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A tool for calculating external costs associated with transportation of goods

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Abstract

This report presents a tool for calculating external costs for freight transportation. The calculations are made for different alternatives for transporting goods between two places. Each alternative comprise a number of routes. The user defines the routes and the tool calculates emissions and external costs. The external cost categories that are included are air pollution, climate change, congestion, noise, accidents, up & downstream, soil & water and nature. The values for external costs are taken from the literature. The report also describes the results of the calculations using the tool for a number of case studies.

1. Introduction

There is a large focus on the environmental and other impacts of transportation of goods. Lately, the main focus is on the emission of the green-house gas carbon dioxide (CO_2) where significant efforts are taken globally to reduce these emissions. Green-house gases have an impact on the earth's climate, resulting in increased desertification, raised sea levels, serious harm to agriculture and other destructive environmental and health-related side-effects[1].The rationale for these efforts are sometimes presented as that it will be much more cumbersome to deal with the effects of global warming in the future than what it is to achieve a reduction in the use of fossil fuels now or in the near future. To explain these differences to policy makers it is powerful to examine the costs associated with measures to reduce the emissions now and to compare with potential future external costs associated with the damages caused by global warming in the future. This approach is taken for example in the Stern Report[2] published in 2006 which gives a list of potential impacts from floods to drought and disparition of species.

Although it is sometimes hard to keep several environmental risks topical simultaneously, one should not forget that there are a number of issues with our present transportation systems other than CO_2. The emission of toxic substances from combustion engines constitutes major health risks and also causes large detrimental effects on the environment. The primary emissions of greatest concern are particulate matter (PM), nitrogen oxides (NO_X), sulphur dioxide (SO_2), carbon monoxide (CO) and volatile organic compounds (VOC). PM is believed to be the main cause of health risks associated with traffic and the European Commission has estimated that the present particle concentration causes an average loss of life time of several months[3]. NO_X causes health risks and contributes to acidification and over-fertilization. SO_2 is a major contributor to the acidification of land and water but also contributes to damage of buildings and constructions and to particle formation. VOC comprises a number of toxic substances and will, in combination with NO_X, lead to the formation of the secondary pollutant ozone (O_3) which in turn has effects both on health and on plants. The emissions of all these pollutants can be associated with a cost for, e.g., premature deaths, hospital treatment, lower harvests of crops, damaged ecosystems, decomposition of buildings etc. On the other hand, there are also typically costs associated with measures to reduce these emissions (more expensive fuels, abatement equipment etc) which would increase the price for transporting goods if they were to be realized.

Other consequences of goods transportation are, e.g., noise, congestion, accidents and land use. The costs for these can be calculated with different methods. These methods may be based on stated preferences involving studies including questionnaires asking respondents for their willingness to pay such as in the case of contingent valuation and choice experiment methods. Other methods are based on revealed preferences that are often based on consumers' or producers' behaviour or actions such as:

- the hedonic price method which is used to estimate the value of environmental effects on properties such as the effect of noise or air pollution on house prices;
- the production function method which is used to estimate the value of the environmental effects on production such as the effect of ground-level ozone on the production of wheat or timber.

In the case of health effects other methods can be used to estimate the impact of externalities. These methods may be HALY, DALY or QALY. The HALY is a Health Adjusted Life Year, a generic term that includes the two most popular measures, the QALY or Quality Adjusted Life

Year and the DALY or Disability Adjusted Life Year. The QALY is simpler. A value of quality of life is assigned from 0 (dead) to 1 (perfect health). The DALY is different in that the reference states are 0 for perfect health and 1 for dead, and it is estimated for particular diseases, instead of as a health state. Further, other valuations of health effects are based on the value of statistical life or (VSL) or the value of lost years (VOLY).

The transportation of goods is of course enormously beneficial for our society but as mentioned there are associated external costs. A highly topical and relevant question is who will cover these costs. Further, it is interesting to evaluate to what extent these costs are paid by the customer having its goods transported. Obviously a large proportion of the costs are paid by others. These costs are usually denoted "external costs" or "externalities" as opposed to internal costs, such as fuel, salaries for drivers, vehicle repair, road toll etc, which are paid by the transport provider and thus ultimately by their customers. In many cases it is difficult to establish exactly what part of the costs that are external respectively internal. For example, congestion costs are paid by everyone getting caught in traffic through loss of productive time while waiting. However, these costs also strike the road carriers through delays and extra costs for wages etc. Accident costs are usually taken primarily by society but may also partly be covered by insurance fees. When it comes to air pollution, these costs are normally paid by society in general but also by farmers and owners of constructions that are affected.

As mentioned, there are different principles for calculating the values of external costs [4]. The main method is to look at the impact on society of the disturbance occurring due to a specific activity. As an example the impact from noise could be health risks and loss of value for properties located close to noisy roads. Another method is to look at costs for avoiding the disturbance. In the example of noise this could be new types of less noisy tyres or noise barriers in the form of fences. In an optimised situation policy measures are in place so that the marginal values of the two types of costs, impact and mitigation, are equal. In this situation technical and other measures to avoid the disturbances are at the right level and further technical measures would be too costly compared with the impacts that they would mitigate. An example where the technical development has lead us close to this situation is for the reduction of some pollutants from cars. Here, very effective exhaust converters are at hand and further improvements are very costly per amount of pollutant that is converted. The external costs for the technical measures themselves should also be considered in this reasoning.

From a company perspective these external costs are of interest for many reasons: They are important if the company wants to evaluate future costs of transportation. Then it is of interest to be able to estimate the external costs (or "actual" costs) for the transportations and the risk (or chance) that these costs will be internalized through taxation, tolls etc. In this context, one generally considers marginal costs rather than average costs.

The objective of the present study is to develop a tool for the calculation of external costs of goods transportation. The tool contains explicit emission calculations and estimations of external costs from these calculations. External costs included are noise, congestion, accidents, up and down stream, soil, water and nature. These are calculated using values for external costs in Euro per tonne-km of transported goods. Most of the values for the external costs are taken from Maibach et al. (2007)[5]. A long list of trucks, ships, airplanes and railways are included in the tool. The tool is mainly thought to be used for calculations where different transport alternatives are compared, e.g. if truck or rail is to be chosen for a specific transport. This information can be used to make decisions on choice of transport mode but also as information for customers. It can also be used to assess future costs for transport services, under the assumption that the external costs are internalised at some point. Further, the tool may be used for obtaining basic information on the impact of transportation for strategic decisions. This can apply e.g. to the location of a facility.

In this report the tool is described together with its application on a number of cases. The basic theories behind the evaluation of values for different external costs are presented in an earlier report [6] but Section 2 contains a specific description of the externalities relevant for goods transportation. A discussion of the risks for internalisation of the external costs is presented in the report by Wolf et al. (2009)[7].

2. External costs in the context of goods transportation

The transport of freight, ranging from raw materials to finished goods, is essential to economic activity and to the quality of life. Well-organised freight transport also contributes to sustainable and energy-efficient operations. Figure 1 below shows the transportation growth of goods and passengers (and GDP) in EU 25 since 1995. As shown, the growth rate is highest for goods and there is a strong connection to GDP.

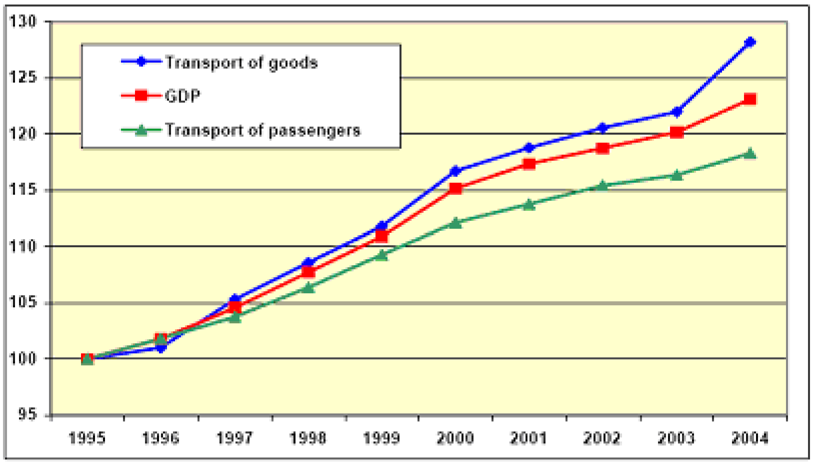


Figure 1. Evolution of transport demand and GDP, EU 25 (1995=100) [8]

The goods transportation growth is predicted to be higher until 2020. The goods transportation is expected to grow in general by 50% and more specifically road, rail, sea and inland waterways will distribute grow as: 55%, 13%, 59% and 28%, respectively within the EU 25 . For aviation demand its growth is estimated to be 108% until 2020.[9]

External costs from the transport sector are estimated in different ways. Whilst externalities existence is conditioned by a polluter and a contaminated (human, environment) they are also case specific, location specific and specific to the mode of transport in question. However, the most used method today to assess transport externalities as well as their external costs is the impact pathway approach [10] including the following steps:

- -inventories of the disturbance
- -dispersion of the disturbance
- -exposure to humans and ecosystems of the disturbance
- -impact of the exposure on humans and ecosystem
- -damage, i.e., actual types of costs and their values

The damage costs are dependent on several variables such as:

-The damage or the degree of harm implied by the externality including the size of this harm, e.g., number of deaths and/or cases of illness as well as exceedance of certain ecosystem thresholds below which the harm may be assumed to be insignificant.
-The cost of the harm, e.g., medical costs in the case of illness or the cost of remediation in the case of ecosystem such as the cost of liming related to acidification.

This method thus considers the impact of the disturbance and calculates the costs from that. Other means to estimate the external costs are:

- The willingness to pay to reduce or to avoid the externality as discussed above.
- The avoidance or mitigation cost to prevent the negative harms. The definition of avoidance cost is not straightforward. At the consumer level this cost is related to the costs devoted to prevent from negative externalities such as expenditure on air cleaners by those receiving the pollutant. At the polluter level these costs are sometimes related to abatement costs to reduce the externalities.

The external costs do in general depend on a number of parameter such as location and time. However, depending on lack of resources, it is sometimes not possible to estimate specific (to location and mode) external costs, and therefore the most used method to adapt estimation is the so called benefit transfer method. Using this method implies adapting for example external costs estimated for a certain region to another one.

The categories of external costs associated with the transportation of goods considered in this report are: congestion, accidents, noise, air pollution, climate change, up and downstream processes, nature and landscape, soil and water pollution. Here follows a brief description of how these different categories usually are treated for the different modes of goods transportation- road, rail, air and sea.

External costs for air pollution are usually obtained following the impact pathway method outlined above.[11]. The most important substances normally considered are NO_X, PM, VOC, CO and the secondary pollutant O_3. Typically health risks are most important but also impact on ecosystems (acidification, eutrophication etc) and by corrosion are important. However, there are a number of other substances that may be considered in the future. The treatment is similar for the different transport modes although the location of the emission is of course very different which must be considered. For electrical carriers (mostly rail) one usually considers the emissions occurring during the production of electricity. Regarding mitigation costs there are a number of technical measures such as exhaust converters, cleaner fuels, electrical vehicles etc to consider.

For noise there are annoyance and health related costs. The different modes have rather different noise characteristics. Air and sea noise is usually confined to areas around airports and harbours. Rail noise can be a severe disturbance, especially at night with sudden noise in an otherwise silent surrounding. Road traffic is of course a major noise source in most urban areas.

The emission of CO_2 and other climate gases is of course a major concern and traffic is a large and growing source.

The Stern review's[2] central result is that the cost of climate change under the IPCC A2 business-as-usual scenario of green-house gas emissions is equivalent to 5% reduction of global GDP, "now and forever". This method calculates the reduction in utility due to climate change over the assessment period, 200 years for Stern, and expresses this damage as the percent reduction in consumption in a constant growth economy that would diminish utility by the same amount.

The main conclusions of the Stern report are that one percent of global gross domestic product (GDP) *per annum* is required to be invested in order to avoid the worst effects of climate change, and that failure to do so could risk global GDP being up to twenty percent lower than it otherwise might be. Stern's report suggests that climate change threatens to be the greatest and widest-ranging market failure ever seen, and it provides prescriptions including environmental taxes to minimize the economic and social disruptions. He states, "our actions over the coming few decades could create risks of major disruption to economic and social activity, later in this century and in the next, on a scale similar to those associated with the great wars and the economic depression of the first half of the 20th century." In June 2008 Stern increased the estimate to 2% of GDP to account for faster than expected climate change.

Stern's estimated cost of 5% GDP accounts for market impacts in agriculture, energy, transportation and forestry sectors under a "baseline climate" scenario predicting a 4.3°C rise in global mean temperature by 2100. The temperature rise and costs are mean values from 1000 iterations of the PAGE2002 Monte Carlo economic model. Stern suggests the likely cost of climate change is much higher than 5% once we account for non-market impacts on health and the environment, and the possibility of greater climate sensitivity.

The central issue in economic debate over the Stern review concerned the discounting procedure used to evaluate flows of costs and benefits occurring in the future. There are four main reasons commonly proposed for placing a lower value on consumption occurring in the future rather than in the present:

- future consumption should be discounted simply because it takes place in the future and people generally prefer the present to the future (inherent discounting)
- consumption levels will be higher in the future, so the marginal utility of additional consumption will be lower
- future consumption levels are uncertain
- improved technology of the future will make it easier to address global warming concerns

Debate over the Stern review initially focused on the first of these points. Previous studies by William Nordhaus and others had adopted inherent discount rates of up to 3 per cent, implying that (other things being equal) an environmental cost or benefit occurring 25 years in the future is worth about half as much as the same benefit today. Stern argued that inherent discounting is ethically inappropriate. His view was endorsed by a number of economists including Brad DeLong who, echoing Frank P. Ramsey and Tjalling Koopmans, wrote "My view--which I admit may well be wrong--of this knotty problem is that we are impatient in the sense of valuing the present and near-future much more than we value the distant future, but that we shouldn't do so." and criticised by others including Hal Varian and Richard Tol who argue that in a democratic society, the preferences of the majority of people are more important than the arguments of philosophers. The difference between Stern's estimates and those of Nordhaus can largely (though not entirely) be explained by the difference in approach regarding inherent discounting.

Estimating damage cost is often based on integrated assessment models such as the PAGE model used to estimate the Stern results. These models are used to estimate the social costs of carbon using different discounting rates (Brännlund 2009)[12]. Below is a meta-analysis of different results from different studies published in Tol (2008)[13]

Table 1 Descriptive statistics to estimate damage costs (€/kg CO_2)* based on results from different studies in Tol (2008)

Year of publication (?)	<1996	1996-2001	>2001
Mean	0.027	0.020	0.018
Median	0.004	0.009	0.005
Standard deviation	0.070	0.028	0.052
Min-max	0.00 – 0.32	0.0 – 0.15	-0.001 – 0.458
Number of observations	21	73	117

*) 1€ = 10 SEK

As shown in Table 1 the median results range between 0.004 €/kg and 0.009 €/kg. These results are almost in the same range as in the Impact pathway approach.

Up and downstream costs are indirect costs for the production of vehicles, fuels, infrastructure etc. A large fraction is usually associated with energy conversion.

Congestion costs stem from different sources. There is a travel time increase that can be evaluated. This is normally the largest part of external congestion costs although there are also costs for increased wear and fuel consumption, for loss in reliability and for scarcity of slots (railway and air freight). There is also a positive externality (the Mohring effect) where congestion leads to better service, e.g., more frequently running public transportation.

Soil and Water external costs can be calculated as repair costs or from impact on human health and crops from, e.g., heavy metals.

Costs on nature and landscape can be calculated as repair costs or by methods to quantify habitat loss and loss of biodiversity.

Abiotic resources are derived from the non-living world (e.g., land, water, and air). Mineral and power resources can be abiotic natural resources. Abiotic resources in this study are about non renewable resources such as fossil fuels.

3. The tool

3.1 General description

The tool (TrExTool) is developed as an Excel spread sheet containing VBA macros for calculations. The technical use is described in a special manual. The tool gives the emissions and the external costs for a specific *alternative* of goods transportation. Each alternative may comprise a number of *routes*, i.e., parts of the way the goods may be taken by different types of vehicles or modes. The user must give a set of data for routes, cargo and vehicles (see Table 2).

Table 2. Input variables for the external cost calculations

1. Distance of the routes
2. Means of transport from list
3. Mass of goods
4. Volume of goods
5. Fraction of distance in urban areas
6. Load factor
7. Alternative routes
8. Cost model

How to choose vehicles etc and how to determine routes are discussed further below. The mass of the freight being transported needs to be known. In the present version of the tool there is no routine for calculating mass from, e.g., number of TEU or number of lane-meters. The volume of the goods is only relevant for goods with low density. In these cases the cargo area of for example a ship may be filled spatially before the maximum mass load is achieved. The tool calculates the number of vehicles/vessels needed from the given values of mass and volume. For most cases the calculations will be based on mass and if the volume is not known one may use the same number of m^3 as tonnes as input values.

The external costs typically vary with the site. For example, there are more severe effects when particles are emitted in populated areas than when emitted far out on an ocean. Therefore external costs given in the literature are often presented with different values for urban and non-urban locations. Sometimes this is divided up further. In principle this division should be made very detailed since the actual external costs will vary strongly between different locations. On the other hand it will be more difficult to calculate the external costs the more detailed the division is. In the tool we have chosen to have two levels, urban and non-urban. Thus the user is required to indicate the fraction of each distance that is within urban areas. If this is not known, default values may be used (see the manual for the tool).

The load factor is of course essential for correct calculations. It is to be given by the user and should be calculated according to the methods described by NTM[14]. The load factor should be related to the goods that are transported. Thus, a half-filled container that is transported with a half-filled train should be given a load factor of 25%. The load factor is thus not equivalent to the utilisation level. For example, a milk truck that run empty from the dairy to a farm and full on the way back will have an utilisation level of 100% while the load factor is 50%. The load factor is a way to allocate all emissions and other externalities to the goods that is transported. Default values can be used within TrExTool if the load factor is not known.

There are number of different values for external costs to be found in the literature. As mentioned, the tool mainly contains data from Maibach et al[5]. However, in the tool there is a possibility to choose between costs for "mitigation" and "impact". This applies only to the emissions and is most important for the green-house gases. The mitigation cost is then the cost for avoiding the emission, for example the cost associated with using biofuels instead of fossil fuels, or the cost for abatement equipment to reduce the emissions of particles. The impact cost is the cost for society for dealing with the effects. For example the costs associated with flooding, draughts, lower crops etc that are expected due to the increased global warming, or hospital costs etc for people becoming ill due to particle emissions. There is also the possibility to define your own cost model in the tool. In general there is a certain spread between values in the literature and this indicates the level of certainty. In the tool there are three levels of values (max, mid, min) for each parameter and calculations are made for all three levels in order to illustrate the uncertainty in the method. As more convergence is obtained regarding external costs values this spread should decrease.

The output from the calculations in the tool comprises the emissions of a number of exhaust components, fuel consumption and external costs for emissions and the other parameters (Table 3).

Table 3. Output from TrExTool

1.	Emission of CO_2 and other climate gases (as CO_2 equivalents)
2.	Emission of NO_X, SO_2, CO, HC, PM
3.	Fuel consumption
4.	External costs for the emissions above
5.	External costs for noise, congestion, accidents, up- and downstream, nature, soil and water
6.	Results for each route
7.	Comparison for alternative means of transportation
8.	Low medium and high values are given for the external costs

The emission of CO_2 is given as fossil CO_2, i.e., a reduction is used of the tailpipe emissions when biofuels are used. For electric motors (presently only for trains) the CO_2 emission is given from a broader view, i.e., electricity production is included, according to the NTM method. For other fuels the CO_2 emissions during production at refineries etc. are included in the category up and down stream. This is in some sense illogical but makes the calculations simpler. The emissions of N_2O and CH_4 are recalculated to CO_2 equivalents and included in the climate gas emission.

The results for external costs for the different alternatives are compared in diagrams and the different categories of externalities are compared in pie charts. There is normally a large spread between the low, medium and high values. This spread originate in the varying values found in the literature for external costs, especially regarding the emission of green-house gases and the use of limited natural resources (i.e., fossil fuel).

3.2 Vehicles and distances

The tool is intended for calculations of external cost and is not primarily a tool for calculating emissions. However, the latter is needed within the tool and is included following the principles of

NTM[14]. The number of vessel and vehicle types is limited basically to what is found in the NTM documents and for road, in the Artemis model[19]. In addition, a number of vessels/vehicles have been added since they were needed in the different case studies.

For trucks the data is obtained from the Artemis model. In the model the emissions are given as mass of emissions per travelled distance for a set of vehicles (Euro class, size, age etc) and type of road. The tool supplies fuel consumption and emission factors for different truck sizes and different European emission standards (Euro classes). Data for an average Swedish truck are also given. The average data are based on the traffic activity of heavy duty trucks of different sizes and emission standards in Sweden 2007. Data for average trucks in some other countries are also included in the tool. That data are assumptions based on the emission standards applied in each country. Emission standards in China, Brazil and Australia are based on the European standards. In Sweden Euro 4 standards for heavy trucks were introduced 2005. In Australia emission standards based on the Euro 4 standards were introduced 07/08, in Brazil, 2006-2009 and in China they will be introduced in 2010. Therefore the average emission factors in Sweden year 2004 are used for Australia and Brazil and the Swedish average for 2002 is used for China. For the US the average emission factors are also based on the Swedish average from 2004. Emission factors and fuel consumption are given for both rural driving (mostly highway driving) and urban driving. A complete list of the trucks and their emission factors are given in the Manual.

The ships are basically from the NTM document[14]. A number of ships have been added for the case studies. There is also the possibility in a few cases to choose a ship that fulfil the Clean Shipping Criteria[15]. These criteria results in a somewhat lower emissions of NO_X, PM and SO_2. The properties regarding emissions for different ships vary strongly and for cases where data on a specific ship used is known it may be a good idea to construct your own ship in the data base. A specific issue for ferries that combine goods and passenger transportation is how to allocate the emissions and other externalities between those. In the present list in the tool there is a ferry where the externalities are divided equally between passengers and goods and a train-ferry where 80% of the externalities are allocated to the goods. A list of the included ships is given in the manual.

Trains are either propelled by diesel engines or electrical engines. A number of trains are included in the list following the NTM document, which in turn use data from Ecotransit[16]. A special issue with trains is that the emissions from electricity production are calculated as emissions from the train. This means that the type of electricity production is essential for the emissions and in the tool. Different emission factors for a number of countries are used, reflecting the type of electricity mix at hand in the respective countries. The train gross weight is a commonly used term and is defined as the total weight pulled by the locomotive, i.e., the weight of both cargo and wagons. However, the maximum cargo capacity is often of more of interest. In the tool the maximum cargo capacity is set to 72 % of the trains' gross weight[16]. There is a list of the trains included in the tool in the manual.

For airplanes there are a number of types included in the tool. The data for the emissions come from a NTM document. The distance a specific plane can travel without refuelling depend on the cargo load. The tool takes this into account and adds a landing for refuelling if the distance chosen is too long for the amount of cargo.

The distances for each route in the cases are to be given by the user. A number of internet sites where calculations of distances can be made are given in the manual. For air freight the NTM document recommends the addition of between 50 and 125 km for each landing/take off in order to account for the in-flight. In the tool all distances are to be given in km.

3.3 Emission calculations

The emissions for each route is calculated from the tabled emission factor for the chosen vehicle, the distance given, the amount of goods and the load factor given. In the tool we use emission factors expressed as mass of emissions per travelled distance and load (in g/tonne-km) and these are obtained by dividing with the maximum load for each vehicle. In each case, the actual emission factor in per tonne-km is thus obtained by dividing with the load factor.

A special situation is at hand for airplanes. Here the emission factors are divided into one for each landing and take-off (LTO), given in kg emission per tonne freight and one for the remaining flight given in g per tonne-km.

Calculating the load factor is often not straightforward and one must not forget to include empty vehicles when present. For example, if a truck drives a certain distance with full load and empty on the way back, the average load factor is 50%. However, for trucks and planes the fuel consumption and the emissions depend on the load so the load factor should be given so that the load is as accurate as possible.

In the case the density of the cargo is low; a vehicle/vessel may be filled through volume restrictions rather than mass restriction. The tool automatically switches between mass and volume based calculations depending on the cargo volume and cargo mass given by the user. The density where a switch from mass to volume based calculation depends on the transport mode and is given in Table 4.

Table 4. The density above which the emission calculation in the tool is based on mass and below on volume

Mode	Density (tonne/m^3)
Truck	1/3
Ship	1
Plane	1/6
Train	2/3

The emission of green-house gases is given in CO_2-equivalents. This is calculated as the sum of the CO_2-emission and 310 times the N_2O-emission and 21 times the CH_4-emission. These factors are taken from the IPCC WG1 AR4 Report[17]. The impact on global warming from the emission of particles and from the formation of secondary pollutants is not included in the model.

3.4 External costs calculations

The theory behind external costs is discussed in a previous report[6] and further discussed in Section 2 of this report. Here we will present the calculations used in the tool. The calculations for external costs for the emissions and the use of fossil fuel is done by multiplying the emission for a route with the value for the external costs in € per mass unit. The tool contains these external costs divided in urban and non-urban values. The fraction of the emission that is multiplied with the respective value is obtained through the urban factor given by the user of the tool for each route. Further, as outlined in Section 2 and in the previous report, there are different views on how to calculate the external costs. For the emissions we have included two lists of external costs. One is called "impact" and is based on calculations of the costs that arise after the emission have taken place due to e. g. hospital treatments, lost of working years, or lower crops. The other list is called "mitigation" and is based on the costs for avoiding the emission, e.g., for abatement equipment or more expensive fuels. For CO_2 emissions the difference between these types of cost is significant since the future costs for dealing with global warming are expected to be high while it is relatively less expensive to avoid these emissions now. The values for the external costs used are taken mainly from Maibach et al.[5] and Steen[18].

Within the EPS[18] system there are costs included for the usage of limited resources (abiotic resources). In the case of goods transportation this applies to the use of fossil fuel. Thus, the external costs for using fossil fuel contain two large items; the emission of CO_2 and the abiotic resources. The latter is included in the effect external cost list but not in the mitigation list. It is calculated in EPS from the costs of replacing fossil fuel with bio fuel. This is the same value as used in the mitigation cost list as a means to avoid CO_2 emissions.

The costs for noise, congestion, up- and down stream, nature, soil and water and accidents are calculated based on a list with values in € per distance travelled for a vehicle/vessel. These values are obtained from Maibach et al[5]. For airplanes these costs typically occur during take-off and landing. The tool thus calculates a cost using values in € per flight for each external cost category.

As mentioned there are three different values (min, med, max) for each item in order to account for the spread in values found in the literature. This spreas reflects uncertainties in the determination of the values and variability dues to, e. g., different locations. However, the spread also sometimes reflects different approaches and basic ideas on how to obtain the costs regarding, e .g., what types of costs that should be counted as external. The specific references for the numbers used are given in the manual.

4. Case studies

4.1 General

A number of different cases have been chosen together with the companies involved in the project. The idea is to evaluate and test the tool with real cases where there is an actual interest in the results. All the cases are thus built up with data from real transport situations. This approach highlights all the difficulties and uncertainties involved in obtaining input data for the calculations. In the remaining of this section, nine different cases are presented together with the results of the calculations. The suitability of this approach for the different cases is discussed in Section 5. In a few cases the obtained external costs are compared with the actual internal costs for the transportation. An overview of the different case studies is given in Table 5.

Table 5. An overview of the case studies

	Customer	**Objective**
Case 1	Chemicals producer	Compare truck and train
Case 2	Chemicals producer	Use return transports
Case 3	Chemicals producer	Compare rail and trucks including ferries
Case 4	Automotive	Compare rail, road, ferry
Case 5	Automotive	Compare two suppliers
Case 6	Manufacturing	Compare sea and air
Case 7	Logistics company	Reduce reloading
Case 8	Logistics company	Increase load factor
Case 9	Logistics company	Compare air and sea

4.2 Case 1

Case study 1 concerns a chemical company and transportation of bulk chemicals in containers from a factory to the customers. The chemicals are produced at a site in Norway and the three different customers are all located in the middle of Sweden, off the Baltic Sea coast. Two alternatives are at hand for these transports. At present trucks are loaded with the chemicals and the goods is taken directly to the customers. These trucks are in this alternative filled and used only for these chemicals. After the delivery the trucks go empty to either the site in Norway or to other sites. The other alternative is to use railways. The goods are then transported within Norway and Sweden on railways using diesel powered engines to a reloading station and from there with trucks to the customers. The containers are then returned empty to the factory.

The data for the two alternatives are summarised below.

<u>Case 1</u>
General data: 64 tonnes of chemicals per week
Alternative 1, trucks:

Route 1: Euro4 trucks, 25 m long, load factor 67%, distances 1710 km, 1700 km, 1560 km (30%, 40%, 30% of the goods for the respective distance), urban factor 7%.

Alternative 2, train:

Route 1: Diesel engines w MK3 fuel, load factor 35%, 1122 km, urban factor 7%;

Route 2: Euro 4 trucks, 25m, load factor 50%, 58 km (average), urban factor 10%

The vehicle/train data are obtained from the customer, the road distances are obtained from Google Earth and the rail distances from Ecotransit. The load factor and the urban factor are obtained from the customer and include the transportation of empty containers.

Using the impact costs model the results of the calculation (se Figure 2) show that the external costs are similar for the two alternatives. This is since diesel engines are used for the train alternative. For the medium values in the cost model, the external costs for one week (64 tonnes) is 976€ and 999€ for alternatives 1 and 2, respectively. There is as expected a significant spread between the minimum and maximum cost alternatives. If we look more closely at the costs (for the medium case) about one third for both cases is for green-house gases. In Figure 3 pie charts are shown for the separation in different cost categories for the two cases. Costs for congestions and accident are relatively speaking higher for alternative 1 while emissions of toxic gases are more costly for alternative 2. The case illustrates the relatively low environmental performance of diesel engines for trains.

The high costs for congestion and accident for the trucks are disputable since the transportation in this case study takes place mainly on the very scarcely populated countryside of northern Sweden while the cost estimates for the medium case can be regarded as an EU value, although for rural areas.

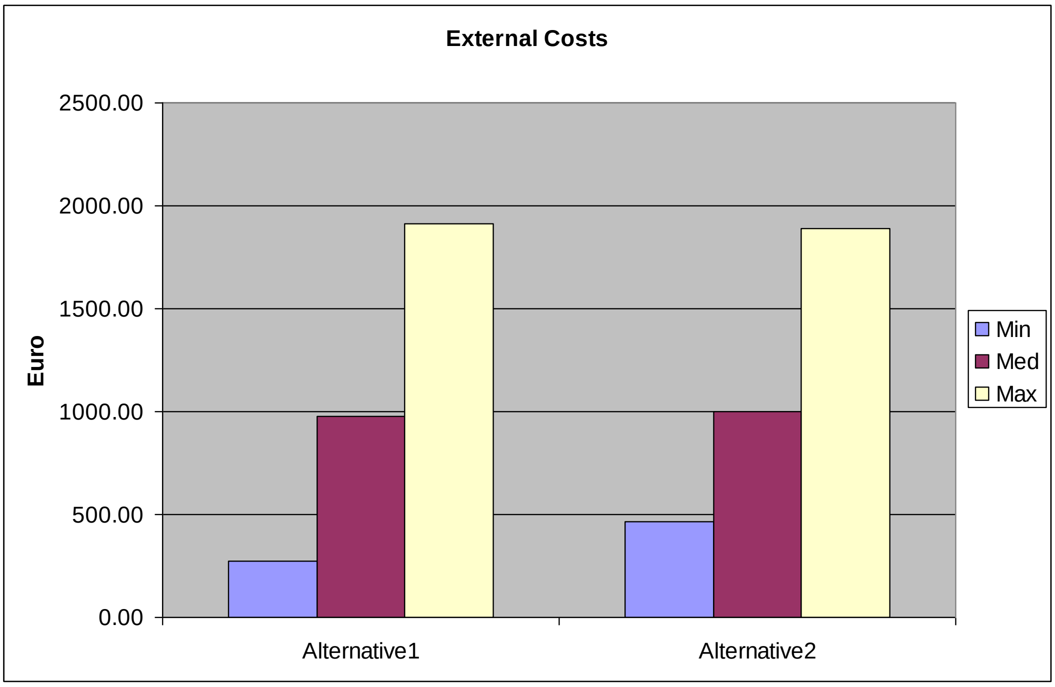


Figure 2. Overview of the external costs for the two alternatives in case 1.

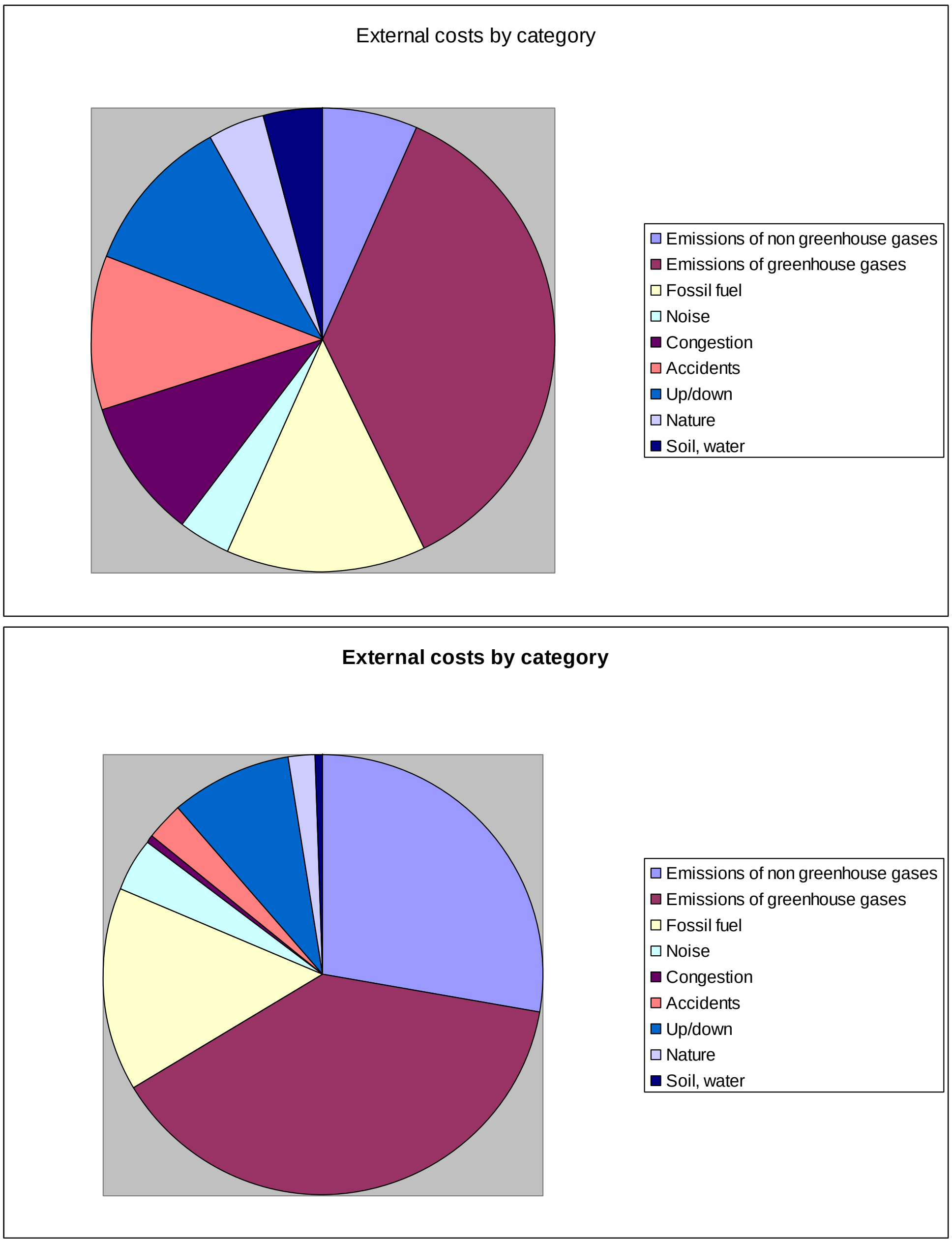


Figure 3. External costs by categories for alternatives 1 and 2 in case 1

4.3 Case 2

Case study 2 also concerns transport of chemicals, in this case from a plant to a harbour for further transportation by ship. The idea with the project that lies behind this case is to take use of a ship that transports another chemical. In practise this leads to shorter total distance for this transport and also that some train routes are replaced by truck routes. The input data for the calculations are:

General data: 1000 tonnes of chemicals.
Alternative 1, new alternative:

Route 1: Road Sweden Truck Euro 3 25m, distance 278 km, load factor 90%, 20% in urban area;
Route 2: Train Swedish electricity mix distance 270 km, load factor 70%, 10% in urban area;

Alternative 2, old alternative:

Route 1: Road Sweden Truck Euro 3 19m, distance 2 km, load factor 100%, 20% in urban area;
Route 2: Train Swedish electricity mix distance 1083 lm, load factor 70%, 10% in urban area;
Route 1: Road Sweden Truck Euro 3 25m, distance 114 km, load factor 70%, 20% in urban area;

Figure 4 shows the external costs calculated in the tool for the two cases. The costs are very similar for the two alternatives. The longer distance in alternative 2 does not show through since there is a large fraction of electric trains. Table 6 shows how the different routes contribute in the two alternatives. It can be seen that the truck routes cause high external costs when related to distance.

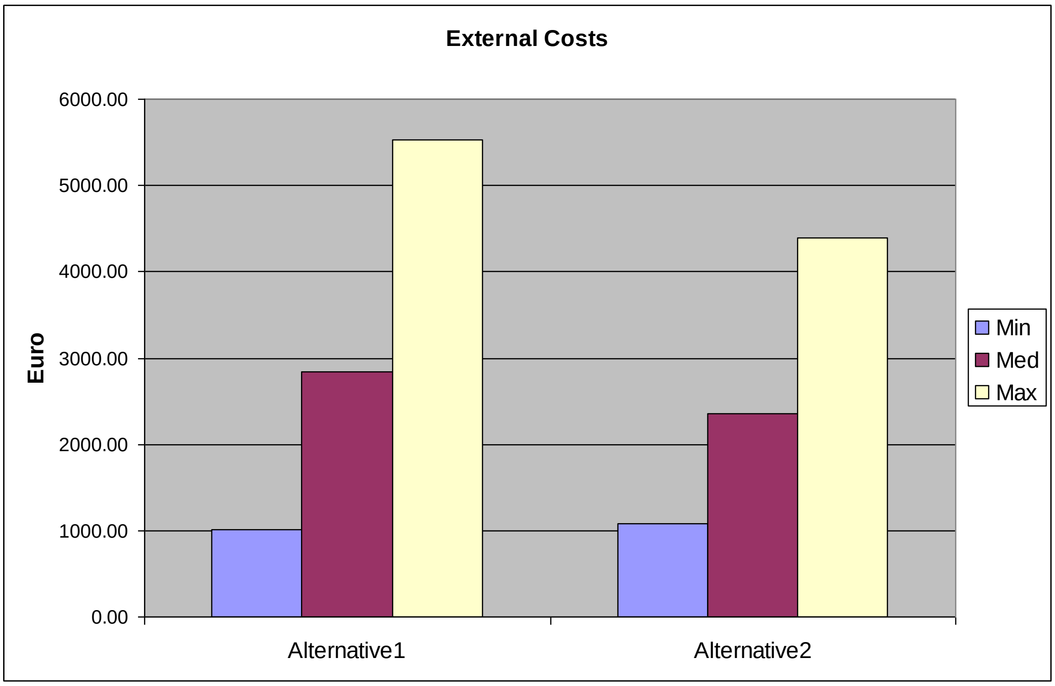


Figure 4. Results for case 2.

Table 6. External costs (med) for the alternatives in case 2 divided into routes.

	Alternative 1		Alternative 2	
	€	€/tonne-km *10^{-3}	€	€/tonne-km*10^{-3}
Route 1	2580	9.28	24	11.8
Route 2	260	0.96	1045	0.96
Route 3			1286	11.3

4.4 Case 3

Case study 3 concerns transportation of a chemical from a site in Bohus in western Sweden to customers in Åbo, Finland. The two alternatives are to use rail or trucks. Rail wagons must be sent empty from Åbo to Helsingborg for cleaning and then, also empty, back to Bohus. Trucks can be used for other purposes from Åbo, i.e., no transportation of empty tanks is necessary.

<u>Case 3</u>
General data: 1250 tonnes of chemicals annually.
Alternative 1, rail:

Route 1: Rail Sweden Swedish electricity mix (Bohus - Stockholm, Stockholm - Helsingborg, Helsingborg - Bohus) distance 1276 km, load factor 70%, 5% in urban area;
Route 2: Train ferry (Stockholm-Åbo-Stockholm), data for M/S Sea Wind (0.5% S in fuel, medium speed engine 7350 kW, 80% of emissions allocated to trains, 1270 lm, 2.2 tonne/lm), distance one way 318 km, load factor 70%, 5% in urban area;
Route 3: Finnish train, 20 km, Nordic electricity mix, and 50% urban, load factor 70%.

Alternative 2, truck:

Route 1: Sweden road (Bohus-Stockholm), distance 488 km, load factor 100%, 5% in urban area, Euro 4 truck, 19m;
Route 2: Ferry (Stockholm-Åbo), Passenger RoRo, distance 318 km, load factor 70%, 50% of emissions allocated to cargo;
Route 3: Truck Finland, distance 10 km, load factor 100%, 50% in urban area, Euro 4 truck, 19m.

The difference between the two alternatives is small. There are larger external costs from the ferries in the Rail alternative, due to the distance being twice as long. This is compensated by the larger external costs for the trucks in the road alternative. Figure 5 shows the resulting external costs.

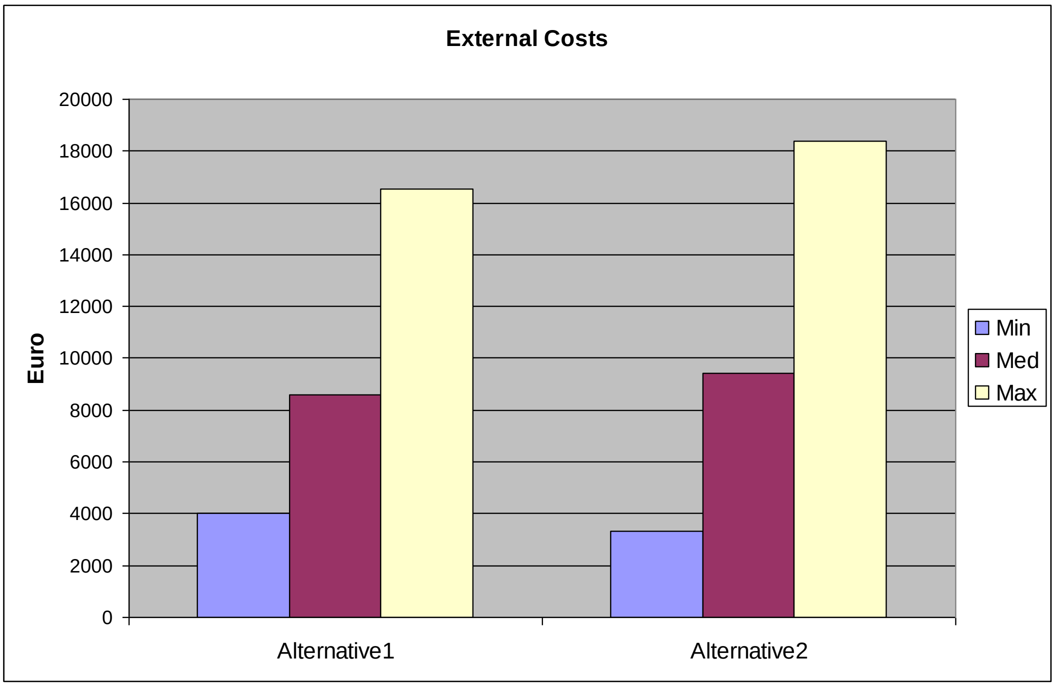


Figure 5. External costs for the alternatives in case 3.

4.5 Case 4

This case deals with the transportation of parts for the automotive industry from Hannover, Germany to an assembly factory in Göteborg, Sweden. Relatively large amounts of goods are to be transported (9900 tonnes per year) so there is the possibility to use a special train which runs five times a week all year. Three alternatives are at hand: 1) to use trucks that takes the Stena RoRo ferry between Travemünde and Göteborg and roads the remaining distances in Germany and Sweden, 2) to use a special train that runs on electricity and takes the parts from site to site, and 3) to use trucks that drive on roads the whole distance via bridges over Öresund and the Belts. The goods are packed in containers with a filling of about 85% of the maximum capacity. The load factor for the trucks is thus 85%. For the train about 80% of the capacity is used. This gives a load factor of about 70%. For the ferry a capacity usage of 70% is assumed giving a load factor for the goods of 60%. The urban factors are all assumptions. The input data for this case is summarised below:

<u>Case 4</u>
General data: 22 tonnes of vehicle parts per shipment, 5 shipments each way per week, 45 weeks per year giving 9900 tonnes per year.
Alternative 1, trucks and ferry:
Route 1: Road (Germany and Sweden), distance 240 km, load factor 85%, 20% in urban area, Euro 3 truck, 19m;
Route 2: Ferry (Kiel-Göteborg), Passenger RoRo, distance 498 km, load factor 60%, 5% in urban area;
Alternative 2, rail:
Route 1: Rail Germany, German electricity mix (Hannover - Flensburg) distance 350 km, load factor 70%, 10% in urban area;
Route 2: Rail Denmark. Danish electricity mix (Flensburg - Copenhagen), distance 350 km, load factor 70%, 10% in urban area;
Route 3: Rail Sweden, Swedish electricity mix (Copenhagen-Göteborg), distance 374 km, load factor 70%, 10% in urban area.
Alternative 3, truck:
Route 1: Road, distance 773 km, load factor 85%, 10% in urban area, Euro 3 truck, 19m.

Further, the impact cost model is used.

An overview of the resulting external costs from the calculations can be seen in Figure 6.

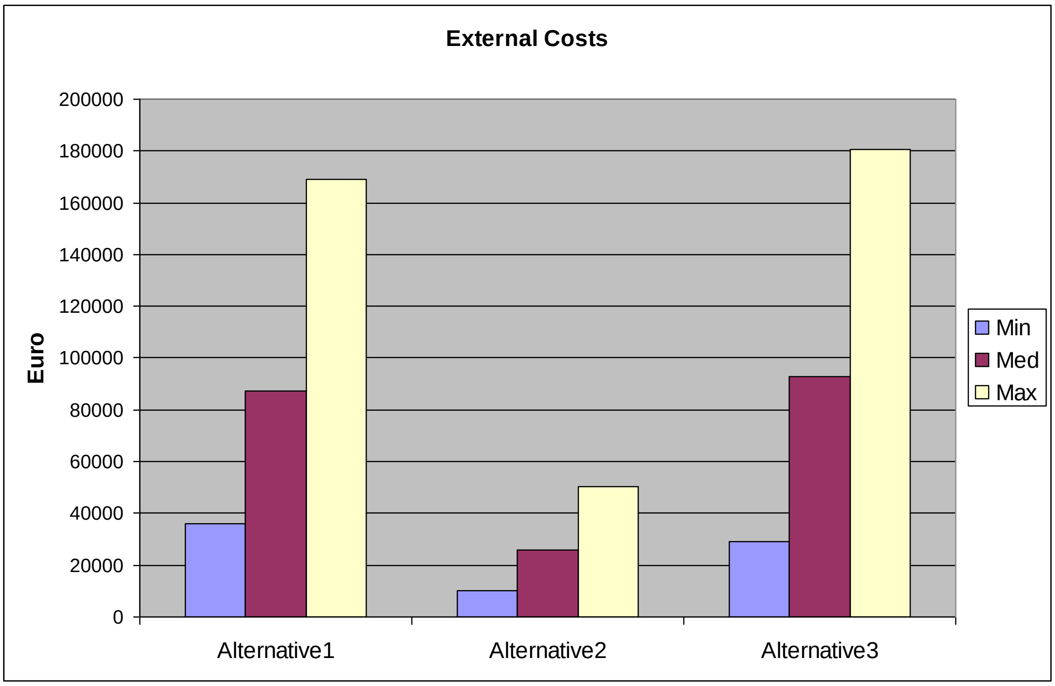


Figure 6. A comparison of the total external costs for the three alternatives for case 4

As expected there is a large spread between the min, med and max costs within each alternative. When comparing the alternatives it is clear that the train alternative gives much lower external costs than the other two alternatives. The external costs for the truck and the truck/ferry alternatives are very similar. Table 7 shows how the external costs divide into the different categories for the three alternatives. When comparing the truck and the truck/ferry alternatives one can note that the ferry causes high costs for the emissions of NO_X, PM and SO_2 (emission of non-greenhouse gases) while the truck alternative gives higher external costs for all the non-emission items. The main advantage with the train is the low costs for emissions but also the external costs for, e.g., accidents and congestion, are significantly lower compared with the other alternatives. Further, when using electric trains there is the possibility to choose the electricity production method. If the electricity mix for all the three routes with trains were to be totally from renewable sources the external cost would decrease from about 26 000 € per year to around 9 000 € per year.

Table 7. External costs for the three alternatives in case 4

Med costs (Euro/year)			
	Alternative1	Alternative2	Alternative3
Emissions of non greenhouse gases	26899	994	10788
Emissions of greenhouse gases	32155	10997	30788
Fossil fuel	12918	4485	11941
Noise	2305	3171	4024
Congestion	3333	0	8830
Accidents	4085	1688	10042
Up/down	3489	2890	9453
Nature	860	1424	3116
Soil, water	1129	211	3636
Sum	87173	25860	92618

For the ferry alternative a way to reduce the external costs is to use emission cleaning and low sulphur fuel. This could decrease the external cost for this alternative by about 25%. For the truck alternative the easiest way to reduce the cost is to choose newer trucks. This can reduce the external costs by about 10%, if a Euro5 truck is chosen instead of the Euro 3 truck.

For this case the tool gives useful information can that be considered when making the decision on which alternative to choose. Clearly the train alternative has large benefits, especially if a renewable source for electricity is chosen.

For this case the mitigation cost model was also used. These costs differ, in the tool, from the impact costs only for emissions and the use of fossil fuel. The resulting costs can be found in Figure 7. The same general picture is seen when comparing the alternatives. The train alternative looks even better with this cost model. The lower costs used for CO_2 in the mitigation cost model is, for the ferry, compensated by a higher cost for NO_X. This is probably not a fair picture since the mitigation (abatement) cost for NO_X comes from estimations for a truck and in reality it is less expensive to convert NO_X on a ship.

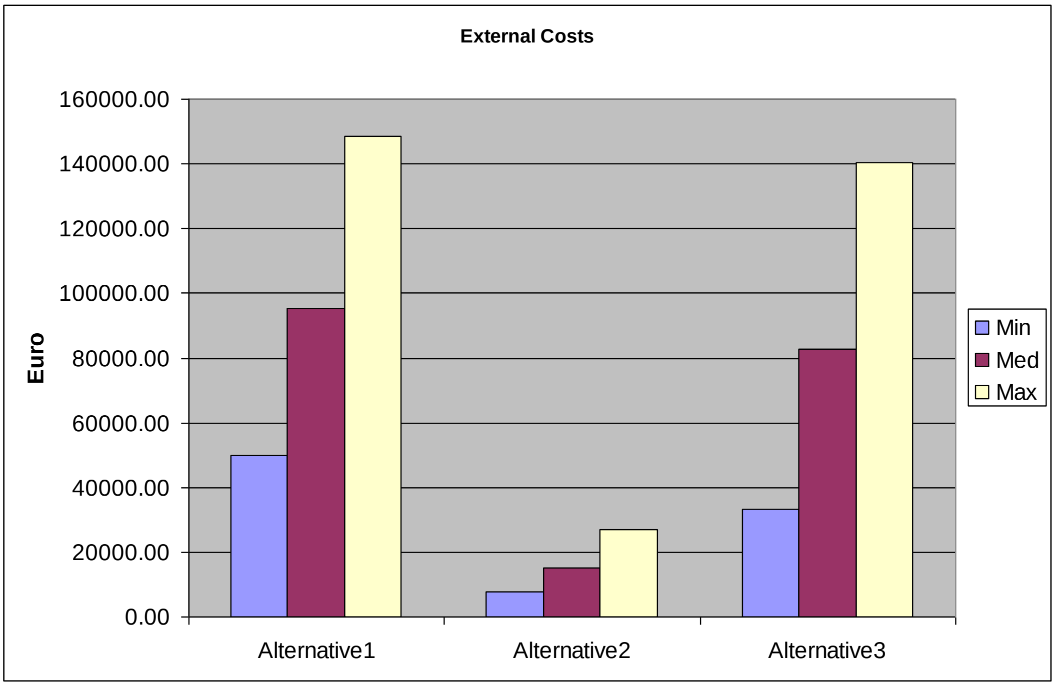


Figure 7. External costs for case 4 when using the mitigation cost model.

4.6 Case 5

This case is somewhat different from the others. It deals with a possible change of supplier for a part that is used in the automotive industry. There are two possible suppliers of this specific part; one in Finland and one in Brazil. The part is to be transported to an assembling factory in Sweden and the direct cost for the part is somewhat lower for the Brazil supplier also when including the direct costs for transportation. The question is if the expected increasing external costs for the longer transportation of the parts eats up this price advantage. The description of the case from the customer contained no details about type of vehicles and ships. Further, distances were obtained from internet tools during the calculations. For the Brazil case it was assumed that some of the parts may have to be flown to Sweden. This fraction was assumed to be 2% and this is calculated as a third alternative. The data used can be summarised as:

<u>Case 5</u>

Alternative 1, Brazil, 3845 tonnes per year.

Route 1: Road Brazil, distance 133 km, load factor 70%, 20% in urban area, Truck Brazil, 19m;
Route 2: Ship (Paranagua-Göteborg) Large container ship, distance 11105 km, load factor 80%, 5% in urban area;
Route 3: Road Sweden, distance 10 km, Truck Sweden, load factor 70%, 50% in urban area.

Alternative 2, Finland, 3895 tonnes per year:

Route 1: Road Finland, distance 100 km, Truck Sweden, load factor 70%, 30% in urban area;
Route 2: Ship (Helsinki-Stockholm), Feeder boat, distance 439 km, load factor 70%, 5% in urban area;
Route 3: Road Sweden (Stockholm-Sollebrunn), Truck Sweden, distance 454 km, load factor 70%, 5% in urban area;

Route 4: Road Sweden (Sollebrunn-Göteborg), Truck Sweden, distance 68 km, load factor 70%, 20% in urban area.

Alternative 3, Brazil ship/2% with plane:

Route 1: Road Brazil, distance 133 km, load factor 70%, 20% in urban area, Truck Brazil, 19m;
Route 2: Ship (Paranagua-Göteborg) Large container ship, distance 11105 km, load factor 80%, 5% in urban area;
Route 3: Road Sweden, distance 10 km, Truck Sweden, load factor 70%, 50% in urban area.
Route 4: Air (Joinville-Göteborg), 77 tonne, distance 11016 km, Boeing 747-400, load factor 70%, 1% in urban area.

Further, the impact cost model was used.

The overall result can be seen in Figure 8. There are higher external costs for the Brazil case than for the Finland case. One can also see the large impact of shipping 2% of the goods with an aeroplane.

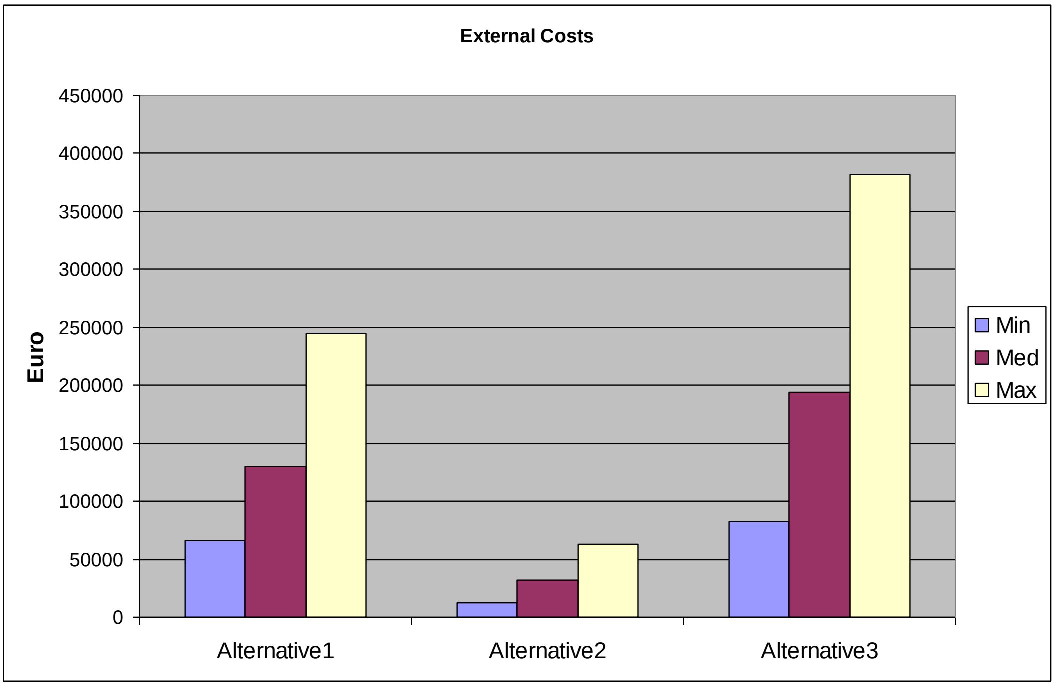
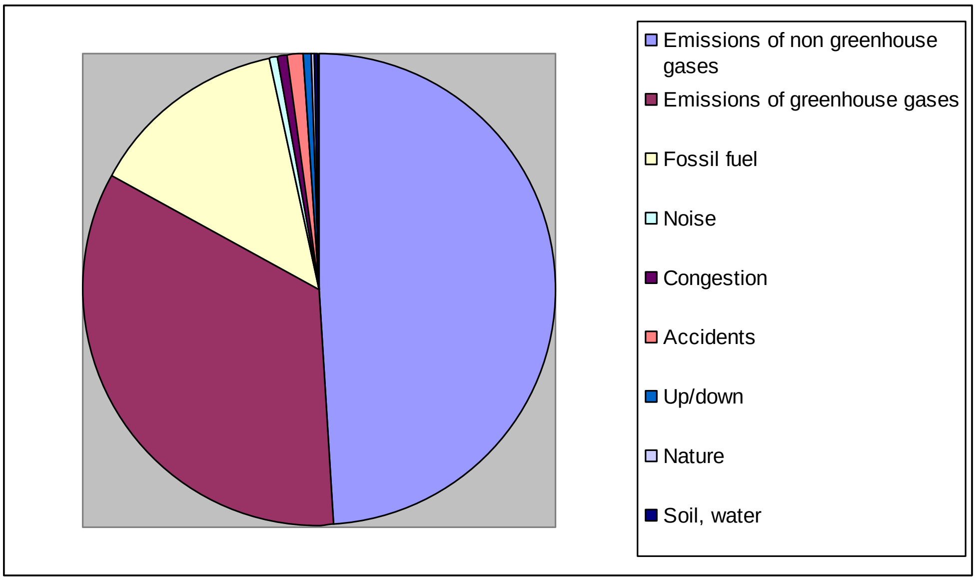
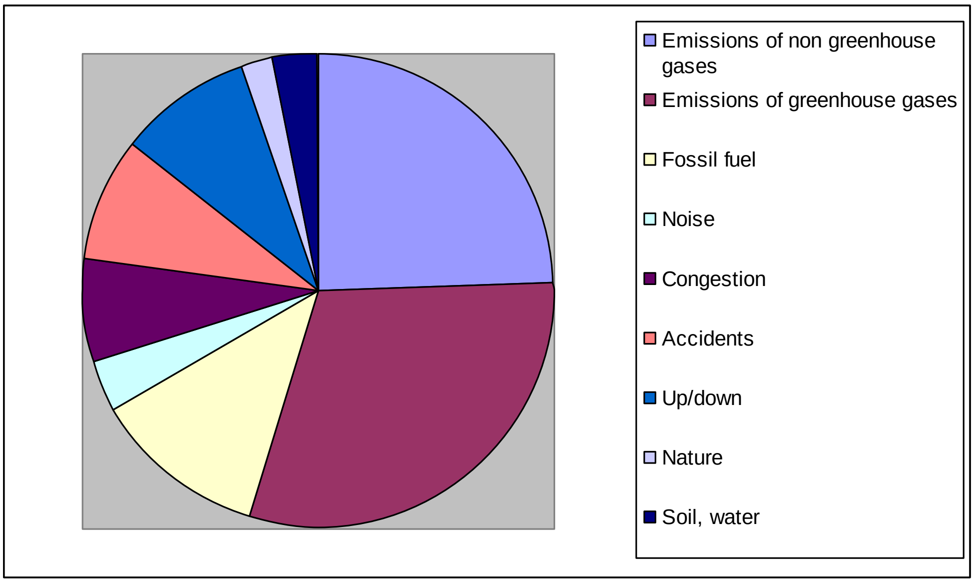


Figure 8. Results for case 5

How the external costs divide into different types can be seen in Figure 9 a-c for the mid-cost calculations. If we look at the Brazil alternative, it is obviously dominated by the emissions of toxic gases and green-house gases, including fuel use. The other items only comprise a few percent. For the Finland case, where there is a large part with trucks, other items such as congestion and accidents are important although the emissions and fuel use dominate also here.


Emissions of non greenhouse gases
Emissions of greenhouse gases
Fossil fuel
Noise
Congestion
Accidents
Up/down
Nature
Soil, water


Emissions of non greenhouse gases
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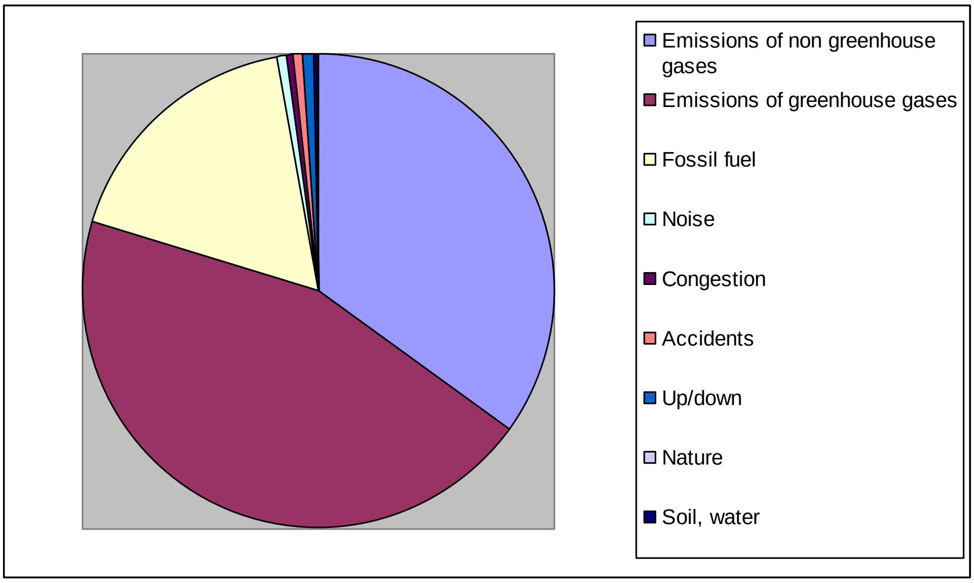


Figure 9 a-c. The division of the external costs for alternatives 1-3 into different categories.

If we consider alternatives 1 and 2 the difference in external costs varies from 54000 (min), via 98000 (med) to 183000 (max) Euro per year. The actual savings made by the company in replacing the supplier in Finland with the one in Brazil is concealed information but are much larger than the increase in external cost due to the longer transportations. Further, the external costs associated with the ship crossing the Atlantic are certainly over-estimated since the cost per tonne-km used are for European waters and will be much lower over the Atlantic where fewer people will be affected by emissions of, e.g., particles.

It is doubtful if the calculated external costs should be compared with the direct costs for the parts paid by the company. For a fair comparison, from a societal point of view, there are a number of other factors to consider such as the impact on local employment, economic growth and environment at the two sites.

4.7 Case 6.

This case looks at an existing transport chain for an industry company where 18 tonnes of a certain part is transported by a chain with a ship for the longest route and 1 tonne is transported via an alternative dominated by air. The transport is from a factory in Shanghai to a factory in Västerås, Sweden. The idea is to assess the impact of the small air transport relative to the large sea transport. The transport chain is illustrated in Figure 10.

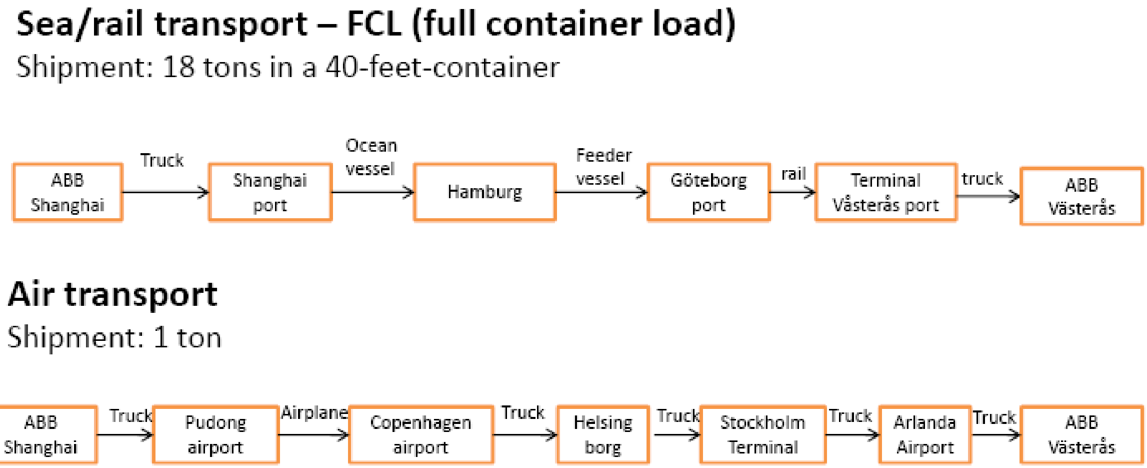


Figure 10. Illustration of the transport chain for case 6

The input data for the external cost calculation can be summarised as:

Case 6

Alternative 1, Ship, 18 tonnes per shipment:

> *Route 1: Truck China, 19m distance 50 km, load factor 70%, 20% in urban area;*
> *Route 2: Ship, large (Shanghai-Hamburg), distance 19961 km, load factor 70%, 5% in urban area;*
> *Route 3: Feeder ship (Hamburg-Göteborg) distance 604 km, load factor 70%, 5% in urban area;*
> *Route 4: Truck, Euro3 25 m (Göteborg-terminal Västerås) distance 373 km, load factor 70%, 20% in urban area;*
> *Route 5: Truck Euro 3 25 m (terminal - factory), distance 10 km, load factor 70%, 20% in urban area.*

Alternative 2, Air, 1 tonne per shipment:

> *Route 1: Truck China, 19m distance 50 km, load factor 70%, 20% in urban area;*
> *Route 2: Airplane, Boeing 747-400 (Shanghai-Copenhagen), distance 8240 km, load factor 70%, 1% in urban area;*
> *Route 3: Truck Euro 3 (Copenhagen--Helsingborg) distance 97 km, load factor 70%, 20% in urban area;*
> *Route 4: Truck, Euro3 25 m (Helsingborg-Stockholm) distance 557 km, load factor 70%, 20% in urban area;*
> *Route 5: Truck Euro 3 (Stockholm-Västerås), distance 107 km, load factor 70%, 20% in urban area.*

The resulting external costs from the calculations are illustrated in Figure 11. The external costs for the airfreight are almost the same as for the shipping although the mass is much lower. This illustrates how the environmental performance of a transport chain can be aggravated if only a fraction is transported by air.

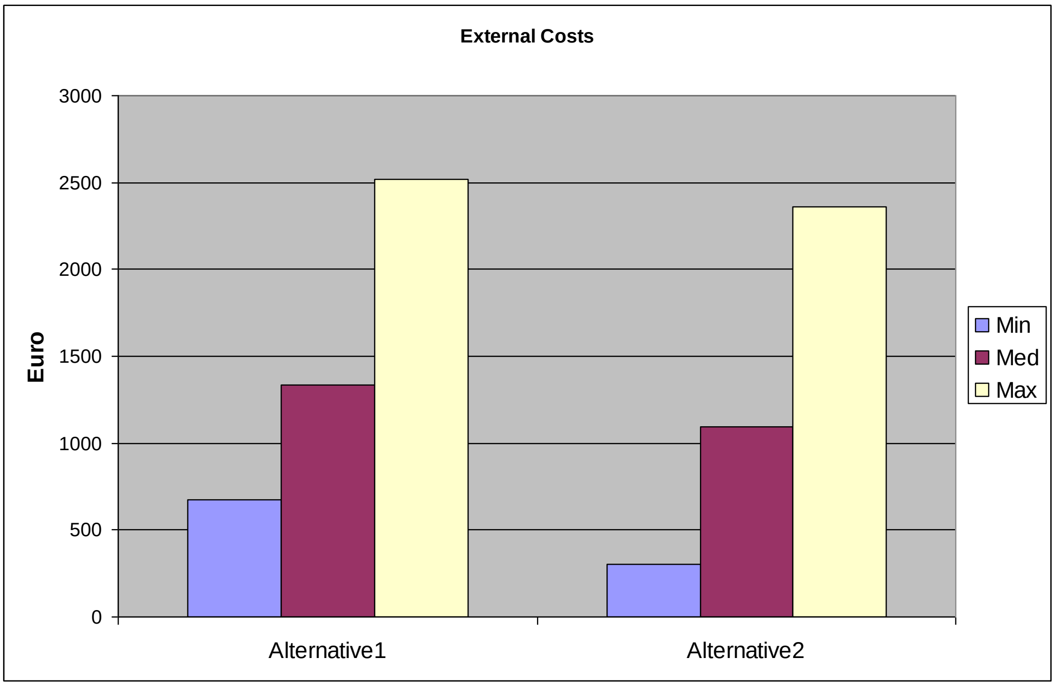
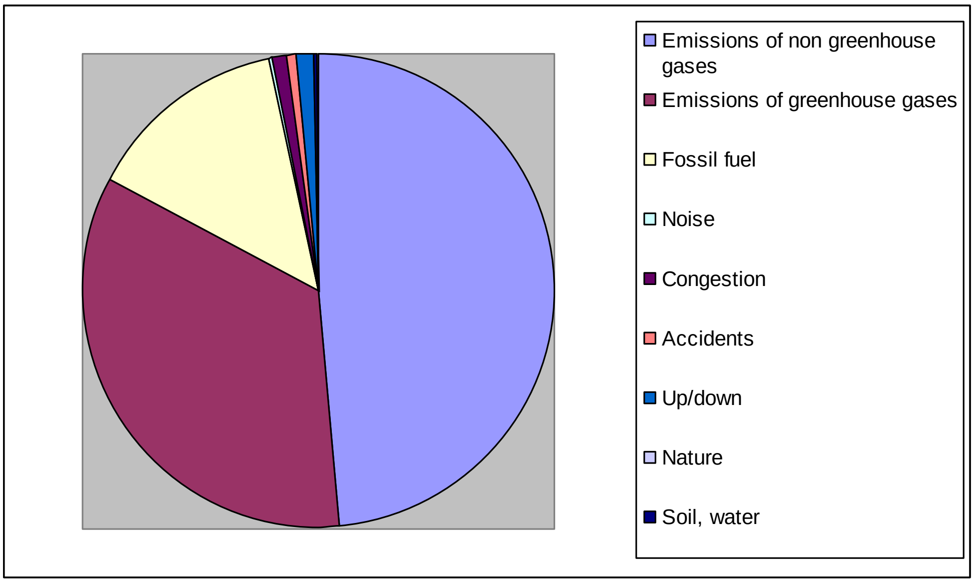


Figure 11. External costs for the two Alternatives in Case 6.

Figure 12 illustrates how the external costs divide into different categories. For the ship alternative almost half of the costs can be attributed to the emissions of non green-house gases such as NO_X, SO_2 and PM. Emission of green-house gases and use of fossil fuel represents also almost half of the external costs while the other categories show small costs for this alternative. This pattern is expected since the alternative is dominated by the ship part. Shipping in general show large emissions of toxic gases while external effects by noise, accidents, congestion etc are expected to be low. The air alternative is totally dominated by the emission of CO_2 and the use of fossil fuel.



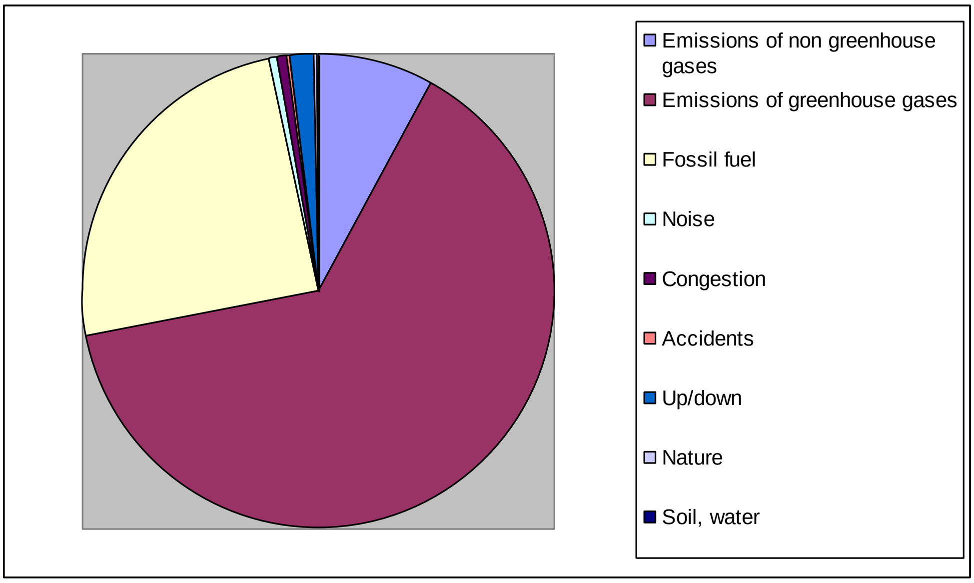


Figure 12 a, b. The division of the external costs for alternatives 1 and 2 into different categories.

4.8 Case 7

This case is for a logistics company and is relatively straight-forward. The company has a Swedish route with trucks going from Borås to Stockholm since a number of years. In an analysis it was observed that there are a large number of customers in Ulricehamn, about 37 km from Borås. Therefore a route was started directly from these customers in Ulricehamn to Stockholm in order to replace the transports that earlier went to the terminal in Borås for reloading prior to the transportation to Stockholm.

The input data for the external cost calculation can be summarised as:

<u>Case 7</u>
General: 15 tonnes and 54 m³ per shipment
Alternative 1, via Borås:

> *Route 1: Ulricehamn-Borås, Truck 40 t, 25m, Euro 3 distance 37 km, load factor 78%, 50% in urban area;*
> *Route 2: Borås-Stockholm, Truck 40 t, 25m, Euro 3 distance 409 km, load factor 78%, 50% in urban area;*

Alternative 2, Air, 1 tonne per shipment:

> *Route 1: Ulricehamn-Stockholm, Truck 40 t, Sweden average, distance 376 km, load factor 78%, 50% in urban area;*

The results are shown in Figure 13 and as can be expected the external costs are lower with the shorter distance in alternative 2. The division on different categories can be found in Table 8.

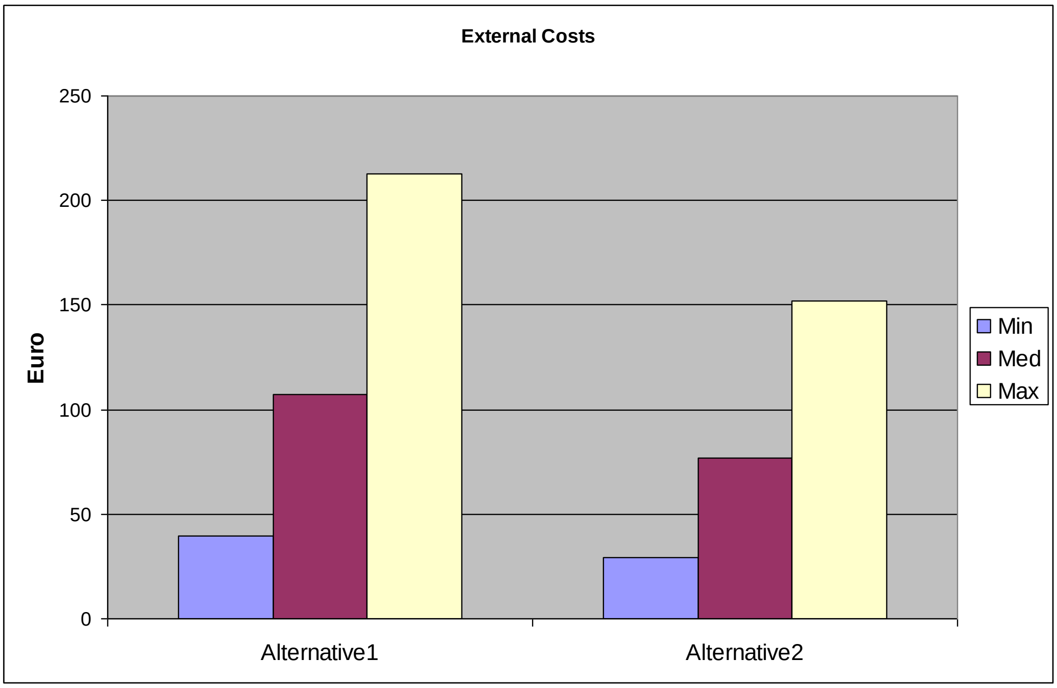


Figure 13. External costs for the alternatives in Case 7.

Table 8. External costs divided into categories.

Med. Cost (Euro/shipment)		
	Alternative1	Alternative2
Emissions of non greenhouse gases	13.00	8.57
Emissions of greenhouse gases	29.36	16.98
Fossil fuel	11.39	6.58
Noise	13.10	11.04
Congestion	12.22	10.30
Accidents	16.73	14.10
Up/down	7.33	6.18
Nature	1.29	1.08
Soil, water	2.70	2.28
Sum	107.11	77.11

If Euro 5 trucks are chosen with otherwise unchanged conditions, the external costs obtained from the total decreases to 95.19 € for alternative 1. There is thus a limited saving since all categories except the emissions of non-greenhouse gases remains the same.

4.9 Case 8

This case is for a project run by a logistics company in trying to increase the load factors of distribution trucks in Stockholm. This lead to somewhat longer distances but much higher load factors.

The input data for the external cost calculation can be summarised as:

Case 8
General: 2 tonnes and 10 m³ for the case
Alternative 1, before the project:
> *Route 1: Outside Stockholm - City centre, Truck 15 t, Euro 3 distance 18 km, load factor 25%, 100% in urban area;*
> *Route 2: Outside Stockholm - City centre, Truck 15 t, Euro 3 distance 18 km, load factor 25%, 100% in urban area;*
> *Route 3: Outside Stockholm - City centre, Truck 15 t, Euro 3 distance 18 km, load factor 25%, 100% in urban area;*
> *Route 4: Outside Stockholm - City centre, Truck 15 t, Euro 3 distance 18 km, load factor 25%, 100% in urban area;*

Alternative 2, after the project:
> *Route 1: Outside Stockholm - City centre, Truck 15 t, Euro 3 distance 20 km, load factor 100%, 100% in urban area;*

The results can be found in Figure 14. The higher load factors obtained in this project have a significant impact on the external costs for society for these transports. In fact they are now about a third of the previous number. The reason is that almost all the different external cost categories go linearly with the number of vehicle-km. An exception is the fuel consumption where a heavily loaded truck has a somewhat higher consumption compared with a lightly loaded truck.

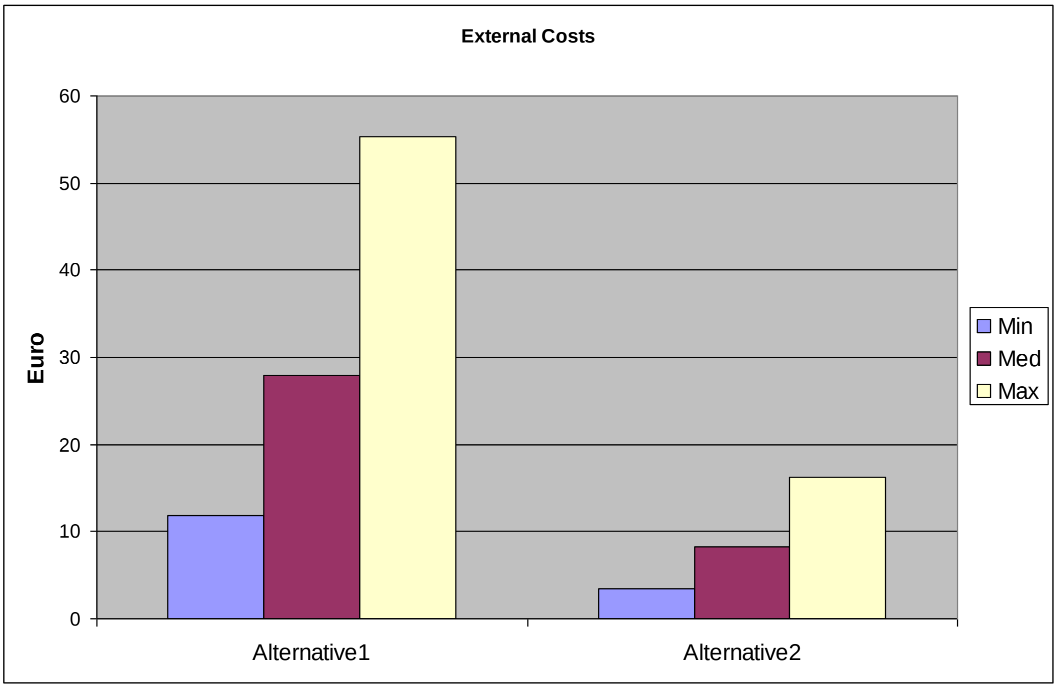


Figure 14. Results for Case 8.

To illustrate the importance of the difference in costs between urban and non-urban areas, calculations were also done with an urban factor of 50% This resulted in a decrease in the total external mid cost from 27.96 € to 19.49 € for alternative 1. This reflects the higher risks associated with emissions of, e.g., particles in densely populated areas, but also higher costs for congestions. Further, the fuel consumption for trucks is higher for urban driving than for rural.

4.10 Case 9

This case is a comparison between air and sea for transportation from Gävle, Sweden to Kuala Lumpur.

The input data for this case is summarised below:

<u>Case 9</u>
General data: 16 tonnes of goods, 57 m³ per shipment
Alternative 1, air:

> *Route 1: Road Sweden, Gävle - Arlanda airport, distance 141 km, load factor 78%, 5% in urban area, Euro 3 truck, 25m;*
> *Route 2: Truck (Arlanda-Frankfurt), Truck Euro 3, 19 m, distance 1486 km, load factor 78%, 1% in urban area;*
> *Route 3: Air, Frankfurt - Kuala Lumpur, Boeing 747-400, distance 9993 km, lad factor 75% urban factor 0%;*
> *Route 4: Road Kuala Lumpur, Truck China av., distance 10 km, load factor 65%, urban factor 20%.*

Alternative 2, ship:

> *Route 1: Road Sweden, Gävle - Göteborg, distance 560 km, load factor 78%, 5% in urban area, Euro 3 truck, 25m;*

Route 2: Ship, Göteborg - Port Kelang, Ship ocean general cargo, distance 15803 km, load factor 80%, 0% in urban area;
Route 3: Road Kuala Lumpur, Truck China av., distance 40 km, load factor 65%, urban factor 5%.

Further, the impact cost model is used.

The results can be found in Figure 15 and Figure 16. .Again we see the large impact of air transportation on the external costs. This case is very similar to Case 6 and the same conclusions can be made.

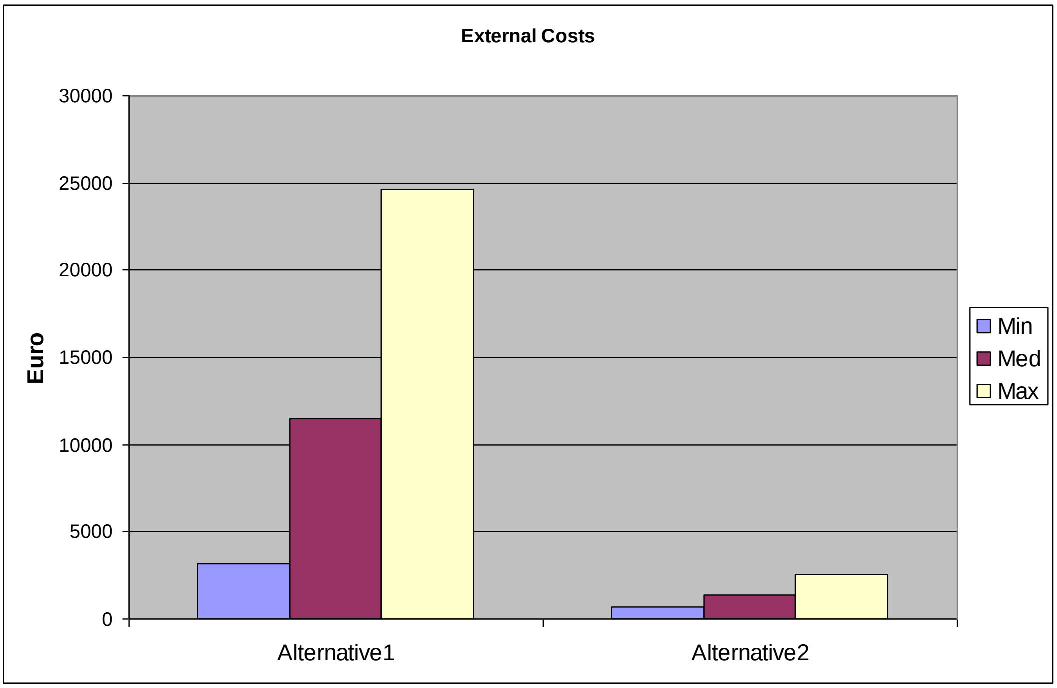
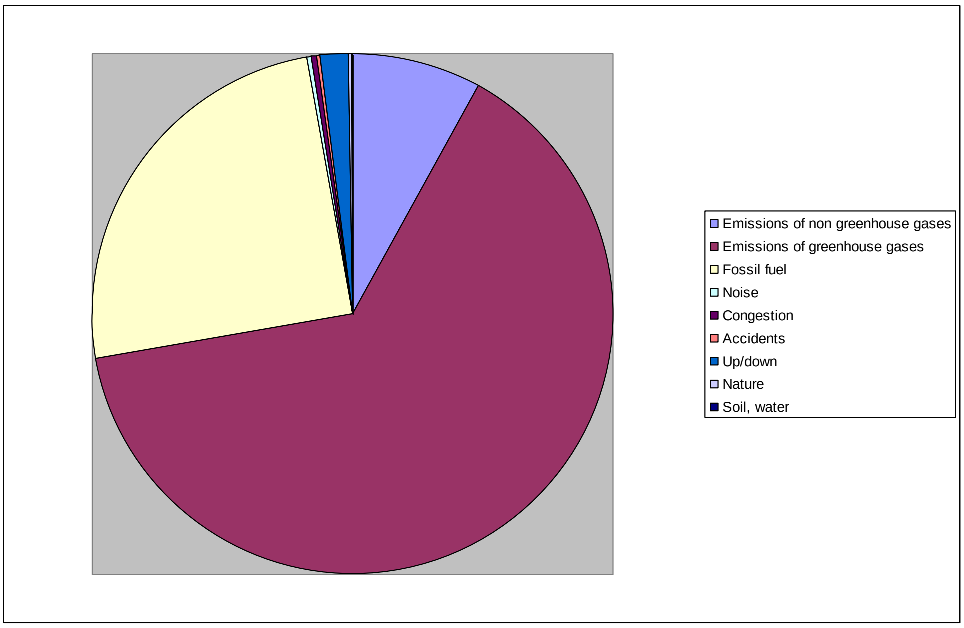


Figure 15. The external costs for the two Alternatives in Case 9.



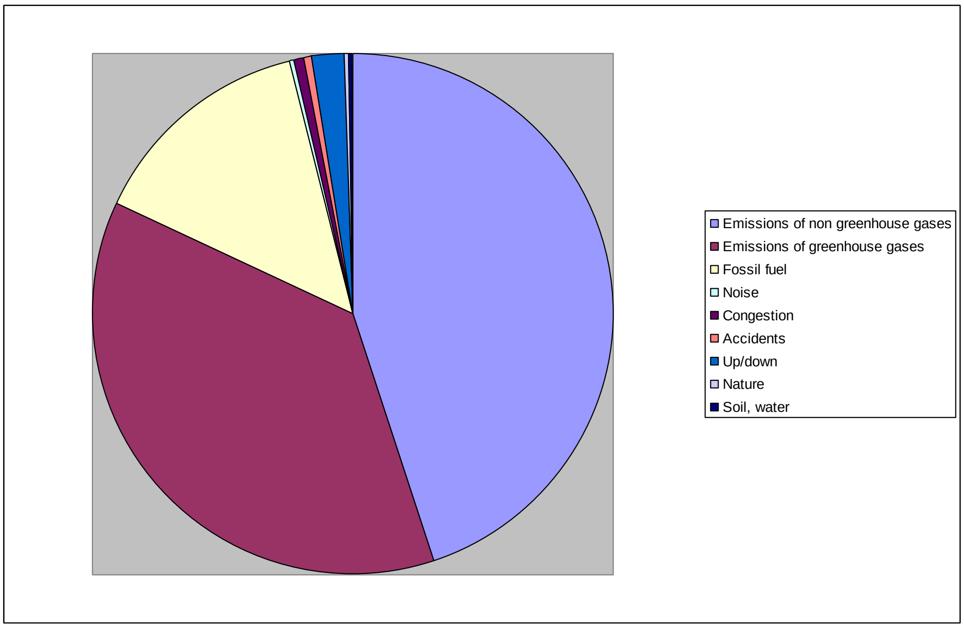


Figure 16. The split of the external costs for Alternatives 1 and 2 for Case 9.

5. Discussion

The tool described in this report can be used for emissions calculations and for calculations of external costs for freight transports. The focus of this discussion is on the external cost part.

An immediate value of the tool is that it serves as an eye-opener. The actual values for the external costs can be compared with the internal costs and the potential for future internalisations can be estimated. The tool is very illustrative when it comes to comparing different alternatives for transporting a specific set of goods. For example, case 4 gives a good picture of the different external costs when using trains or trucks and also illustrates the external cost level of a ferry transport. The tool is also useful in finding out which routes of a specific transport alternative that constitute the main share of external costs. Another use is to study the effects of choosing different vehicles. In case 7, the choice of truck was investigated, and it became clear that a modern truck decreased the external costs by about 10% due to lower emissions. Different types of ships were investigated in case 9 and it is obvious that the ship type has a great influence on the amount of external costs. The tool also gives information about how the external costs divide into different categories. The main issues that are addressed by the tool are thus:

- comparing different alternatives for the transport of specific goods
- identifying the impacts from the different routes within one alternative
- comparing the performance of different vehicles/vessels
- studying the consequences of different models for assessing external cost values
- examining the costs in different external cost categories
- relate external costs to internal costs
- estimate quantified risks for future increases in costs for transportation

The main uncertainty in the results lies in the estimation of external costs in € per tonne-km or € per kg of emission. This uncertainty reflects the spread in values within the current literature on the subject. Especially for green-house gases the span of values is large. Within the tool we use three sets of values (min, mid and max) throughout the calculations and in the presentation of the results. The purpose of this is to illustrate the uncertainty and to remind the user that the specific numbers should be used with care. However, when comparing different alternatives, these uncertainties are less important since then the same principles for calculating the external cost values are used for all alternatives.

When using the tool a number of parameters should be given by the user. Sometimes the type of vehicle used is not known in detail which leads to uncertainties in the results. The fill factor is often even harder to establish. This is a very common problem in emissions calculations and will have a direct reflection in uncertainties in the results. In the calculation of the external costs another often unknown factor, namely the urban fraction, poses a problem. This factor reflects that the costs for emitting toxic substances, noise and congestion costs will be higher in densely populated areas. One way to estimate this uncertainty is to vary the input value and see how the results change. This was done in case 8 where a change from 100% to 50% in the urban factor gave a significant decrease in the calculated external costs.

The tool is meant to be used for general calculations in widespread areas. It should also be relatively simple to use. This leads to that some compromises have to be made. For example, the external costs for emission of particles will vary strongly between sites depending on the population density of a specific location. In the tool we only have values divided into urban and non-urban locations. If detailed information is needed for a specific place, the external costs in € per kg emission should be determined specifically for that location. In principle the tool could be extended with cost tables covering different regions in much more detail. The user would then have to specify the regions in detail. The values used can also give unrealistic results. For example, the tool will calculate significant costs due to congestions in the Swedish northern inland, which is very scarcely populated. In such cases the user should be observant and use the "min" values given by the tool.

With regard to the sensitivity of the results from the tool and the relation to input data, we can divide the calculations into three parts: emission calculations, external costs calculations for emissions and other external costs calculations. In most cases, the emissions (including green-house gases) form by far the largest share of external costs. However, the uncertainty in the emission calculations must be considered as *relatively* low. For road traffic, the emissions are well described in the Artemis model[19]. For sea traffic, the problem is that ships are individuals and if no data for the specific ships are available, the results may be very uncertain. Air and rail traffic are relatively well described, provided that the respective electricity mix (if applicable) is known. Concerning the external costs of the emissions there is a large spread in the uncertainty. The parameter with the lowest degree of agreement is CO2. This is discussed in Section 2, and it is obvious that it has a large impact on the uncertainty. Furthermore, the costs associated with the use of the limited resource "fossil fuel" are treated very differently. Sometimes, the fact that fossil fuel stems from a limited natural resource is not considered at all; and sometimes it is calculated from reasoning about the costs for replacing the fossil fuel with, e.g., bio-fuel. In some studies also costs for security (military expenses etc) used in securing the supply of oil are included, or a cost for the uncertainty in future delivery. The other categories of costs have a smaller impact in most cases and thus their uncertainties have a lower impact on the result. However, the uncertainty of many of the costs is large as illustrated by the spread in values.

To try to quantify the uncertainties we calculated the relative spread in the cost values (the difference between the max and the min values divided by the max value) and the relative importance of the different categories. The former is obtained for each category from the average of the min and max values obtained in the 20 alternatives of the 9 case studies. The latter is obtained as averages for each external cost category from the 20 alternatives of the 9 case studies. The product of these two parameters gives an indication of what uncertainties that are important. The results are given in Table 9. It can be seen from that table that the uncertainty in the emission of CO_2 has the largest influence (34%) followed by the emission of toxic gases and use of abiotic fossil fuel. This way of making the analysis implies no uncertainties in the emissions calculations (they can normally assumed to be relatively small) and, further, would only strengthen the conclusion that the uncertainties in external costs for emissions and fuel consumption are the most important ones.

Table 9. Sensitivity analysis for the cost categories obtained from the results of the 9 case studies. The second column gives the average relative spread in the obtained max and min values for the respective category. The third column gives the average relative influence of each category on the result. The fourth column gives the product of the second and third columns.

Category	Uncertainty (max-min)/max	Relative influence	Weighted uncertainty
Emissions of non greenhouse gases	0.52	0.309	0.160
Emissions of greenhouse gases	0.89	0.382	0.339
Fossil fuel	0.90	0.150	0.135
Noise	0.63	0.023	0.015
Congestion	0.98	0.030	0.029
Accidents	1.26	0.039	0.049
Up/down	0.62	0.041	0.026
Nature	1.00	0.013	0.013
Soil, water	0.00	0.012	0.000
Average/sum	0.78	1.000	

The case studies give a quantification of the results from efforts to reduce the environmental impact from transportation. This is useful when relating to the internal costs of the efforts and in communication with customers and authorities. The results should also be useful for policymakers when deciding on instruments and levels to internalise the external costs.

In principle the tool utilises marginal costs rather than average costs, i.e., the costs of the additional specific transportation are considered in the context of an otherwise assumed fixed traffic situation. The costs used for congestion are marginal costs which are significantly higher than average costs. For emissions the average and marginal costs are usually considered to be the same although for some impacts (such as acidification) the marginal costs are likely to be higher. The main costs here are health-related and expected to be linear and the tool uses average costs. For accidents the marginal costs are usually similar or higher than the average costs. We use the approach described in the Handbook[5] where average costs are considered. For land usage etc., the marginal costs are expected to be significantly lower than the average costs. The Handbook uses marginal costs. The relationship between marginal and average costs of noise is complex and probably the marginal costs are somewhat lower. For climate gases the marginal costs are likely to be higher than the average costs.

The risk for internalisation of external costs from goods transportation should in a perfect world be obtained from the value of the costs. Today, these external costs are not covered by taxes and fees. For heavy road vehicles, for instance, taxes charged are consistently low in relation to the marginal costs, and for rail transport, SIKA makes the assessment that the actual marginal costs are considerably higher than today's rail infrastructure charges.[20]. It is not straightforward to assess which part of the costs associated with negative impacts are internalised already. This is discussed further in another report[7]. The taxes and fees charged in the transport sector are often motivated by infrastructure costs, which are not considered in the tool presented here. One may also note that the policy measures taken and the levels of fees and taxes are usually not motivated by the actual external costs that should be internalised, but by the objectives behind them, e.g., lower fuel consumption or less traffic. According to the study by Wolf et al the most realistic case of short-term internalisation of external transport costs is expected to happen via the "Eurovignette" directive. This directive focuses on internalisation of external costs for congestions, accidents and air pollution but not, e.g. climate gases. These three categories represent some 38% of the costs (see Table 9).

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