External and infrastructure costs of HGVs in the EU28 in 2013

Update of the total cost figures from 'Are trucks taking their toll?'

CE Delft

Committed to the Environment

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Summary

Background

Transport, and particularly freight transport, is an important driver of economic growth. However, it also results in infrastructure and external costs (e.g. air pollution, accidents, congestion). These costs are not reflected in market prices of freight transport and hence they are not taken into account in transport decisions of transport companies and shippers. In case these costs are not 'internalised' by taxes and/or charges, they result in distortions on the transport market and hence to inefficient transport volumes.

Over the last decade, internalisation of external costs is one of the main objectives of the European Commission with respect to (freight) transport. In policy debates on this topic, the total infrastructure and external cost figures of HGVs in Europe from the study 'Are trucks taking their toll?' were intensively used. In this study we have updated these figures.

Results

The total infrastructure and external costs of HGVs in the EU28 in 2013 amount to approximately 143 billion euro (119-167 billion euro). Most of these costs (40%) are caused by infrastructure costs. From the external cost categories, congestion contributes most to the total costs (25%), followed by climate change costs (12%). Emissions causing air pollution and accident costs both have a share of roughly 10% in the total external and infrastructure costs.

Table 1   Total external and infrastructure costs from HGVs in the EU28 in 2013

Cost category	External costs in billion euro (2013)
Air pollution	15
Climate change	17 (2-31)
Upstream emissions	4 (3-5)
Noise	2
Accidents	14
Congestion	36 (27-44)
Infrastructure	57
Total	**143 (119-167)**

Some of the main uncertainties regarding the estimation of the external costs of HGVs are reflected by the bandwidths presented in Table 1.
Further discussion on the uncertainties in the cost estimates can be found in Section 9.3.

Comparison with results 'Are trucks taking their toll?'

In 'Are trucks taking their toll?' the total external and infrastructure costs in the EU in 2006 were estimated at 144 billion euro, which is comparable to the central value estimated in this study. However, at the level of the individual cost categories there are significant differences. For example, the climate change costs are estimated significantly higher, which is due to the use of a higher shadow price. Also the congestion cost estimates are higher, which is due to the use of more advanced estimates from the literature. On the other hand, the noise costs are significantly lower than in the previous study; this is mainly because a lower number of people exposed to traffic noise was found by using more detailed data (from the Noise maps). Also the accident costs have decreased significantly, which is mainly the result of a reduction in the number of fatalities and injuries due to HGV-involved traffic accidents in 2013 compared to 2006.

1 Introduction

1.1 Background

Transport is an integral part of any society. It exhibits a very close relation to the style of life, the range and location of activities and the goods and services which will be available for consumption. Transport, and particularly freight transport, is often regarded as an important driver of economic growth.

However, next to these positive impacts of transport on society, it also results in some societal costs. Governments spend a significant part of their budgets on the construction and maintenance of transport infrastructure, while transport also results in various types of external costs (air pollution, climate change, congestion, accidents, etc.). The contribution of heavy duty vehicles (HGVs) to these infrastructure and external costs is significant.

In 2009, CE Delft published the study 'Are trucks taking their toll?'. In this study, which was commissioned by Transport & Environment (T&E), the total infrastructure and external costs of HGVs in Europe were estimated.
Over the last years, these results were used intensively in policy debates.
T&E requested CE Delft to update these total cost figures. The results of this assessment are presented in this report.

1.2 Objectives & scope

The objective of this study is to estimate the total external and infrastructure costs of HGVs in the EU28 in 2013. The results are compared to the values estimated by 'Are trucks taking their toll?' (CE Delft, 2009).
The main differences between both studies are discussed.

The scope of this study is as follows:
-   The following externalities/costs are taken into account: air pollution, GHG emissions (climate change), emissions from fuel production, noise, accidents, congestion and infrastructure costs.
-   Only the total costs for HGVs in the EU28 are estimated and presented. Where necessary, we have (partly) differentiated our calculations to individual countries and/or other modes (e.g. when applying a top-down approach to estimate the costs). The results of these more disaggregated calculations are not presented in this report.
-   All results are presented for the year 2013. Additionally, the results are expressed in euro price level 2013 (PPP adjusted). Data from sources that were expressed in price levels of other years have been translated to price level 2013 by use of relevant consumer price indices.
-   To estimate the external and infrastructure costs, state-of-the-art methodologies and cost figures are used. A brief discussion on these methodologies can be found in Annex A. Additionally, per cost category a (very) brief description of the methodology applied is given in Chapter 2 to Chapter 8. For more information on the methodologies and cost figures used to estimate external costs we refer to Ricardo-AEA et al. (Ricardo-AEA, et al., 2014); (CE Delft, et al 2011) and (CE Delft, et al., 2008).

1.3 Outline of the report

In Chapters 2 to 8 we present the estimations for the various cost categories, discussing the definition of the costs considered, the methodology applied and the results. In Chapter 9 the overall results are presented and interpreted. Additionally, a comparison with the results of 'Are trucks taking their toll?' is made.
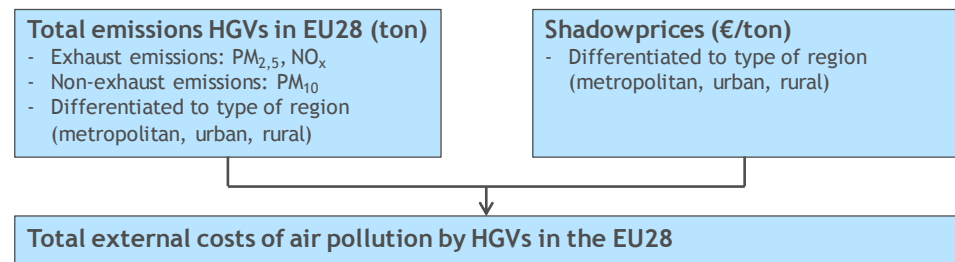
2 External costs of air pollution

2.1 Defining external costs of air pollution

HGVs are the biggest road transport emitters of air pollutant emissions (EEA, 2013). For example, HGVs are responsible for up to 40-50% of road transport NO_x emissions in EU countries (NERI, 2011). The main air pollutant emissions of HGVs are particular matter (both exhaust ($PM_{2.5}$) and non-exhaust (PM_{10}) and nitrogen oxide (NO_x). These air pollutant emissions result in different types of external costs. The main costs are related to adverse health impacts[1], e.g. due to cardiovascular and respiratory diseases. Other external costs are associated with damage to buildings and materials, crop losses and impacts on biodiversity and ecosystems.

2.2 Method

The methodology used to estimate the external costs of air pollution of HGVs in the EU28 is shown in Figure 1.

Figure 1   Methodology to estimate air pollution costs

Total emissions HGVs in EU28 (ton)	Shadowprices (€/ton)
- Exhaust emissions: $PM_{2.5}$, NO_x - Non-exhaust emissions: PM_{10} - Differentiated to type of region (metropolitan, urban, rural)	- Differentiated to type of region (metropolitan, urban, rural)

Total external costs of air pollution by HGVs in the EU28

First, the total air pollutant emissions of HGVs in European countries are estimated by use of data from the EEA Air pollutant emissions data viewer (LRTAP Convention)[2]. This database does not provide any data on non-exhaust PM emissions. These emissions are therefore estimated by multiplying the total number of vehicle kilometres (from Eurostat) by relevant emission factors (from the TREMOVE database). To estimate the total external costs, the total emissions are multiplied by relevant shadow prices.

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[1]   These costs include immaterial costs (pain, grief, etc.), medical costs and productivity losses.

[2]   This database presents the exhaust emissions for HGVs and busses together. Based on (CE Delft et al., 2011)) the share of HGVs in these emissions is estimated. It should be noticed that this top-down approach results in higher total emission figures for HGVs than a bottom-up approach (based on vehicle kilometres multiplied by emission factors) as applied in (CE Delft et al., 2011). It is unclear what explains these differences.

NEEDS shadow prices (NEEDS, 2008) are used for NO_x, as recommended by Ricardo-AEA et al. (2014). NEEDS also provide values for PM emissions, but these are not appropriate for transport[3]. Therefore, in line with CE Delft et al. (2011) the shadow prices for $PM_{2.5}$ and PM_{10} are based on HEATCO (2006). The PM shadow prices are differentiated by region type, such that the impact of population density on the external cost of air pollution can be taken into account (air pollutants emitted in regions with high population density affect more people and hence have larger adverse impacts).

2.3   Results

Figure 2 shows that the total costs of air pollution caused by HGVs were roughly 15 billion euro in 2013[4,5]. Most costs are related to rural regions (70%, i.e. 10.6 billion euro), as the largest share of the total kilometres driven by HGVs is also in these regions, followed by urban (25%, i.e. 3.6 billion euro) and metropolitan (5%, i.e. 0.6 billion euro) regions.
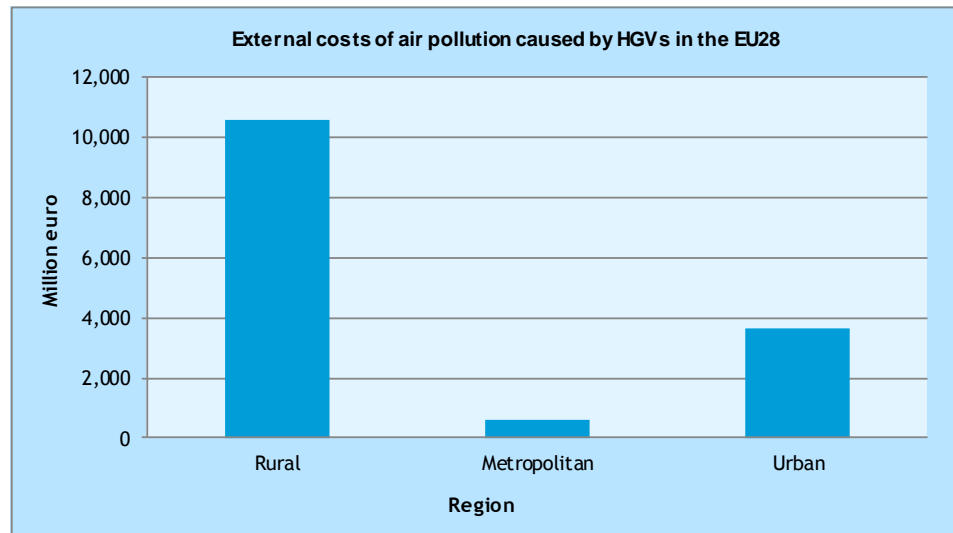
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[3]   NEEDS values for PM mainly refer to damage costs of air pollution due to energy production, where the emitted particles are generally larger and having less severe health effects. They are also emitted on higher levels above ground than in transport and hence people are less (directly) exposed to these vehicles. Furthermore, as the NEEDS values are not differentiated to region type, the impact of population density on the total adverse health impacts of PM emissions are less accurately reflected.

[4]   In recent studies (WHO, 2015); (OECD, 2014), cost estimates of the health impacts of air pollution are presented that are considerably higher than the values presented in this study. For example, OECD (2014) estimates that the external costs due to health impacts of road transport related air pollution in the EU are about 280 billion euro. Assuming that 24% of these costs can be allocated to HGVs (CE Delft et al., 2011), the external costs of air pollution of HGVs is equal to 68 billion euro, which is approximately nine times higher than the value presented in this study. The main cause for this large difference between both estimates is the fact that in OECD (2014) mortality impacts are valuated using the Value of Statistical Life (VSL), while the shadow prices used in this study are based on the Value Of a Life Year lost (VOLY). According to (NEEDS, 2008)valuation of mortality due to air pollution using VOLY is superior to valuation with VSL, mainly because VSL fails to take into account that the loss of life expectancy per death is very much less for air pollution deaths (around six months) than for the typical traffic accidents (30-40 years) on which VSL calculations are based (in other words, air pollution impacts mainly on death at end-of-life, while traffic accidents are often in mid-life).

[5]   As discussed in Footnote 2 the total air pollutant emissions estimated by a top-down approach are higher than figures estimated by using a bottom-up approach. Hence, this also results in higher external cost values. If the external air pollution costs were estimated using a bottom-up approach (based on Eurostat and TREMOVE data) the overall costs are equal to ca. 8 billion euro. Please notice that these costs are considerably lower than the cost estimates in 'Are trucks taking their tolls?' (i.d. 16 million euro), although the latter estimates were also based on a bottom-up approach. This difference is mainly caused by the fact that in the current study (and also in CE Delft et al., 2011) another source is used for the vehicle kilometres in estimating the total air pollutant costs by a bottom-up approach: Eurostat instead of TREMOVE. The vehicle kilometres from the latter database are nearly twice as high compared to Eurostat, which obviously causes significantly higher total emissions (and hence external costs). Although there are good indications that the vehicle kilometres from Eurostat are more reliable than the ones from TREMOVE, the large difference between both sources emphasize again the need for a better understanding of total vehicle kilometres and emissions of the various road transport modes in the EU Member States.

Figure 2   Air pollution costs of HGVs in the EU28 in 2013

External costs of air pollution caused by HGVs in the EU28

4.D64 – External and infrastructure costs of HGVs in the EU28 in 2013

3 External costs of GHG emissions

3.1 Defining external costs of GHG emissions

HGVs cause about 25% of the greenhouse gas (GHG) emissions from road transport in the EU and about 4% of the EU's total greenhouse gas emissions (AEA, 2011). These emissions contribute to global warming, resulting in impacts such as sea level rise, agricultural impacts (due to changes in temperatures and rainfall), health impacts (e.g. increase in heat stress, expansion of areas amenable to parasitic and vector borne diseases like malaria), increase in extreme weather effects, etc. (IPCC, 2014).

The main GHG emissions are carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Recent studies also mention black carbon (root) as a potentially important GHG emission, although the impact on global warming is still uncertain (IPCC, 2014). Therefore, we do not take the latter into account in this study.

3.2 Methodology

As shown in Figure 3, a similar approach as for air pollution is applied to estimate the external costs of GHG emissions. First, the total GHG emissions of HGVs in the EU28 are estimated by applying a top-down approach. The total EU28 GHG emissions of road transport are taken from the EEA GHG data viewer[6]. Next, the share of HGVs in these emissions is estimated based on AEA et al. (2011)[7]. In order to make a direct comparison between the various GHG emissions possible, they are translated to CO_2 equivalents by using Global Warming Potentials (IPCC, 2014). These CO_2 eq. are valuated by using a shadow price of 80 euro per tonne CO_2 eq. This CO_2 price is based on the cost for meeting the long term target for keeping CO_2 eq. level in the atmosphere below 450 ppm in order to keep global temperature rise below 2°Celsius (Kuik et al., 2009)[8]. Since the uncertainty in this CO_2 price is large (see CE Delft et al., 2011), also a low (€ 10) and high (€ 150) value for the CO_2 price is applied (in line with CE Delft et al., 2011). The low CO_2 price is based on the costs to meet the 2020 CO_2 reduction target of the European Commission (20% reduction compared to the 1990 level) (CE Delft, 2014), while the high cost is based on the upper bound of the estimations of Kuik et al. (2009) to meet the 2°C target.

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[6]   This database provides the GHG emissions the EU Member States have to report to the UNFCCC.

[7]   The share of HGVs in total fuel consumption and hence GHG emissions of road transport in the EU28 are rather uncertain. AEA et al. (2011) estimate this share on about 25%. CE Delft et al. (2011), on the other hand, estimate the share on 15% (estimation based on Eurostat data on vehicle kilometres and TREMOVE data on fuel consumption figures). Other estimates from TREMOVE and PRIMES range from 18 to 35%. It is unclear how these differences can be explained.

[8]   Although a damage cost approach is preferred from a theoretical point of view, abatement cost figures are applied here. The main reason is that the costs of risks for the potentially high damages of climate change cannot be quantified well. See Annex A.3 for more information on both the damage cost and abatement cost approach.

Figure 3   Methodology to estimate the external cost of GHG emissions

3.3   Results

Based on EEA data it was estimated that HGVs emitted roughly 208 Mt CO_2 equivalent in the EU28 in 2013. Multiplying these emissions with the shadow prices results in total climate costs ranging from 2.1 billion to 31.2 billion euro in the EU28 in 2013[9]. The best guess estimate is 16.7 billion euro, which are the climate costs of keeping the global temperature raise below 2°Celsius (i.e. calculated with a shadow price of 80 euro per ton CO_2 eq). The large range in the estimated climate costs show the relatively large uncertainty in the CO_2 price that should be applied to valuate the GHG emissions of HGVs.

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[9]   As explained in Footnote 7 the total GHG emissions of HGVs in the EU28 is rather uncertain. In case these emissions are estimated based on a bottom-up approach (based on vehicle kilometres from Eurostat and emission figures from TREMOVE) the total climate costs are equal to 0.8 to 12.1 billion euro. Please notice that these figures differ from the estimates of the external costs of GHG emissions in 'Are trucks taking their toll?' (i.d. 1–9 billion euro), although also in the latter study a bottom-up approach was applied. These differences are mainly methodological. On the one hand, a new shadow price for CO_2 have been used (an average price of 25 euro per ton in the previous study vs. 80 euro per ton in this study) which drastically increases the climate costs. However, on the other hand, we applied vehicle kilometres from Eurostat instead of TREMOVE. As the latter are about twice as high, the total GHG emissions estimated by the bottom-up approach is considerably lower than in the previous study. Combining these two effects explains the major part of the difference in the external costs of GHG emissions between both studies.

4 External costs of emissions of fuel production

4.1 Defining external costs of emissions of fuel production

Fuel production causes climate emissions and emissions from air pollutants due to extraction of raw materials and the production and transport of fuels[10]. These so-called well-to-tank (WTT) emissions lead to external effects, i.e. air pollution costs (health effects, etc.) and climate change costs.
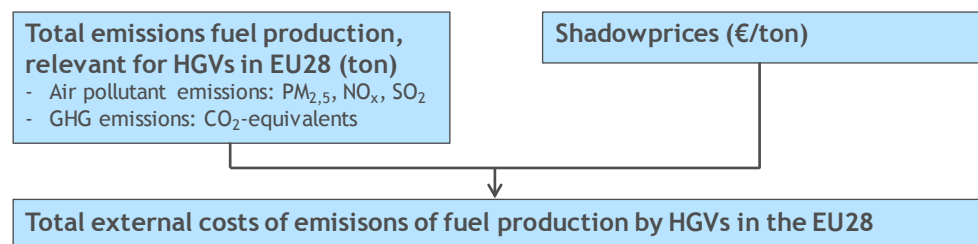
As mentioned by CE Delft et al. (CE Delft; INFRAS; Fraunhofer-ISI, 2011), the production of fuels may also lead to all kinds of risks which potentially result in high external costs.
For example, oil spills due to deep sea drilling of oil have a relatively high disaster risk and hence significant external costs are associated with this risk. However, due to a lack of reliable cost factors, these effects are not considered in this study.

4.2 Methodology

To estimate the external costs of emissions of fuel production, a similar approach as for air pollution and GHG emissions is used. First, the total emissions are estimated, which are multiplied by relevant shadow prices. The same shadow prices as the ones used to estimate the external costs of air pollution and GHG emissions are applied (see Chapters 2 and Chapter 3), with one exception: for PM emissions no transport-specific shadow prices are applied (as was the case in Chapter 2), but shadow prices appropriate for industrial processes are used from (NEEDS, 2008). Furthermore, external costs from SO_2 were not taken into account for exhaust air pollution costs (as these emissions are negligible), but are taken into account for upstream processes. The shadow prices used are based on NEEDS (2008) as well.

Figure 4   Methodology to estimate the external costs of emissions of fuel production

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[10]   The emissions of fuel production can be considered upstream effects of HGV transport. Other upstream processes are the production, maintenance and disposal of vehicles and infrastructure (CE Delft et al., 2011). These processes lead to emission of air pollutants and GHGs and therefore to external costs. However, these costs are not considered in this study due to a lack of data. Moreover, these external costs have another dimension as the other external cost categories (as these costs are not directly related to the actual use of HGVs).

4.3 Results

Total external costs from upstream processes of HGVs in the EU28 in 2013 range from 2.5 billion to 4.6 billion euro. The bandwidth results from the different shadow prices used for CO_2 emissions (i.e. shadow prices of air pollutants are not varied). The best guess estimate is 3.5 billion euro, which are the costs from upstream processes in case a shadow price of 80 euro per ton of CO_2 eq is used.

5 External noise costs

5.1 Defining external noise costs

Noise can be defined as the unwanted sound or sound of duration, intensity or other quality that causes physical or psychological harm to humans. In general, two main impacts of traffic noise are distinguished[11]:

- Annoyance; traffic noise may irritate people, resulting in a wide range of responses (e.g. anger, dissatisfaction, depression, exhaustion, etc. (WHO, 2011)), which lead to a decrease of their well-being.
- Health impacts; traffic noise may increase the risk of cardiovascular diseases (heart diseases, high blood pressure), cognitive impairment, sleep disturbance and tinnitus[12] (WHO, 2011). These adverse health impacts result in both mortality and morbidity costs.

5.2 Methodology

A top-down approach is used to estimate the external noise costs of HGVs in the EU28. First, the total external noise costs of road traffic are estimated by multiplying the number of people affected by road traffic noise by relevant shadow prices. The total number of affected people is based on data from the noise maps which Member States are required to deliver (by Directive 2002/49/EC) to the European Commission. It is assumed that no adverse effects on annoyance and health occur for noise levels below 55 dB(A)[13]. As recommended by Ricardo-AEA (2014), state-of-the-art shadow prices from HEATCO (2006) are used to estimate the costs these affected people experience from road traffic noise.

In a second step, the total noise costs of road traffic are allocated to the various transport modes (including HGVs) based on vehicle kilometres which are corrected by specific noise weighting factors (see CE Delft et al., 2011). By using these weighting factors the fact that some vehicles (including trucks) are noisier than other ones can be taken into account.

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[11] In addition to annoyance and health impacts, Defra (2014) mention productivity losses (e.g. due to loss of concentration, tiredness due noise-related sleep disturbance) and environmental impacts (e.g. disturbing breeding patterns of wildlife or affecting quiet areas) as potential adverse impacts of transport noise. However, they conclude that available evidence is not sufficient to quantify and valuate these impacts.

[12] Sound perception (e.g. hissing, ringing) that cannot be attributed to an external noise source.

[13] From the literature it is clear that also noise levels below 55 dB(A) may have effect on annoyance and human health. However, since no data is available on the people exposed to noise levels below 55 dB, we were not able to estimate the costs for these noise levels. The resulting noise costs should therefore be considered an underestimation.

Figure 5   Methodology to estimate external noise costs

Number of people affected by road traffic noise - Threshold: 50 dB(A)	Shadow price per person exposed - Annoyance costs - Health costs

↓

Total external noise costs of road traffic in the EU28

↓

Allocation of total external noise costs to vehicle categories based on weighting factors

↓

Total external noise costs of HGVs in the EU28

5.3   Results

Within the EU28, nearly 80 million inhabitants are exposed to noise levels higher than 55 dB(A) from road transport. This results in total noise costs of 10 billion euro. Roughly 1.7 billion euro can be attributed to HGVs in 2013, which is roughly 17% of the total noise costs resulting from road transport in the EU28.

As mentioned in Footnote 13, the estimated noise cost should be considered an underestimation of the actual noise costs, as the costs of adverse impacts on annoyance and human health of noise levels below 55 dB(A) are not considered. These costs could be significant; for example, CE Delft and Free University (2014) show that in the Netherlands about 25% of the total noise costs of road transport are related to noise levels below 55 dB(A).

6 External accident costs

6.1 Defining external accident costs

HGVs are involved in a large share of the fatal crashes and accidents with severe injuries, since their high mass leads to sever consequences for other road users in crashes. Traffic accidents result in several social costs, i.e. immaterial costs (lifetime shortening, suffering, pain, sorrow, etc.), medical costs, production losses and administrative costs (e.g. costs for police, justice, etc.)[14].

Only the accident costs that are not anticipated by road users are considered as external costs. In literature (e.g. (GRACE, 2006); (UNITE, 2000); (CE Delft et al., 2011)), it is usually assumed that road users do take their own accident risks into account, but not the risk they impose on other road users. Hence, we assume that the costs associated with road users' own risks are internalised, while the costs associated with the risks for others are assumed external. This implies that the costs experienced by the truck drivers themselves are not taken into account, as these costs are considered internalised. We also assumed that costs covered by insurances are internalised and hence are no part of the external accident costs[15].

6.2 Methodology

A top-down approach is applied to estimate the external accident costs of HGVs (see Figure 6). First, the total external costs of HGV-involved accidents are calculated by multiplying the total number of casualties (from the CARE database) by relevant cost values. The immaterial costs of fatalities are estimated using the Value of Statistical Life (VSL; EU-average value: 1.95 million euro), while for severe and slight injuries these values are 13 and 1% of the VSL, respectively (Ricardo-AEA et al., 2014). Additionally, other economic costs (medical costs, net production losses and administrative costs) are estimated at 10, 2 and 0.1% of the VSL for fatalities, severe and slight injuries respectively (ibid.). A distinction is made between single and multiple vehicle accidents. For the former, only the other economic costs are taken into account, while for the latter accidents costs are the sum of both immaterial and other economic costs.

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[14] Accidents also result in material damage. Due to a lack of data these costs are not considered in this study.

[15] This is in line with previous studies on external costs of transport (e.g. CE Delft et al., 2008; CE Delft et al., 2011; Ricardo-AEA et al., 2011). However, it may be discussed to what extent insurances completely internalise part of the accident costs, as this will only be the case as the insurance rates are based on the main drivers of these costs (e.g. driving behaviour). Without a detailed analysis of the insurance schemes used in the various EU Member States it is not possible to conclude on this issue and hence we applied that the assumption that insurances do internalise part of accident cost perfectly. This may result in an underestimation of the actual external accident costs.

In a second step the total external costs of HGV-involved accidents are allocated to the modes involved based on the intrinsic risk approach, i.e. victims are allocated to the other vehicle involved in the accident[16] (CE Delft et al., 2011).
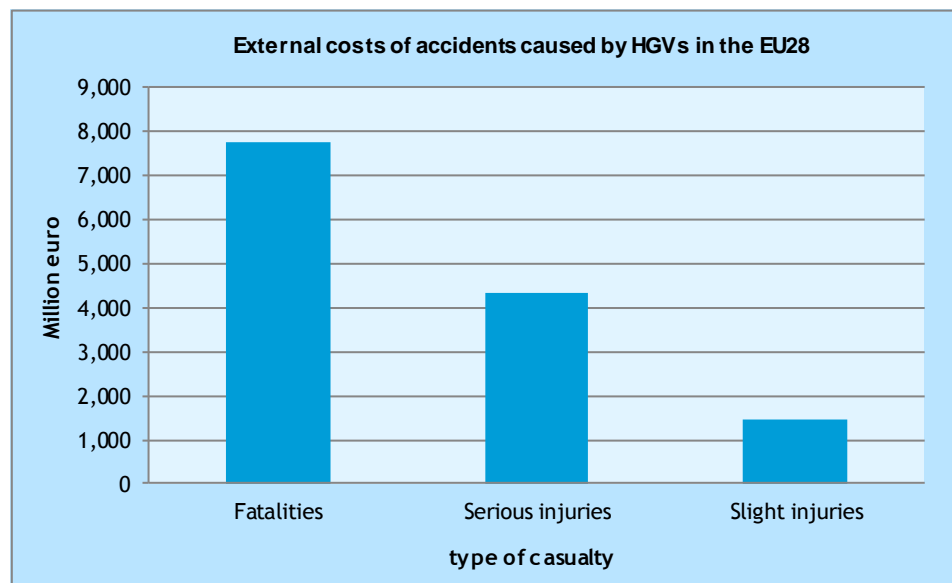
Figure 6   Methodology to estimate the external accident costs

Number of casualties in accidents in which HGVs are involved - Fatilities, severe injuries, slight injuries	Social cost per casualty - Risk value - Human capital loss - Medical care - Administrative costs

Total external costs of HGV involved accidents in the EU28

Allocation of total external costs to vehicle category based on damage potenial (intrinsic risk)

Total external accident costs of HGVs in the EU28

6.3   Results

In 2013, roughly 80,000 casualties have been caused by HGVs, of which 92% concerned multiple vehicle accidents. Hence, HGVs cause significant accident costs. Total external costs from accidents with HGVs are 13.5 billion euro in 2013. Although there were relatively few fatalities (4,000) compared to seriously and slightly injured casualties (15,000 and 60,000 respectively), Figure 7 shows that roughly 60% (7.8 billion euro), 30% (4.3 billion euro) and 10% (1.4 billion euro) of the total accident costs are related to fatalities, serious injuries and slight injuries, respectively. This is particular due to the significantly higher immaterial costs in case of fatalities.

Figure 7   Accident costs HGVs in the EU28 in 2013

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[16]   This implies that casualties in trucks are allocated to other vehicles involved and hence only the casualties in other vehicles involved in truck-related accidents are allocated to trucks. In case of single-vehicle accidents, the victims are allocated to their own vehicles.

7 External congestion costs

7.1 Defining external congestion costs

Congestion arises from the mutual disturbance of road users competing for limited road capacity. It increases with traffic load, but it is present at almost all levels of demand. Even if capacity limits of a road are not yet reached, users may experience mutual disturbance leading to lower speeds. Congestion may cause several costs (CE Delft et al., 2008):
- travel time increases is the most important component of congestion;
- reduction of travel time reliability; utility of road users decrease as their travel times becomes less predictable/reliable;
- additional operational and fuel costs, e.g. fuel consumption of vehicles increase under stop-and-go conditions.

In contrast to most of the other external costs, congestion costs are mainly borne by market participants who are identical to those causing it.
For that reason, it is often claimed that congestion costs are not external. However, as we consider a sub-segment of road transport (HGVs), only a small part of the congestion costs caused by HGVs are borne by themselves; the main part of these costs is imposed on other users of road networks (CE Delft et al.,2011). Furthermore, also the part of the external congestion costs borne by the HGV sector is affecting other road users (from a marginal perspective) and hence results in economically sub-optimal outcomes.
For these reasons, we will consider congestion costs as external in this study.

7.2 Methodology

Estimating congestion costs of HGVs in the EU28 requires extensive modelling exercises by a transport model. This is out of the scope of this study. Therefore, we will make use of the congestion costs estimates provided by CE Delft et al. (2011), which are translated to 2013 values by correcting for GDP-developments and inflation.

The estimates of congestion costs by CE Delft et al. (2011) were based on runs by the TRANS-TOOLS model, supplemented by results from a review of literature on road congestion costs. Based on this approach two types of congestion costs were estimated. First, the deadweight loss[17] caused by congestion was estimated. Although this is a good indicator to measure the welfare impact of the existence of congestion, it is not consistent with the way the other external costs are estimated. Secondly, the total delay costs are estimated based on the total delays caused by congestion (against a reference speed of 60 km/h). This measure is in line with the way the other external costs are estimated and, moreover, is more appropriate to estimate the total (external) congestion costs. Therefore, we will use the total delay costs from CE Delft et al. (2011) to estimate the external congestion costs of HGVs in the EU28.

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[17] Welfare loss due to the inefficient allocation of traffic caused by congestion. Notice that the deadweight loss of congestion is smaller than the total congestion costs, as reducing all congestion is not efficient from an economic point of view (at a certain level of congestion the costs of reducing congestion levels a bit more are higher than the benefits of it).

Finally, the congestion cost values provided by CE Delft et al. (2011) do contain the additional fuel and operational costs, next to the costs of travel time delays. The costs of reduced travel time reliability are not included in these estimates.

7.3 Results

Based on the approach described in Section 7.2, the congestion costs of HGVs in the EU28 in 2013 are estimated to be equal to 27 to 44 billion euro. The lower bound of this range is based on results from the literature review, while the upper bound is based on TRANS-TOOLS estimations (both performed in CE Delft et al., 2011). In this study we use 36 billion euro (average of the high and low value) as central estimate of the congestion costs.

The large range in congestion cost estimates reflect the uncertainty associated to the estimation of these costs. As there is no consistent European database on congestion levels in Europe available, estimates of congestion costs are usually based on model exercises, which cannot be verified on empirical data. Consequently, the congestion costs estimated should be considered as a rough indication of the actual congestion costs.

8 Infrastructure costs

8.1 Defining infrastructure costs

Infrastructure can be defined as the physical and organisational network, which allows movements between different locations (High Level Group, 1999). This definition includes roads, but also the organisation of the traffic (e.g. traffic management systems). The costs to provide this infrastructure include direct expenditures as well as financing costs, where the latter are expressed by the interest on capital. Direct expenditures are related to enhancement of the infrastructure (e.g. new roads), renewal of (parts of) the road network, maintenance and operational activities.

A distinction often made is between fixed and variable infrastructure costs (Ecorys; CE Delft, 2006). Fixed costs refer to costs that do not vary with transport volume while the functionality of the infrastructure remains unchanged, or costs that enhance the functionality or lifetime of the infrastructure. Variable costs, on the other hand, do vary with transport volumes (while the functionality of the infrastructure remains unchanged. Construction costs and land values are examples of fixed costs, while (part of the) maintenance and operational costs are examples of variable costs.

8.2 Methodology

No EU-wide datasets are available on investment, maintenance and operational expenditures with respect to road infrastructure. Estimating these costs ourselves is therefore out of the scope of this study. However, Fraunhofer-ISI and CE Delft (2008) provides a rough estimate of the infrastructure costs of the various EU countries in 2005, by extrapolating the results from a few national studies[18] to all EU countries. First, they estimated the average infrastructure costs per kilometre road network (distinguishing motorways, urban roads and other roads) based on the national studies. Based on information on the road network length in all EU Member States, these costs are extrapolated to all other EU countries. Next, the total infrastructure costs were allocated to the various vehicle types based on relevant cost drivers. In this approach, different cost types and accompanying cost drivers were distinguished:

- Capacity dependent fixed costs (e.g. investment and enhancement costs); these are costs made to increase the capacity of the road network. They are allocated based on passenger car equivalent (PCE) corrected vehicle kilometres, as this cost driver reflects the capacity demand of the various modes.
- Other fixed costs (e.g. costs of police and signalling), which are allocated based on vehicle kilometres.
- Weight related variable costs (e.g. renewing road surfaces), which are allocated based on axle load corrected vehicle kilometres.
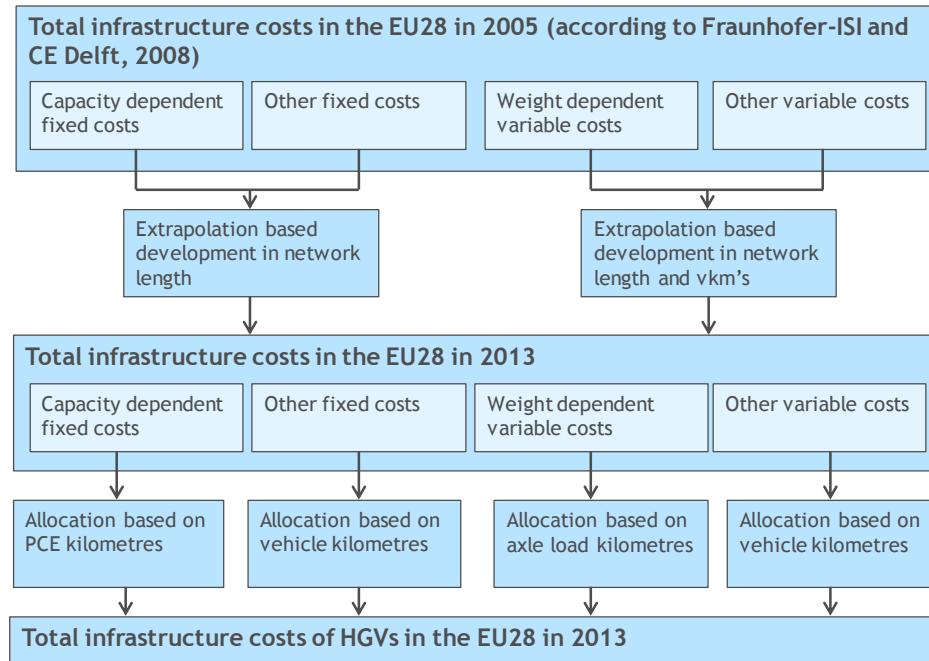- Other variable costs (e.g. cleaning of roads), which are allocated based on vehicle kilometres.

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[18] For Austria, Germany, Denmark, France, Italy, Portugal and Sweden.

In this study, we have updated the results from Fraunhofer-ISI and CE Delft (2008) to 2013 by (see Figure 8):

− extrapolating the total infrastructure costs based on developments in network length and vehicle kilometres as well as correcting for inflation;
− allocate part of the total infrastructure costs to HGVs based on the same approach as used in Fraunhofer-ISI and CE Delft (2008).

Figure 8   Methodology to estimate the infrastructure costs

Total infrastructure costs in the EU28 in 2005 (according to Fraunhofer-ISI and CE Delft, 2008)			
Capacity dependent fixed costs	Other fixed costs	Weight dependent variable costs	Other variable costs

Extrapolation based development in network length	Extrapolation based development in network length and vkm's

Total infrastructure costs in the EU28 in 2013			
Capacity dependent fixed costs	Other fixed costs	Weight dependent variable costs	Other variable costs

Allocation based on PCE kilometres	Allocation based on vehicle kilometres	Allocation based on axle load kilometres	Allocation based on vehicle kilometres

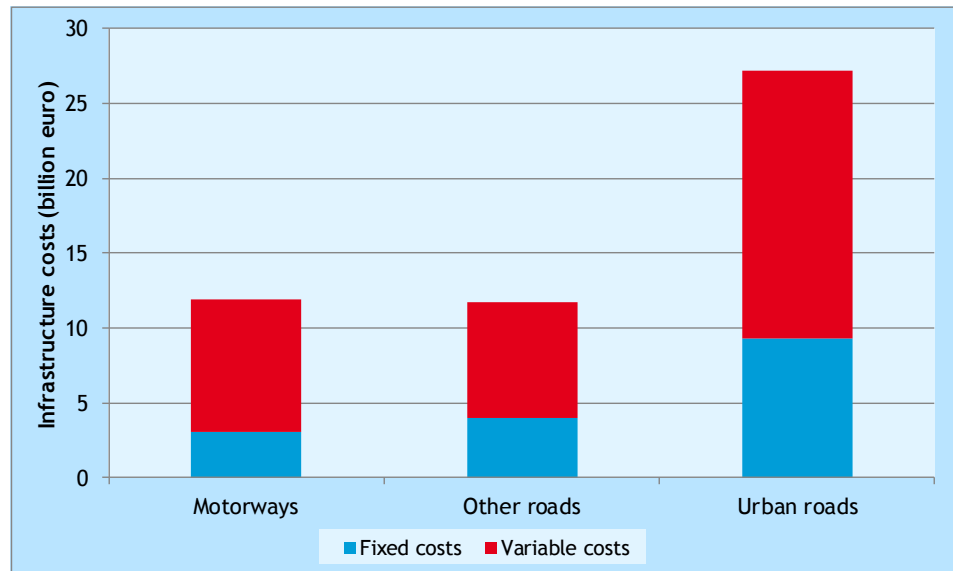**Total infrastructure costs of HGVs in the EU28 in 2013**

8.3   Results

The total infrastructure costs attributable to HGVs in the EU28 in 2013 are estimated at 58 billion euro. About 35% of these costs can be considered fixed, while the remaining 65% can be seen as variable (see Figure 9). The main part of the costs is related to urban roads (due to the relatively high overall costs associated with urban roads), namely 27 billion euro. The costs of motorways and other roads are equal to 11.9 and 11.7 billion euro, respectively.

Figure 9   Infrastructure costs of HGVs in the EU28 in 2013

The uncertainty in the infrastructure cost estimates is relatively large. Because of the lack of an EU-wide database on infrastructure expenditures, the infrastructure costs are estimated based on a few national studies which are extrapolated to all EU countries. Consequently, the infrastructure costs estimated should be considered as a rough indication of the actual infrastructure costs.
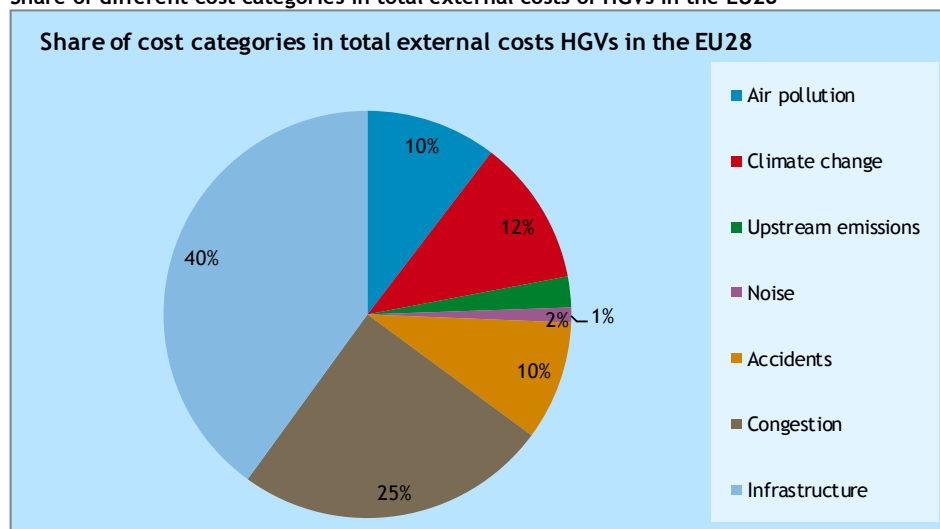
9 Results

9.1 Overview external and infrastructure costs HGVs in EU28

Table 2 summarises the results presented in Chapter 2 to 8, which results in total external and infrastructure costs of 143 billion euro (€ 119–167) caused by HGVs in the EU28 in 2013. Figure 10 shows that infrastructure costs cause most of these costs (40%). When zooming in on the external cost categories it becomes clear that congestion contributes most to the total costs (25%), followed by GHG emissions (12%), air pollution (10%) and accidents (10%).

Table 2   Total external costs from HGVs in the EU28 in 2013

Cost category	External costs in billion euro (2013)
Air pollution	14.8
Climate change	16.6 (2.1-31.2)
Upstream emissions	3.5 (2.5-4.6)
Noise	1.7
Accidents	13.5
Congestion	35.5 (27-44)
Infrastructure	57.1
Total	**142.7 (119-167)**

Figure 10   Share of different cost categories in total external costs of HGVs in the EU28

Note: This figure is based on the best guess values for the various external cost categories.

9.2 Comparison with results 'Are trucks taking their toll?'

Table 3 summarises the main results of this study and of the previous study ('Are trucks taking their toll?') and highlights the main explanation for the differences between both. Hereafter, the differences are explained in more detail for each cost category.

Table 3   Comparison of results this study with results of 'Are trucks taking their toll'

Cost category	Results of this study in billion euro	Results of 'Are trucks taking their toll?' in billion euro	Main explanations
Air pollution	15	16	– Total emission are estimated based on different method (top-down instead of bottom-up). – Reduced emission factors (g/vkm) HGVs.
Climate change	17 (2-31)	5 (1-9)	– Different shadow prices. – Total GHG emissions based on top-down approach instead of bottom-up approach.
Upstream emissions	4	n/a	– Upstream emissions were not included in the previous study.
Noise	2	18	– Different methodology (noise maps). – Decrease in the number of people exposed.
Accidents	14	30	– Different number of fatalities and injuries.
Congestion	36 (27-44)	24	– Different methodology (literature review vs. model exercises).
Infrastructure	57	51	– Increase in length of road network. – GDP and inflation developments.
Total	143 (119-167)	144	

Air pollution
External air pollution costs are roughly comparable in this study compared to the previous one. In this study we estimated the total air pollutant emissions by using a top-down approach, while in the previous study we used a bottom-up approach. Both approaches result in comparable total air pollutant emissions[19]. The use of an alternative approach undoes the reduction in emissions per kilometre in 2013 compared to 2006 (base year of 'Are trucks taking their toll?' due to the introduction of EURO standards and differences in vehicle kilometres.

Climate change
Climate change costs are roughly 12 billion euros higher in this study compared to the previous one. The main explanation for this difference is methodological. First, new shadow prices for CO_2 have been used (25 euro per

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[19]   As explained in Footnote 5, applying a bottom-up approach in this study as well results in considerably lower total air pollutant emissions. This is mainly caused by the use of lower vehicle kilometer figures (from Eurostat instead of TREMOVE) in the current study compared to the previous one. We refer to Footnote 5 for a more detailed discussion on this issue.

ton in the previous study vs. 80 euro per ton in this study) which drastically increases the climate costs. In case similar shadow prices would have been used, climate costs would have been 16 billion euros in 'Are trucks taking their toll', which is in line with this study. As for air pollutant emissions, we have changed the approach to estimate the total GHG emissions; instead of a bottom-up approach we applied a top-down approach[20]. This change in approach undoes the reduction in vehicle kilometres and emissions per kilometre.

Upstream emissions
Upstream emissions were not included in the previous study.

Noise
The noise maps which Member States have to publish provide much more detailed information on the number of people exposed to the different noise levels. At the time of the previous study, this was not yet available. Hence, the methodology of both studies is significantly different. The methodology for this study was also used in CE Delft et al., 2011, which reports noise costs of HGVs of 3.5 billion euros in the EU27 in 2008, which therefore aligns better with the results of this study. The difference is likely to be caused by a decrease in vkms of HGVs (and hence in the attribution of the total road noise costs to the different road modes) and by measures that have been taken to reduce noise levels in the meantime (e.g. noise walls).

Accidents
External accident costs are roughly 45% lower in this study compared to the previous one. This is mainly the result of a reduction in the number of fatalities and injuries due to traffic accidents in 2013 compared to 2006. For example, the number of fatalities that is allocated to HGVs have been reduced from approximately 6,500 in 2006 to 4,000 in 2013, while the number of severe injuries have been reduced from approximately 70,000 in 2006 to 15,000 in 2013.

Congestion
The congestion costs in this study are significantly higher compared to the values presented in the previous study. The main explanation for this difference is methodological. In the previous study a rough estimation of the total congestion costs was based on results of a literature review, while in this study also the results of model exercises were included as upper bound of the congestion costs. The latter are significantly higher than the values found in literature, resulting in higher average congestion costs.

Infrastructure
The infrastructure costs estimated in this study are in the same range as in 'Are trucks taking their toll?'. The slight increase in infrastructure costs are mainly explained by corrections made for GDP developments and inflation and an increase of the road network length.

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[20] As explained in Footnote 9, applying a bottom-up approach in this study as well results in considerably lower total GHG emissions. As for air pollutant emissions, this is mainly caused by the use of lower vehicle kilometer figures (from Eurostat instead of TREMOVE) in the current study compared to the previous one. We refer to Footnote 9 for a more detailed discussion on this issue.

9.3 Discussion on methodologies and data quality

The external and infrastructure costs presented in this study have been based on the latest scientific evidence and methodologies. In general, the scientific basis for the various cost categories is quite advanced. The data basis is generally good, but differs per cost category. Particularly for congestion costs and infrastructure costs consistent European databases are missing. As a consequence, these costs are based on model exercises and/or (a few) national studies, which results in a rather high level of uncertainty.

The valuation of GHG emissions is rather uncertain, which is closely linked to uncertain but potentially dramatic damages of climate change. To reflect this large uncertainty, we have presented a range for the costs of GHG emissions. Furthermore, there is a considerable uncertainty on the total GHG emissions of HGVs, as statistics available on emissions and traffic performances of these vehicles are not consistent. The same holds for the total air pollutant emissions. For air pollution and noise further study on their health impacts and methods to valuate them are recommended. For air pollution, particularly the health impacts of NO_2 and ultra-fine particles are probably not completely reflected by the state-of-the-art shadow prices (CE Delft; Free University Amsterdam, 2014); (WHO, 2013). For noise, increasing evidence on the impact of traffic noise on cognitive impairment and different types of cardiovascular diseases has become available (WHO, 2011). However, this evidence is not yet reflected in the most recent shadow prices. Therefore, it may be assumed that the external costs of air pollution and noise, as estimated in this study, are an underestimation. Additionally, for noise the total external costs are underestimated due to the fact that adverse impacts on noise levels below 55 dB(A) are not taken into account due to a lack of data on the number of exposed people to these noise levels. With respect to accident costs, relatively large uncertainties are related to the valuation of immaterial costs of injured casualties, as for these types of casualties no specific valuation factors exist.

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Annex A Methodologies to estimate external costs

A.1 Introduction

Externalities are not traded on actual markets and hence no market prices are available for them. Therefore, alternative approaches are used to quantify and monetarise external costs. In this annex we briefly discuss the main methodological elements of these approaches. A more extended discussion can be found in Ricardo-AEA et al. (2014) and CE Delft et al. (2008).
The approach to estimate infrastructure costs is not discussed in this annex, as these costs can be estimated based on market prices.

Total external costs of transport can be estimated based on a top-down or bottom-up approach. Both approaches are discussed in Section A.2.
Next, methods to estimate shadow prices (i.e. constructed prices for goods of production factors that are not traded on actual markets) of external costs of transport are presented in Section A.3. Finally, the value transfer procedure applied in this study is explained in Section A.4.

A.2 Top-down and bottom-up approach

To estimate the external costs of transport both a bottom-up and top-down approach can be applied. In this study we use a bottom-up approach to estimate the external costs of air pollution, GHG emissions and emissions of fuel production, while for the estimation of the external costs of accidents, noise and congestion a top-down approach is applied.

In a bottom-up approach, first the impacts of an individual vehicle are estimated (e.g. amount of emissions per vehicle kilometre), which are subsequently translated to overall impacts (per vehicle category) by multiplying them by the total number of vehicles (or vehicle kilometres). The overall impacts (e.g. total PM emissions of HGVs) are multiplied with relevant shadow prices to estimate the total external costs. In a top-down approach, the starting point is the total impact of road traffic (e.g. total number of people exposed to road traffic noise). Based on this information the total external costs of road traffic are estimated (by using relevant shadow prices), which are subsequently allocated to different vehicle kilometres based on appropriate cost drivers (e.g. in case of noise, vehicle kilometres corrected by noise weight factors).

A.3 Damage cost and abatement cost approach

Shadow prices are a crucial element in the estimation of external costs (both in bottom-up and top-down approaches). As mentioned before, externalities are not traded on actual markets and hence no market prices are available for them. Therefore, (shadow) prices have to be constructed for externalities by applying alternative approaches. In general, two types of approaches can be distinguished: the damage cost approach and the abatement cost approach.

The *damage cost approach* valuates all damage experienced by individuals as a result of the existence of an externality (e.g. health impacts due to air pollution). Since often no market prices are available for the damage experienced, the willingness to pay (WTP) of individuals to (partly) avoid the damage is measured to obtain a measure of individual preferences. There are several methods available for estimating WTP, falling broadly in two categories: stated preference methods and revealed preference methods. Stated preference methods use questionnaires to assess people's WTP for avoiding (negative) externalities. Revealed preference methods, on the other hand, estimate the WTP based on price developments on other economic markets, e.g. the real estate market. For example, the WTP to avoid transport-related noise nuisance can be derived from variations in house prices, determined partly by differences in ambient noise levels.

The abatement cost approach estimates shadow prices by determining the cost to achieve a particular policy target (e.g. EU CO_2 reduction targets). This is done by estimating an abatement cost function, which provides a proxy for the supply of environmental quality. It determines how much it would cost to supply an additional level of environmental quality (e.g. reduction of one additional kilogram NO_x). The shadow price is determined to find on the abatement cost curve the costs that are required to realise the policy target set. The assumption is that these policy targets reflect collective preferences with respect to the externality concerned.

In general, economists prefer the damage cost approach to estimate the WTP of individuals to avoid externalities, as this method directly measures the WTP. However, if the (physical) impacts of externalities are hard to estimate (as is the case for climate change) or if clear policy targets are set for a specific externality, the abatement cost approach may be preferred.

A.4   Value transfer procedure

In all estimation approaches described above, shadow prices are used to monetarise the externalities of transport. Shadow prices reflecting the most recent scientific evidence on the impacts of the various externalities are applied in this study. These are gathered from European studies, in which they are often defined for a specific EU country. However, as mentioned by CE Delft et al. (2008), it is often assumed that shadow prices are linked with income: if people's income increases, their WTP to avoid externalities also increases (i.e. avoiding (negative) externalities can be regarded as a luxury good), and hence shadow prices increases. According to NEEDS (2008) this relationship is not completely linear; it can be defined by an income elasticity of 0.85 (meaning that a 10% increase in income results in 8.5% higher shadow prices).

To take the impact of income level on shadow prices into account, a value transfer based on GDP per capita (PPP adjusted) is applied to estimate country specific (or EU average) shadow prices. More specifically, the following formula is used: $SP_i = SP_R \times \left[\frac{Y_i}{Y_R}\right]^{\varepsilon}$

where:
SP = shadow price
Y = GDP/capita
i = country for which the shadow price is calculated
R = reference country, for which the shadow price is known
ε = income elasticity