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The True Costs of Automobility: External Costs of Cars Overview on existing estimates in EU-27

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1. INTRODUCTION, SCOPE AND APPROACH

Transport in two perspectives: Individual User vs. Society

(1) Transport is an important part of daily life and of our society. Without any doubt, transport creates huge benefits. As in all aspects of our life, we have to differentiate between the perspective of the individual (a transport user) and that of society (which is the set of all other people, all future times (generations) and all other regions (countries).

(2) Starting with the perspective of the individual, one has to recognize that transport is an essential part of everybody´s life. With the help of the instrument "transport" (which comprises all vehicles, infrastructures, rules and organisations in "transport"), individuals can reach destinations and services to satisfy their individual needs. From an individual´s perspective, the benefits of transport are huge and for each and every trip, the benefits are higher than the costs; otherwise the trip would not have been made. In all further and in all public discussions, this needs to be said first: the benefits of transport for transport users are huge, and there is always an individual´s surplus of benefits over costs, depending on the nature of the trip and on the framework conditions which are set by society (e.g.: subsidies for a certain trip).

(3) Switching to the perspective of society, however, a completely different picture arises. The fact that a trip has an individual surplus of benefits over costs does not automatically mean that benefits to society of this trip are higher than the costs for society. An example may prove that point: if an airport is built using money from EU-cohesion funds and if a Low-Cost-Airline offers cheap flights to far-off destinations, an individual person may very well use this opportunity to travel to that destination "just for fun" – If the fun outweights the small cost. For society, however, the benefits are not so obvious: what are benefits – to other people, other countries and future generations – of this individual having taken this flight just to have a party at the destination? At the same time, the costs to society may be much higher: the costs have to include for instance costs covered by taxpayers for airport construction; costs for taxpayers because air travel usually does not pay fuel taxes (other modes of transport do, so there is a level of discrimination); noise costs for residents living near the airport; pollution costs such as people getting sick from airplane exhaust gases; and costs to future generations from airplane greenhouse gas (GHG) emissions. From the perspective of society, a much more detailed analysis of "total social costs" and "total social benefits" is needed.

(4) Such an analysis at the level of a society is a much more complex task than at the level of the individual. For an analysis at the level of society, all "external costs and benefits" have to also be included. The European Commission has been discussing the external effects of transport (and of other sectors, such as energy) for many years. The negative influences on uninvolved people, regions and

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generations generated by transport activities are usually called externalities. Transport externalities are defined by the European Commission as follows:

"Transport externalities refer to a situation in which a transport user either does not pay for the full costs (e.g. including the environmental, congestion or accident costs) of his/her transport activity or does not receive the full benefits from it." [1]

For the common good it is necessary to internalise all currently external costs, because transport users can only act efficiently when price levels represent scarcity. To develop these steps, we have to balance all costs for society (i.e. the costs from a certain trip to all people, all countries and all generations) against the benefits of this trip for society (also to all people, all countries and all generations).

(5) This task seems to be - and in fact is - impossible to achieve in a purely scientific way. It is impossible to calculate, for instance, the detailed benefits for future generations from a trip today, and it is also impossible to calculate the costs for future generations arising from climate change and weather pattern changes from a certain CO_2 emission today. However, it is not necessary to calculate detailed cost balances, it is only necessary to initiate a continuous process for monitoring and updating cost (and benefit) estimates for other people, other countries and other generations, and to make these signals clear to the user. To sum up:

Under real world conditions, it is completely sufficient to establish a process of constant monitoring and estimating external effects, to estimate them "as well as possible" at every time – and to adjust the price signals to the users accordingly. It is obvious that we will never arrive in a perfect state of true prices (where price signals include fully internalised costs and benefits) but it is absolutely necessary that we try to achieve **less inaccurate prices** constantly year after year.

(6) To make things even easier, the task of estimating external costs and benefits is not as tiresome as it seems: All recent economic literature shows that there are both external costs and external benefits of transport – but the majority of benefits from transport apply to the individual and are internalised in nature. Even after many years of seeking external technological benefits, only very few have been identified. The external technological benefits that have been identified can be quantified at approximately one hundredth of the external (i.e. non-internalised) technological costs. In the first stage of a process of internalisation of external effects it is sufficient to concentrate on external costs.

(7) The volume of external costs from transport, however, is considerable. Today's transport users are not covering large parts of the costs of noise emissions, pollutants emissions, greenhouse gas emissions and other cost factors. Costs of accidents are covered in part (mostly through the mechanism of insurances), but still some part of accident costs are paid for by society. In the first stage of a process of internalisation of external effects it is necessary to identify the most relevant external costs from transport and to estimate them. Today's transport causes considerable damage to the environment. Even though external costs do not have an explicit market

1. *European Commission, 1995, p. 4*

value, they can be observed in expenditures on police and infrastructure management, hospital charges, public health spending and the loss of quality of life. [2]

(8) This report analyses the external costs of car use within the EU-27 by evaluating the existing literature in the field and developing a database from these figures. No own field research has been carried out for the preparation of this report; all input data has been published and discussed previously. The data used is described in more detail below.

(9) The results of this report can (and should) be used for political discussions and for decision making at European level. The results identify fields in which the market mechanism in transport is not working currently; here, political action is needed. The importance of this conclusion cannot be overestimated; this is the crucial and essential key to a fair and efficient economy and society:

The question of how to build an innovative and efficient European Union cannot be answered fully without continuous estimates of uncovered external costs and corresponding political framework-setting (mostly through prices and regulations). More realistic and accurate prices are the key element of any agenda for an innovative and efficient development which is economically, socially and environmentally more sustainable than the situation we have today.

(10) There is no longer any scientific debate that holds that any considerable non-internalised external effects exist in the transport area. However, steps to reduce external factors are often rejected "because transport benefits are much larger (Point A) and because transport is contributing much more to society through taxes and fees (Point B)". The answer to Point A has already been discussed above: yes, there are huge benefits, but these are internal to transport users[3] and these should not initiate any political action[4]. Point B, however, needs more consideration. Is it really a fact that either transport in general, or road or air transport "are the cash cows of our society"?

(11) Again, it is clear that in all member states of the EU transport users pay a fairly large number of costs: taxes, charges, fees etc. Infrastructure operators, cities, states, governments, companies etc. receive charges, fees, tolls, taxes and many other types of revenue from transport users. Here, a strict distinction is necessary:

- Fees, charges, tolls and all other types of cost which are connected to a special service or good or use of infrastructure are not taxes – and all these payments are in direct connection to the service granted. Hence, all these costs could not be "used a second time" to make up for other types of external cost. A congestion charge, a road toll or a parking fee is specifically for that type of service; and these charges cannot be deducted from the balance of external costs. This holds also true for infrastructure costs, no matter in which form users pay for it (directly or indirectly).
- Taxes, however, are all types of payment in which the taxpayer is not entitled to receive any service in exchange. Taxes are needed for

2. European Commission, 2008, p. 3

3. US Department of Transportation - Federal Highway Administration, 1982, p. E9) stated for instance: "the preponderance of expert opinion probably lies on the side of saying that there are no external benefits of highway consumption beyond the benefits to the users."

4. Compare list of references in (Victoria Transport Policy Institute, 2009, p. 6) many services in which no connected revenue could be generated. Taxes are needed to grant services to the public; consequently, this money could never be used to pay external costs. There is scientific consensus that "general taxes" like fuel taxes or VAT or labour taxes cannot be seen as a contribution of transport users, for instance to offset environmental damage from their travel.

- Another, specific form of taxes comprises "Taxes with earmarking or hypothecation". These are taxes that need to be used for a special purpose by the government (or an agency). Usually, in the tax regulation it is stated that part or all of these taxes has to go into a special fund which is used to cover expenses for a specific purpose. Here, again, a special service is provided so that revenues and expenses for this purpose can be balanced against each other.

(12) To sum up: money which is used for a specific purpose cannot be used a second time, for instance to cover external costs. In addition, (general) taxes cannot be used to balance external costs of transport. The external costs of transport which are analysed in this study (GHG, noise, pollution, accidents, etc.) could only be balanced against a specific "earmarked revenue" (be it fee, charge, toll or "earmarked tax") for this revenue to compensate or to reduce these cost types. This implies:

The figures that are estimated in this study as "external costs of transport" should, in efficient societies and in market economies, be internalised as completely and as quickly as possible. The reduction of these figures based on the fact that transport is paying other types of charges, fees or taxes should not take place unless this special type of revenue is dedicated to cover the cost types discussed here.

(13) It may be noted that this line of argument follows both theoretical principles of taxation and common knowledge; not only is there widespread scientific consensus, but also if they are explained properly to them, the "average Joe and Jane" can connect these positions with their own personal experiences ("money cannot be spent twice", etc.). So, if an association comes forward with a position "transport taxes, charges, fees, tolls etc. are too high anyway!" it must be made clear that appropriate positions are at hand to counter this approach: "Taxes are taxes, they are meant to support society – and you can never balance them against any environmental damage!" may serve as an example. In the case of charges with "earmarking or hypothecation", it has to be made clear that this money is balanced for a particular benefit that is received or to compensate for clearly defined damages; the money can only be attributed for these purposes, never for other purposes. [5]

(14) This report is structured as follows: Firstly, the most important literature in this field is described. Next, in Chapters 3 and 4, the methodology used to estimate uncovered external costs is described. Chapter 3 is dedicated to costs from noise, accidents, pollution, up- and downstream-effects etc. These costs are usually damage costs. Chapter 4 deals with CO_2 and climate change costs. As these costs occur mainly in the (far) future, a specific approach is needed here. Additionally, these costs are of high political importance. Finally, Chapter 5 will sum up the magnitude of external costs and identify approaches for political action.

5. Difficulties arise when these definitions are used in certain fields or nations differently or when they are mixed within a specific tax. The German example of Ökosteuer (ecotax) or Energiesteuer (fuel tax) shows this confusion: In general, this is a typical tax, so there is no chance of balancing it against pollution costs. But some tax increases have been earmarked, too: The Ökosteuer-increases some 10 years ago were specifically earmarked to subsidize labour costs, so this part of the tax could be balanced "against damage done to labour markets".

2. LITERATURE REVIEW

2.1. Overview of Existing Studies

(1) Starting in the early 1990s, a number of studies and extensive research projects has been conducted with the aim of improving estimations of cost and the methodology used for estimations of external cost. These studies include a number of projects funded by the European Union (e.g. UNITE (Nash, 2003), ExternE (Bickel & R., 2005), NEEDS) but also national or privately funded research projects (e. g. INFRAS/IWW (Schreyer, et al., 2004), Swiss Federal Office for Spatial Development (ARE, without year), CE Delft et al. (CE Delft; Infras; Fraunhofer ISI, 2011)). Of course, the scope of this project limits the number of studies to be evaluated. We therefore conducted an extensive literature review to generate a comprehensive literature database. From this, we extracted the most relevant studies based on the following criteria:

- We included the most recent studies presenting the current state of knowledge regarding the methodology of cost estimation. Here, the "Handbook on the estimation of external costs" and the "Methodological Convention for Estimates of Environmental Externalities" provide a comprehensive representation of current evaluation practices.
- In addition, we included the most recent external cost estimations for Europe and for some selected European countries. While the European studies are fundamental for providing a consistent data basis, estimations for single countries are used largely for comparison of cost figures and evaluation approaches.

In the following, we introduce the main sources used in the report.

(2) IMPACT 2006-2008:

Commissioned by the European Union, the IMPACT project (Internalisation Measures and Policies for All external Cost of Transport) summarized existing literature as well as practical knowledge on external cost estimation. As a result of this, the "Handbook on estimation of external costs in the transport sector" was developed (Maibach, et al., 2007). The Handbook provides a comprehensible overview of approaches through focusing on the marginal costs of transport activity as the basic principle of internalisation policies in the EU. Furthermore, the Handbook provides recommendations for calculation methods, suitable default values and estimated default unit values for different traffic situations. The Handbook was developed following amendments of the European Parliament in the course of the Eurovignette discussion. It provides the basis for a comprehensive and standardized basis for all internalisation measures.

(3) UBA Methodenkonvention 2007-2008:

The "Methodological Convention for Estimates of Environmental Externalities" produced by the German Federal Environmental Agency (Federal Environmental Agency, 2008) intends to develop a standardized and transparent method for estimating external costs. The main focus is set on the economic estimation of environmental damages. In addition, criteria for the evaluation and the choice of the individual estimation methods are described. Hence, a guideline for further projects for estimating ecological damages was designed. This work gives an overview of existing methods and the shortcomings and advantages of certain approaches.

(4) External Costs of Transport in Switzerland 2008:

On behalf of the Swiss Federal Office of Spatial Development (ARE), this study (Sommer, et al., 2008) updates the external cost estimation in the transportation sector in Switzerland to the year 2005. Here, for the first time, uncertainties are defined by using Monte Carlo simulation approaches. New databases as well as new findings in research are included to estimate the external costs in the fields of accidents, noise, air pollution, climate, nature and landscape, harvest losses, forest and soil damages, additional costs in urban areas and up- and downstream processes. The approaches are also described in a substantiated and understandable manner.

(5) External Costs of Transport in Europe 2000:

This study (Schreyer, et al., 2004) is an update of the former UIC study on external effects, and calculates the total and average external costs of transportation on a European level as well as the European average marginal costs. By using state-of-the-art estimation methods, the study aims to improve the empirical basis of external transportation costs. The results cover the main cost categories and are differentiated by means of transport. For the estimation of climate change costs, two scenarios are generated with different prices for CO_2.

(6) External Costs of Transport in Europe 2008: Based on Schreyer et al. (Schreyer, et al., 2004), the UIC commissioned an update study (CE Delft; Infras; Fraunhofer ISI, 2011) taking into account the recent developments in European transport policy such as the EC Greening Transport Package from 2008, the 2011 EU White Paper and the latest revision of the Eurovignette Directive. Overall, this study comprises the most advanced overview of the total, average and marginal external costs in the enlarged EU-27 transport sector. The results build an important base for the comparison of various transport modes, transport pricing and cost benefits analysis. Because this multinational study for the EU member states is both consistent and up to date, most figures stated in the present report are based on it. The authors may very well be viewed as the most experienced researchers in this area in the EU.

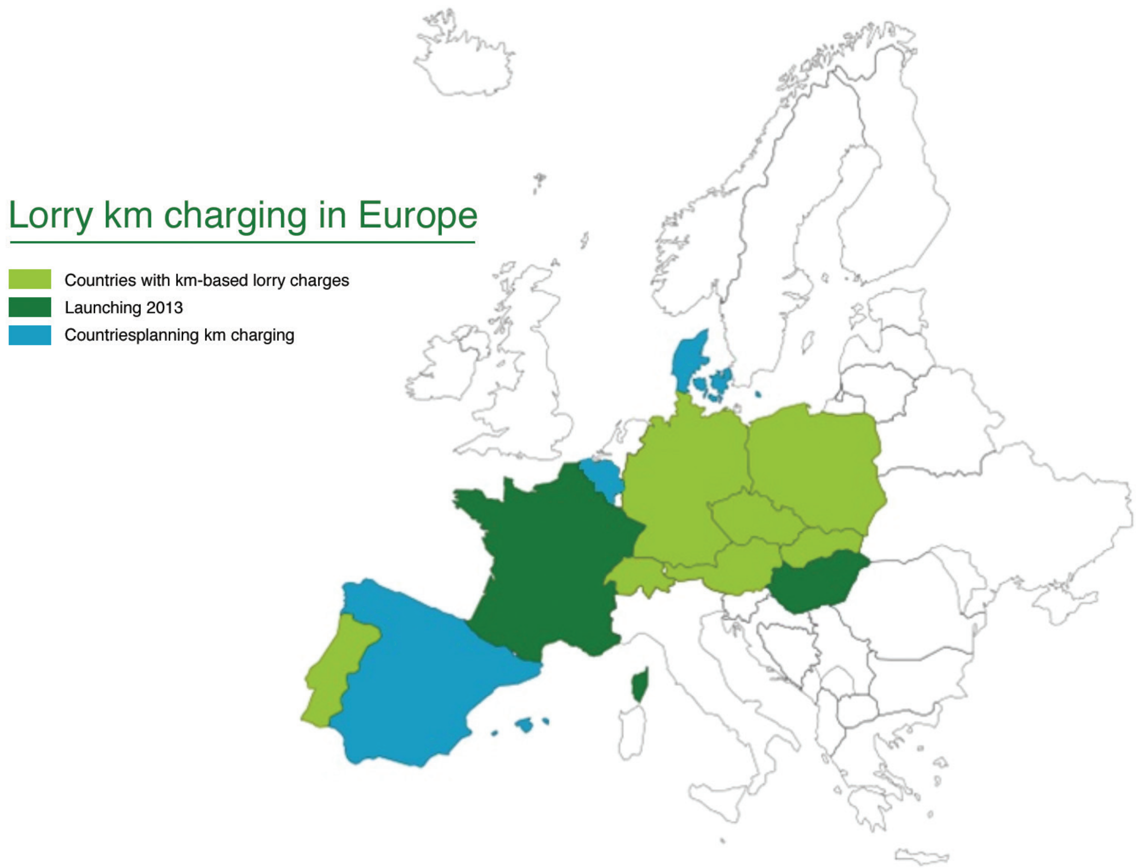
2.2. Existing Applications of the Internalisation of External Costs Principle

(1) The European Union has already set up a number of instruments which try to internalise external costs of transport, or parts of them. Internalisation can take place with the help of strict regulations regarding for example emission limits for new cars; but from an economic point of view, the key to internalisation measures lies in the signals that are given to users when prices show true costs. Therefore, internalisation measures should always try to give price signals to transport users which will initiate efficient behaviour. Three recent initiatives of the European Union are presented in the following:

(2) Taxation of heavy goods vehicles, the Eurovignette Directive:

Directive 2011/76/EU of the European Parliament and of the Council (27th September 2011) amends the Directive 1999/62/EC on the charging of heavy goods vehicles for the use of certain infrastructures. The aim of this European framework regulation is to set the legal framework for member states which intend to levy a toll which also allows the consideration of external costs. The level of toll can be differentiated depending on the emissions of the vehicle, the distance travelled, and the location and time of road use. An external cost charge on lorries, complementing the already existing infrastructure charge, is optional for the member states. The current status of implementation in the member states is shown in Figure 1.

Figure 1: Map of lorry tolls in the EU in 2012 [6]



As one of the many national examples, this directive sets the legal basis for road charging in Germany. Since 2005, Germany has been charging national as well as foreign heavy goods vehicles for the use of motorways and some highways. The toll is obligatory for vehicles used for the transportation of road freight with a total weight of over 12 tons. The costs depend on the kilometres travelled, and differ according to the number of axles and the emissions standard of the vehicle. The total revenues amounted to around 4.5 billion€ in 2011.

(3) Greenhouse gas emission allowance trading scheme:

Directive 2009/29/EC of the European Parliament and of the Council (23rd April 2009), amending Directive 2003/87/EC, regulates the improvement and extension of the greenhouse gas emission allowance trading scheme of the European Community. The air travel trading scheme came into operation in 2012 and includes all flights starting and landing in the European Union. The air traffic sector receives tradable emission permits according to their average emissions of carbon dioxide per year between 2004 and 2006. As of today, 85% of these emission permits are divided proportionally between the aerospace companies, the remaining 15% are being auctioned. Current prices for CO_2 certificates are low because the allocation procedure was “very generous” to reduce opposition to the scheme. Hence, the prices paid today cannot be used as reliable indicators for challenging CO_2 reduction efforts.

6. Picture source: Transport & Environment 2012

(4) CO_2 emissions reporting rules for ships:

In the absence of an international solution, the European Commission recently announced a proposal to curb emissions from the shipping sector. Unlike in the aviation sector, the proposal does not yet include a cap or charge on emissions. Nevertheless, the European Commission will put forward rules on monitoring, reporting and verification of CO_2 emissions from shipping, based on fuel consumption, starting in early 2013. This proposal will be part of the Commission's legislative plans to regulate the emissions from international shipping in European waters. As it does not yet aim at the reduction of GHGs, NGOs such as Sea at Risk criticize the proposal and call for an early decision on an EU market-based measurement. However, for the European Commission, the monitoring of shipping CO_2 emissions is a necessary starting point for establishing a market-based system, e.g. emission trading, or a compensation fund financed on a charge on fuel.[7]

(5) Preparing the legislative grounds for the possible application of national road infrastructure charges for cars:

In the Transport White Paper 2011 the European Commission states that road pricing is seen as an important tool to "offer high quality mobility services while using resources more efficiently".[8] This also includes full and mandatory internalization of external and infrastructure costs for road and rail traffic until 2020. Against this background, the Commission realizes the need to provide consistent information and incentives to member states intending to introduce road pricing systems for cars. As a first step, a recent communication of the European Commission clarifies legal requirements for the introduction of national vignette systems for light duty vehicles [9].

(6) The list of literature on "external effects" is abundant:

The few examples we have mentioned here may only serve as examples. It should be made clear that the question of internalizing external costs into user prices is a key element of all approaches to make the European Union less unsustainable in social, environmental and economic respect. From an economic perspective, it is not "a key element"; it is "the key element" of efficiency and fairness.

7. ENDSeurope, 2012)
8. European Commission, 2011, p. 5
9. European Commission, 2012

3. METHODOLOGY TO ESTIMATE NOISE, AIR POLLUTION AND ACCIDENT COSTS

3.1. Introduction

(1) This report is intended to give an overview of the extent of external costs created in car transport within the EU-27. To ensure consistency, the majority of the data was taken from the most recent CE Delft et al. study (CE Delft; Infras; Fraunhofer ISI, 2011) which was commissioned by the International Union of Railways (UIC). Where certain values were not available and had to be calculated, we also based the assumptions and initial figures on this study.

(2) The CE Delft report covers all countries of the European Union (EU-27), but has not calculated costs for Malta and Cyprus due to limited availability of data and the small number of cases (e.g. road accidents). For this reason, we used the figures for total external costs of the remaining 25 countries to estimate values for Malta and Cyprus based on the ratio of person kilometres (pkm) travelled. This procedure seems appropriate since the effort to build a consistent basis of input value data for these states is high while their overall influence on the total external costs for Europe is low.

(3) External costs in this report are stated for passenger cars on roads in the following six cost categories:

- Accidents
- Air pollution
- Noise
- Upstream and downstream effects (covering all effects before and after the utilization phase)
- Smaller other effects (land use, separational effects etc.)
- Climate Change (described in section 4)

(4) This study focuses on the larger environmental costs of car traffic (plus accident costs not covered by insurance). That means that neither infrastructure costs (area purchase, construction, maintenance, demolition, administration of infrastructure) nor congestion costs are included.[10] Costs for nature and landscape (water and soil pollution, resealing of land, habitat fragmentation and restoration, scenic beauty, biodiversity, etc.) are covered under "smaller other costs", as are costs due to fragmentation of space and land use costs.

(5) In some cases, it is not easy to decide how to allocate external costs to a specific country. Transport activities do not only take place in the national territory where the car is registered. In addition, external effects partly affect foreign countries. In general, external cost calculations can be based on two main perspectives:

10. Congestion costs are sometimes included in other studies, though normally in a separate presentation and without being adding in to the other cost categories. This is due to a still lively scientific discussion regarding the nature and adequate quantification of congestion costs. (Cerwenka & Meyer-Rühle, 2010), (CE Delft; Infras; Fraunhofer ISI, 2011, p. 54). Additionally, and in contrast to all other cost categories, congestion only impacts users of the same congested transport mode. Their internalisation is therefore more a matter of reaching efficiency within a certain transport sector and less of reaching efficiency in the overall economy. Infrastructure costs are also a strong argument in the discussion on strengthening the user-pays-principle. Their quantification and the possibility of charging the users might be the preferred way to go in order to secure adequate infrastructure provision and maintenance. Nonetheless, infrastructure costs are generally not included in external cost calculations since they do not occur as an unintended and unwanted by-product of transport activities. They might rather be classified as service for the public or subsidy to the transport user.

- The people-oriented "nationality perspective" considers all transport-related externalities caused by the people living within a specific country without taking into account the place where these costs are generated.
- The area oriented "territorial perspective" considers all transport related externalities being caused within the area of a specific country without regarding the nationality of the causer." [11]

All cost figures in this report are principally based on the nationality perspective,[12] although the calculation methodology for some cost categories does not allow an accurate cost assignment according to this principle (e. g. noise costs). For most countries, aggregated costs calculated according to nationality vs. territorial perspective will not differ significantly; however, results have to be interpreted with caution in the case of smaller transit countries.

3.2. Data sources used in the report

(1) As stated above, the majority of data was taken from the most recent CE Delft et al. study (CE Delft; Infras; Fraunhofer ISI, 2011) which was commissioned by the International Union of Railways (UIC). Where certain values were not available and needed to be calculated, we have also based the assumptions and initial figures on this study. Due to the dependency of our results on the CE Delft et al. study, we use sections 3.3 to 3.6 to describe the calculation procedure used by CE Delft et al. Section 3.7 then describes our approach for estimating external costs for car use based on the results of the CE Delft et al. study.

(2) In the CE Delft et al. study (CE Delft; Infras; Fraunhofer ISI, 2011), the transport demand data for cars is taken from national statistics and from the TREMOVE data-base. The transport performance of cars measured in person kilometres or passenger kilometres [pkm] is taken from EUROSTAT as a total per country. For 17 countries, EUROSTAT provided additional data on the level of vehicle kilometres driven within the country [vkm]. For the remaining countries, values from TREMOVE have been used after adjusting them to match the EUROSTAT data. TREMOVE is a transport and emission model which "estimates the transport demand, the modal split, the vehicle stock turnover, the emissions of air pollutants and the welfare" [13].

(3) TREMOVE also provides emission factors for cars. The database is considered to be the most "comprehensive up-to-date database on emission factors for all countries"[14].CE Delft et al. (CE Delft; Infras; Fraunhofer ISI, 2011) uses differentiated emission factors by region (metropolitan, other urban, non-urban) and fuel type (gasoline, diesel) to take into account that the European Union is not homogenous. Based on that, total emissions of greenhouse gases and air pollutants are calculated.

(4) Cost factors used by CE Delft et al. (CE Delft; Infras; Fraunhofer ISI, 2011) are mostly taken from Maibach (Maibach, et al., 2007). With the exception of climate change costs, these cost factors are also reflected in the figures stated in this report. Specific information on the cost factors used can be found in the following sections. Table 1 gives a short overview on the methodological approach taken by CE Delft et al.

11. CE Delft; Infras; Fraunhofer ISI, 2011, p. 23
12. CE Delft; Infras; Fraunhofer ISI, 2011, p. 23
13. Transport & Mobility Leuven, 2007, p. 1
14. CE Delft; Infras; Fraunhofer ISI, 2011, p. 22

Table 1: Overview of the methodological approach used by CE Delft et al. [15]

Cost category	Cost elements and valuation approach	Data sources + input data
Accidents	*Cost elements: Medical costs, production losses, loss of human life.* *Valuation: Willingness to pay approach for Value of Statistical Life (VSL)/Value of Life Years Lost (VLYL).* *Cost allocation to different vehicle categories on roads based on the damage potential approach.* *Degree of externality of accident costs: risk value for the included cost elements is taken as 100% external (none of the costs are internalised).*	*National accident data available in the IRTAD database, CARE project and EUROSTAT (highly differentiated by transport mode, network type and vehicle category).*
Air pollution	*Health/medical costs (VLYL), crop losses, building damages, biodiversity losses due to air pollution.* *Valuation: Impact-Pathway-Approach. Dose-Response functions based on the EcoSense Model (ExternE, HEATCO). Willingness-to-pay values from NEEDS, HEATCO and CAFE CBA.*	*Air pollutant emissions based on TREMOVE emission factors and harmonised transport data (see section 2.4). Damage cost factors per ton of air pollutant based on NEEDS, HEATCO and UBA.*
Climate change	*Cost elements: Avoidance costs to reduce risk of climate change.* *Valuation: Unit cost per tonne of greenhouse gas (short term acc. to Kyoto targets, long-term acc. to IPCC aims).*	*CO_2 emissions per transport mode based on TREMOVE emission factors and harmonized transport data.* *New findings on avoidance costs based on recent literature. Two different scenarios (low and high value).*
Noise	*Annoyance costs, health costs. Valuation: Cost factors for annoyance and health effects per person and dBA.*	*Noise exposure data: Noise maps based on Directive 2002/49/EC, extrapolation of data for missing regions or countries. Valuation based on HEATCO.*

3.3. Specific Methodology for Accidents

(1) Road traffic accidents cause social costs including material damages, administrative costs, medical costs, production losses and immaterial costs (lifetime shortening, suffering, pain, sorrow, etc.). Market prices are available for material costs and they are often insured. No market prices are available for any immaterial costs and proxy cost factors; these costs are not covered sufficiently by private insurance systems. Therefore, other approaches (e.g. "willingness to pay" surveys) have to be used for the estimation. "The sum of material and immaterial costs builds the total social accident costs."[16]

(2) Not all social accident costs are external accident costs. All cost components covered through transfers from the insurance system are paid for by the motorists and, consequently, they are already internalised. This does not apply to any health costs covered by public health insurances which are funded by the whole of society.

15. CE Delft; Infras; Fraunhofer ISI, 2011, pp. 20-21
16. CE Delft; Infras; Fraunhofer ISI, 2011, p. 29

Figure 2: Effects of car accidents on society

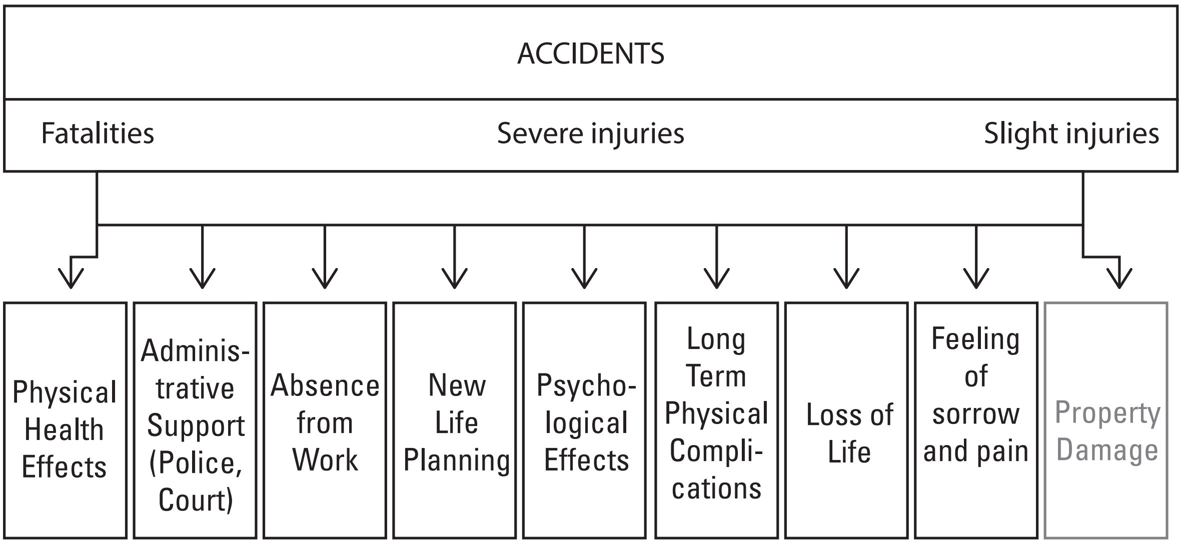


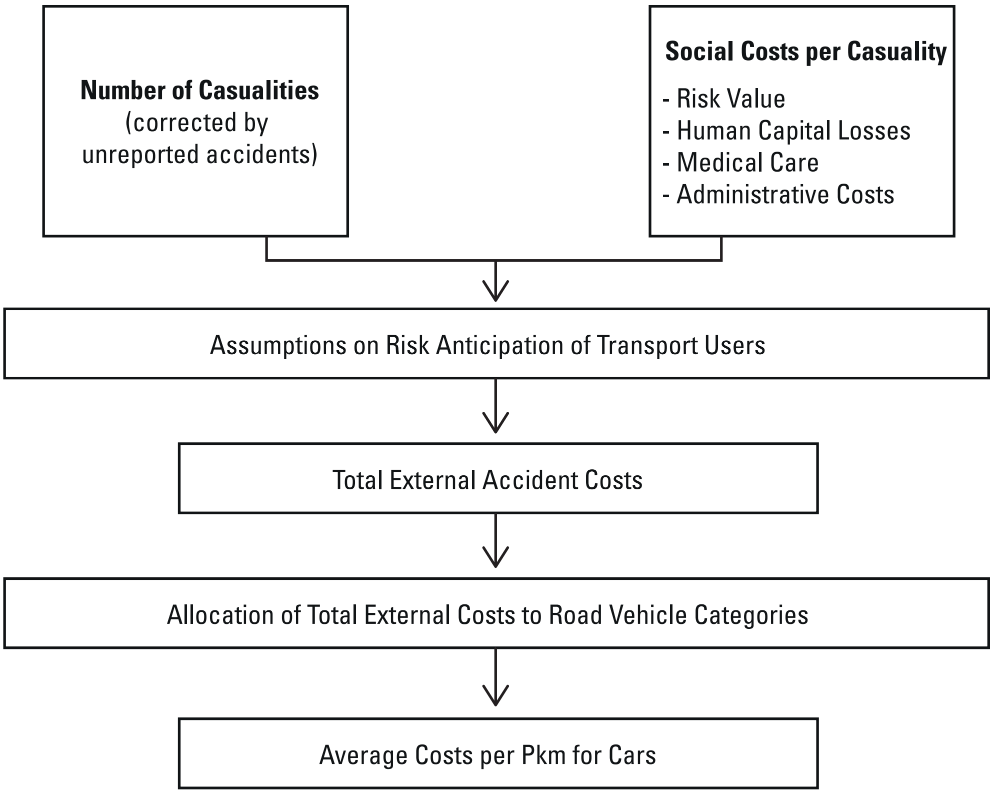
Figure 2 shows the cost components caused by accidents and indicates (black/grey font) which part is considered in the cost figures stated in this report. The components "value of human life", "production losses" and the parts of medical/ administrative costs which are not covered by insurances are to be included in external cost calculations.

(3) All cost calculations in CE Delft et al. (CE Delft; Infras; Fraunhofer ISI, 2011) are based on road accident data from the European Road Accident Database CARE, which has been corrected to account for unrecorded and unreported casualties. The database includes casualties of accidents for all EU-27 countries for the year 2008. Figure 3 summarises the methodology.

(4) A particular question is how to proceed in cases where cars are involved in one accident with trains, buses, trucks or streetcars. Here, different approaches are possible. The CE Delft study (CE Delft; Infras; Fraunhofer ISI, 2011) allocated all costs of accidents at railway level crossings to cars completely. "Multi party accidents" of different vehicle types were treated using the damage potential approach which is based on the moral assumption that the responsibility for an accident and its consequences is shared by all parties, whether in error or not. Here, an intrinsic risk is assumed for all road transport users (damage potential) which depends for example on speed and vehicle size and mass. As a result, all victims in a certain vehicle involved in a multiple party accident are attributed to the other vehicle involved and vice versa (example: a fatality to a cyclist in a bike-car collision would be attributed to car).

16. *CE Delft; Infras; Fraunhofer ISI, 2011, p. 29*

Figure 3: Approach for the calculation of external accident costs



(5) The cost figures described here include human losses such as suffering, pain, loss of pleasure of living (for victims as well as for family/friends), production losses and uncovered medical and administrative costs. The boundaries and the applied values of these components can be described as follows:

- The valuation of human losses is controversially discussed from an ethical perspective. Critics argue that the value of life cannot be determined and is to be assumed to be of "unlimited value". This may be true from an individual perspective, but as we are talking about the society perspective and as we are dealing with statistical risks only, we follow the pragmatic approach of setting a value to these statistical events. This is in line with all large scale statistical analysis in modern societies. [17]
- The Value of a Statistical Life (VSL) is most commonly used in economics for the valuation of fatalities. The values are derived from stated preference surveys where the respondents are asked for their willingness to pay for a reduction of the accident risk. The results provide standardized values for statistical lives.[18]
- International literature values for VSL vary in wide ranges. The CE Delft study (CE Delft; Infras; Fraunhofer ISI, 2011) uses a VSL of 1.5 million € (1998 for EU-15) which was recommended by the UNITE project. The value has been adjusted to prices for the year 2008. To reflect differences among EU member states, the values are standardized using the GDP per capita figures of all countries in order to take into consideration differences in purchasing power. The European average value of VSL for 2008 is 1.67 million € €country specific values vary somewhat, and the calculation was carried out for each country separately.

17. Federal Environmental Agency, 2008, p. 72
18. Federal Environmental Agency, 2008, p. 72
19. CE Delft; Infras; Fraunhofer ISI, 2011, p. 23

3.4. Specific Methodology for air pollution

(1) The estimation of external air pollution costs in car traffic is generally based on three data sources: car transport demand measured in vehicle kilometres (vkm per year) is multiplied by specific emission factors (g/vkm): The results are total emissions for a specific pollutant or cost category [tons per year]. Next, this product of the first two inputs is multiplied with the cost factor or damage factor per pollutant [€/ton].

(2) Transport, and especially road transport, contributes to total air pollution. The pollutants lead to different kinds of external costs. The largest role is played by health costs, which have to be paid by the society as a whole. The costs are mainly caused by cardiovascular and respiratory diseases. Other effects typically considered in external costs estimations are damages to buildings and materials, crop losses and biodiversity impacts resulting from acidification.

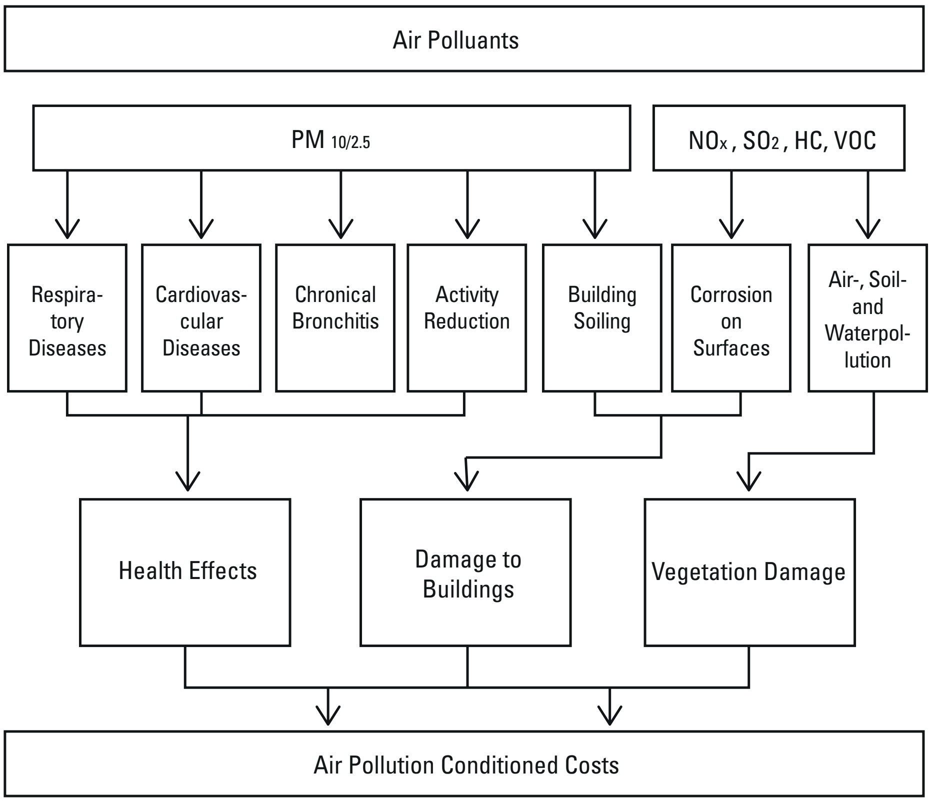
(3) The cost figures stated in the report consider the most relevant transport related air pollutants which are fine particulate matter (PM_{10}, $PM_{2.5}$), nitrogen oxide (NO_X), sulphur dioxide (SO_2), volatile organic compounds (VOC) and Ozone (O_3) as a pollutant caused by chemical reaction.[20]

(4) The number of available studies on the methodology of air pollution costs as well as applications of these methods is quite large. The theoretical and practical foundation is well established, and the tools are advanced. Most external cost calculations apply a bottom up approach based on the impact pathway approach which was developed in the ExternE project of EU (ExternE), see Figure 4. The starting point is the sum of all transport activities with pollutants emissions. The emissions are transported through the air, finally deposited and cause physical impacts afterwards. The relationship between exposure and effect is described by dose-response relationships. In a last step, the welfare losses for society caused by the physical impact are monetized.[21]

20. CE Delft; Infras; Fraunhofer ISI, 2011, p. 23

21. Maibach, et al., 2007, pp. 47-49

Figure 4: Impact pathway approach for air pollution



(5) The CE Delft study (CE Delft; Infras; Fraunhofer ISI, 2011) considers the following cost elements (see also Figure 4):

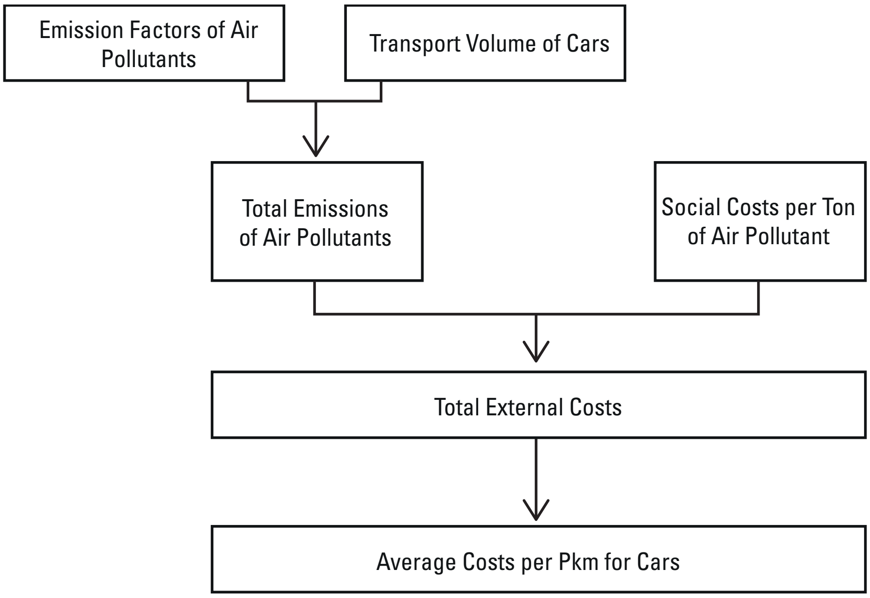
- "Health effects: The aspiration of air transport emissions increases the risk of respiratory and cardiovascular diseases. The main source of disease is particles (mainly PM_{10}, $PM_{2.5}$). [22]
- Building and material damages: Air pollutants can cause damages to buildings and materials in two ways: a) soiling of building surfaces by particles and dust; b) degradation of facades and materials through corrosive processes due to acidifying pollutants (mainly NO_X, SO_2).
- Crop losses: Ozone as a secondary air pollutant (formed due to the emission of VOC and NOX) and acidifying substances (NO_X, SO_2) cause crop damages. This means an enhanced concentration of these substances leads to a decrease in the volume of the crop.
- Impacts on ecosystems and biodiversity: Ecosystem damages are caused by air pollutants leading to acidification (NO_X, SO_2) and eutrophication (NO_X, NH_3). Acidification and eutrophication have an impact on biodiversity which is mainly negative." [23]

(6) The external costs have been calculated by CE Delft et al. (CE Delft; Infras; Fraunhofer ISI, 2011) using unit cost factors; all calculations are based on emission factors (TREMOVE-database) and transport volume data (EUROSTAT). The cost factors per ton of pollutant consider increased mortality and morbidity, damages and losses (see also Figure 5)[24]. To monetize the

22. World Health Organization, 2005, pp. 128-149
23. CE Delft; Infras; Fraunhofer ISI, 2011, p. 35
24. CE Delft; Infras; Fraunhofer ISI, 2011, pp. 36-37

health effects, willingness to pay data is used as described in section 3.3. The cost factors used are presented in more detail in CE Delft et al. (CE Delft; Infras; Fraunhofer ISI, 2011, p. 38).

Figure 5: Methodology for Calculating Air Pollution Costs



(7) Biodiversity losses due to air pollution are indirect effects resulting from nitrogen oxides (NOX) and sulphur oxide (SO2). Nitrogen oxide causes an increase of nitrates in the soil (eutrophication), resulting in danger to species of wildlife. Nitrogen and sulphur oxides are transformed into nitric/sulphuric acid, resulting in acidification of the soil.[25] The NEEDS-study uses an approach based on restoration of acidified and eutrophic land to a natural state. The cost factors of biodiversity losses are evaluated per ton of air pollutant (CE Delft; Infras; Fraunhofer ISI, 2011).

3.5. Specific methodology for noise

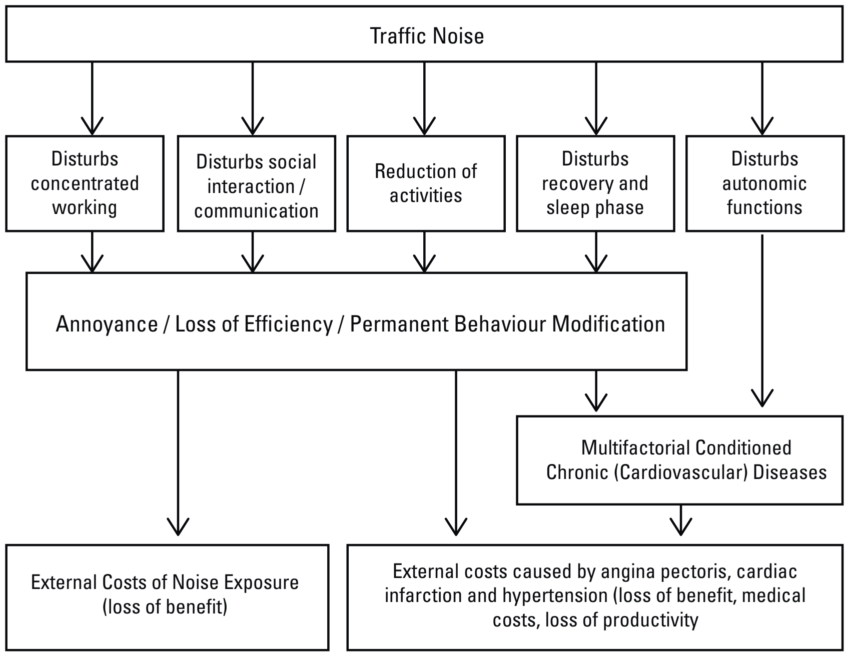
(1) Noise can be defined as any "unwanted or harmful outdoor sound"[26] which may also be harmful to human health due to its quality and characteristic. The literature distinguishes two types of negative impacts (see also Figure 6):

- "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.

25. Becker, et al., 2009, pp. 95-99
26. European Commission, 2002, p. 2

- Health costs: Noise from transport causes physical health damage. Noise levels above 55 to 65 dBA (depending on day/night and on country characteristics) may result in nervous stress reactions, such as change of heart beat frequency, increase of blood pressure and hormonal changes.[27] In addition, noise exposure increases as a co-factor the risk of cardiovascular diseases (heart and blood circulation) and decreases subjective sleep quality. "[…] The negative impacts of noise on human health result in various types of costs, such as medical costs, costs of productivity loss, and the costs of increased mortality."[28]

Figure 6: Noise effects and related costs

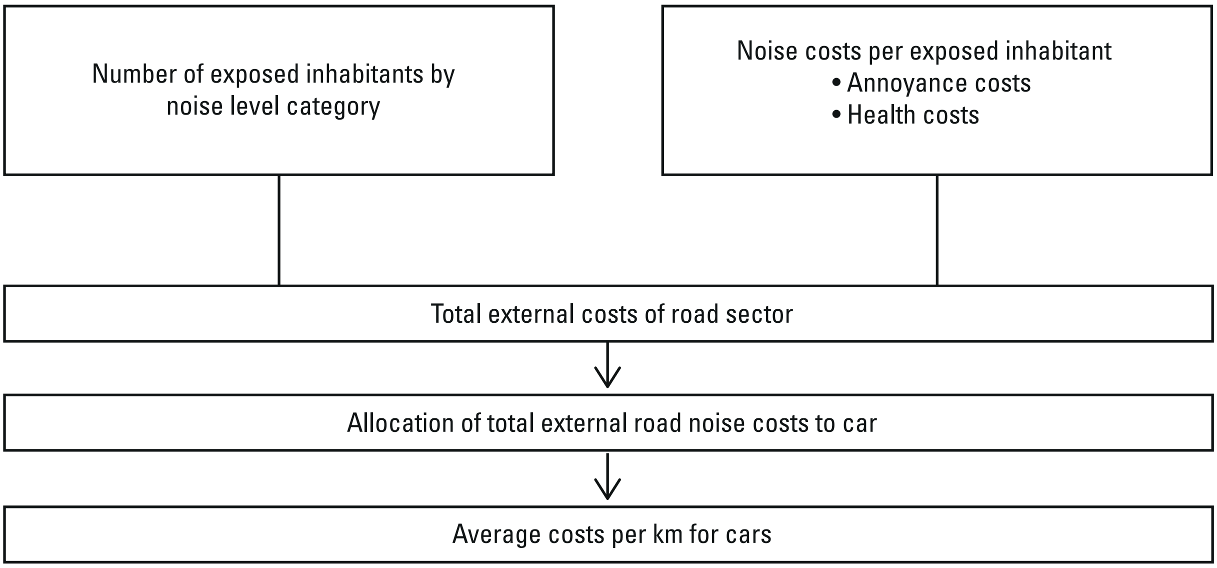


(2) The CE Delft study estimated noise costs using a bottom-up approach which consists of the following steps (see also Figure 7):

- The number of affected individuals at their location of residence is calculated based on strategic noise maps. All member states are required (by Directive 2002/49/EC) to publish the standardized noise maps for large urban areas and along major transport corridors. The number of affected individuals is reported to the European Commission for road noise in specified noise classes above the threshold level of 55 dBA. In order to consider areas outside agglomerations, the exposure level was extrapolated to other areas assuming half of the traffic density.

27. World Health Organization, 2011, p. 16
28. Maibach, et al., 2007, p. 61

Figure 7: Methodology of Calculating Noise Costs



- The noise costs are calculated by multiplication of the number of affected individuals and the noise cost factors specified for each noise exposure level.

(3) The noise cost factors are based on literature values recommended by the IMPACT-handbook (Maibach, et al., 2007), which are adapted according to GDP/capita to all countries. They consist of the two components “annoyance” and “health costs”. Annoyance costs consider the willingness to pay for a quieter environment. The cost factors can be assessed either by analysing differences within the property market (hedonic pricing) or preferences stated in surveys. Both approaches show fairly similar results, but stated preference results are used here. Health costs take into account the costs for medical treatment, the costs of absence from work and the economic effects from mortality. Typically, heart attacks, heart diseases and high blood pressure are considered due to their robust dose-response-functions.

3.6. Specific methodology for up- and downstream effects and for “other effects”

(1) Transport activities cause indirect effects which do not originate from the location of the vehicle use or the time of operation. In the life cycle of a vehicle, considerable effects are generated by the vehicle production and disposal, the provision of infrastructure and the production of energy. CE Delft et al. (CE Delft; Infras; Fraunhofer ISI, 2011) consider climate effects and air pollution caused by the energy production.

(2) The category “other costs” includes loss of natural habitats, time losses for pedestrians due to separation effects and soil and water pollution. Their combined effect is relatively low with a share of about 3.4% of the total costs.

3.7. Our approach for estimating external costs of car use in EU-27

(1) Total and average external costs per pkm on the EU level are provided by CE Delft et al. and are disaggregated by cost category and transport mode.[29] Additionally, average external costs per pkm car travel are presented at country level. [30] No cost figures disaggregated to cost categories, transport mode and country are provided. In this report, costs of car travel are presented disaggregated to cost categories and countries. For each cost category, a specific methodology had to be used due to differences in the data availability.

(2) For noise, external costs per country caused by road traffic as a whole have been calculated based on the number of exposed people and cost factors stated in CE Delft et al.[31] A share of the road noise costs has then been allocated to car traffic by considering the total vehicle kilometres per road transport mode and a mode specific weighting factor.[32] The weighting factors of cars are much lower than those of other vehicle types (e. g. motorcycles, heavy duty vehicles), since - in a comparable traffic situation - cars emit less noise than other vehicle types. On average for all countries, 32% of the external noise costs from road transport is attributed to cars in our approach. It has to be noted that this approach involves some uncertainties, since we worked with transport data (vkm) aggregated to the country level. A more precise estimation would have required working with transport data disaggregated to the infrastructure type (urban road, non-urban and motorway). However, this data was not available.

(3) In the case of air pollution, the detailed figures for cars were kindly provided by CE Delft for all countries.

(4) Climate change costs have been calculated based on CO_2 car emissions stated in the CE Delft et al. study.[33] As explained in section 4.4, the cost factors used in the present study differ from the ones applied by CE Delft et al.

(5) Up- and downstream costs are directly linked to CO_2 exhaust emissions. They have been treated as a fixed percentage value of exhaust emissions and the same methodology, with emission data and cost factors, is applied. It has to be noted that for consistency we apply the somewhat higher CO_2 cost estimates for climate change effects (see section 4.4) for up- and downstream effects as well.

(6) The combined effect of "other external costs" is relatively low, with a share of about 3.4% of the total costs. Therefore, in order not to over-complicate less important sections, a simplified method has been used, applying average EU figures to all countries.

(7) Accident costs have then been calculated as the difference between total external costs and costs within the other cost categories. Values have been verified by additionally calculating accident costs of car use at country level only considering the immaterial costs of fatalities and severe injuries. Accident figures for Ireland stated in CE Delft et al. have been implausibly low, and they have been corrected using higher car accident figures. For instance, based on the Road Safety Authority (Road Safety Authority, 2008), we estimated the number of fatalities attributable to car transport according to the damage potential approach to be about 200, rather than 17 as stated in CE Delft et al. [34]

29. CE Delft; Infras; Fraunhofer ISI, 2011, p. 74
30. CE Delft; Infras; Fraunhofer ISI, 2011, p. 83
31. CE Delft; Infras; Fraunhofer ISI, 2011, pp. 149-151
32 CE Delft; Infras; Fraunhofer ISI, 2011, p. 51 for specific weighting factors
33. CE Delft; Infras; Fraunhofer ISI, 2011, p. 142
34. CE Delft; Infras; Fraunhofer ISI, 2011, p. 146

(8) Figures in the CE Delft et al. study are presented for the EU-27 without Malta and Cyprus, but additionally for Norway and Switzerland. In this report, figures are presented for the EU-27. We have used the figures for total external costs of the remaining 25 countries to estimate values for Malta and Cyprus based on the ratio of person kilometres (pkm) travelled. This procedure seems appropriate since the effort required to build a consistent data basis of input values for these states would be high while their overall influence on the total external costs of Europe is low.

3.8. Accuracy of Estimations

(1) Estimations of external costs cannot be considered to be exact calculations as we are used to in daily life. Instead, they remain estimations. The general idea of calculating external costs is to be able to state the magnitude of costs for areas of economy where no market exists so far. Any result coming from such estimations depends on methodological choices and data input, so in reality they may be lower or – more likely – higher than stated. The purpose of the studies is not to provide exact balances but to give an impression of the size and the relative proportions of the costs in order to set priorities for political decisions.

(2) The different research projects carried out during the last decade ensure a methodology which has been discussed in the scientific community; the general approaches are widely accepted. Presenting this methodology and the boundaries is an essential step in appraising the results. Typical differences in the methodology may be:

- Effects associated with high uncertainties or without a proven dose-response-function are treated differently by different studies.
- Different regional boundaries are used, e.g. exclusion of international aviation to/from countries outside the EU-27.
- The input data may be different depending on the data source used. Not all statistics are as well standardized as the EU statistics used here.
- Approaches of appraisal (see Chapter 3) and methods of cost factors depend on the purpose of the study and the intentions of the authors.
- Some studies suggest "staying on the safe side of calculations" by using approaches that keep figures and cost estimates as low as possible "in order to avoid exaggerations". This may be understood for reasons of public acceptance ("otherwise nobody believes us"); but the authors of the present study feel that this downplaying of the problem is inappropriate. In economics and in business, if there are risks which cannot be measured exactly, a provision is made so that the risk is always smaller than the provision. Using this principle, our societies should "stay on the safe side" by using estimates and cost factors which are always at the high end of expectations. In this study, we have tried to develop a somewhat intermediate approach.
- Evaluation of assumptions like discounting of future damages or risk is very different in different studies (see section 4.4). Discounting is used most of the time but some studies suggest not discounting at all. [35]

35. Friedemann, et al., 2010, pp. 9-10

4. METHODOLOGY FOR ESTIMATING CLIMATE CHANGE COSTS

(1) Transport is responsible for about one quarter of total European GHG emissions (2009). Emissions are clearly dominated by the road sector, contributing around 70% of total emissions. Transport emissions have been growing during recent decades, leading to almost 30% higher GHG emissions in 2009 than in 1990. [36] Consequently, the European Union is now increasing its effort to substantially reduce transport CO_2 emissions.

(2) To come up with one greenhouse gas cost figure or with one CO_2 cost figure per tonne of emission is difficult; it may even be impossible. Stated cost figures for climate change vary substantially depending on the scope and methodological approach of the study. Therefore, the aim of the present chapter is to discuss a price estimate for CO_2 which indicates the effort necessary to reach the EU emission reduction targets for 2050. Additionally, some abatement measures in car transport are summarized and discussed, enabling us to comment on the feasibility of proposed reduction targets.

4.1. Methodological approach: damage costs versus avoidance costs

(1) Global warming has a variety of effects, in both a mid-term and a long-term perspective. Key effects stated in the literature include for instance higher average temperatures, extended dry seasons in some regions, a rise of sea levels and a further acidification of oceans, as well as an increase in the occurrence of extreme weather events and a higher risk for so-called major events, for example the loss of ice sheets, methane outbursts, instability or collapses of ecosystems and a transformation of the Indian monsoon or the gulf stream. These effects will have severe impacts on energy use, agriculture, water supply and public health, as well as ecosystems and biodiversity. [37]

(2) Of course, the identification of damage cost figures would also be very helpful with climate change cost estimates. However, the estimation of costs related to these impacts is quite difficult, due to complex, global impact pathways, high uncertainties in the quantification of effects, and long timescales considered. For that reason, external cost calculations are often based on estimated avoidance costs rather than damage costs.

(3) Avoidance costs follow a very different methodological approach. They describe costs which are linked to a reduction of a specific amount of CO_2 compared to a reference technology or reference point in time. This includes the costs of consumption as well as the investment and operating costs. [38]

(4) From a scientific perspective, the calculation of damage costs would be the theoretically preferred way, because then the external effects and the related costs are quantified directly. As described above, the complex impact pathways and high uncertainties related to the physical impacts, as well as some specific methodological issues (e. g. the consideration of equity weighting) prevent us from choosing this approach. On the other hand, the calculation of external costs based on the avoidance cost approach does not necessarily stand in conflict with economic theory. If cost factors are based on official

36. It is important to note that all figures stated in this paragraph include international aviation and maritime shipping. (EEA, 2011, p. 23). When excluding international bunkers, the absolute numbers change slightly; the trend however remains the same.

37. Maibach, et al., 2007, p. 72 f.

38. Forschungsstelle für Energiewirtschaft e.V., 2009 binding policy targets, it can be assumed that these targets correctly represent people's preferences towards a socially optimal emission of GHG. Avoidance costs can then be seen as a society's willingness to pay (WTP) for a certain emission reduction. WTP analyses are an established methodological approach for obtaining the monetary value of non-market goods in the area of external cost calculation.

(5) From a political perspective, the calculation of avoidance costs might be appealing for further reasons:

- Avoidance costs allow the comparison of different measures to reduce greenhouse gas emissions. This makes it possible to find the most cost-effective measures to reach a certain political emission target.
- Within the European Union, political emission targets have already been set. Cost estimates for these targets (and different pathways towards the targets) might underpin the importance of a stringent climate policy.

(6) For these reasons, cost factors used in the report are based on the avoidance cost approach. Generally, a wide variety of avoidance cost estimations exist in the literature. However, published estimations are based on varying assumptions and model inputs. The following are the key aspects leading to different final cost factors:

- Stricter emission targets may be more difficult to reach than more relaxed targets. If more expensive measures have to be included to reach higher reduction targets, this will increase avoidance costs.
- The time frame available to reach a target plays an important role. If investment cycles have to be shortened to reach a certain reduction target, this will cause a rise in costs.
- Avoidance costs also differ between various branches of the economy. For some sectors, substitution of carbon-intensive energy carriers might be easier than for others. Additionally, further improvements in an already very efficient sector are more difficult to reach than improvements in less efficient sectors, due to increasing marginal avoidance costs. Costs will therefore be different when calculated for the whole economy than they will be when calculated for the transport sector alone.
- Within branches, avoidance costs also vary depending on the measures included in the modelling. Some cost estimations are based on technical measures only, thereby neglecting the potential of behaviour-related measures.
- Assumptions on the general development of energy costs have an important impact on the cost-effectiveness of energy-saving-measures. With high energy costs, energy saving measures amortize faster.
- Finally, uncertainties related to the prediction of GHG emissions and the availability, acceptance, impact and costs of reduction measures are naturally high for long time frames. In the case of the White Paper, the time frame is almost 40 years. For that reason, bandwidths are often stated instead of single numbers.

(7) In the following section avoidance cost factors are discussed which focus on emission targets needed to reach the 2°C overall target. Table 2 states the respective emission targets and milestones outlined for the European Union as a whole and for the transport sector.

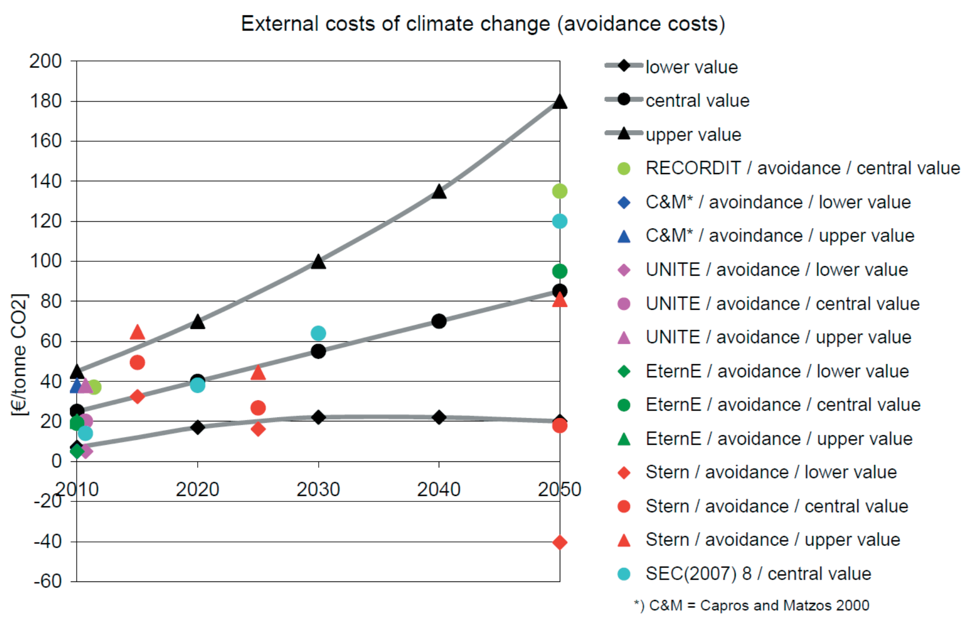
Table 2: EU emission targets and milestones (base year 1990) [39]

Scope	target year	target	source
European Union, domestic reduction	2050	-80%	(European Commission, 2011a), p. 4
European Union, total reduction	2050	-95%	(European Commission, 2011a), p. 4
European Union	2020	-25%	(European Commission, 2011a), p. 4
European Union	2030	-40%	(European Commission, 2011a), p. 4
European Union	2040	-60%	(European Commission, 2011a), p. 4
EU, transport sector	2030	+8%	(European Commission, 2011b), p. 3
EU, transport sector	2050	-54 -67%	(European Commission, 2011a), p. 6
EU, transport sector	2050	-60%	(European Commission, 2011b), p. 3
EU, cars, lifecycle emissions	2050	-70%	(Hill & Morris, 2012)
EU, cars, direct emissions	2050	75%	(Hill & Morris, 2012)

4.2. State of the literature – general avoidance cost factors

(1) As Figure 8 shows, a variety of cost estimations exist. Cost factors as well as uncertainties regarding the cost factors increase over time. All of the cost factors stated in the following are estimated for the whole economy. Transport specific cost factors are not yet available in a ready-to-use disaggregation.

Figure 8: Comparison of avoidance cost factors stated in literature [40]



39. European Commission, 2011a, European Commission, 2011b, Hill & Morris, 2012
40. Maibach, et al., 2007, p. 264

(2) The cost factors which are shown in Figure 8 are calculated for varying target years. Only a few models have assessed costs for reaching the somewhat strict target of 2°C by 2050. Selected model results from these studies are summarized in Table 3.

(3) Our cost factor is based on the meta-analysis of Kuik et al.[41] The three authors conducted a meta-analysis of existing avoidance cost estimations. In their study, a consistent set of avoidance cost figures is presented, which is extracted from the results of 26 different models. As we can only obtain reliable results if we use the expertise of as many sources as possible, we use this study as a primary source. This, again, is in line with the CE Delft study cited above, which uses the same source as basis for cost factors. However, cost factors stated there differ from ours due to a different approach for discounting the values from the meta-analysis.

(4) The results of the work of Kuik et al. is described below, together with results from other very recent studies and a general overview on CO_2 cost factors recommended elsewhere (see Table 3). As one can see, there is a range of 70 € to 486 € €

Table 3: Overview of typical CO_2 cost figures for the target year 2050.

Author	Time frame	Regional Scope	Central value [42]	Range
(Federal Environmental Agency, 2008), recommended value	*2050*		*70 €/t CO_2* [42]	*20-280 €/t CO_2* [35]
(Maibach, et al., 2007)	*2050*		*85 €/t CO_2* [35]	*20-180 €/t CO_2* [35]
(Kuik, Brader, & Tol, 2009)	*2025 (450 ppm)*	*world*	*129 €$_{2005}$ /t CO_{2eq}*	*69-241 €$_{2005}$ /t CO_{2eq}*
(Kuik, Brader, & Tol, 2009)	*2050 (450 ppm)*	*world*	*225 €$_{2005}$ /t CO_{2eq}*	*128-396 €$_{2005}$ /t CO_{2eq}*
(Morris, Paltsev, & Reilly, 2012)	*2050 (-50%)*	*European Union*	*44 €$_{2005}$/t CO_{2eq}* [44]	
(Akashi & Hanaoka, 2012)	*2050 (-50%)*	*World*	*486 €$_{2005}$ / t CO_{2eq}*	

4.3. State of the Literature – avoidance costs for specific transport measures

(1) In this study, the target we assume for transport is the 60% reduction target stated in the 2011EU White Paper for Transport. For this target, no sector specific avoidance cost estimation exists. Nonetheless, several studies have estimated avoidance costs for single measures in the transport sector, or sometimes also for policy measures chosen to reach specific reduction targets (other than the 60% target for transport). Results from these studies help to capture the magnitude of costs arising in the future as well as to compare the cost-effectiveness of different measures. The studies summarized in the following section include European research projects as well as studies funded by national institutions and the private sector (associations and lobby groups). A table of possible reduction measures and – if applicable – assumed costs and potentials is presented in the appendix (Table 5).

(2) **McKinsey & Company, 2009:** The study "Pathway to a low-carbon Economy" is a comprehensive assessment of around 200 mostly technical emission reduction measures. Global reduction potentials and costs of these measures until

41. Kuik, et al., 2009

42. If applicable, prices have been converted into EUR using a currency conversion factor of 0.81 EUR/USD (compare: Maibach, et al., 2007, p. 240).

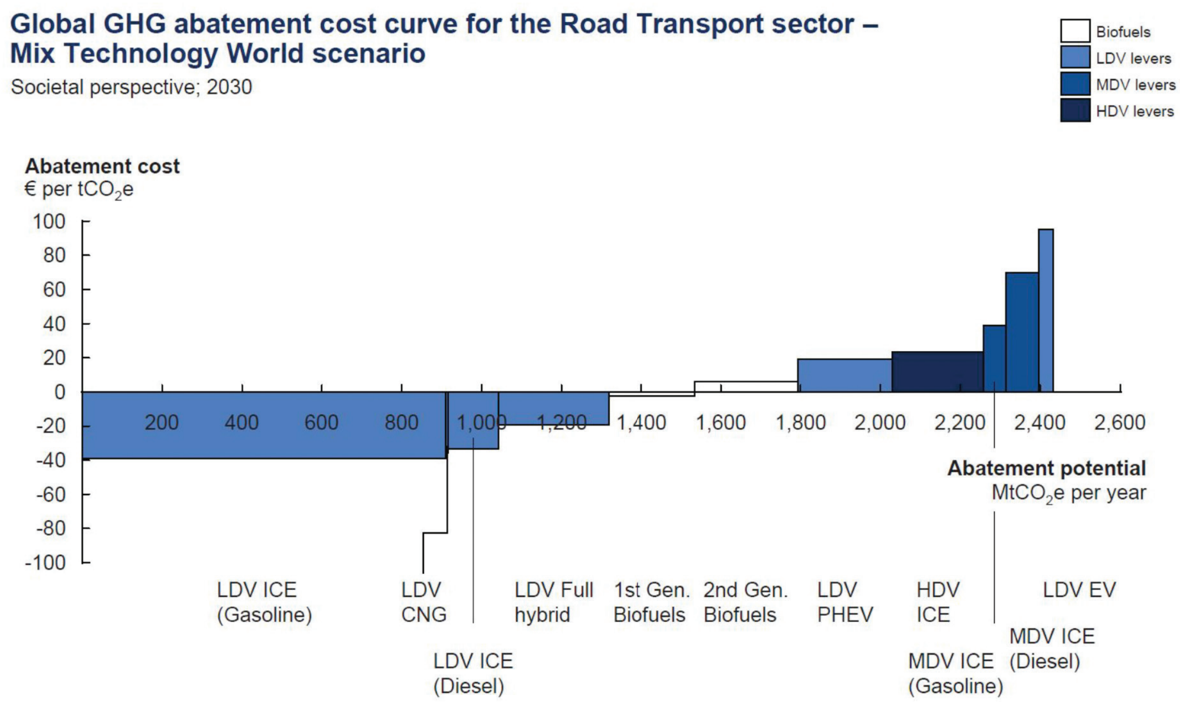
43. These sources did not state a basis year for recommended values. It is most likely that values are price based

44. Cost factors here are somewhat low, probably due to the fact that emission reduction requirements assumed for the EU are lower than those used in the other studies stated.

the year 2030 have been evaluated in cooperation with various companies from the perspectives of business, consumers and society. Results show the distribution of abatement opportunities between regions, sectors and technical solutions as well as the magnitude of costs being incurred for enterprises and consumers. In a follow-up study, McKinsey & Company also evaluated avoidance potentials and costs until 2020/2030 across and within sectors for Germany. [45]

(3) Results for global costs and potentials in the transport sector are shown in Figure 9. A high potential has been associated with the improvement of conventional gasoline and diesel cars, which also leads to cost savings for society due to lower fuel costs. Biofuels (1st and 2nd generation) are stated to have comparably low costs, whereas the global potential for electric and hybrid cars until 2030 is evaluated to be fairly low, and costly to achieve.

Figure 9: Global avoidance potential and costs for the transport sector until 2030 [46]



(4) **GHG-TransPoRD:** The GHG-TransPoRD project (2009-2011) was funded by the European Commission to develop an integrated European strategy to achieve substantial GHG emission reductions in transport. As part of the project, GHG-TransPoRD evaluated potentials and costs for a variety of mode-specific reduction measures in the transport sector, including technologies, urban measures, behavioural changes, policies, etc. Within a model based approach, scenarios have been developed with the aim to show feasible emission pathways towards a 60-80% reduction in transport emissions by 2050. Up to now, only results from the first work packages are publicly available. [47]

(5) **EU Transport GHG:** Routes to 2050 (I and II): The original project (2009-2010) as well as the follow-up project (2011-2012) were funded by the DG Climate Action of the European Commission, to support the discussion about efficient routes towards a more sustainable and less carbon-intensive mobility in 2050. In the course of the project, SULTAN - a stand-alone Excel-calculation tool - was developed, allowing interested parties to investigate the impact of different policy

45. McKinsey & Company, 2007; McKinsey & Company, 2009a

46. McKinsey & Company, 2009b, p. 100

47. Akkermans, et al., 2010

strategies on European transport demand, transport GHG emissions and associated internal and external costs. With the help of SULTAN, a number of policy scenarios were evaluated by the project team, allowing a preliminary assessment of the amount of effort necessary to reach the emission reduction targets stated in the Transport White Paper. Cost calculation was primarily restricted to the calculation of car operating costs, thus not allowing for assessment of the total costs arising.

(6) **TOSCA:** This is a project to identify and evaluate the most promising drive and fuel innovations helping to reduce transport GHG emissions; it was also funded by the EU FP7 (2009-2011). Costs and potential for different drive concepts (electric cars, hybrid cars, fuel cell cars) and fuels were estimated. The project concluded that technological measures alone will hardly be enough to reach the Transport White Paper emission target. [48]

(7) **CO_2 Emissions Reduction in the Transport Sector in Germany:** The federal environment agency of Germany has issued a status report (in German, with a short summary in English) which quantifies CO_2 emission reduction potential in the German transport sector until 2020 or 2030.[49] Contrary to other studies cited so far, this report focusses mainly on non-technical measures, showing the high potential associated with them.

(8) A comprehensive list of measures and estimated potentials and costs can be found in the appendix in Table 5. Caution is, however, necessary, as potentials often refer to a maximum potential associated with ambitious assumptions regarding market penetration and cost development. Costs and potentials therefore should be treated as rough indicators for the magnitude of effects only. Simple addition of stated potentials is not possible either, since reduction measures interact and in part overlap in their effect, often leading to smaller realistic emission savings than stated in the table.

4.4. Specific Methodology for Climate Costs used in this report

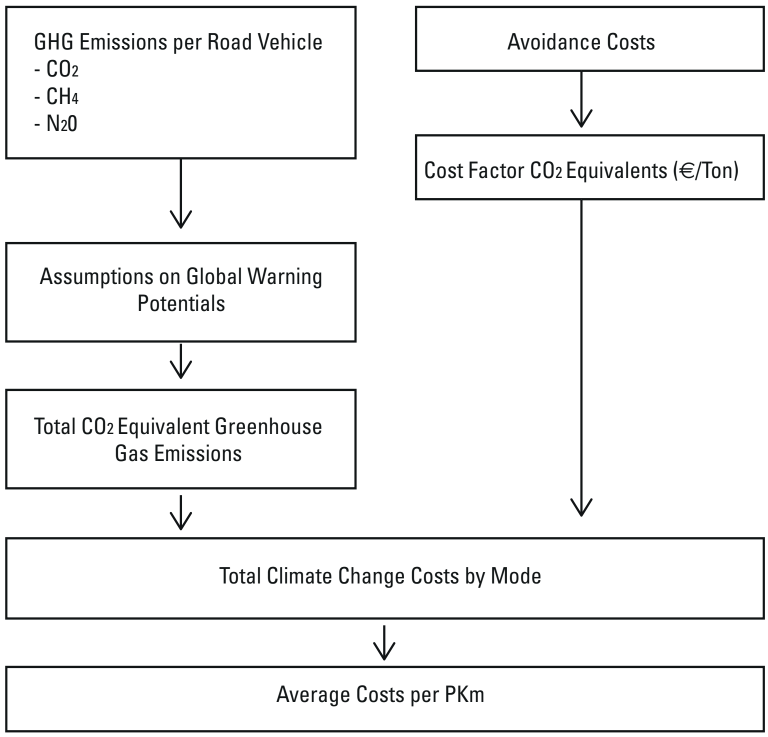
(1) As described above, avoidance cost estimates vary significantly depending on scope and methodology employed. The following section presents the calculation approach used for the cost figures stated in this report.

(2) Generally speaking, cost calculations for climate change costs in the transport sectors follow a fairly simple approach [50] (see Figure 10):

- Assessment of total vehicle kilometres by type of vehicle, according to area, region or country. This differentiation allows for the utilization of more specific emission factors.
- Multiplication of vehicle kilometres by emission factors (in g/km) for all green-house gases (CO_2, N_2O, CH_4 and to a smaller extent hydrofluorocarbons from mobile air conditioners).
- Weighting the emissions according to their global warming potential and summing up individual contribution to the total emissions of greenhouse gas emissions in CO_2 equivalent.
- Multiplication of the total greenhouse gas emissions by the external cost factor.

48. Schäfer, et al., 2011, p. 25
49. Federal Environmental Agency, 2010
50. Maibach, et al., 2007, p. 73

Figure 10: Methodology for calculating Climate Costs



(3) Our calculation of external climate change costs is based on the CO_2 emissions of passenger cars per country stated in the CE Delft study. [51] Since the focus here lies more specifically on the estimation of avoidance costs for reaching the 60% emission reduction target stated in the Transport White Paper 2011, we decided to deviate from the cost factors applied in the CE Delft study. The reasons are the following:

- The cost figures used in this report are intended to reflect the transport emission target stated in the White Paper as much as possible. Targets for the transport sector are based on the overall reduction target for the EU of minus 80-95% by 2050. Our cost figures (both low and high value) are therefore based on this long-term target.
- Although avoidance costs for the measures implemented today on this long path will be low (or possibly negative due to realized energy savings), we assume that it is helpful to base our cost estimations on the higher marginal avoidance costs for stricter reductions necessary in future years. The reason for that is that fundamental path decisions and basic investments (e.g. in new car models or efficient power plants) which are necessary for strong emission reductions in 2025 and 2050 have to be made now, since investment cycles are about 5-10 years for cars and indeed up to 30-60 years for power generation plants etc. It is therefore necessary to set a strong incentive for investing sufficiently in emission reduction measures today.[52] Cost factors used in

51. CE Delft; Infras; Fraunhofer ISI, 2011, p. 142
52. Compare e. g. Maibach, et al., 2007, p. 82

this study therefore reflect marginal abatement costs (“real prices”, price base 2008) for reductions necessary at some time around the year 2025.

- The cost figures used in this report are somewhat higher than cost figures used in other studies, e. g. CE Delft et al. (CE Delft; Infras; Fraunhofer ISI, 2011), Maibach (Maibach, et al., 2007), Umweltbundesamt (Federal Environmental Agency, 2008). On the one hand this reflects the recently published concerns, that stated cost figures so far may underestimate actual costs due to selection bias.[53] On the other hand, this also reflects the intent to express specific avoidance cost factors for the transport sector. Avoidance costs are generally expected to be higher in the transport sector due to its strong dependency on carbon-intensive fuels. At the same time, Maibach (Maibach, et al., 2007) argues that the willingness to pay for emission reductions in the transport sector is actually higher than assumed from studies of the whole economy. This is supported by the example of the biofuel directive and the EU policy to reduce CO_2 emissions from new passenger cars. [54]

(4) Again, the cost factors used in this report are based on (Kuik, et al., 2009) [55] and are derived from a comprehensive meta-analysis. They also express the effort necessary to reach the global 2°C target. We also decided to use the Marginal Abatement cost factors applicable to abatement measures in the year 2025 as this year is roughly halfway between now and 2050. These cost factors are on the one hand high enough to stimulate investments necessary today for reaching significant emission reductions in the future, and are on the other hand associated with lower uncertainties and bandwidths than cost factors stated for 2050. To give a good picture of the range of climate costs, we work with the lower and upper boundaries of the marginal avoidance cost factors stated in (Kuik, et al., 2009).

(5) Another important issue to be discussed is the discount rate. When evaluating the costs of emission reduction measures, the time frame in which costs arise plays a major role. In general, costs arising in the future have to be discounted to present value with the help of a certain discount rate. The selection of a “proper” discount rate is often the deciding factor for estimating external cost. In the case of climate change in particular, costs arise far in the future, leading to very small present values of cost factors when high interest rates are applied.

(6) The “Methodological Convention for Estimates of Environmental Externalities” produced by the German Federal Environmental Agency recommends the following approach: [56]

- For costs arising within the next 20 years, a market interest rate of 3% is applied. We feel that this value (which was developed in 2006 and before) is too high for the current situation. Today inflation rates are much lower due to the financial fluctuations between 2008 and 2012.
- For time spans longer than 20 years (inter-generational effects), a social discount rate of 1.5% is used.
- Sensitivity analyses with a social discount rate of 0% are recommended.

We used the discount rate recommended by (Federal Environmental Agency, 2008) of 1.5% for converting the $€_{2005}$ to $€_{2008}$ values.

(8) For the calculation of external costs of climate change, we therefore use the following cost factors:

Low value: 72 $€_{2008}$/t CO_2

High Value: 252 €$€_{2008}$/t CO_2

53. Tavoni & Tol, 2010

54. Maibach, et al., 2007, p. 72

55. see Table 3

56. Federal Environmental Agency, 2008, p. 34

(9) These cost figures are multiplied by the CO_2 emissions of cars stated in CE Delft; Infras; Fraunhofer ISI, 2011. By following this approach, total climate change costs for cars can be calculated for every year and every country, based on vehicle fuel consumption.

(10) Of course, the selection of any value for climate change costs is somewhat arbitrary. Given the uncertainties described above, however, we feel that these figures give an impression of the order of magnitude of the adaptation process in front of us. The results show that on one hand GHG emission reduction is not for free, but on the other it is also not impossible. The costs are in the same range as the costs for other effects.

5. EXTERNAL COSTS OF CAR USE: RESULTS SECTION

(1) Having described the method and the data, it is now possible to proceed to results. The following chapter consists of an overview of the results on the average and total external costs for cars. In the first part, the total and average costs for the EU-27 countries are presented. Then, the distribution of cost categories is presented. The figures in this chapter generally reflect the high cost scenario for climate change and the up- and downstream effects. Table 4 also states the values for the lower boundary chosen for climate costs and up- and downstream effects. All costs are in Euro and for the base year 2008.

(2) Table 4 provides a detailed summary of the main results of the study. For all 27 EU member states and all the external cost types the sum of the uncovered costs is given. The grand total is 373 billion € per year, roughly 3.0% of the GDP of the EU (285 billion € for the lower cost scenario for climate change and up- and downstream effects). It has to be noted that total external costs of car use per country differ from the values stated in the CE Delft study due to the use of different climate change cost factors. Additionally, accident figures for Ireland are implausible in this study, and we have also corrected this value (see section 3.7 for further information).

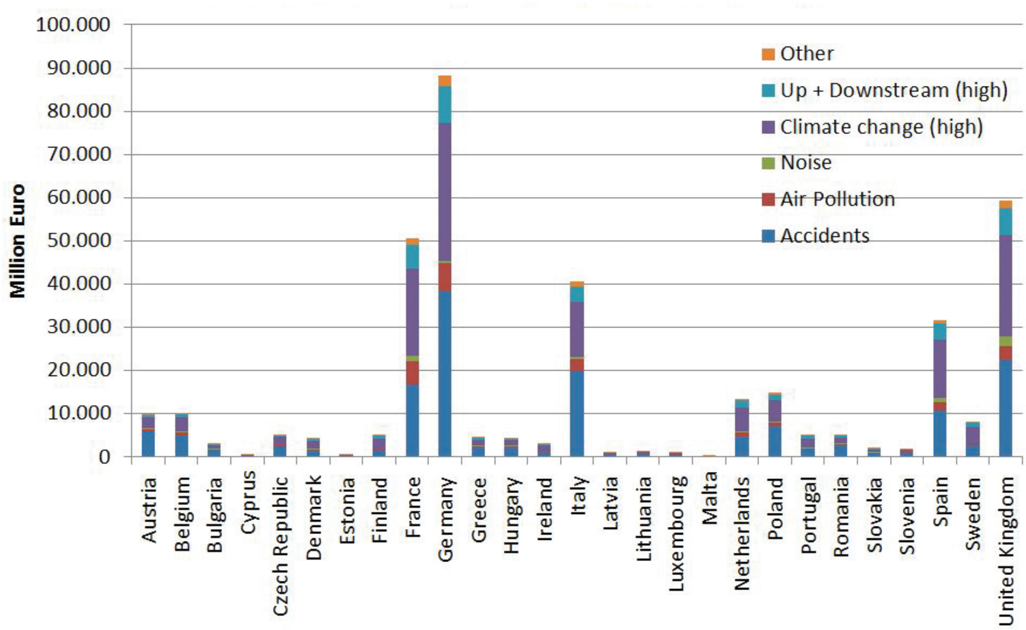
Table 4: Total external costs of cars 2008 for EU-27 by cost category and country

	Accidents	Air Pollution	Noise	Climate change (low)	Climate change (high)	Up + Downstream (high)	Up + Downstream (low)	Other	Total
	Mio €€/a	Mio €€/a	Mio €€/a	Mio €€/a	Mio €€/a	Mio €€/a	Mio €€/a	Mio €€/a	Mio €€/a
Austria	5.811	674	177	683	2.384	646	362	296	9.988
Belgium	4.790	851	174	928	3.240	877	492	290	10.222
Bulgaria	1.647	78	85	224	782	212	119	84	2.888
Cyprus	185	32	10	17	101	27	9	12	368
Czech Republic	2.416	394	174	446	1.559	422	237	146	5.112
Denmark	1.504	250	73	510	1.780	482	270	112	4.200
Estonia	191	19	4	52	183	49	28	12	459
Finland	1.331	347	37	704	2.460	666	373	126	4.968
France	16.756	5.402	1.093	5.832	20.369	5.516	3.091	1.362	50.498
Germany	38.366	6.351	621	9.121	31.856	8.628	4.834	2.442	88.263
Greece	2.234	111	239	388	1.354	367	206	127	4.432
Hungary	2.128	345	122	366	1.280	347	194	125	4.346
Ireland	1.221	142	148	300	1.050	284	159	45	2.890
Italy	19.977	2.578	685	3.634	12.694	3.438	1.926	1.153	40.525
Latvia	392	38	41	103	360	98	55	26	955
Lithuania	679	55	22	106	372	101	56	36	1.265
Luxembourg	447	98	6	70	245	66	37	26	889
Malta	69	12	4	6	38	10	3	5	137
Netherlands	4.620	1.038	220	1.613	5.634	1.526	855	357	13.396
Poland	7.180	775	259	1.405	4.908	1.329	745	419	14.870
Portugal	1.828	192	125	597	2.085	565	316	131	4.925
Romania	2.766	171	189	389	1.360	368	206	146	5.000
Slovakia	857	174	92	180	628	170	95	56	1.978
Slovenia	943	106	17	146	508	138	77	51	1.764
Spain	10.695	2.035	987	3.868	13.509	3.659	2.050	844	31.728
Sweden	2.610	320	80	1.085	3.789	1.026	575	208	8.032
United Kingdom	22.396	3.174	2.222	6.712	23.443	6.349	3.558	1.603	59.188
Total EU-27	**154.042**	**25.762**	**7.905**	**39.486**	**137.969**	**37.366**	**20.930**	**10.240**	**373.284**

(3) Figure 11 shows the total external costs of cars for each of the EU-27 countries. It can be seen that climate change costs and uncovered accident costs are of similar size, followed by air pollution costs (where reductions from previous estimates can be clearly identified). The total costs for all countries add up to 373 billion € for 2008. With close to 500 million people living in the EU-27 in 2008, this translates into 750 € of externalized transport costs per European Union resident per year. In other words:

(4) Every citizen of the EU-27 pays for his or her private transport. On average, however, every person living in the EU-27, old or young, male or female, externalizes 750 € per year on to other people, other countries or other generations. Over a period of 10 years, a family of four accumulates a "debt" of 30,000 €.

Figure 11: Total external costs from cars per year (2008) by country



(5) Clearly, country size and economic influence have an impact on the results, with the large countries – Germany, United Kingdom, France, Italy and Spain – dominating the picture. To take the country size into consideration, Figure 12 presents the external costs per inhabitant. Most of the newer member states have relatively low per capita costs, at less than 500 €€per year. Germany, Austria and Luxembourg have the highest per capita costs, in the range between 1,000 € and 2,000 €€

Beyond actual differences in the environmental impact of transport in the member states, there are other reasons for the variation in cost figures:

- Several cost components (e.g. accidents) are based on cost factors which have been weighted by the GDP per capita. This means for example that costs associated with a specific accident outcome will be higher in Luxembourg by a factor of around 2.3 than they would be for example in Germany.[57] This alone makes comparisons between individual countries difficult, if not impossible. On the other hand, it ensures that cost figures correctly reflect the impact of transport related damages within each country and for the inhabitants of this country.

57. The two countries serve as an example here. Adjustment values for all countries can be found in CE Delft et al. (CE Delft; Infras; Fraunhofer ISI, 2011, p. 127)

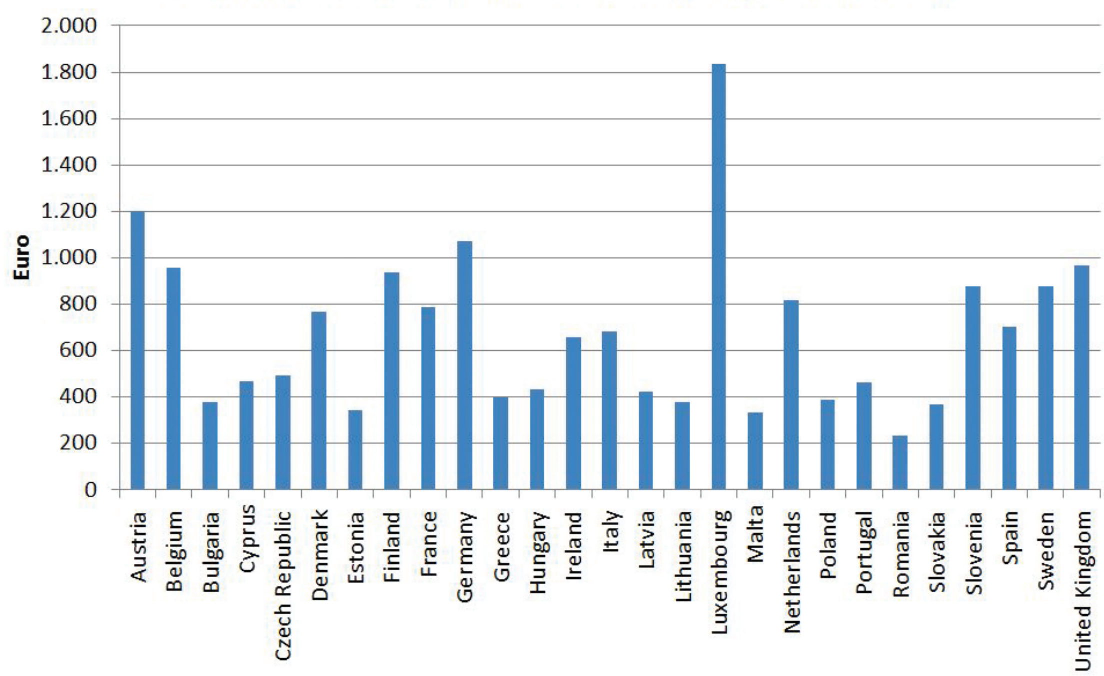
- In transit countries, an additional uncertainty occurs: although calculations in the CE Delft study are based on the nationality perspective, the calculation methodology for some cost categories does not allow an accurate cost assignment according to this principle. This is true for instance for noise, since noise costs are calculated depending on the number of exposed people, without considering whether the noise emitters are nationals of the country in question or not. For most countries, aggregated costs calculated according to nationality vs. territorial perspective will not differ significantly; however results have to be interpreted with caution in the case of smaller transit countries, such as Austria.

- Besides the effect of the high GDP, a possible contribution to the high value of Luxembourg may be the effect of many commuters from the neighbouring countries. In addition, low fuel taxes encourage lorries to make a detour through Luxembourg, which influences the traffic performance statistics. For EU-wide analyses this figure is negligible, for a national analysis it needs more consideration.

- In the case of Austria (and also Luxembourg), it has to be added that traffic safety is still a little below European average.[58] In combination with the comparably high GDP values, this triggers high external costs per inhabitant.

An average European citizen causes a cost of about 750 € per year.

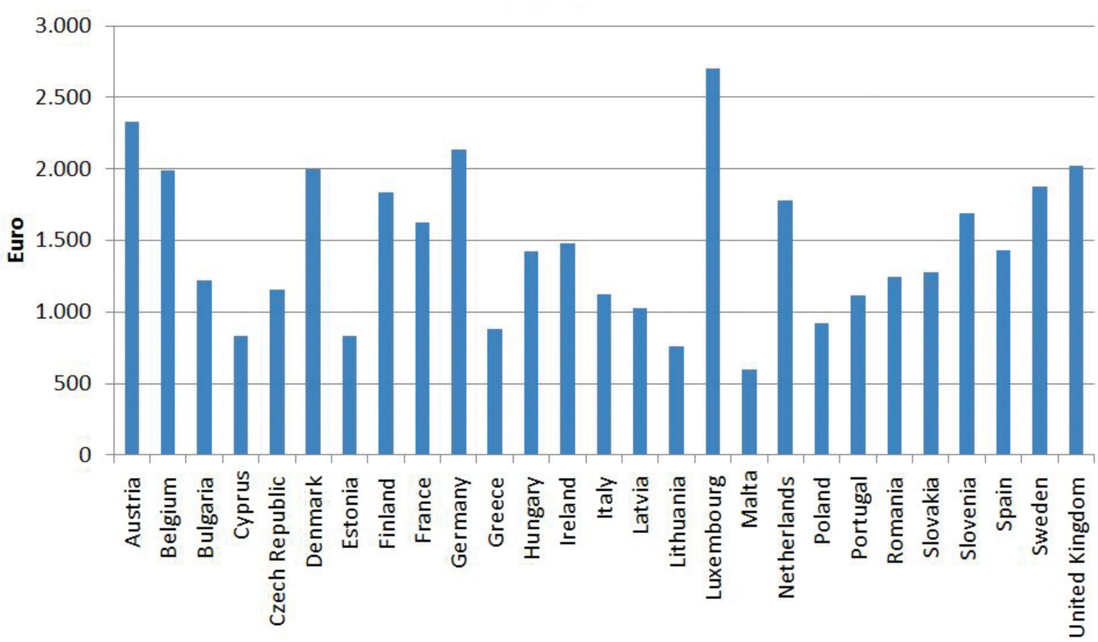
Figure 12: External costs from cars per inhabitant and year (2008) by country



58. bmvit, 2012, p. 25

(6) Car ownership rates differ widely between the EU countries. Figure 13 shows the total external costs in each country per each registered vehicle and year. Malta, Lithuania, Estonia and Cyprus have the lowest ratio (<850 €); five countries have at least 2000 € uncovered costs for every one of their registered cars. For an average European car, about 1,600 € external costs are accumulated every year. Given a lifespan of around 10 years (in later years, not so many kilometres are driven), the cost to society per new car sold may be in the range of around 16,000 € per car. In some countries (e.g. Singapore) vehicle purchase taxes are in that price range or even above.

Figure 13: External costs from cars per registered vehicle and year (2008) by country



(7) Figure 14 and 15 show the distribution of external costs to the separate cost categories in the high climate cost scenario and in the low climate cost scenario respectively. Accident costs and climate costs are the main cost elements in the high climate cost scenario, contributing 41% and 37% respectively to the total external costs. Accident costs play the largest role in the low climate cost scenario.

Figure 14: Share of cost categories for cars in EU-27 (high climate costs)

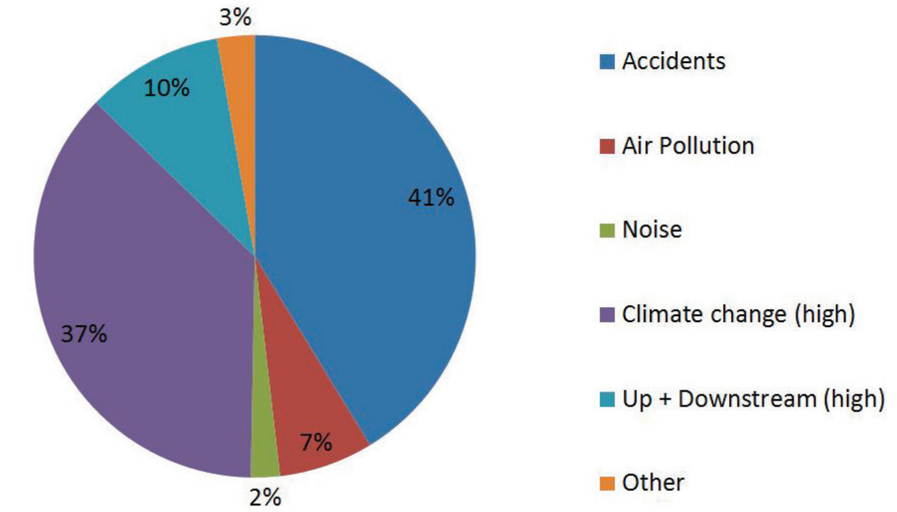
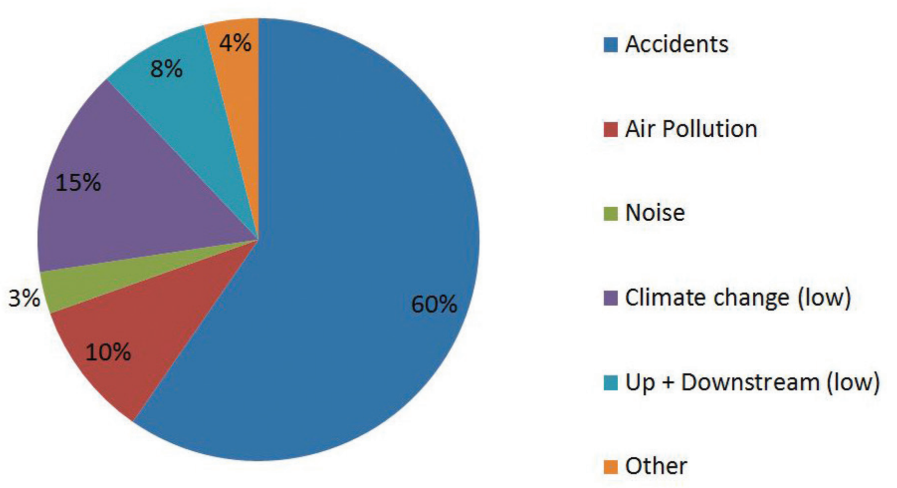
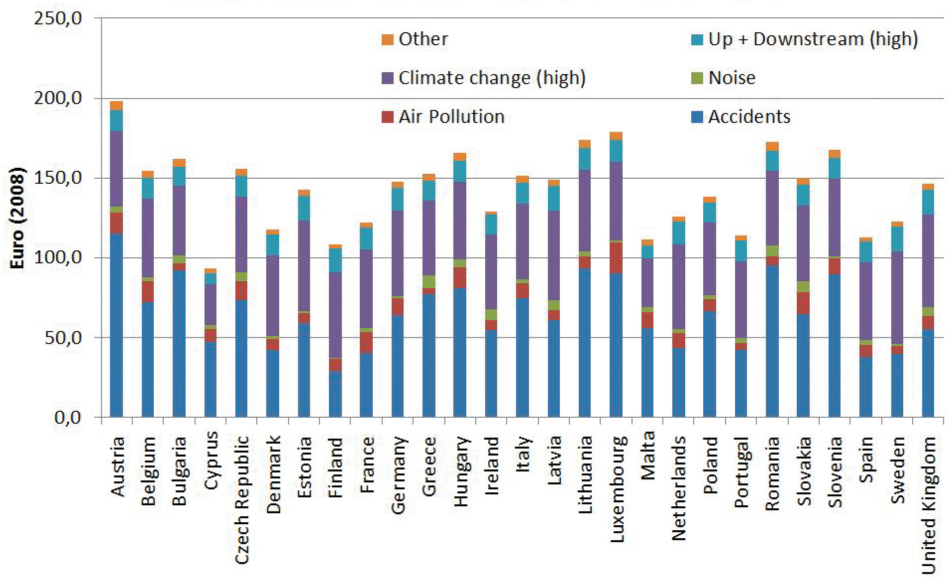


Figure 15: Share of cost categories for cars in EU-27 (low climate costs)



(8) Figure 16 presents the average external costs per 1,000 vehicle kilometres driven. This figure is useful as it corresponds to actual vehicle usage. All values are given for a driving distance of 1,000 vehicle kilometres. The lowest value – below 100 €/1,000 vkm – occurs for Cyprus. Romania, Lithuania, Luxembourg and Austria have the highest costs; between 150 € € and 200 € € Average climate change costs with their constant CO_2 cost factor are fairly stable for all countries, varying around 50 € per 1,000 vkm. Using this figure of 50 € per 1,000 vkm, we arrive at a proposed level of 5 eurocents per kilometre for a car charge depending on distance. In all European countries, a "Climate protection Charge" of around 5 eurocents per km would need to be established in order to move forward towards "user pays principles". The largest cost component, again, is the cost of uncovered accidents. Accident costs are country specific (GDP-weighted); consequently variation is high.

Figure 16: Average external costs from cars per 1,000 vkm by country [59]



(9) The database allows comparisons along many different lines. It must be stated as above, however, that comparisons between different countries are sometimes not directly possible for the following methodological reasons:

- Structural specifications of a country (e.g. accident levels) or strong differences within a country (e.g. rural/urban ratio) restrict the explanatory power of the average values we have calculated.
- Cost factors for accidents, noise and air pollution are weighted by national GDP. In any given situation, these factors should be taken in line with the specific situation in that country to make it comparable to other economic data.
- The methodology applied by CE Delft tries to avoid biased cost allocations between countries by using the nationality perspective. Uncertainties in the calculation based on this principle might however still influence the results for some countries. Examples are countries with a large degree of transit traffic (e.g. Austria) or a large number of commuters into/out of a country (e.g. Luxembourg); as well as very small countries, where small case numbers might possibly lead to artificial results. Therefore it is suggested that close analysis of the individual figures of each country is made before discussions are started in individual countries.

(10) Although comparisons between countries are not recommended without looking closely at the details, the results for a single country are nevertheless valuable and helpful. Each country value gives the national stakeholders and citizens a good impression of the magnitude of external car costs in their specific country.

59. No vehicle kilometer data available for Malta. Average EU-value used instead as factor for person kilometer

6. CONCLUSIONS: MAGNITUDE OF EXTERNAL COSTS, APPROACHES FOR POLITICAL ACTION

(1) Based on the assumptions described in this study, the cars used within the EU-27 externalize about 373 billion € per year (high estimate) on to other people, other regions and other generations (low estimate: 258 billion €). This is a considerable sum, and it leads to a level of car use that is inefficient from the perspective of society. Because "others" pay for large parts of the costs of transport, Europeans travel by car too much to enable an efficient situation. This in part also explains why there is a high level of congestion in parts of the EU.

(2) The findings of this study clearly show that the frequent claim "that cars cover all their internal and external costs" [60] cannot be sustained. Although no detailed estimation of charges and earmarked taxes of cars attributable to external costs has been made in this study, it is obvious that a sum in the range of 300 to 400 billion € of earmarked funds against these costs cannot be reached. On the contrary; it must be stated that car traffic in the EU is highly subsidized by other people and other regions and will be by future generations: residents along an arterial road; taxpayers; elderly people who do not own cars; neighbouring countries; and children, grandchildren and all future generations subsidize today´s traffic. They have to pay, or will have to pay, part of the bill.

(3) These findings suggest that political action is urgently needed. The sooner this happens, the more the transition process can be designed in a smooth, efficient, socially acceptable and environmentally friendly manner. The longer that action is delayed, the stricter, more severe and more expensive this process will be.

The results of this study advocate that the European Union should embark as soon as possible on a process that estimates external costs regularly and develops a smooth integration path of these costs into transport prices: Slowly and steadily, designed well in advance of implementation, with accompanying measures to support adaptation. Let it be remembered that there is no intention of creating additional revenue from transport users: the intention is to give price signals so that everybody adapts and hopefully nobody has to pay these prices. Then, all costs would be reduced, efficiency would be increased.

(4) Economic price settings and regulatory measures, framework settings and (land use) planning measures need at least as much political attention as technology. User price increases by internalising the external costs in consumer prices, while offering alternatives to car use, can change behaviour substantially – and this may be the cheapest option. Reducing the total number of vehicle kilometres travelled has the greatest effect on greenhouse gas emissions, and there is no risk of rebounding effects.

60. Baum, et al., 2008

(5) Technology measures such as biofuels or electric vehicles focus mostly on higher energy efficiencies and on reduction of greenhouse gases. Their effects on all other cost components of external costs are smaller. Noise and air pollution, as well as the large cost component of accidents, remain high, causing ongoing negative effects on society.

(6) Many projections of avoidance curves are based on new technologies aimed only at achieving greenhouse gas emission reductions. The discussion about greenhouse gas reductions in transport is primarily left to automobile technology experts. This approach is misleading because other fields (like economic approaches or land use approaches or behavioural changes) are neglected; and these are fields in which reductions come at a much cheaper price. The TransPoRD-project as a key research project on European greenhouse gas reduction measures in the transport sector concludes: "Technologies known today will not be sufficient to achieve GHG reduction targets of -60% to -80% by 2050"[61] . Consequently, a combination of all possible approaches is needed: internalisation of external costs, pricing measures, technology development, land use changes, strong regulation (e.g. banning fossil fuel cars in certain regions after certain years). Modal split changes are needed to tackle the problem.

61. Schade, 2011, p. 11

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8. APPENDICES

Table 5. Overview of CO_2 reduction measures and its potentials and costs

Name of Package	Measures included	Cost [€/Ton CO_2 if not stated otherwise]	Potential CO_2 reduction (Mt CO_2), EU-27, 2050 if not stated otherwise	Source
Injection Technology	*HCCI (Homogeneous Charge Compression Ignition)*	*933*	*211*	*(Akkermans, et al., 2010), p. 178*
Drive and Transmission	*Continuous variable transmission*	*14,427*	*50*	*(Akkermans, et al., 2010), p. 225*
	Direct-Shift Gearbox	*> 1,000*		*McKinsey, 2007*
	Reduction engine friction	*<20*		*McKinsey, 2007*
		70 €/vehicle	*3% less fuel*	*Mock, P., 2010*
Heat/Cooling Management	*Latent-heat storage, exhaust heat recuperation, intercooling, dual cooling circuits, cooling fluid shutdown system*	*1,022*	*122*	*(Akkermans, et al., 2010) , p. 186*
	Heat cooling management	*<20*		*McKinsey, 2007*
	Dual cooling circuits, exhaust heat recuperation	*170 €€/vehicle*	*3% less fuel*	*Mock, P., 2010*
Engine Control System	*Variable compression ratio (depending on load situation), cylinder deactivation, start-stop system, variable valve timing, fuel quality sensor*	*3,335*	*112*	*(Akkermans, et al., 2010) , p. 194*
Electrical System - Energy Supply	*Solar panels on vehicle roofs, energy efficient alternators, intelligent battery sensors*	*2,956*	*178*	*(Akkermans, et al., 2010) , p. 182*
Electrical System - Energy Demand	*LED lights, electric power steering (steering assistance only in case of steering activities), electric vacuum pumps, intelligent fuel pumps*		*64*	*(Akkermans, et al., 2010) , p. 212*
Lightweight Construction	*Utilization of advanced lightweight design and materials, elimination of unnecessary convenience features, smaller capacity fuel tanks to avoid additional weight*	*7,644*	*152*	*(Akkermans, et al., 2010) , p. 190*
	Not specified	*2-10 €/kg weight reduction*	*0.3 l/km and 100 kg weight reduction*	*Mock, P., 2010*

Name of Package	Measures included	Cost [€/Ton CO_2 if not stated otherwise]	Potential CO_2 reduction (Mt CO_2), EU-27, 2050 if not stated otherwise	Source
Aerodynamics/ Resistance	Improved aerodynamics, reduced engine friction losses, low resistance tyres, tyre-pressure monitoring system, low viscosity lubricants	1,059	83	(Akkermans, et al., 2010) , p. 202
	Low resistance tyres	30 €€/set of	2% less fuel	Mock, P., 2010
	Improved aerodynamics	75 €/vehicle	1.5% less fuel	Mock, P., 2010, p. 30
Hybrid Vehicles	Substitution of conventional by hybrid cars (mild and full)	5,928	159	(Akkermans, et al., 2010) , p. 198
Hydrogen Fuel Cell Vehicles	Replacement of fossil fuel cars by hydrogen fuel cell vehicles according to the ADAM 2 Degree Scenario projections		70	(Akkermans, et al., 2010), p. 218
Battery Electric Vehicles	Substitution of internal combustion engines by electric engines (complete substitution by 2050)	5,542	689	(Akkermans, et al., 2010) , p. 209
CNG/LPG	Substitution of gasoline and diesel by CNG cars	4,525	75	(Akkermans, et al., 2010) , p. 206
Biofuels	Ethanol as substitute for gasoline	130-320		McKinsey, 2007
	Hydrogenated vegetable oil as substitute for diesel	190-240		
Land Use policy	Measures which alter the form of urban areas and promote greater density of activity with a view to reducing travel distance between activities.		21	(Akkermans, et al., 2010) , p. 255
Urban traffic control systems	Urban traffic control systems (signal setting)			(Akkermans, et al., 2010) , p. 251
National road user charging	7 eurocent / km on average		248	(Akkermans, et al., 2010), p. 247
Urban cordon charges	4 € peak, 2 € off-peak		13	(Akkermans, et al., 2010), p. 245
Urban distance based charging	7 eurocent / km		64	(Akkermans, et al., 2010), p. 446
Feebate	Tax-subsidy, depending on CO_2 emissions		49	(Akkermans, et al., 2010) , p. 326

Name of Package	Measures included	Cost [€/Ton CO_2 if not stated otherwise]	Potential CO_2 reduction (Mt CO_2), EU-27, 2050 if not stated otherwise	Source
Fuel duty, CO_2-tax & ETS	*Pricing instruments targeting operational cost of use of transport equipment (via differentiated excise fuel tax, CO_2 tax or ETS)*		*182*	*(Akkermans, et al., 2010) , p. 330*
Parking	*Halving public parking supply*		*16*	*(Akkermans, et al., 2010) , p. 260*
	Doubling public parking charges		*11*	*(Akkermans, et al., 2010) , p. 259*
	Parking cash out scheme (the employer offers the employee some form of cash incentive to forgo their parking)			*(Akkermans, et al., 2010) , p. 266*
	Levy on private non-residential parking spaces (including workplace parking space)			*(Akkermans, et al., 2010) , p. 265*
Car labelling	*Mandatory car labelling*	*0*	*-*	*(Akkermans, et al., 2010), p. 304*
Fuel consumption monitoring/ benchmarking	*Policy measures for companies, fleet owners and private vehicle owners, technological measures such as the use of fuel economy devices in vehicles.*	*very cost-efficient*	*1,321*	*(Akkermans, et al., 2010) , p. 299*
Eco driving	*Schooling, media campaigns, incentives, etc. for eco-efficient driving, technological measures e. g.: gearshift indicators and pedal feedback*	*low*	*132*	*(Akkermans, et al., 2010) , p. 299*
Eco Driving	*Gear shift indicator, fuel consumption display, tyre pressure monitoring system, optimising usage of air conditioner*	*-30*		*McKinsey, 2007*
Optimized vehicle utilization	*Trip sharing, vehicle sharing, route planning, etc. Measures can be identified on various levels: ITS, company policies, personal behaviour*		*67*	*(Akkermans, et al., 2010), p. 311*
Vehicle maintenance	*Vehicle maintenance: use of proper engine lubricants, tire inflation, engine tuning, air filter, etc. This can be combined with mandatory vehicle inspections.*		*59*	*(Akkermans, et al., 2010) , p. 307*
Speed enforcement current limits	*A variety of possible measures which enforce current speed limits either through use of standard measures such as signing and speed cameras or through use of Intelligent Speed Adaptation (ISA).*		*21*	*(Akkermans, et al., 2010) , p. 286*
Speed limit reduction	*(70mph down to 60mph)*		*42*	*(Akkermans, et al., 2010) , p. 287*
Modal changes	*Modal shifts can be obtained in various ways: legislations prohibiting some forms of road transport, taxation and pricing policies, etc.*	*Depends on measure*	*-*	*(Akkermans, et al., 2010) , p. 316*
Public transport fare reduction	*Halving urban bus/train/metro fares In urban areas*		*21*	*(Akkermans, et al., 2010) , p. 270*

Name of Package	Measures included	Cost [€/Ton CO_2 if not stated otherwise]	Potential CO_2 reduction (Mt CO_2), EU-27, 2050 if not stated otherwise	Source
Bus frequency	*50% increase in Bus/train/metro frequency in urban areas*			*(Akkermans, et al., 2010), p. 270*
Walking and cycling – basic	*Measures encouraging walking and cycling – some infrastructure provision, but mainly soft measures*	*low*	*64*	*(Akkermans, et al., 2010) , p. 277*
Walking and cycling – visionary (p. 278)	*Visionary approach oriented towards European best practice examples (infrastructure provision, cultural change as well as measures to encourage)*	*low*	*214*	*(Akkermans, et al., 2010) , p. 278*
Smarter choices (p. 282)	*'Soft' measures: personalised journey planning, car clubs, travel plans, public transport information and marketing, cycling and walking promotion and travel awareness campaigns.*	*low*	*96*	*(Akkermans, et al., 2010) , p. 282*

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