Circular Economy & Environmental
Princetonlaan 6
3584 CB Utrecht
Postbus 80015
3508 TA Utrecht

www.tno.nl

T +31 88 866 42 56

TNO report

TNO 2017 R11689

Elemental carbon emission factors of vehicles for Dutch air-quality assessments

Date	20 September 2018
Author(s)	N.E. Ligterink PhD
Number of pages	37 (incl. appendices)
Number of appendices	1
Sponsor	RIVM Emissieregistratie
Project name	Emissieregistratie 2017
Project number	060.22922

Summary

Since a number of years, indicative elemental carbon (EC) emission factors have been circulating in the Netherlands. These numbers had no official status, but grew from a collection of sources. Some important numbers in this collection were questionable, based on outdated test results, or different vehicle technology categories not applicable to new vehicle technologies. Most important GDI's (gasoline direct injection) EC emissions test results were missing. From the Pollutant Release and Transfer Register (PRTR) there is an interest in the EC emission factors, since EC emissions are used as an estimate to report BC emissions to the Convention of Long-Range Transboundary Air Pollution (CLRTAP). The PRTR have requested this study, to make the results generally available. The Ministry of Infrastructure and the Environment provided additional sponsoring for the emission tests on GDI vehicles. In the process of giving EC emission factors a more official status in the Netherlands, additional tests and analyses were carried out, and this report summarizes aspects related to EC emissions and emission factors.

With complex after-treatment systems the fractional contribution of elemental carbon to total particulate matter in exhaust seems to be decreasing. An increasing fraction of the vehicle fleet is equipped with a particulate filter. Eventually, the remaining differences in elemental carbon contributions for the different after-treatments are of decisive importance for total elemental carbon emissions and for the fractional contribution to total particulate matter. Currently, older diesel vehicles without after-treatment and thus with high particulate emissions and relatively high elemental carbon contributions are the dominant source of PM and EC emissions and thereby determine the correlation between both in the ambient air. In the future, this correlation will change, as older diesel vehicle will phase out.

This report is an overview of the research of the recent years culminating in the publication of the complete set of verified PM10 and EC emission factors of road transport for all vehicle categories (see Appendix A), as used for national models. The intention is to provide the information to ensure a consistent bottom-up determination of emission totals and air-quality prognoses. This report is therefore supportive to the national monitoring of elemental carbon in the ambient air.

Combustion exhaust aerosols are experimentally characterised by measurements of different properties such as particulate number concentration, light absorption (blackness), morphology and its refractoriness. Due to the different applied measurement techniques, the association between the parameters is not unambiguous and the correlations are not well defined. The advantage of using elemental carbon as central marker is that, unlike other metrics, elemental carbon is unaffected by atmospheric processes such as chemical reactions and condensation. Hence, measurements at the source, i.e., at the tailpipe, and air-quality measurements are directly comparable. This will still depend on the measurement protocol used.

A few groups of vehicles required additional investigations to confirm, or adapt, the current estimates based on limited data of elemental carbon emission factors:

- The petrol vehicles with direct injection (GDI) have high fractions of elemental carbon in the particulate matter, but, on the other hand, low overall particulate matter emissions. Particulate matter emissions from petrol cars are associated mainly with deterioration.
- Another group of specific interest is Euro-V heavy-duty vehicles without filter, but with Selective Catalytic Reduction (SCR). They have lower fractions of elemental carbon than older vehicles without SCR. Seemingly, the SCR changes the composition of the particulate matter. Moreover, the exhaust gas temperature generates history effects which can delay the actual particulate emissions for minutes to hours.

The main uncertainty in current emission factors is the malfunctioning and tampering of the vehicles, which generates much higher particulate emissions than a properly functioning vehicle. This uncertainty is still remaining for both particulate matter and elemental carbon emission factors. Such malfunctions are not uncommon. Estimates are one-in-ten to one-in-twenty vehicles show malfunctions with a manifold increase in emissions. The number of vehicles tampered with, i.e., the filter removed, is unknown. Malfunctions of the combustion technology are associated with high elemental carbon fractions. Malfunctions of the particulate filter are associated with lower fractions of elemental carbon. The removal of a soot filter will bring the emission levels and elemental fractions back to Euro-3 or Euro-4 levels.

Contents

1 Introduction

This report supplies the necessary background to the publication of elemental carbon emission factors of all vehicle categories in the national emission inventory. Elemental carbon is that part of particulate matter in ambient air which is directly related to combustion processes. In many cases, in urban environments, the main source is the exhaust gas of vehicles, in particular older diesel vehicles. Both the temporal and the spatial distribution of the concentrations of elemental carbon are closely linked to the diurnal traffic flows. Because elemental carbon is correlated to the toxic particulate matter in the exhaust gas, and because recently a monitoring network for black carbon is established, there is increasing interest in linking air-quality observations of black carbon and elemental carbon concentrations with elemental carbon emissions. Emission factors for elemental carbon from emission measurements provide direct evidence for the different vehicle categories contribution to the elemental carbon particulates in the atmosphere.

Although it is difficult to establish the direct link between elemental carbon and health problems, the link between particulate matter in diesel combustion gas and health problems is well established, for example by the IARC (International Agency for Research on Cancer). Even more, the cocktail of vehicles emissions of elemental carbon, polluting exhaust gases like NO_2, metals from brake wear, and organic compounds is likely to be more toxic than the separate components. The concentration of elemental carbon in the ambient air can at least serve as a marker or health risk indicator of the vehicle particulate emissions. This marker is also more constant than many other markers, like total particulate mass and the particulate number concentration, which readings depends very much ambient air chemistry and the ambient conditions.

There is no international obligation to supply the elemental carbon emissions inventories, but there is an international obligation to report black carbon (BC) emissions inventories to the Convention on Long-Range Transboundary Air Pollution (CLRTAP), as described in the Guidelines for Reporting Emissions and Projections Data (ECE/EB.AIR/125). The Dutch PRTR uses the calculated EC emissions to report the BC emissions. Moreover, there seems to be little consensus on the best method to determine the elemental carbon, or black smoke, or black carbon, concentration. Many studies of correlation between different test methods are based on a single, or a limited number of combustion and engine technologies. Experiences with different technologies show that there is already a large variation in the formation and nature of particulate matter before it leaves the exhaust tailpipe.

1.1 Indicative numbers for vehicle elemental carbon emission factors

For a number of years there have been indicative numbers for vehicle elemental carbon emission factors, collected from different sources. These numbers have been used by a number of parties. Although, not all elemental carbon emissions results are consistent which each other. Moreover, for a number of categories the underlying data is limited. In the last couple of years there has been some studies to fill in these gaps in knowledge.

The complete picture for road transport, presented in this report, is meant to be part of the Dutch Pollutant Release and Transfer Register, which also has sponsored part of the analyses.

The limited information of the elemental carbon fraction was not necessarily a large problem for the indicative numbers. Elemental carbon is a fraction of the total particulate matter emissions, and it can therefore not exceed the particulate matter emissions. With the substantial decrease of particulate matter emissions of the main vehicle source, the diesel vehicles, the elemental carbon emissions have decreased as well. Even if the fraction of elemental carbon has increased for some technologies, the total emissions has dropped. For example, the indicative emission factors for passenger cars, show the dominance of older diesel vehicles in the total particulate emissions. In Figure 1 the indicative emission factors of different light-duty vehicle categories are show together. Current values are hardly visible on the scale set by the older diesel vehicles. Many modern vehicles emit around 1 mg/km, while in the past the emissions where close to 1 g/km.

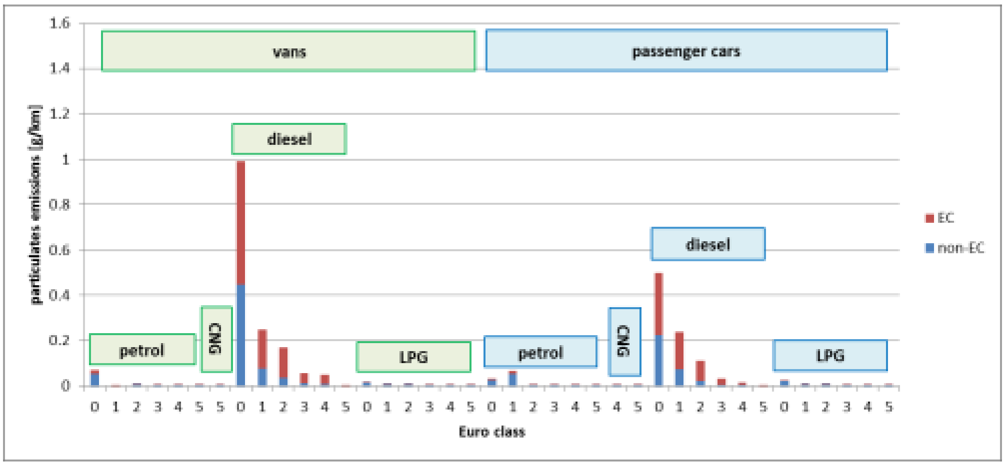


Figure 1 The total particulate matter emissions and the elemental fraction therein. The fraction of elemental carbon has only limited effect on the significant decrease over the years, because the elemental carbon emission factor of one Euro class is more than the total particulate matter emission of the next Euro class.

Hence, at the scales in consideration the laboratory particulate filter measurements are a good indication of the current elemental carbon emissions, due to the factor 100 or more difference between the high and low particulate matter emissions.

These filter measurements have been carried out steadily from the 1980’s in more or less the same manner, collecting the finer particles on a paper filter, and weighing the filter before and after the exposure to the hot and diluted exhaust gas. Hence, these results yield a good comparison across the categories. The conditions during collection on a filter are somewhat different than the typical Dutch ambient conditions after the exhaust tailpipe. The laboratory conditions are such that no condensation and limited accumulation will occur. Consequently, the mass on the filter is typically lower than with other methods. But this difference should not be exaggerated and since in the laboratory settings also the gaseous organic compounds are determined, the possible ambient chemistry can be reproduced, from the total composition of exhaust gas determined in the laboratory.

Consequently, the gaseous hydrocarbons will yield an upper bound to the total particulate matter in other conditions than the laboratory conditions. In many cases the hydrocarbon emissions are from different engine operation conditions; low load rather than high load. If the emissions of particulate matter and hydrocarbons do not occur simultaneously, they cannot form compounds different from the composition collected on the filter.

The complex emission-reduction after-treatment systems of modern diesel vehicles does seem to have altered the nature and formation of diesel particulates after the engine. For example, high-pressure exhaust gas recirculation (HP-EGR), will re-introduce particulate matter in the engine again and it will likely yield a larger fraction of elemental carbon in this second round combustion. Furthermore, catalytic after-treatment technology will affect the exhaust gas composition in many complex ways. Consequently, it is important that the measurement of particulate matter and elemental carbon should be executed on common technology and in representative situations for the emission factors. The storage and release of particulates from the after-treatment components depends on the built-up and the temperature management which can be related to urban or motorway driving the previous day.

1.2 Data gaps in the indicative numbers

The indicative emission factors and the development of vehicle technologies have been key in establishing the major gaps in the current knowledge regarding elemental carbon emissions. In that case the Euro-V trucks, the last diesel vehicles without particulate filter, and the Euro-4 diesel passenger cars, the last light-duty vehicles without particulate filter, are the dominant categories. Some increase in particulate matter emissions and elemental carbon emissions are expected with the introduction of gasoline direct injection (GDI). In the light of the low emissions of port-injection petrol vehicles, the increase may be substantial. Especially cold start emissions and high load emissions are reasons for concern. The GDI's have been tested for particulate mass, particulate mass, and elemental carbon emissions.[1]

A few years ago, a Euro-V engine with SCR have been used to determine elemental carbon emissions.[2] Apart from the cross correlation of different methods, this study gave indications that the heat up of the after-treatment system affects the results.

1.3 Elemental carbon emission factors in this report

This report is the background to the publication of the elemental carbon emissions factors for all categories of vehicles. Indicative elemental carbon emission factors have been used indicatively from 2011 onwards. In order to link these emissions to particular sources a backlog of vehicle categories is updated in the emission factors database at TNO. Additional tests are carried out and used to update and expand the list of emission factors.

---

[1] TNO 2016 R11247 Emissions of three common GDI vehicles, Norbert E. Ligterink

[2] TNO 2015 R11041 HD Euro-V truck PM10 and EC emission factors, Uilke Stelwagen and Norbert Ligterink

It should be noted, however, that special particulate matter reduction technologies, as was common around 2000-2009, with, for example, the CRT (Continuous Regenerating Trap) technology with the stricter EEV emission standards for busses are not properly represented in the data underlying these emission factors.

Another feature, regarding particulate matter emissions, which would require further study for a complete picture is the deterioration of the particulate emissions. It is expected that with the aging of vehicles, and, e.g., the increase of the lubricant consumption, the particulate matter emissions are expected to increase. Currently, for example, the particulate emissions of older diesel vehicles are based on measurements from the past, when these vehicles had a lower mileage, combined with a limited deterioration factor based on conservative estimates of the deterioration. The number of vehicles concerned is small, but the emissions are high compared to newer and petrol vehicles.

Hence, current elemental emission factors are suitable to determine total and the average elemental carbon emissions. The comparison of the relative impact of different vehicle categories must be done with great care. For a number of cases the relative difference between vehicle categories is uncertain. This uncertainty is large for two cases: First, the emissions below 5 mg/km is close to the standard measurement accuracy. Results in the order of 1-2 mg/km require dedicated testing, to ensure the collection of enough material on the filter. Moreover, for example filter regenerations in diesel vehicles occur about once every 500 km, contributing significantly to the total emissions of a few mg/km, but of unclear composition. The second case is special technologies and fuels, which also include CNG, LPG, bio-admixture in fuel, all known to affect the particulate emissions, but without enough test results to distinguish relative effects accurately. As it is unlikely the emissions are more than twofold higher than the conventional counterparts, they have received little attention because of the limited impact on the emission totals.

Chapter 2 provides a general description of the elemental carbon emissions from vehicle exhaust, including a description of measurement techniques and the importance of certain vehicle categories. Chapter 3 discusses the indicative elemental carbon emission factors and the results of recent testing on elemental carbon emission factors, providing the background data on the PM and EC emission factors (as presented in Appendix A). The effects of driving behaviour and vehicle usage on emission factors are discussed in chapter 4. Chapter 5 provides the conclusions.

2 Elemental carbon emission from the vehicle exhaust

Elemental carbon is a fraction of the total particulate matter. In exhaust emissions, the fractions typically vary between 10% and 95%. Diesel vehicles with EGR but without after-treatment technology generally have the highest elemental carbon fraction and mopeds the lowest. In its most strict sense, determination of elemental carbon emissions requires chemical analysis of an inert filter, typically quartz, which collects exhaust gas directly from the tailpipe, prior to subsequent reactions in the ambient air. References to “elemental carbon” are often based on simpler, approximate methods, like black carbon or opacity meters. However, many alternative proxy methods have been used, to establish elemental carbon emission factors. In the recent testing, some methods have been compared. In other cases, the emission measurements have been conform the air-quality methods as much as possible. For diesel vehicles with a filter (DPF, Diesel Particulate Filter) the emissions were often so low that an accurate determination of the EC fraction was not possible.

Paragraph 2.1 provides a description of different measurement methods and the possible drawbacks of these measurement methods, while paragraph 2.2 and 2.3 provides a more detailed description of the measurement possibilities and drawbacks.
Paragraph 2.4 describes the international reporting of elemental carbon concentrations in ambient air and paragraph 2.5 describes the health effects. In paragraph 2.6, a description of important vehicle categories with regard to EC emissions is provided.

2.1 Particulate mass, particulate number, and elemental carbon measurement techniques

Black smoke, black carbon and elemental carbon are different measures to quantify the dark exhaust smoke. Elemental carbon is the mass amount of thermally stable carbon. On the other hand, black carbon and black smoke are based on the light absorption properties of the particulate matter. The black smoke, or smoke, has been the initial measure of a performance of a vehicle on particulate matter, developed by the combustion engineers themselves. Different tests are correlated by comparable scales, such as Bosch smoke number, Hartridge smoke units and light absorption in $[m^{-1}]$. Black smoke is visible from 0.15 g/m^3[3]. This corresponds to about 1 g/kWh under normal engine operation; double the Euro-I emission limit. These measurement techniques have been replaced in the European legislation with a filter weight measurement, and recently with particle number measurements. The filter results reproduced better, at the time, than the variety of smoke measurement techniques, some of which are rather historic.

This paragraph provides information on the different definitions and different measurement methods to express black carbon. Black Carbon (BC) is quantitatively not well defined and it is a generally descriptive term given to a collection of optical techniques. Emission sources of incomplete combustion processes, BC is particulate matter, which contains a lot of carbon and is strongly light absorbing.

---

[3] Benzine en dieselmotoren. H. Grohe.

It is a primary source, linking emissions with ambient concentrations, in the sense that it cannot be formed in the atmosphere from other precursor species. When definitions are given, it often does not become more clear how to measure it, e.g., US, EPA (2012)[4] defines BC as a solid form of mostly pure carbon that absorbs solar radiation (light) at all wavelengths. BC is the most effective form of PM, by mass, at absorbing solar energy, and is produced by incomplete combustion. IPCC (2013)[5] states that “BC is an operationally defined aerosol species based on measurement of light absorption and chemical reactivity and/or thermal stability. It is sometimes referred to as soot”. Recently Petzold et al. (2013)[6] concluded that BC is a **qualitative** description when referring to light absorbing carbonaceous substances in atmospheric aerosol. Most importantly, BC has four properties (Bond et al., 2013)[7]:

1. Chemically stable: Refractory with vaporization temperature near 4000 K [8]
2. Strong visible light absorption at 550 nm [9]
3. Aggregate morphology [10]
4. Insolubility in water and common organic solvents[11]:

The properties 3 and 4 (on morphology and solubility) find their applications more frequent in academic studies. The properties 1 and 2 are measured and can be used to quantify black carbon.

EC (Elemental Carbon) refers to chemically stable carbon (property 1), whereas opacity meters, smoke meters, and absorption photometers rely on the absorption property (property 2). Both properties measure a property of black carbon, but both properties are different and so are the outcomes. Both methods EC and light absorption refer to the black carbon and associations are thus to be expected, correlations depend on the specific sampling conditions.

2.2 Absorption measurements for determining equivalent black carbon

Opacity instruments are quick and cheap and designed and used for inspection and maintenance or periodical technical inspection. However, better filtering and after-treatment techniques put the usability of opacity meters under pressure.
E.g., the cleaner exhaust brings the meters to their lower detection limit, with stronger particulate emission reduction as compared to NO2, the cross sensitivity of NO2 absorption becomes increasingly important, and thirdly opacity meters are

---

[4] EPA, 2012. Report to congress on black carbon. EPA-450/R-12-01. Mach 2012.

[5] IPCC, 2013. Climate Change 2013. The Physical Science Basis. Contribution of Working Group I to the Fifth assessment Report of the Intergovernmental Panel on Climate Change.

[6] Petzold, A., et al., 2013, 'Recommendations for the interpretation of "black carbon" measurements', Atmospheric Chemistry and Physics, (13) 9 485–9 517.

[7] Bond TC, et al., 2013. Bounding the role of black carbon in the climate system: a scientific assessment. J Geophys Res. 118(11), 5380–5552.

[8]. Schwarz, J.P. et al., Single-Particle Measurements of Midlatitude Black Carbon and Light-Scattering Aerosols from the Boundary Layer to the Lower Stratosphere. J. Geophys. Res. Atmos., 111(D16).

[9] Bond, T. C., and R. W. Bergstrom (2006), Light absorption by carbonaceous particles: An investigative review, Aerosol Sci. Technol.,41(1), 27–47

[10] Medalia, A. I., and Heckman, F. A. (1969). Morphology of Aggregates II. Size and Shape Factors of Carbon Black Aggregates from Electron Microscopy. Carbon 7:567–582.

[11] Fung, K., Particulate Carbon Speciation by MnO2 Oxidation, 1990, Aerosol Science and Technology 12(1):122-127.

insensitive to the smallest particles (e.g. <200nm) that becomes relatively more abundant in modern exhaust emissions.

Smoke meters that rely on transmission or reflection of light through a particle laden filter, report in different units such as Filter Smoke Number, Bosch Smoke unit, or Hartridge Smoke Units.[12] The advantage of these techniques is that they are comparable to ambient air monitoring that rely on the same principle. The daily average Black Smoke Index that faded into oblivion, is now replaced by filter based absorption photometers such as Aethalometer and Multi Angle Absorption Photometer (MAAP) that provide temporally resolved light absorption coefficients. With the appropriate mass specific extinction coefficient, i.e., how much light is absorbed per unit of mass, the absorption photometers report the convenient equivalent Black Carbon mass concentrations that are easily compared to air quality model calculations. The drawback of filter-based metrics is the sensitivity to condensable co-emitted species and thus the sampling temperature and dilution conditions. In automotive measurements these conditions are prescribed to achieve reproducible results. Moreover, this hampers the inter-comparability between emission measurements and ambient air monitoring that are not representative for same conditions. Finally, the aerosol light absorption properties are not constant after emissions, because during aging coatings are formed that may enhance the light absorption.

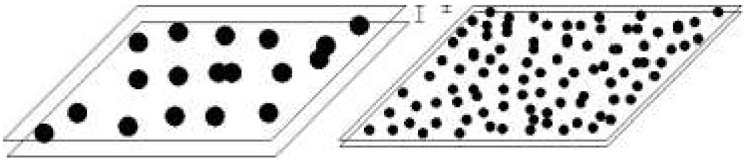


Figure 2 For the same opacity, fewer larger particles are needed, which, however correspond to a higher total mass as the required volume for the same frontal area is larger. Hence, the link between opacity (smoke) and particulate mass (carbon) requires fixed particulate characteristics.

The size and composition of the particles determine the opacity. Smaller particles require less mass, and volume, to achieve the same opacity. However, sub-micrometer particles will diffract light rather than absorb it, which yields opacity variations for the same frontal, or projected surface. Modern diesel injectors operating at higher pressures will spray the fuel better, such that the larger particle sizes have decreased somewhat over the years. Hence a statement relating opacity to particle number or particle mass is related to the injection and combustion technology, and for vehicles with after-treatment systems also the exhaust-gas flow pattern.

Optical methods are preferred to determine elemental carbon concentration, because they are simple, fast and stable.
But optical methods have the drawback that the elemental carbon mass is a derived quantity, which depends on the size, structure and composition of the particulate matter.

---

[12] Peter Eastwood, Particulate emissions from vehicles, Wiley-SAE, 2008.

Hence the correlation with mass, of any optical methods, may vary with the combustion technology and the path between combustion and measurement instrument.

Depending on the particle concentration, duration, and flow, particles may coagulate or cluster. At concentrations in the dilution tunnel and the ambient air this process will take hours to days to produce the larger particles of 200 nm. Hence this will only play a limited role in experiments with an engine test bed. The initial nucleation, to 20-30 nm occurs already in the combustion chamber. The medium accumulation from 30 nm to 100 nm will occur rapidly, and this may be affected by the dilution ratio, flow profiles, and residence time, in the experiment.

During sampling, conditions such as temperature and composition of the ambient air are important, because it will affect the measurements of equivalent black carbon. To avoid formation of droplets and evaporation of e.g. hydrates and sulphates from the soluble organic fraction, the dry air temperatures should be kept between 20 and 52 degrees Celsius.

Most of the drawbacks for measuring equivalent black carbon, can be overcome when elemental carbon is used in the monitoring networks, i.e. air quality measurements and modelling, and when emission factors are based on elemental carbon. The disadvantage is that EC measurements in a network are more time consuming (costly) and for high quality data 24-hour sampling is the standard, so that information on diurnal time scales is lost. Measurement networks therefore frequently rely on absorption photometers (MAAP). The advantage of harmonized high quality EC emission factors outweigh the lacking direct comparability to air quality measurement metrics of (equivalent) black carbon.

2.3 EUSAAR/SUNSET method of determining elemental carbon fractions

The elemental carbon fraction, as opposed to the carbon which is part of organic material, is determined in physical-chemical analysis, where the filter material is exposed to increasing temperatures in an oven in different atmospheres. The filter material must be inert not to contaminate the results. Therefore quartz filters are used. Quartz filters are brittle, so parts can break off such that the mass of the filter before and after the emission test is no longer a measure of the amount of particulate matter deposited. This disadvantage is taken on board in the use of quartz filters in repeat experiments in different projects. The filters were subsequently analysed for elemental carbon and organic carbon fractions. The separation between OC and EC is based on the thermal and chemical stability of the aerosol, i.e., OC comes off the filter at lower temperatures in an inert Helium atmosphere and EC leaves the filter at higher temperatures when oxygen is added.

The method is less accurate for the total amount of material as two features play a role: the material may not have been deposited homogenously, such that the result of a part of the filter cannot be scaled to the total result. Second, the method tests only for the states of matter of carbon. The total mass contains organic matter, which may be a larger fraction than it used to be due to the use of oxygenated fuels. Moreover, metal and other non-organic mineral material, like ash, may be present on the filter in small fractions. Some bounds on limitations are given in Table 1. Non-organic material does not come up in the EUSAAR analysis.

Moreover, with bio-admixture like ethanol, FAME, MTBE, and ETBE added to fuel in substantial amounts, oxygen may be part of the total particulate mass.

Table 1 For direct injection technology without particulate filter the carbon fraction is high, the other compounds are estimated to play a minor part.

	Fraction of PM10	Of which carbon
EC	>60%	100%
Organic matter	<30%	85%
carbon-free fraction	<15%	-

Modern fuels have about 85% carbon, 12.5% hydrogen, and 2.5% oxygen in weight. Hence, while converting the organic carbon to the total organic material about 18% additional weight should be added to the organic carbon, assuming a similar composition of the fuel and the organic particulate material.

Non-organic material is commonly referred to as ash. It consists of minerals, metals, and metal oxides, in the past in combination of sulphates. Presently, the sulphate content in fuel is ultralow, and sulphates are less common. The non-organic material is expected to be only a minor part of the particulate matter of a modern vehicle with modern fuel.

2.4 International reporting of elemental carbon concentrations

Currently, there is no obligation to report the elemental carbon concentrations internationally, but the Netherlands fulfils a voluntary request for reporting. A single measurement point is sampled frequently, and the filters are analysed with the EUSAAR-2 method as reference, but occasionally also the NIOSH method for determining the fraction elemental carbon on the filter is used. The results are reported as fractions, absolute levels are not determined.

Separately, also ambient black smoke (equivalent black carbon), or soot concentrations, are determined, in a national network of about 25 measurement stations. These consist of the stations of the cities of Amsterdam and Rotterdam, augmented with stations in other parts of the Netherlands from the RIVM. There is a correlation between the optical MAAP measurements, used in the network, and the reference value for elemental carbon. Experts suggest that within a 30% bandwidth, the elemental carbon concentrations and the optical equivalent of filter blackness volume are correlated.

2.5 Chemical soup theory versus isolated effects

Adverse health effects from diesel exhaust gas are well established from epidemiological studies. However, the detailed processes and the specific components in the exhaust gas are less clear. From diesel exhaust gas the particulate matter is considered the most relevant component for health issues. Within particulate matter, there are at least three aspects considered relevant for health: small, solid particles, or nano-particles, which enter deep in the bronchia, the carcinogenic compounds such as poly-aromatic hydrocarbons (PAH) in the soluble organic fraction, and elemental carbon in the particles.

For mopeds with poor combustion characteristics, the organic matter may play a more important role in the toxic nature of the exhaust gas. The elemental carbon fraction is smaller for these vehicles and determining the relative impact of moped solely on the basis of elemental carbon emission may underestimate the relevance for health.

2.6 Important vehicle categories for total emissions and local hotspots

Vehicle PM emissions range between 1 mg/km and 1000 mg/km, and a similar range for EC emissions. This wide range implies that a few strongly emitting vehicles make up a large fraction of total emissions. For example, one old diesel vehicle will fully compensate the effect of emission reduction measures of hundreds of diesel vehicles that are fitted with a wall-flow diesel particulate filter (DPF). The DPF technology, that is more or less compulsory since the European vehicle legislation, effectively reduces particulate emissions to a factor five to ten below the limit. Generally, ambient air contains more particulates than the diesel exhaust gas after the DPF. The fact that some vehicle categories dominate the (uncertainty of) emission totals and/or concentrations, these categories received special attention in this work.

For the future, the last of the heavy-duty trucks and busses without DPF are an important vehicle category, Euro-V, for particulate emissions. A number of studies have been devoted to determine the elemental carbon emissions, and to link the emission to driving behaviour. Since elemental carbon is obtained from a filter measurement, i.e., the results over longer time, relating the results back to instantaneous behaviour is not trivial.

Another emerging vehicle category for particulate and elemental carbon emissions are the GDI. This is not because of the high emissions, but because of the number of vehicles and the lifespan of sixteen years or more, on the Dutch road. The majority of the kilometres on the Dutch roads are driven with petrol passenger cars. The new cars have direct injection technology in large numbers. Consequently, 1 mg/km extra elemental carbon emissions of GDIs can mean 50 tons of elemental carbon emissions every year, least up to 2030. The difference of 1 mg/km is a very small number, close to the measuring uncertainty. But the total number of vehicles and the mileages associated generates one of the largest impacts. Therefore, this technology was studied to complete the picture on elemental carbon.

The diesel passenger cars without particulate filter are exported in large numbers, but also a number of these vehicles are imported. Consequently, a small group of older diesel passenger cars are retained in the Netherlands. It is not a large group but with particulate mass emissions of 30 mg/km and more, and a large fraction of elemental carbon, and typically larger annual mileages the contribution of this group of vehicles to elemental carbon is quickly tenfold of what one would expect based on the number of vehicles solely. That is to say, if 1% of the vehicles is a diesel vehicle without a particulate filter, they are likely to contribute around 10% to the total elemental carbon emissions. A minor check on the elemental carbon fraction of 90% and on the total emissions of these vehicles is the minimal requirement to establish the remaining uncertainty.

3 Recent testing for elemental carbon emissions

This chapter gives an overview of the sources of data underlying the current EC emission factors, and the use of these emission factors so far in comparison with air quality. The emission factors circulated already for many years. They have been updated and improved on the fly. But given their indicative nature, they were never reported. This chapter reconstructs as well as possible the underlying sources used to determine these emission factors.

Early indicative numbers for elemental carbon emission factors are circulating for a few years. They were initially based on COPERT and additional studies and entered into the VERSIT+ database. Additional data was checked against the available bandwidth, and from time to time errors were corrected, and numbers were changed to reflect the current understanding of different vehicle technologies in Europe and the Netherlands. An initial project[13] in 2011 to establish the need and use of soot concentration measurements lay the basis of the EC emission factors.

For four years, indicative numbers were published and compared with air-quality results and top-down assessments by the RIVM. This generated confidence that the bottom-up elemental carbon emissions matched the common understanding of the contribution of the current vehicle fleet to the air-quality measurements.

The main uncertainties, relevant for the total emissions, were with Euro-V trucks and GDIs. Before the publication of elemental carbon emission factors, these figures required additional validation. For Euro-V trucks two internal research programs gave the opportunity to have a closer look at these elemental carbon emissions factors. For GDIs the Ministry of Infrastructure and Environment sponsored a small test program to investigate elemental carbon emission factors of this category.

Additionally, from a larger test program for the European Commission[14] on mopeds a number of filters were analysed for elemental carbon. Mopeds are a complex urban problem, and the emissions are unlike the modern passenger cars and trucks. The hydrocarbon and carbon monoxide emissions are high. The question remains if elemental carbon is part of the chemical soup, and how. The testing gave an opportunity to investigate this. However, no conclusive EC emission factor can be deduced from this testing, because of the large variation in the results. In absolute sense, moped emissions of EC are relatively low, compared to diesel vehicles without filter and also most of the petrol passenger cars. Combined with the limited distance covered, the mopeds play only a minor part in the total EC emissions. Only because of their presence on the cycle lanes, local exposure of cyclists and inner-city dwellers, mopeds may be an issue.

---

[13] TNO-060-UT-2011-02161 Verantwoording operationalisering roetindicator in Nederland, M.P Keuken et al..

[14] TNO 2017 R10565 Effect study of the environmental step Euro 5 for L-category vehicles.

3.1 Important vehicle categories and their emission legislation

In the total elemental carbon emissions, the older diesel vehicles play an important role. Unlike NO_x emission control, the particulate emissions control is more robust, i.e., it requires technology which functions more or less irrespectively of the circumstances. Therefore, the real-world particulate emissions of diesel cars follow the same trend as the emission limits. The evolution of the emission limits is shown in Table 2. Hence, for elemental carbon a similar trend is expected, with a thirtyfold decrease in emission limits over 25 years. The real world emissions have decreased even more, because of the diesel particulate filter. The emission legislation has stimulated a hundredfold decrease in real-world PM emissions. The real-world values have decreased from about 200-300 mg PM10/km at the start of Euro-0 to 1-2 mg PM10/km for Euro-5 and Euro-6.

Table 2 The introduction dates and legislation limits for particulate mass (PM) and particulate number (PN) emissions of passenger cars.

	introduction dates		PM [mg/km]		PN [#/km]	
	new models	all models	diesel	GDI	diesel	GDI
Euro-1	1-Jul-1992	1-Jan-1993	140	-	-	-
Euro-2	1-Jan-1996	1-Jan-1997	80	-	-	-
Euro-3	1-Jan-2001	1-Jan-2002	50	-	-	-
Euro-4	1-Jan-2005	1-Jan-2006	25	-	-	-
Euro-5a	1-Sep-2009	1-Sep-2010	5	5	-	-
Euro-5b	1-Sep-2011	1-Sep-2012	4.5	4.5	6.0E+11	-
Euro-6	1-Sep-2014	1-Sep-2015	4.5	4.5	6.0E+11	6.0E+12
Euro-6c	1-Sep-2017	1-Sep-2018	4.5	4.5	6.0E+11	6.0E+11

These results do not take into account the effect of deterioration on PM emissions. A Euro-4 diesel vehicle without filter was tested to determine the elemental carbon fraction of this important category in the total elemental carbon emissions. Not only was the elemental carbon fraction of 90% of the total particulate matter high, also was the particulate emission of this older vehicle with 52-174 mg/km (see Table 4); much higher than the current emission factors of 16 mg/km to 35 mg/km, varying with traffic conditions. In part this difference may be due to the more demanding test, but it is expected that the deterioration also contributed to the higher number.

The results on the single Euro-4 diesel vehicle confirms the elemental carbon fraction for these vehicles of around 90%, but raises some concern on the correct attribution of cold start emissions. Currently, there cold start effects are assumed to be limited for diesel vehicles.

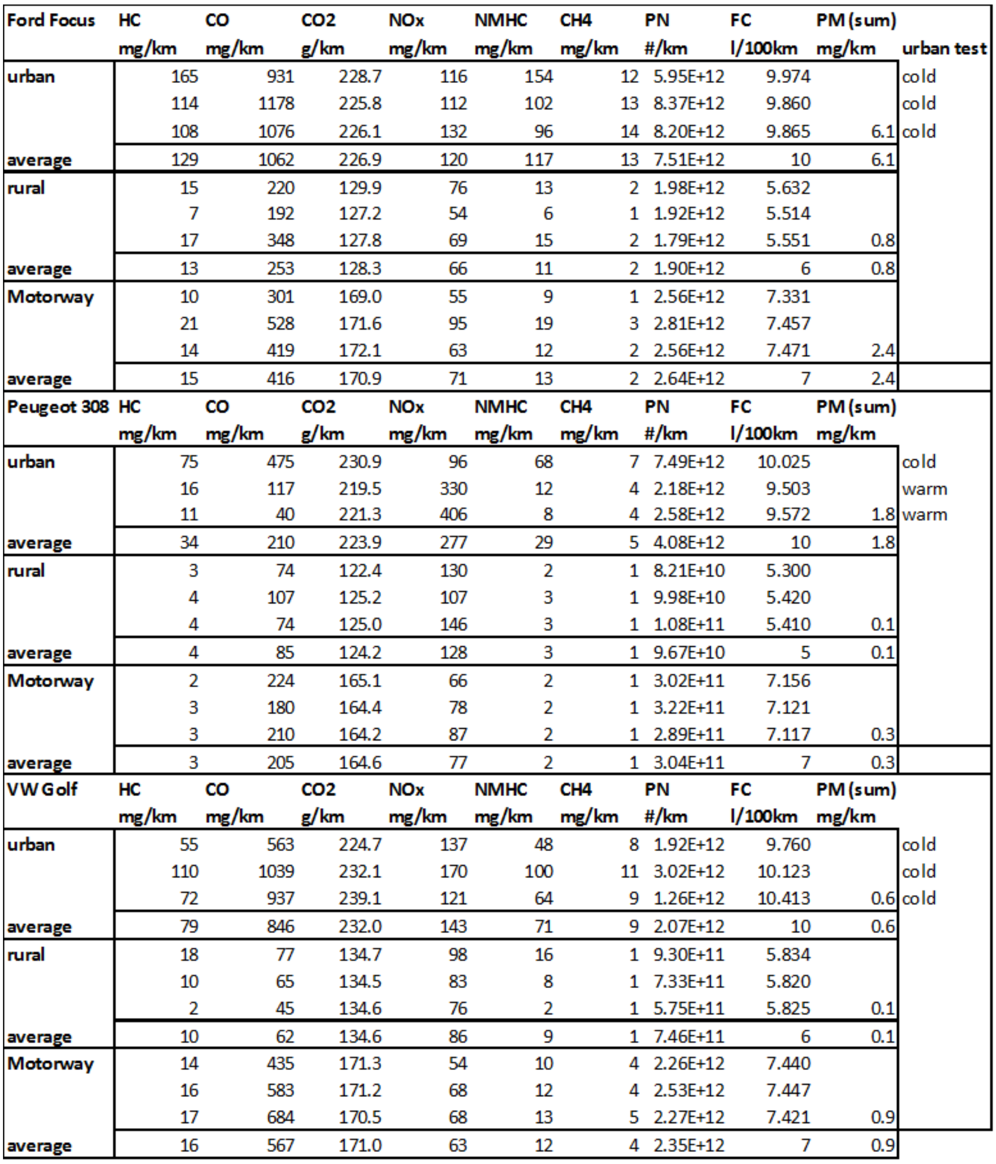
Emissions from new vehicles are more or less the same, due to the emission standard, but they all age in a different manner because of the different reduction techniques that are applied. Therefore, it is very difficult to establish an appropriate PM or EC emission factor for aged vehicles. It would require a lot of testing with probably inconclusive results for the current fleet.

3.2 Gasoline Direct Injection (GDI) vehicles

For GDI’s, a separate test program was executed in 2015 to fill in the gap in knowledge regarding the elemental carbon emissions.

The EC fraction was expected to be much higher than the elemental carbon emissions of port-injection petrol cars, but on the other hand there is little information on the absolute emissions and the relation with driving behaviour and circumstances. Some intermittent testing by for example VTT in Finland and the University of Prague gave indications that the cold start and the high load may lead to high particulate mass emissions from GDI's. In the recent TNO test program, emissions of urban, rural, and motorway driving are separately determined, with the cold start factored into the urban test. In this manner the results already match for a greater part the three main road types for which emission factors are determined.

Table 3 The test results of the GDI's as reported in TNO report 2016[15]



Ford Focus	**HC** **mg/km**	**CO** **mg/km**	**CO2** **g/km**	**NOx** **mg/km**	**NMHC** **mg/km**	**CH4** **mg/km**	**PN** **#/km**	**FC** **l/100km**	**PM (sum)** **mg/km**	**urban test**
urban	165	931	228.7	116	154	12	5.95E+12	9.974		cold
	114	1178	225.8	112	102	13	8.37E+12	9.860		cold
	108	1076	226.1	132	96	14	8.20E+12	9.865	6.1	cold
average	129	1062	226.9	120	117	13	7.51E+12	10	6.1	
rural	15	220	129.9	76	13	2	1.98E+12	5.632		
	7	192	127.2	54	6	1	1.92E+12	5.514		
	17	348	127.8	69	15	2	1.79E+12	5.551	0.8	
average	13	253	128.3	66	11	2	1.90E+12	6	0.8	
Motorway	10	301	169.0	55	9	1	2.56E+12	7.331		
	21	528	171.6	95	19	3	2.81E+12	7.457		
	14	419	172.1	63	12	2	2.56E+12	7.471	2.4	
average	15	416	170.9	71	13	2	2.64E+12	7	2.4	
Peugeot 308	**HC** **mg/km**	**CO** **mg/km**	**CO2** **g/km**	**NOx** **mg/km**	**NMHC** **mg/km**	**CH4** **mg/km**	**PN** **#/km**	**FC** **l/100km**	**PM (sum)** **mg/km**	
urban	75	475	230.9	96	68	7	7.49E+12	10.025		cold
	16	117	219.5	330	12	4	2.18E+12	9.503		warm
	11	40	221.3	406	8	4	2.58E+12	9.572	1.8	warm
average	34	210	223.9	277	29	5	4.08E+12	10	1.8	
rural	3	74	122.4	130	2	1	8.21E+10	5.300		
	4	107	125.2	107	3	1	9.98E+10	5.420		
	4	74	125.0	146	3	1	1.08E+11	5.410	0.1	
average	4	85	124.2	128	3	1	9.67E+10	5	0.1	
Motorway	2	224	165.1	66	2	1	3.02E+11	7.156		
	3	180	164.4	78	2	1	3.22E+11	7.121		
	3	210	164.2	87	2	1	2.89E+11	7.117	0.3	
average	3	205	164.6	77	2	1	3.04E+11	7	0.3	
VW Golf	**HC** **mg/km**	**CO** **mg/km**	**CO2** **g/km**	**NOx** **mg/km**	**NMHC** **mg/km**	**CH4** **mg/km**	**PN** **#/km**	**FC** **l/100km**	**PM (sum)** **mg/km**	
urban	55	563	224.7	137	48	8	1.92E+12	9.760		cold
	110	1039	232.1	170	100	11	3.02E+12	10.123		cold
	72	937	239.1	121	64	9	1.26E+12	10.413	0.6	cold
average	79	846	232.0	143	71	9	2.07E+12	10	0.6	
rural	18	77	134.7	98	16	1	9.30E+11	5.834		
	10	65	134.5	83	8	1	7.33E+11	5.820		
	2	45	134.6	76	2	1	5.75E+11	5.825	0.1	
average	10	62	134.6	86	9	1	7.46E+11	6	0.1	
Motorway	14	435	171.3	54	10	4	2.26E+12	7.440		
	16	583	171.2	68	12	4	2.53E+12	7.447		
	17	684	170.5	68	13	5	2.27E+12	7.421	0.9	
average	16	567	171.0	63	12	4	2.35E+12	7	0.9	

---

[15] TNO 2016 R11247 Emissions of three common GDI vehicles.

Table 4 The PM emissions and the elemental carbon fraction therein of GDI vehicles (Euro-5/Euro-6) and the Euro-4 diesel vehicle. CS refers to the number of cold starts in the urban test. The VW Passat is the Euro-4 diesel vehicle without DPF.

	PM [mg/km]	EC fraction (carbon)
Ford Focus GDI		
urban (3xCS)	6.1	82.6%
rural	0.8	33.4%
motorway	2.4	59.8%
Golf 7 GDI		
urban (3xCS)	0.6	89.5%
rural	0.9	54.8%
motorway	0.1	37.7%
Peugeot 308 GDI		
urban (1xCS)	1.8	80.6%
rural	0.3	54.3%
motorway	0.1	28.0%
VW Passat diesel without DPF		
urban (1xCS)	52.3	89.5%
rural	174.6	93.4%
motorway	73.8	84.0%

3.3 Euro-4 diesel vehicle without particulate filter

In the recent test program of GDIs in 2015, also one Euro-4 diesel passenger car without particulate filter was tested as well. This is one of the last diesel passenger car without a diesel particulate filter. The results shown in Table 4, confirm the earlier findings, used in the indicative emission factors of an elemental carbon fraction around 90%, but the absolute emissions are higher than expected. This can partly be explained by the test program, where a higher road load and vehicle mass is used than in the testing in the past, another explanation may be the deterioration of the particulate emissions of the vehicle. Given the large variation in the emissions it is expected that the higher engine load contributes significantly to the higher particulate mass emissions of this vehicle. A rough estimate would be a deterioration of 40% and an effect of dynamics of 100%.

3.4 Euro-5 and Euro-6 diesel passenger cars with broken particulate filters

Diesel vehicles with wall-flow, or closed diesel particulate filters (DPF) have very low particulate emissions. In fact, such cars may clean the air of particulates while passing the engine. Broken particulate filters, for example cracked filters will give an increase in particulate emissions. In 2016, a number of cars with DPF with increased emissions have been tested in the laboratory,[16] and the filters have been analysed for the EC fractions. The results show a large variation in the EC fractions, but generally the EC fraction is low, between 10% and 20%, but with some high results up to 90%.

3.5 Euro-V heavy duty vehicles

One of the most common heavy-duty engines on the Dutch roads is a Euro-V engine without DPF (diesel particulate filter) but with an SCR (Selective Catalyst Reduction) installation to remove NO_x from the exhaust gas.

---

[16] TNO 2017 R10530 Investigation into a Periodic Technical Inspection (PTI) test method to check for presence and proper functioning of Diesel Particulate Filters in light-duty diesel vehicles

The catalyst requires a large surface area for the reaction of urea (AdBlue) with the nitrogen oxides and contains therefore many small channels. Zeolite is a common material used for the inert catalyst surface.

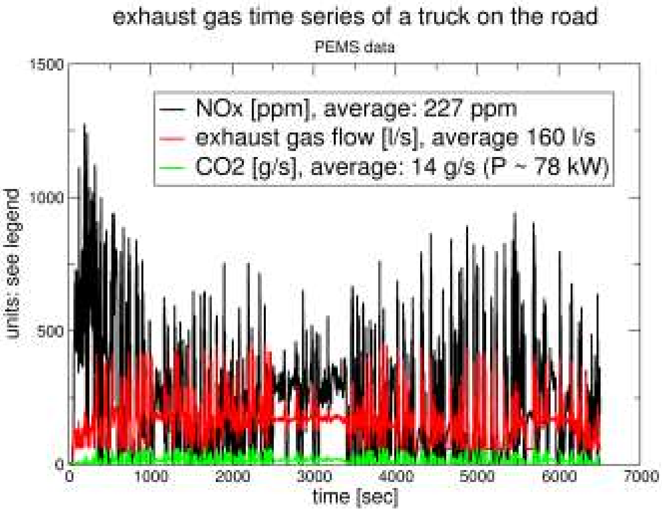


Figure 3 PEMS (Portable Emission Measurement System) time-series data of a typical Euro-V truck. Currently, particulate matter cannot be measured properly with the PEMS system.

With Euro-VI DPF and coated SCR surfaces are more common. Hence the exhaust gas flow is disturbed and large shear flows may occur in the catalyst, which can also affect the post-engine processes of particulate accumulation and coagulation, thus forming larger aggregates of solid matter. Furthermore, shear flows include also near stagnant exhaust gas, hence the SCR may function as a partial buffer of the particulate matter, in particular for the larger particles. From the experiments there are clear indications this has been the case, at least at the time scale of minutes.

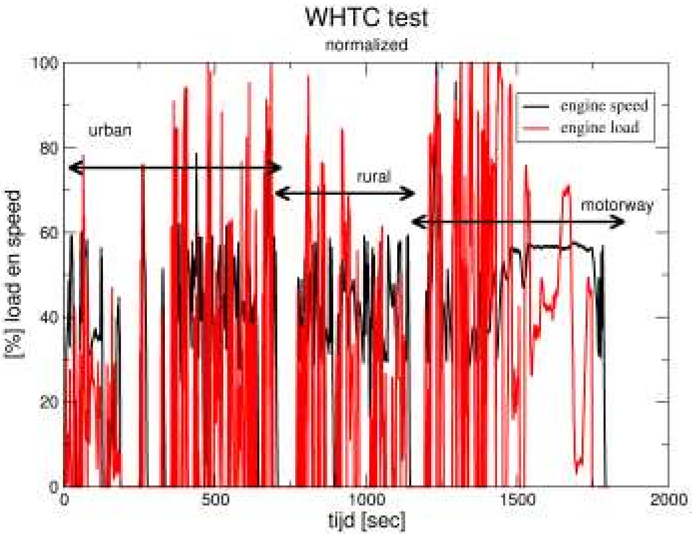


Figure 4 The WHTC engine test for Euro-VI legislation, with the normalized speed and load of the engine. Three separate parts: urban, rural, and motorway are normally executed consecutively.

The cycles used for the engine tests are the constant load, the official ETC (European Transient Cycle) test and the parts of the WHTC (World Harmonized Transient Cycle) tests: urban, rural and motorway each repeated three or four times. The whole set of tests is repeated twice. The WHTC test is known as a low load test. Only the motorway part has a similar load to the ETC test. Unlike for NO_x emissions, particulate emissions are more common for high load. The results will confirm this.

A typical long-haul and distribution vehicle has a gross weight of 30 ton. The associated fuel consumption is about 30 liter per 100 km, which produces about 800 grams of CO_2 per kilometer. The amount of energy produced per kilometer by the engine is little over one kWh. Given the PM emission limit of Euro-V: 30 mg/kWh, 30-50 mg per kilometer is expected as particulate matter emission. Common vehicle usage and air-to-fuel ratios indicate that on average for the energy of one kWh 7.5 m^3 exhaust gas is produced. Hence the raw exhaust gas has about 0.5-1 mg/m^3. This is 10 to 20 times the European annual concentration limits for particulate matter. For NO_x the dilution from exhaust gas to air-quality concentrations is a factor 8 higher. Both PM and NO_2 air-quality norms are met only with effort. One can argue that NO_x is much more a local problem, with specific emissions and a shorter lifetime, associated with the high dilution from exhaust gas levels, while PM has a more even spread across the region with longer lifespan. The picture is complicated by the multiple sources of both particulate matter and nitrogen dioxide in the air.

3.5.1 *Euro-V engine tests on heavy duty vehicles in 2012*

The experience from earlier tests, prior to 2012, was a poor reproducibility. Hence, the test program was set up to have repetitive parts within each test with a single filter. This complete set of cycles was carried out twice consecutively, for the reproducibility of the filter weight tests.

Black smoke was measured via two different means: an automotive opacity meter and an ambient air black carbon instrument, used in the national monitoring network. The latter is using the discoloration of filter material to determine average concentration levels.

The engine test was carried out on an engine test bed with a dilution tunnel. The exhaust-gas black smoke sampling was carried out with the AVL439 opacity equipment in the exhaust gas. The ambient-air black carbon was measured by diluting the gas in the dilution tunnel by another factor twenty, by a TSI 3302A diluter. The Thermo Model 5012 MAAP detector sampled this doubly-diluted gas on a minute-by-minute basis. The AVL439 sampled the tunnel gas at a higher rate, but the data was down sampled for comparison with the MAAP result.

Table 5 The test sequence for the filter samples. The WHTC tests themselves consisted of 3 and 4 repetitions of the same subcycle. The tests were carried out in the order as in the table.

Label	Test type	Duration
E0	ETC test	1800 sec
U1	3 x WHTC urban	2250 sec
R1	4 x WHTC rural	1800 sec
M1	3 x WHTC motorway	1800 sec
E1	ETC test	1800 sec
U2	3 x WHTC urban	2250 sec
R2	4 x WHTC rural	1800 sec
M2	3 x WHTC motorway	1800 sec
E2	ETC test	1800 sec
S0	1400 rpm @ 50% load	1200 sec
S1	1400 rpm @ 50% load	1200 sec
S2	1400 rpm @ 50% load	1200 sec
M3	3 x WHTC motorway	1800 sec

The tests spanned three days, with no separate conditioning in between. The repetitive cycles and sub-cycles are meant to ensure identical conditioning. The Euro-V engine was a new small-size engine, which was available for testing. The engine was previously used to test novel after-treatment technology, but was brought the original state.

For the actual results, not only the order of the tests but also the time between the tests is important. It should be noted that between R1 and M1 and between E2 and S0 overnight soaks occurred. Between the other tests typically half an hour to an hour soak time occurred. Both the cycles after the overnight soaks and the cycles outside the repetitive pattern had a lower reproducibility, signalling a possible dependence on conditioning by to the previous cycles.

The engine loads of the ETC and the WHTC motorway cycle are very similar, and higher than the 50% load at 1400 RPM. The difference between the WHTC Motorway and the ETC is the higher dynamics of the latter. Consequently, the fuel consumption and CO_2 emission on the ETC is higher.

Table 6 The average power and specific CO_2 emission on the respective tests. The spread is in the order of 0.2%.

Test	Average power [kW]	CO_2 [g/kWh]
1400 rpm @ 50% load	26.7	N/A
ETC test	35.4	719
WHTC Motorway	35.3	692
WHTC Urban	13.2	769
WHTC Rural	11.8	825

The engine loads on the urban, and in particular, the rural cycles of the WHTC are very low: down to one third of the engine load on the motorway cycle. For NO_x emission and fuel consumption these low-load tests are difficult tests to achieve low values. However, for particulate emissions the values are much lower than on the higher load tests.

Table 7 Results from the PM filter test, per cycle, sorted by value.

Test	Min [mg/kWh]	Mid [mg/kWh]	Max [mg/kWh]
1400 RPM @ 50% load	12	17	31 (morning start)
ETC (after motorway)	36	39 (first test)	46
Motorway (after rural)	24 (after stationary test)	40 (morning start)	59
Urban (after ETC)	30	N/A	31
Rural (after Urban)	21	N/A	26

The first test in the morning yields higher values for the filter test, compared with the other runs of the same test. Furthermore, the well-known fact that stationary operations yield the lowest specific PM is confirmed here. The higher mass on the morning tests are somewhat related to the higher soluble organic fraction (SOF) and, thus, less elemental carbon, but the evidence is not strong. The elemental carbon seems much more constant per kWh than any other result.

The transient engine loads on the urban test yield similar filter masses compared with the higher load tests. Hence, the dynamics of transients is the main contributor to the total emission (PM and black smoke), rather than the average engine load. The black carbon seems more related to the engine load.

Table 8 Fraction of EC mass to total PM from filter tests, per cycle, sorted by value.

Test	Min EC [%]	Mid EC [%]	Max EC [%]
1400 RPM @ 50% load	30 (morning start)	51	70
ETC (after Motorway)	18	21	23
Motorway (after Rural)	13	18 (morning start)	34 (after stationary test)
Urban (after ETC)	36	N/A	38
Rural (after Urban)	37	N/A	44

The total particulate matter in the successive stationary cycle at 50% load decreases from cycle to cycle, while the elemental carbon remains nearly constant at 8.6-9.1 g/kWh. Hence the soluble organic fraction (SOF) decreases. Possibly, the heating of the SCR, during this period makes it function as an oven to evaporate the SOF. The black carbon measurement remains near constant, while the AVL smoke opacity shows an erratic behaviour from cycle to cycle, with a drift upwards during the cycle. See Figure 6.

There are strong indications that the conditioning has played an essential part in the test results. The time-resolved data confirms this conjecture only partly. The stationary tests do not yield constant values for neither the AVL439 nor the MAAP equipment. The AVL seems to drift, the MAAP shows a small reproducible oscillation across the 1200 seconds of the stationary tests. The stationary test seems to purge the system of soluble organic fraction. The repetitive parts in the Urban, Rural, and Motorway test are hardly recognizable in the time series. The reproducibility of the MAAP results is good. However, the correlation with the filter test, EC, or the AVL439 is limited.

The AVL439 failed on two of the three motorway tests, yielding negative opacity values. The reason is not clear. The data is included for completeness sake in the time-series plots, as part of the data seems viable. The drift in the stationary tests is substantial, but the mean values are also far apart. The AVL439 has also a fair reproducibility, taking the double, or possibly triple, failure at the Motorway test out.

Table 9 Test results for the MAAP, AVL439, and filters. The overnight soak effect, visible in the filter tests, are not present in the MAAP and AVL averages. The AVL yield high urban values similar to ETC, while for the MAAP and the filter the urban values are more in line with rural tests.

Label	Test type	AVL [m^{-1}]	MAAP [EC mg/m^3]	Filter [EC mg/kWh]	EC [%]
E0	ETC test	0.29	5800	39	21
U1	3 x WHTC urban	0.41	2660	31	36
R1	4 x WHTC rural	0.31	2440	21	44
	Overnight soak				
M1	3 x WHTC motorway	N/A	5100	40	19
E1	ETC test	0.24	5900	36	23
U2	3 x WHTC urban	0.33	2630	31	38
R2	4 x WHTC rural	0.21	2530	26	37
M2	3 x WHTC motorway	0.19 (error?)	5160	59	13
E2	ETC test	0.29	5820	46	18
	Overnight soak				
S0	1400 rpm @ 50% load	0.15	4610	30	30
S1	1400 rpm @ 50% load	0.33	4600	17	51
S2	1400 rpm @ 50% load	0.18	4210	12	70
M3	3 x WHTC motorway	N/A	5680	24	34

The elemental carbon emission has limited variation over all the tests: 7.2 – 11.3 g/kWh. The rural and especially urban tests have the highest elemental carbon emissions per kWh. Hence the variation in filter mass is in the soluble organic fraction. From the MAAP the black carbon seems lowest on these tests, so the correlation between MAAP and filter values is not possible.

For the AVL439 the conditioning seems play a bigger part than for the MAAP. Deviations in the start of the ETC and the urban tests, between test and between the first sub-cycle and the latter sub-cycles indicate a history effect of about 200 seconds. Most interesting, the large effects from the morning start, observed in the filter tests, are not visible in neither the MAAP nor the AVL data.

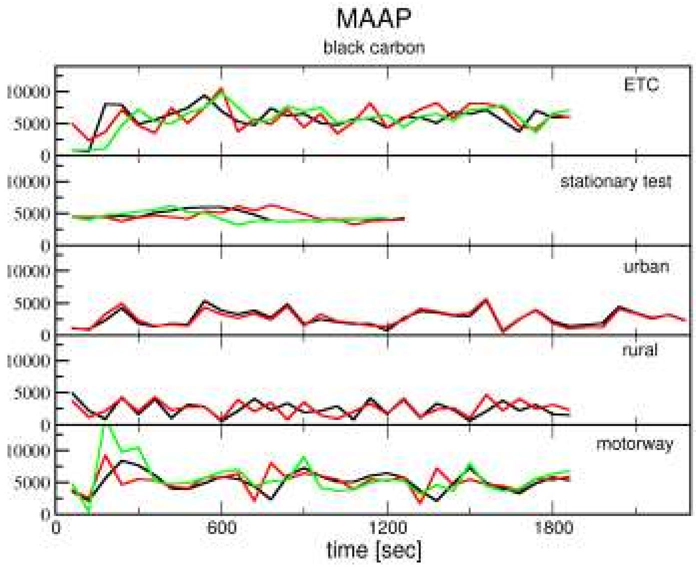


Figure 5 Overview of all the time-resolved MAAP black-carbon data. The units are ng/m^3 are close to near road dilutions. The black line is the first test in the sequence, the red the second test, and the green the third test.

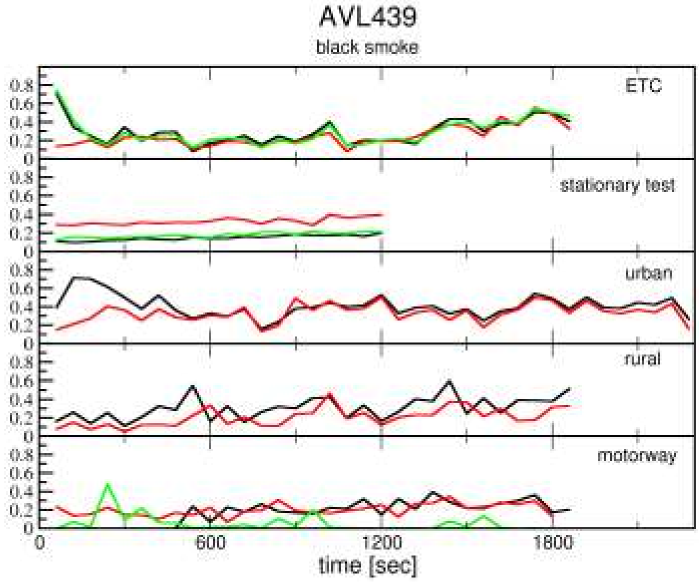


Figure 6 Overview of the time-resolved AVL439 data. The units are m^{-1}. The black line is the first test in the sequence, the red the second test, and the green the third test. In the case over the motorway tests, the unit failed twice, maybe even all three times. The initial variation, and deviation second and third sub-cycle seems to indicate some conditioning eff effect. All the tests, except for the ETC which is not a repetitive pattern of sub-cycles, seem to suggest some drift upwards.

3.5.2 *Euro-V engine tests on heavy duty vehicles in 2015*

In a study of toxicological effects of diesel exhaust gas on an engine test bed with Euro-V engines also information on the particulate number and the elemental carbon emissions have been collected. The test cycle used was a bus cycle, which has typically high load variations with limited average load. The results are shown in Table 10 and Table 11.

Table 10 The concentration of particulate matter components with a warm start and a cold start bus-cycle test.

Euro-V	cold start	warm	stdev
PM10 (ug/m3)	456	295	
OC (ug/m3)	151	66	
EC (ug/m3)	119	136	23
TC (ug/m3)	271	243	80
EC fractie [%]	44%	56%	

Table 11 The normalized emissions to the engine work. A typical bus requires 1-1.5 kWh for 1 kilometre distance.

Euro-V	cold start	warm	stdev
PM10 (mg/kWh)	37.0	19.0	
OC (mg/kWh)	11.2	4.3	
EC (mg/kWh)	7.2	8.8	1.48
TC (mg/kWh)	18.4	15.7	5.16
EC fractie [%]	39%	56%	

The results of these tests compare best to the urban test of the 2012 study. The 2015 study yields a larger fraction of elemental carbon of 56%. However, the absolute elemental carbon emissions of both test programs lie around 10 mg/kWh. The larger fraction is associated with a smaller particulate mass. This is in line with the observation that the hydrocarbons and the organic fraction may depend strongly on the conditioning and the temperature in the after-treatment system, which may vary substantially, but that the elemental carbon fraction is more stable as it is the direct result of the combustion process and it “survives” the after-treatment system unchanged.

3.6 Euro-VI trucks with particulate filter

The filters of a few tests with heavy-duty vehicles with particulate filter (DPF) have been available from different test programs, from other laboratories. Since the diesel particulate filter for heavy-duty vehicles is similar to the filters for light-duty vehicles, the results are expected to be similar. Indeed, in this case the elemental carbon fraction is low from 2% to 50%. For vehicles with DPF the quartz filter loading is limited, many tests are combined on a single filter, to achieve sufficient loading. Given the findings of light-duty vehicles, it is estimated that vehicles with a diesel particulate filter, have an EC fraction in the order of 20%.

3.7 Mopeds

For a large project, a number of mopeds have been tested and the filters were made available for chemical analyses. The vehicles were common 50cc scooters. Such vehicles are the dominant group of urban powered two-wheelers.

The problem with current scooter for Dutch urban use is the speed delimiter. The fuel consumption, hydrocarbon emissions, and temperature increases substantially for most scooters if it is driven against the speed delimiter. Hence, the state of the scooter, as it is known that many scooters are tampered with, and the test execution will play an essential role in the final emission result. The tested scooters were in a proper state and the test cycle avoided the activation of the speed delimiter for most of the time.

In total ten filters from eight different powered two-wheelers were analysed (2 filters from two-stroke vehicles, the others were 4-stroke vehicles Euro-2 and Euro-3). The results vary greatly. Only older 4-stroke moped with high PM emissions had nearly 100% EC fraction. The 2-stroke vehicles have the lowest EC fraction in the range 2%-20%. Apart from the older, probably faulty, moped with the high emissions and high EC fraction, the EC fractions are in the range of 1%-52%. For new 4-stroke mopeds the average EC fraction is expected to be in the order of 15%. The 2-stroke mopeds will have a higher absolute particulate emission, but therein a smaller fraction of about 10% of EC. It is of some concern that high emissions from individual mopeds are associated with high EC fractions. This may affect the overall EC fraction significantly.

4 Driving behaviour and vehicle usage effects

The relatively new determination of EC emission factors, also means that for all vehicle categories, and all causes of high emissions, the consequences for EC emissions should be revisited. If EC emission factors will be part of the emission inventory and air-quality assessment, proper attention should be given to the variations and uncertainties observed. This chapter gives an overview of the known issues.

4.1 Emissions from high engine load

Emission factors of the Euro-V testing were used for all the heavy duty vehicles using the variation in engine load as seen in the different Euro-V engine applications. In particular at moments of high load the particulate emission occurs. But the moments of high load are, for trucks, directly related to the payload of the truck and the road type. Large heavy loaded trucks on rural roads have the most moments of high engine loads. This is reflected in the emission factor for PM10, but even more so in the emission factor for elemental carbon, which seems even more directly related to the high engine loads. For passenger cars, this effect seems less pronounced, if it can be found at all, because the engine load of a passenger car is in many cases small compared to the rated power. High engine loads for passenger cars typically only occur when overtaking on the motorway or driving at a very low engine speed, or high gear.

4.2 Emissions from cold start

With GDI vehicles, the cold start shows a clear increase in particulate emissions. Moreover, the EC fraction is larger as well. It is expected that the combustion at cold start is affected by the cold cylinder walls and it will lead to poorer combustion. Hence, for GDI’s the cold start effect should be included in the emissions. This must be weighed with the number of cold starts per kilometre. For petrol vehicles altogether, cold start conditions in cold ambient conditions will lead to much higher cold start emissions.

4.3 Deterioration effects on PM emissions

In a number of cases, from moped to diesel vehicles with a particulate filter, high particulate emissions are observed. The emissions are often an order of magnitude higher than in the case of properly functioning technology. For faults with the DPF alone the EC fraction is expected to be low. But in the case of faults with the combustion, and maybe the subsequent failure of the filter, the EC fraction is high: 90% or more. This problem may occur with mopeds, GDIs, and diesel vehicles, and span almost the complete vehicle fleet. It has been observed for a number of different vehicles. Moreover, vehicles with the prolonged periods of visible black smoke are regularly observed on the road. The fact that the smoke is visible means the emissions are very likely at least a factor ten higher than the normal emissions of vehicles without a particulate filter, and a factor hundred or more higher than a vehicle with a properly functioning filter.

Hence, faults in the combustion technology will lead to increased particulate emissions and in many cases an even larger increase in EC emissions. The magnitude of the effect, and the fact that it is typically observed in about one in ten to twenty older vehicles (be it mopeds or passenger cars), give rise to concern about the contribution of faulty combustion technology and faulty or removed filters in the total particulates and EC emissions of road transport. The relative contribution will increase as the well-functioning vehicles will be cleaner and the relative increase is greater, and the technology which may develop faults, such as direct injection, will be more ubiquitous.

Two main effects of deterioration are discussed here. They are known effects for older vehicles in particular.

4.3.1 Injection fouling

The injection fouling will increase the droplet sizes of the injected fuel. Large droplets may not burn completely and yield partly burned products in the exhaust gas. Poor fuel quality, like for example, the use of vegetable oil in diesel engines, may aggravate the problem of injector fouling to the point of engine failure. Unburned fuel will reduce the power and efficiency of the engine.

4.3.2 Lubricant consumption

At some point the piston wear will leave more space between the piston head and the cylinder wall. Consequently, lubricants can end up in the combustion chamber and burn with the fuel. Lubricants are not meant to be burned and consist generally of larger molecules and additives which are a source of particulate emissions. Also, an oil level in the engine which is too high can increase the burning of lubricants. If a vehicle uses one litre of lubricant per 5000 km of driving, and, roughly, 2% of the lubricants is emitted as particulates, it is expected that the additional particulate emissions are in the range of 4 mg/km. Such oil consumption is not uncommon in older vehicles. These are large particulate emissions for modern vehicles by all accounts. The lubricant usage and contribution to particulate emissions are in a realistic range. This raises some concern on the end-of-life usage of vehicles, well beyond their durability requirements in combination with, possibly, reduced maintenance. These effects are partially covered by the emission tests, as vehicles have some mileage when tested, but end-of-life effects, or effects above 100,000 km, are not covered.

There has been a limited investigation into the increase of particulate emissions from lubricant burning with the aging of the vehicles. However, it is expected that these emissions are not negligible to the total particulate emissions from the exhaust.

5 Conclusions

Elemental carbon emission factors are a relatively new type of emission factors, linked to the interest in toxic particulate concentration in the ambient air beyond the total particulate mass concentration set out in European regulations. They have been used indicatively from 2011 onwards and were compared with EC and BC concentrations in the ambient air.

In order to link these emissions to particular sources, a backlog of vehicle categories had to be updated in the emission factors database at TNO. Additional tests were carried out, and in the running test programs quartz filters were used to allow for the physical-chemical analyses to determine the elemental carbon fraction, via the EUSAAR method, in the total particulate matter, or PM10.

The results confirmed the existing elemental carbon emission factors and they provided the necessary confidence for the publication and general use of these elemental carbon emission factors. It should be noted that GDI vehicles emit a higher elemental fraction than the port-injection petrol vehicles, but the absolute particulate emissions are low, such that no increase in elemental carbon emissions from petrol cars is to be expected.

A number of older vehicles, passenger cars and mopeds have an increased particulate emission. If the increase in these emissions is linked to a malfunction or deterioration of the combustion technology, it is also linked to a substantial increase in the elemental fraction in the particulate matter.

The set of current PM and EC emission factors are presented in Appendix A. Given the large variation in the EC fractions, encountered in different tests, only EC emission factors in the database with a systematic deviation from the current findings were corrected.

It is important to note, that vehicle technology and vehicle usage strongly influence the EC emission factors. Current results are suitable to use to determine average EC emissions for a normal fleet. The emission factors do not allow for comparison of technologies in detail. The vehicle categories are grouped at a high aggregate level and a limited number of vehicles are tested in a few representative tests. Consequently, some detail will be missing from these emission factors.

Importantly, EC emissions are part of PM emissions. The level of EC emissions is bounded by the level of the PM emission. Given the longstanding testing of PM emissions, and the rapid decrease of PM emissions with new vehicle legislation, the EC emission factors follow the same trend. The fraction of EC in PM varies mainly with technology. Generally said, more and more complex after-treatment technology will bring the EC fraction down. On the other hand, the history effects: buffering, heat-up, and chemical reactions in catalysts, seem to reduce the repeatability of PM and EC emission tests without a lengthy and well-described preconditioning.

6 Signature

Name and address of the principal
RIVM
T.a.v. mevrouw M. van Zanten
Postbus 1
3720 BA Bilthoven

Names of the cooperators
N.E. Ligterink PhD

Date upon which, or period in which the research took place
January 2016 until December 2017

Name and signature reviewer

J.S. Henzing PhD

Signature:

R. Dröge MSc
Projectleader

Release:

R.A.W. Albers MSc MPA
Research Manager

Appendix A: List of PM10 and elemental carbon emission factors

The list of emissions factors of exhaust emissions PM10 and EC dated 1-1-2017. Vehicle categories are according to the definitions of the Taakgroep Verkeer en Vervoer (Taskforce Transport) from the Emissieregistratie (Dutch emission inventory).

road type	urban		rural		motorway		urban	rural	motorway
	exhaust PM	EC	exhaust PM	EC	exhaust PM	EC	EC/PM	EC/PM	EC/PM
vehicle category	g/km	g/km	g/km	g/km	g/km	g/km	%	%	%
buses									
BABBEUR0	0.3941	0.0788	0.3988	0.0798	0.4031	0.0806	20%	20%	20%
BABCEEV5	0.0304	0.0026	0.0362	0.0012	0.0369	0.0005	9%	3%	1%
BABCEUR4	0.0449	0.0067	0.0196	0.0029	0.0076	0.0011	15%	15%	15%
BABCEUR6	0.0151	0.0026	0.0091	0.0012	0.0071	0.0005	17%	13%	6%
BABDEEV5SCR	0.0365	0.0274	0.0434	0.0326	0.0080	0.0060	75%	75%	75%
BABDEUR0	1.1286	0.5643	0.6503	0.3251	0.4991	0.2495	50%	50%	50%
BABDEUR1	0.4754	0.3090	0.3112	0.2023	0.2237	0.1454	65%	65%	65%
BABDEUR2	0.3054	0.1985	0.2812	0.1828	0.1112	0.0723	65%	65%	65%
BABDEUR2DPF	0.0304	0.0046	0.0362	0.0054	0.0143	0.0022	15%	15%	15%
BABDEUR2HOF	0.1754	0.1316	0.1712	0.1284	0.1112	0.0834	75%	75%	75%
BABDEUR3	0.2254	0.1578	0.1912	0.1338	0.1090	0.0763	70%	70%	70%
BABDEUR3DPF	0.0304	0.0046	0.0362	0.0054	0.0206	0.0031	15%	15%	15%
BABDEUR3DPFSCR	0.0304	0.0046	0.0362	0.0054	0.0206	0.0031	15%	15%	15%
BABDEUR3HOF	0.1254	0.0941	0.1212	0.0909	0.1090	0.0818	75%	75%	75%
BABDEUR4	0.0975	0.0570	0.0425	0.0249	0.0192	0.0097	59%	58%	51%
BABDEUR4EGR	0.1054	0.0791	0.1012	0.0759	0.1011	0.0758	75%	75%	75%
BABDEUR4SCR	0.0754	0.0566	0.0512	0.0384	0.0511	0.0383	75%	75%	75%
BABDEUR5EGR	0.1054	0.0791	0.1012	0.0759	0.1011	0.0758	75%	75%	75%
BABDEUR5SCR	0.0754	0.0566	0.0512	0.0384	0.0511	0.0383	75%	75%	75%
BABDEUR6	0.0151	0.0053	0.0091	0.0023	0.0071	0.0009	35%	25%	13%
BABLEUR0	0.0985	0.0197	0.0997	0.0199	0.1008	0.0202	20%	20%	20%
BABE	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000			
BABH	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000			
light commercial vehicles	exhaust PM	EC	exhaust PM	EC	exhaust PM	EC	EC/PM	EC/PM	EC/PM
LBAB1982	0.0660	0.0165	0.0454	0.0114	0.0153	0.0038	25%	25%	25%
LBAB1983	0.0620	0.0155	0.0415	0.0104	0.0142	0.0036	25%	25%	25%
LBAB1984	0.0580	0.0145	0.0375	0.0094	0.0131	0.0033	25%	25%	25%
LBAB1985	0.0540	0.0135	0.0336	0.0084	0.0121	0.0030	25%	25%	25%
LBAB1986	0.0500	0.0125	0.0296	0.0074	0.0110	0.0027	25%	25%	25%
LBAB1987	0.0530	0.0133	0.0316	0.0079	0.0153	0.0038	25%	25%	25%
LBAB1988	0.0530	0.0133	0.0316	0.0079	0.0153	0.0038	25%	25%	25%
LBAB1989	0.0530	0.0133	0.0316	0.0079	0.0153	0.0038	25%	25%	25%
LBAB1990	0.0530	0.0133	0.0316	0.0079	0.0153	0.0038	25%	25%	25%
LBAB1991	0.0530	0.0133	0.0316	0.0079	0.0153	0.0038	25%	25%	25%
LBAB1992	0.0530	0.0133	0.0316	0.0079	0.0153	0.0038	25%	25%	25%
LBABEUR1	0.0023	0.0006	0.0012	0.0003	0.0019	0.0005	25%	25%	25%
LBABEUR2	0.0075	0.0019	0.0051	0.0013	0.0050	0.0013	25%	25%	25%
LBABEUR3	0.0038	0.0006	0.0014	0.0002	0.0050	0.0008	15%	15%	15%
LBABEUR4	0.0042	0.0006	0.0015	0.0002	0.0050	0.0008	15%	15%	15%
LBABEUR5	0.0034	0.0008	0.0012	0.0003	0.0050	0.0013	25%	25%	25%
LBABEUR6	0.0034	0.0012	0.0012	0.0004	0.0050	0.0018	35%	35%	35%
LBABPR82	0.0954	0.0239	0.0616	0.0154	0.0180	0.0045	25%	25%	25%
LBABR3WC	0.0075	0.0019	0.0012	0.0003	0.0004	0.0001	25%	25%	26%
LBACEUR5	0.0029	0.0004	0.0013	0.0002	0.0050	0.0008	15%	15%	15%
LBACEUR6	0.0029	0.0004	0.0013	0.0002	0.0050	0.0008	15%	15%	15%
LBAD1982LCH	1.4992	0.8246	0.7445	0.4095	0.2480	0.1364	55%	55%	55%
LBAD1982ZWA	1.4992	0.8246	0.7445	0.4095	0.2491	0.1370	55%	55%	55%
LBAD1983LCH	1.2625	0.6944	0.6484	0.3566	0.2194	0.1207	55%	55%	55%
LBAD1983ZWA	1.2625	0.6944	0.6484	0.3566	0.2203	0.1212	55%	55%	55%
LBAD1984LCH	1.0521	0.5787	0.5764	0.3170	0.1812	0.0997	55%	55%	55%
LBAD1984ZWA	1.0521	0.5787	0.5764	0.3170	0.1820	0.1001	55%	55%	55%
LBAD1985LCH	0.8154	0.4485	0.4803	0.2642	0.1526	0.0839	55%	55%	55%
LBAD1985ZWA	0.8154	0.4485	0.4803	0.2642	0.1533	0.0843	55%	55%	55%
LBAD1986LCH	0.7365	0.4051	0.4323	0.2378	0.1526	0.0839	55%	55%	55%
LBAD1986ZWA	0.7365	0.4051	0.4323	0.2378	0.1533	0.0843	55%	55%	55%
LBAD1987LCH	0.6839	0.3761	0.3842	0.2113	0.1526	0.0839	55%	55%	55%
LBAD1987ZWA	0.6839	0.3761	0.3842	0.2113	0.1533	0.0843	55%	55%	55%
LBAD1988LCH	0.6313	0.3472	0.3362	0.1849	0.1526	0.0839	55%	55%	55%
LBAD1988ZWA	0.6313	0.3472	0.3362	0.1849	0.1533	0.0843	55%	55%	55%
LBAD1989LCH	0.5787	0.3183	0.3122	0.1717	0.1526	0.0839	55%	55%	55%
LBAD1989ZWA	0.5787	0.3183	0.3122	0.1717	0.1533	0.0843	55%	55%	55%
LBAD1990LCH	0.5787	0.3183	0.3122	0.1717	0.1526	0.0839	55%	55%	55%
LBAD1990ZWA	0.5787	0.3183	0.3122	0.1717	0.1533	0.0843	55%	55%	55%
LBAD1991LCH	0.5787	0.3183	0.3122	0.1717	0.1526	0.0839	55%	55%	55%
LBAD1991ZWA	0.5787	0.3183	0.3122	0.1717	0.1533	0.0843	55%	55%	55%
LBAD1992LCH	0.5787	0.3183	0.3122	0.1717	0.1526	0.0839	55%	55%	55%
LBAD1992ZWA	0.5787	0.3183	0.3122	0.1717	0.1533	0.0843	55%	55%	55%
LBADEUA6CL1	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
LBADEUA6CL2	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
LBADEUA6CL3	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
LTRDEUA6CL3	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
LBADEUC6CL1	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
LBADEUC6CL2	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
LBADEUC6CL3	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
LTRDEUC6CL3	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
LBADEUR1CL1	0.2099	0.1470	0.1032	0.0722	0.1246	0.0872	70%	70%	70%

LBADEUR1CL2	0.2099	0.1470	0.1032	0.0722	0.1246	0.0872	70%	70%	70%
LBADEUR1CL3	0.2618	0.1832	0.1353	0.0947	0.1647	0.1153	70%	70%	70%
LBADEUR2CL1	0.1310	0.1048	0.0696	0.0557	0.1342	0.1074	80%	80%	80%
LBADEUR2CL2	0.1310	0.1048	0.0696	0.0557	0.1342	0.1074	80%	80%	80%
LBADEUR2CL3	0.1784	0.1428	0.0988	0.0790	0.1903	0.1523	80%	80%	80%
LBADEUR3CL1HOF	0.0286	0.0224	0.0234	0.0184	0.0474	0.0372	78%	78%	78%
LBADEUR3CL2HOF	0.0286	0.0224	0.0234	0.0184	0.0474	0.0372	78%	78%	78%
LBADEUR3CL3HOF	0.0408	0.0320	0.0334	0.0262	0.0677	0.0531	78%	78%	78%
LBADEUR3CL1	0.0440	0.0374	0.0360	0.0306	0.0729	0.0619	85%	85%	85%
LBADEUR3CL2	0.0440	0.0374	0.0360	0.0306	0.0729	0.0619	85%	85%	85%
LBADEUR3CL3	0.0628	0.0534	0.0514	0.0437	0.1041	0.0885	85%	85%	85%
LBADEUR4CL1DPF	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
LBADEUR4CL2DPF	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
LBADEUR4CL3DPF	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
LBADEUR4CL1	0.0328	0.0285	0.0163	0.0142	0.0349	0.0304	87%	87%	87%
LBADEUR4CL2	0.0328	0.0285	0.0163	0.0142	0.0349	0.0304	87%	87%	87%
LBADEUR4CL3	0.0786	0.0684	0.0391	0.0341	0.0838	0.0729	87%	87%	87%
LBADEUR5CL1	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
LBADEUR5CL2	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
LBADEUR5CL3	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
LTRDEUR5CL3	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
LBADPR82LCH	2.3725	1.3049	1.1431	0.6287	0.4063	0.2235	55%	55%	55%
LBADPR82ZWA	2.3725	1.3049	1.1431	0.6287	0.4081	0.2244	55%	55%	55%
LBAE	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000			
LBAL1982	0.0170	0.0043	0.0099	0.0025	0.0138	0.0035	25%	25%	25%
LBAL1983	0.0170	0.0043	0.0099	0.0025	0.0138	0.0035	25%	25%	25%
LBAL1984	0.0170	0.0043	0.0099	0.0025	0.0138	0.0035	25%	25%	25%
LBAL1985	0.0170	0.0043	0.0099	0.0025	0.0138	0.0035	25%	25%	25%
LBAL1986	0.0170	0.0043	0.0099	0.0025	0.0138	0.0035	25%	25%	25%
LBAL1987	0.0170	0.0043	0.0099	0.0025	0.0138	0.0035	25%	25%	25%
LBAL1988	0.0170	0.0043	0.0099	0.0025	0.0138	0.0035	25%	25%	25%
LBAL1989	0.0170	0.0043	0.0099	0.0025	0.0138	0.0035	25%	25%	25%
LBAL1990	0.0170	0.0043	0.0099	0.0025	0.0138	0.0035	25%	25%	25%
LBAL1991	0.0170	0.0043	0.0099	0.0025	0.0138	0.0035	25%	25%	25%
LBAL1992	0.0170	0.0043	0.0099	0.0025	0.0138	0.0035	25%	25%	25%
LBALEUR1	0.0070	0.0017	0.0051	0.0013	0.0050	0.0013	25%	25%	25%
LBALEUR2	0.0070	0.0017	0.0051	0.0013	0.0050	0.0013	25%	25%	25%
LBALEUR3	0.0035	0.0005	0.0016	0.0002	0.0050	0.0008	15%	15%	15%
LBALEUR4	0.0035	0.0005	0.0016	0.0002	0.0050	0.0008	15%	15%	15%
LBALEUR5	0.0028	0.0004	0.0013	0.0002	0.0050	0.0008	15%	15%	15%
LBALEUR6	0.0028	0.0004	0.0013	0.0002	0.0050	0.0008	15%	15%	15%
LBALPR82	0.0170	0.0043	0.0099	0.0025	0.0138	0.0035	25%	25%	25%
LBALR3WC	0.0070	0.0017	0.0051	0.0013	0.0051	0.0013	25%	25%	25%
LBEDEUR5	0.0042	0.0004	0.0021	0.0002	0.0045	0.0005	10%	10%	10%
LBEDEUR6	0.0031	0.0003	0.0016	0.0002	0.0034	0.0003	10%	10%	10%
powered two-wheelers	exhaust PM	EC	exhaust PM	EC	exhaust PM	EC	EC/PM	EC/PM	EC/PM
LMFBEUR0	0.0166	0.0025	0.0166	0.0025	0.0172	0.0026	15%	15%	15%
LMFBEUR1	0.0155	0.0039	0.0155	0.0039	0.0162	0.0041	25%	25%	25%
passenger cars	exhaust PM	EC	exhaust PM	EC	exhaust PM	EC	EC/PM	EC/PM	EC/PM
LPAB1982LCH	0.0460	0.0092	0.0315	0.0063	0.0315	0.0063	20%	20%	20%
LPAB1982MED	0.0460	0.0092	0.0315	0.0063	0.0315	0.0063	20%	20%	20%
LPAB1982ZWA	0.0460	0.0092	0.0315	0.0063	0.0315	0.0063	20%	20%	20%
LPAB1983LCH	0.0420	0.0084	0.0286	0.0057	0.0286	0.0057	20%	20%	20%
LPAB1983MED	0.0420	0.0084	0.0286	0.0057	0.0286	0.0057	20%	20%	20%
LPAB1983ZWA	0.0420	0.0084	0.0286	0.0057	0.0286	0.0057	20%	20%	20%
LPAB1984LCH	0.0380	0.0076	0.0256	0.0051	0.0256	0.0051	20%	20%	20%
LPAB1984MED	0.0380	0.0076	0.0256	0.0051	0.0256	0.0051	20%	20%	20%
LPAB1984ZWA	0.0380	0.0076	0.0256	0.0051	0.0256	0.0051	20%	20%	20%
LPAB1985LCH	0.0340	0.0068	0.0226	0.0045	0.0226	0.0045	20%	20%	20%
LPAB1985MED	0.0340	0.0068	0.0226	0.0045	0.0226	0.0045	20%	20%	20%
LPAB1985ZWA	0.0340	0.0068	0.0226	0.0045	0.0226	0.0045	20%	20%	20%
LPAB1986LCH	0.0300	0.0060	0.0197	0.0039	0.0197	0.0039	20%	20%	20%
LPAB1986MED	0.0300	0.0060	0.0197	0.0039	0.0197	0.0039	20%	20%	20%
LPAB1986ZWA	0.0300	0.0060	0.0197	0.0039	0.0197	0.0039	20%	20%	20%
LPAB1987LCH	0.0300	0.0060	0.0177	0.0035	0.0236	0.0047	20%	20%	20%
LPAB1987MED	0.0300	0.0060	0.0177	0.0035	0.0236	0.0047	20%	20%	20%
LPAB1987ZWA	0.0300	0.0060	0.0177	0.0035	0.0236	0.0047	20%	20%	20%
LPAB1988LCH	0.0300	0.0060	0.0177	0.0035	0.0236	0.0047	20%	20%	20%
LPAB1988MED	0.0300	0.0060	0.0177	0.0035	0.0236	0.0047	20%	20%	20%
LPAB1988ZWA	0.0300	0.0060	0.0177	0.0035	0.0236	0.0047	20%	20%	20%
LPAB1989LCH	0.0300	0.0060	0.0177	0.0035	0.0236	0.0047	20%	20%	20%
LPAB1989MED	0.0300	0.0060	0.0177	0.0035	0.0236	0.0047	20%	20%	20%
LPAB1989ZWA	0.0300	0.0060	0.0177	0.0035	0.0236	0.0047	20%	20%	20%
LPAB1990LCH	0.0300	0.0060	0.0177	0.0035	0.0236	0.0047	20%	20%	20%
LPAB1990MED	0.0300	0.0060	0.0177	0.0035	0.0236	0.0047	20%	20%	20%
LPAB1990ZWA	0.0300	0.0060	0.0177	0.0035	0.0236	0.0047	20%	20%	20%
LPAB1991LCH	0.0300	0.0060	0.0177	0.0035	0.0236	0.0047	20%	20%	20%
LPAB1991MED	0.0300	0.0060	0.0177	0.0035	0.0236	0.0047	20%	20%	20%
LPAB1991ZWA	0.0300	0.0060	0.0177	0.0035	0.0236	0.0047	20%	20%	20%
LPAB1992LCH	0.0300	0.0060	0.0177	0.0035	0.0236	0.0047	20%	20%	20%

LPAB1992MED	0.0300	0.0060	0.0177	0.0035	0.0236	0.0047	20%	20%	20%
LPAB1992ZWA	0.0300	0.0060	0.0177	0.0035	0.0236	0.0047	20%	20%	20%
LPABEUR1	0.0670	0.0168	0.0068	0.0017	0.0025	0.0006	25%	25%	25%
LPABEUR2	0.0046	0.0012	0.0023	0.0006	0.0050	0.0013	25%	25%	25%
LPABEUR3	0.0023	0.0007	0.0012	0.0004	0.0025	0.0008	30%	30%	30%
LPABEUR4	0.0023	0.0007	0.0012	0.0004	0.0025	0.0008	30%	30%	30%
LPABEUR5	0.0019	0.0006	0.0009	0.0003	0.0025	0.0008	30%	30%	30%
LPABEUR6	0.0019	0.0006	0.0009	0.0003	0.0025	0.0008	30%	30%	30%
LPABO3WCLCH	0.0125	0.0025	0.0053	0.0011	0.0069	0.0014	20%	20%	20%
LPABO3WCMED	0.0125	0.0025	0.0053	0.0011	0.0069	0.0014	20%	20%	20%
LPABPR82LCH	0.0626	0.0125	0.0438	0.0088	0.0407	0.0081	20%	20%	20%
LPABPR82MED	0.0626	0.0125	0.0438	0.0088	0.0407	0.0081	20%	20%	20%
LPABPR82ZWA	0.0626	0.0125	0.0438	0.0088	0.0407	0.0081	20%	20%	20%
LPABR3WC	0.0100	0.0020	0.0068	0.0014	0.0068	0.0014	20%	20%	20%
LPACEUR1	0.0670	0.0168	0.0068	0.0017	0.0025	0.0006	25%	25%	25%
LPACEUR2	0.0046	0.0012	0.0023	0.0006	0.0050	0.0013	25%	25%	25%
LPACEUR3	0.0046	0.0007	0.0023	0.0004	0.0050	0.0008	15%	15%	15%
LPACEUR4	0.0046	0.0007	0.0023	0.0004	0.0050	0.0008	15%	15%	15%
LPACEUR5	0.0037	0.0006	0.0019	0.0003	0.0050	0.0008	15%	15%	15%
LPACEUR6	0.0037	0.0006	0.0019	0.0003	0.0050	0.0008	15%	15%	15%
LPAD1982LCH	0.6234	0.3429	0.3303	0.1817	0.2385	0.1312	55%	55%	55%
LPAD1982MED	0.6234	0.3429	0.3303	0.1817	0.2385	0.1312	55%	55%	55%
LPAD1982ZWA	0.6234	0.3429	0.3303	0.1817	0.2385	0.1312	55%	55%	55%
LPAD1983LCH	0.5250	0.2887	0.2877	0.1582	0.2110	0.1161	55%	55%	55%
LPAD1983MED	0.5250	0.2887	0.2877	0.1582	0.2110	0.1161	55%	55%	55%
LPAD1983ZWA	0.5250	0.2887	0.2877	0.1582	0.2110	0.1161	55%	55%	55%
LPAD1984LCH	0.4375	0.2406	0.2557	0.1406	0.1743	0.0959	55%	55%	55%
LPAD1984MED	0.4375	0.2406	0.2557	0.1406	0.1743	0.0959	55%	55%	55%
LPAD1984ZWA	0.4375	0.2406	0.2557	0.1406	0.1743	0.0959	55%	55%	55%
LPAD1985LCH	0.3390	0.1865	0.2131	0.1172	0.1468	0.0807	55%	55%	55%
LPAD1985MED	0.3390	0.1865	0.2131	0.1172	0.1468	0.0807	55%	55%	55%
LPAD1985ZWA	0.3390	0.1865	0.2131	0.1172	0.1468	0.0807	55%	55%	55%
LPAD1986LCH	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPAD1986MED	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPAD1986ZWA	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPAD1987LCH	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPAD1987MED	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPAD1987ZWA	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPAD1988LCH	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPAD1988MED	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPAD1988ZWA	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPAD1989LCH	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPAD1989MED	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPAD1989ZWA	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPAD1990LCH	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPAD1990MED	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPAD1990ZWA	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPAD1991LCH	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPAD1991MED	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPAD1991ZWA	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPAD1992LCH	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPAD1992MED	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPAD1992ZWA	0.3062	0.1684	0.1918	0.1055	0.1468	0.0807	55%	55%	55%
LPADEUA6	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
LPADEUC6	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
LPADEUR1	0.2362	0.1654	0.1011	0.0708	0.0809	0.0566	70%	70%	70%
LPADEUR2	0.1113	0.0891	0.0453	0.0362	0.0920	0.0736	80%	80%	80%
LPADEUR3	0.0314	0.0267	0.0257	0.0219	0.0521	0.0442	85%	85%	85%
LPADEUR3HOF	0.0204	0.0160	0.0167	0.0131	0.0338	0.0265	78%	78%	78%
LPADEUR4	0.0328	0.0260	0.0163	0.0130	0.0349	0.0352	79%	80%	101%
LPADEUR4DPF	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
LPADEUR5	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
LPADPR82LCH	0.9865	0.5426	0.5071	0.2789	0.3908	0.2150	55%	55%	55%
LPADPR82MED	0.9865	0.5426	0.5071	0.2789	0.3908	0.2150	55%	55%	55%
LPADPR82ZWA	0.9865	0.5426	0.5071	0.2789	0.3908	0.2150	55%	55%	55%
LPAE	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000			
LPAL1982LCH	0.0270	0.0054	0.0207	0.0041	0.0439	0.0088	20%	20%	20%
LPAL1982MED	0.0240	0.0048	0.0187	0.0037	0.0390	0.0078	20%	20%	20%
LPAL1982ZWA	0.0210	0.0042	0.0167	0.0034	0.0342	0.0068	20%	20%	20%
LPAL1983LCH	0.0270	0.0054	0.0207	0.0041	0.0439	0.0088	20%	20%	20%
LPAL1983MED	0.0240	0.0048	0.0187	0.0037	0.0390	0.0078	20%	20%	20%
LPAL1983ZWA	0.0210	0.0042	0.0167	0.0034	0.0342	0.0068	20%	20%	20%
LPAL1984LCH	0.0270	0.0054	0.0207	0.0041	0.0439	0.0088	20%	20%	20%
LPAL1984MED	0.0240	0.0048	0.0187	0.0037	0.0390	0.0078	20%	20%	20%
LPAL1984ZWA	0.0210	0.0042	0.0167	0.0034	0.0342	0.0068	20%	20%	20%
LPAL1985LCH	0.0270	0.0054	0.0207	0.0041	0.0439	0.0088	20%	20%	20%
LPAL1985MED	0.0240	0.0048	0.0187	0.0037	0.0390	0.0078	20%	20%	20%
LPAL1985ZWA	0.0210	0.0042	0.0167	0.0034	0.0342	0.0068	20%	20%	20%
LPAL1986LCH	0.0160	0.0032	0.0097	0.0019	0.0300	0.0060	20%	20%	20%
LPAL1986MED	0.0137	0.0027	0.0084	0.0017	0.0066	0.0013	20%	20%	20%

LPAL1986ZWA	0.0098	0.0020	0.0061	0.0012	0.0176	0.0035	20%	20%	20%
LPAL1987LCH	0.0160	0.0032	0.0097	0.0019	0.0300	0.0060	20%	20%	20%
LPAL1987MED	0.0137	0.0027	0.0084	0.0017	0.0066	0.0013	20%	20%	20%
LPAL1987ZWA	0.0098	0.0020	0.0061	0.0012	0.0176	0.0035	20%	20%	20%
LPAL1988LCH	0.0160	0.0032	0.0097	0.0019	0.0300	0.0060	20%	20%	20%
LPAL1988MED	0.0137	0.0027	0.0084	0.0017	0.0066	0.0013	20%	20%	20%
LPAL1988ZWA	0.0098	0.0020	0.0061	0.0012	0.0176	0.0035	20%	20%	20%
LPAL1989LCH	0.0160	0.0032	0.0097	0.0019	0.0300	0.0060	20%	20%	20%
LPAL1989MED	0.0137	0.0027	0.0084	0.0017	0.0066	0.0013	20%	20%	20%
LPAL1989ZWA	0.0098	0.0020	0.0061	0.0012	0.0176	0.0035	20%	20%	20%
LPAL1990LCH	0.0160	0.0032	0.0097	0.0019	0.0300	0.0060	20%	20%	20%
LPAL1990MED	0.0137	0.0027	0.0084	0.0017	0.0066	0.0013	20%	20%	20%
LPAL1990ZWA	0.0098	0.0020	0.0061	0.0012	0.0176	0.0035	20%	20%	20%
LPAL1991LCH	0.0160	0.0032	0.0097	0.0019	0.0300	0.0060	20%	20%	20%
LPAL1991MED	0.0137	0.0027	0.0084	0.0017	0.0066	0.0013	20%	20%	20%
LPAL1991ZWA	0.0098	0.0020	0.0061	0.0012	0.0176	0.0035	20%	20%	20%
LPAL1992LCH	0.0160	0.0032	0.0097	0.0019	0.0300	0.0060	20%	20%	20%
LPAL1992MED	0.0137	0.0027	0.0084	0.0017	0.0066	0.0013	20%	20%	20%
LPAL1992ZWA	0.0098	0.0020	0.0061	0.0012	0.0176	0.0035	20%	20%	20%
LPALEUR1	0.0089	0.0022	0.0051	0.0013	0.0050	0.0013	25%	25%	25%
LPALEUR2	0.0089	0.0022	0.0051	0.0013	0.0050	0.0013	25%	25%	25%
LPALEUR3	0.0054	0.0008	0.0016	0.0002	0.0050	0.0008	15%	15%	15%
LPALEUR4	0.0044	0.0007	0.0022	0.0003	0.0050	0.0008	15%	15%	15%
LPALEUR5	0.0036	0.0005	0.0018	0.0003	0.0050	0.0008	15%	15%	15%
LPALEUR6	0.0036	0.0005	0.0018	0.0003	0.0050	0.0008	15%	15%	15%
LPALO3WCLCH	0.0160	0.0032	0.0097	0.0019	0.0300	0.0060	20%	20%	20%
LPALO3WCMED	0.0160	0.0032	0.0097	0.0019	0.0300	0.0060	20%	20%	20%
LPALPR82LCH	0.0395	0.0079	0.0301	0.0060	0.0642	0.0128	20%	20%	20%
LPALPR82MED	0.0270	0.0054	0.0207	0.0041	0.0439	0.0088	20%	20%	20%
LPALPR82ZWA	0.0240	0.0048	0.0187	0.0037	0.0390	0.0078	20%	20%	20%
LPALR3WC	0.0089	0.0018	0.0051	0.0010	0.0127	0.0025	20%	20%	20%
LPEBEUR5	0.0022	0.0003	0.0011	0.0002	0.0030	0.0005	15%	15%	15%
LPEBEUR6	0.0022	0.0003	0.0011	0.0002	0.0030	0.0005	15%	15%	15%
LPEDEUR5	0.0020	0.0011	0.0010	0.0006	0.0021	0.0015	56%	56%	71%
LPEDEUA6	0.0004	0.0000	0.0004	0.0000	0.0011	0.0001	11%	11%	10%
LPEDEUC6	0.0004	0.0000	0.0004	0.0000	0.0011	0.0001	11%	11%	10%
LPHBEUR4	0.0046	0.0007	0.0023	0.0004	0.0050	0.0008	15%	15%	15%
LPHBEUR5	0.0037	0.0006	0.0019	0.0003	0.0050	0.0008	15%	15%	15%
LPHBEUR6	0.0037	0.0006	0.0019	0.0003	0.0050	0.0008	15%	15%	15%
LPHDEUR5	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
LPHDEUR6	0.0005	0.0001	0.0005	0.0001	0.0015	0.0002	10%	10%	10%
heavy-duty vehicles	exhaust PM	EC	exhaust PM	EC	exhaust PM	EC	EC/PM	EC/PM	EC/PM
MVABEUR0LCH	0.3884	0.0777	0.3988	0.0798	0.4029	0.0806	20%	20%	20%
MVADEDE5LCHSCR	0.0099	0.0048	0.0066	0.0026	0.0055	0.0018	49%	40%	33%
MVADEDE5SCRZWA	0.0198	0.0095	0.0133	0.0052	0.0112	0.0036	48%	39%	32%
MVADEUG5EGRLCH	0.0110	0.0057	0.0068	0.0029	0.0054	0.0018	51%	42%	33%
MVADEUG5EGRZWA	0.0219	0.0108	0.0139	0.0055	0.0110	0.0035	49%	40%	32%
MVADEUG5LCHSCR	0.0087	0.0048	0.0057	0.0026	0.0048	0.0016	55%	45%	33%
MVADEUG5SCRZWA	0.0178	0.0091	0.0117	0.0049	0.0095	0.0031	51%	42%	33%
MVADEUR0LCH	0.5396	0.2698	0.3273	0.1637	0.2689	0.1344	50%	50%	50%
MVADEUR0ZWA	0.9790	0.4895	0.5548	0.2774	0.4352	0.2176	50%	50%	50%
MVADEUR1LCH	0.2649	0.1722	0.1588	0.1032	0.1319	0.0857	65%	65%	65%
MVADEUR1ZWA	0.4880	0.3172	0.2672	0.1737	0.2104	0.1368	65%	65%	65%
MVADEUR2LCH	0.1069	0.0695	0.0771	0.0501	0.0666	0.0433	65%	65%	65%
MVADEUR2ZWA	0.1913	0.1244	0.1190	0.0773	0.0992	0.0645	65%	65%	65%
MVADEUR3DPFLCH	0.0075	0.0011	0.0045	0.0007	0.0032	0.0005	15%	15%	15%
MVADEUR3DPFZWA	0.0135	0.0020	0.0075	0.0011	0.0056	0.0008	15%	15%	15%
MVADEUR3HOFLCH	0.0747	0.0560	0.0448	0.0336	0.0322	0.0241	75%	75%	75%
MVADEUR3HOFZWA	0.1353	0.1015	0.0753	0.0565	0.0555	0.0417	75%	75%	75%
MVADEUR3LCH	0.1244	0.0871	0.0747	0.0523	0.0536	0.0375	70%	70%	70%
MVADEUR3ZWA	0.2255	0.1578	0.1255	0.0879	0.0926	0.0648	70%	70%	70%
MVADEUR4LCH	0.0254	0.0190	0.0138	0.0104	0.0102	0.0077	75%	75%	75%
MVADEUR4ZWA	0.0461	0.0346	0.0239	0.0180	0.0180	0.0135	75%	75%	75%
MVADEUR6LCH	0.0061	0.0020	0.0042	0.0011	0.0037	0.0008	32%	25%	21%
MVADEUR6ZWA	0.0126	0.0035	0.0086	0.0018	0.0074	0.0014	28%	21%	19%
MVALEUR0LCH	0.0971	0.0194	0.0997	0.0199	0.1007	0.0201	20%	20%	20%
ZTRBEUR0	0.3884	0.0777	0.3988	0.0798	0.4024	0.0805	20%	20%	20%
ZTRDEDE5LCHSCR	0.0272	0.0128	0.0198	0.0071	0.0159	0.0049	47%	36%	31%
ZTRDEDE5SCRZWA	0.0428	0.0181	0.0533	0.0128	0.0551	0.0108	42%	24%	20%
ZTRDEUG5EGRLCH	0.0296	0.0135	0.0227	0.0076	0.0164	0.0049	45%	34%	30%
ZTRDEUG5EGRZWA	0.1056	0.0230	0.0784	0.0155	0.0590	0.0113	22%	20%	19%
ZTRDEUG5LCHSCR	0.0254	0.0120	0.0164	0.0064	0.0129	0.0042	47%	39%	32%
ZTRDEUG5SCRZWA	0.0988	0.0238	0.0540	0.0124	0.0241	0.0064	24%	23%	27%
ZTRDEUR0	1.4090	0.7045	0.8247	0.4123	0.6097	0.3048	50%	50%	50%
ZTRDEUR1	0.7632	0.4961	0.4317	0.2806	0.3119	0.2027	65%	65%	65%
ZTRDEUR2	0.3366	0.2188	0.2024	0.1315	0.1655	0.1075	65%	65%	65%
ZTRDEUR3	0.3023	0.2116	0.1677	0.1174	0.1242	0.0869	70%	70%	70%
ZTRDEUR3DPF	0.0181	0.0027	0.0101	0.0015	0.0075	0.0011	15%	15%	15%
ZTRDEUR3HOF	0.1814	0.1360	0.1006	0.0755	0.0745	0.0559	75%	75%	75%
ZTRDEUR4	0.0591	0.0444	0.0295	0.0222	0.0212	0.0159	75%	75%	75%

ZTRDEUR6LCH	0.0300	0.0045	0.0150	0.0023	0.0107	0.0016	15%	15%	15%
ZTRDEUR6ZWA	0.0300	0.0045	0.0150	0.0023	0.0107	0.0016	15%	15%	15%
ZTRLEUR0	0.0971	0.0194	0.0997	0.0199	0.1006	0.0201	20%	20%	20%
ZVADEDE5ANHLCHSCR	0.0257	0.0098	0.0227	0.0065	0.0189	0.0050	38%	29%	26%
ZVADEDE5ANHSCRZWA	0.0387	0.0143	0.0391	0.0100	0.0317	0.0075	37%	26%	24%
ZVADEDE5SCR	0.0276	0.0129	0.0207	0.0072	0.0162	0.0050	47%	35%	31%
ZVADEUG5ANHEGRLCH	0.0448	0.0119	0.0281	0.0071	0.0210	0.0053	27%	25%	25%
ZVADEUG5ANHEGRZWA	0.0860	0.0190	0.0536	0.0115	0.0360	0.0082	22%	21%	23%
ZVADEUG5ANHLCHSCR	0.0243	0.0094	0.0152	0.0052	0.0124	0.0039	39%	35%	31%
ZVADEUG5ANHSCRZWA	0.0659	0.0170	0.0278	0.0081	0.0183	0.0054	26%	29%	30%
ZVADEUG5EGR	0.0300	0.0135	0.0233	0.0077	0.0168	0.0050	45%	33%	30%
ZVADEUG5SCR	0.0258	0.0122	0.0166	0.0064	0.0131	0.0042	47%	39%	32%
ZVADEUR0	1.3824	0.6912	0.8184	0.4092	0.6252	0.3126	50%	50%	50%
ZVADEUR0ANHLCH	1.1155	0.5577	0.6844	0.3422	0.5474	0.2737	50%	50%	50%
ZVADEUR0ANHZWA	1.5840	0.7920	0.9690	0.4845	0.7654	0.3827	50%	50%	50%
ZVADEUR1	0.7171	0.4661	0.4084	0.2654	0.3181	0.2068	65%	65%	65%
ZVADEUR1ANHLCH	0.5991	0.3894	0.3552	0.2309	0.2942	0.1912	65%	65%	65%
ZVADEUR1ANHZWA	0.8317	0.5406	0.5019	0.3263	0.4080	0.2652	65%	65%	65%
ZVADEUR2	0.3125	0.2031	0.1910	0.1242	0.1615	0.1050	65%	65%	65%
ZVADEUR2ANHLCH	0.2936	0.1908	0.1809	0.1176	0.1581	0.1028	65%	65%	65%
ZVADEUR2ANHZWA	0.4126	0.2682	0.2571	0.1671	0.2212	0.1438	65%	65%	65%
ZVADEUR3	0.3033	0.2123	0.1676	0.1173	0.1272	0.0891	70%	70%	70%
ZVADEUR3ANHDPFLCH	0.0138	0.0021	0.0084	0.0013	0.0066	0.0010	15%	15%	15%
ZVADEUR3ANHDPFZWA	0.0183	0.0028	0.0111	0.0017	0.0089	0.0013	15%	15%	15%
ZVADEUR3ANHHOFLCH	0.1379	0.1035	0.0835	0.0627	0.0660	0.0495	75%	75%	75%
ZVADEUR3ANHHOFZWA	0.1834	0.1375	0.1111	0.0833	0.0888	0.0666	75%	75%	75%
ZVADEUR3ANHLCH	0.2299	0.1609	0.1392	0.0975	0.1100	0.0770	70%	70%	70%
ZVADEUR3ANHZWA	0.3056	0.2140	0.1852	0.1296	0.1480	0.1036	70%	70%	70%
ZVADEUR3DPF	0.0182	0.0027	0.0101	0.0015	0.0076	0.0011	15%	15%	15%
ZVADEUR3HOF	0.1820	0.1365	0.1005	0.0754	0.0763	0.0573	75%	75%	75%
ZVADEUR4	0.0612	0.0459	0.0313	0.0235	0.0232	0.0174	75%	75%	75%
ZVADEUR4ANHLCH	0.0414	0.0310	0.0242	0.0182	0.0181	0.0136	75%	75%	75%
ZVADEUR4ANHZWA	0.0546	0.0410	0.0316	0.0237	0.0236	0.0177	75%	75%	75%
ZVADEUR6	0.0186	0.0047	0.0123	0.0024	0.0101	0.0018	25%	19%	18%
ZVADEUR6ANHLCH	0.0180	0.0032	0.0111	0.0019	0.0095	0.0014	18%	17%	15%
ZVADEUR6ANHZWA	0.0263	0.0042	0.0157	0.0024	0.0132	0.0018	16%	15%	14%