Health impacts and costs of diesel emissions in the EU

CE Delft

Committed to the Environment

Health impacts and costs of diesel emissions in the EU

This report was prepared by:

Delft, CE Delft, November 2018

Publication code: 18.4R30.140

Diesel / Emissions / Air pollution / Effects / Health / Costs / Policy

Client: European Public Health Alliance (EPHA)

Publications of CE Delft are available from www.cedelft.eu

Further information on this study can be obtained from the contact person Huib van Essen (CE Delft).

CE Delft
Committed to the Environment

Through its independent research and consultancy work CE Delft is helping build a sustainable world. In the fields of energy, transport and resources our expertise is leading-edge. With our wealth of know-how on technologies, policies and economic issues we support government agencies, NGOs and industries in pursuit of structural change. For 40 years now, the skills and enthusiasm of CE Delft's staff have been devoted to

Content

Summary

Background and objective of the study

Air pollution is a major environmental contributor to public health problems worldwide. The World Health Organization (WHO) estimates the number of premature deaths which can be attributed to ambient air pollution to be over 4 million annually (WHO, 2018). The scientific literature is clear that air pollution has large adverse impacts on human health.

In this study, the current social costs (both market and non-market) of road vehicle diesel emissions in the EU28 are assessed, as well as the social benefits of phasing out diesels and switching to electric road and other alternative forms of zero emissions mobility. For nine separate EU Member States, the study has been performed in more detail, by looking at what part of the national public budgets went to health costs related to diesel road vehicle emissions and how much can be saved by their governments when making a switch to electric road vehicles. The selected countries are Austria, Bulgaria, Estonia, Germany, Hungary, Poland, Romania, Slovenia and Spain. Factsheets with results per country can be found in the Annexes.

Health effect of air pollutants

The main pollutants from road transport are particulate matter (PM) and NO_x. Other air pollutants from road transport are ozone (a secondary pollutant), non-methane volatile organic compounds (NMVOC) and polycyclic aromatic hydrocarbons (PAH). The main health effects of these air pollutants are summarized in Table 1. However, there is emerging evidence that pollutant emissions may also cause other kinds of health impacts such as diabetes type 2, prenatal or postnatal effects such as low birth weight and premature birth and conditions to the central nervous system, such as Alzheimer's disease and depression.

Ambient particulate matter is ranked as the 6th risk factor for total deaths globally, through cancer, lower- and chronic respiratory diseases and cardiovascular diseases. This makes it the most harmful element of diesel exhaust to the human health. Particulate matter from diesel exhaust is so harmful because it mainly consists of (ultra)small particles that can penetrate far into the human body. The evidence of adverse health impacts of NO_x have long not been attributed to the compounds itself (mainly NO_2), but rather to $PM_{2.5}$ and ozone as these are formed by NO_x. However, in recent years experts have stated that substantial evidence has become available for health effects of both short-term and long-term exposure directly attributional to NO_2.

Table 1 - Proven and probable causally related health effects of exposure to NO_2, $PM_{2.5}$, ozone, NVMOCs and PAHs

	Effect proven		Effect probable	
	Short term exposure	**Long term exposure**	**Short term exposure**	**Long term exposure**
$PM_{10}/PM_{2.5}$ (Dutch Health Council, 2018) (HEI, 2018)	– Cardiovascular effects – Respiratory effects – Acute mortality (Cardiovascular) – All cause mortality	– All-cause mortality – Lung cancer	Respiratory effects	
Ozone (HEI, 2018), (Dutch Health Council, 2018)	Respiratory effects (including acute respiratory mortality)	COPD	– All-cause mortality – Cardiovascular effects	– Respiratory effects – Incidence of asthma in children
NO_2 (EPA, 2016), (COMEAP, 2015)	Respiratory effects		– Cardiovascular effects – Acute mortality	– Incidence of asthma in children
NMVOCs		Cancer		
PAHs (WHO Europe, 2015)		Cancer		

Costs of road air pollution in the EU in 2016: € 67 to 80 billion

Based on the latest scientific evidence, the costs of air pollution have been estimated. When calculating with the COPERT emission factors, the total costs of road traffic related air pollution in the EU28 in 2016 was € 66,700,000,000 (€ 66.7 billion). The share of diesel vehicles in these cost amounts 83%. NO_x emissions have the largest share in the total costs (both health and non-health related) of air pollutants (65%), followed by $PM_{2.5}$ (32%).

In the nine Member States that have been assessed in detail, about three quarter of the total health costs of air pollution are borne by governments and compulsory insurances. When assuming that this is representative for the EU28 as a whole, these total cost of road emission air pollution in the EU amounts about € 45.4 billion a year.

Recent work in the TRUE Initiative has revealed that real world NO_x emission factors for cars are higher than expected and reported by COPERT (and also by other sources). Therefore a sensitivity analysis has been carried out. When calculating with adjusted emission factors (based on TRUE), the total costs of road traffic related air pollution (both health and non-health related) in the EU28 in 2016 was € 79.8 billion, so 20% higher than when using COPERT, 75% of these costs caused by diesel.

Costs of air pollution in 2030 significantly lower

Both NOx and PM2.5 emission are expected to decrease significantly between 2016 and 2030. With COPERT emission factors, the total of the health and non-health related costs of road traffic related air pollution in the EU28 in 2030 is estimated at €19.5 billion; of which € 18.3 billion are health-related, 71% lower than in 2016. When using the adjusted emission factors (TRUE), the sum of the 2030 health and non-health related costs amount €25.6 billion (of which € 23.3 billion are health-related), 68% lower than in 2016. The health costs borne by governments and compulsory insurances are with these emission factors €17.4 billion, more than € 35 billion (and so 67%) lower than in 2016.

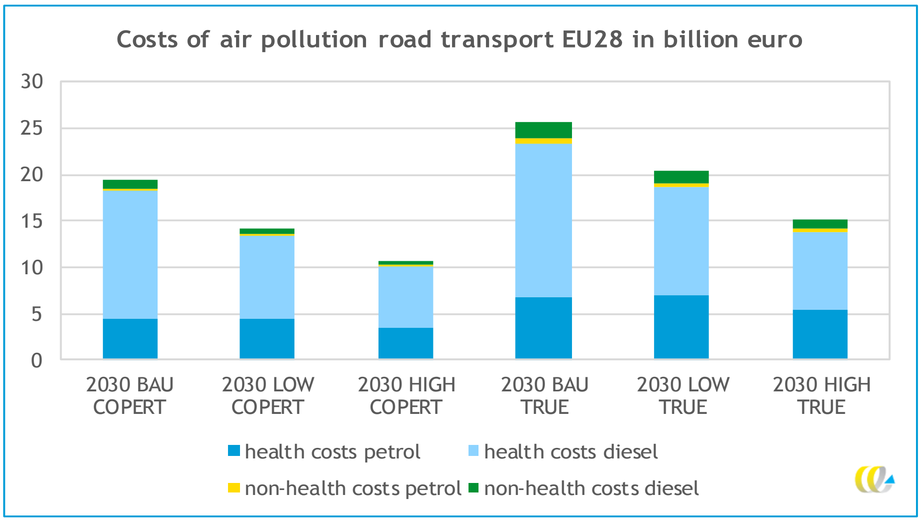
The cost factors used reflect the cost for which the causal relation between emissions and health impacts has been proven. However, for some potential health problems, a causal relation is suspected but proven (yet). When it turns out that these relations can be proven by ongoing research, this will also result in higher cost estimates. Other uncertainties are the speed of fleet renewal and the resulting shares of different Euro standards in the 2030 vehicle fleet and remaining uncertainties with respect to emission factors related to the effectiveness and robustness of emission reducing technology.

Impacts of additional policies

Stringent emission policies can result in large reduction of societal damage costs of air pollution and significant cost saving for governments and health insurers. Two scenarios have been assessed. The low ambition scenario assumes a faster uptake of zero emission vehicles than in the baseline and also a ban of all pre-Euro 6 vehicles in all major cities (100,000 + inhabitants). In the high ambition scenario the uptake of zero emission vehicles is even higher and the ban applies to all roads. In addition, it assumes road pricing and various urban policies to reduce car use in cities.

The Low ambition scenario reduces the total cost for the EU28 by 27% compared to the Baseline in 2030; the High ambition scenario by 46%. The reduction percentages compared to 2016 are 79% (low ambition scenario) and 84% (high ambition scenario). In the high ambition scenario, the annual cost savings of these total reductions in 2030 amount € 56 billion compared to 2016 and € 9 billion compared to the baseline scenario in 2030. When using the adjusted emission factors, the impacts of the scenarios are rather similar. In the Low ambition scenario the total cost for the EU28 are reduced by 20% compared to the Baseline in 2030 and 74% compared to 2016. In the High ambition scenario, costs are reduced by 41% compared to the baseline in 2030 and even 81% compared to 2016. In the high ambition scenario, the annual cost savings of these total reductions in 2030 amount € 64 billion compared to 2016 and € 11 billion compared to the baseline scenario in 2030. Figure 1 shows the 2030 costs in the various scenarios for 2030, both with COPERT and TRUE emission factors.

Figure 1 - Comparison of total Air Pollution Costs EU28 in 2030 BAU and policy scenarios – for both COPERT and adjusted emission factors based on TRUE Initiative



Summary of key results

Table 2 summarizes the main results of this study. The lion share of all air pollution costs from road transport is caused by diesel emissions. When using TRUE-based emission factors, costs are higher than when using COPERT, but the ratios between costs for 2016 and for the various scenarios in 2030 are very similar.

The results makes clear that an ambitious policy strategy for reducing air pollutant emissions can lead to annual cost savings of € 9 to 12 billion a year (depending on the emission factors used) and possibly even more when all health impacts of air pollution would be fully understood.

Table 2 - Main results: costs of air pollution from road transport in EU28 in 2016 and various scenarios for 2030

Costs in million €	Total costs	Cost savings compared to 2016	Health costs	Health costs (% of total)	Health costs borne by governments (73% of health costs)
COPERT					
2016	66,709		62,081	93%	45,362
2030 - BAU	19,484	47,225	18,311	94%	12,956
2030 - LOW	14,143	52,566	13,432	95%	9,815
2030 - HIGH	10,584	56,125	10,091	95%	7,374
TRUE					
2016	79,820		72,348	91%	52,865
2030 - BAU	25,618	54,202	23,337	91%	17,384
2030 - LOW	20,388	59,432	18,586	91%	13,581
2030 - HIGH	15,065	64,755	13,744	91%	10,043

1 Introduction

1.1 Background

Air pollution is a major environmental contributor to public health problems worldwide. The World Health Organization (WHO) estimates the number of premature deaths which can be attributed to air pollution to be around 8 million annually (WHO, 2018). A distinction can be made between household air pollution — for instance caused by heating and cooking — and ambient air pollution, part of which is due to transport emissions. Ambient air pollution globally causes 4 million deaths each year.

For Europe, the WHO estimate for the number of premature deaths attributed to air pollution is over 500,000 (WHO Europe, 2018), with 400.000 early deaths in the EU-28. In contrast to other regions in the world, household air pollution does not play a large part in this number compared to outdoor air pollution. In this respect, (road) transport contributes significantly to air pollution in the European region, which is confirmed by data from the European Environmental Agency (EEA, 2018). In Europe, road transport is a major contributor to the emission of primary particulate matter (PM_{10} and $PM_{2.5}$, amongst which soot), non-methane volatile organic compounds (NMVOCs), and CO, as well as the largest source of NO_x emissions (which includes NO and NO_2). Some of these gases and particles are — next to being harmful themselves — precursors for secondary pollutants as well. These are not directly emitted by a source, but rather formed by the other (polluting) compounds in the air. An example of such a secondary pollutant of which exposure to it is associated to adverse health effects, is ozone (O_3). Air pollution is a phenomenon that does not know borders — an emitted pollutant does not always stay within the country it was emitted in. As such, it makes sense to analyze and address this problem on a broader-than-country scale.

1.2 Objective and scope

In this study, the current social costs (both market and non-market) of road vehicle diesel emissions in the EU28 are assessed, as well as the social benefits of phasing out diesels and switching to electric road and other alternative forms of low or zero emission transport such as public transport, walking, biking. As such, different scenarios for the amount of diesels versus electric road vehicles in 2030 as compared to 2016 have been evaluated. For nine separate EU member states, the study has been performed in more detail, by looking at what part of the national public budgets went to health costs related to diesel road vehicle emissions and how much can be saved by their governments when making a switch to electric road vehicles. The selected countries are Austria, Bulgaria, Estonia, Germany, Hungary, Poland, Romania, Slovenia and Spain.

Of course, (diesel) road vehicles are not the only source of air pollution. Other major sources such as aviation, shipping, agriculture (ammonia) and coal-fired power plants (PM, NO_x, sulfur dioxide) have not been analyzed in this study, but it should be noted that they contribute to the problem as well.

1.3 Approach and outline

The study as described in Section 1.2, has been divided into three main parts: a literature overview (including expert interviews) about the impacts of air pollution on human health (Chapter 2), establishing the (health) costs of (diesel) road transport related air pollutants (Chapter 3) and the evaluation of different scenarios for phasing out diesel road transport (Chapter 4). In Chapter 5, the overall conclusions of this study are presented. Factsheets with results per country can be found in the Annexes.

2 Impacts of air pollution

Diesel exhaust emissions contribute considerably to air pollution in Europe. For this chapter, the human health impacts of air pollutants from diesel exhaust have been reviewed. First, the pollutants will be introduced by explaining their occurrence, the way they negatively affect the human body and what health effects can be causally related to them, based on scientific evidence.

2.1 Diesel exhaust air pollutants

Many air pollutants which are associated to negative human health effects, are emitted directly or indirectly by diesel road vehicles. Here, an overview is given. The health effects of air pollutants are determined by a combination of epidemiological, toxicological and clinical studies.

Not every European citizen is exposed to the same level of air pollution due to diesel exhaust as others. For instance, the level of exposure in urban areas is much higher than in rural areas. Similarly, people living close to a road, will on average breath higher concentrations of pollutants than people who do not. Children, elderly, pregnant women and people who already suffer from diseases such as asthma and chronic obstructive pulmonary disease (COPD), will be more sensitive to air pollutants and experience more health effects than others (for children and prenatal, see for instance (WHO, 2018)). Additionally, the impact varies with duration and concentration of exposure. Short-term exposure to air pollutants is exposure of a few hours to a week or month, while long-term exposure can be of several years. Additionally, studies are emerging showing that children and babies — as they are closer to the ground —inhale higher concentrations of air pollution caused by road transport than adults do (Sharma & Kumar, 2018). All of these factors influence the effect of air pollution on an individual.

It could be wondered whether negative health effects of air pollution outweigh the positive health effects of exercising, such as cycling or walking next to a road. Some studies have been carried out about this, but no consistent answer has been found yet. The WHO advises that the benefits of exercising outweigh the negative effects of air pollution. A 2010 review study showed that this is indeed the case (Hartog, et al., 2010). A recent study on this topic in London showed that it highly depends on the amount of traffic directly next to where you exercise: at some locations the positive effects outweigh the negative, and at other it is the other way around (Sinharay, et al., 2018).

In Table 3, scientifically proven and probable causally related effects of the most important diesel health pollutant are shown. Sulfur dioxide (SO_2) has not been described here as, since fuels for road traffic in Europe are desulfurized; they do not significantly account anymore for the health effects of road traffic emissions.

For most of the diseases/symptoms related to air pollution, the evidence tells that it is exacerbated by the given pollutant rather than that exposure to the air pollution has caused its incidence. The reason for this is that it is very hard to prove that only one environmental factor (here: air pollution, or even more specific, one air pollutant) can be the cause of the incidence of a disease. Exacerbations (short-term changes) of symptoms are much easier to prove — in that way, air pollution would be an additional risk factor.

Table 3 - Proven and probable causally related health effects of exposure to NO_2, $PM_{2.5}$, ozone, NVMOCs and PAHs

	Effect proven		Effect probable	
	Short term exposure	**Long term exposure**	**Short term exposure**	**Long term exposure**
PM_{10}/$PM_{2.5}$ (Dutch Health Council, 2018) (HEI, 2018)	– Cardiovascular effects – Respiratory effects – Acute mortality (Cardiovascular) – All cause mortality	– All-cause mortality – Lung cancer	Respiratory effects	
Ozone (HEI, 2018), (Dutch Health Council, 2018)	Respiratory effects (including acute respiratory mortality)	COPD	– All-cause mortality – Cardiovascular effects	– Respiratory effects – Incidence of asthma in children
NO_2 (EPA, 2016), (COMEAP, 2015)	Respiratory effects		– Cardiovascular effects – Acute mortality	– Incidence of asthma in children
NMVOCs		Cancer		
PAHs (WHO Europe, 2015)		Cancer		

Nitrogen oxides

Primary nitrogen oxides (NO_x) from combustion of fuels is mainly composed of NO which can be oxidized to secondary NO_2 in the presence of oxygen (from air). However, it should be noted that the share of primary NO_2 in diesel vehicle exhaust is higher than in petrol vehicle exhaust, as NO is already oxidized in the diesel vehicle's exhaust treatment system. NO_x is part of the gas phase emissions of diesel engines.

NO_x enters the body by inhalation and is adsorbed through the respiratory system tissue into the circulation (Finnish Institute for Occupational Health, 2016). The evidence of adverse health impacts of NO_x have long not been attributed to the compounds itself (mainly NO_2), but rather to $PM_{2.5}$ and ozone as these are formed by NO_x. Double-counting of health effects has to be avoided. However, in recent years experts have stated that substantial evidence has become available for health effects of both short-term and long-term exposure directly attributional to NO_2 (COMEAP, 2015) (EPA, 2016). Now a relation between short-term NO_2 exposure and respiratory symptoms such as inflammation, aggravation of symptoms in asthma patients and aggravation of allergic reactions in the respiratory tract have been proven. Additionally, the incidence of asthma in children due to long-term exposure to NO_2 is probable. However, experts in this field say that the discussion about whether or not NO_2 is directly accountable for negative health effects caused by air pollution, is still open. This is illustrated by the recently published statement of COMEAP on NO_2 mortality effects: experts of the COMEAP group state that they were not able to reach consensus about all the outcomes in the report (COMEAP, 2018). Nevertheless, there is consensus on that this is an important discussion especially for diesel road vehicles, as particulate matter filters and improved cars causes a decline in the emission of PM, increasing the share of NO_2.

NO_x emissions from diesel vehicles have been in the spotlights in recent years, as they were subject of the 'Dieselgate'. During this scandal, it was discovered that several car manufacturers had manipulated NO_x emissions tests for years by installing software which could detect whether the car was in a laboratory or on the road and adjust its emissions accordingly. In a study by Jonson et al. (J.E. Jonson, 2017) it is estimated that 10,000 premature deaths of adults over 30 in 2013 in the EU28 and Switzerland, can be attributed to NO_x emissions from diesel cars and light commercial vehicles. Of these, 50% could have been avoided had the on-road NO_x emissions been at the level of the laboratory tests.

Ozone

Tropospheric (also known as ground-level) ozone (O_3) is a secondary air pollutant. It is formed via multiple reactions between NO_x, CO and volatile organic compounds (VOCs), in the presence of light (e.g. photo-chemically). Under certain weather conditions, a high concentration of ozone in the air can lead to smog which is especially a problem in warm urban areas. In some places the occurrence of smog is highly related to the season.

Short-term exposure to ozone has proven to be causally related to respiratory effects such as inflammation, aggravation of asthmatic symptoms, increase in hospital admissions and respiratory related acute mortality. Additionally, it is a cause of chronic obstructive pulmonary disease (COPD) and is probably related to cardiovascular effects and acute all-cause mortality. In warm weather, acute impacts of elevated ground-level ozone levels can be experienced by both healthy people and people with already reduced lung function. Long-term exposure may cause an increase of incidence of asthma amongst children. Globally, ozone is ranked as the 33th risk factor for total deaths, due to its severe causal relation to chronic respiratory diseases (HEI, 2018).

Particulate matter

Particulate matter is a collective term for liquid and solid particles in the air (also known as aerosols). Different particulates are commonly classified by their size: PM_{10}, $PM_{2.5}$ and $PM_{0.1}$. The subscript means: "with an aerodynamic diameter of {*number*} μm and smaller".
All three size groups of PM are associated with diesel road vehicles. However, whereas PM_{10} pollution can be attributed to the wear of brakes, tires and roads, $PM_{2.5}$ and $PM_{0.1}$ are mainly related to the exhaust emissions from the tailpipe of diesel vehicles. Next to primary PM directly emitted by diesel vehicles, secondary PM is mainly formed through chemical reactions between SO_2, NH_3, NO_x and VOCs.

Ambient particulate matter is ranked as the 6th risk factor for total deaths globally, through cancer, lower- and chronic respiratory diseases and cardiovascular diseases (HEI, 2018). This makes it the most harmful element of diesel exhaust to the human health. The reason for this is that the most dominant way the human body takes up air pollutants is by breathing. After inhalation, they can spread throughout the entire respiratory system — where they will finally end up depends mainly on their size. The severance of the harm caused is largely determined by how far a certain pollutant can penetrate into the human body. The smaller a pollutant is, the further into the tissue of the lungs it can get.
That's the reason why the particulate matter from diesel exhaust is so harmful: it mainly consists of $PM_{2.5}$ and $PM_{0.1}$. Experts interviewed for this study, stated that for ultrafine particulate matter ($PM_{0.1}$), the toxicological evidence that it is very harmful exists. However, these particulates do not travel far; about 300 meters away from the emission source, the concentration of $PM_{0.1}$ will be around the background concentration. This makes

it very hard to prove its specific impacts in epidemiologic studies and to distinguish these from the impacts of bigger $PM_{2.5}$ emissions.

Diseases which have been proven to be causally relatable to $PM_{2.5}$ (and $PM_{0.1}$) are ischemic heart disease, stroke, lung cancer, lower respiratory infections, and chronic obstructive pulmonary disease (COPD) (HEI, 2018). Both long- and short-term exposure to $PM_{2.5}$ has negative respiratory and cardiovascular effects, including acute and chronic cardiovascular mortality. More research is necessary to prove a relation between exposure to $PM_{2.5}$ and other adverse health effects such as neurological disorders and diabetes, as well as birth defects (See textbox “Emerging evidence for new diseases related to air pollution” at the end of this section).

Soot particles (measured and also known as elemental carbon or black carbon) are part of the particulate matter ($PM_{2.5}$ and $PM_{0.1}$) emitted by — amongst other sources — diesel exhaust systems. It only makes up a small part of all the particulate matter in ambient air, but contributes largely to the adverse health effects related to it. In the past years, it has become more clear that, for human health, it is one of the most dangerous elements of $PM_{2.5}$ emitted by road traffic. In streets with a high amount of traffic, the concentration of these particulates in the air is a 100% higher than in a street with little traffic (RIVM, 2013). The health effects associated with them do not only lie in their small size, but as well in the fact that they can carry traces of heavy metals or PAHs and NMVOCs on their surface: these enter your body when soot does. Soot has been characterized as being a carcinogen by the International Cancer Research Organization.

According to the experts interviewed, the amount of studies about the health effects of PM_{10} emitted by the wear of tires and breaks of road vehicles is increasing. One of the main reasons for this is sharp reduction in tailpipe emissions and the uptake of electric vehicles that have no tailpipe emissions at all. Therefore the reduction of emissions from brakes and tires becomes relatively more important.

NMVOCs

Non-methane volatile organic compounds (NMVOCs) are formed upon incomplete combustion of fuels such as diesel, which are found in the gas phase of diesel exhaust. They are a great contributor to the formation of ozone and as such indirectly responsible for health effects caused by it. Additionally, some NMVOCs have been classified as carcinogens, amongst some of which occur in diesel exhaust. Examples are benzene, formaldehyde and 1,3-butadiene (Wierzbicka & others, 2014).

PAHs

PAHs are polycyclic aromatic hydrocarbons (organic compounds containing two or more rings), which can be found in both the gas phase (mostly those with two or three rings) as bound to the particulates of diesel exhaust (the larger PAHs with more than five rings). The particulate bound PAHs are of most damage to human health. They have causally related to the carcinogenic nature of diesel exhaust (WHO, 2010). Additionally, new evidence is arising for its non-cancer health effects, such as cardiovascular diseases, neurological and prenatal effects (WHO Europe, 2015).

Emerging evidence for new diseases related to air pollution

Whether there is a proven causal relation between a certain pollutant and a health effect, is decided through formal evaluation and meta-analyses of toxicological, epidemiological and clinical studies and by expert groups for an authoritative (health) agency. This is only done when enough and different types of studies show the same result, while for the opposite (no relation between an air pollutant and a health effect), there is no reliable evidence. Because of this procedure and the fact that especially epidemiological studies are not easy to carry out, there are quite some health effects which have been linked to air pollution, but for which the causal relation has not been proven yet.

Examples are diabetes type 2 (T2DM, see for instance (Eze, et al., 2015)), prenatal or postnatal effects such as low birth weight and premature birth and conditions to the central nervous system, such as Alzheimer's disease and depression. Studies conducted about these diseases have not yet been abundant/conclusive enough to have given a homogeneous answer as to whether their relation with exposure to air pollutants should be included in the list of causally related air pollution health effects.

Health effects specifically linked to diesel exhaust

The following diseases and conditions have been specifically linked to air pollution from diesel exhaust:
- lung cancer;
- asthma;
- chronic Obstructive Pulmonary Disease (COPD);
- stroke;
- ichaemic heart disease;
- acute respiratory infection;
- dementia (probable);
- diabetes type 2 (probable).

Non-health related impact of diesel exhaust air pollutants

Next to impact on human health, diesel exhaust emissions have a negative impact on other things. Even though those are out of the scope of this study, they are worth noting as including them in the (social) costs of the air pollution caused by diesel road vehicles is common and increases these costs.

NO_x

Nitrogen oxides form acidic compounds in the air, lead to acidification of waters and soil, thus negatively affecting ecosystems. Through the air, acidic compounds affect plants (amongst which crops) and buildings as well. Additionally, elevated levels of tropospheric ozone can be attributed to NO_x, and as such its negative impact.

Ozone

Next to humans (and animals), plants can be negatively affected by ozone as well. It can enter the plant's cells, making them more sensitive and reducing their growth and ability to perform photosynthesis. Additionally, materials and products such as rubber, plastics, textile and paint are sensitive to ozone.

Particulate matter

Particulates can deposit on buildings and streets, visually affecting them and resulting in soiling. This leads to increased cleaning costs. Elemental carbon (soot, black carbon) contributes to global warming both directly by absorbing heat and indirectly by depositing on ice and snow, darkening the white, reflective surface of the earth.

2.2 Air quality guidelines from WHO and EU

As over the recent decades more and more proof has shown that air pollution is related to adverse health effects, both the European Union (through the Ambient Air Quality (AQQ) Directives) and the World Health Organization have introduced exposure limits for NO2, PM10 and PM2.5. In addition, there is a vast body of legislation tackling air pollution at the source, that is reducing emissions including the NEC Directive, the Euro standards and the industrial emissions Directive. An important difference is that the limit values set by the EU are legally binding, while the WHO values are recommendations. However, the latter ones are solely health-based, while EU limit values are the result of political compromise.

As can be seen in Table 4, the air quality standards for nitrogen oxide and ozone are equal for the EU and WHO, but for both types of particulate matter, the WHO norm is lower than for the EU (e.g. the EU is less strict when it comes to emitting particulate matter).
The guidelines for the WHO and the EU were established in 2005 and 2008, respectively.

Recently, experts have called for an update of the WHO air quality guidelines, based on the increase in evidence of causally relatable health effects to both short- and long-term exposure to for instance ozone and NO_2 that has become available in the last years (WHO Europe, 2015). An update of the WHO air quality guidelines is expected in 2020 (WHO, 2018a).

Additionally, the EU air quality guidelines are currently undergoing a fitness check which is expected to be finished in 2019 (European Commission, 2018). After this, it could be that the EU guidelines will be re-opened for evaluation again as well.

Table 4 - Air quality guidelines WHO (WHO, 2018) and EU (European Commission, 2017)

	EU	WHO
$PM_{2.5}$	25 µg/m^3 annual mean	10 µg/m^3 annual mean 25 µg/m^3 24-hour mean
PM_{10}	40 µg/m^3 annual mean 50 µg/m^3 24-hour mean (limit can be exceeded 35 times per year)	20 µg/m^3 annual mean 50 µg/m^3 24-hour mean
NO_2	40 µg/m^3 annual mean 200 µg/m^3 1-hour mean (limit can be exceeded 18 times per year)	40 µg/m^3 annual mean 200 µg/m^3 1-hour mean
Ozone	120 µg/m^3 daily 8-hour mean (limit can be exceeded 25 days averaged over 3 years)	100 µg/m^3 8-hour mean
PAHs	1 ng/m^3 (expressed as concentration of benzo(a)pyrene)	-

As mentioned in the previous paragraph, one of the reasons for re-evaluating air quality guidelines is the emerging evidence on the link between health effects such as pre- and postnatal effects, diabetes and neurological conditions and air pollution, which have gained much more attention in studies on (ambient) air pollution. Also, the evidence on direct health effects caused by specific air pollutants such as NO_2 has accumulated in recent years. Additionally, research is being conducted at more locations in the world, which can help quantify the effects of different level of air pollution and create concentration-response curves which are more locally applicable. Finally, more is known about what particles and compounds from air pollution are the source adverse human health effects (for instance, for PAHs). Not only can air quality guidelines can be updated by reanalyzing the available studies on the health effects of air pollution, but accordingly, updates can be made for relative risk factors and concentration response functions and new ones can be created.

3 Costs of air pollution in 2016

3.1 Introduction

In this chapter, the costs of air pollution related to road traffic will be determined. In order to do so, first the valuation of the negative effects of relevant air pollutants has to be performed. The approach of how this was done in this study is described in Section 3.2. That section will describe the valuation approach which was followed to calculate damage costs for 2016. A similar, but slightly adjusted, approach will be used to calculate damage costs for 2030. The results of the approach described in Section 3.2 will be presented in Section 3.3. Here, tables showing the damage costs of road traffic related air pollutants on average and differentiated towards health effects are given.

In Section 3.4 the total costs of road traffic related air pollution are given for the selected countries in this study and the EU28 as a whole. Again, these are presented for overall effects and differentiated towards health effects. For each country that is part of the scope of this study, the part of the air pollution costs borne by their government will be presented in Section 3.5. Section 3.6 presents the results of a sensitivity on the emission factors used. The main uncertainties in the approach and results are discussed in Section 3.7. Factsheets with results per country can be found in the Annexes.

3.2 Approach for valuating emissions

3.2.1 Overview method: impact pathway approach

In order to eventually be able to estimate the health costs of air pollution caused by diesel road vehicles, first a valuation of the health impacts caused by different air pollutants has to be made. This chapter will further elaborate on this method and the outcomes of the method will be given in the form of damage costs (differentiated to health and transport) caused by different air pollutants for the EU28 on average and at member state level for the countries selected in this study.

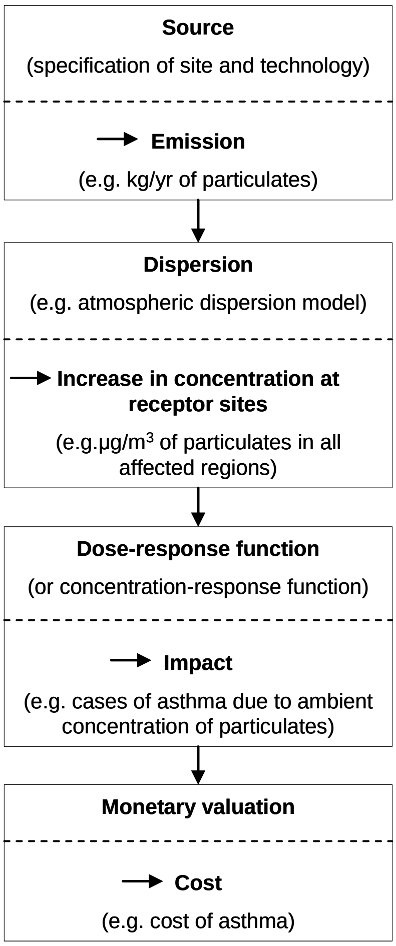
The method used for damage cost estimation is the same as is followed in the Handbook Environmental Prices (CE Delft, 2017). It is based on a combination of two models:
- Economic damage cost estimates, as performed in NEEDS (2008);
- Lifecycle Assessment, as performed in RECIPE (2013).

For the present project especially the NEEDS model is relevant. The core of the NEEDS-project is an Impact-Pathway model (EcoSense) that estimates the relationship between emissions and eventual impacts. We have adapted this model to reflect the most recent insights on the relationship between emissions and damage.

The starting point of the quantification are the NEEDS (2008) results as have been published in e.g. (Desgauilles et al., 2011) and further elaborated in Rabl et al. (2014). Within the NEEDS model, the impact pathway approach is followed, in which an emission – through dispersion – results in an intake at receptor points. The Impact Pathway Approach (IPA) has been used in several international research projects initiated by the European Commission, starting with the original ExternE study implemented in mid-1990s.

The idea behind the Impact Pathway Approach is as follows (see Figure 2). A given activity leads to emissions. In the case of transport emissions, these emissions are primarily emissions to the air (a certain amount of tire wear can end up as emissions to soils or water, but these have not been taken into account in this study). These emissions are subsequently transported through the atmosphere to other regions where they are added to existing emission concentrations. This concentration then leads to changes in 'endpoints' relevant to human welfare. An example of such an endpoint — and the most important endpoint in this study — is human health. The changes can be monetarily valued by quantifying the amount of damage caused at the endpoints. The entire chain from emissions, nuisance and resources through to damage in monetary terms is the subject of the present study. The effectiveness of interventions or policy measures is beyond the scope of this study. Additionally, as mentioned in Chapter 1, other sources of air pollution than (diesel) road vehicles (such as agriculture) have been left out of the scope of this study.

Figure 2 - The Impact Pathway Approach



Source: CE Delft, 2010, based on NEEDS, 2008.

3.2.2 Typology of relevant endpoints

In this study we distinguish three relevant endpoints for which damage costs will be calculated:
1. Human health (morbidity, i.e. sickness and disease, and premature mortality modelled as a reduction in life expectancy).
2. Ecosystem services (biodiversity and crops).
3. Buildings and materials (man-made capital).

The focus of this study is human health and as such damage costs for this endpoint will be presented individually. However, in order to give a more general idea about the damage costs of particular air pollutants, those in which the effects on all three endpoints are taken into account, will be provided as well.

3.2.3 Adjusting the NEEDS and EcoSense modelling results

Since 2009 there have been no further developments of NEEDS and also not of the rival model of CAFE-CBA (IIASA, 2014). The handbooks for shadow prices for Belgium, the Netherlands (CE Delft, 2017) and Germany (UBA, forthcoming) are in their core still based on the NEEDS methodology owing to its far greater transparency. However, one cannot simply take the NEEDS values and apply them to air pollution because the estimation results are over a decade old and many things have changed: background concentration levels, knowledge about impacts from pollution and the valuation framework. For that reason, adaptations to the NEEDS framework must be made. This is possible since we have the possession of a great deal of modelling outcomes from the NEEDS model so that we can make required changes to reflect more recent insights.
In total, five adjustments were made to the NEEDS results. These adjustments are broadly the same as in the Environmental Pricing Handbook (CE Delft, 2017), but they are now applied to the EU context. These five adjustments can be described as follows (all the changes that were made are discussed in the Sections 3.2.4–3.2.8):
1. Concentration Response Functions (Step 3 in Figure 2) have been adapted to the WHO (2013) study. The taken steps are being described in Annex A.
2. The population size and population structure (age cohorts) are based on the most recent data from Eurostat.
3. The influence of the background concentration is estimated on the basis of the relationship between damage and emissions for various emission scenarios from NEEDS (2008). On this basis, by letting all other factors remain the same, we can estimate the impact of a change in emissions on the harmfulness of these emissions. This harmfulness is then the result of the change in the background concentration.
4. The valuation has been adjusted to the most recent insights with respect to valuation. We refer to Section 3.2.7 for a more elaborate discussion about this.
5. Finally, a subdivision was made for both $PM_{2.5}$ and NO_2 to the population density (people living in cities or in rural areas have different damage from pollution). For $PM_{2.5}$ a further distinction was being made to transport emissions and other sources of emissions. For $PM_{2.5}$ and NO_x also specific emission damages from electricity generation have been calculated, as this information may be relevant to estimate the damage costs of electrical vehicles.

3.2.4 Changes in concentration response functions

The NEEDS project was largely based on health impact information as it was presented in the WHO (2006) study on the harmful impacts of air pollution. In 2013 and 2014, the WHO presented a major update of the health impacts of air pollution. In the present study all the concentration response functions (CRFs) used in the NEEDS project were individually checked and discussions were held on whether they still reflect the latest scientific understanding. On this basis, the CRFs for especially ozone pollution (> 35 ppb) and NO_x were adjusted upwards and new impact factors have been included. In addition, a few categories of $PM_{2.5}$ pollution were revised (e.g. impact on asthmatic part of the population from $PM_{2.5}$ pollution).

In Annex A a detailed account of the changes in RR that have been adopted compared to the NEEDS estimate are given. In total we have updated about 7 of the 18 CRF functions in NEEDS and have introduced four new CRF functions of impacts that are reported in the WHO (2013) but have not been taken into account in the NEEDS estimates. The result is an up-to-date and precise calculation of the impacts of air pollution on human health.

The CRFs for $PM_{2.5}$ have been applied to PM_{10} as well taking into account the fraction in PM_{10} that is being $PM_{2.5}$. This is relationship between PM_{10} and $PM_{2.5}$ emissions is based on country-specific emissions of both pollutants as reported by Eurostat (2016 values have been taken). We have assumed that within the EU, 28% of the population is living in areas with annual NO_2 concentrations larger than 20/ug/m^3.

3.2.5 Changes in population

The size and age cohorts of the population matters for estimating the damage costs of air pollution, especially for morbidity, since some impacts (e.g. cardiovascular diseases) only mostly affect elderly people and other impacts (e.g. asthma) only affect younger people. Therefore we have adjusted the age cohorts in the NEEDS study with the demographic statistics from Eurostat for the EU28.

3.2.6 Change in emission concentrations

Parts of the NEEDS model, such as the dispersion matrixes and atmospheric-chemistry models, are not publicly available. However, because there are numerous NEEDS modelling runs available for estimating emission reduction scenarios, the underlying model structure can to a certain extent be derived. It was opted to proceed from the 2010 and 2020 emission scenarios in the NEEDS Excel tool (as used in the EcoSense dispersion model). Recent (2016) EU27 emissions (e.g. EU28 excluding Croatia) were then used to scale to the difference between the 2010 and 2020 values. These results were shared and discussed with atmospheric-chemistry experts and explanations for a rise or fall in damage costs per kg pollutant elaborated

In this way an adjustment was made for the lower background pollutant levels in 2015 and their influence on damage estimates. It proved that this was particularly important for the amount of ammonia in the atmosphere. NH_3, NO_x and SO_2 all react to form secondary particulates, but in the case of NO_x the relationship is linear, while for NH_3 it is quadratic. Thus as long as NH_3 do not decrease twice as fast as NO_x, an additional emission of NO_x and SO_2 will cause more damage because of the available ammonia in the air, as there will be relatively more atmospheric NH_3 for the NO_x and SO_2 to react with. This is the main reason that lower emissions of NO_x and SO_2, if unaccompanied by an equal decline in NH_3 emissions, lead to higher damage costs per kg emission for these pollutants. This impact is included in our estimates because of the basis in the NEEDS modelling results.

3.2.7 Valuation of human health (VOLY)

The VOLY (Value of a Life Year or Value of One Year Lost) has been used in this study to value the impact on human health by air pollution. It can be defined as the willingness of people to pay for one year of additional life expectancy. In literature, many different values for the VOLY have been suggested over the past years. Here, an EU28 VOLY of € 70,000 has been used (based on 2016 prices). For the selected countries, this value has been differentiated.

3.2.8 Differentiation towards source and location of pollution

The values at the level of EU28 represent average values for average emissions in the year 2015. These have been differentiated in three different ways:

1. Towards average values for individual countries which are investigated in this study (Austria, Bulgaria, Estonia, Germany, Hungary, Poland, Romania, Slovenia and Spain).
2. Towards emissions specifically applying for the transport sector and location of pollution (cities/rural).
3. Towards emissions applying for electricity generation (relevant for electrical vehicles).

This differentiation has been done by observing ratios in the NEEDS model between damage costs of EU28 compared to the national averages, and by observing ratios in the literature between the various sources of exhaust emissions (Heatco, 2006; UBA, 2012). This yields insights in the likely damage costs per country for transport emissions.

We, as authors and researchers, fully acknowledge that such an approach where ratios are being used is less preferred than a new modelling effort in which the impact-pathway of emissions through the environment is being modelled for different countries and different heights of exhaust stacks as the damage costs of especially particulate matter depends greatly on the height of the tail pipes. However, this is a very labor intensive trajectory that has only been established in very large pan-European research programs, like ExternE, CASES, Newext, CAFÉ-CBA and NEEDS. Such an effort is out of the scope of this project, which is why we have to use ratios from these bigger projects in order to estimate the likely relationship between the here calculated average EU28 damage costs and the damage cost per type of emission per country. We also observe that such a 'value transfer' approach has been used more frequently in the literature (see e.g. Heatco, 2006; UBA, 2012; CE Delft 2017). The key here is to be transparent about the modifications that have been made to the general EU figures.

Hereafter we will elaborate on the empirical basis of our modifications.

Differentiation between countries

Within the NEEDS project, an Excel tool was developed. From this we have calculated the difference between the individual country estimate of damage costs and the EU28 average, as was reported in the NEEDS background documentation of the Ecosense model resulting in the Excel tool that was put online in 2008. We have used the information from the unknown height of release, damage costs in the year of release, based on average meteorology (assuming equivalent damage from secondary particles as to primary particles)-corresponding to emissions from all sectors. We find here information from the EU28 average and a value per individual MS. This results in a ratio for emissions of NO_x, NH_3, NMVOC, SO_2, $PM_{2.5}$ and PM_{coarse} (e.g. PM with a diameter larger than 2.5 micrometer). For the value corresponding value of PM_{10} we have assumed that this is the sum of the share of $PM_{2.5}$ in the emissions of PM_{10} of that particular country plus the damage of PM_{coarse}.

For the share of $PM_{2.5}$ in PM_{10} we have used information on the national emissions of $PM_{2.5}$ and PM_{10} for the year 2015 in Eurostat.

Differentiation for transport emissions and location

For transport we have used the information from Heatco (2006) that provides YOLL estimates for transport related impacts of emissions of $PM_{2.5}$. The relative risk of $PM_{2.5}$ emissions in Heatco is the same as applied in our study for mortality (which explains over 70% of the damage costs of $PM_{2.5}$), while the impacts on morbidity are only slightly different. We have used this information and applied the VOLY to the YOLL estimates. Heatco (2006) does not provide values for Romania, Croatia and Bulgaria. For Bulgaria and Romania we have taken here the average from the YOLL values of two nearby countries: Greece and Hungary. For determining the value for EU28, for Croatia we have taken the YOLL as an average of Austria and Italy.

As Heatco differentiates between the emissions from a metropole region (e.g. cities with > 0.5 million of inhabitants) and emissions outside built areas, we use this differentiation as well. In order to obtain an estimate for small and medium sized cities, we took the relationship between metropole emissions and small and medium-sized cities from a previous version from the IMPACT handbook (CE Delft, 2008). This learns that the impacts on small- and medium-sized cities are about 1/3 of the impact of the metropole cities.

For NO_x a differentiation between cities and rural sources of NO_x emissions has been calculated. We have taken here the assumption that 80%[1] of people living in a city is exposed to annual NO_2 values larger than 20/ug/m^3 while only 10% people living in the country side are not exposed to annual NO_2 concentrations larger than 20/ug/m^3 (this will be mostly people living nearby motorways). These values have then be used to calculate a specific value for emissions of NO_x located in city or rural areas for stacks up to 100 meter by adjusting the RGF (Risk Group Factor) in the NEEDS modelling result (see Annex B). Although there are indication that NO_2 emitted at ground level may be more dangerous than NO_2 emitted from higher stacks, we do not have information that would make it possible to differentiate between both sources.

Differentiation for electricity emissions

For electricity emissions we have used the ratio between the average emissions (unknown height of release) and the electricity emissions in the NEEDS project. This ratio differs per country where more densely populated countries tend to have a higher relative impact from electricity emissions than more sparsely populated countries.

3.3 External cost factors per type of pollutant

On the basis of the routine explained in Section 3.2 we have derived the damage costs of different air pollutants for the EU28 on average and for the countries that are under investigation in this study. Table 5 gives the specific values for $PM_{2.5}$ and NO_x that are recommended for use in transport, as well as the overall damage costs for SO_2, NMVOC and PM_{10}. The damage costs of PM_{10} are related to emissions caused by the wear and tear of tires and breaks.

[1] This is a best guess but the number can be calculated more precisely on the basis of Eurostat statistics if needed.

One should notice that these values may differ from the national values for the Netherlands, as have been calculated in CE Delft (2017) because of the income elasticity that has been chosen in this study. In the Netherlands it was decided not to use an income elasticity for health related issues due to the declining marginal utility from living longer at the end of ones live. Therefore the VOLY applied in that study corresponds to the West-European average of € 70,000.[2]

2 Also the CRFs and population structure have been calculated in the CE Delft (2017) study on the level of the Netherlands. This may give different values than those calculated on the basis of the ratios in the NEEDS Excel tool. In general country specific values calculated tend to be more precise.

Table 5 - Transport related damage costs (in €/kg), of emissions in 2016 from an average location and overall damage costs of NMVOC, SO_2 and PM_{10}

Cost in euro per kg	Transport related damage costs							Overall damage costs		
	$PM_{2.5}$ transport metropole*	$PM_{2.5}$ transport city	$PM_{2.5}$ transport rural	NO_x cities (cars, industries, buildings)	NO_x rural (cars, buildings, industries)	$PM_{2.5}$ electricity generation	NO_x electricity generation > 100 m stack	NMVOC	SO_2	PM_{10}, average
Austria	466	151	87	41.4	24.3	26.8	21.9	2.3	16.2	30.9
Bulgaria	191	61	30	10	5.9	7.1	5.7	0	4.2	5.4
Estonia	na*	102	35	5.4	3.4	5.9	3.2	0.3	5.2	4.9
Germany	448	144	93	36.8	21.6	37.7	20.2	1.8	16.5	39.6
Hungary	317	102	59	26.8	15.8	20.4	15.3	0.8	9.9	19
Poland	282	91	52	14.7	8.9	16.3	8.0	0.7	8.2	16.1
Romania	272	88	42	19.4	11.2	12.5	9.3	0.5	7.3	12
Slovenia	na*	93	52	22.3	13.7	16.1	13.1	1.2	9.2	15.2
Spain	348	112	46	8.5	5.1	9.9	4.9	0.7	6.8	11.9
EU28	**381**	**123**	**70**	**21.3**	**12.6**	**19.4**	**10.9**	**1.2**	**10.9**	**22.3**

* Metropole only applies to cities larger than 0.5 million inhabitants. Some countries do not have such cities hence these damage values are hence not being reported. This is the case for Slovenia and Estonia.

Most of the damage costs for traffic air pollution are related to health costs (90-100%). Table 5 gives the specific values for health related costs in these national totals. For transport, health damage costs account for almost the entire costs of air pollution. Table 6 gives the transport related damage costs for health effects.

Table 6 - Transport related damage costs (in €/kg), only for human health effects, of emissions in 2016 from an average location

Cost in euro per kg	$PM_{2.5}$ transport metropole*	$PM_{2.5}$ transport city	$PM_{2.5}$ transport rural	NO_x cities (cars, industries, buildings)	NO_x rural (cars, buildings, industries)	$PM_{2.5}$ electricity generation	NO_x electricity generation > 100 m stack	NMVOC	SO_2	PM_{10}
Austria	465	151	87	38.6	21.5	26.8	19.1	2.2	15.7	30.5
Bulgaria	191	61	30	9.3	5.2	7.1	5.0	0	4.2	5.2
Estonia	na*	102	35	4.4	2.5	5.9	2.3	0.3	5.1	4.6
Germany	447	144	93	34.3	19.1	37.6	17.7	1.7	16	39.3
Hungary	317	102	59	24.8	13.8	20.3	13.3	0.7	9.7	18.8
Poland	282	90	52	13.1	7.3	16.3	6.4	0.6	7.9	15.9
Romania	272	88	42	18.5	10.3	12.4	8.3	0.4	7.2	11.8
Slovenia	na*	93	52	19.4	10.8	16.0	10.2	1.1	8.7	14.9
Spain	348	112	46	7.5	4.2	9.8	3.9	0.6	6.8	11.6
EU28	**381**	**123**	**70**	**19.1**	**10.3**	**19.4**	**9.8**	**1.1**	**10.8**	**22.3**

* Metropole only applies to cities larger than 0.5 million inhabitants. Some countries do not have such cities hence these damage values are not reported. This is the case for Slovenia and Estonia.

3.4 Total costs (both health and non-health-related) of air pollution of transport

In Table 7, the total costs of air pollution caused by transport over 2016 for the EU28 and the nine selected Member States are given. These are based on the damage costs as given in Section 3.3. The costs have also been differentiated to road vehicle type and fuel type. From Table 7 it can be concluded that the sum of the costs of road traffic related air pollution in the EU28 in 2016 was € 66.7 billion. The share of diesel vehicles in these cost amounts 83%.

NO_x emissions have the largest share in the total cost of air pollutants (65%), followed by $PM_{2.5}$ (32%). PM_{10} (non-exhaust), SO_2 and NMVOC emissions have only minor shares of about 1%, 0.1% and 2%, respectively.

Table 7 - Total costs of road traffic related air pollution in 2016 (in million €) both health and non-health related), based on COPERT emission factors

Cost in 2016 in million euro		Passenger car		Bus	Coach	MC	LCV		HGV	Total		
		Petrol	Diesel	Diesel	Diesel	Petrol	Petrol	Diesel	Diesel	Petrol	Diesel	Total
EU28		**8,938**	**23,372**	**1,354**	**2,671**	**1,843**	**326**	**15,160**	**13,046**	**11,107**	**55,603**	**66,709**
Austria	AT	119	828	23	100	33	3	654	247	155	1,853	2,007
Bulgaria	BG	197	145	32	34	1	1	41	160	199	413	612
Estonia	EE	29	33	4	4	0	0	11	12	29	64	93
Germany	DE	2,007	5,036	297	400	292	11	1,807	2,898	2,311	10,437	12,748
Hungary	HU	104	172	34	102	21	13	238	301	138	847	984
Poland	PL	775	628	163	97	19	23	395	1,433	817	2,716	3,533
Romania	RO	266	281	77	70	3	57	138	405	326	970	1,296
Slovenia	SI	34	120	3	17	2	1	58	120	36	317	354
Spain	ES	379	1,700	29	132	217	8	555	895	604	3,312	3,916

Table 8 shows the share of diesel vehicles in the total air pollution cost of road transport (both health and non-health related) in 2016. Diesel is responsible for the lion share of the air pollution cost in the EU (83%). Also in each of the nine Member States that have been assessed in more detail, the share of diesel is high (66% up to 92%) and mainly depends on the share of diesel vehicles in the fleet.

Table 8 - Share of diesel in total air pollution costs road transport in 2016 (both health and non-health related, based on COPERT emission factors)

		Share of total road air pollution costs caused by diesel vehicles
EU28		**83%**
Austria	AT	92%
Bulgaria	BG	68%
Estonia	EE	66%
Germany	DE	82%
Hungary	HU	86%
Poland	PL	77%
Romania	RO	75%
Slovenia	SI	90%
Spain	ES	85%

3.5 Health related air pollution costs and share borne by governments and compulsory insurances

The air pollution cost in the previous section include both costs related to human health as well as other costs (e.g. damage to biodiversity, building and agriculture). Table 9 lists the share of health related costs in the total damage costs of air pollution in 2016. It makes clear that health costs have by far the largest share in the total costs.

The second column of Table 9 lists rough estimates for the share of the health costs directly borne by governments and health compulsory insurances. By the lack of more specific data, these shares have been based on OECD statistics on the coverage of total health costs in EU Member States, assuming that these shares for total health costs are also representative for the specific health costs related to air pollution (OECD, 2018). The overview shows that the total health costs of air pollution borne by governments and compulsory insurances on average about three quarter. When applying this to the total cost of road emission air pollution in the EU, the total health costs from road air pollution borne by governments and compulsory insurances amounts about € 45 billion a year.

Table 9 - Share of total air pollution costs road transport (in billion €) that is caused by health and costs borne by governments and compulsory insurances, based on COPERT emission factors

Cost in 2016 in billion euro		Share of health in total costs	Estimate of the share of health costs borne by governments and compulsory health insurances	Estimate of the total health related air pollution costs borne by governments and compulsory health insurances (in million euro in 2016)
EU28		**93%**	**73%***	**45,362**
Austria	AT	94%	74%	1,398
Bulgaria	BG	94%	72%	411
Estonia	EE	88%	76%	62
Germany	DE	94%	85%	10,142
Hungary	HU	93%	66%	606
Poland	PL	89%	70%	2,206
Romania	RO	96%	72%	887
Slovenia	SI	87%	73%	223
Spain	ES	94%	71%	2,634

* Assuming that the average for the nine selected Member States is representative for EU28.

3.6 Sensitivity analysis on emission factors (TRUE)

The emission data set used stem from the latest version of COPERT 5, which is a widely used emission data set. However, given 'diesel gate' and discussions on real world emissions, the emission factors used have been checked and a sensitivity analysis has been carried out.

The COPERT emission factors have been compared to those from other sources:
- Handbuch Emissions Faktoren, HBEFA (Germany);
- Taakgroep Verkeer, based on data from TNO (the Netherlands);
- The TRUE initiative (TRUE, 2018).

Based on this assessment we conclude that the COPERT emission factors are generally well in line with the data from HBEFA and TNO. However, the TRUE initiative revealed that the NO_x emission factors of diesel passenger cars can be significantly higher, particularly for EURO classes 1 to 5. In the TRUE initiative, new techniques are used to measure real-world emissions. In the first TRUE initiative report published — of which the results have been used in the assessment described here: (TRUE, 2018) — remote sensing was used to establish new real-world emission factors for NO_x from passenger cars. These TRUE NO_x emission factors for both diesel and petrol passenger cars have been used as a basis for a sensitivity analysis.

TRUE has not yet provided emission factors for other vehicle types than passenger cars. For LCVs and motorcycles we have assumed that the relative correction of TRUE compared to COPERT for cars applies as well. For buses, coaches and HGVs, we have used the COPERT emission factors, without correction, as there is no TRUE data available and no other basis for correcting NO_x emission factors.

For $PM_{2.5}$ emissions, Transport & Environment has revealed that 4% of the Diesel Particulate Filters of passenger cars are not functioning well (or at all), resulting in much higher emission factors for those vehicles (Transport & Environment, 2018). Based on this, we have assumed that 4% of all diesel vehicles of Euro 5/V and newer have $PM_{2.5}$ emission factors of the level of Euro 3/III. For petrol vehicles, no corrections have been made as they are not equipped with particulate filters.

PM_{10}, NMVOC and SO_2 have not been adjusted at all; for these emissions the COPERT values have been used.

The total air pollution cost (both health and non-health related) with this alternative set of emission factors is presented in Table 10. With this set, the total cost of air pollution form road transport is 20% higher than calculated with COPERT.

Table 10 - Total costs (in million €) of road traffic related air pollution in 2016 (both health and non-health related), based adjusted real-world emission factors (TRUE)

Cost in 2016 in million euro		Passenger car		Bus	Coach	MC	LCV		HGV	Total		
		Petrol	Diesel	Diesel	Diesel	Petrol	Petrol	Diesel	Diesel	Petrol	Diesel	Total
EU28		**16,232**	**30,785**	**1,480**	**2,890**	**2,292**	**1,163**	**11,743**	**13,235**	**19,686**	**60,133**	**79,820**
Austria	AT	262	1,255	23	100	54	3	1,053	247	318	2,679	2,997
Bulgaria	BG	288	202	32	34	1	0	61	160	289	489	778
Estonia	EE	43	40	4	4	0	1	17	12	45	77	121
Germany	DE	4,401	7,774	297	400	467	24	2,991	2,898	4,893	14,358	19,251
Hungary	HU	257	251	34	102	28	234	384	301	519	1,072	1,591
Poland	PL	1,364	852	116	69	26	107	654	1,433	1,497	3,124	4,621
Romania	RO	324	393	77	70	3	172	207	405	499	1,151	1,650
Slovenia	SI	114	185	3	17	4	1	81	120	119	405	524
Spain	ES	686	2,084	29	132	279	18	714	895	983	3,854	4,836

Table 11 shows the share of diesel in the cost (both health and non-health related) in 2016, when these alternative emission factors are used. The share of diesel appears to be slightly lower. The reason is that on average, the corrections for petrol are somewhat larger than for diesel. Table 12 shows the shares of health in the total costs and the costs borne by governments.

Table 11 - Share of diesel in total air pollution costs road transport (both health and non-health related, based on adjusted real-world emission factors)

		Share of total road air pollution costs caused by diesel vehicles
EU28		**75%**
Austria	AT	89%
Bulgaria	BG	63%
Estonia	EE	63%
Germany	DE	75%
Hungary	HU	67%
Poland	PL	68%
Romania	RO	70%
Slovenia	SI	77%
Spain	ES	80%

Table 12 - Share of total air pollution costs (in million €) road transport that is caused by health and costs borne by governments and compulsory insurances, based on adjusted real-world emission factors

Cost in 2016 in million euro		Share of health in total costs	Estimate of the share of health costs borne by governments and compulsory health insurances	Estimate of the total health related air pollution costs borne by governments and compulsory health insurances (in million euro in 2016)
EU28		**91%**	**73%***	**52,865**
Austria	AT	93%	74%	2,073
Bulgaria	BG	93%	72%	520
Estonia	EE	88%	76%	79
Germany	DE	93%	85%	15,194
Hungary	HU	92%	66%	971
Poland	PL	89%	70%	2,860
Romania	RO	95%	72%	1,126
Slovenia	SI	86%	73%	328
Spain	ES	93%	71%	3,204

* Assuming that the average for the nine selected Member States is representative for EU28.

3.7 Discussion on uncertainties

The results presented in this chapter reflect the state of the art on the valuation of air pollutant emissions. However, there are various uncertainties in the results presented:

- The cost factors used reflect the cost for which the causal relation between emissions and health impacts has been proven. However, for some potential health problems, a causal relation is suspected but proven (yet). When it turns out that these relations can be proven by ongoing research, this will also result in higher cost estimates.
- The valuation of immaterial damage (i.e. value of life year lost, VOLY) is based on a solid scientific basis, but results from various studies vary significantly.
- There is also some discussion among scientists on whether or not own consumption is incorporated in the WTP or not. Generally it is assumed that it is included, but some argue it is not. The VOLY used in this study follows the most common approach, but with the alternative approach the cost factors would be higher, resulting in higher total damage costs of air pollution.
- We were not able to carry out a sensitivity analysis with TRUE real world emission factors for buses, coached and HGVs, as these are not yet available. Such emission factors could affect the results to some extent and result in somewhat higher cost of air pollution, although impacts on the total air pollution cost for the EU are expected to be modest.
- The shares of different Euro standards in the fleet in COPERT do not fully match with the data in GAINS, which shows that there is also some uncertainty with respect to the exact fleet composition. The fleet composition in 2030 is even more uncertain. GAINS assumes a certain fleet renewal rate, but a faster or lower fleet renewal would result in different shares of the various Euro standards in the fleets in 2030 and could significantly affect the total emissions and cost in the baseline in 2030.

4 Policy scenarios

4.1 Introduction

This chapter presents the impact of policies that ban polluting vehicles and stimulate clean ways of transport, both for the selected Member States and the EU28 as a whole. This is done for the year 2030.

This chapter starts in Section 4.2 with the definition of the baseline scenario in 2030 which reflects as business as usual situation without additional policies for reducing air pollutant emissions from road transport. Next in Section 4.3, two policy scenarios are defined which are assessed on their impacts on the costs of air pollution in the EU28 and in each of the nine selected Member States. The results of this assessment are presented and discussed in Section 4.4. Factsheets with results per country can be found in the Annexes.

4.2 Baseline scenario (BAU)

Baseline for 2030 with COPERT emission factors

The baseline scenario (or Business As Usual — BAU — scenario) describes how the share of diesel (and other) vehicles and vehicle emissions will develop between 2016 and 2030 with only current (policy) measures in place. Due to existing policy measures (such as Euro standards) the vehicle fleet composition and the emissions per kilometre will change over this time frame. Additionally, autonomous trends such as population growth, economic growth and energy prices impact the type of vehicles people drive and how much they drive in them. Overall the main changes that determine the 2030 emissions are:

- fleet renewal - with current emission legislation in place the vehicle fleets are expected to be significantly cleaner in 2030 than in 2016;
- the uptake of zero emission vehicles (BEV, PHEV, FCEV);
- development of transport performance (vehicle kilometres driven per vehicle type).

To estimate the emissions in 2030 for the EU28 and each of the 9 selected countries, we have used data on the development of the NO_x and PM emissions between 2016 and 2030 from the GAINS model (scenario used: TSAP Report #16, WPE_2014_CLE). Its European implementation covers 43 countries in Europe including the European part of Russia. GAINS includes detailed data on emissions per vehicle type and country both for 2016 and 2030. The GAINS model and its predecessor, the RAINS model, have been applied to assist key policy negotiations on improving air quality in Europe. In recent years it has been the key assessment tool for the revision of the NEC Directive which entered into force on 31 December 2016 (European Commission, 2018). As part of this exercise, Member States were required to report their air pollutant emissions inventories and projections based on current policies in place. These country specific historic and future emissions have been integrated in the GAINS model and made publicly available at http://gains.iiasa.ac.at/models/index.html. The GAINS data contains the same level of disaggregation as the COPERT data with respect to the transport (or mode) categories which we use in this study for calculating the 2016 costs of air pollution.

For some data (e.g. on transport performance and fleet composition) the data in GAINS do not fully match with the Eurostat data and COPERT data used in this study for calculating the 2016 emissions. To remain consistent and ensure that the 2030 results can be compared to the results for 2016, we constructed the 2030 emission data for the baseline scenario, by extrapolating COPERT 2016 data using the vehicle type specific growth rates in NO_x and PM emissions between 2016 and 2030 that follow from the GAINS model. This takes account of both fleet renewal and growth in vehicle-kilometres for each vehicle category. In addition we applied the shares of the different Euro classes in 2030 according to GAINS. It should be noted that the shares of different Euro standards in 2016 in GAINS differ from those in COPERT. However, as there are no COPERT data for 2030, we applied the shares from GAINS (see Annex C).

The results show that NO_x and $PM_{2.5}$ emissions are expected to decrease significantly between 2016 and 2030 for each of the nine Member States and the EU28 as a whole. NMVOC emissions decrease by 50%, NO_x and SO_2 emissions decrease by 69% and $PM_{2.5}$ emissions decrease by 80%.

Unlike NMVOC, NO_x, SO_2 and $PM_{2.5}$, PM_{10} emissions from wear and tear of tires and brakes are expected to increase, as the emissions per vehicle-km are expected to remain constant and the number of kilometres driven in EU28 is in the BAU scenario considerably higher in 2030 than it was in 2016. For the EU28 as a whole the data from GAINS show an increase by 29%.

In Table 13 the total costs of air pollution caused by transport (both health and non-health related) in 2030 for the EU28 and the nine selected Member States are given. These are based on the damage costs as given in Section 3.3. Analogous to Chapter 3, costs have been differentiated to road vehicle type and fuel type. From Table 13 it can be concluded that the sum of the costs of diesel road traffic related air pollution in the EU28 in 2030 is € 19.4 billion. This is a decrease compared to 2016 of € 47.2 billion (or 71%).

Impact of using the 2016 shares of Euro standards from GAINS instead of COPERT

When taking the 2016 shares of the different Euro standards from GAINS and combining these with the emission factors from COPERT, we get somewhat lower values for total emissions in 2016. With the shares provided by GAINS, the total NO_x emissions in 2016 are 7% lower and the $PM_{2.5}$ emissions 49% lower. This means that when calculating with the shares from GAINS, also the total external cost of air pollution in 2016 is somewhat lower as well. With the shares from GAINS they amount € 52.9 billion for the EU28, so 21% lower than when using the shares from COPERT. This means that also the impact of fleet renewal on the reduction between 2016 and 2030 would be somewhat lower, when using the shares from GAINS for 2016, the damage cost reduction changes to 62% instead of 71%.

Table 13 - Baseline for 2030 - COPERT emission factors Total costs of road traffic related air pollution in 2030 (in million €, both health and non-health related)

Cost in 2030 in million euro		Passenger car		Bus	Coach	MC	LCV		HGV	Total			Reduction 2016-2030
		Petrol	Diesel	Diesel	Diesel	Petrol	Petrol	Diesel	Diesel	Petrol	Diesel	Total	
EU28		**3,391**	**6,585**	**312**	**617**	**1,246**	**43**	**5,165**	**2,125**	**4,680**	**14,804**	**19,484**	**71%**
Austria	AT	45	188	7	30	19	1	284	42	66	551	617	69%
Bulgaria	BG	33	67	11	11	1	0	15	53	34	157	191	69%
Estonia	EE	5	10	2	2	0	0	4	3	5	20	25	73%
Germany	DE	943	1,183	54	73	139	1	575	446	1,083	2,331	3,414	73%
Hungary	HU	46	63	5	15	10	2	83	47	57	213	270	73%
Poland	PL	165	180	50	30	19	3	128	578	186	966	1,152	67%
Romania	RO	43	107	30	27	2	7	43	142	51	350	402	69%
Slovenia	SI	15	51	1	4	2	0	42	38	17	136	153	57%
Spain	ES	140	463	5	22	130	2	155	80	271	725	996	75%

Based on these reductions of total air pollution costs (both health and non-health related) in 2030, the health costs borne by governments and compulsory insurances has been calculated, amounting to € 13.0 billion for the EU28 in 2030, which is also a reduction of 71%.

Baseline for 2030 with adjusted emission factors (based on TRUE)

The results presented in Table 14 are based on the COPERT emission factors. Just like we did for 2016 in Section 3.6 for 2016, a sensitivity analysis has been carried out on the emission factors used. Table 14 shows the total costs (both health and non-health related) of air pollution from road transport in EU28 and selected countries when the adjusted emission factors are used in 2030. The table shows that the total cost would then amount € 25.6 billion in 2030, which is 24% higher than when calculating with COPERT. In this case, the reduction in air pollution costs between 2016 and 2030 is 68%. In both cases the shares of emission standards in 2030 have been based on GAINS.

Table 14 - Baseline 2030 - adjusted (TRUE) emission factors - Total costs of road traffic related air pollution in 2030 (in million €, both health and non-health related)

Cost in 2030 in million euro		Passenger car		Bus	Coach	MC	LCV		HGV	Total			Reduction 2016-2030
		Petrol	Diesel	Diesel	Diesel	Petrol	Petrol	Diesel	Diesel	Petrol	Diesel	Total	
EU28		**5,486**	**8,951**	**320**	**754**	**1,770**	**108**	**5,605**	**2,624**	**7,364**	**18,254**	**25,618**	**68%**
Austria	AT	106	306	4	23	73	2	416	31	182	780	962	68%
Bulgaria	BG	42	85	14	14	1	0	19	67	43	199	242	69%
Estonia	EE	6	16	1	1	0	0	4	3	6	25	32	74%
Germany	DE	1,903	2,009	71	92	247	8	1,196	323	2,158	3,691	5,850	70%
Hungary	HU	53	73	4	17	13	3	119	32	68	246	315	80%
Poland	PL	152	215	30	21	15	5	184	481	172	931	1,103	76%
Romania	RO	70	103	19	22	3	9	48	114	83	307	390	76%
Slovenia	SI	19	83	0	13	2	0	47	17	21	160	182	65%
Spain	ES	202	741	4	24	185	2	247	97	388	1,113	1,501	69%

Based on these reductions of total air pollution costs (both health and non-health related) in 2030, the health costs borne by governments and compulsory insurances has been calculated, amounting to € 17.4 billion for the EU28 in 2030, which is also a reduction of 63%.

4.3 Policy scenario definition

Two policy scenarios have been defined — a low and high ambition scenario — to assess how additional policy efforts would impact emission levels and related costs in 2030. In both scenarios we distinguish between EU, national and local policies. Table 15 shows in short the policy elements that are part of both scenarios and what impacts have been assumed for the various measures. The assumptions and sources used are listed in Table 15.

Table 15 - Overview of policy elements in the low and high ambition scenario

Policies		Low ambition scenario		High ambition scenario	
		Policy	Impact	Policy	Impact
Uptake ZEVs (new car sales)	EU	CO_2 regulation and technology development in line with Tech scenario; shares in car sales 2030: 15% BEV 8% PHEV 2% FCEV	Shares in car fleet 2030: 4.8% BEV 2.6% PHEV 0.9% FCEV	CO_2 regulation and technology development in line with Tech scenario; shares in car sales 2030: 36% BEV 36% PHEV 3% FCEV	Shares in car fleet 2030: 9.5% BEV 10.4% PHEV 1.3% FCEV
Fuel taxes	National and EU	As in reference scenario	None	Higher fuel tax on diesel resulting in 20% higher diesel price	6% less diesel car kms; half of them shifting to petrol; 4% less LCV and HGV kms
Kilometre charging trucks	National and EU	As in reference scenario	None	In all MSs, mandatory and strong differentiation to air pollution	6% less HGV kms
Kilometre charging cars/vans	National and EU	As in reference scenario	None	In all MSs (mandatory and strong differentiation to air pollution)	12% less car and LCV kms
Access restrictions to cities for most polluting vehicles or even all diesel vehicles	National and local	Banning all pre-Euro 6 vehicles in all major cities (100,000 + inhabitants)	For 90% of urban kms and 50% of other kms: pre-Euro 6/VI replaced by Euro 6/VI	Banning all pre-Euro 6/VI vehicles from all roads	All pre-Euro 6/VI replaced by Euro 6/VI
Scrappage schemes	National and local	In all EU countries		In all EU countries	
Urban policies, congestion charging parking policies, car free days, etc. for stimulating modal shift to public transport, cycling and walking	National and local	As in reference scenario	None	In all EU countries	10% reduction in urban/ metropolitan car kms

EU policies affect the share of different vehicle technologies available on the market. Thes ecan be influenced with more stringent CO_2 legislation for road vehicles which ensures the production of particular shares of low and zero emission vehicles. An example of more stringent regulation (compared to current legislation) could be the introduction of a Zero Emission Vehicle (ZEV) mandate.
For this study we adopt ZEV's uptake scenario's from the study *Low-carbon cars in Europe: A socio-economic assessment* (Cambridge Econometrics, 2018). We use both the TECH (High

Technology) scenario and the TECH OEM (High Technology, Ambitious uptake) scenario. The latter has higher shares of ZEV in new car sales and is included in high ambition scenario. The ZEV market shares have been differentiated to Member State according to the ZEV shares in the car fleets in EU28 and each Member State in 2016 according to GAINS. ZEV market share for other vehicles have been chosen as follows:

- the ZEV share for LCVs and motorcycles are chosen the same as for cars;
- the ZEV share for buses are set at twice the share for cars;
- the ZEV share for HGVs and coaches are set ate a third of the share for cars.

For a PHEVs it is assumed that 38% of the kms is driven electric and 62% on petrol (source (CE Delft, 2015).

On top of a faster uptake of ZEVs, various other policies have been added. For this the following assumptions and sources have been used:

- Impact of fuel taxes for cars based on fuel price elasticities from 'Effecten van prijsbeleid in verkeer en vervoer – kennisoverzicht, PBL (2010) and the assumption that in case of an tax increase for diesel only half of the reduction in diesel car kms will shift to petrol.
- Impact of fuel taxes for HGVs based on fuel price elasticities from Price sensitivity of road freight transport - Towards a better understanding of existing results, Significance (2010). For diesel LCVs the same elasticities have been applied.
- The impact for a kilometre charge for trucks has been based on: Analyse Regeerakkoord Rutte-III: Effecten Op Klimaat En Energie, PBL (2017). This has been applied to all countries, assuming that the countries that have already a kilometre charge either increase the charge levels or enlarge the part of the road network for which the charge needs to be paid.
- The impact for a kilometre charge for cars has been based on a recent study for the Netherlands 'Kansrijk Mobiliteitsbeleid', CPB (2016).
- Impact of access restrictions combined with scrappage schemes based on expert judgement, taking account of evaluations of existing and past schemes. For some countries this could also mean an import stop of (pre Euro 6/VI) diesel vehicles.
- Impact of urban policies based on expert judgement, taking account of evaluation studies on urban policies.
- WTT emission have not been included in the analysis. However, as emission from power productions are expected to decrease quickly and WTT emissions for petrol and diesel increase, these impacts are expected to be limited.

4.4 Policy scenario results

Results for COPERT emission factors

Table 16 and Table 17 show the damage costs of air pollution in 2030 for the low and high ambition scenario, respectively. The Low ambition scenario reduces the total cost for the EU28 by 27% compared to the Baseline in 2030 and the High ambition scenario 46%. The reduction percentages compared to 2016 are 79% (low ambition scenario) and 84% (high ambition scenario).

These figures show that stringent emission policies can result in large reduction of societal damage costs of air pollution and significant cost saving for governments and health insurers.

Table 16 - LOW AMBITION POLICY SCENARIO Total costs of road traffic related air pollution in 2030 (both health and non-health related) - COPERT emission factors

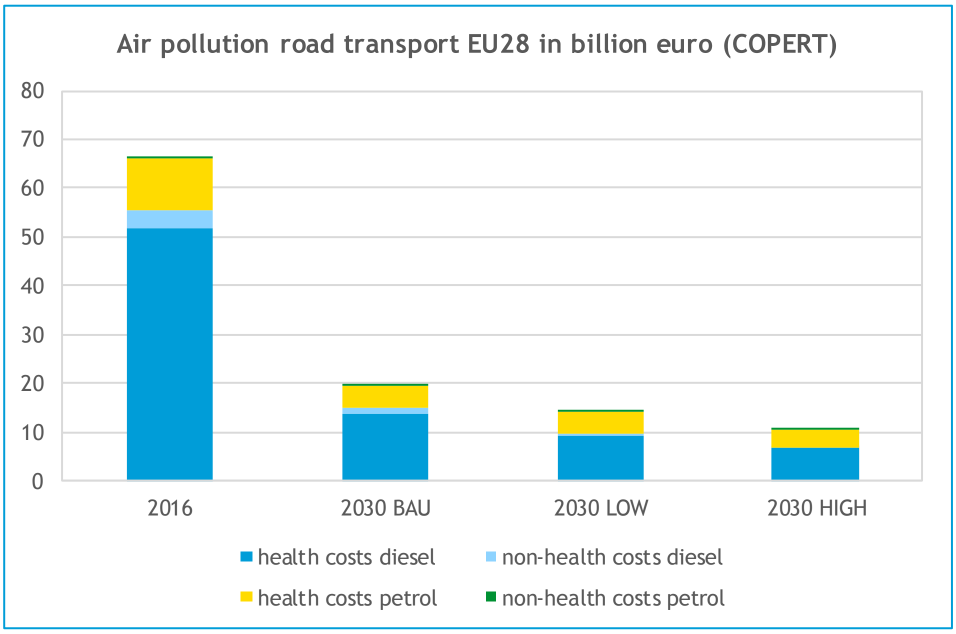
Cost in 2030 in million euro		Passenger car		Bus	Coach	MC	LCV		HGV	Total		
		Petrol	Diesel	Diesel	Diesel	Petrol	Petrol	Diesel	Diesel	Petrol	Diesel	Total
EU28		**3,297**	**3,947**	**152**	**427**	**1,205**	**45**	**3,300**	**1,769**	**4,548**	**9,596**	**14,143**
Austria	AT	41	151	3	25	18	1	199	36	60	413	473
Bulgaria	BG	34	41	4	5	1	0	9	23	35	82	117
Estonia	EE	4	4	0	1	0	0	2	1	4	8	13
Germany	DE	821	808	23	62	119	1	421	380	941	1,693	2,634
Hungary	HU	45	41	4	13	9	2	59	39	56	155	212
Poland	PL	156	137	21	13	18	3	47	265	176	482	659
Romania	RO	32	72	12	11	1	7	27	55	40	178	218
Slovenia	SI	12	32	0	3	2	0	37	29	14	102	116
Spain	ES	133	267	3	18	123	1	96	64	258	448	706

Table 17 - HIGH AMBITION POLICY SCENARIO - Total costs of road traffic related air pollution in 2030 (both health and non-health related) - COPERT emission factors

Cost in 2030 in million euro		Passenger car		Bus	Coach	MC	LCV		HGV	Total		
		Petrol	Diesel	Diesel	Diesel	Petrol	Petrol	Diesel	Diesel	Petrol	Diesel	Total
EU28		**2,589**	**2,576**	**125**	**371**	**984**	**39**	**2,510**	**1,388**	**3,613**	**6,971**	**10,584**
Austria	AT	31	98	2	23	14	1	146	30	46	300	346
Bulgaria	BG	28	25	2	3	1	0	7	15	29	52	81
Estonia	EE	3	2	0	0	0	0	1	1	3	4	7
Germany	DE	567	469	17	56	83	1	290	313	651	1,147	1,798
Hungary	HU	37	26	4	12	8	2	45	33	47	120	167
Poland	PL	128	93	11	7	15	2	11	121	145	243	388
Romania	RO	24	48	7	7	1	6	20	32	31	114	145
Slovenia	SI	9	20	0	3	1	0	30	24	11	78	89
Spain	ES	104	166	2	17	101	1	73	54	207	312	519

The total air pollution cost for road transport in 2016, the 2030 baseline and the two policy scenarios are shown in Figure 3. This shows that with the emission factors used from COPERT and the reduction path from GAINS, the fleet renewal results in significant cost reduction in 2030. With additional policies, the costs can be further reduced to less than a sixth of the current damage costs.

Figure 3 - Comparison of total Air Pollution Costs EU28 in 2016 and 2030 BAU, low and high ambition policy scenarios - COPERT emission factors



Based on these reduction of total air pollution costs, the reductions in health costs borne by governments and compulsory insurances have been calculated. For the low ambition scenario they amount 9.8 billion euro for the EU28 in 2030, which is a reduction of 24% compared to the 2030 baseline and 78% reduction compared to 2016. For the high ambition scenario they amount to € 7.4 billion for the EU28 in 2030, which is a reduction of 43% compared to the 2030 baseline and 84% reduction compared to 2016.

Table 18 - Health related air pollution cost from road transport borne by governments and compulsory insurances - COPERT emission factors

Cost in million euro		2016	2030		
			BAU	Low	High
EU28		**45,362***	**12,956***	**9,815***	**7,374***
Austria	AT	1,398	428	328	240
Bulgaria	BG	411	128	78	54
Estonia	EE	82	25	13	7
Germany	DE	10,142	2,723	2,100	1,434
Hungary	HU	606	165	129	102
Poland	PL	2,206	713	406	242
Romania	RO	887	275	148	99
Slovenia	SI	223	96	73	56
Spain	ES	2,634	658	463	340

* Assuming that the average for the nine selected Member States is representative for EU28.

Results for adjusted emission factors (based on TRUE)

Table 19 and Table 20 show the total damage costs of air pollution (both health and non-health related) in 2030 for the low and high ambition scenario, respectively when adjusted emission factors are used. The tables make clear that in this case, slightly smaller reductions are found in the total cost or air pollution, compared to the scenarios using COPERT emission factors. In the Low ambition scenario the total cost for the EU28 are reduced by 20% compared to the Baseline in 2030 and in the High ambition scenario by 41%. The reduction percentages compared to 2016 are 74% (low ambition scenario) and 81% (high ambition scenario).

Table 19 - LOW AMBITION POLICY SCENARIO - Total costs of road traffic related air pollution in 2030 (both health and non-health related) - adjusted emission factors

Cost in 2030 in million euro		Passenger car		Bus	Coach	MC	LCV		HGV	Total		
		Petrol	Diesel	Diesel	Diesel	Petrol	Petrol	Diesel	Diesel	Petrol	Diesel	Total
EU28		**5,595**	**6,641**	**167**	**496**	**1,751**	**105**	**3,954**	**1,679**	**7,451**	**12,937**	**20,388**
Austria	AT	97	243	2	20	66	2	292	26	164	582	746
Bulgaria	BG	43	52	5	6	1	0	11	29	44	104	149
Estonia	EE	5	7	0	1	0	0	2	1	5	11	16
Germany	DE	1,642	1,385	27	76	211	7	881	264	1,860	2,634	4,493
Hungary	HU	52	47	3	14	13	3	86	26	67	176	244
Poland	PL	144	163	13	9	14	5	65	218	163	467	630
Romania	RO	54	70	8	9	2	9	30	44	66	160	226
Slovenia	SI	16	52	0	10	2	0	41	13	18	116	134
Spain	ES	192	434	2	19	175	1	163	71	369	690	1,059

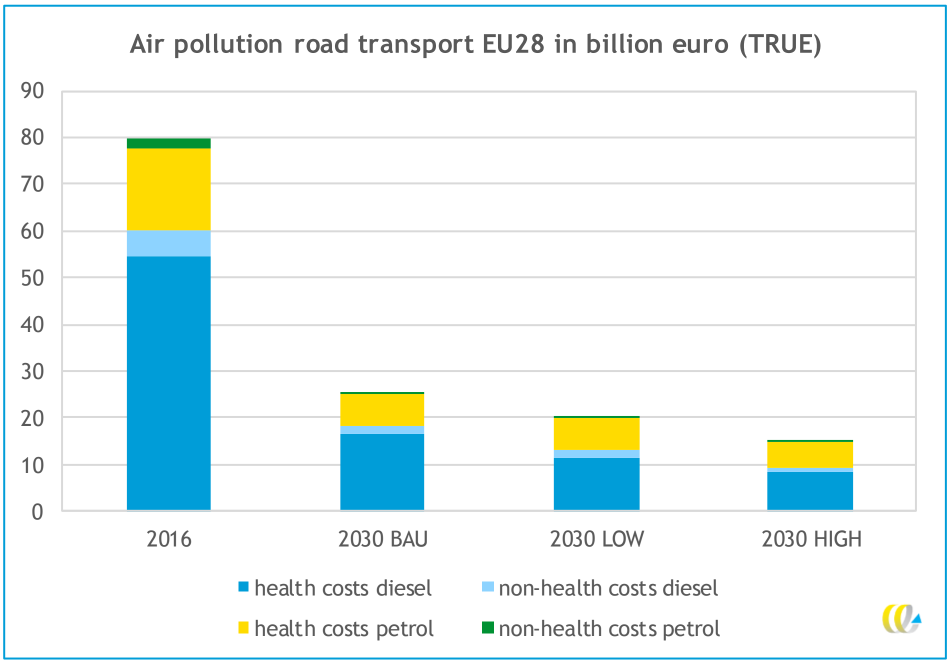
43 52 5 6 1 0 11 29

Table 20 - HIGH AMBITION POLICY SCENARIO - Total costs of road traffic related air pollution in 2030 (both health and non-health related) - adjusted emission factors

Cost in 2030 in million euro		Passenger car		Bus	Coach	MC	LCV		HGV	Total		
		Petrol	Diesel	Diesel	Diesel	Petrol	Petrol	Diesel	Diesel	Petrol	Diesel	Total
EU28		**4,359**	**4,335**	**135**	**423**	**1,428**	**91**	**2,995**	**1,300**	**5,877**	**9,188**	**15,065**
Austria	AT	71	158	2	18	51	2	215	21	124	414	538
Bulgaria	BG	35	32	3	4	1	0	9	18	36	66	103
Estonia	EE	3	3	0	0	0	0	1	1	4	5	9
Germany	DE	1,112	800	19	69	147	6	606	217	1,265	1,711	2,976
Hungary	HU	43	30	3	13	11	2	67	21	56	134	190
Poland	PL	118	110	7	5	12	4	12	99	134	232	366
Romania	RO	41	46	5	6	2	8	23	25	51	104	155
Slovenia	SI	12	32	0	10	1	0	34	11	14	86	100
Spain	ES	150	270	2	17	144	1	125	60	295	475	770

The total air pollution cost for road transport in 2016, the 2030 baseline and the two policy scenarios for the analysis with the adjusted emission factors (TRUE) are shown in Figure 4. The patterns are very similar to that in Figure 3, but with somewhat higher costs both in 2016 and in all scenarios for 2030.

Figure 4 - Comparison of total Air Pollution Costs EU28 in 2016 and 2030 BAU, low and high ambition policy scenarios - adjusted emission factors (TRUE)



Like for the COPERT emission factors, the health costs borne by governments and compulsory insurances have been calculated for the TRUE emission factors, as well, as shown in Table 21. For the low ambition scenario they amount € 13.6 billion for the EU28 in 2030, which is a reduction of 22% compared to the 2030 baseline and 74% reduction compared to 2016. For the high ambition scenario they amount to € 7.4 billion for the EU28 in 2030, which is a reduction of 42% compared to the 2030 baseline and 81% reduction compared to 2016.

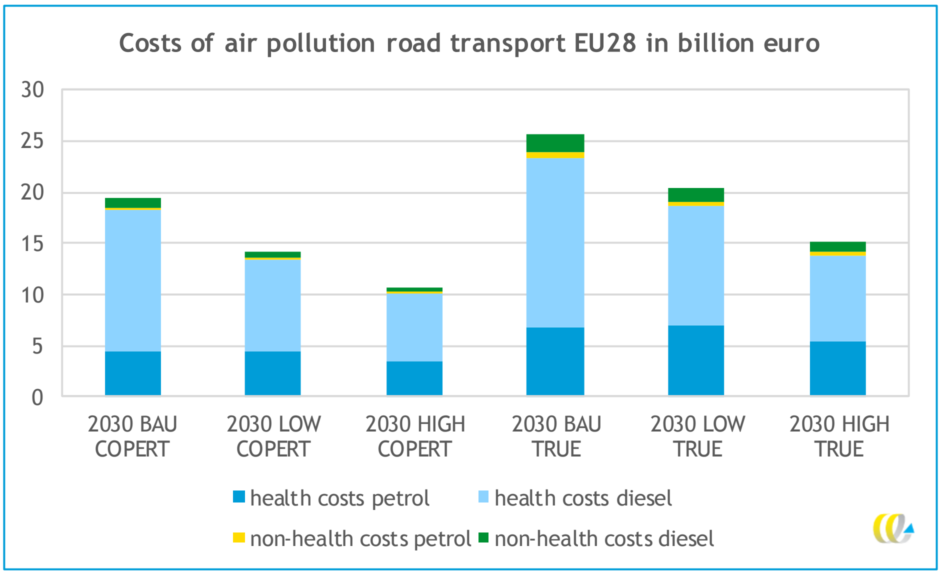
Table 21 - Health related air pollution cost from road transport borne by governments and compulsory insurances - adjusted emission factors (TRUE)

Cost in 2030 in million euro		2016	2030		
			BAU	LOW	HIGH
EU28		**52,865***	**17,384***	**13,581***	**10,043***
Austria	AT	2,073	665	516	372
Bulgaria	BG	520	163	100	70
Estonia	EE	79	32	16	9
Germany	DE	15,194	4,657	3,578	2,371
Hungary	HU	971	193	149	116
Poland	PL	2,860	689	393	231
Romania	RO	1,126	267	154	106
Slovenia	SI	328	114	84	63
Spain	ES	3,204	992	697	508

* Assuming that the average for the nine selected Member States is representative for EU28.

Figure 5 shows the various scenarios for 2030 in one graph: both the baseline and policy scenarios with COPERT and with adjusted emission factors based on TRUE. The graph makes clear that the remaining air pollution costs in 2030 are higher when calculating with the adjusted emission factors. Moreover it shows that the additional policy scenarios are expected to result in a significant reduction in air pollutant costs.

Figure 5 - Comparison of total Air Pollution Costs EU28 in 2030 BAU and policy scenarios - for both COPERT and adjusted emission factors based on TRUE Initiative



5 Conclusions

5.1 Health impacts from air pollution

The scientific literature is clear that air pollution has large adverse impacts on human health. The main pollutants from road transport are particulate matter and NO_x.

Particulate matter

Ambient particulate matter is ranked as the 6th risk factor for total deaths globally, through cancer, lower- and chronic respiratory diseases and cardiovascular diseases.
This makes it the most harmful element of diesel exhaust to the human health.
The severance of the harm caused is largely determined by how far a certain pollutant can penetrate into the human body after entering by the respiration system. The smaller a pollutant is, the further into the tissue of the lungs and body it can get.

Particulate matter from diesel exhaust is so harmful because it mainly consists of $PM_{2.5}$ and $PM_{0.1}$. Ultrafine particulate matter ($PM_{0.1}$) hare very harmful but do not travel far from where they are emitted. This makes it very hard to prove their specific impacts in epidemiologic studies and to distinguish these from the impacts of bigger $PM_{2.5}$ emissions.

Diseases which have been proven to be causally relatable to $PM_{2.5}$ (and $PM_{0.1}$) are ischemic heart disease, stroke, lung cancer, lower respiratory infections, and chronic obstructive pulmonary disease (COPD). Both long- and short-term exposure to $PM_{2.5}$ has negative respiratory and cardiovascular effects, including acute and chronic cardiovascular mortality. More research is necessary to prove a relation between exposure to $PM_{2.5}$ and other adverse health effects such as neurological disorders and diabetes, as well as birth defects.

Soot particles (measured and also known as elemental carbon or black carbon) make up a small part of all the particulate matter ($PM_{2.5}$ and $PM_{0.1}$) in ambient air, but are among the most dangerous elements of $PM_{2.5}$ emitted by road traffic. In streets with a high amount of traffic, the concentration of these particulates in the air is twice as high than in a street with little traffic. The health effects associated with them do not only lie in their small size, but as well in the fact that they can carry traces of heavy metals or PAHs and NMVOCs on their surface: these enter your body when soot does. Soot has been characterized as being a carcinogen by the International Cancer Research Organization.

The amount of studies about the health effects of PM_{10} emitted by the wear of tires and breaks of road vehicles is increasing. One of the main reasons for this is sharp reduction in tailpipe emissions and the uptake of electric vehicles that have no tailpipe emissions at all. Therefore the reduction of emissions from brakes and tires becomes relatively more important.

NO_x

The evidence of adverse health impacts of NO_x have long not been attributed to the compounds itself (mainly NO_2), but rather to $PM_{2.5}$ and ozone as these are formed by NO_x. However, in recent years experts have stated that substantial evidence has become available for health effects of both short-term and long-term exposure directly attributional to NO_2. A relation between short-term NO_2 exposure and respiratory symptoms such as inflammation, aggravation of symptoms in asthma patients and aggravation of allergic reactions in the respiratory tract have been proven. Additionally, the incidence of asthma in children due to long-term exposure to NO_2 is probable. Nevertheless, some experts in this field say that the discussion about whether or not NO_2 is directly accountable for negative health effects caused by air pollution, is still open.

The so called 'diesel-gate' has revealed that the real world NO_x emissions of road vehicles are much higher than what could be expected based on test results. About 10,000 premature deaths of adults over 30 in 2013 in the EU28 and Switzerland that can be attributed to NO_x emissions from diesel cars and light commercial vehicles. Half this could have been avoided if the NO_x emissions of those vehicles would have been at the level of the laboratory tests.

Ozone

Tropospheric (also known as ground-level) ozone (O3) is a secondary air pollutant. It is formed via multiple reactions between NO_x, CO and volatile organic compounds (VOCs), in the presence of light (e.g. photo-chemically). Under certain weather conditions, a high concentration of ozone in the air can lead to smog which is especially a problem in warm urban areas. In some places the occurrence of smog is highly related to the season. Short-term exposure to ozone has proven to be causally related to respiratory effects such as inflammation, aggravation of asthmatic symptoms, increase in hospital admissions and respiratory related acute mortality. Additionally, it is a cause of chronic obstructive pulmonary disease (COPD) and is probably related to cardiovascular effects and acute all-cause mortality. In warm weather, acute impacts of elevated ground-level ozone levels can be experienced by both healthy people and people with already reduced lung function. Long-term exposure may cause an increase of incidence of asthma amongst children. Globally, ozone is ranked as the 33th risk factor for total deaths, due to its severe causal relation to chronic respiratory diseases (HEI, 2018).

Non-methane volatile organic compounds

Non-methane volatile organic compounds (NMVOCs) are formed upon incomplete combustion of fuels such as diesel, which are found in the gas phase of diesel exhaust. They are a great contributor to the formation of ozone and as such indirectly responsible for health effects caused by it. Additionally, some NMVOCs have been classified as carcinogens, amongst some of which occur in diesel exhaust.

Polycyclic aromatic hydrocarbons

PAHs are polycyclic aromatic hydrocarbons (organic compounds containing two or more rings), which can be found in both the gas phase (mostly those with two or three rings) as bound to the particulates of diesel exhaust (the larger PAHs with more than five rings). The particulate bound PAHs are of most damage to human health. They are causally related to the carcinogenic nature of diesel exhaust. Additionally, new evidence is arising for its non-cancer health effects, such as cardiovascular diseases, neurological and prenatal effects.

5.2 Costs of road air pollution

2016 with COPERT emission factors

When calculating with the COPERT emission factors, the total costs of road traffic related air pollution in the EU28 in 2016 was € 66.7 billion. The share of diesel vehicles in these cost amounts 83%. Also in each of the nine Member States that have been assessed in more detail, the share of diesel is high (67% up to 92%) and mainly depends on the share of diesel vehicles in the fleet.

NO_x emissions have the largest share in the total costs (both health and non-health related) of air pollutants (65%), followed by $PM_{2.5}$ (32%). PM_{10} (non-exhaust), SO_2 and NMVOC emissions have only a minor share of about 1%, 0.1% and 2% respectively.

In the nine Member States that have been assessed in detail, about three quarter of the total health costs of air pollution are borne by governments and compulsory insurances. When assuming that this is representative for the EU28 as a whole, these total cost of road emission air pollution in the EU amounts about € 45.4 billion a year.

2016 with adjusted emission factors based on TRUE

The COPERT emission factors are a respected and widely used set. However, recent work in the TRUE Initiative has revealed that real world NO_x emission factors for cars are higher than expected and reported by COPERT (and also by other sources). Therefore a sensitivity analysis has been carried out with a set of adjusted emission factors which take account of these latest finding by TRUE and assume higher NO_x emission factors for both cars and LCVs. In addition $PM_{2.5}$ emission factors have been adjusted to take account of malfunctioning of diesel particulate filters in part of 4% of the diesel vehicle fleet.

When calculating with these adjusted emission factors, the total costs of road traffic related air pollution (both health and non-health related) in the EU28 in 2016 was € 79.8 billion, so 20% higher than when using COPERT, 75% of these costs caused by diesel.

2030

Both NO_x and $PM_{2.5}$ emission are expected to decrease significantly between 2016 and 2030 for each of the nine Member States and the EU28 as a whole. When calculating with COPERT emission factors, NMVOC emissions decrease by 50%, NO_x and SO_2 emissions decrease by 69% and $PM_{2.5}$ emissions decrease by 80%. Unlike NO_x and $PM_{2.5}$, PM_{10} emissions from wear and tear of tires and brakes are expected to increase (on average by 29%), as the emissions per vehicle-km are expected to remain more or less constant and the number of kilometres driven in EU28 is expected to increase.

With COPERT emission factors, the sum of the health and non-health related costs of road traffic related air pollution in the EU28 in 2030 is estimated at € 19.5 billion; of which € 18.3 billion are health-related. This is a decrease compared to 2016 of € 47.2 billion (or 71%). The health costs borne by governments and compulsory insurances are estimated at € 13.0 billion for the EU28 in 2030, which is a reduction of 71% compared to 2016.

When using the adjusted emission factors (TRUE), the reductions are slightly smaller. In that case the sum of the 2030 health and non-health related costs amount € 25.6 billion (of which € 23.3 billion are health-related), 68% lower than in 2016. The health costs borne by governments and compulsory insurances are with these emission factors € 17.4 billion, 67% lower than in 2016.

Uncertainties

The cost factors used reflect the cost for which the causal relation between emissions and health impacts has been proven. However, for some potential health problems, a causal relation is suspected but proven (yet). When it turns out that these relations can be proven by ongoing research, this will also result in higher cost estimates.

Another uncertainty is related to the shares of different Euro standards in the fleet. These share in COPERT do not fully match with GAINS. The fleet composition in 2030 is even more uncertain. In this study we have used a certain fleet renewal rate, according to GAINS, but a faster or lower fleet renewal would result in different shares of the various Euro standards in the fleets in 2030 and could significantly affect the total emissions and cost in the baseline in 2030.

Finally, there are still uncertainties with respect to emission factors. We were not able to carry out a sensitivity analysis with TRUE real world emission factors for buses, coached and HGVs, as these are not yet available. Such emission factors could affect the results to some extent and result in somewhat higher cost of air pollution.

5.3 Impacts of additional policies

Stringent emission policies can result in large reduction of societal damage costs of air pollution and significant cost saving for governments and health insurers.

The Low ambition scenario that was developed and assessed in this study, reduces the total cost for the EU28 by 27% compared to the Baseline in 2030; the High ambition scenario by 46%. The reduction percentages compared to 2016 are 79% (low ambition scenario) and 84% (high ambition scenario). In the high ambition scenario, the annual cost savings of these total reductions in 2030 amount € 56 billion compared to 2016 and € 9 billion compared to the baseline scenario in 2030.

For the Low ambition scenario the health costs borne by governments and compulsory insurances amount € 9.8 billion for the EU28 in 2030, which is a reduction of 24% compared to the 2030 baseline and 78% reduction compared to 2016. For the high ambition scenario they amount € 7.4 billion for the EU28 in 2030, which is a reduction of 43% compared to the 2030 baseline and 84% reduction compared to 2016.

When using the adjusted emission factors, the impacts of the scenarios are similar. In the Low ambition scenario the total cost for the EU28 are reduced by 20% compared to the Baseline in 2030 and 74% compared to 2016. In the High ambition scenario, costs are reduced by 41% compared to the baseline in 2030 and even 81% compared to 2016. In the high ambition scenario, the annual cost savings of these total reductions in 2030 amount € 64 billion compared to 2016 and € 11 billion compared to the baseline scenario in 2030.

5.4 Summary of key results

Table 22 summarizes the main results of this study. The results show clearly that the lion share of all air pollution costs from road transport are caused by diesel emissions.
When using TRUE-based emission factors, costs are higher than when using COPERT, but the ratios between costs for 2016 and for the various scenarios in 2030 are very similar.
The results show clearly that the lion share of all air pollution costs from road transport are caused by diesel emissions.

Table 22 - Main results: costs of air pollution from road transport in EU28 in 2016 and various scenarios for 2030

Costs in million €	COPERT					TRUE				
	Total costs	Health costs	Health costs (% of total)	Health costs borne by governments	Health costs borne by governments (% of health costs)	Total costs	Health costs	Health costs (% of total)	Health costs borne by governments	Health costs borne by governments (% of health costs)
2016	66,709	62,081	93%	45,362	73%*	79,820	72,348	91%	52,865	73%*
2030 - BAU	19,484	18,311	94%	12,956	73%*	25,618	23,337	91%	17,384	73%*
2030 - LOW	14,143	13,432	95%	9,815	73%*	20,388	18,586	91%	13,581	73%*
2030 - HIGH	10,584	10,091	95%	7,374	73%*	15,065	13,744	91%	10,043	73%*

6 References

Cambridge Econometrics, 2018. *Fuelling Europe's Future,* Cambridge: Cambridge Econometrics.
CE Delft, 2015. *STREAM personenvervoer 2014, versie 1.1 - Studie naar TRansportEmissies van Alle Modaliteiten,* Delft: CE Delft.
CE Delft, 2017. *Handboek Milieuprijzen,* Delft: CE Delft.
CE Delft, 2018, forthcoming. *Handbook on the external costs of transport - Version 2018.* Delft: CE Delft.
COMEAP, 2015. *Statement on the evidence for the effects of nitrogen dioxide on health,* Chilton: Committee on the Medical Effects of Air Pollutants (COMEAP).
COMEAP, 2018. *Associations of long-term average concentrations of nitrogen oxide with mortality,* Chilton: Committee on the Medical Effects of Air Pollutants (COMEAP).
Dutch Health Council, 2018. *Gezondheidswinst door schonere lucht,* Den Haag: Gezondheidsraad (Dutch Health Council).
EEA, 2017. *European Union emission inventory report 1990-2015 under the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP)* , Copenhagen: European Environmental Agency.
EEA, 2018. *Air quality in Europe* , Copenhagen: European Environmental Agency.
EPA, 2016. *Integrated Science Assessment for Oxides of Nitrogen - Health Criteria,* North Carolina: Environmental Protection Agency (EPA).
European Commission, 2017. *Air Quality Standards.* [Online]
Available at: http://ec.europa.eu/environment/air/quality/standards.htm
[Geopend 13 July 2018].
European Commission, 2018. *Air Quality - AQD Fitness Check.* [Online]
Available at: http://ec.europa.eu/environment/air/quality/aqd_fitness_check_en.htm
[Geopend 13 July 2018].
European Commission, 2018. *Reduction of National Emissions.* [Online]
Available at: http://ec.europa.eu/environment/air/reduction/implementation.htm
Eze, I. C. et al., 2015. Association between Ambient Air Pollution and Diabetes Mellitus in Europe and North America: Systematic Review and Meta-Analysis. *Environmental Health Perspectives,* pp. 381-389.
Finnish Institute for Occupational Health, 2016. *149. Diesel Engine Exhaust,* Gothenburg: Nordic Expert Group & Dutch Expert Committee on Occupational Safety .
Hartog, J. d., Boogaard, H., Nijland, H. & Hoek, G., 2010. Do the health benefits of cycling outweigh the risks?. *Enviromental Health Perspectives,* Issue 118, pp. 1109-1116.
HEI, 2017. *State of Global Air 2017,* Boston: Health Effects Institute (HEI).
HEI, 2018. *State of Global Air* , Boston: Health Effects Institute.
Holland, M., 2014. *Cost-benefit Analysis of Final Policy Scenarios for the EU Clean Air Package Version 2 Corresponding to IIASA TSAP Report 11, Version 1,* sl: EMRC.
IIASA, 2014. *A flexibility mechanism for complying with national emission ceilings for air pollutants. TSAP report #15,* Laxenburg: International Institute for Applied Systems Analysis (IIASA).
J.E. Jonson, J. B.-K. D. S. A. N. M. P. C. H., 2017. Impact of excess NOx emissions from diesel cars on air quality, public health and eutrophication in Europe. *Environmental Research Letters,* Issue 12.
NEEDS, 2007b. *Final report on casual links between pollutants and health impacts. Deliverable RS 1b D 3.7. : A set of concentration-response functions. (...),Sub-priority 6.1.3.2.5: Socio-economic tools and concepts for energy strategy,* Brussels: European Commission.

NEEDS, 2007. *Deliverable 3.7 - RS1b/WP3: “A set of concentration-response functions”,* Belgium; United Kingdom; France: VITO; IOM; Armines.
OECD, 2018. *Health expenditure and financing.* [Online]
Available at: https://stats.oecd.org/Index.aspx?DataSetCode=SHA#
RIVM, 2013. *Roet als extra indicator voor de nadelige gezondheidseffecten van deeltjes naast PM10 en PM2.5.* [Online]
Available at: http://slideplayer.nl/slide/2211029/
[Geopend 29 May 2018].
Sharma, A. & Kumar, P., 2018. A review of factors surrounding the air pollution exposure to in-pram babier and mitigation strategies. *Environmental International,* pp. 262-278.
Sinharay, R. et al., 2018. Respiratory and cardiovascular responses to walking down a traffic-polluted road compared with walking in a traffic-free area in participants aged 60 years and older with chronic lung or heart disease and age-matched healthy controls: a randomised, crosso. *The Lancet,* Issue 391, pp. 339-349.
Transport & Environment, 2018. *Cars with engines: can they ever be clean?,* Brussels: Transport & Environment.
TRUE, 2018. *Determination of real-world emissions from passenger vehicles using remote sensing data,* sl: TRUE.
WHO Europe, 2015. *WHO Expert Consultation: Available evidence for the future update of the WHO Global Air Quality Guidelines (AQGs): Meeting report,* Copenhagen: World Health Organization .
WHO Europe, 2018. *Over half a million premature deaths annually in the European Region attributable to household and ambient air pollution.* [Online]
Available at: http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/news/news/2018/5/over-half-a-million-premature-deaths-annually-in-the-european-region-attributable-to-household-and-ambient-air-pollution
[Geopend 2 May 2018].
WHO, 2010. Polycyclic aromatic hydrocarbons. In: *WHO Guidelines for Indoor Air Quality: Selected Pollutants.* sl:World Health Organication.
WHO, 2013. *Health risks of air pollution in Europe – HRAPIE project. Recommendations for concentration-response functions for cost–benefit analysis of particulate matter, ozone and nitrogen dioxide,* Copenhagen: World Health Organization Europe (WHO).
WHO, 2018. *9 out of 10 people worldwide breathe polluted air, but more countries are taking action.* [Online]
Available at: http://www.who.int/news-room/detail/02-05-2018-9-out-of-10-people-worldwide-breathe-polluted-air-but-more-countries-are-taking-action
[Geopend 2 May 2018].
WHO, 2018a. *Ambient (outdoor) air quality and health.* [Online]
Available at: http://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health
WHO, 2018. *Air Pollution and Child Health - Prescribing clean air ,* Geneva: World Health Organization.
WHO, 2018. *Ambient (outdoor) air quality and health.* [Online]
Available at: http://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health
[Geopend 13 July 2018].
WHO, 2018. *www.who.int/airpollution,* Switzerland: WHO.
Wierzbicka, A. & others, 2014. Detailed diesel exhaust characteristics including particle surface area and lung deposited dose for better understanding of health effects in human chamber exposure studies. *Atmospheric Environment,* Issue Volume 86, pp. 212-219.

A Updates in concentration response functions

A.1 General overview

The updates in the Concentration Response functions have been set up by comparing the NEEDS outcome on the Concentration Response functions with the WHO (2013) recommended values and approaches. This is not straightforward as both studies report different units. Whereas the NEEDS study reports CRF functions, expressed in ug/m^3, works the WHO with Relative Risks (RR).

Most epidemiological studies report their results in terms of relative risk RR, defined as the ratio of the incidence observed at two different exposure levels. The RR thus can be interpreted as the increase in percentages in the relative risk in the reported impact due to an increase in exposure levels of 10/µg/m^3. To quantify damages one needs to translate this RR in terms of an concentration response function, also called exposure response function (Rabl et al., 2014). For this one needs to know the existing risk on these incidents. So for an RR of 1.046 per 10/µg/m^3 for Working Days Loss due to $PM_{2.5}$ lung diseases, one needs to understand how often the population already is suffering from these diseases. Then the CRF can then be regarded as the product of the baseline and the Delta RR.

We have started from the Table of health impacts in NEEDS as can be seen in the following Table.

Figure 6 – Parameter values for health impacts (core endpoints) according to NEEDS

Core Endpoints	Pollutant	Risk group (RG)	RGF value	Age Groupe (AG)	AGF value	CRF [1/(µg/m3)]	phys. Impact per person per µg per m3 [1/(µg/m3)]	unit	Monet Val per case or per YOLL [Euro]	External costs per person per µg per m3 [1/(µg/m3)]
primary and SIA < 2.5, i.e. Particle < 2.5µm										
Life expectancy reduction - YOLLchronic	PM2.5	all	1.000	Total	1	6.51E-04	6.51E-04	YOLL	40,000	2.60E+01
netto Restricted activity days (netRADs)	PM2.5	all	1.000	MIX	1	9.59E-03	9.59E-03	days	130	1.25E+00
Work loss days (WLD)	PM2.5	all	1.000	Adults_15_to_64_years	0.672	2.07E-02	1.39E-02	days	295	4.10E+00
Minor restricted activity days (MRAD)	PM2.5	all	1.000	Adults_18_to_64_years	0.64	5.77E-02	3.69E-02	days	38	1.40E+00
primary and SIA < 10, i.e. Particle < 10µm										
Increased mortality risk (infants)	PM10	infants	0.002	Total	0.009	4.00E-03	6.84E-08	cases	3,000,000	2.05E-01
New cases of chronic bronchitis	PM10	all	1.000	Adults_27andAbove	0.7	2.65E-05	1.86E-05	cases	200,000	3.71E+00
Respiratory hospital admissions	PM10	all	1.000	Total	1	7.03E-06	7.03E-06	cases	2,000	1.41E-02
Cardiac hospital admissions	PM10	all	1.000	Total	1	4.34E-06	4.34E-06	cases	2,000	8.68E-03
Medication use / bronchodilator use	PM10	Children meeting PEACE criteria - EU average	0.200	Children_5_to_14	0.112	1.80E-02	4.03E-04	cases	1	4.03E-04
Medication use / bronchodilator use	PM10	asthmatics	0.045	Adults_20andAbove	0.798	9.12E-02	3.27E-03	cases	1	3.27E-03
Lower respiratory symptoms (adult)	PM10	symptomatic_adults	0.300	Adults	0.83	1.30E-01	3.24E-02	days	38	1.23E+00
Lower respiratory symptoms (child)	PM10	all	1.000	Children_5_to_14_years	0.112	1.86E-01	2.08E-02	days	38	7.92E-01
Ozone [µg/m3] - from SOMO35										
Increased mortality risk	SOMO35	Baseline_mortality	0.0099	Total (YOLL = 0.75a/case	1	3.00E-04	2.23E-06	YOLL	60,000	1.34E-01
Respiratory hospital admissions	SOMO35	all	1.000	Elderly_65andAbove	0.158	1.25E-05	1.98E-06	cases	2,000	3.95E-03
MRAD	SOMO35	all	1.000	Adults_18_to_64_years	0.64	1.15E-02	7.36E-03	days	38	2.80E-01
Medication use / bronchodilator use	SOMO35	asthmatics	0.045	Adults_20andAbove	0.798	7.30E-02	2.62E-03	cases	1	2.62E-03
LRS excluding cough	SOMO35	all	1.000	Children_5_to_14_years	0.112	1.60E-02	1.79E-03	days	38	6.81E-02
Cough days	SOMO35	all	1.000	Children_5_to_14_years	0.112	9.30E-02	1.04E-02	days	38	3.96E-01

Abbreviations: Risk Group, RG: group within the general population with a handicap; RGF value: share of RG within the general population; Age group, AG: groups distinguished by different age cohorts; AG value: share of different age cohorts; CRF: concentration-response function; YOLL: Years of Life Lost; RAD: Restricted Activity Days; SIA: Secondary Inorganic Aerosols; SOMO35: sum of ozone means over 35 ppb; WLD: Work Loss Days; MRAD: Minor Restricted Activity Days; LRS: lower respiratory symptoms. Table constructed for the whole of Europe. Source: NEEDS (2008a), based on NEEDS (2007b).

Hereafter we will discuss for various impact groups the relevance of these CRFs for our work in the light of the recent WHO (2013) update. We will first discuss the mortality impacts and then identify the morbidity impacts.

A.2 Mortality impacts

Mortality impacts occur because of $PM_{2.5}$, ozone pollution (also called SOMO-35,Sum Of Means Over 35 ppb, e.g. the excess of max daily 8-hour averages over 35 ppb which is about 70 µg/m^3).

A. All-cause mortality $PM_{2.5}$

The HRAPIE experts recommended estimation of the impact of long-term (annual average) exposure to $PM_{2.5}$ on all-cause (natural) mortality in adult populations (age 30+ years) for cost–effectiveness analysis (Group A). A linear ERF, with an RR of 1.062 (95% CI = 1.040, 1.083) per 10 µg/m^3, has been recommended – even though some recent evidence has suggested a RR of 1.066. We observe that these RRs are practically similar to the used RR of

1.06 in the NEEDS project. As the Iref is probably nowadays slightly lower due to better health in population due to healthier lifestyles. ***Therefore our conclusion is that this value will not be altered compared to the NEEDS estimates***.

B. All-cause mortality SOMO 35
The NEEDS project only includes acute mortality (e.g. heart attack) with an RR of 1.003 per 10 ug/m^3 compared to the normal change of having an heart attack (which was established as 1% of population). The valuation of acute mortality is 50% higher than for chronic impacts. WHO (2013 and 2014) provide insights that there also chronical components included in ozone pollution. For a population 30 years old or older, the WHO (2013) recommends adopting a relative risk factor (RR) of 1.014 per 10 μg/m^3 in the summer months (April–September) for 8-hours concentration higher than 35 ppb. As explained in Jerrett et al. (2009), this may increase the CRF with a factor 9 compared to the acute impact. This is not only due to the higher RR, but also due to taking a different incidence rate. However, the precise impact is very uncertain. In our model we proposed to use the factor 3.5 as a lower bound and the factor 9 as an upper bound, so that the average factor through which the NEEDS outcomes need to be multiplied is equivalent to a factor 6.
We therefore propose to include the mortality impacts by calculating them as a factor 6 higher compared to NEEDS (2008) and by keeping the incidence rate the same (% of population with a heart attack).

C. Mortality N_2O
The REVIHAAP project (WHO, 2013) reports that since 2004 a growing number of studies have been published identifying short- and long-term correlations between NO_2 and mortality and morbidity that come on top of the impacts of NO_2 on PM formation and of NO_2 on acute mortality due to ozone formation. There is thus a third category that is not associated with particulate matter formation or ozone formation and that has here been added to the theme of acidification. These have not yet been included in the NEEDS project.

At the time of the NEEDS project these impacts were not included because the team was unable to identify sufficient studies that properly quantified these epidemiological impacts (NEEDS, 2007b). Today (2016) the situation has changed and the WHO (2013) recommends adopting a higher CRF for NO_2 than was previously used. The HRAPIE experts (WHO, 2013) recommend including the long-term mortality impacts (all-cause and cardiovascular) of NO_2 and advise adopting a linear CRF for NO_2 for all-cause mortality, translating to an RR of 1.055 per 10 μg/m^3 (WHO, 2013). In this context the WHO (2014) notes that when employing this RR-value in multi-emission studies due care should be taken to avoid double-counting with respect to the impact of NO_2 on PM formation, which they state can be as much as 33%.

To make this double-counting explicit, we examined the contribution of NO_2 to the RR-value for PM formation. For PM, NEEDS (2007b) uses an overall RR for premature mortality of 1.06 per 10 μg/m^3. The relative contribution of NO_2 to PM formation can be derived from the characterization factors.
For characterizing NO_2 with respect to PM formation, ReCiPe takes a value of 0.22.
This means that 22% of the RR increase can be attributed to impacts already been taken into account under the theme of PM-formation, equal to an RR of 1.013 per 10 μg/m^3.[3]
Assuming, in line with WHO (2014), a linear CRF for NO_2-values over the 20 μg/m^3 threshold, it can be concluded that the *additional* NO_2 RR-value must be 1.042 per 10 μg/m^3 for

[3] This estimate is feasible because in ReCiPe PM formation is considered only in terms of its impacts on the endpoint 'human health'.

pollution in areas above the threshold level. This implies that the chronic health damage attributable to NO_2 should be a factor 3 higher than assumed in NEEDS, based on its contribution to PM formation.

To this factor two additional corrections should be made:
1. The mortality applies only to people older than 30 years.
2. The mortality applies only to population living in areas with an annual mean concentration of pollution above 20 µg/m^3.

A.3 Morbidity impacts

For the morbidity impacts we have consulted WHO (2014), annex 6, and WHO (2013). Hereafter we will discuss first the morbidity impacts of particulate matter, ozone pollution and NO_2.

A.3.1 Morbidity impacts of $PM_{2.5}$ and PM_{10}

A. Cardiac hospital admissions
The value in Rabl et al. (2016) has been taken. This is taken from Hurley et al. *(2005) and* based on a RR of 1.006 per 10/ug/m^3 PM_{10}. Calculated to $PM_{2.5}$ we use the factor 1.6 as in the Handbook Environmental Prices, which implies that this would translate itself to a RR of 1.0096 per 10 ug/m^3 $PM_{2.5}$. This in turn is more or less equivalent to the recommended value of 10091 from the WHO. ***Therefore our conclusion is that this value will not be altered compared to the NEEDS estimates***.

B. $PM_{2.5}$ Net restricted activity days
The analysis in WHO (2014) is based on the same sources as NEEDS (2008) and Rabl et al. (2016). We use here the routine in the EcoSense model where the Restricted Activity Days have been netted by subtracting the working days loss, the minor restricted activity days and the hospital admissions due to $PM_{2.5}$ pollution from the RR from WHO. We have followed this routine here as well and have used the values from the EcoSense model. ***Therefore our conclusion is that this value will be taken from the EcoSense model***.

C. $PM_{2.5}$: Minor restricted activity days (MRAD)
This category has not been included in WHO (2014) separately but is added to the net restricted activity days. We follow here NEEDS as the valuation of both days differs and our aim is to include this differentiation in our calculations. ***Therefore our conclusion is that this value will be taken from the EcoSense model***.

D. $PM_{2.5}$ Working days loss
The approach and data in the NEEDS (2008) project are the same as in WHO (2014, background paper 6). ***Therefore our conclusion is that this value will not be altered compared to the NEEDS estimates***.

E. Respiratory hospital admissions
The WHO (2014) reports a RR of 1.019 for the whole population on the basis of a meta-analysis. This is slightly lower than the RR that has been used in the NEEDS project, which would be around 1.022 recalculated on the basis of the factor between $PM_{2.5}$ and PM_{10}. Since these values only differ slightly we have decided not to update this estimate. **Therefore our conclusion is to update the NEEDS estimate with the estimate from the WHO (2014).**

F. Medication use and lower respiratory symptoms because of asthma.
These categories relate to the costs of medication and disutility for asthmatic people from additional coughing days. The additional medication use is valued at 1 €/day and the disutility is valued at 38 €/day. has been estimated by recent WHO (2014) update advices to only take impacts on children (age 5-19) into account. They report an RR of 1.028 for children with asthma. In Europe, on average, 4.5% of the children suffer from asthma. Taking the incidence rate of 17% of the days that they suffer from asthma, the ERF becomes: 0.17*(1.028-1)=0.00476 days. **Our conclusion is to follow here the WHO (2014) approach and only use medication use and lower respiratory symptoms for asthmatic children.** The costs have been based on Ready et al. (2004), as quoted in Rabl et al., (2014) where we assumed that every fourth cough day for children leads to an additional visit to the doctor. The medical costs are then calculated as 11 €/day.

G. New cases of chronic bronchitis and COPD for adults
WHO (2014) advices to use an RR differentiated between children and adults. The RR for adults is 1.117 and for children 1.08. There is quite some discussion on the basic incidence rate (see e.g. Hurley, 2005), but the WHO proposes to use an incidence rate of 18.6% for children and 0.39% of adults. The NEEDS project used an RR of 1.07 per 10/ug/m^3.and an incidence rate of 0.378%. This implies that the new RR is about 70% higher. We used thus a 70% higher ERF in our modelling. In addition, WHO (2014) advices to use this factor for all population older than 18, whereas NEEDS used this impact only for 27 and older. **Therefore our conclusion is that the NEEDS estimate underestimates the recent WHO Guidelines and we have updated our estimates using a 70% higher estimate.** One should notice that the WHO classifies this information with a 'B' label indicating that these impacts are more uncertain than other impacts. We also have decided not to include potential new cases of chronic bronchitis for children (also labelled as 'B', as the unit in which this indicator is not an endpoint in the NEEDS modelling effort).

A.3.2 Morbidity impacts of ozone (SOMO-35)

A. Hospital admissions
WHO (2014) reports hospital admissions from ozone both for respiratory and cardiac diseases. NEEDS (2008) has only used respiratory diseases. The RR used in NEEDS for respiratory diseases is very similar to the one proposed in WHO (2014). **Therefore our conclusion is to follow WHO and extend this category by including cardiac hospital admissions.**

B. Minor restricted activity days
The background studies and assumed RR is the same for NEEDS (2008) and WHO (2014). **Therefore our conclusion is that this value will not be altered compared to the NEEDS estimates**.

C. Medication use, lower respiratory symptoms and cough days
These impacts have not been included in WHO (2014). **We propose here to follow WHO (2014) and not include these symptoms in the cost calculations.**

A.3.3 Morbidity impacts of NO_2

Morbidity impacts of NO_2 have not been included in the NEEDS project as scientific evidence was not yet overwhelming as to the chronic impacts from NO_2 pollution. WHO (2013) recommends including these in cost-benefit analysis.

A. Prevalence of bronchitis in asthmatic children
For calculation of the impacts of bronchitis, we follow the same routine as in the impacts of $PM_{2.5}$ on bronchitis and medication use for asthmatic children. Assuming a European average of 4.5% of children are being asthmatic we estimated the additional costs in a similar way as in Section B.3.1 – bullet F. The additional costs of NO_2 pollution is very small.

B. Hospital admissions respiratory problems.
We follow the same routine as in Hurley et al. (2015) where the estimated baseline of hospital admissions related to respiratory problems is 617 per 100,000 inhabitants.

The C-R function and estimated baseline rates can be linked to provide an impact function:
Annual rate of attributable emergency respiratory hospital admissions
= background incidence rate (617/100,000) × change per 10 $\mu g/m^3$ NO_2 (1.8%)
= 7.03 (95% CI 3.83, 10.30) per 10 $\mu g/m^3$ PM_{10} per 100,000 people (all ages)

Also here the additional impact of NO_2 on hospital admissions is very small and do not influence the final results.

A.4 Outcome

The following table presents the adapted changes from the NEEDS project for the EU population. All cells in green (CRF functions) and orange (population) are adaptations from the original NEEDS project.

Figure 7 - Adapted parameter values for health impacts (core endpoints), as used in this study

Core Endpoints	pollutant	risk group (RG)	RGF value	Age Group (AG)	AGF value	CRF [1/ug/m3]	unit
Primary and SIA < 2.5 i.e. Particle < 2,5 um							
Life expectancy reduction - YOLLchronic	PM2.5	all	1	Total	1	6,51E-04	YOLL
netto Restricted activity days (netRADs)	PM2.5	all	1	MIX	1	9,59E-03	days
Work loss days (WLD)	PM2.5	all	1	Beroepsb	0,4131472	2,07E-02	days
Minor restricted activity days (MRAD)	PM2.5	all	1	Adults_18	0,6232605	5,77E-02	days
Primary and SIA < 10 i.e. Particle < 10 um							
Increased mortality risk (infants)	PM10	infants	0,0019	Total	0,0102755	4,00E-03	cases
New cases of chronic bronchitis	PM10	all	1	Adults_18	0,812034	4,51E-05	cases
respiratory hospital admissions	PM10	all	1	Total	1	7,03E-06	cases
cardiac hospital admissions	PM10	all	1	Total	1	4,34E-06	cases
medication use/bronchodilator use	PM10	Children with severe astma	0,045	Children_	0,1046751	4,76E-03	cases
medication use/bronchodilator use	PM10	asthmatic	0,045	Adults_20	0,7907585	0,00E+00	cases
lower respiratory symptoms (adult)	PM10	symptoma	0,3	Adults	0,812034	0,00E+00	days
lower respiratory symptoms (child)	PM10	all	1	Children_	0,1046751	0,00E+00	days
Ozone [ug/m3] - from SOMO35							
Increased mortality risk	SOMO35	baseline_	0,0099	Total (YOL	1	3,00E-04	YOLL
respiratory hospital admissions	SOMO35	all	1	Elderly_65	0,1887735	1,25E-05	cases
MRAD	SOMO35	all	1	Adults_18	0,6232605	1,54E-02	days
medication use/bronchodilator use	SOMO35	asthmatic	0,045	Adults_20	0,7907585	7,30E-02	cases
LRS excluding cough	SOMO35	all	1	Children_	0,1046751	1,60E-02	days
Cough days	SOMO35	all	1	Children_	0,1046751	9,30E-02	days
NO2 [ug/m3] -							
Increased mortality risk	NO2	all	0,28	Adults 30+	0,6690976	4,41E-04	YOLL
Prevalence of bronchitis in asthmatich chi	NO2	all	0,045	Children_	0,1578638	5,25E-03	cases
Hospital admissions due to respiratory dis	NO2	all	1	Total	1	1,11E-05	cases

Abbreviations: Risk Group, RG: group within the general population with a handicap; RGF value: share of RG within the general population; Age group, AG: groups distinguished by different age cohorts; AG value: share of different age cohorts; CRF: concentration-response function; YOLL: Years of Life Lost; RAD: Restricted Activity Days; SIA: Secondary Inorganic Aerosols; SOMO35: sum of ozone means over 35 ppb; WLD: Work Loss Days; MRAD: Minor Restricted Activity Days; LRS: lower respiratory symptoms.

Source: Adjusted from NEEDS (2008a), based on NEEDS (2007b) with own recalculations of the green and orange cells.

B Interviews

- Prof. dr. ir. Bert Brunekreef, professor of Environmental Epidemiology, Institute for Risk Assessment Sciences (Utrecht University).
- Dr. Francesco Forastiere, head of department of epidemiology of the regional health authority in Roma, Italy.
- Prof. Dr. med. Barbara Hoffmann MPH, professor of Environmental Epidemiology, Centre for Health and Society (Heinrich-Heine-University Düsseldorf).

C GAINS Euro class fleet shares 2030

As presented in the scenario TSAP Report #16, WPE_14_CLE.

Note: for diesel passenger cars and LCVs, Euro 6 has been introduced in two phases. As such, the newer Euro 6 vehicles (denoted by Euro 6-2 here) have different emission factors. In the GAINS activity shares, no differentiation between these two Euro 6 phases had been made. We have assumed the distribution between the two for 2030 as shown below.

Passenger cars, 2016, diesel	EU28	Austria	Bulgaria	Estonia	Germany	Hungary	Poland	Romania	Slovenia	Spain
Euro 0	2%	0%	1%	0%	0%	9%	0%	2%	1%	1%
Euro 1	3%	0%	2%	6%	0%	6%	0%	0%	1%	3%
Euro 2	6%	1%	9%	9%	0%	9%	7%	4%	5%	11%
Euro 3	13%	17%	23%	29%	5%	8%	15%	21%	27%	15%
Euro 4	26%	30%	28%	31%	23%	14%	30%	33%	36%	30%
Euro 5	43%	47%	27%	23%	63%	48%	41%	32%	31%	36%
Euro 6-1	6%	5%	9%	2%	8%	6%	7%	9%	0%	4%
Euro 6-2	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Passenger cars, 2030, diesel	EU28	Austria	Bulgaria	Estonia	Germany	Hungary	Poland	Romania	Slovenia	Spain
Euro 0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Euro 1	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Euro 2	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%
Euro 3	1%	0%	3%	4%	1%	1%	1%	3%	2%	2%
Euro 4	3%	0%	7%	11%	2%	2%	2%	6%	4%	6%
Euro 5	10%	7%	13%	15%	6%	15%	6%	4%	15%	12%
Euro 6-1	10%	11%	9%	8%	11%	9%	11%	10%	9%	9%
Euro 6-2	75%	82%	67%	62%	81%	71%	80%	77%	69%	71%

Passenger cars, 2016, petrol	EU28	Austria	Bulgaria	Estonia	Germany	Hungary	Poland	Romania	Slovenia	Spain
Euro 0	5%	0%	17%	13%	0%	0%	8%	25%	0%	2%
Euro 1	4%	3%	3%	11%	1%	6%	5%	0%	0%	4%
Euro 2	9%	8%	12%	6%	3%	16%	11%	7%	1%	9%
Euro 3	16%	12%	24%	18%	6%	15%	17%	12%	20%	15%
Euro 4	25%	24%	25%	18%	41%	21%	23%	22%	19%	23%
Euro 5	33%	43%	15%	26%	40%	33%	29%	26%	61%	38%
Euro 6-1	8%	10%	4%	7%	8%	9%	6%	7%	0%	8%

Passenger cars, 2030, petrol	EU28	Austria	Bulgaria	Estonia	Germany	Hungary	Poland	Romania	Slovenia	Spain
Euro 0	0%	0%	0%	1%	0%	0%	0%	2%	0%	0%
Euro 1	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%
Euro 2	0%	0%	0%	1%	0%	0%	0%	1%	0%	0%
Euro 3	1%	0%	2%	5%	0%	0%	2%	3%	0%	0%
Euro 4	2%	1%	4%	7%	1%	0%	4%	6%	1%	2%
Euro 5	7%	5%	8%	12%	5%	3%	7%	6%	10%	6%
Euro 6-1	89%	93%	85%	72%	94%	97%	87%	81%	89%	92%

LCV, 2016, diesel	EU28	Austria	Bulgaria	Estonia	Germany	Hungary	Poland	Romania	Slovenia	Spain
Euro 0	12%	1%	7%	4%	1%	10%	2%	0%	0%	3%
Euro 1	5%	1%	2%	5%	4%	5%	7%	0%	1%	4%
Euro 2	9%	5%	14%	15%	8%	9%	13%	6%	1%	10%
Euro 3	12%	12%	26%	24%	10%	13%	28%	19%	5%	24%
Euro 4	22%	29%	27%	36%	29%	37%	26%	31%	23%	23%
Euro 5	41%	51%	24%	16%	48%	25%	24%	44%	70%	36%
Euro 6-1	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Euro 6-2	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

LCV, 2030, diesel	EU28	Austria	Bulgaria	Estonia	Germany	Hungary	Poland	Romania	Slovenia	Spain
Euro 0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Euro 1	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%
Euro 2	0%	0%	1%	1%	1%	1%	1%	0%	0%	0%
Euro 3	3%	1%	5%	4%	1%	2%	3%	3%	0%	3%
Euro 4	5%	3%	8%	15%	3%	7%	5%	6%	1%	4%
Euro 5	11%	12%	15%	20%	6%	12%	11%	4%	7%	13%
Euro 6-1	10%	11%	9%	7%	11%	10%	10%	11%	12%	10%
Euro 6-2	70%	74%	63%	53%	78%	67%	70%	77%	81%	69%

LCV, 2016, petrol	EU28	Austria	Bulgaria	Estonia	Germany	Hungary	Poland	Romania	Slovenia	Spain
Euro 0	12%	7%	40%	17%	1%	8%	6%	23%	3%	34%
Euro 1	5%	4%	3%	5%	4%	2%	5%	0%	3%	11%
Euro 2	9%	12%	35%	10%	13%	2%	21%	16%	10%	8%
Euro 3	12%	9%	12%	17%	7%	3%	27%	11%	9%	10%
Euro 4	22%	19%	10%	22%	27%	19%	22%	20%	25%	6%
Euro 5	41%	49%	0%	30%	48%	66%	18%	30%	49%	30%
Euro 6-1	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

LCV, 2030, petrol	EU28	Austria	Bulgaria	Estonia	Germany	Hungary	Poland	Romania	Slovenia	Spain
Euro 0	1%	0%	1%	0%	0%	0%	0%	2%	3%	0%
Euro 1	1%	0%	3%	2%	0%	0%	0%	0%	0%	0%
Euro 2	3%	0%	26%	4%	0%	0%	3%	6%	0%	2%
Euro 3	5%	1%	16%	7%	0%	0%	5%	6%	0%	8%
Euro 4	6%	4%	13%	11%	2%	1%	8%	12%	3%	5%
Euro 5	16%	18%	4%	18%	15%	6%	14%	14%	6%	22%
Euro 6-1	68%	77%	36%	59%	83%	93%	70%	59%	89%	64%

Motorcycle, 2016, petrol	EU28	Austria	Bulgaria	Estonia	Germany	Hungary	Poland	Romania	Slovenia	Spain
Euro 0	17%	7%	18%	23%	18%	19%	20%	16%	21%	11%
Euro 1	17%	23%	25%	10%	13%	18%	26%	18%	15%	5%
Euro 2	27%	16%	32%	20%	24%	32%	28%	32%	20%	35%
Euro 3	39%	54%	24%	46%	45%	31%	26%	34%	44%	50%

Motorcycle, 2030, petrol	EU28	Austria	Bulgaria	Estonia	Germany	Hungary	Poland	Romania	Slovenia	Spain
Euro 0	2%	0%	6%	4%	0%	1%	3%	0%	0%	0%
Euro 1	5%	3%	13%	9%	1%	1%	7%	6%	1%	2%
Euro 2	9%	7%	26%	18%	3%	2%	12%	8%	2%	6%
Euro 3	85%	90%	55%	70%	96%	95%	78%	86%	97%	93%

HGV, 2016, diesel	EU28	Austria	Bulgaria	Estonia	Germany	Hungary	Poland	Romania	Slovenia	Spain
Euro 0	5%	1%	24%	0%	0%	6%	6%	9%	0%	0%
Euro 1	2%	1%	1%	3%	0%	2%	4%	0%	1%	0%
Euro 2	7%	3%	11%	10%	4%	6%	11%	7%	1%	8%
Euro 3	18%	9%	27%	32%	12%	7%	25%	24%	8%	21%
Euro 4	19%	13%	14%	24%	11%	19%	23%	23%	14%	30%
Euro 5	26%	32%	14%	27%	36%	32%	17%	20%	46%	19%
Euro 6-1	22%	40%	9%	4%	37%	28%	13%	16%	30%	22%
Euro 6-2	-									

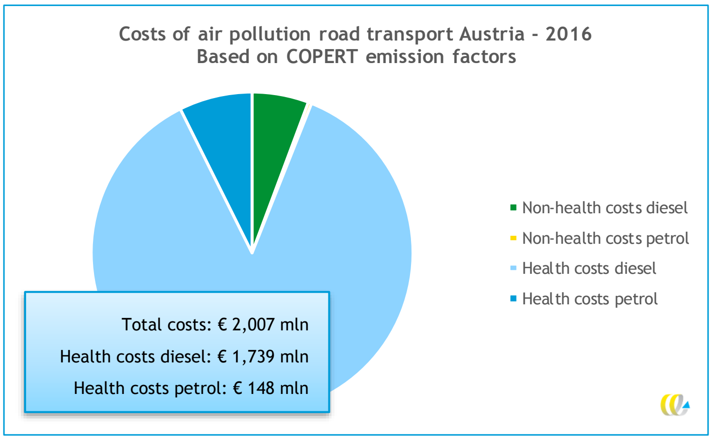
HGV, 2030, diesel	EU28	Austria	Bulgaria	Estonia	Germany	Hungary	Poland	Romania	Slovenia	Spain
Euro 0	0%	0%	1%	0%	0%	0%	1%	0%	0%	0%
Euro 1	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%
Euro 2	0%	0%	1%	0%	0%	0%	2%	0%	0%	0%
Euro 3	2%	0%	5%	3%	0%	0%	6%	6%	0%	0%
Euro 4	3%	0%	10%	6%	0%	1%	9%	11%	1%	0%
Euro 5	8%	1%	18%	18%	1%	2%	13%	10%	3%	3%
Euro 6-1	86%	99%	65%	73%	99%	97%	68%	72%	96%	97%
Euro 6-2	-									

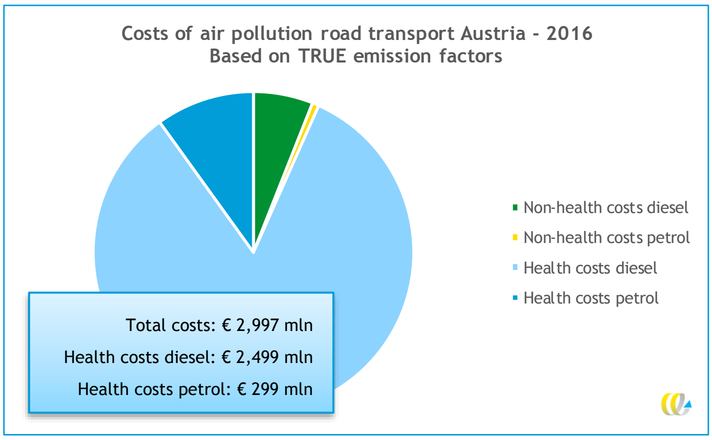
Bus & coach, 2016, diesel	EU28	Austria	Bulgaria	Estonia	Germany	Hungary	Poland	Romania	Slovenia	Spain
Euro 0	7%	8%	30%	8%	1%	3%	8%	27%	2%	2%
Euro 1	4%	3%	0%	9%	1%	1%	6%	0%	2%	1%
Euro 2	9%	10%	6%	17%	8%	6%	12%	4%	10%	7%
Euro 3	16%	15%	21%	19%	20%	5%	21%	17%	12%	16%
Euro 4	17%	15%	10%	23%	12%	12%	17%	13%	16%	24%
Euro 5	25%	24%	16%	22%	29%	34%	18%	18%	39%	24%
Euro 6-1	23%	25%	17%	2%	30%	39%	19%	21%	19%	27%
Euro 6-2	-									

Bus & coach, 2030, diesel	EU28	Austria	Bulgaria	Estonia	Germany	Hungary	Poland	Romania	Slovenia	Spain
Euro 0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Euro 1	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%
Euro 2	1%	1%	1%	4%	1%	0%	1%	1%	0%	0%
Euro 3	3%	3%	7%	7%	2%	0%	5%	7%	1%	1%
Euro 4	4%	4%	9%	12%	2%	1%	6%	10%	1%	2%
Euro 5	9%	7%	19%	19%	6%	2%	11%	9%	5%	3%
Euro 6-1	83%	85%	64%	58%	89%	97%	76%	73%	93%	94%
Euro 6-2	-									

D Country Factsheets

D.1 The costs of road vehicle air pollution - Austria





The costs (both health and non-health related) of air pollution have been calculated for the current (2016) situation and for three 2030 scenarios:

2030 BAU: Business-as-usual

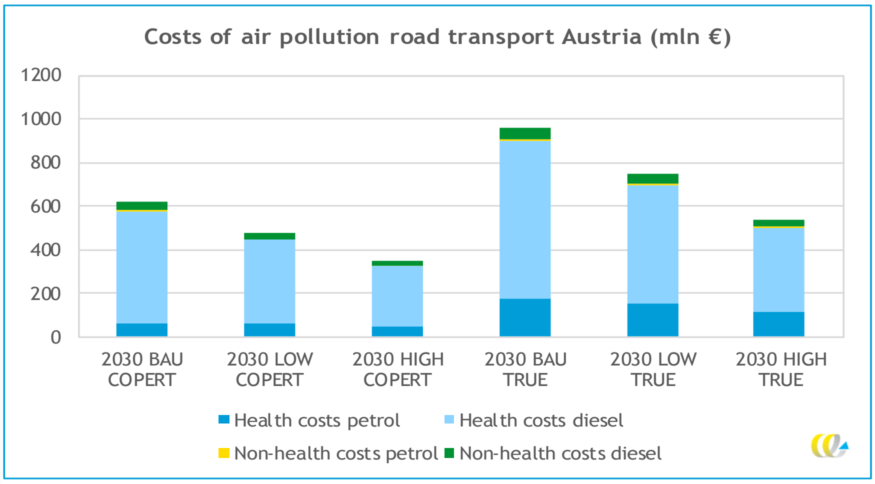
2030 LOW: a low ambition policy scenario with an increase in electric vehicles and ban of pre-Euro-6 in cities.

2030 HIGH: a high ambition policy scenario (HIGH) with strong increase in electric vehicles, a ban of diesel cars and pre-Euro-6 vehicles on all roads, kilometer charges and higher diesel taxes.

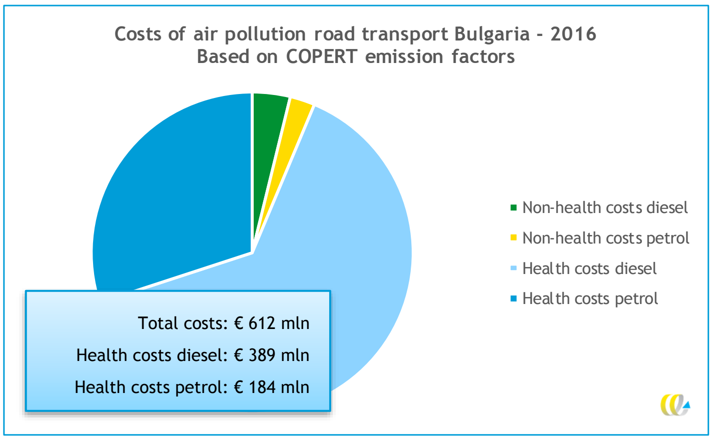
Scenarios 2030

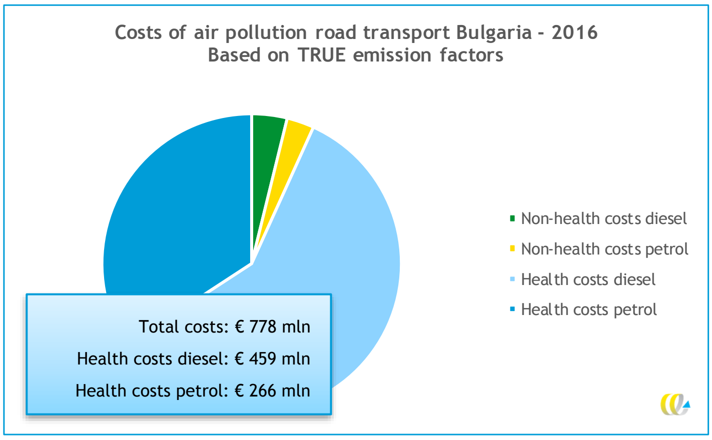
Total costs COPERT:
2030 BAU: € 617 mln
2030 LOW: € 473 mln
2030 HIGH: € 346 mln

Total costs TRUE:
2030 BAU: € 897 mln
2030 LOW: € 746 mln
2030 HIGH: € 538 mln



D.2 The costs of road vehicle air pollution - Bulgaria





The costs (both health and non-health related) of air pollution have been calculated for the current (2016) situation and for three 2030 scenarios:

2030 BAU: Business-as-usual

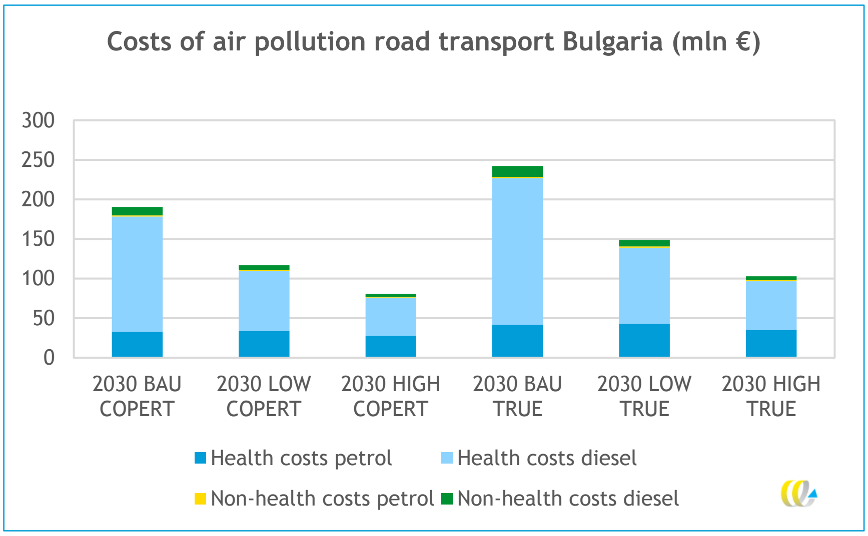
2030 LOW: a low ambition policy scenario with an increase in electric vehicles and ban of pre-Euro-6 in cities.

2030 HIGH: a high ambition policy scenario (HIGH) with strong increase in electric vehicles, a ban of diesel cars and pre-Euro-6 vehicles on all roads, kilometer charges and higher diesel taxes.

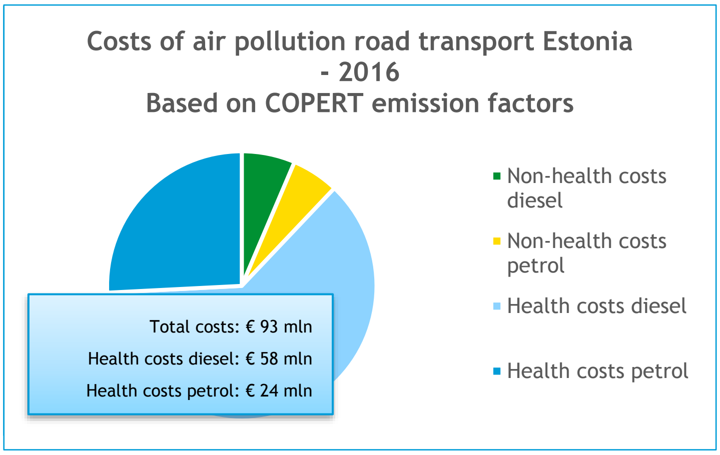
Scenarios 2030

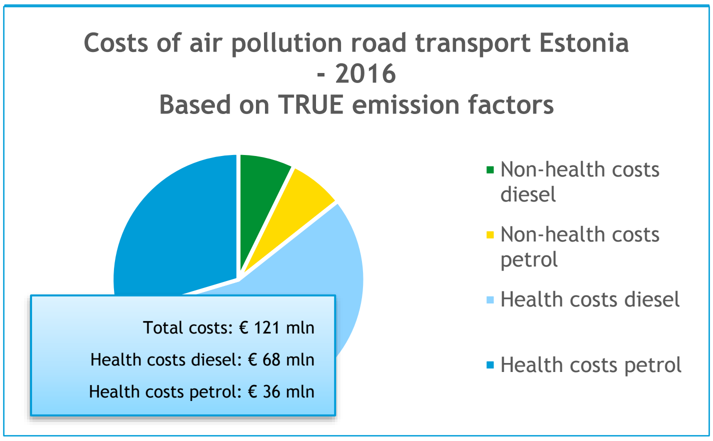
Total costs COPERT:
2030 BAU: € 191 mln
2030 LOW: € 117 mln
2030 HIGH: € 81 mln

Total costs TRUE:
2030 BAU: € 242 mln
2030 LOW: € 149 mln
2030 HIGH: € 103 mln



D.3 The costs of road vehicle air pollution - Estonia





The costs (both health and non-health related) of air pollution have been calculated for the current (2016) situation and for three 2030 scenarios:

2030 BAU: Business-as-usual

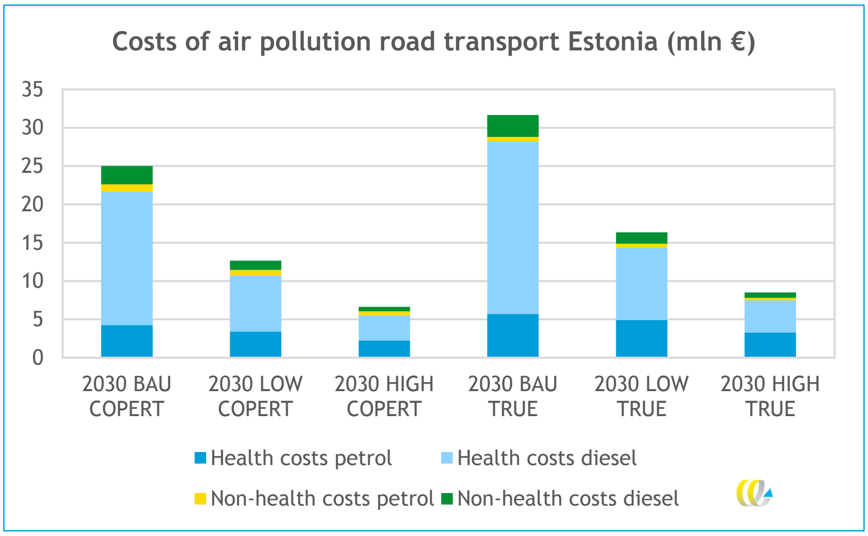
2030 LOW: a low ambition policy scenario with an increase in electric vehicles and ban of pre-Euro-6 in cities.

2030 HIGH: a high ambition policy scenario (HIGH) with strong increase in electric vehicles, a ban of diesel cars and pre-Euro-6 vehicles on all roads, kilometer charges and higher diesel taxes.

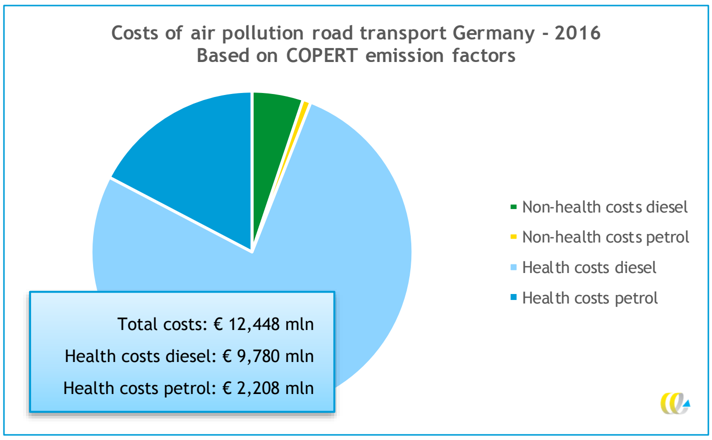
Scenarios 2030

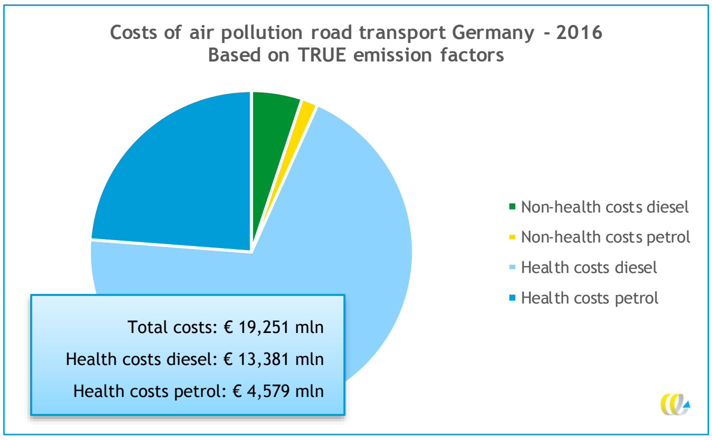
Total costs COPERT:
2030 BAU: € 25 mln
2030 LOW: € 13 mln
2030 HIGH: € 7 mln

Total costs TRUE:
2030 BAU: € 32 mln
2030 LOW: € 16 mln
2030 HIGH: € 9 mln



D.4 The costs of road vehicle air pollution - Germany





The costs (both health and non-health related) of air pollution have been calculated for the current (2016) situation and for three 2030 scenarios:

2030 BAU: Business-as-usual

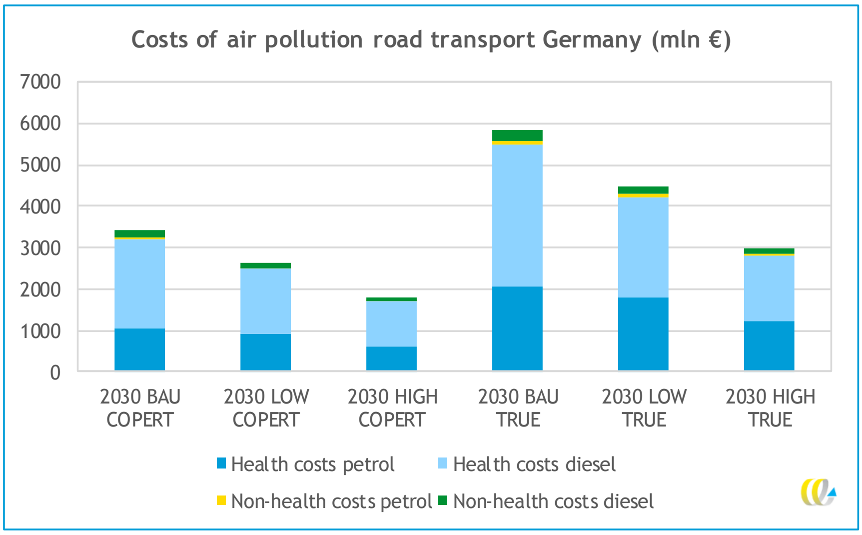
2030 LOW: a low ambition policy scenario with an increase in electric vehicles and ban of pre-Euro-6 in cities.

2030 HIGH: a high ambition policy scenario (HIGH) with strong increase in electric vehicles, a ban of diesel cars and pre-Euro-6 vehicles on all roads, kilometer charges and higher diesel taxes.

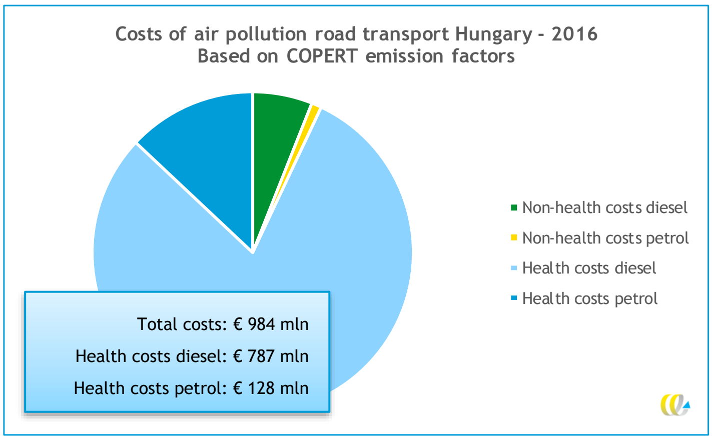
Scenarios 2030

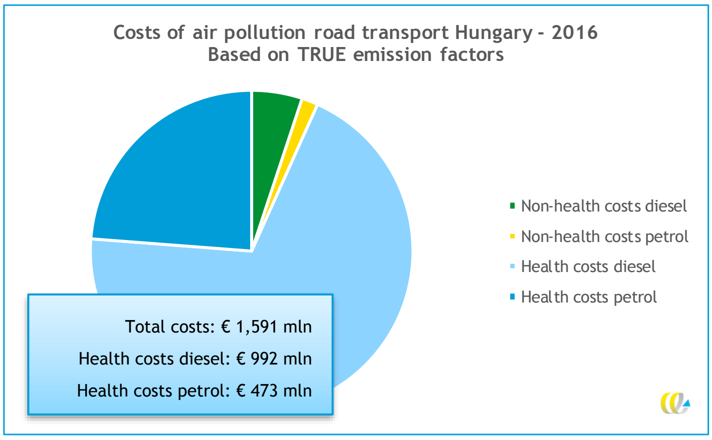
Total costs COPERT:
2030 BAU: € 3,414 mln
2030 LOW: € 2,634 mln
2030 HIGH: € 1,798 mln

Total costs TRUE:
2030 BAU: € 5,850 mln
2030 LOW: € 4,493 mln
2030 HIGH: € 2,976 mln



D.5 The costs of road vehicle air pollution - Hungary





The costs (both health and non-health related) of air pollution have been calculated for the current (2016) situation and for three 2030 scenarios:

2030 BAU: Business-as-usual

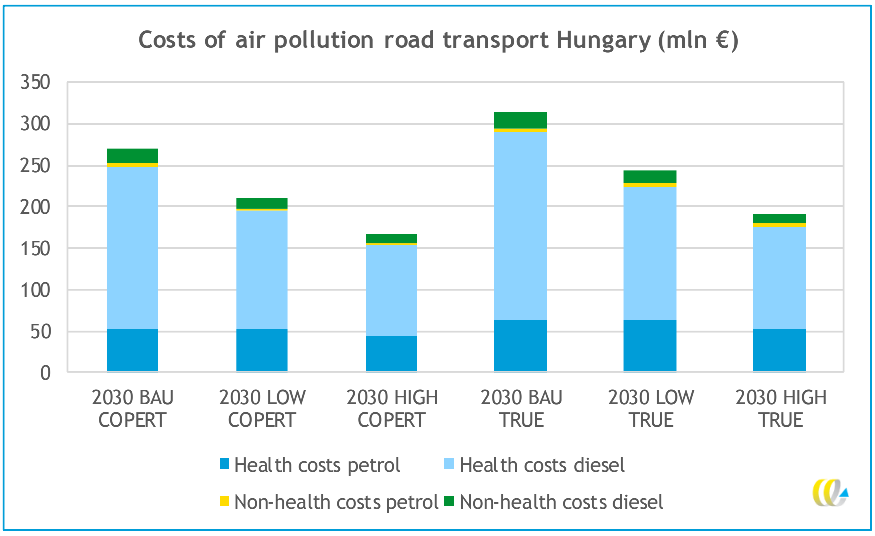
2030 LOW: a low ambition policy scenario with an increase in electric vehicles and ban of pre-Euro-6 in cities.

2030 HIGH: a high ambition policy scenario (HIGH) with strong increase in electric vehicles, a ban of diesel cars and pre-Euro-6 vehicles on all roads, kilometer charges and higher diesel taxes.

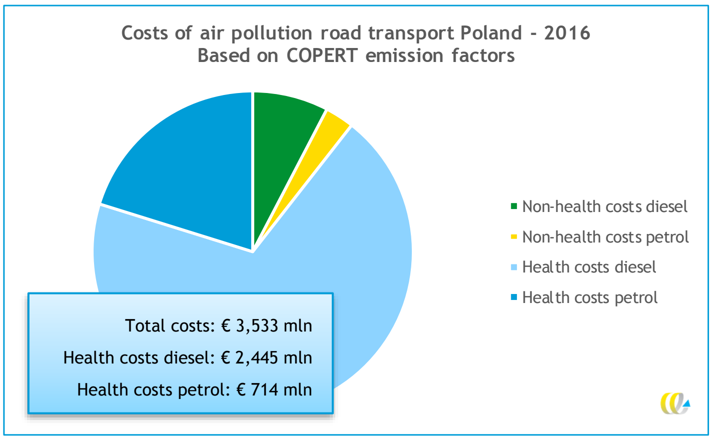
Scenarios 2030

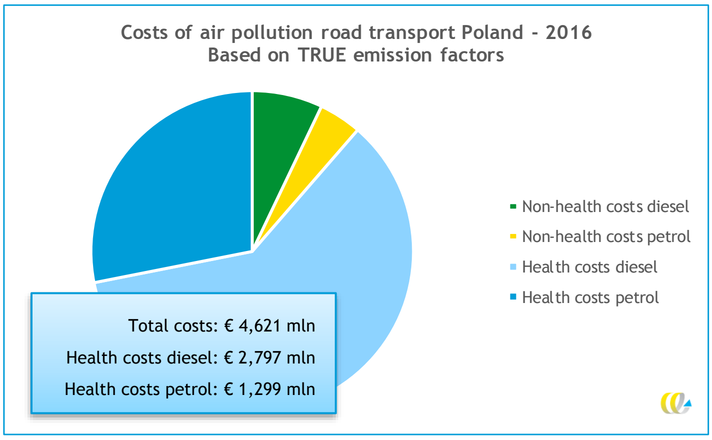
Total costs COPERT:
2030 BAU: € 270 mln
2030 LOW: € 212 mln
2030 HIGH: € 167 mln

Total costs TRUE:
2030 BAU: € 315 mln
2030 LOW: € 244 mln
2030 HIGH: € 190 mln



D.6 The costs of road vehicle air pollution - Poland





The costs (both health and non-health related) of air pollution have been calculated for the current (2016) situation and for three 2030 scenarios:

2030 BAU: Business-as-usual

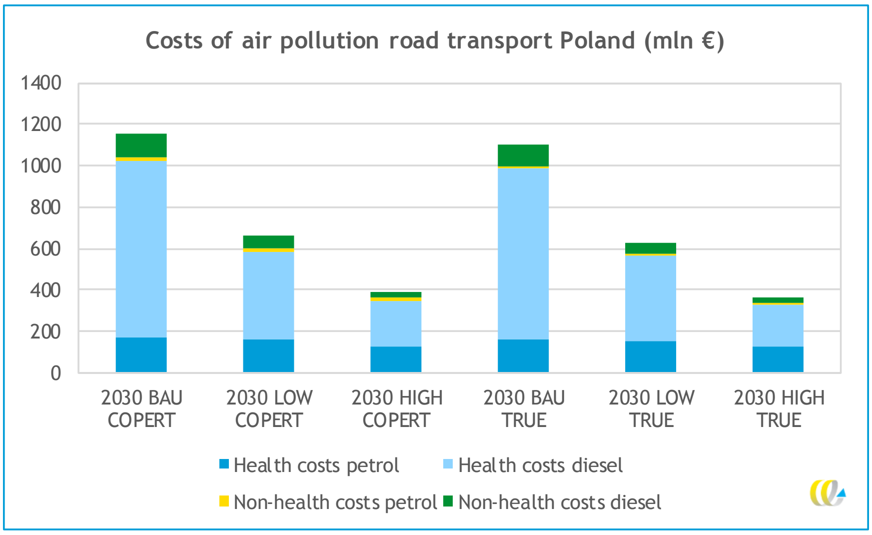
2030 LOW: a low ambition policy scenario with an increase in electric vehicles and ban of pre-Euro-6 in cities.

2030 HIGH: a high ambition policy scenario (HIGH) with strong increase in electric vehicles, a ban of diesel cars and pre-Euro-6 vehicles on all roads, kilometer charges and higher diesel taxes.

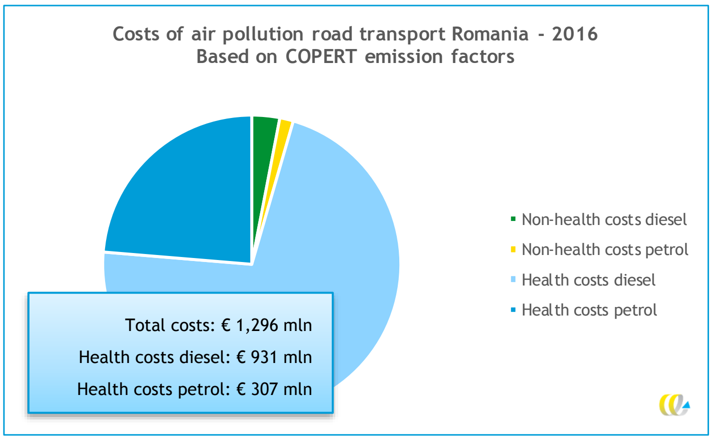
Scenarios 2030

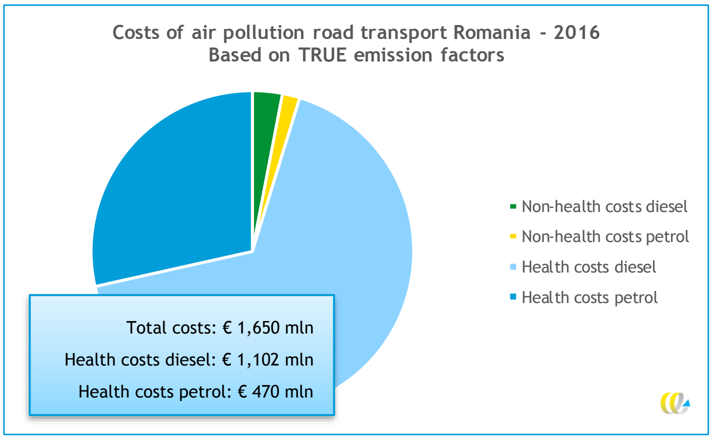
Total costs COPERT:
2030 BAU: € 1,152 mln
2030 LOW: € 659 mln
2030 HIGH: € 388 mln

Total costs TRUE:
2030 BAU: € 1,103 mln
2030 LOW: € 630 mln
2030 HIGH: € 366 mln



D.7 The costs of road vehicle air pollution - Romania





The costs (both health and non-health related) of air pollution have been calculated for the current (2016) situation and for three 2030 scenarios:

2030 BAU: Business-as-usual

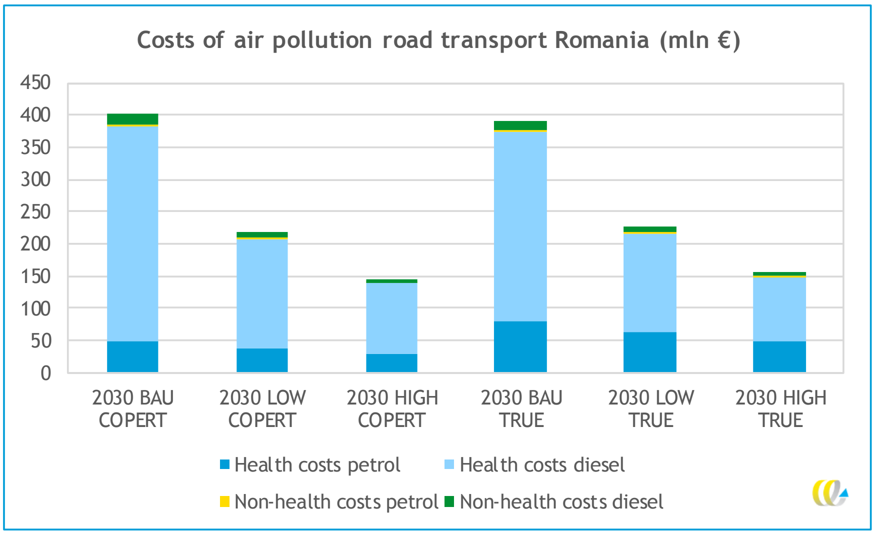
2030 LOW: a low ambition policy scenario with an increase in electric vehicles and ban of pre-Euro-6 in cities.

2030 HIGH: a high ambition policy scenario (HIGH) with strong increase in electric vehicles, a ban of diesel cars and pre-Euro-6 vehicles on all roads, kilometer charges and higher diesel taxes.

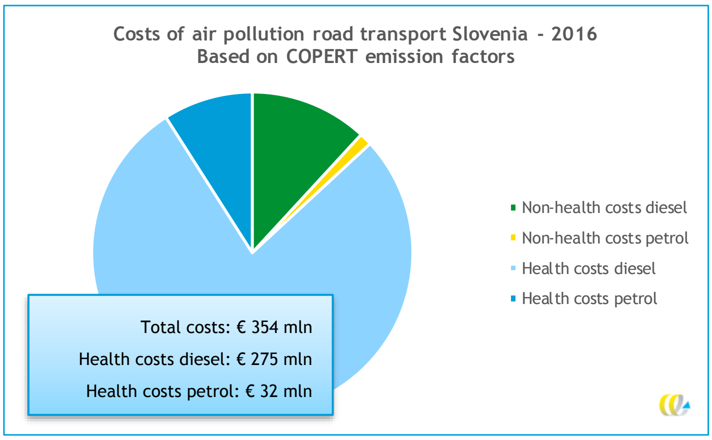
Scenarios 2030

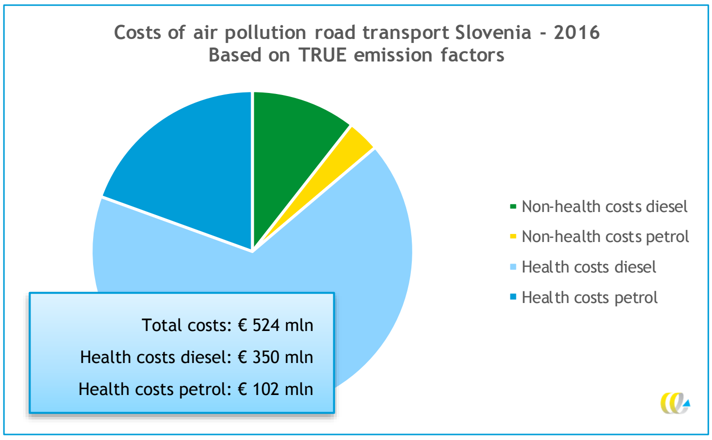
Total costs COPERT:
2030 BAU: € 402 mln
2030 LOW: € 218 mln
2030 HIGH: € 145 mln

Total costs TRUE:
2030 BAU: € 390 mln
2030 LOW: € 226 mln
2030 HIGH: € 155 mln



D.8 The costs of road vehicle air pollution - Slovenia





The costs (both health and non-health related) of air pollution have been calculated for the current (2016) situation and for three 2030 scenarios:

2030 BAU: Business-as-usual

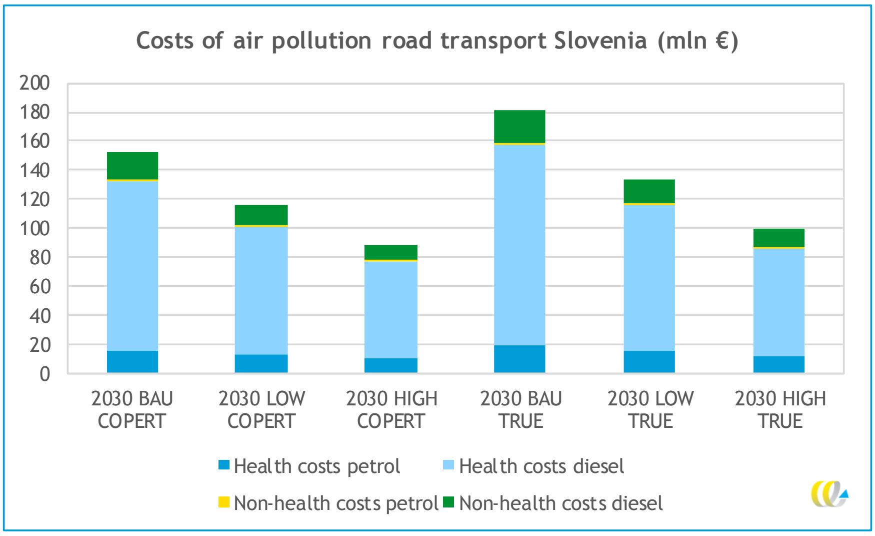
2030 LOW: a low ambition policy scenario with an increase in electric vehicles and ban of pre-Euro-6 in cities.

2030 HIGH: a high ambition policy scenario (HIGH) with strong increase in electric vehicles, a ban of diesel cars and pre-Euro-6 vehicles on all roads, kilometer charges and higher diesel taxes.

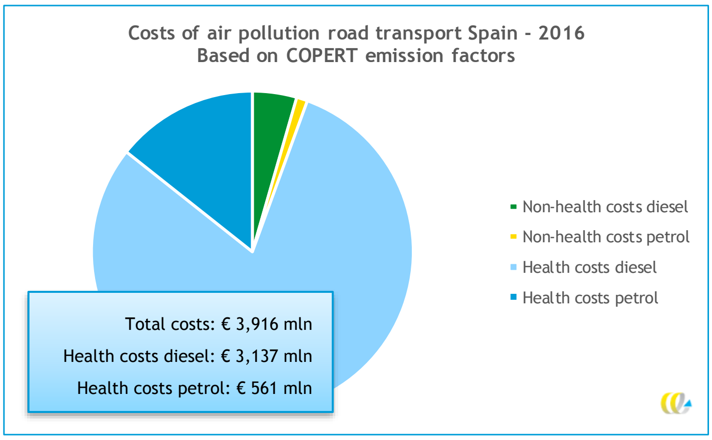
Scenarios 2030

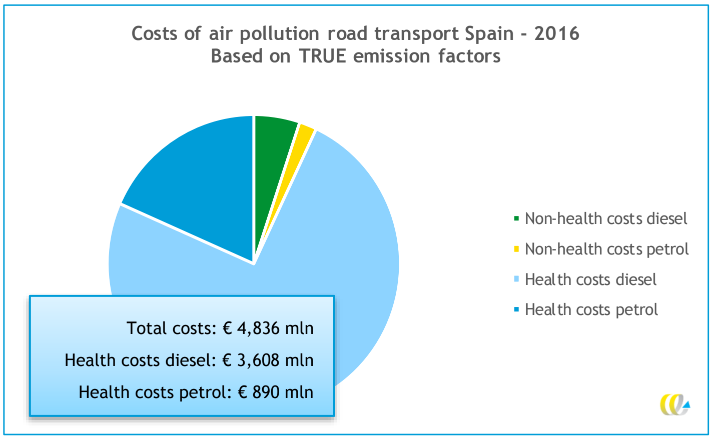
Total costs COPERT:
2030 BAU: € 153 mln
2030 LOW: € 116 mln
2030 HIGH: € 89 mln

Total costs TRUE:
2030 BAU: € 182 mln
2030 LOW: € 134 mln
2030 HIGH: € 100 mln



D.9 The costs of road vehicle air pollution - Spain





The costs (both health and non-health related) of air pollution have been calculated for the current (2016) situation and for three 2030 scenarios:

2030 BAU: Business-as-usual

2030 LOW: a low ambition policy scenario with an increase in electric vehicles and ban of pre-Euro-6 in cities.

2030 HIGH: a high ambition policy scenario (HIGH) with strong increase in electric vehicles, a ban of diesel cars and pre-Euro-6 vehicles on all roads, kilometer charges and higher diesel taxes.

Scenarios 2030

Total costs COPERT:
2030 BAU: € 996 mln
2030 LOW: € 706 mln
2030 HIGH: € 519 mln

Total costs TRUE:
2030 BAU: € 1,501 mln
2030 LOW: € 1,059 mln
2030 HIGH: € 770 mln