Coughlin, 2007, Spatial Hedonic Models of Airport Noise, Proximity, and Housing Prices. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=898635

DEFRA, 2007, Reducing the Exteral Costs of the Domestic Transportation of Food by the Food Industry.

Delucchi M.A., 2007, Do motor-vehicle users in the US pay their way? *Transportation Research Part A*. 41: 982-1003.

Delucchi, M.A., 2004. Summary of the Nonmonetary Externalities of Motor-Vehicle Use, report no. 9 in the series: The Annualized Social Cost of Motor-Vehicle Use in the United States, based on 1990–1991 Data, UCD-ITS-RR-96-3(9), Institute of Transport Studies. Davis, University of California. Available at http://www.its.ucdavis.edu/publications/2004/UCD-ITS-RR-96-03(09)_rev1.pdf

de Blaeij A., Raymond J. G. M. Florax, Piet Rietveld, Erik Verhoef**,** *2003,* The value of statistical life in road safety: a meta-analysis. *Accident Analysis & Prevention*, Volume 35, Issue 6, Pages 973-986.

De Borger B., S. Wouters, Transport externalities and optimal pricing and supply decisions in urban transportation: a simulation analysis for Belgium. Regional Science and Urban Economics 28 (1998) 163–197.

De Kluizenaar, Y., Passchier-Vermeer, W., Miedema, H.M.E (2001), Adverse effects of noise exposure on health – a state of the art summary, TNO report 2001.171, Leiden.

Doll, 2002, Transport User Cost and Benefit Case Studies, Deliverable 7,

EEA (2008), Climate for a transport change. TERM 2007: indicators tracking transport and environment in the European Union. *EEA Report No 1/2008***.** Available at http://reports.eea.europa.eu/eea_report_2008_1/en/EEA_report_1_2008_TERM.PDF

Entec (2005) Entec UK Limited. European Commission Directorate General Environment Service Contract on Ship Emissions: Assignment, Abatement and Market-based Instruments. London, England. August 2005. Available at http://ec.europa.eu/environment/air/transport.htm

Eirksen K.S., 1999, Calculating External Costs of Transportation in Norway. Principles and Results. Paper presented at the NECTAR Conference in Delft, October 1999. Available on line: http://www.ejtir.tudelft.nl/issues/2000_00/pdf/2000_01.pdf

Espey, M. and H. Lopez. 2000. "The Impact of Airport Noise and Proximity on Residential Property Values," *Growth and Change*, 31, 408–419.

European Environmental Bureau, European Federation for Transport and Environment (T&E), Seas at Risk, Swedish NGO Secretariat on Acid Rain, Air pollution form ships, updated November 2004, 15 p. Available at http://www.transportenvironment.org/docs/Publications/2004Pubs/2004-11_joint_ngo_air_pollution_from_ships.pdf

Gibbons E., M. O'Mahony**,** 2002, External cost internalisation of urban transport: a case study of Dublin *Journal of Environmental Management*, *Volume 64, Issue 4*, *Pages 401-410*

Gillen D. 2007, Estimation of Noise Costs due to Road, Rail and Air Transportation in Canada. Report prepared for Transport Canada. Available at http://www.tc.gc.ca/pol/en/Report/FullCostInvestigation/Transmodal/t004/t004.pdf

Graham B., Jon Shaw, 2008, Low-cost airlines in Europe: Reconciling liberalization and sustainability, *Geoforum*, Volume 39, Issue 3, May 2008, Pages 1439-1451

Hammingh P., J.M.M. Aben, W.F. Blom, B.A. Jimmink, W.J. de Vries, M. Visser (eds), Effectiveness of international emission control measures for North Sea shipping on Dutch air quality, (MNP Report 500092004/2007), Netherlands Environmental Assessment Agency (MNP), Bilthoven, September 2007. Available at http://www.mnp.nl/bibliotheek/rapporten/500092004.pdf

IER, ARMINES/ENSMP, PSI, Université de Paris I, University of Bath, VITO, 2004, "New Elements for the assessment of External Costs from Energy Technologies", NEWEXT Publishable Report to the European Commission, DG Research, September. Available at http://www.ier.uni-stuttgart.de/forschung/projektwebsites/newext/

EPA, 1999, *The Benefits and Costs of the Clean Air Act 1990 to 2010*. Report to the congress. Available on line: http://www.epa.gov/air/sect812/1990-2010/fullrept.pdf

IIASA, Met.No and UK Limited (2006), *Analysis of Policy Measures to Reduce Ship Emissions in the Context of the Revision of the National Emissions Ceilings Directive*. Interim Report. Available at http://www.iiasa.ac.at/rains/reports/IR06-107_Ships.pdf.

IMO, 2005, PREVENTION OF AIR POLLUTION FROM SHIPS. Report of the Working Group, July 2005. Available at http://ec.europa.eu/environment/air/pdf/report_wg.pdf

Jakob A., Craig J.L., Fisher G., 2006, Transport cost analysis: a case study of the total costs of private and public transport in Auckland. *Environmental Science and Policy*. 9: 55-66.

Janic M., (2007), Modelling the full costs of an intermodal and road freight transport network. *Transportation Research Part D* 12: 33–44.

Johnstone N., K. Karousakis, 1999, Economic incentives to reduce pollution from road transport: the case for vehicle characteristics taxes *Transport Policy*, Volume 6, Issue 2, Pages 99-108.

Koomen, E., Groen, J., Borsboom, J., Scholten, H., 2002, Modelling the fragmentation of open space. A framework for assessing the impact of land use change on open space. Paper presented at the 42th Annual conference of the European Regional Science Association. Available at http://www.ersa.org/ersaconfs/ersa02/cd-rom/papers/208.pdf

Künzli N., Kaiser R., Medina S., Studnicka M., Chanel O., Filliger P., Herry M., Horak F Jr, Puybonnieux-Texier V, Quenel P, Schneider J, Seethaler R, Vergnaud JC, Sommer H 2000, 'Public health impact of outdoor and trafficrelated air pollution: a European assessment', *The Lancet*, vol. 356, pp. 795–801.

Lindberg, G (2006), Marginal cost case studies for road and rail transport Deliverable D 3, GRACE. Funded by Sixth Framework Programme. ITS, University of Leeds, Leeds, November 2006

Lindberg, G (2002) Deliverable 9, Marginal accident costs – case studies. UNITE (UNIfication of accounts and marginal costs for Transport Efficiency) Deliverable 9. Funded by 5th Framework RTD Programme. ITS, University of Leeds, Leeds, July 2002.

Lvovsky K., G. Hughes, D. Maddison, B. Ostro and D. Pearce, 2000, Environmental Costs of Fossil Fuels A Rapid Assessment Method with Application to Six Cities. *Paper no. 78 Pollution Management Series*. Environment Department, The World Bank. Available at http://www.cleanairnet.org/cai/1403/articles-34285_env_cost_fossil_fuels.pdf

Maibach M., C. Schreyer, D. Sutter (INFRAS), H.P. van Essen, B.H. Boon, R. Smokers, A. Schroten (CE Delft); C. Doll (Fraunhofer Gesellschaft – ISI); B. Pawlowska, M. Bak (University of Gdansk), 2007, *Handbook on estimation of external cost in the transport sector*. Internalisation Measures and Policies for All external Cost of Transport (IMPACT). Delft, CE.

Maddison D., Pearce D., Johansson E., Litman T. and E. Verhoef, (1997), *The True cost of Road Transport*. Blueprint 5. Earthscan Publication, London.

Marbek Resource Consultants Ltd., 2007, *Evaluation of Total Cost of Air Pollution Due to Transportation in Canada*. Final Report submitted to Transport Canada. Available at http://www.tc.gc.ca/pol/en/Report/FullCostInvestigation/Transmodal/t006/t006.pdf

Mayeres et al., 1996, The marginal external costs of urban transport. *Transportation Research Part D* 2: 111-130.

Napier University, Heriot-Watt University and Industry Partners, UK Marine Motorways Study: Summary Final Report (LINK Future Integrated Transport (FIT) Programme), March 2003, 22 p. Available at http://www.sml.hw.ac.uk/logistics/pdf/MarineMotorways.pdf

Navrud S., Trædal Y., A. Hunt, A. Longo, A. Greßmann, C. Leon, R. E. Espino, R. Markovits-Somogyi and F. Meszaros, (2006), Economic values for key impacts valued in the Stated Preference surveys. Deliverable 4 HEATCO Project.

NERA Economic Consulting, Economic Instruments for Reducing Ship Emissions in the European Union, European Commission, Directorate-General Environment, 26 September 2005. Available at http://ec.europa.eu/environment/air/pdf/task3_final.pdf

Nijland,, H.A., Van Kempena E.E.M.M., Van Weeb G.P., Jabbena J., (2003) Costs and benefits of noise abatement measures. *Transport Policy* 10: 131–140.

NZMOT (2005), *Surface Transport Costs and Charges Study* (STCC). *Summary of Main Findings and Issues*, New Zealand Ministry of Transport

Panis L. Int, L. De Nocker, E. Cornelis, R. Torfs, 2004, An uncertainty analysis of air pollution externalities from road transport in Belgium in 2010. *Science of The Total Environment*, Volumes 334-335, Pages 287-298.

Peris-Mora E., Diez Orejas J.M., Subirats A. , S. Ibañez, P. Alvarez, (2005), A Development of a system of indicators for sustainable port management, *Marine Pollution Bulletin* 50 1649–1660.

Piecyk M. and A.C. McKinnon, 2007, Internalising the External Costs of Road Freight Transport in the UK.

Quinet E., 2004, A meta-analysis of Western European external costs estimates. *Transportation Research Part D*. 9: 465-476.

Rouwendal J., E. T. Verhoef, 2006, Basic economic principles of road pricing: From theory to applications *Transport Policy*, Volume 13, Issue 2, March, Pages 106-114

Sansom *et al*. (2000), The overall UNITE methodology. Deliverable 1, ITS, University of Leeds, May 2000.

Sanson T, Nash CA, Mackie PJ, Shires J, Watkiss P (2001), Surface Transport Costs and Charges: Great Britain 1998. Final report for the Department of the Environment, Transport and the Regions. Institute for Transport Studies, University of Leeds. Available on line: http://www.its.leeds.ac.uk/projects/STCC/downloads/SurfaceTransportCostsReport.pdf

Schmid, S. A., Bickel, P., Friedrich, R. (2001), External Cost Calculation for Selected Corridors. RECORDIT (Real Cost Reduction Of Door-To-Door Intermodal Transport) Deliverable 4. IER Universität Stuttgart.

Safirova, E. and Gillingham, K., (2003), Measuring Marginal Congestion Costs of Urban Transportation: Do Networks Matter? Resource for the future Discussion Paper 03–56 http://www.rff.org/documents/RFF-DP-03-56.pdf

SIKA (2003), The External Costs of Transport. SIKA Report 2004:4. Available on line: http://www.sika-institute.se/Doclib/Import/104/sr_2004_4s.pdf

SIKA (2001), The External Costs of Transport. SIKA Report 2001:7 http://www.sika-institute.se/Doclib/Import/105/sr_2001_7s.pdf

Sirikijpanichkul A., Iyengar M. and Ferreira L. (2006) , Valuing Air Quality Impacts of Transportation: A Review of Literature. Available at http://eprints.qut.edu.au/archive/00004643/01/4643.pdf

The Swedish NGO Secretariat on Acid Rain, Cost-benefit analysis of using 0,5% marine heavy fuel oil in European sea areas. http://www.acidrain.org/pages/publications/reports/cba_briefing_jan05.pdf

Theo E. Notteboom, (2004), Container shipping and ports: an overview. *Review of Network Economics*, Vol.3: 86-106

Tol R., (2005), The marginal damage costs of Carbon Dioxine Emissions: An assessment of the uncertainties. *Energy Policy*, 33(16): 2064-2074.

Watkiss *et al*., 2005a, *The Impacts and Costs of Climate Change*. Final Report prepared as task 1 of the project 'Modelling support for Future Actions: Benefits and Cost of Climate Change Policies and Measures', Brussels: DG Environment. http://europa.eu.int/comm/environment/climat/pdf/final_report2.pdf

Watkiss, P., Anthoff, D., Downing, T., Hepburn, C., Hope, CHR., Hunt, A., Tol, R. (2005b): The Social Cost of Carbon (SCC) Review – Methodological Approaches for Using SCC Estimates in Policy Assessment. Final Report November 2005. Research on behalf of UK Defra.

Viscusi, W. Kip. (1993). "The Value of Risks to Life and Health", *Journal of Economic Literature* 31(4), 1912–1946.

Viscusi, W. Kip, and Joseph E. Aldy. (2003). "The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World", *Journal of Risk and Uncertainty* 27(1), 5–76.

Zhang A., Anthony E. Boardman, David Gillen and W.G. Waters II (2005), *Towards Estimating the Social and Environmental Costs of Transportation in Canada*, Centre for Transportation Studies, University of British

Columbia (www.sauder.ubc.ca/cts), for Transport Canada; available at www.sauder.ubc.ca/cts/docs/Full-TC-report-Updated-November05.pdf.

9. Websites

EU - funded projects' websites

GRACE (www.grace-eu.org)

UNITE (http://www.its.leeds.ac.uk/projects/unite/)

HEATCO (http://heatco.ier.uni-stuttgart.de/)

ExternE (http://externe.jrc.es/trans.pdf; http://www.externe.info/)

NewExt (http://www.ier.uni-stuttgart.de/forschung/projektwebsites/newext/)

AirNet (http://airnet.iras.uu.nl/)

RECORDIT (www.recordit.org)

Revenue (http://www.isi.fraunhofer.de/n/e-projekte/e-revenue.htm)

SPECTRUM (http://www.its.leeds.ac.uk/projects/spectrum/summary.html)

Imprint http://www.imprint-net.org/

European Commission

EUR 23714 EN – Joint Research Centre – Institute for Environment and Sustainability

Title: Maritime Transport – Report 1: Review of the measurement of external costs of transportation in theory and practice.

Author(s): A., Miola , V. Paccagnan, M. Turvani, V. Andreoni, A., Massarutto, A. Perujo

Luxembourg: Office for Official Publications of the European Communities

2008 – 78 pp. – 21 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1018-5593

ISBN 978-92-79 -11279-9

DOI 10.2788/77724

.

Abstract

In the last years public concerns regarding the environmental impacts of maritime transport have been increasing. This is due to the fact that, despite the better environmental performance of this mode of transport with respect to other modes, its overall impacts will be out weighted by the expected increase in the volume of ship movements. In order to define effective measures to internalise the external costs of maritime transport it is necessary to assess these costs and find adequate methodologies to evaluate them.Besides external costs estimation, it is important to understand the degree of internalization of such costs, so as to give some insights on how to apply policy instruments that should be informed by efficiency and equity principles.

This report summarises the state of the art in evaluation of transport externalities. Different transport modes have been considered through a comprehensive review of theoretical and empirical studies, by carrying out both EU funded research and national studies. the analytical approach adopted to assess environmental costs (with particular reference to those relating to air emissions) in order to be applicable to maritime transport have to be adjusted to consider the following aspects. 1. The existing literature on climate change external costs focus on shadow price of CO_2. However, in maritime transport other GHGs, such as NO_x, are relevant. As a consequence, a shadow price for NO_x needs to be defined; 2.Health effects of ship emissions depend on exposure to pollutants. Of course this occurs only for activities at ports, whilst health effects of other activities (like cruising) could turn to be negligible to the absence of exposure. Dose response function should consider this aspect.

How to obtain EU publications

Our priced publications are available from EU Bookshop (http://bookshop.europa.eu), where you can place an order with the sales agent of your choice.

The Publications Office has a worldwide network of sales agents. You can obtain their contact details by sending a fax to (352) 29 29-42758.

The mission of the JRC is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.

EUROPEAN COMMISSION

LB-NA-23714-EN-C

Publications Office
Publications.eu.int

ISBN 978-92-79-11279-9