

Category		Title
NFR	1.A.3.b.i	Passenger cars
	1.A.3.b.ii	Light commercial trucks
	1.A.3.b.iii	Heavy-duty vehicles including buses
	1.A.3.b.iv	Mopeds & motorcycles
SNAP	0701	Passenger cars
	0702	Light commercial vehicles < 3.5 t
	0703	Heavy-duty vehicles > 3.5 t and buses
	0704	Mopeds and motorcycles < 50 cm ³
	0705	Motorcycles > 50 cm ³
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1 Overview

1.1 General description

This chapter provides the methodology, emission factors and relevant activity data to enable exhaust emissions to be calculated for the following categories of road vehicles:

- passenger cars (NFR code 1.A.3.b.i)
- light commercial vehicles ⁽¹⁾ (< 3.5 t) (NFR code 1.A.3.b.ii)
- heavy-duty vehicles ⁽²⁾ (> 3.5 t) and buses (NFR code 1.A.3.b.iii)
- mopeds & motorcycles ⁽³⁾ (NFR code 1.A.3.b.iv)

It does not cover non-exhaust emissions such as fuel evaporation from vehicles (NFR code 1.A.3.b.v), tyre wear and brake wear (NFR code 1.A.3.b.vi), or road wear (NFR code 1.A.3.b.vii).

The most important pollutants emitted by road vehicles include:

- ozone precursors (CO, NO_x, NMVOCs ⁽⁴⁾);
- greenhouse gases (CO₂, CH₄, N₂O);
- acidifying substances (NH₃, SO₂);
- particulate matter mass (PM) including black carbon (BC) and organic carbon (OC);
- carcinogenic species (PAHs ⁽⁵⁾ and POPs ⁽⁶⁾);
- toxic substances (dioxins and furans);
- heavy metals.

The Definition of PM, and NMVOC EFs

All PM mass emission factors reported in this chapter refer to PM_{2.5}, as the coarse fraction (PM_{2.5-10}) is negligible in vehicle exhausts. Emission factors for particulate matter are presented in terms of particle number and surface area for different size ranges. PM mass emission factors correspond to primary emissions from road traffic and not formation of secondary aerosol from chemical reactions in the atmosphere minutes or hours after release. It should be further clarified that the measurement procedure regulated for vehicle exhaust PM mass characterisation requires that samples are taken at a temperature lower than 52°C. At this temperature, PM contains a large fraction of condensable species. Hence, PM mass emission factors in this chapter are considered to include both filterable and condensable material.

Also, fuel/energy consumption figures can be calculated. For NMVOCs, emission factors for 68 separate substances are provided.

⁽¹⁾ LCVs

⁽²⁾ HDVs

⁽³⁾ This sector includes mini cars and ATVs, and will be labeled L-category in specific sections in this report

⁽⁴⁾ NMVOCs = non-methane volatile organic compounds

⁽⁵⁾ PAHs = polycyclic aromatic hydrocarbons

⁽⁶⁾ POPs = persistent organic pollutants

1.2 Structure and origins of this chapter

The original Corinair 1985 emissions inventory (Eggleston et al, 1989) has been updated a number of times. The Tier 1 and Tier 2 emission factors included in this chapter were calculated on the basis of the Tier 3 methodology, by applying some default values, by the team at Aristotle University, Thessaloniki and later by EMISIA SA. Annex 2 provides a brief history of the previous versions of this chapter.

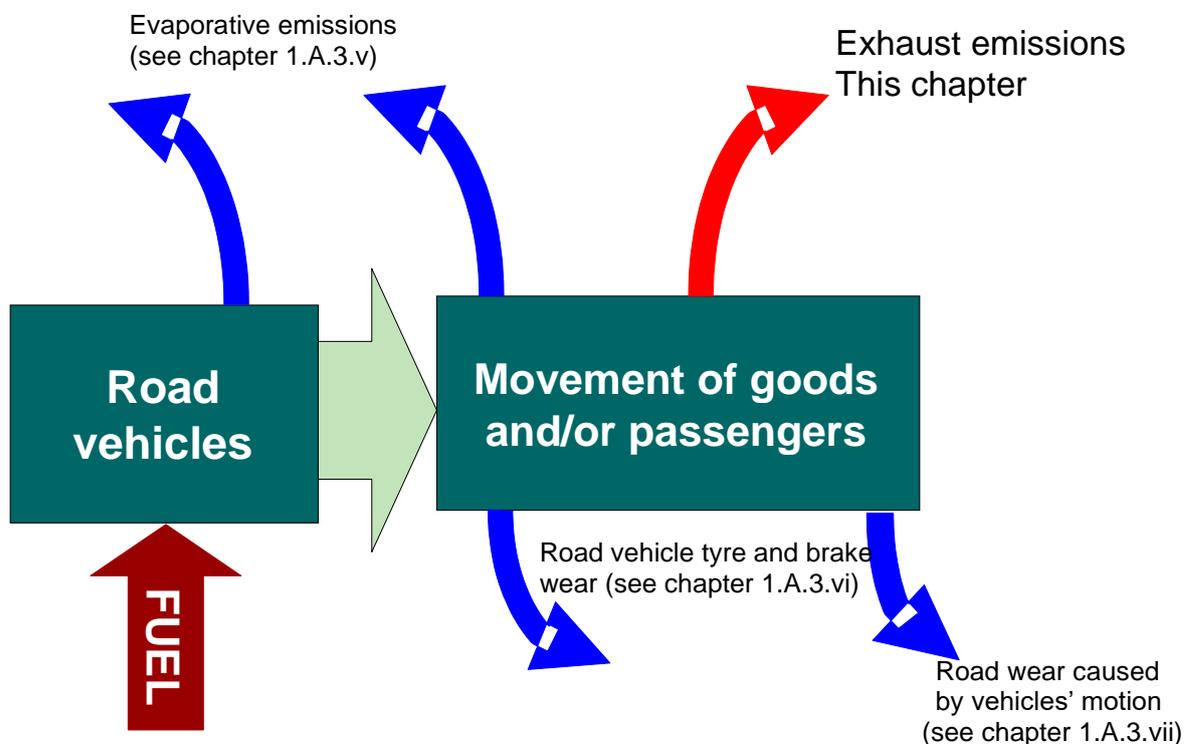
2 Description of sources

2.1 Process description

2.1.1 Overview

Exhaust emissions from road transport arise from the combustion of fuels such as petrol, diesel, liquefied petroleum gas (LPG), and natural gas in internal combustion engines. The air/fuel charge may be ignited by a spark ('spark-ignition' or 'positive-ignition' engines), or it may ignite spontaneously when compressed ('compression-ignition' engines). The emissions from road vehicles are illustrated schematically in Figure 2-1, with red, the exhaust emissions being those covered in this chapter, whilst the other emission processes are covered in other chapters.

Figure 2-1: Flow diagram emissions from road transport.



Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

2.1.2 Summary of activities covered

Exhaust emissions from road transport are reported according to the four different NFR codes listed in subsection 1.1. The correspondence between these NFR codes and the vehicle categories specified by the United Nations Economic Commission for Europe (UNECE) is explained in Table 2-1. For more detailed emission estimation methods these four categories are often sub-divided according to the fuel used, and by engine size, weight or technology level of the vehicle. For certain pollutants, the emission factors can be further sub-divided according to three types of driving: 'highway', 'rural' and 'urban'.

Table 2-1: Definition of road vehicle categories

NFR Code	Vehicle category		Official Classification
1.A.3.b.i	Passenger Cars		M1: vehicles used for the carriage of passengers and comprising not more than eight seats in addition to the driver's seat.
	Petrol	Mini	
	Petrol	Small	
	Petrol	Medium	
	Petrol	Large-SUV-Executive	
	Diesel	Mini	
	Diesel	Small	
	Diesel	Medium	
	Diesel	Large-SUV-Executive	
	Petrol Hybrid	Mini	
	Petrol Hybrid	Small	
	Petrol Hybrid	Medium	
	Petrol Hybrid	Large-SUV-Executive	
	Petrol PHEV	Small	
	Petrol PHEV	Medium	
	Petrol PHEV	Large-SUV-Executive	
	Diesel PHEV	Large-SUV-Executive	
	LPG Bi-fuel	Mini	
	LPG Bi-fuel	Small	
	LPG Bi-fuel	Medium	
LPG Bi-fuel	Large-SUV-Executive		
CNG Bi-fuel	Mini		
CNG Bi-fuel	Small		
CNG Bi-fuel	Medium		
CNG Bi-fuel	Large-SUV-Executive		
1.A.3.b.ii	Light Commercial Vehicles < 3.5 t		N1: vehicles used for the carriage of goods and having a maximum weight not exceeding 3.5 tonnes.
	Petrol	N1-I	
	Petrol	N1-II	
	Petrol	N1-III	
	Diesel	N1-I	
	Diesel	N1-II	
	Diesel	N1-III	

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1.A.3.b.iii	Heavy-Duty Vehicles		<p>N2: vehicles used for the carriage of goods and having a maximum weight exceeding 3.5 tonnes but not exceeding 12 tonnes.</p> <p>N3: vehicles used for the carriage of goods and having a maximum weight exceeding 12 tonnes.</p>	
	Petrol	>3,5 t		
	Diesel	Rigid <=7,5 t		
	Diesel	Rigid 7,5 - 12 t		
	Diesel	Rigid 12 - 14 t		
	Diesel	Rigid 14 - 20 t		
	Diesel	Rigid 20 - 26 t		
	Diesel	Rigid 26 - 28 t		
	Diesel	Rigid 28 - 32 t		
	Diesel	Rigid >32 t		
	Diesel	Articulated 14 - 20 t		
	Diesel	Articulated 20 - 28 t		
	Diesel	Articulated 28 - 34 t		
	Diesel	Articulated 34 - 40 t		
	Diesel	Articulated 40 - 50 t		
	Diesel	Articulated 50 - 60 t		
	Diesel	Urban Buses Midi <=15 t		<p>M2: vehicles used for the carriage of passengers and comprising more than eight seats in addition to the driver's seat, and having a maximum weight not exceeding 5 tonnes.</p> <p>M3: vehicles used for the carriage of passengers and comprising more than eight seats in addition to the driver's seat, and having a maximum weight exceeding 5 tonnes.</p>
	Diesel	Urban Buses Standard 15 - 18 t		
	Diesel	Urban Buses Articulated >18 t		
	Diesel	Coaches Standard <=18 t		
Diesel	Coaches Articulated >18 t			
Diesel Hybrid	Urban Diesel Buses Hybrid			
CNG	Urban CNG Buses			
Biodiesel	Urban Biodiesel Buses			
1.A.3.b.iv	L-Category		<p>L1e: Light two-wheel powered vehicles with an engine cylinder capacity not exceeding 50 cm³, a maximum design speed not exceeding 45 km/h and a maximum continuous or net power ≤ 4000 W</p> <p>L2e: Three-wheel mopeds with a maximum design speed not exceeding 45 km/h, a maximum continuous rated or net power ≤ 4000 W and mass in running order ≤ 270 kg.</p> <p>L3e: Two-wheel motorcycle with an engine cylinder capacity exceeding 50 cm³ or a design speed exceeding 45 km/h, or a maximum continuous or net power exceeding 4000 W.</p> <p>L4e: Two-wheel motorcycle with side-car, with a maximum of four seating positions including the driver on the motorcycle, with side car and a maximum of two seating positions for passengers in the side car.</p> <p>L5e: Powered tricycle with mass in running order ≤ 1000 kg and three-wheel vehicle that cannot be classified as a L2e vehicle.</p>	
	Petrol	Mopeds 2-stroke <50 cm ³		
	Petrol	Mopeds 4-stroke <50 cm ³		
	Petrol	Motorcycles 2-stroke >50 cm ³		
	Petrol	Motorcycles 4-stroke <250 cm ³		
	Petrol	Motorcycles 4-stroke 250 - 750 cm ³		
	Petrol	Motorcycles 4-stroke >750 cm ³		

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Diesel	Mini-cars	L6e: Light quadricycle with maximum design vehicle speed ≤ 45 km/h and mass in running order ≤ 425 kg and engine capacity ≤ 50 cm ³ if a PI engine, or engine capacity ≤ 500 cm ³ if a CI engine. L7e: Heavy quadricycle with mass in running order ≤ 450 kg for the transport of passengers, or ≤ 600 kg for the transport of goods.
Petrol	All Terrain Vehicles	

Emission factors for L-category vehicles in this methodology do not cover all types and sub-types of vehicles in this category. This is a very diverse category of vehicles ranging from small electric bicycles to diesel tractors. Their numbers are still quite small compared to other vehicle types in Europe. Significant growth dynamic seem to exist for some of these types, such as L6e and L7e vehicle types. Hence, new emission factors have been developed and presented in this chapter. For the vehicles sub-types not included in the methodology, it is recommended to allocate them to the moped or motorcycles categories available or even in the newly generated small petrol car category (especially the petrol tricycle and quadricycle vehicles). Similarly, diesel quadricycles should be allocated to the smaller category of diesel passenger cars (mini), in the absence of better information. The error is considered small due to the small size of the stock.

2.2 Techniques

The combustion process produces CO₂ and H₂O as the main products. Unfortunately, combustion also produces several by-products which either originate from incomplete fuel oxidation (CO, hydrocarbons (THC), particulate matter (PM)) or from the oxidation of non-combustible species present in the combustion chamber (NO_x from N₂ in the air, SO_x from S in the fuel and lubricant, etc.). In order to comply with emission legislation, vehicle manufacturers have installed various aftertreatment devices — such as catalytic converters and diesel particle filters (DPFs) — to reduce pollutant emissions. However, such devices may, as a result of their action, also produce small quantities of pollutants such as NH₃ and N₂O.

Gasoline (and other spark-ignition) engines are used in small vehicles of up to 3.5 t gross vehicle weight (GVW), primarily because of their superior power:weight ratio and their wider operational range compared with diesel engines, but also for reasons such as lower noise and more refined operation. For very small vehicles (mopeds and motorcycles), two-stroke engines have been favoured, especially in the past, because they provide the highest power:weight ratio of all concepts. However, such engines have become less and less popular in recent years due to the strict emission regulations. On the other hand, diesel (and other compression-ignition) engines dominate in heavy-duty applications because of their greater fuel efficiency and torque compared with petrol engines. However, in recent years there has been a significant shift to diesel engines in the passenger car market, and in several European countries diesel cars have the largest share of new registrations. Member States' data on passenger car registrations, collected by the European Environment Agency in accordance with Regulation (EC) No 443/2009, show that more than 40% of passenger cars in Europe in 2014 were diesel, with shares exceeding 55% for countries like Belgium, France, Ireland, Luxembourg and Spain. This is a result of the higher fuel efficiency of diesel engines and technological improvements which have led to an increased power output for a given engine size.

A number of new technologies are designed to reduce both energy consumption and pollutant emissions. These technologies include the following:

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

- new types of internal combustion engine, such as gasoline direct injection (GDI), controlled auto-ignition (CAI), homogeneous charge compression ignition (HCCI);
- new fuels, such as CNG, reformulated grades, and hydrogen;
- alternative powertrains, such as hybrids (i.e. a combination of an internal combustion engine and an electric motor), plug-in hybrids that can be recharged from the grid power, fuel cell vehicles, electric, etc.

Some of these technologies (e.g. GDI, hybrids) have already become quite popular, whereas others (such as electric and fuel cells) are still in the development phase.

Given the diversity in propulsion concepts, the calculation of emissions from road vehicles is a complicated and demanding procedure which requires good quality activity data and emission factors. This chapter of the Guidebook aims to cover the emissions from all the technologies which are currently in widespread use, in a systematic manner that will allow the production of high-quality emission inventories.

2.3 Controls

Emissions from road vehicles have been controlled by European legislation since the 1970s. In order to meet the increasingly stringent requirements of the legislation, vehicle manufacturers have continually improved engine technologies and have introduced various emission-control systems. As a result, modern vehicles have emission levels for regulated pollutants (CO, NO_x, THC) which are more than an order of magnitude lower than the those of vehicles entering service two decades ago.

Road vehicles are usually classified according to their level of emission control technology, which is actually defined in terms of the emission legislation with which they are compliant. Using the vehicle classes described in

Table 2-1 different groups can be identified, each with its own relevant legislation. These groups are described in more detail in the following subsections.

It should also be noted that, in accordance with the legislation, a slightly different notation is used in this chapter to refer to the emission standards for Light Commercial Vehicles (LCVs), Heavy Duty Vehicles (HDVs) and two-wheel vehicles. For LCVs and L-category vehicles Arabic numerals are used (e.g. Euro 1, Euro 2, etc.), whereas for HDVs roman numerals are used (e.g. Euro I, Euro II, etc.).

The table below lists the different vehicle technologies addressed by the methodology as well as the introduction year (year of first registration) in the vehicle fleet based on European legislation. Minor differences with respect to the date of introduction across countries are expected, however they are not included in the table. A more detailed description of the emission standards may be found in Appendix 3.

Table 2-2: Implementation years of the European emission standards

Vehicle category	Type	Euro Standard	Start Date	End Date
Passenger Cars	All Petrol	PRE ECE		up to 1971
		ECE 15/00-01	1972	1977
		ECE 15/02	1978	1980
		ECE 15/03	1981	1985
		ECE 15/04	1985	1992
		Improved Conventional	1985	1990

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

Vehicle category	Type	Euro Standard	Start Date	End Date	
		Open Loop	1985	1990	
		Euro 1	1992	1996	
		Euro 2	1996	1999	
		Euro 3	2000	2004	
		Euro 4	2005	2009	
		Euro 5	2011	2014	
		Euro 6 a/b/c	2014	2016	
		Euro 6 d-temp	2019	2020	
	Euro 6 d	2021 and later			
	All Diesel	Conventional			up to 1992
		Euro 1	1992	1996	
		Euro 2	1996	2000	
		Euro 3	2000	2005	
		Euro 4	2005	2010	
		Euro 5	2010	2014	
		Euro 6 a/b/c	2014	2019	
	Euro 6 d-temp	2019	2020		
	Euro 6 d	2021 and later			
	All LPG	Conventional			up to 1991
		Euro 1	1992	1996	
		Euro 2	1996	1999	
		Euro 3	2000	2004	
		Euro 4	2005	2009	
		Euro 5	2010	2014	
		Euro 6 a/b/c	2015	2016	
	Euro 6 d-temp	2017	2019		
	Euro 6 d	2020 and later			
	All CNG	Euro 4	2005	2009	
Euro 5		2010	2014		
Euro 6 a/b/c		2015	2016		
Euro 6 d-temp		2017	2019		
Euro 6 d	2020 and later				
2 stroke	Conventional				
Light Commercial Vehicles	All Petrol	Conventional		up to 1993	
		Euro 1	1993	1997	
		Euro 2	1997	2001	
		Euro 3	2001	2006	
		Euro 4	2006	2010	
		Euro 5	2011	2015	
		Euro 6 a/b/c	2016	2017	
	Euro 6 d-temp	2018	2020		
	Euro 6 d	2021 and later			
	All Diesel	Conventional			up to 1993
		Euro 1	1993	1997	
		Euro 2	1997	2001	
		Euro 3	2001	2006	
		Euro 4	2006	2011	
Euro 5		2011	2015		

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Vehicle category	Type	Euro Standard	Start Date	End Date	
		Euro 6 a/b/c	2015	2017	
		Euro 6 d-temp	2018	2020	
		Euro 6 d	2021 and later		
Heavy Duty Trucks	All Diesel	Conventional			
		Euro I	1992	1995	
		Euro II	1996	2000	
		Euro III	2000	2005	
		Euro IV	2005	2008	
		Euro V	2008	2013	
		Euro VI A/B/C	2013	2019	
		Euro VI D/E	2019 and later		
L-Category	All Mopeds Mini-cars	Conventional		up to 1999	
		Euro 1	1999	2002	
		Euro 2	2002	2006	
		Euro 3	2006	2016	
		Euro 4	2016	2020	
			Euro 5	2020 and later	
	All Motorcycles	Conventional			up to 1999
		Euro 1	1999	2003	
		Euro 2	2003	2006	
		Euro 3	2006	2013	
		Euro 4	2016	2020	
				Euro 5	2020 and later

2.3.1 Summary of vehicle technologies / control measures

Table 2.2 provides a summary of all vehicle categories and technologies (emission standards) covered by the present methodology.

Table 2-3: Summary of all vehicle classes covered by the methodology

Vehicle category	Type	Euro Standard
Passenger Cars	Petrol Mini	Euro 4
		Euro 5
		Euro 6 a/b/c
		Euro 6 d-temp
		Euro 6 d
	Petrol Small Petrol Medium Petrol Large-SUV-Executive	PRE ECE
		ECE 15/00-01
		ECE 15/02
		ECE 15/03
		ECE 15/04
		Improved Conventional
		Open Loop
		Euro 1
		Euro 2
		Euro 3
		Euro 4

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Vehicle category	Type	Euro Standard
		Euro 5
		Euro 6 a/b/c
		Euro 6 d-temp
		Euro 6 d
	Diesel Mini	Euro 4
		Euro 5
		Euro 6 a/b/c
		Euro 6 d-temp
	Diesel Small Diesel Medium Diesel Large-SUV-Executive	Euro 6 d
		Conventional
		Euro 1
		Euro 2
		Euro 3
		Euro 4
		Euro 5
		Euro 6 a/b/c
	Petrol Hybrid all categories	Euro 6 d-temp
		Euro 6 d
		Euro 4
		Euro 5
	Petrol PHEV all categories	Euro 6 a/b/c
		Euro 6 d-temp
		Euro 6 d
	Diesel PHEV all categories	Euro 6 a/b/c
		Euro 6 d-temp
		Euro 6 d
	LPG Bi-fuel Mini	Euro 4
		Euro 5
		Euro 6 a/b/c
		Euro 6 d-temp
		Euro 6 d
	LPG Bi-fuel Small LPG Bi-fuel Medium LPG Bi-fuel Large-SUV- Executive	Conventional
		Euro 1
		Euro 2
		Euro 3
		Euro 4
		Euro 5
		Euro 6 a/b/c
		Euro 6 d-temp
	CNG Bi-fuel all categories	Euro 6 d
Euro 4		
Euro 5		
Euro 6 a/b/c		
Light Commercial Vehicles	Petrol N1-I Petrol N1-II Petrol N1-III	Euro 6 d-temp
		Euro 6 d
		Conventional
		Euro 1
		Euro 2
		Euro 3
		Euro 4
		Euro 5
		Euro 6 a/b/c
		Euro 6 d-temp
Euro 6 d		

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Vehicle category	Type	Euro Standard
	Diesel N1-I Diesel N1-II Diesel N1-III	Conventional
		Euro 1
		Euro 2
		Euro 3
		Euro 4
		Euro 5
		Euro 6 a/b/c
		Euro 6 d-temp
		Euro 6 d
Heavy Duty Trucks	Petrol >3,5 t	Conventional
	All Rigid/Articulated categories	Conventional
		Euro I
		Euro II
		Euro III
		Euro IV
		Euro V
		Euro VI A/B/C
		Euro VI D/E
Buses	Urban Buses all categories	Conventional
		Euro I
		Euro II
		Euro III
		Euro IV
		Euro V
		Euro VI A/B/C
		Euro VI D/E
	Coaches all categories	Conventional
		Euro I
		Euro II
		Euro III
		Euro IV
		Euro V
		Euro VI A/B/C
		Euro VI D/E
	Urban CNG Buses	Euro I
		Euro II
		Euro III
		EEV
		Euro VI
		Euro VI
	Urban Diesel Hybrid	Euro VI
	Urban Biodiesel Buses	Conventional
Euro I		
Euro II		
Euro III		
Euro IV		
Euro V		
Euro VI A/B/C		
Euro VI D/E		
L-Category	Mopeds all categories	Conventional
		Euro 1
		Euro 2
		Euro 3
		Euro 4
	Euro 5	
	Motorcycles all categories	Conventional
		Euro 1
		Euro 2
		Euro 2
Euro 2		

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Vehicle category	Type	Euro Standard
		Euro 3
		Euro 4
		Euro 5
	Mini-cars	Conventional
		Euro 1
		Euro 2
		Euro 3
		Euro 4
	All Terrain Vehicles (ATVs)	Euro 5
		Conventional
		Euro 1
		Euro 2
		Euro 3
		Euro 4
		Euro 5

Note:

The methodology and emission factors presented in the subsequent chapters can be also applied in countries not following the Euro standards, provided that a correspondence between the national technological classification and European legislation classes can be approximated. This, most probably, will require some assumptions regarding the emission control technology in the vehicle, year of manufacturing/registration of the vehicle and general maintenance level of the operating stock. In some cases, a limited number of emission measurements may be available at the national level. These can be used to classify vehicles in one of the technology classes of this methodology by comparing the emission factors proposed with the emission level of the measured vehicles.

3 Calculation methods

The emission estimation methodology covers exhaust emissions of CO, NO_x, NMVOC, CH₄, CO₂, N₂O, NH₃, SO_x, exhaust PM, PAHs and POPs, dioxins and furans, PCBs, HCB, and heavy metals contained in the fuel and lubricant (lead, arsenic, cadmium, copper, chromium, mercury, nickel, selenium and zinc). NO_x emissions are further split into NO and NO₂. PM is also divided into elemental carbon and organic carbon as a function of vehicle technology. A detailed speciation of NMVOCs is also provided, and this covers homologous series such as alkanes, alkenes, alkynes, aldehydes, ketones and aromatics compounds. PM mass emissions in vehicle exhaust mainly fall in the PM_{2.5} size range. Therefore, all PM mass emission factors are assumed to correspond to PM_{2.5}. Emission factors for particle number and surface are also provided for different particle size ranges.

According to the level of detail available, and the approach adopted for the calculation of emissions, the aforementioned pollutants can be divided into the following four groups:

Group 1: pollutants for which a detailed methodology exists, based on specific emission factors and covering different traffic situations (i.e. urban, rural, highway) and engine conditions. The pollutants included in this group are listed in Table 3-1.

Group 2: emissions of Group 2 pollutants are estimated based on fuel consumption, and the results are of the same quality as those for the pollutants in Group 1. These pollutants are listed in Table 3-2.

Group 3: pollutants for which a simplified methodology is applied, mainly due to the absence of detailed data. This Group contains the pollutants listed in Table 3-3.

Group 4: pollutants which are derived as a fraction of total NMVOC emissions. The small fraction of 'residual' NMVOCs is considered to be PAHs. The speciation of NMVOCs covers the homologous series listed in Table 3-4.

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Table 3-1: Pollutants included in Group 1 and equivalent terms in methodology

Pollutant	Equivalent
Carbon monoxide (CO)	Given as CO
Nitrogen oxides (NO _x : NO and NO ₂)	Given as NO ₂ equivalent
Volatile organic compounds (VOCs)	Given as CH _{1,85} equivalent (also given as HC in emission standards)
Methane (CH ₄)	Given as CH ₄
Non-methane VOCs (NMVOCs)	Given as VOCs (or HC) minus CH ₄
Nitrous oxide (N ₂ O)	Given as N ₂ O
Ammonia (NH ₃)	Given as NH ₃
Particulate matter (PM)	The mass of particles collected on a filter kept below 52 °C during diluted exhaust sampling. This corresponds to total (filterable and condensable) PM _{2.5} . Coarse exhaust PM (i.e. > 2.5 µm diameter) is considered to be negligible, hence PM=PM _{2.5} .
PM number and surface area	Given as particle number and particle active surface per kilometre, respectively

Table 3-2: Pollutants included in Group 2 and equivalent terms in methodology

Pollutant	Equivalent
Carbon dioxide (CO ₂)	Given as CO ₂
Sulphur dioxide (SO ₂)	Given as SO ₂
Lead (Pb)	Given as Pb
Arsenic (As)	Given as As
Cadmium (Cd)	Given as Cd
Chromium (Cr)	Given as Cr
Copper (Cu)	Given as Cu
Mercury (Hg)	Given as Hg
Nickel (Ni)	Given as Ni
Selenium (Se)	Given as Se
Zinc (Zn)	Given as Zn

Table 3-3: Pollutants included in Group 3 and equivalent terms in methodology

Pollutant	Equivalent
Polycyclic aromatic hydrocarbons (PAHs) and persistent organic pollutants (POPs)	Detailed speciation, including indeno(1,2,3-cd) pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(g,h,i)perylene, fluoranthene, benzo(a)pyrene
Polychlorinated dibenzo dioxins (PCDDs) and polychlorinated dibenzo furans (PCDFs)	Given as dioxins and furans respectively
Polychlorinated biphenyls (PCBs) and hexachlorobenzene (HCB)	Given as PCB and HCB respectively

Table 3-4: Pollutants included in Group 4 and equivalent terms in methodology

Pollutant	Equivalent
Alkanes (C _n H _{2n+2}):	Given in alkanes speciation
Alkenes (C _n H _{2n}):	Given in alkenes speciation
Alkynes (C _n H _{2n-2}):	Given in alkynes speciation
Aldehydes (C _n H _{2n} O)	Given in aldehydes speciation
Ketones (C _n H _{2n} O)	Given in ketones speciation
Cycloalkanes (C _n H _{2n})	Given as cycloalkanes
Aromatic compounds	Given in aromatics speciation

3.1 Choice of method

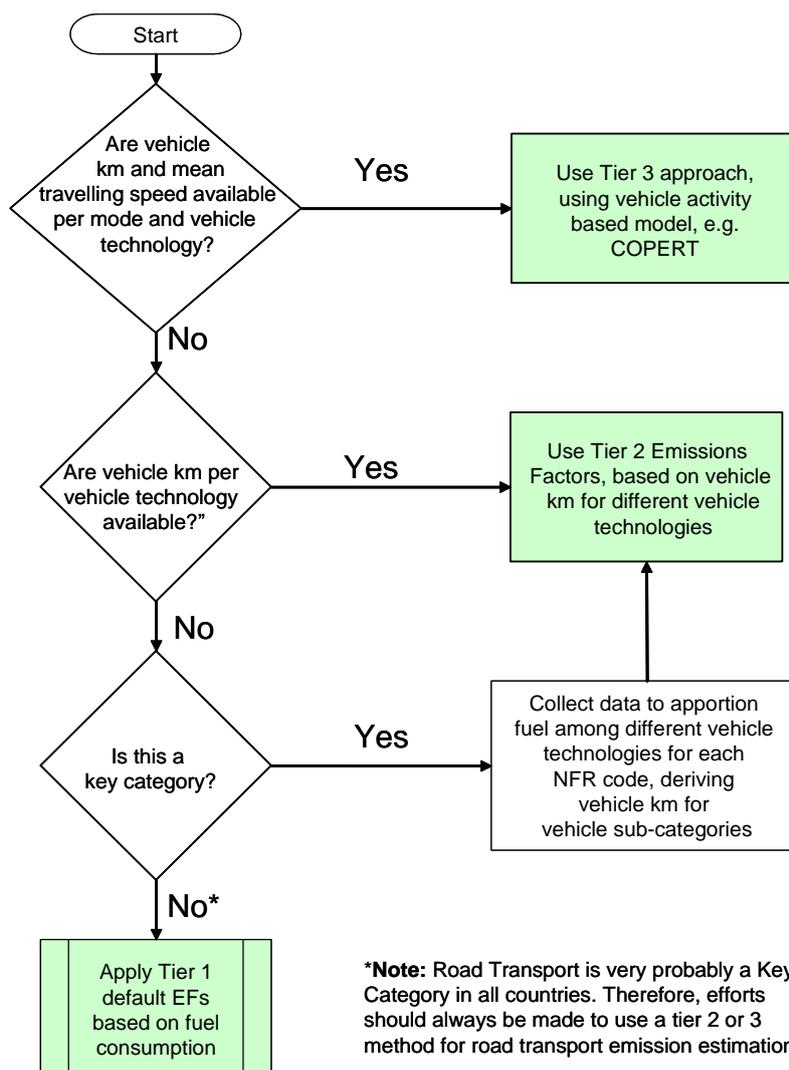
In Figure 3-1 a procedure is presented to enable a method for estimating exhaust emissions from road transport to be selected. This decision tree is applicable to all nations.

The Tier 1 methodology uses fuel as the activity indicator, in combination with average fuel-specific emission factors. It is similar to the Tier 1 methodology described in the IPCC 2006 guidelines, and provides an inventory that is disaggregated according to the four NFR codes for exhaust emissions. It is also similar to the 'simpler methodology' described in previous versions of this Guidebook (Ntziachristos and Kouridis, 2007), except that default emission factors are provided for all nations, with appropriately wide upper and lower values. Country-specific values are provided in Table A1-0-1 to

Table A1-0-31 of Appendix 1.

In practice, road transport is very probably a key category in all countries. Therefore, the Tier 1 method should only be used in the absence of any more detailed information than fuel statistics. Furthermore, in such a situation the country needs to make every effort to collect the detailed statistics required for use with the higher Tier methods, preferably Tier 3.

Figure 3-1: Decision tree for exhaust emissions from road transport



3.2 Tier 1 method

3.2.1 Algorithm

The Tier 1 approach for exhaust emissions uses the following general equation:

$$E_i = \sum_j \left(\sum_m (FC_{j,m} \times EF_{i,j,m}) \right) \quad (1)$$

Where:

E_i	=	emission of pollutant i [g],
$FC_{j,m}$	=	fuel consumption of vehicle category j using fuel m [kg],
$EF_{i,j,m}$	=	fuel consumption-specific emission factor of pollutant i for vehicle category j and fuel m [g/kg].

The vehicle categories to be considered are passenger cars, light commercial vehicles, heavy-duty vehicles and L-category vehicles. The fuels to be considered include petrol, diesel, LPG and natural gas.

This equation requires the fuel consumption/sales statistics to be split by vehicle category, as national statistics do not provide vehicle category details. Guidance on splitting fuel consumption/sales for Tier 1 is provided in subsection 3.2.3.

3.2.2 Tier 1 emission factors

The Tier 1 emission factors ($EF_{i,j,m}$) have been calculated based on the Tier 3 method, assuming a typical EU-15 fleet and activity data for 1995, taken from [EC4MACS](http://www.ec4macs.eu) - www.ec4macs.eu), so as to be applicable to countries with older vehicle fleets. The emission factors are given in Table 3-5 to

Table 3-12. The lead emission factors originate from the Danish heavy metal inventory by Winther and Slentø (2010).

However, a consequence of this approach, in the context of the legislative emission requirements for more modern vehicles, is that the Tier 1 emission factors will give somewhat higher emission values than a Tier 2 or 3 methodology for countries whose fleet comprises vehicles which comply with more recent (i.e. Euro 2 / Euro II and later) emission standards.

In Table 3-5 to

Table 3-9, the maximum values correspond to uncontrolled vehicle technology, and the minimum values correspond to a European average in 2005 (before the introduction of Euro 4). Table 3-11 proposes black carbon (BC) fractions of PM.

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
 Passenger cars, light commercial trucks, heavy-duty vehicles including
 buses and motor cycles

Table 3-5: Tier 1 emission factors for CO and NMVOCs

Category	Fuel	CO			NMVOC		
		(g/kg fuel)			(g/kg fuel)		
		Mean	Min	Max	Mean	Min	Max
PC	Petrol	84.7	49.0	269.5	10.05	5.55	34.42
	Diesel	3.33	2.05	8.19	0.70	0.41	1.88
	LPG	84.7	38.7	117.0	13.64	6.10	25.66
LCV	Petrol	152.3	68.7	238.3	14.59	3.91	26.08
	Diesel	7.40	6.37	11.71	1.54	1.29	1.96
HDV	Diesel	7.58	5.73	10.57	1.92	1.33	3.77
	CNG (Buses)	5.70	2.20	15.00	0.26	0.10	0.67
L-category	Petrol	497.7	331.2	664.5	131.4	30.0	364.8

**Passenger cars, light commercial trucks, heavy-duty vehicles including
buses and motor cycles**

Table 3-6: Tier 1 emission factors for NO_x and PM

Category	Fuel	NO _x			PM		
		(g/kg fuel)			(g/kg fuel)		
		Mean	Min	Max	Mean	Min	Max
PC	Petrol	8.73	4.48	29.89	0.03	0.02	0.04
	Diesel	12.96	11.20	13.88	1.10	0.80	2.64
	LPG	15.20	4.18	34.30	0.00	0.00	0.00
LCV	Petrol	13.22	3.24	25.46	0.02	0.02	0.03
	Diesel	14.91	13.36	18.43	1.52	1.10	2.99
HDV	Diesel	33.37	28.34	38.29	0.94	0.61	1.57
	CNG (Buses)	13.00	5.50	30.00	0.02	0.01	0.04
L-category	Petrol	6.64	1.99	10.73	2.20	0.55	6.02

Table 3-7: Tier 1 emission factors for N₂O and NH₃

Category	Fuel	N ₂ O			NH ₃		
		(g/kg fuel)			(g/kg fuel)		
		Mean	Min	Max	Mean	Min	Max
PC	Petrol	0.206	0.133	0.320	1.106	0.330	1.444
	Diesel	0.087	0.044	0.107	0.065	0.024	0.082
	LPG	0.089	0.024	0.202	0.080	0.022	0.108
LCV	Petrol	0.186	0.103	0.316	0.667	0.324	1.114
	Diesel	0.056	0.025	0.072	0.038	0.018	0.056
HDV	Diesel	0.051	0.030	0.089	0.013	0.010	0.018
	CNG (Buses)	n.a.	0.000	0.000	n.a.	0.000	0.000
L-category	Petrol	0.059	0.048	0.067	0.059	0.048	0.067

Table 3-8: Tier 1 emission factors for ID(1,2,3-cd)P and B(k)F

Category	Fuel	ID(1,2,3-cd)P			B(k)F		
		(g/kg fuel)			(g/kg fuel)		
		Mean	Min	Max	Mean	Min	Max
PC	Petrol	8.90E ⁻⁰⁶	5.90E ⁻⁰⁶	1.33E ⁻⁰⁵	3.90E ⁻⁰⁶	3.90E ⁻⁰⁶	3.90E ⁻⁰⁶
	Diesel	2.12E ⁻⁰⁵	1.11E ⁻⁰⁵	4.05E ⁻⁰⁵	1.18E ⁻⁰⁵	3.00E ⁻⁰⁶	4.58E ⁻⁰⁵
	LPG	2.00E ⁻⁰⁷					
LCV	Petrol	6.90E ⁻⁰⁶	3.90E ⁻⁰⁶	1.21E ⁻⁰⁵	3.00E ⁻⁰⁶	2.60E ⁻⁰⁶	3.50E ⁻⁰⁶
	Diesel	1.58E ⁻⁰⁵	8.70E ⁻⁰⁶	2.84E ⁻⁰⁵	8.70E ⁻⁰⁶	2.40E ⁻⁰⁶	3.21E ⁻⁰⁵
HDV	Diesel	7.90E ⁻⁰⁶	7.30E ⁻⁰⁶	8.6E ⁻⁰⁶	3.44E ⁻⁰⁵	3.18E ⁻⁰⁵	3.72E ⁻⁰⁵
	CNG (Buses)	n.a.			n.a.		
L-category	Petrol	1.02E ⁻⁰⁵	1.00E ⁻⁰⁵	1.04E ⁻⁰⁵	6.80E ⁻⁰⁶	6.70E ⁻⁰⁶	7.00E ⁻⁰⁶

**Passenger cars, light commercial trucks, heavy-duty vehicles including
buses and motor cycles**

Table 3-9: Tier 1 emission factors for B(b)F and B(a)P

Category	Fuel	B(b)F			B(a)P		
		(g/kg fuel)			(g/kg fuel)		
		Mean	Min	Max	Mean	Min	Max
PC	Petrol	7.90E ⁻⁰⁶	5.40E ⁻⁰⁶	1.14E ⁻⁰⁵	5.50E ⁻⁰⁶	4.80E ⁻⁰⁶	6.20E ⁻⁰⁶
	Diesel	2.24E ⁻⁰⁵	9.60E ⁻⁰⁶	5.26E ⁻⁰⁵	2.14E ⁻⁰⁵	1.00E ⁻⁰⁵	4.55E ⁻⁰⁵
	LPG				2.00E ⁻⁰⁷	2.00E ⁻⁰⁷	2.00E ⁻⁰⁷
LCV	Petrol	6.10E ⁻⁰⁶	3.60E ⁻⁰⁶	1.03E ⁻⁰⁵	4.20E ⁻⁰⁶	3.20E ⁻⁰⁶	5.60E ⁻⁰⁶
	Diesel	1.66E ⁻⁰⁵	7.50E ⁻⁰⁶	3.69E ⁻⁰⁵	1.58E ⁻⁰⁵	7.90E ⁻⁰⁶	3.19E ⁻⁰⁵
HDV	Diesel	3.08E ⁻⁰⁵	2.84E ⁻⁰⁵	3.33E ⁻⁰⁵	5.10E ⁻⁰⁶	4.70E ⁻⁰⁶	5.50E ⁻⁰⁶
	CNG (Buses)	n.a			n.a		
L-category	Petrol	9.40E ⁻⁰⁶	9.20E ⁻⁰⁶	9.60E ⁻⁰⁶	8.40E ⁻⁰⁶	8.20E ⁻⁰⁶	8.60E ⁻⁰⁶

Table 3-10: Tier 1 emission factors for lead (Pb)

Category	Fuel	Pb		
		(g/kg fuel)		
		Mean	Min	Max
PC	Petrol	3.30E ⁻⁰⁵	1.70E ⁻⁰⁵	2.00E ⁻⁰⁴
	Diesel	5.20E ⁻⁰⁵	1.60E ⁻⁰⁵	1.94E ⁻⁰⁴
	LPG	n.a		
LCV	Petrol	3.30E ⁻⁰⁵	1.70E ⁻⁰⁵	2.00E ⁻⁰⁴
	Diesel	5.20E ⁻⁰⁵	1.60E ⁻⁰⁵	1.94E ⁻⁰⁴
HDV	Diesel	5.20E ⁻⁰⁵	1.60E ⁻⁰⁵	1.94E ⁻⁰⁴
	CNG (Buses)	n.a		
L-category	Petrol	3.30E ⁻⁰⁵	1.70E ⁻⁰⁵	2.00E ⁻⁰⁴

Table 3-11: Tier 1 BC fractions of PM

Vehicle category	f-BC
Petrol passenger cars	0.12
Petrol light duty vehicles	0.05
Diesel passenger cars	0.57
Diesel light duty vehicles	0.55
Diesel heavy duty vehicles	0.53
Petrol L-category	0.11

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

Table 3-12: Tier 1 CO₂ emission factors for different road transport fossil fuels

Subsector units	Fuel	kg CO ₂ per kg of fuel ¹
All vehicle types	Petrol	3.169
All vehicle types	Diesel	3.169
All vehicle types	LPG ²	3.024
All vehicle types	CNG ³ (or LNG)	2.743
All vehicle types	E5 ⁴	3.063
All vehicle types	E10 ⁴	2.964
All vehicle types	E85 ⁴	2.026
All vehicle types	ETBE11 ⁵	3.094
All vehicle types	ETBE22 ⁵	3.021

Notes:

¹ CO₂ emission factors are based on an assumed 100% oxidation of the fuel carbon (ultimate CO₂).² LPG assumed to be 50% propane + 50% butane.³ CNG and LNG assumed to be 100% methane.⁴ E5, E10 and E85 blends assumed to consist of 5, 10 and 85% vol. respectively ethanol (bio-ethanol or synthetic ethanol) and 95, 90 and 15% respectively petrol.⁵ ETBE11 and ETBE22 blends assumed to consist of 11 and 22% vol. respectively ETBE and 89 and 78% respectively petrol.**Table 3-13: Tier 1 CO₂ emission factors from combustion of lubricant oil¹**

Category	Fuel	CO ₂ from lubricant (g/kg fuel)		
		Mean	Min	Max
		PC	Petrol	8.84
Diesel	8.74		8.01	11.3
LPG	8.84		7.83	9.89
LCV	Petrol	6.07	4.76	7.28
	Diesel	6.41	5.41	7.72
HDV	Diesel	2.54	1.99	3.32
	CNG (Buses)	3.31	3.09	3.50
L-category	Petrol	53.8	33.3	110

Note: ¹ These emission factors assume typical consumption values for lubricant oil used in automotive applications.

The emissions of SO₂ per fuel-type *m* are estimated by assuming that all sulphur in the fuel is transformed completely into SO₂, using the formula:

$$E_{SO_2,m} = 2 \times k_{s,m} \times FC_m \quad (2)$$

where:

E_{SO₂,m} = emissions of SO₂ per fuel *m* [g],k_{s,m} = weight related sulphur content in fuel of type *m* [g/g fuel],FC_m = fuel consumption of fuel *m* [g].

Typical values for fuel sulphur content are given below for the periods before mandatory improved fuel specifications, following the first improvement in fuel specification (January 2000 = Fuel 2000), the second (January 2005 = Fuel 2005) and the regulation of fuel sulphur to maximum 10 ppm by January

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

2009 (Fuel 2009). Again, typical emission factors for Tier 1 for a number of countries can be found in Appendix 1.

Table 3-14: Tier 1 — Typical sulphur content of fuel (1 ppm = 10⁻⁶ g/g fuel)

Fuel	1996 Base fuel (Market average)	Fuel 2000	Fuel 2005	Fuel 2009 and later
Petrol	165 ppm	130 ppm	40 ppm	5 ppm
Diesel	400 ppm	300 ppm	40 ppm	3 ppm

3.2.3 Activity data

The Tier 1 approach requires relevant fuel statistics, i.e. the volumes (or weights) of fuel sold for road transport use, and for each type of fuel used.

For the majority of fuels (petrol, diesel, LPG) these statistics are usually available at a national level. However, for slow-fill CNG vehicles (often filled from the natural gas grid), data could be more challenging to obtain and estimations may need to be made. However, for most countries this is probably a negligible contribution to road transport consumption and emissions at present.

The Tier 1 methodology also requires that the fuel sales are disaggregated according to the four vehicle categories. Hence, the inventory compiler should also make sure when using the Tier 1 algorithm that the total amount of each type of fuel sold is equal to the sum of the fuel consumed by the different vehicle categories, i.e.:

$$FC_m = \sum_j (FC_{j,m}) \quad (3)$$

Table 3-15 shows which fuel types are used in which vehicle categories.

The basis for this disaggregation may be the nation's vehicle statistics combined with estimates of annual usage, such as km driven, and fuel consumption (kg/km) for the different vehicle categories.

Table 3-15: Tier 1 — Typical fuel consumption figures, per km, by category of vehicle

Vehicle category (j)	Fuel	Typical fuel consumption (g/km)
Passenger cars	Petrol	70
	Diesel	60
	LPG	57.5
	E85	86.5
	CNG	62.6
LCV	Petrol	100
	Diesel	80
HDV	Diesel	240
	CNG (buses)	500
L-category	Petrol	35

A more detailed approach for estimating the fuel consumption split by vehicle category is provided in Tier 3 methodology.

3.3 Tier 2 method

3.3.1 Algorithm

The Tier 2 approach considers the fuel used by different vehicle categories and their emission standards. Hence, the four broad vehicle categories used in the Tier 1 approach to describe the four NFR codes are sub-divided into different technologies *k* according to emission-control legislation (see Table 3-16).

Table 3-16: Summary of all vehicle classes covered by the Tier 2 methodology

Vehicle category (j)	Type	Legislation/technology (k)
Passenger cars	Petrol Mini	Euro 4, Euro 5, Euro 6
	Petrol Small, Medium, Large-SUV-Executive	PRE ECE, ECE 15/00-01, ECE 15/02, ECE 15/03, ECE 15/04, Improved Conventional, Open-Loop, Euro 1 – Euro 6
	Diesel Mini	Euro 4 - Euro 6
	Diesel Small, Medium, Large-SUV-Executive	Conventional, Euro 1 – Euro 6
	LPG Mini	Euro 4 - Euro 6
	LPG Small, Medium, Large-SUV-Executive	Conventional, Euro 1 – Euro 6
	2-stroke	Conventional
	Petrol Hybrids	Euro 4 - Euro 6
	Petrol PHEV	Euro 6 up to 2016 – Euro 6
	Diesel PHEV	Euro 5 - Euro 6
	CNG	Euro 4, Euro 5, Euro 6
Light commercial vehicles	Petrol	Conventional, Euro 1 – Euro 6
	Diesel	Conventional, Euro 1 – Euro 6
Heavy-duty vehicles	Petrol and Diesel	Conventional, Euro I - Euro VI
Buses	Urban CNG buses	Euro I, Euro II, Euro III, EEV
	Urban buses, Coaches	Conventional, Euro I - Euro VI
	Urban Diesel Hybrid	Euro VI
	Urban biodiesel buses	Conventional, Euro I - Euro VI
Mopeds	2-stroke < 50 cm ³	Conventional, Euro 1 - Euro 5
	4-stroke < 50 cm	
Motorcycles	2-stroke > 50 cm ³	Conventional, Euro 1 - Euro 5
	4-stroke 50–250 cm ³	Conventional, Euro 1 - Euro 5
	4-stroke 250–750 cm ³	Conventional, Euro 1 - Euro 5
	4-stroke > 750 cm ³	Conventional, Euro 1 - Euro 5
Mini-cars	Diesel	Conventional, Euro 1 - Euro 5
ATVs	Petrol	Conventional, Euro 1 - Euro 5

Therefore, the user needs to provide the number of vehicles and the annual mileage per technology (or the number of vehicle-km per technology). These vehicle-km data are multiplied by the Tier 2 emission factors.

Hence, the algorithm used is:

$$E_{ij} = \sum_k (<M_{j,k}> \times EF_{i,j,k}) \quad (4)$$

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
**Passenger cars, light commercial trucks, heavy-duty vehicles including
buses and motor cycles**

or

$$E_{i,j} = \sum_k (N_{j,k} \times M_{j,k} \times EF_{i,j,k}) \quad (5)$$

where,

- <M_{j,k}> = total annual distance driven by all vehicles of category *j* and technology *k* [veh-km],
- EF_{i,j,k} = technology-specific emission factor of pollutant *i* for vehicle category *j* and technology *k* [g/veh-km],
- M_{j,k} = average annual distance driven per vehicle of category *j* and technology *k* [km/veh],
- N_{j,k} = number of vehicles in nation's fleet of category *j* and technology *k*.

It is repeated that the vehicle categories *j* are passenger cars, light commercial vehicles, heavy-duty vehicles and L-category vehicles. The vehicle technologies *k* were given in Table 3-16.

3.3.2 Emission factors

The Tier 2 emission factors are stated in units of grammes per vehicle-kilometre, and for each vehicle technology are given Table 3-16. These average European emission factors were determined using the Tier 3 methodology which follows in using typical values for driving speeds, ambient temperatures, highway-rural-urban mode mix, trip length, etc.

The following Tables contain technology- and fuel-specific emission factors for CO, NMVOC, NO_x, N₂O, NH₃, Pb, PM (considered to be PM_{2.5}), four PAHs, and CO₂ from the combustion of lube oil. For information of BC fractions of PM, the values of Table 3-102 can be used. A figure for fuel consumption (g/km) is provided, derived from carbon balance, so that fuel-based pollutants (SO₂, As, Cr, Cu, Ni, Se, Zn, Cd, and Hg) can be calculated using the Tier 1 emission factors (mass of pollutant per mass of fuel used).

It is worth noting here that the Tier 3 methodology enables emissions to be calculated for a wider range of HDV weight categories. For Tier 2 inventories, interpolation between the neighbouring weight classes should be used to cover the whole weight range.

Table 3-17: Tier 2 exhaust emission factors for passenger cars, NFR 1.A.3.b.i

Type	Technology	CO	NMVOC	NO _x	N ₂ O	NH ₃	Pb	CO ₂ lube
Units		g/km	g/km	g/km	g/km	g/km	g/km	g/km
Notes			Given as THC-CH4	Given as NO ₂ equivalent				due to lube oil
Petrol Mini	Euro 4 - 98/69/EC II	0.67	0.048	0.056	0.002	0.0339	1.82E-05	0.398
	Euro 5 - EC 715/2007	0.67	0.048	0.056	0.0013	0.0123	1.82E-05	0.398
	Euro 6 a/b/c	0.67	0.048	0.056	0.0013	0.0123	1.82E-05	0.398
	Euro 6 d-temp	0.67	0.048	0.056	0.0013	0.0123	1.82E-05	0.398
	Euro 6 d	0.67	0.048	0.056	0.0013	0.0123	1.82E-05	0.398
Petrol Small	PRE ECE	37.3	2.77	1.91	0.01	0.0020	1.82E-05	0.663
	ECE 15/00-01	29.6	2.19	1.91	0.01	0.0020	1.82E-05	0.663
	ECE 15/02	21.7	2.06	2.12	0.01	0.0020	1.82E-05	0.663
	ECE 15/03	21.1	2.06	2.30	0.01	0.0020	1.82E-05	0.663
	ECE 15/04	13.1	1.68	2.07	0.01	0.0020	1.82E-05	0.663
	Open Loop	11.3	0.96	1.53	0.01	0.0020	1.82E-05	0.663
	Euro 1 - 91/441/EEC	4.88	0.467	0.426	0.01	0.0922	1.82E-05	0.596
	Euro 2 - 94/12/EEC	2.42	0.206	0.229	0.006	0.1043	1.82E-05	0.530
	Euro 3 - 98/69/EC I	2.07	0.089	0.090	0.002	0.0342	1.82E-05	0.464
	Euro 4 - 98/69/EC II	0.69	0.048	0.056	0.002	0.0341	1.82E-05	0.398
	Euro 5 - EC 715/2007	0.69	0.048	0.056	0.0013	0.0123	1.82E-05	0.398
	Euro 6 a/b/c	0.69	0.048	0.056	0.0013	0.0123	1.82E-05	0.398

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	Euro 6 d-temp	0.69	0.048	0.056	0.0013	0.0123	1.82E-05	0.398
	Euro 6 d	0.69	0.048	0.056	0.0013	0.0123	1.82E-05	0.398
Petrol Medium	PRE ECE	37.3	2.8	2.53	0.01	0.0020	1.82E-05	0.663
	ECE 15/00-01	29.6	2.19	2.53	0.01	0.0020	1.82E-05	0.663
	ECE 15/02	21.7	2.060	2.40	0.01	0.0020	1.82E-05	0.663
	ECE 15/03	21.1	2.06	2.51	0.01	0.0020	1.82E-05	0.663
	ECE 15/04	13.4	1.68	2.66	0.01	0.0020	1.82E-05	0.663
	Open Loop	6.49	0.29	1.29	0.01	0.0020	1.82E-05	0.663
	Euro 1 - 91/441/EEC	3.92	0.530	0.485	0.01	0.0922	1.82E-05	0.596
	Euro 2 - 94/12/EEC	2.04	0.251	0.255	0.006	0.1043	1.82E-05	0.530
	Euro 3 - 98/69/EC I	1.82	0.119	0.097	0.002	0.0342	1.82E-05	0.464
	Euro 4 - 98/69/EC II	0.62	0.065	0.061	0.002	0.0342	1.82E-05	0.398
	Euro 5 - EC 715/2007	0.62	0.065	0.061	0.0013	0.0123	1.82E-05	0.398
	Euro 6 a/b/c	0.62	0.065	0.061	0.0013	0.0123	1.82E-05	0.398
	Euro 6 d-temp	0.62	0.065	0.061	0.0013	0.0123	1.82E-05	0.398
	Euro 6 d	0.62	0.065	0.061	0.0013	0.0123	1.82E-05	0.398
Petrol Large-SUV-Executive	PRE ECE	37.3	2.77	3.9	0.01	0.0020	1.82E-05	0.663
	ECE 15/00-01	29.6	2.19	3.9	0.01	0.0020	1.82E-05	0.663
	ECE 15/02	21.7	2.1	2.70	0.01	0.0020	1.82E-05	0.663
	ECE 15/03	21.1	2.1	3.52	0.01	0.0020	1.82E-05	0.663
	ECE 15/04	13.4	1.679	2.9	0.01	0.0020	1.82E-05	0.663
	Euro 1 - 91/441/EEC	3.41	0.43	0.467	0.011	0.0922	1.82E-05	0.596
	Euro 2 - 94/12/EEC	1.67	0.196	0.242	0.006	0.1043	1.82E-05	0.530
	Euro 3 - 98/69/EC I	1.50	0.088	0.091	0.002	0.0342	1.82E-05	0.464
	Euro 4 - 98/69/EC II	0.53	0.048	0.059	0.002	0.0343	1.82E-05	0.398
	Euro 5 - EC 715/2007	0.53	0.048	0.059	0.0013	0.0123	1.82E-05	0.398
	Euro 6 a/b/c	0.53	0.048	0.059	0.0013	0.0123	1.82E-05	0.398
	Euro 6 d-temp	0.53	0.048	0.059	0.0013	0.0123	1.82E-05	0.398
	Euro 6 d	0.53	0.048	0.059	0.0013	0.0123	1.82E-05	0.398
	Euro 4 - 98/69/EC II	0.092	0.014	0.58	0.01	0.0010	1.82E-05	0.398
Diesel Small	Euro 5 - EC 715/2007	0.049	0.010	0.55	0.004	0.0019	1.82E-05	0.398
	Euro 6 a/b/c	0.040	0.010	0.45	0.004	0.0019	1.82E-05	0.398
	Euro 6 d-temp	0.040	0.010	0.35	0.004	0.0019	1.82E-05	0.398
	Euro 6 d	0.040	0.010	0.17	0.004	0.0019	1.82E-05	0.398
Diesel Medium	Conventional	0.688	0.159	0.546	0.00	0.0010	1.82E-05	0.663
	Euro 1 - 91/441/EEC	0.414	0.047	0.690	0.003	0.0010	1.82E-05	0.596
	Euro 2 - 94/12/EEC	0.296	0.035	0.716	0.005	0.0010	1.82E-05	0.530
	Euro 3 - 98/69/EC I	0.089	0.02	0.773	0.007	0.0010	1.82E-05	0.464
	Euro 4 - 98/69/EC II	0.092	0.014	0.58	0.01	0.0010	1.82E-05	0.398
	Euro 5 - EC 715/2007	0.040	0.0080	0.55	0.004	0.0019	1.82E-05	0.398
	Euro 6 up to 2016	0.049	0.0080	0.45	0.004	0.0019	1.82E-05	0.398
	Euro 6 2017-2019	0.049	0.0080	0.35	0.004	0.0019	1.82E-05	0.398
	Euro 6 2020+	0.049	0.0080	0.17	0.004	0.0019	1.82E-05	0.398
Diesel Large-SUV-Executive	Conventional	0.688	0.159	0.87	0.00	0.0010	1.82E-05	0.663
	Euro 1 - 91/441/EEC	0.414	0.070	0.690	0.003	0.0010	1.82E-05	0.596
	Euro 2 - 94/12/EEC	0.296	0.10	0.716	0.005	0.0010	1.82E-05	0.530
	Euro 3 - 98/69/EC I	0.089	0.037	0.77	0.01	0.0010	1.82E-05	0.464
	Euro 4 - 98/69/EC II	0.092	0.014	0.58	0.01	0.0010	1.82E-05	0.398
	Euro 5 - EC 715/2007	0.040	0.0080	0.55	0.004	0.0019	1.82E-05	0.398
	Euro 6 a/b/c	0.049	0.0080	0.45	0.004	0.0019	1.82E-05	0.398
	Euro 6 d-temp	0.049	0.0080	0.35	0.004	0.0019	1.82E-05	0.398
	Euro 6 d	0.049	0.0080	0.17	0.004	0.0019	1.82E-05	0.398
LPG	Conventional	6.832	1.05	2.36	0.00	0.0020	1.82E-05	0.663
	Euro 1 - 91/441/EEC	3.57	0.723	0.414	0.02	0.0880	1.82E-05	0.596
	Euro 2 - 94/12/EEC	2.48	0.342	0.180	0.008	0.1007	1.82E-05	0.530
	Euro 3 - 98/69/EC I	1.79	0.120	0.090	0.004	0.0338	1.82E-05	0.464
	Euro 4 - 98/69/EC II	0.62	0.10	0.056	0.004	0.0338	1.82E-05	0.398
	Euro 5 - EC 715/2007	0.62	0.10	0.056	0.004	0.0338	1.82E-05	0.398
	Euro 6 - EC 715/2007	0.62	0.10	0.056	0.004	0.0338	1.82E-05	0.398
2-Stroke	Conventional	11.4	8.9	0.730	0.005	0.0015	1.82E-05	na
Hybrid Petrol Small	Euro 4 and later	0.042	0.001	0.013	0.0002	0.0328	1.82E-05	0.398
Hybrid Petrol Medium	Euro 4 and later	0.043	0.001	0.013	0.0002	0.0327	1.82E-05	0.398
Hybrid Petrol Large	Euro 4 and later	0.043	0.001	0.013	0.0002	0.0327	1.82E-05	0.398
PHEV Petrol Small	Euro 6 and later	0.042	0.001	0.013	0.0002	0.0328	1.82E-05	0.398
PHEV Petrol Medium	Euro 6 and later	0.043	0.001	0.013	0.0002	0.0327	1.82E-05	0.398
PHEV Petrol Large	Euro 6 and later	0.043	0.001	0.013	0.0002	0.0327	1.82E-05	0.398

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

PHEV Diesel Large	Euro 5 and later	0.049	0.0080	0.45	0.004	0.0019	1.82E-05	0.398
E85	Euro 4 and later	0.459	0.062	0.053	0.002	0.0339	1.82E-05	0.398
CNG	Euro 4 and later	0.616	0.035	0.056	0.001	0.0338	1.82E-05	0.398

Table 3-18: Tier 2 exhaust emission factors for passenger cars, NFR 1.A.3.b.i

Type	Technology	PM2.5	ID(1,2,3,cd)P	B(k)F	B(b)F	B(a)P	
Units		g/km	g/km	g/km	g/km	g/km	
Notes		PM2.5=PM10-TSP					
Petrol Mini	Euro 4 - 98/69/EC II	0.0011	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
	Euro 5 - EC 715/2007	0.0014	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
	Euro 6 a/b/c	0.0014	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
	Euro 6 d-temp	0.0016	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
	Euro 6 d	0.0016	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
Petrol Small	PRE ECE	0.0022	1.03E-06	3.00E-07	8.80E-07	4.80E-07	
	ECE 15/00-01	0.0022	1.03E-06	3.00E-07	8.80E-07	4.80E-07	
	ECE 15/02	0.0022	1.03E-06	3.00E-07	8.80E-07	4.80E-07	
	ECE 15/03	0.0022	1.03E-06	3.00E-07	8.80E-07	4.80E-07	
	ECE 15/04	0.0022	1.03E-06	3.00E-07	8.80E-07	4.80E-07	
	Open Loop	0.0022	1.03E-06	3.00E-07	8.80E-07	4.80E-07	
	Euro 1 - 91/441/EEC	0.0022	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
	Euro 2 - 94/12/EEC	0.0022	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
	Euro 3 - 98/69/EC I	0.0011	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
	Euro 4 - 98/69/EC II	0.0011	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
	Euro 5 - EC 715/2007	0.0014	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
	Euro 6 a/b/c	0.0014	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
	Euro 6 d-temp	0.0016	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
	Euro 6 d	0.0016	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
	Petrol Medium	PRE ECE	0.0022	1.03E-06	3.00E-07	8.80E-07	4.80E-07
ECE 15/00-01		0.0022	1.03E-06	3.00E-07	8.80E-07	4.80E-07	
ECE 15/02		0.0022	1.03E-06	3.00E-07	8.80E-07	4.80E-07	
ECE 15/03		0.0022	1.03E-06	3.00E-07	8.80E-07	4.80E-07	
ECE 15/04		0.0022	1.03E-06	3.00E-07	8.80E-07	4.80E-07	
Open Loop		0.0022	1.03E-06	3.00E-07	8.80E-07	4.80E-07	
Euro 1 - 91/441/EEC		0.0022	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
Euro 2 - 94/12/EEC		0.0022	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
Euro 3 - 98/69/EC I		0.0011	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
Euro 4 - 98/69/EC II		0.0011	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
Euro 5 - EC 715/2007		0.0014	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
Euro 6 a/b/c		0.0014	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
Euro 6 d-temp		0.0016	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
Euro 6 d		0.0016	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
Petrol Large-SUV-Executive		PRE ECE	0.0022	1.03E-06	3.00E-07	8.80E-07	4.80E-07
	ECE 15/00-01	0.0022	1.03E-06	3.00E-07	8.80E-07	4.80E-07	
	ECE 15/02	0.0022	1.03E-06	3.00E-07	8.80E-07	4.80E-07	
	ECE 15/03	0.0022	1.03E-06	3.00E-07	8.80E-07	4.80E-07	
	ECE 15/04	0.0022	1.03E-06	3.00E-07	8.80E-07	4.80E-07	
	Euro 1 - 91/441/EEC	0.0022	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
	Euro 2 - 94/12/EEC	0.0022	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
	Euro 3 - 98/69/EC I	0.0011	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
	Euro 4 - 98/69/EC II	0.0011	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
	Euro 5 - EC 715/2007	0.0014	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
	Euro 6 a/b/c	0.0014	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
	Euro 6 d-temp	0.0016	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
	Euro 6 d	0.0016	3.90E-07	2.60E-07	3.60E-07	3.20E-07	
	Diesel Small	Euro 4 - 98/69/EC II	0.0314	1.62E-06	1.53E-06	1.95E-06	1.74E-06
		Euro 5 - EC 715/2007	0.0021	1.62E-06	1.53E-06	1.95E-06	1.74E-06
Euro 6 a/b/c		0.0015	1.62E-06	1.53E-06	1.95E-06	1.74E-06	
Euro 6 d-temp		0.0015	1.62E-06	1.53E-06	1.95E-06	1.74E-06	
Euro 6 d		0.0015	1.62E-06	1.53E-06	1.95E-06	1.74E-06	
Diesel Medium	Conventional	0.2209	1.62E-06	1.53E-06	1.95E-06	1.74E-06	
	Euro 1 - 91/441/EEC	0.0842	1.62E-06	1.53E-06	1.95E-06	1.74E-06	
	Euro 2 - 94/12/EEC	0.0548	1.62E-06	1.53E-06	1.95E-06	1.74E-06	
	Euro 3 - 98/69/EC I	0.0391	1.62E-06	1.53E-06	1.95E-06	1.74E-06	
	Euro 4 - 98/69/EC II	0.0314	1.62E-06	1.53E-06	1.95E-06	1.74E-06	
	Euro 5 - EC 715/2007	0.0021	1.62E-06	1.53E-06	1.95E-06	1.74E-06	
	Euro 6 a/b/c	0.0015	1.62E-06	1.53E-06	1.95E-06	1.74E-06	
	Euro 6 d-temp	0.0015	1.62E-06	1.53E-06	1.95E-06	1.74E-06	
Diesel Large-SUV-Executive	Conventional	0.2209	1.62E-06	1.53E-06	1.95E-06	1.74E-06	
	Euro 1 - 91/441/EEC	0.0842	1.62E-06	1.53E-06	1.95E-06	1.74E-06	
	Euro 2 - 94/12/EEC	0.0548	1.62E-06	1.53E-06	1.95E-06	1.74E-06	

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

	Euro 3 - 98/69/EC I	0.0391	1.62E-06	1.53E-06	1.95E-06	1.74E-06
	Euro 4 - 98/69/EC II	0.0314	1.62E-06	1.53E-06	1.95E-06	1.74E-06
	Euro 5 - EC 715/2007	0.0021	1.62E-06	1.53E-06	1.95E-06	1.74E-06
	Euro 6 a/b/c	0.0015	1.62E-06	1.53E-06	1.95E-06	1.74E-06
	Euro 6 d-temp	0.0015	1.62E-06	1.53E-06	1.95E-06	1.74E-06
	Euro 6 d	0.0015	1.62E-06	1.53E-06	1.95E-06	1.74E-06
LPG	Conventional	0.0022	1.00E-08	1.00E-08	0.00E+00	1.00E-08
	Euro 1 - 91/441/EEC	0.0022	1.00E-08	1.00E-08	0.00E+00	1.00E-08
	Euro 2 - 94/12/EEC	0.0022	1.00E-08	1.00E-08	0.00E+00	1.00E-08
	Euro 3 - 98/69/EC I	0.0011	1.00E-08	1.00E-08	0.00E+00	1.00E-08
	Euro 4 - 98/69/EC II	0.0011	1.00E-08	1.00E-08	0.00E+00	1.00E-08
2-Stroke	Conventional	n.a.	1.03E-06	3.00E-07	8.80E-07	4.80E-07
Hybrid Petrol Small	Euro 4 - 98/69/EC II	n.a.	3.9E-07	2.60E-07	3.60E-07	3.20E-07
Hybrid Petrol Medium	Euro 4 - 98/69/EC II	n.a.	3.9E-07	2.60E-07	3.60E-07	3.20E-07
Hybrid Petrol Large	Euro 4 - 98/69/EC II	n.a.	3.9E-07	2.60E-07	3.60E-07	3.20E-07
PHEV Petrol Small	Euro 6 and later	n.a.	3.9E-07	2.60E-07	3.60E-07	3.20E-07
PHEV Petrol Medium	Euro 6 and later	n.a.	3.9E-07	2.60E-07	3.60E-07	3.20E-07
PHEV Petrol Large	Euro 6 and later	n.a.	3.9E-07	2.60E-07	3.60E-07	3.20E-07
PHEV Diesel Large	Euro 5 and later	0.0015	1.62E-06	1.53E-06	1.95E-06	1.74E-06
E85	Euro 4 - 98/69/EC II	0.0011	3.90E-07	2.60E-07	3.60E-07	3.20E-07
CNG	Euro 4 - 98/69/EC II	0.0011	3.90E-07	2.60E-07	3.60E-07	3.20E-07

Table 3-19: Tier 2 exhaust emission factors for light commercial vehicles, NFR 1.A.3.b.ii

Type	Technology	CO	NM VOC	NO _x	N ₂ O	NH ₃	Pb	CO ₂ lube
Units		g/km	g/km	g/km	g/km	g/km	g/km	g/km
Notes			Given as THC-CH ₄	Given as NO ₂ equivalent				due to lube oil
Petrol	Conventional	25.5	3.44	3.09	0.010	0.0025	2.82E-06	6.63E-01
	Euro 1 - 93/59/EEC	8.82	0.614	0.563	0.025	0.0758	3.31E-06	5.96E-01
	Euro 2 - 96/69/EEC	5.89	0.304	0.230	0.025	0.0910	3.31E-06	5.30E-01
	Euro 3 - 98/69/EC I	5.05	0.189	0.129	0.028	0.0302	3.31E-06	4.64E-01
	Euro 4 - 98/69/EC II	2.01	0.128	0.064	0.013	0.0302	3.31E-06	3.98E-01
	Euro 5 - EC 715/2007	1.30	0.096	0.064	0.0013	0.0123	3.31E-06	3.98E-01
	Euro 6 a/b/c	1.30	0.096	0.064	0.0013	0.0123	3.31E-06	3.98E-01
	Euro 6 d-temp	1.30	0.096	0.064	0.0013	0.0123	3.31E-06	3.98E-01
Diesel	Euro 6 d	1.30	0.096	0.064	0.0013	0.0123	3.31E-06	3.98E-01
	Conventional	1.34	0.133	1.66	0.000	0.0012	4.65E-06	6.63E-01
	Euro 1 - 93/59/EEC	0.577	0.141	1.22	0.003	0.0012	4.17E-06	5.96E-01
	Euro 2 - 96/69/EEC	0.577	0.149	1.22	0.006	0.0012	4.17E-06	5.30E-01
	Euro 3 - 98/69/EC I	0.473	0.094	1.03	0.009	0.0012	4.17E-06	4.64E-01
	Euro 4 - 98/69/EC II	0.375	0.035	0.831	0.009	0.0012	4.17E-06	3.98E-01
	Euro 5 - EC 715/2007	0.075	0.035	1.15	0.004	0.0019	4.17E-06	3.98E-01
	Euro 6 a/b/c	0.075	0.035	0.96	0.004	0.0019	4.17E-06	3.98E-01
Euro 6 d-temp	0.075	0.035	0.496	0.004	0.0019	4.17E-06	3.98E-01	
Euro 6 d	0.075	0.035	0.248	0.004	0.0019	4.17E-06	3.98E-01	

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

Table 3-20: Tier 2 exhaust emission factors for light commercial vehicles, NFR 1.A.3.b.ii

Type	Technology	PM2.5	ID(1,2,3,cd)P	B(k)F	B(b)F	B(a)P
Units		g/km	g/km	g/km	g/km	g/km
Notes		PM2.5=PM10=TSP				
Petrol	Conventional	0.0023	1.03E-06	3.00E-07	8.80E-07	4.80E-07
	Euro 1 - 93/59/EEC	0.0023	3.90E-07	2.60E-07	3.60E-07	3.20E-07
	Euro 2 - 96/69/EEC	0.0023	3.90E-07	2.60E-07	3.60E-07	3.20E-07
	Euro 3 - 98/69/EC I	0.0011	3.90E-07	2.60E-07	3.60E-07	3.20E-07
	Euro 4 - 98/69/EC II	0.0011	3.90E-07	2.60E-07	3.60E-07	3.20E-07
	Euro 5 - EC 715/2007	0.0014	3.90E-07	2.60E-07	3.60E-07	3.20E-07
	Euro 6 a/b/c	0.0012	3.90E-07	2.60E-07	3.60E-07	3.20E-07
	Euro 6 d-temp	0.0012	3.90E-07	2.60E-07	3.60E-07	3.20E-07
Diesel	Conventional	0.356	2.54E-06	2.87E-06	3.30E-06	2.85E-06
	Euro 1 - 93/59/EEC	0.117	7.00E-07	1.90E-07	6.00E-07	6.30E-07
	Euro 2 - 96/69/EEC	0.117	7.00E-07	1.90E-07	6.00E-07	6.30E-07
	Euro 3 - 98/69/EC I	0.0783	7.00E-07	1.90E-07	6.00E-07	6.30E-07
	Euro 4 - 98/69/EC II	0.0409	7.00E-07	1.90E-07	6.00E-07	6.30E-07
	Euro 5 - EC 715/2007	0.0010	7.00E-07	1.90E-07	6.00E-07	6.30E-07
	Euro 6 a/b/c	0.0009	7.00E-07	1.90E-07	6.00E-07	6.30E-07
	Euro 6 d-temp	0.0009	7.00E-07	1.90E-07	6.00E-07	6.30E-07
Euro 6 d	0.0009	7.00E-07	1.90E-07	6.00E-07	6.30E-07	

Table 3-21: Tier 2 exhaust emission factors for heavy-duty vehicles, NFR 1.A.3.b.iii

Type	Technology	CO	NM VOC	NOx	N2O	NH3	Pb	CO2 lube
Units		g/km	g/km	g/km	g/km	g/km	g/km	g/km
Notes			Given as THC-CH4	Given as NO2 equivalent				due to lube oil
Petrol >3.5 t	Conventional	59.5	5.25	6.60	0.006	0.0019	5.84E-06	1.99
Diesel <=7.5 t	Conventional	1.85	1.07	4.70	0.029	0.0029	6.47E-06	4.86E-01
	Euro I - 91/542/EEC I	0.657	0.193	3.37	0.005	0.0029	5.43E-06	4.86E-01
	Euro II - 91/542/EEC II	0.537	0.123	3.49	0.004	0.0029	5.22E-06	4.86E-01
	Euro III - 2000	0.584	0.115	2.63	0.003	0.0029	5.47E-06	4.86E-01
	Euro IV - 2005	0.047	0.005	1.64	0.006	0.0029	5.17E-06	4.86E-01
	Euro V - 2008	0.047	0.005	0.933	0.017	0.011	5.17E-06	4.86E-01
	Euro VI A/B/C	0.047	0.005	0.180	0.017	0.009	5.17E-06	4.86E-01
	Euro VI D/E	0.047	0.005	0.180	0.017	0.009	5.17E-06	4.86E-01
Diesel 7.5 - 16 t	Conventional	2.13	0.776	8.92	0.029	0.0029	9.48E-06	4.86E-01
	Euro I - 91/542/EEC I	1.02	0.326	5.31	0.008	0.0029	8.36E-06	4.86E-01
	Euro II - 91/542/EEC II	0.902	0.207	5.50	0.008	0.0029	8.05E-06	4.86E-01
	Euro III - 2000	0.972	0.189	4.30	0.004	0.0029	8.39E-06	4.86E-01
	Euro IV - 2005	0.071	0.008	2.65	0.012	0.0029	7.85E-06	4.86E-01
	Euro V - 2008	0.071	0.008	1.51	0.034	0.011	7.85E-06	4.86E-01
	Euro VI A/B/C	0.071	0.008	0.291	0.033	0.009	7.85E-06	4.86E-01
	Euro VI D/E	0.071	0.008	0.291	0.033	0.009	7.85E-06	4.86E-01
Diesel 16 - 32 t	Conventional	1.93	0.486	10.7	0.029	0.0029	1.31E-05	4.86E-01
	Euro I - 91/542/EEC I	1.55	0.449	7.52	0.008	0.0029	1.14E-05	4.86E-01
	Euro II - 91/542/EEC II	1.38	0.29	7.91	0.007	0.0029	1.11E-05	4.86E-01
	Euro III - 2000	1.49	0.278	6.27	0.004	0.0029	1.13E-05	4.86E-01
	Euro IV - 2005	0.105	0.010	3.83	0.012	0.0029	1.06E-05	4.86E-01
	Euro V - 2008	0.105	0.010	2.18	0.034	0.011	1.06E-05	4.86E-01
	Euro VI A/B/C	0.105	0.010	0.422	0.032	0.009	1.06E-05	4.86E-01
	Euro VI D/E	0.105	0.010	0.422	0.032	0.009	1.06E-05	4.86E-01
Diesel >32 t	Conventional	2.25	0.534	12.8	0.029	0.0029	1.54E-05	4.86E-01
	Euro I - 91/542/EEC I	1.90	0.510	9.04	0.012	0.0029	1.36E-05	4.86E-01
	Euro II - 91/542/EEC II	1.69	0.326	9.36	0.012	0.0029	1.33E-05	4.86E-01
	Euro III - 2000	1.79	0.308	7.43	0.007	0.0029	1.36E-05	4.86E-01
	Euro IV - 2005	0.121	0.012	4.61	0.018	0.0029	1.26E-05	4.86E-01
	Euro V - 2008	0.121	0.012	2.63	0.053	0.011	1.26E-05	4.86E-01
	Euro VI A/B/C	0.121	0.012	0.507	0.049	0.009	1.26E-05	4.86E-01
	Euro VI D/E	0.121	0.012	0.507	0.049	0.009	1.26E-05	4.86E-01

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

Table 3-22: Tier 2 exhaust emission factors for heavy-duty vehicles, NFR 1.A.3.b.iii

Type	Technology	PM2.5	ID(1,2,3,c d)P	B(k)F	B(b)F	B(a)P
Units		g/km	g/km	g/km	g/km	g/km
Notes		PM2.5=P M10=TS P				
Petrol >3.5 t	Conventional	0.000	1.03E-06	3.00E-07	8.80E-07	4.80E-07
Diesel <=7.5 t	Conventional	0.333	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro I - 91/542/EEC I	0.129	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro II - 91/542/EEC II	0.061	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro III - 2000	0.0566	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro IV - 2005	0.0106	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro V - 2008	0.0106	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro VI A/B/C	0.0005	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Diesel 7.5 - 16 t	Euro VI D/E	0.0005	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Conventional	0.3344	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro I - 91/542/EEC I	0.201	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro II - 91/542/EEC II	0.104	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro III - 2000	0.0881	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro IV - 2005	0.0161	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro V - 2008	0.0161	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Diesel 16 - 32 t	Euro VI A/B/C	0.0008	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro VI D/E	0.0008	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Conventional	0.418	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro I - 91/542/EEC I	0.297	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro II - 91/542/EEC II	0.155	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro III - 2000	0.13	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro IV - 2005	0.0239	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Diesel >32 t	Euro V - 2008	0.0239	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro VI A/B/C	0.0012	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro VI D/E	0.0012	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Conventional	0.491	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro I - 91/542/EEC I	0.358	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro II - 91/542/EEC II	0.194	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro III - 2000	0.151	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Euro IV - 2005	0.0268	1.40E-06	6.09E-06	5.45E-06	9.00E-07	
Euro V - 2008	0.0268	1.40E-06	6.09E-06	5.45E-06	9.00E-07	
Euro VI A/B/C	0.0013	1.40E-06	6.09E-06	5.45E-06	9.00E-07	
Euro VI D/E	0.0013	1.40E-06	6.09E-06	5.45E-06	9.00E-07	

Table 3-23: Tier 2 exhaust emission factors for buses, NFR 1.A.3.b.iii

Type	Technology	CO	NM VOC	NOx	N2O	NH3	Pb	CO2 lube
Units		g/km	g/km	g/km	g/km	g/km	g/km	g/km
Notes			Given as THC-CHA	Given as NO2 equivalent				due to lube oil
Urban CNG Buses	Euro I - 91/542/EEC I	8.400	0.371	16.500	n.a.	n.a.	2.89E-05	1.860
	Euro II - 91/542/EEC II	2.700	0.313	15.000	n.a.	n.a.	2.68E-05	1.590
	Euro III - 2000	1.000	0.052	10.000	n.a.	n.a.	2.37E-05	1.590
	EEV	1.000	0.045	2.500	n.a.	n.a.	2.37E-05	n.a.
Urban Buses Standard	Conventional	5.710	1.990	16.500	0.029	0.0029	1.90E-05	2.650
	Euro I - 91/542/EEC I	2.710	0.706	10.100	0.012	0.0029	1.61E-05	2.050
	Euro II - 91/542/EEC II	2.440	0.463	10.700	0.120	0.0029	1.55E-05	1.480
	Euro III - 2000	2.670	0.409	9.380	0.001	0.0029	1.62E-05	0.861
	Euro IV - 2005	0.223	0.022	5.420	0.012	0.0029	1.54E-05	0.265
	Euro V - 2008	0.223	0.022	3.090	0.032	0.011	1.54E-05	0.265
	Euro VI A/B/C	0.223	0.220	0.597	0.040	0.009	1.54E-05	0.265
Urban Hybrid Buses	Euro VI D/E	0.223	0.220	0.597	0.040	0.009	1.54E-05	0.265
	Euro VI A/B/C	0.223	0.220	0.597	0.040	0.009	1.54E-05	0.265
Coaches Standard	Conventional	2.270	0.661	10.600	0.029	0.0029	1.37E-05	0.663
	Euro I - 91/542/EEC I	1.850	0.624	8.100	0.009	0.0029	1.26E-05	0.630

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

	Euro II - 91/542/EEC II	1.600	0.416	8.950	0.008	0.0029	1.25E-05	0.596
	Euro III - 2000	1.910	0.399	7.510	0.004	0.0029	1.35E-05	0.563
	Euro IV - 2005	0.150	0.021	4.510	0.012	0.0029	1.28E-05	0.530
	Euro V - 2008	0.150	0.021	2.570	0.034	0.011	1.28E-05	0.530
	Euro VI A/B/C							
	Euro VI D/E	0.150	0.021	0.496	0.033	0.009	1.28E-05	0.530

Table 3-24: Tier 2 exhaust emission factors for buses, NFR 1.A.3.b.iii

Type	Technology	PM2.5	ID(1.2.3.cd)P	B(k)F	B(b)F	B(a)F
Units		g/km	g/km	g/km	g/km	g/km
Notes		PM2.5=PM10=TSP				
Urban CNG Buses	Euro I - 91/542/EEC I	0.0200	n.a.	n.a.	n.a.	n.a.
	Euro II - 91/542/EEC II	0.0100	n.a.	n.a.	n.a.	n.a.
	Euro III - 2000	0.0100	3.00E-08	4.00E-08	8.00E-08	5.00E-08
	EEV	0.0050	1.00E-08	1.00E-08	1.00E-08	3.00E-08
Urban Buses Standard	Conventional	0.9090	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro I - 91/542/EEC I	0.4790	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro II - 91/542/EEC II	0.2200	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro III - 2000	0.2070	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro IV - 2005	0.0462	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro V - 2008	0.0462	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro VI A/B/C	0.0023	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Urban Hybrid Buses	Euro VI D/E	0.0023	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro VI D/E	0.0023	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Coaches Standard	Conventional	0.4700	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro I - 91/542/EEC I	0.3620	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro II - 91/542/EEC II	0.1650	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro III - 2000	0.1780	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro IV - 2005	0.0354	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro V - 2008	0.0354	1.40E-06	6.09E-06	5.45E-06	9.00E-07
	Euro VI A/B/C					
Euro VI D/E	0.0018	1.40E-06	6.09E-06	5.45E-06	9.00E-07	

Table 3-25: Tier 2 exhaust emission factors for L-category vehicles, NFR 1.A.3.b.iv

Type	Technology	CO	NM VOC	NO _x	N ₂ O	NH ₃	Pb	CO ₂ lube
Units		g/km	g/km	g/km	g/km	g/km	g/km	g/km
Notes			Given as THC-CH ₄	Given as NO ₂ equivalent				due to lube oil
2-stroke <50 cm ³	Conventional	14.7	8.38	0.056	0.001	0.001	1.10E-05	4.24
	Mop - Euro 1	4.6	3.18	0.18	0.001	0.001	1.10E-05	3.53
	Mop - Euro 2	2.8	2.56	0.17	0.001	0.001	1.10E-05	2.83
	Mop - Euro 3 and later	1.8	1.78	0.17	0.001	0.001	1.10E-05	2.12
4-stroke <50 cm ³	Conventional	14.7	8.18	0.056	0.001	0.001	1.1E-05	4.24
	Mop - Euro 1	6.7	0.74	0.22	0.001	0.001	1.1E-05	3.53
	Mop - Euro 2	4.2	0.77	0.17	0.001	0.001	1.1E-05	2.83
	Mop - Euro 3 and later	2.7	0.52	0.17	0.001	0.001	1.1E-05	2.12
2-stroke >50 cm ³	Conventional	24.3	9.97	0.067	0.002	0.0019	1.10E-06	4.24
	Mot - Euro 1	16.3	5.82	0.028	0.002	0.0019	8.22E-07	3.53
	Mot - Euro 2	11.2	1.84	0.104	0.002	0.0019	7.49E-07	2.83
	Mot - Euro 3 and later	2.73	0.806	0.280	0.002	0.0019	5.74E-07	2.12
4-stroke <250 cm ³	Conventional	32.8	2.06	0.225	0.002	0.0019	1.06E-06	0.398
	Mot - Euro 1	13.6	1.08	0.445	0.002	0.0019	1.19E-06	0.309
	Mot - Euro 2	7.17	0.839	0.317	0.002	0.0019	1.19E-06	0.221
	Mot - Euro 3 and later	3.03	0.465	0.194	0.002	0.0019	1.19E-06	0.133
4-stroke 250 - 750 cm ³	Conventional	25.7	1.68	0.233	0.002	0.0019	1.23E-06	0.398
	Mot - Euro 1	13.8	1.19	0.477	0.002	0.0019	1.19E-06	0.309

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

	Mot - Euro 2	7.17	0.918	0.317	0.002	0.0019	1.19E-06	0.221
	Mot - Euro 3 and later	3.03	0.541	0.194	0.002	0.0019	1.19E-06	0.133
4-stroke >750 cm ³	Conventional	21.1	2.75	0.247	0.002	0.0019	1.48E-06	0.398
	Mot - Euro 1	10.1	1.50	0.579	0.002	0.0019	1.53E-06	0.309
	Mot - Euro 2	7.17	0.994	0.317	0.002	0.0019	1.53E-06	0.221
	Mot - Euro 3 and later	3.03	0.587	0.194	0.002	0.0019	1.53E-06	0.133
Mini-cars	Conventional	1.15	0.283	0.589	0.005	0.001	1.82E-05	0.530
	Euro 1	0.93	0.147	0.814	0.005	0.001	1.82E-05	0.530
	Euro 2	0.93	0.155	0.814	0.005	0.001	1.82E-05	0.530
	Euro 3	0.93	0.158	0.814	0.005	0.001	1.82E-05	0.530
	Euro 4	0.93	0.119	0.689	0.005	0.001	1.82E-05	0.530
ATVs	Conventional	33.54	16.47	0.047	0.002	0.0019	1.53E-06	0.398
	Euro 1	13.32	8.908	0.300	0.002	0.0019	1.53E-06	0.309
	Euro 2	7.77	2.236	0.300	0.002	0.0019	1.53E-06	0.221
	Euro 3	7.77	2.27	0.300	0.002	0.0019	1.53E-06	0.133
	Euro 4	1.79	0.553	0.187	0.002	0.0019	1.53E-06	0.133
	Euro 5	1.00	0.038	0.060	0.002	0.0019	1.53E-06	0.133

Table 3-26: Tier 2 emission factors for L-category vehicles, NFR 1.A.3.b.iv

Type	Technology	PM2.5	ID(1,2,3,cd)P	B(k)F	B(b)F	B(a)P
Units		g/km	g/km	g/km	g/km	g/km
Notes		PM2.5=PM1 0=TSP				
2-stroke <50 cm ³	Conventional	0.176	2.06E-07	6E-08	1.76E-07	9.6E-08
	Mop - Euro 1	0.045	7.8E-08	5.2E-08	7.2E-08	6.4E-08
	Mop - Euro 2	0.026	7.8E-08	5.2E-08	7.2E-08	6.4E-08
	Mop - Euro 3 and later	0.018	7.8E-08	5.2E-08	7.2E-08	6.4E-08
4-stroke <50 cm ³	Conventional	0.176	2.06E-07	6E-08	1.76E-07	9.6E-08
	Mop - Euro 1	0.04	7.8E-08	5.2E-08	7.2E-08	6.4E-08
	Mop - Euro 2	0.007	7.8E-08	5.2E-08	7.2E-08	6.4E-08
	Mop - Euro 3 and later	0.004	7.8E-08	5.2E-08	7.2E-08	6.4E-08
2-stroke >50 cm ³	Conventional	0.16	n.a.	n.a.	n.a.	n.a.
	Mot - Euro 1	0.064	n.a.	n.a.	n.a.	n.a.
	Mot - Euro 2	0.032	n.a.	n.a.	n.a.	n.a.
	Mot - Euro 3 and later	0.0096	n.a.	n.a.	n.a.	n.a.
4-stroke <250 cm	Conventional	0.014	3.90E-07	2.60E-07	3.60E-07	3.20E-07
	Mot - Euro 1	0.014	3.90E-07	2.60E-07	3.60E-07	3.20E-07
	Mot - Euro 2 and later	0.0035	3.90E-07	2.60E-07	3.60E-07	3.20E-07
4-stroke 250 - 750 cm ³	Conventional	0.014	3.90E-07	2.60E-07	3.60E-07	3.20E-07
	Mot - Euro 1	0.014	3.90E-07	2.60E-07	3.60E-07	3.20E-07
	Mot - Euro 2 and later	0.0035	3.90E-07	2.60E-07	3.60E-07	3.20E-07
4-stroke >750 cm ³	Conventional	0.014	3.90E-07	2.60E-07	3.60E-07	3.20E-07
	Mot - Euro 1	0.014	3.90E-07	2.60E-07	3.60E-07	3.20E-07
	Mot - Euro 2 and later	0.0035	3.90E-07	2.60E-07	3.60E-07	3.20E-07
Mini-cars	Conventional	0.250	1.62E-06	1.53E-06	1.95E-06	1.74E-06
	Euro 1	0.150	1.62E-06	1.53E-06	1.95E-06	1.74E-06
	Euro 2	0.150	1.62E-06	1.53E-06	1.95E-06	1.74E-06
	Euro 3	0.150	1.62E-06	1.53E-06	1.95E-06	1.74E-06
	Euro 4	0.080	1.62E-06	1.53E-06	1.95E-06	1.74E-06
	Euro 5	0.001	1.62E-06	1.53E-06	1.95E-06	1.74E-06
ATVs	Conventional	0.200	3.90E-07	2.60E-07	3.60E-07	3.20E-07
	Euro 1	0.080	3.90E-07	2.60E-07	3.60E-07	3.20E-07
	Euro 2	0.040	3.90E-07	2.60E-07	3.60E-07	3.20E-07
	Euro 3	0.040	3.90E-07	2.60E-07	3.60E-07	3.20E-07
	Euro 4	0.010	3.90E-07	2.60E-07	3.60E-07	3.20E-07
	Euro 5	0.002	3.90E-07	2.60E-07	3.60E-07	3.20E-07

The preceding tables provided emission factors for different vehicle categories, fuels and vehicle technologies, and for the principal pollutants which are affected by vehicle technology. Other pollutants (e.g. SO₂ and heavy metals) originate directly from the fuel and lubricant combustion.

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

Therefore, Table 3-27 provides the fuel/energy consumption for each different combination of vehicle type, fuel and vehicle technology. These data, when multiplied by the Tier 1 emission factors for pollutants originating directly from fuel consumption (

Table 3-12 to Table 3-14) give the Tier 2 emission factors.

Table 3-27: Tier 2 average fuel/energy consumption values

Vehicle category	Sub-category	Technology	FC (g/km)	EC (MJ/km)*
Passenger cars	Petrol Mini	Euro 4 and later	49	2.14
	Petrol Small	PRE-ECE to open loop	65	2.85
		Euro 1 and later	56	2.45
	Petrol Medium	PRE-ECE to open loop	77	3.37
		Euro 1 and later	66	2.89
	Petrol Large-SUV-Executive	PRE-ECE to open loop	95	4.16
		Euro 1 and later	86	3.76
	Diesel Small	Euro 4 and later	38	1.62
	Diesel Medium	Conventional	63	2.69
		Euro 1 and later	55	2.35
	Diesel Large-SUV-Executive	Conventional	75	3.2
		Euro 1 and later	73	3.12
	LPG	Conventional	59	2.75
		Euro 1 and later	57	2.65
	2-stroke	Conventional	82	3.59
	Hybrid Petrol Small	Euro 4 and later	34	1.49
	Hybrid Petrol Medium	Euro 4 and later	34	1.49
	Hybrid Petrol Large-SUV-Executive	Euro 4 and later	34	1.49
	PHEV Petrol Small	Euro 6 and later	34	1.49
PHEV Petrol Medium	Euro 6 and later	34	1.49	
PHEV Petrol Large-SUV-Executive	Euro 6 and later	34	1.49	
PHEV Diesel Large-SUV-Executive	Euro 5 and later	73	3.12	
E85	Euro 4 and later	87	3.33	
CNG	Euro 4 and later	63	3.02	
Light commercial vehicles	Petrol	Conventional	85	3.72
		Euro 1 and later	70	3.06
	Diesel	Conventional	89	3.8
		Euro 1 and later	80	3.42
Heavy-duty trucks	Petrol > 3.5 t	Conventional	177	7.75
	<=7.5 t	Conventional	125	5.34
		Euro I and later	101	4.31
	7.5-16 t	Conventional	182	7.77
		Euro I and later	155	6.62
	16-32 t	Conventional	251	10.72
		Euro I and later	210	8.97
	> 32 t	Conventional	297	12.68
Euro I and later		251	10.72	
Buses	Urban CNG buses	HD Euro I	555	26.64
		HD Euro II	515	24.72
		HD Euro III	455	21.84
		EEV	455	21.84
	Urban buses, standard	Conventional	366	15.63
		Euro I and later	301	12.85
	Coaches, standard	Conventional	263	11.23
		Euro I and later	247	10.55
Urban Diesel Hybrid	Euro VI	301	12.85	
L-category	Mopeds 2-stroke < 50 cm ³	Conventional	25	1.09

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	Euro 1	20	0.88
Mopeds 2-stroke < 50 cm ³	Euro 2	20	0.88
	Euro 3 and later	20	0.88
	Conventional	25	1.09
Mopeds 4-stroke < 50 cm ³	Euro 1	20	0.88
	Euro 2	20	0.88
	Euro 3 and later	20	0.88
Motorcycles 2-stroke > 50 cm ³	Conventional	33	1.44
	Euro 1	25	1.09
	Euro 2	23	1.01
Motorcycles 4-stroke < 250 cm ³	Euro 3 and later	17	0.74
	Conventional	32	1.4
	Euro 1 and later	36	1.58
Motorcycles 4-stroke 250–750 cm ³	Conventional	37	1.62
	Euro 1 and later	36	1.58
Motorcycles 4-stroke > 750 cm ³	Conventional	45	1.97
	Euro 1 and later	46	2.01
Mini cars Diesel	Conventional	34	1.44
	Euro 1	30	1.26
	Euro 2	30	1.26
	Euro 3	30	1.26
	Euro 4	27	1.13
ATVs	Euro 5	27	1.13
	Conventional	47	2.07
	Euro 1	41	1.79
	Euro 2	41	1.79
	Euro 3	41	1.79
	Euro 4	40	1.74
	Euro 5	40	1.74

*based on the default calorific values included in Table 3-28

3.3.3 Activity data

In principal, traffic activity data are available from the national statistics offices of all countries, and from international statistical organisations and institutes (e.g. Eurostat, International Road Federation (IRF)). These statistics tend to be vehicle-orientated, providing details on fleet composition. Detailed data on vehicle stocks for all EU-28 countries and CH, NO, TR can be also found on the COPERT website (<https://www.emisia.com/utilities/copert/>). These data have no official status but are a result of a research project (TRACCS, Ntziachristos et al., 2013). However, they can be used as a good guide in the absence of more detailed information.

For the annual distance driven per vehicle technology (typical values can be found also on the COPERT website, as above), the energy consumption calculated on the basis of appropriate assumptions for annual mileage of the different vehicle categories can be balanced with available energy statistics. Then by applying a trial-and-error approach, it is possible to reach a good match between the calculated and the statistical energy consumption per fuel. This is a good indication that the activity data that have been used to estimate emissions are consistent with the total energy consumed in the country for road transportation.

3.4 Tier 3 method

In the Tier 3 method described here, exhaust emissions are calculated using a combination of firm technical data (e.g. emission factors) and activity data (e.g. total vehicle km). This approach was entitled 'Detailed Methodology' in the previous version of the Guidebook, and is implemented in COPERT. Alternative Tier 3 methods can be found in tools such as Artemis, the DACH-NL Handbook of Emission Factors, and other national models (for example EMV in Sweden, Liipasto in Finland, and Versit+ in the Netherlands).

3.4.1 Algorithm

In the following Tier 3 approach, total exhaust emissions from road transport are calculated as the sum of hot emissions (when the engine is at its normal operating temperature) and emissions during transient thermal engine operation (termed 'cold-start' emissions). It should be noted that, in this context, the word 'engine' is used as shorthand for 'engine and any exhaust aftertreatment devices'. The distinction between emissions during the 'hot' stabilised phase and the transient 'warming-up' phase is necessary because of the substantial difference in vehicle emission performance during these two conditions. Concentrations of some pollutants during the warming-up period are many times higher than during hot operation, and a different methodological approach is required to estimate the additional emissions during this period. To summarise, total emissions can be calculated by means of the following equation:

$$E_{TOTAL} = E_{HOT} + E_{COLD} \quad (6)$$

where,

E_{TOTAL} = total emissions (g) of any pollutant for the spatial and temporal resolution of the application,

E_{HOT} = emissions (g) during stabilised (hot) engine operation,

E_{COLD} = emissions (g) during transient thermal engine operation (cold start).

Vehicle emissions are heavily dependent on the engine operation conditions. Different driving situations impose different engine operation conditions, and therefore a distinct emission performance. In this respect, a distinction is made between urban, rural and highway driving.

As will be demonstrated later, different activity data and emission factors are attributed to each driving situation. Cold-start emissions are attributed mainly to urban driving (and secondarily to rural driving), as it is expected that a limited number of trips start at highway conditions. Therefore, as far as driving conditions are concerned, total emissions can be calculated by means of the equation:

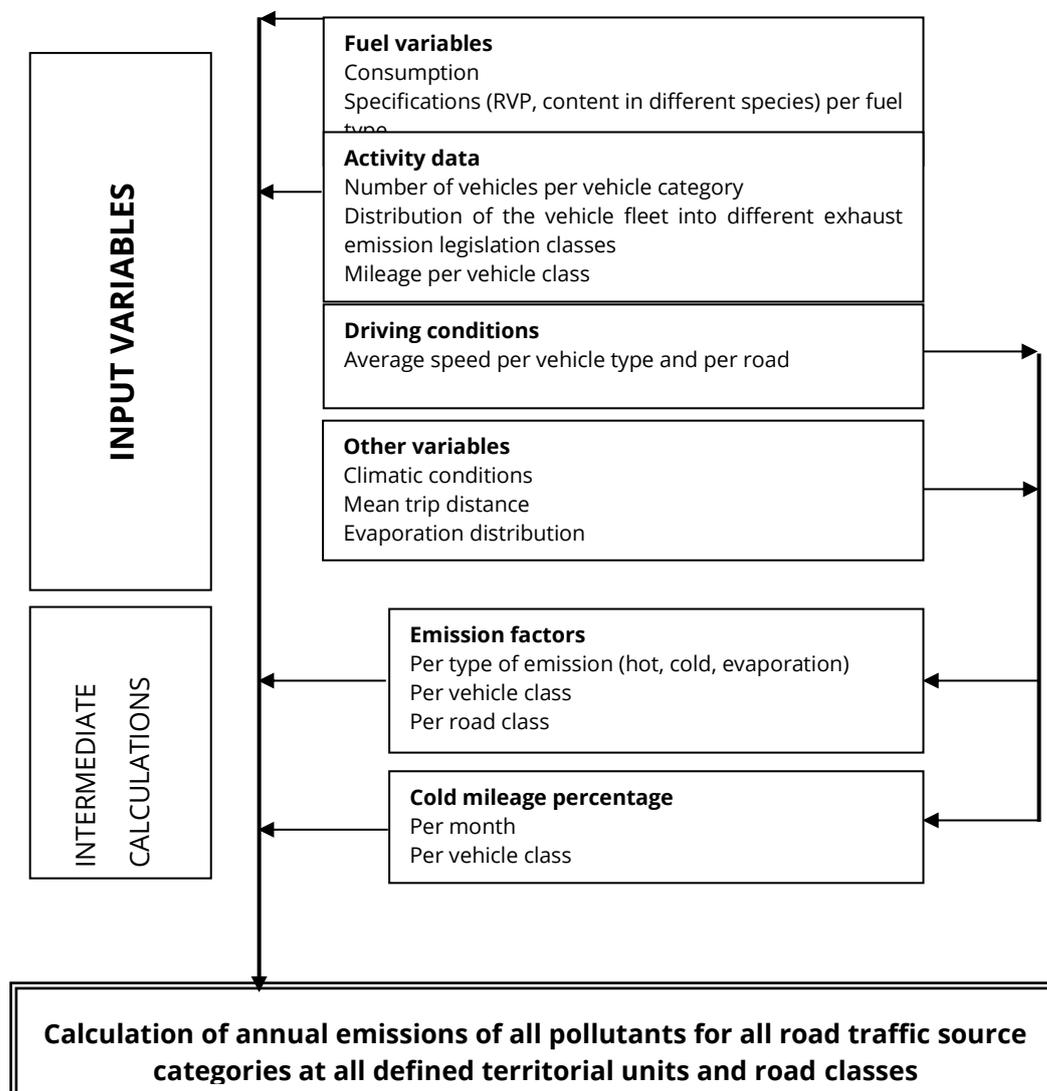
$$E_{TOTAL} = E_{URBAN} + E_{RURAL} + E_{HIGHWAY} \quad (7)$$

where:

E_{URBAN} , E_{RURAL} and $E_{HIGHWAY}$ are the total emissions (g) of any pollutant for the respective driving situations.

Total emissions are calculated by combining activity data for each vehicle category with appropriate emission factors. The emission factors vary according to the input data (driving situations, climatic conditions).

Figure 3-2: Flow chart of the application of the baseline methodology



Hot emissions

Hot exhaust emissions depend upon a variety of factors, including the distance that each vehicle travels, its speed (or road type), its age, its engine size and its weight. As will be explained later, many countries do not have robust data for these parameters. Therefore, a method to estimate emissions from the available data has been proposed. However, it is important that each country uses the best data available; this is an issue to be resolved by each individual country.

The basic formula for estimating hot emissions for a given time period, and using experimentally obtained emission factors, is:

$$\text{emission [g]} = \text{emission factor [g/km]} \times \text{number of vehicles [veh]} \times \text{mileage per vehicle [km/veh]}$$

Different emission factors, numbers of vehicles and mileages per vehicle need to be used for each vehicle category and class. The time period (month, year, etc.) depends upon the application.

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Therefore, the formula to be applied for the calculation of hot emissions of pollutants in Groups 1 and 3, and in the case of an annual emission estimation, yields:

$$E_{HOT; i, k, r} = N_k \times M_{k,r} \times e_{HOT; i, k, r} \quad (8)$$

where,

$E_{HOT; i, k, r}$ = hot exhaust emissions of the pollutant i [g], produced in the period concerned by vehicles of technology k driven on roads of type r ,

N_k = number of vehicles [veh] of technology k in operation in the period concerned,

$M_{k,r}$ = mileage per vehicle [km/veh] driven on roads of type r by vehicles of technology k ,

$e_{HOT; i, k, r}$ = emission factor in [g/km] for pollutant i , relevant for the vehicle technology k , operated on roads of type r .

The pollutants, vehicle classes and road classes are as follows:

i pollutants in Group 1 and Group 3,

k vehicle technologies in Table 2-3,

r road class ('urban', 'rural', and 'highway').

Note: the same formula is also applied for the calculation of the total energy consumed by vehicles of the specific class. However, in the case of energy consumption, an additional distinction needs to be made for different fuel types.

Vehicle speed, which is introduced into the calculation via the different driving modes, has a major influence on exhaust emissions, and different approaches have been developed to take this into account. For the emission factors presented in this chapter, two alternative methods can be used:

- to select a single average speed which representative of each of the road types 'urban', 'rural' and 'highway' (e.g. 20 km/h, 60 km/h and 100 km/h, respectively), and to apply the emission factor values presented in subsection 3.4.3;
- to define mean speed distribution curves $f_{j,k}(V)$ and to integrate over the emission curves, i.e.:

$$e_{HOT; i, k, r} = \int [e(V) \times f_{k,r}(V)] dV \quad (9)$$

where,

V = speed of vehicles on the different road classes,

$e(V)$ = expression of the speed-dependency of $e_{HOT; i, k, r}$,

$f_{k,r}(V)$ = equation (e.g. formula of 'best fit' curve) describing the frequency distribution of the mean speeds which corresponds to the driving patterns of vehicles on road classes 'rural', 'urban' and 'highway'. The term $f_{k,r}(V)$ is a function of vehicle technology k and road type r .

It is evident that the first approach mentioned above is much easier, and is likely to be the one chosen by most countries. Additionally, given the uncertainty in the estimation of the emission factors, the improvement brought about by the second approach cannot really be substantiated.

Cold-start emissions

Cold starts result in additional exhaust emissions. They take place under all driving conditions. However, they seem to be most likely for urban and rural driving, as the number of starts in highway conditions is relatively limited (in principle starts from parking lots next to highways). They occur for all vehicle categories, but emission factors are only available, or can be reasonably estimated, for petrol, diesel and LPG cars and — assuming that these vehicles behave like passenger cars — light commercial vehicles, as well as most recent diesel heavy duty vehicles and buses technologies,, so that only these categories are covered by the methodology. Moreover, they are not considered to be a function of vehicle age.

Cold-start emissions are calculated as an extra emission over the emissions that would be expected if all vehicles were only operated with hot engines and warmed-up catalysts. A relevant factor, corresponding to the ratio of cold over hot emissions, is applied to the fraction of kilometres driven with a cold engine. This factor varies from country to country. Driving behaviour (varying trip lengths) and climatic conditions affect the time required to warm up the engine and/or the catalyst, and hence the fraction of a trip driven with a cold engine.

Cold-start emissions are introduced into the calculation as additional emissions per km using the following formula:

$$E_{\text{COLD}; i, j} = \beta_{i, k} \times N_k \times M_k \times e_{\text{HOT}; i, k} \times (e^{\text{COLD}} / e^{\text{HOT}} |_{i, k} - 1) \quad (10)$$

where,

- $E_{\text{COLD}; i, k}$ = cold-start emissions of pollutant i (for the reference year), produced by vehicle technology k ,
- $\beta_{i, k}$ = fraction of mileage driven with a cold engine or the catalyst operated below the light-off temperature for pollutant i and vehicle technology k ,
- N_k = number of vehicles [veh] of technology k in circulation,
- M_k = total mileage per vehicle [km/veh] in vehicle technology k ,
- $e_{\text{HOT}; i, k}$ = hot emission factor for pollutant i and vehicles of k technology,
- $e^{\text{COLD}} / e^{\text{HOT}} |_{i, k}$ = cold/hot emission quotient for pollutant i and vehicles of k technology.

The β -parameter depends upon ambient temperature t_a (for practical reasons the average monthly temperature can be used), and the pattern of vehicle use — in particular the average trip length l_{trip} . However, since information on l_{trip} is not available in many countries for all vehicle classes, simplifications have been introduced for some vehicle categories. According to the available statistical data (André et al., 1998), a European value of 12.4 km has been established for the l_{trip} value. Moreover, the value of l_{trip} should be between 8 km and 15 km. Therefore, it is proposed that a value of 12.4 km can be used unless a firm national estimate is available. Table 3-35 presents the l_{trip} values used in the COPERT 1990 inventories by different Member States.

Note

l_{trip} is the mean trip distance in km. The definition of a “trip” and a “journey” are not always unequivocal. A trip is sometimes referred to as a small journey, with a journey having the meaning of a complete sequence of events with different destinations, different segments, etc. However, in calculating emissions, a “trip” should be seen as the travel segment defined between a key-on and a key-off event. For example travelling between office and home with an intermediate stop to buy grocery. The first trip is this between office (key-on) and the grocery store (key-off). The second trip is between the store (second key-on) and home (second key-off). However, a travel between home and office with an intermediate stop to drop-off kids at school is a single trip, as only one engine-on/engine-off sequence is taking place. Trips for passenger cars can occur at any distance between a few meters (local commuting) to several hundred kilometres (interurban trips). The probability distribution of trips is a skewed one with a long tail of low frequency for long trips. According to research and national statistics, the average trip for a passenger car is in the order of ~12 km. National statistics of citizens’ mobility can provide more robust values. The cold-start methodology included in this Guidebook is applicable only on passenger cars and light commercial vehicles. Care should be therefore given to take into account the mean distance of trips travelled with such vehicles only and not other means of transport.

Detailed numbers of vehicles and mileage per technology can be found on the following website: <http://www.emisia.com/copert>.

The introduction of more stringent emission standards for catalyst petrol vehicles has imposed shorter periods for the catalyst to reach the light-off temperature. This is reflected in the lower mileage driven under cold-start conditions. Therefore, the β -parameter is also a function of the level of emission-control legislation for petrol catalyst vehicles. Table 3-41 presents factors to be used for calculating the reduction in the β -parameter for current and future catalyst vehicles per pollutant.

The cold/hot emission quotient $e^{\text{COLD}}/e^{\text{HOT}}$ also depends on the ambient temperature and the pollutant being considered. Although the model introduced in the initial version of this methodology is still used for the calculation of emissions during the cold-start phase, updated quotients were introduced for catalyst-equipped petrol vehicles in previous updates of this chapter. These quotients were based on the Methodologies to Estimate Emissions from Transport (MEET) project (MEET, 1999).

As has already been discussed, cold start emissions are normally only attributed to urban driving. However, a portion of cold start emissions may also be attributed to rural driving in cases where the mileage fraction driven under non-thermally stabilised engine conditions (β -parameter) exceeds the mileage share attributed to urban conditions (S_{URBAN}). This requires a transformation of equation (10), which yields the following:

If $\beta_{i,k} > S_{\text{URBAN}}$

$$E_{\text{COLD URBAN}; i,k} = S_{\text{URBAN}; k} \times N_k \times M_k \times e_{\text{HOT URBAN}; i,k} \times (e^{\text{COLD}} / e^{\text{HOT}} |_{i,k} - 1) \quad (11)$$

$$E_{\text{COLD RURAL}; i,k} = (\beta_{i,k} - S_{\text{URBAN}; k}) \times N_k \times M_k \times e_{\text{HOT URBAN}; i,k} \times (e^{\text{COLD}} / e^{\text{HOT}} |_{i,k} - 1)$$

In this case, it is considered that the total mileage driven under urban conditions corresponds to warm-up conditions, while the remaining excess emissions are attributed to rural driving. The case demonstrated by equation (11) is rather extreme for a national inventory, and can only happen in

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
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cases where a very small value has been provided for I_{trip} . Note also that the urban hot emission factor is used in both forms of equation (11). This is because total cold-start emissions should not be differentiated according to place of emission.

The calculation of N_2O , NH_3 and CH_4 emissions is based on 'cold urban', 'hot urban', 'rural' and 'highway' driving conditions. The following paragraphs present the calculation algorithm that is used in order to calculate the emissions of these pollutants. In particular, for methane (CH_4) the estimation is of importance because NMVOC emissions are calculated as the difference between VOCs and CH_4 .

Firstly, one needs to check whether the mileage fraction driven under thermally non-stabilised engine conditions (β - parameter) exceeds the mileage share attributed to urban conditions (S_{URBAN}). For each vehicle category j and pollutant ($i = CH_4, N_2O, NH_3$) the calculation takes the form:

$$\text{if } \beta_{i,k} > S_{URBAN;k} \quad (12)$$

$$E_{COLD\ URBAN;i,k} = \beta_{i,k} \times N_k \times M_k \times e_{COLD\ URBAN;i,k} \quad (a)$$

$$E_{COLD\ RURAL;i,k} = 0 \quad (b)$$

$$E_{HOT\ URBAN;i,k} = 0 \quad (c)$$

$$E_{HOT\ RURAL;i,k} = [S_{RURAL;k} - (\beta_{i,k} - S_{URBAN;k})] \times N_k \times M_k \times e_{HOT\ RURAL;i,k} \quad (d)$$

$$E_{HOT\ HIGHWAY;i,k} = S_{HIGHWAY;k} \times N_k \times M_k \times e_{HOT\ HIGHWAY;i,k} \quad (e)$$

$$\text{else if } \beta_{i,k} \leq S_{URBAN;k} \quad (13)$$

$$E_{COLD\ URBAN;i,k} = \beta_{i,k} \times N_k \times M_k \times e_{COLD\ URBAN;i,k} \quad (a)$$

$$E_{COLD\ RURAL;i,k} = 0 \quad (b)$$

$$E_{HOT\ URBAN;i,k} = (S_{URBAN;k} - \beta_{i,k}) \times N_k \times M_k \times e_{HOT\ URBAN;i,k} \quad (c)$$

$$E_{HOT\ RURAL;i,k} = S_{RURAL;k} \times N_k \times M_k \times e_{HOT\ RURAL;i,k} \quad (d)$$

$$E_{HOT\ HIGHWAY;i,k} = S_{HIGHWAY;k} \times N_k \times M_k \times e_{HOT\ HIGHWAY;i,k} \quad (e)$$

where,

$S_{URBAN;k}$	=	mileage share attributed to urban conditions for vehicle technology k ,
$S_{RURAL;k}$	=	mileage share attributed to rural conditions for vehicle technology k ,
$S_{HIGHWAY;k}$	=	mileage share attributed to highway conditions for vehicle technology k ,
$e_{COLD\ URBAN;i,k}$	=	urban cold-start emission factor for pollutant i , by vehicle technology k ,
$e_{HOT\ URBAN;i,k}$	=	urban hot emission factor for pollutant i , by vehicle technology k ,
$e_{HOT\ RURAL;i,k}$	=	rural hot emission factor for pollutant i , by vehicle technology k ,
$e_{HOT\ HIGHWAY;i,k}$	=	highway hot emission factor for pollutant i , by vehicle technology k .

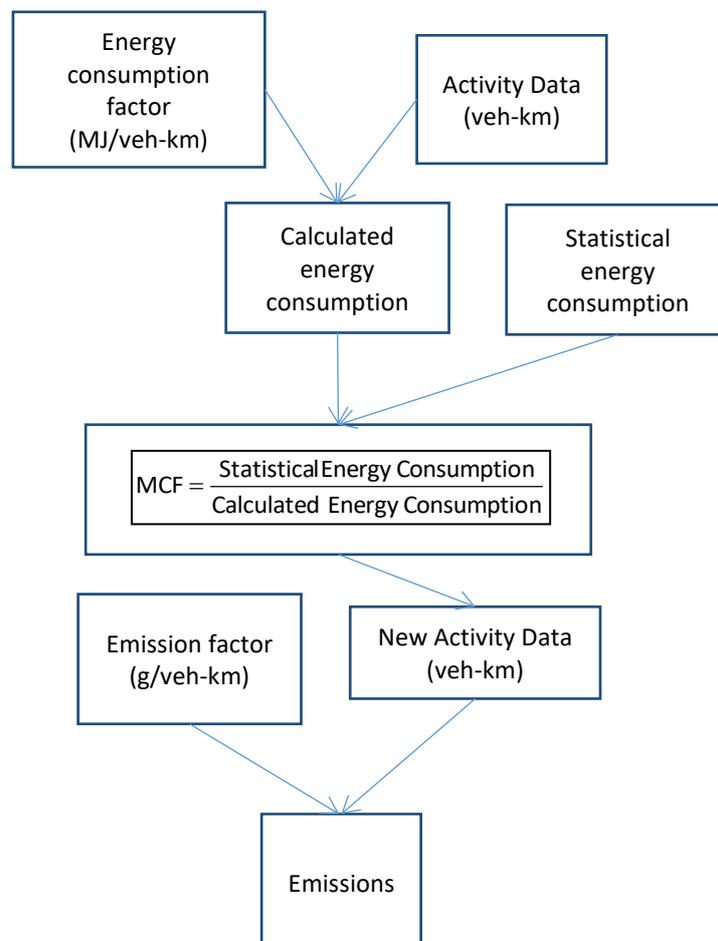
Note

When compiling an urban inventory, the urban share (S_{URBAN}) should be set equal to 100%, whereas both rural (S_{RURAL}) and highway ($S_{HIGHWAY}$) shares should be set equal to zero. In any case, the sum of the three shares should always equal 100%, otherwise an error is introduced in the calculations.

Energy Balance

In previous versions of this chapter it was suggested to carry out a fuel balance in order to ensure that all statistical fuel sold was accounted for in the calculations. However, since vehicles are using blends of fuels with different energy content (e.g. E5, B7, etc.), an energy balance is more appropriate, as the calorific value of the fuel available to the user may significantly differ per country. When performing the energy balance, the activity data is most frequently modified so that calculated energy consumption meets the statistical one reported by the country. Most often, this can be achieved by adjusting the annual kilometres travelled.

When calculating the vehicle fleet energy consumption a mileage correction factor (MCF) is applied to the mean activity to balance the statistical and calculated energy consumption. For the calculation of air pollutant emissions the adjusted mean activity values are used. The following figure presents the adjustment algorithm.

Figure 3-3: Flow chart of the fuel energy balance algorithm

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

A summary of the variables required — and the intermediate calculated values — is given in the flow chart of Figure 3-2.

To facilitate the energy balance, energy consumption factors are introduced to replace the previously used fuel (mass) consumption factors. The conversion has been realised by using default calorific values for the fuel types presented in Table 3-28. These values refer to primary fuels, i.e. fuels produced at the refinery and which can subsequently be blended with other fuels to produce the end fuel (e.g. E5, E85, B7, etc.).

Table 3-28: Default calorific and density values of primary fuels

Fuel	Density [kg/m ³]	CV [MJ/kg]
Petrol	750	43.774
Diesel	840	42.695
LPG	520	46.564
CNG	175	48
Biodiesel	890	37.3
Bioethanol	794	28.8
MTBE	740	35.1
ETBE	736	36.2

Fuel consumption-dependent emissions (excluding CO₂)

In principle, total emissions for pollutants which are dependent upon fuel consumption should be derived on the basis of the statistical (true) energy consumption, which is generally known from statistical sources. However, the necessity to allocate emissions to different vehicle categories (and technologies) cannot be covered solely by means of the statistical consumption, as this is not provided separately for each vehicle class. In order to achieve both aims, fuel-dependent emissions should be calculated after the energy balance has been carried out as described above.

In this respect, the total emission estimate for any fuel-dependent pollutant is derived by the statistical energy consumption (except CO₂ due to the use of biofuels) while there is still information provided for the allocation of emissions to different vehicle classes.

Carbon dioxide emissions (CO₂)

Emissions of **ultimate CO₂** originate from three sources:

- Combustion of fuel
- Combustion of lubricant oil
- Addition of carbon-containing additives in the exhaust

Ultimate in this case means that the carbon contained in either for the three sources is fully oxidized into CO₂. The following paragraphs describe the methodology to calculate CO₂ in each case.

CO₂ due to fuel combustion

In the case of an oxygenated fuel described by the generic chemical formula $C_xH_yO_z$ the ratio of hydrogen to carbon atoms, and the ratio of oxygen to carbon atoms, are, respectively:

$$r_{H:C} = \frac{y}{x}$$

$$r_{O:C} = \frac{z}{x}$$
(14)

If the fuel composition is known from ultimate chemical analysis, then the mass fractions of carbon, hydrogen and oxygen atoms in the fuel are c , h , and o , where $c + h + o = 1$. In this case, the ratios of hydrogen to carbon and oxygen to carbon in the fuel are respectively calculated as:

$$r_{H:C} = 11.916 \frac{h}{c}$$

$$r_{O:C} = 0.7507 \frac{o}{c}$$
(15)

With these ratios, the mass of CO₂ emitted by vehicles in technology k , combusting fuel m can be calculated as:

$$E_{CO_2,k,m}^{CALC} = 44.011 \times \frac{FC_{k,m}^{CALC}}{12.011 + 1.008r_{H:C,m} + 16.000r_{O:C,m}}$$
(16)

Where FC^{CALC} is the fuel consumption of those vehicles for the time period considered.

Table 3-29 gives hydrogen:carbon and oxygen:carbon ratios for different fuel types. These originate from relevant regulations, which reflect ratios of the corresponding reference fuels used for vehicle testing (UN, 2015). Corresponding values for actual market fuels may substantially differ from the values quoted in Table 3-29. Also, calculated ratios for non-reference fuel blends are included in the table for guidance.

Oxygen in the fuel may be increased due to blending with oxygenated components and/or biofuels. In diesel fuel, the most widespread source of oxygen is biodiesel. Biodiesel is produced by the transesterification of organic oils derived from biomass (plant seeds, waste). It comprises a mix of fatty acid methylesters with speciation and proportions that depend on the feedstock. For example, rapeseed oil mostly consists of C18 acids, while coconut oil is lighter and comprises C12 oils (Karavalakis et al., 2010). The neat biodiesel ratios quoted in Table 3-29 try to cover this range.

In petrol, oxygen is found by blending fossil-derived petrol with oxygenated biofuels or synthetic fuels. Methanol, ethanol and their derivative ethers MTBE (Methyl Tertiary Butyl Ether) and ETBE (Ethyl Tertiary Butyl Ether) are the most widespread oxygen-carrying components for petrol fuel. Bioethanol is produced by fermenting sugars into alcohol. These sugars can come from a variety of agricultural sources such as cereals, sugar cane, potatoes, other crops, and increasingly even organic waste materials. However, ethanol may also be produced synthetically from ethylene, in which case it does not count as a biofuel. ETBE and MTBE are obtained by reacting ethanol and methanol respectively with isobutylene. Again, the ethanol used as a feedstock for their production may be of bio- or synthetic origin. However, as isobutylene is always of synthetic origin, ETBE and MTBE cannot be counted as neat biofuels.

When reporting CO₂ emissions, only the fossil fuel statistical consumption should be taken into account in the calculation. This is consistent with the IPCC 1996 and IPCC 2006 guidelines, according to which emissions associated with use of biofuels are attributed to the Land Use, Land-Use Change

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and Forestry sector under IPCC. Hence, for reporting, the CO₂ calculated per vehicle category should be corrected according to equation:

$$E_{CO_2,k,m}^{CORR} = E_{CO_2,k,m}^{CALC} \times \frac{FC_m^{STAT, FOSSIL}}{\sum_k FC_{k,m}^{CALC}} \quad (17)$$

In equation (17), the calculated CO₂ emission should be derived from equation (16), without considering the oxygen content of the biofuel part.

It should be noted that, depending on the production process, biodiesel might have a non-zero fossil fuel fraction, resulting in a not entirely carbon neutral fuel. One study (Ofgem, 2015) has, for example, shown that different production pathways may result to a fossil fuel carbon content of about 5.5%.

Table 3.30 contains the kg of fossil CO₂ per kg of FAME for the different production pathways.

Table 3-29: Ratios of hydrogen to carbon and oxygen to carbon atoms for different reference blend fuels (REF) used in vehicle testing and estimated values for non-reference fuels and blends

Fuel (m)	Typical Molecule	Ratio of hydrogen to carbon (r _{H:C})	Ratio of oxygen to carbon (r _{O:C})	kg CO ₂ per kg of fuel ¹
Petrol	[CH _{1.86}] _x	1.86	0.0	3.169
Diesel	[CH _{1.86}] _x	1.86	0.0	3.169
Ethanol	C ₂ H ₅ OH	3.00	0.5	1.911
Methanol	CH ₃ OH	4.00	1.00	1.373
Biodiesel	[CH] _x -COOH	1.95-2.03	0.11-0.13	2.797-2.727
ETBE	C ₆ H ₁₄ O	2.33	0.167	2.584
MTBE	C ₅ H ₁₂ O	2.40	0.20	2.496
Natural Gas / Biogas (REF)	CH ₄ , market fuels also contain heavier HC	4.00	0.00	2.473
LPG (REF)	C ₃ H ₈ (15%)-C ₄ H ₁₀ (85%), market fuels may contain different proportions	2.525	0.00	3.024
E5		1.92	0.026	3.063
E10 (REF)		1.98	0.053	2.694
E75		2.73	0.38	2.111
E85 (REF)		2.84	0.429	2.026
ETBE11		1.91	0.018	3.094
ETBE22		1.96	0.036	3.021
B7 (REF)		1.86	0.007	3.144
B10		1.86	0.010	3.133
B20		1.87	0.020	3.096
B30		1.88	0.030	3.059

Notes:

¹ CO₂ emission factors are based on an assumed 100% oxidation of the fuel carbon (ultimate CO₂).

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E5 and E10 are widely available in Europe and can be used directly in petrol vehicles without any modifications to the engine. E85 is used in engines modified to accept higher content of ethanol. Such flexi-fuel vehicles (FFV) are designed to run on any mixture of petrol or ethanol with up to 85% ethanol by volume. E85 is widely used in Sweden and also available in other European countries, e.g. Finland.

Table 3-30: Overview of biodiesel production pathways and the respective fossil CO₂ ratio in FAME CO₂

Production pathway	kg fossil CO ₂ / kg FAME
Sunflower	0.150
Rapeseed	0.147
Palm oil	0.145
Cottonseed	0.152
Tallow	0.148
Lard	0.147

CO₂ due to lubricant oil

New and properly maintained vehicles normally consume small amounts of lubrication oil, due to the oil film developed on the inner cylinder walls. This oil film is exposed to combustion and is burned along with the fuel. Wear due to prolonged engine operation usually increases lube oil consumption, so this should be expected to increase, on an average, with vehicle age. A different vehicle category, operating with 2-stroke engine, consumes much more lubricant oil as this is fed in the intake of the vehicle in blend form with the fuel or through a separate injector. A much higher lube oil quantity is needed in this case, which is practically completely combusted in the cylinder. Oil combustion, although a less important factor than fuel combustion, also leads to CO₂ production and should be taken into account in the national totals for completeness.

Table 3-31 contains typical oil consumption factors for different vehicle types, fuel used and vehicle age. All values are in mass of oil consumed (kg) per 10 000 km of vehicle operation. This dataset was compiled using input from various sources, such as internet references, and interviews with vehicle maintenance experts and fleet operators in Greece. The definition of an 'old' vehicle is ambiguous; in general a vehicle is considered old at or beyond its typical useful life (normally ~150 000 for a passenger car).

Table 3-31 : Lubricant oil consumption rate for different vehicle types, fuel and age in kg/10 000km

Category	Fuel/engine category	Age	kg/10 000 km		
			Mean	Min	Max
PC	Petrol	Old	1.45	0.85	2.13
	Petrol	New	1.28	0.85	1.70
	Diesel	Old	1.49	0.85	2.13
	Diesel	New	1.28	0.43	2.13
LCV	Petrol	Old	1.45	0.85	2.13
	Petrol	New	1.28	0.85	1.70
	Diesel	Old	1.49	0.85	2.13
	Diesel	New	1.28	0.43	2.13
Urban Buses	Diesel	Old	8.50		
	Diesel	New	0.85		

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Coaches	Diesel	Old	1.91	1.70	2.13
	Diesel	New	1.70	1.28	2.13
HDV	Diesel	Any	1.56		
Mopeds	2-stroke	Old	10.20	6.80	13.60
	2-stroke	New	6.80	5.10	8.50
Motorcycles	4-stroke	Any	0.43		
Mini-cars	Diesel	Any	1.28	0.85	2.13
ATVs	Petrol	Any	0.43		

CO₂ emissions due to lube oil consumption can be calculated by means of equation (16), where fuel consumption should be replaced by the values of Table 3-31. This will lead to CO₂ emitted in kg per 10 000 km which has to be converted to t/km by multiplying with 10⁻⁷. Typical values for lube oil hydrogen to carbon ratio (r_{H:C}) is 2.08, while oxygen to carbon ratio (r_{O:C}) is 0.

CO₂ due to exhaust additives

Aftertreatment systems used to reduce NO_x emissions utilize an aqueous solution of urea as a reducing agent. These are common in Euro V and Euro VI heavy duty vehicles and expected to become widespread in Euro 6 diesel light commercial vehicles as well. Urea has a chemical type of (NH₂)₂CO and when it is injected upstream of a hydrolysis catalyst in the exhaust line, then the following reaction takes place:



The ammonia formed by this reaction is the primary agent that reacts with nitrogen oxides to reduce them to nitrogen. However, this hydrolysis equation also leads to the formation of a carbon dioxide molecule that is released to the atmosphere. This contributes to total CO₂ emitted from these vehicles.

The specifications of commercially available urea solution as an SCR agent for mobile use are regulated by DIN 70070, which specifies that urea should be in aqueous solution at a content of 32.5% wt (±0.7%) and a density of 1.09 g/cm³. If total commercial urea solution sales are known (UC in litres), then total ultimate CO₂ emissions (in kg) by the use of the additive can be calculated by means of the following equation:

$$E_{CO_2,urea} = 0.26 \times UC \quad (18)$$

The coefficient 0.26 (kg CO₂/lt urea solution) takes into account the density of urea solution, the molecular masses of CO₂ and urea and the content of urea in the solution. If total urea consumption is known in kg, then the coefficient needs to change to 0.238 (kg CO₂/kg urea solution).

If total urea solution consumption is not known, then one may assume that the consumption of urea solution is ~5-7% of fuel consumption at a Euro V level and ~3-4% of fuel consumption at a Euro VI level. Therefore, one first needs to calculate the share of SCR-equipped vehicles in each technology class and calculate their fuel consumption, then apply a coefficient in the range proposed above and sum up to calculate UC. After doing so, CO₂ emission can be calculated by applying equation (18).

Sulphur dioxide (SO₂) emissions

Emissions of SO₂ are estimated by assuming that all the sulphur in the fuel as well as the sulphur contained in the consumed lubricant is completely transformed into SO₂. To calculate the emitted SO₂ the following formula is used:

$$E = 2 \times k_{S,m} \times FC_{k,m}^{Calc} + 2 \times k_{S,l} \times LC_{k,l}^{Calc} \quad (19)$$

where,

$k_{S,m}$ = weight-related sulphur content in fuel of type m [kg/kg fuel]
 $k_{S,l}$ = weight-related sulphur content in lubricant of type l [kg/kg lubricant]

Lead (Pb) and other heavy metals emissions

Emissions of lead have been significantly dropped in Europe, as a result of unleaded petrol introduction already from the early 1990s. In the case of the few instances where leaded fuel is still available, Hassel et al. (1987) identified that only approximately 75% of the total lead is emitted to the atmosphere. Therefore for inventories referring to the early 1990s it is advised to provide a reduced fuel lead content in the fuel specifications according to the abovementioned observation. This is mathematically expressed in the following equation.

$$E_{Pb,k}^{CALC} = 0.75 \times k_{Pb,m} \times FC_{k,m}^{CALC} \quad (20)$$

where,

$k_{Pb,m}$ = weight-related lead content of petrol (type m) in [kg/kg fuel].

With regard to the emission of all other heavy metal species, as well as trace lead content of unleaded petrol, the fuel metal content factors provided ($\mu\text{g}/\text{kg}$) are assumed to include fuel and engine wear. Therefore, these are apparent fuel metal content which should provide equivalent heavy metal emissions to fuel and engine-wear. In this case, it is considered that the total quantity is emitted to the atmosphere (i.e. there are no losses in the engine). Therefore, emissions of heavy metals included in Group 2 are calculated by means of the equation:

$$E_{i,k}^{CALC} = k_{i,m} \times FC_{k,m}^{CALC} \quad (21)$$

where,

$k_{i,m}$ = weight-related content of heavy metal i in fuel type m [mg/kg fuel].

Lubricant oil also contains a number of heavy metals which is assumed to be emitted to the atmosphere when oil burning occurs in the combustion chamber (especially in the case of 2-stroke engines). A similar approach is followed in order to calculate emissions of heavy metals from lubricant oil by using the following equation:

$$E_{i,k}^{CALC} = k_{i,m} \times LC_{k,m}^{CALC} \quad (22)$$

where,

$k_{i,m}$ = weight-related content of heavy metal i in lubricant type m [mg/kg lubricant].

Similarly to CO₂ emissions, SO₂ and HM emissions must also be reported separately, especially in the case of 2-stroke engines. Lubricant consumption in 2-stroke engines is considered intentional, therefore emissions must be reported under 1A3b. On the other hand 4-stroke engine lubricant consumption is undesirable and should not take place. However small amounts are consumed in the combustion chamber and their emissions should be reported in 2G.

The apparent fuel metal content factors considered originate from the work of Winther and Slentø (2010) and have been reviewed by the TFEIP expert panel in transport. Despite the efforts to obtain reliable values, available information has been very limited and the uncertainty in the estimate of these values is still considered quite high.

Emission corrections

Equations (8) – (9) are used to calculate **baseline** emissions. Corrections are applied to the results in order to accommodate the variation in emissions resulting from the following:

- *vehicle age (mileage)*. The baseline emission factors to be used in equation (8) correspond to a fleet of average mileage (30 000–60 000 km) and a degradation factor is therefore inherent. For petrol and diesel passenger cars and light commercial vehicles only, further emission degradation — due to increased mileage — should be modelled using additional degradation factors. However, for the sake of consistency between the Member States, it is proposed not to introduce such corrections when compiling a baseline inventory up to the year 2000 because of the relatively low fleet age. However, when inventories and forecasts for future years need to be made, it is advisable to correct emission factors according to mileage to introduce the effect of vehicle age in the calculations.
- *improved fuels*. Improved fuels have become mandatory in the EU since 2000. The effects of improved fuels on emissions from current and older vehicles can again be accommodated using appropriate correction factors. These corrections should only be applied in inventories compiled for years after the introduction of the improved fuels.
- *road gradient and vehicle load*. Corrections need to be made to heavy-duty vehicle emissions for uphill and downhill driving. The corrections should only be applied in national inventories by those Member States where statistical data allow for a distinction of heavy-duty vehicle mileage on roads of positive or negative gradient. Also, by default, a factor of 50% is considered for the load of heavy-duty vehicles. In cases where significant deviations exist for the mean load factor of the heavy-duty vehicle fleet, respective corrections should be applied.

Emission degradation due to vehicle age

Correction factors need to be applied to the baseline emission factors for petrol and diesel passenger cars and light commercial vehicles to account for different vehicle age. These correction factors are given by equation:

$$MC_{C,i} = A_M \times M_{MEAN} + B_M \quad (23)$$

where,

- | | | |
|------------|---|--|
| $MC_{C,i}$ | = | the mileage correction factor for a given mileage (M_{av}) and pollutant i , |
| M_{MEAN} | = | the mean fleet mileage of vehicles for which correction is applied, |
| A_M | = | the degradation of the emission performance per kilometre, |
| B_M | = | the emission level of a fleet of brand new vehicles. |

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Degradation of the emissions is assumed that starts after 50 000 km and does not further increase after 200 000 km. Therefore, MC is equal to 1 below 50 000 km and remains stable above 200 000 km.

Fuel effects

Fuels of improved specification became mandatory in Europe in two steps: January 2000 (Fuel 2000) and January 2005 (Fuel 2005) respectively. The specifications of these fuels are displayed in Table 3-32 (petrol) and Table 3-33 (diesel). Because of their improved properties, the fuels result in lower emissions from vehicles. Therefore, the stringent emission standards of Euro 3 technology (introduced ~2000) are achieved with Fuel 2000, and the more stringent emission standards of Euro 4 and 5 with Fuel 2005. Table 3-34 shows the base emission factors for fuel considered for each vehicle class.

However, the use of such fuels also results in reduced emissions from pre-Euro 3 vehicle technologies, for which the 1996 market average fuel is considered as a basis (Table 3-34). These reductions are applicable to both hot and cold-start emissions. To correct the hot emission factors, equations derived in the framework of the The European Programme on Emissions, Fuels and Engine Technologies (EPEFE) programme (ACEA and Europia, 1996) are applied. Table 3-94, Table 3-95 and Table 3-96 display the equations for different vehicle categories and classes.

Table 3-32: Petrol fuel specifications

Property	1996 base fuel (market average)	Fuel 2000	Fuel 2005
Sulphur [ppm]	165	130	40
RVP [kPa]	68 (summer) 81 (winter)	60 (summer) 70 (winter)	60 (summer) 70 (winter)
Aromatics [vol. %]	39	37	33
Benzene [vol. %]	2.1	0.8	0.8
Oxygen [wt %]	0.4	1.0	1.5
Olefins [vol. %]	10	10	10
E100 [%]	52	52	52
E150 [%]	86	86	86
Trace Lead [g/l]	0.005	0.002	0.00002

Table 3-33: Diesel fuel specifications

Property	1996 base fuel (market average)	Fuel 2000	Fuel 2005
Cetane number [-]	51	53	53
Density at 15 °C [kg/m ³]	840	840	835
T ₉₅ [°C]	350	330	320
PAH [%]	9	7	5
Sulphur [ppm]	400	300	40
Total Aromatics [%]	28	26	24

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
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Table 3-34: Base fuels for each vehicle class

Vehicle Class	Base Fuel	Available Improved Fuel Qualities
Pre- Euro 3	1996 base fuel	Fuel 2000, Fuel 2005
Euro 3	Fuel 2000	Fuel 2005
Euro 4	Fuel 2005	Fuel 2009
Euro 5 and later	Fuel 2009	-

The hot emission factors are corrected according to the equation:

$$FC_{e_{HOT}; i, k, r} = FC_{Corr; i, k, Fuel} / FC_{Corr; i, k, Base} \times e_{HOT; i, k, r} \quad (24)$$

where,

- $FC_{e_{HOT}; i, k, r}$: = the hot emission factor, corrected for the use of improved fuel for pollutant i of vehicle technology k driven on road class r ,
- $FC_{Corr; i, k, Fuel}$: = the fuel correction for pollutant i , vehicle technology k , calculated with equations given in Table 3-94, Table 3-95 and Table 3-96 for the available improved fuel qualities (Table 3-34),
- $FC_{Corr; i, k, Base}$: = the fuel correction for pollutant i , calculated with equations given in Table 3-94, Table 3-95 and Table 3-96 for the base fuel quality of vehicle technology k (Table 3-34).

Equation (24) should not be used to provide the deterioration of emissions where an older fuel is used in a newer technology (e.g. use of Fuel 2000 in Euro 4 vehicles) by inversion of FC coefficients. The emission factor calculated via equation (24) should be introduced in equations (8) and (10) or (11) respectively to estimate hot and cold-start emissions.

3.4.2 Relevant activity statistics

In principle, vehicle statistics are readily available from the national statistical offices of all countries, and from international statistical organisations and institutes (e.g. Eurostat, IRF). However, it must be stressed that these statistics are almost exclusively vehicle-oriented (i.e. comprising fleet data), with information about aggregated categories only (e.g. passenger cars, trucks, buses, motorcycles). In addition, little information referring to the age and technology distribution can be found in a consistent form, and very little information is available as regards activity (with the exception of fuel statistics). In addition, more detailed traffic data required for the calculations (such as average trip length for cold start emissions) are available only in a few countries. Detailed data on vehicle stocks for all EU-27 countries and CH, HR, NO, TR can be also found on the COPERT web-site (<http://www.emisia.com/copert>). These data have no official status but are a result of a research project (Ntziachristos et al., 2008). However, they can be used as a good guide in the absence of more detailed information. Data for several other countries can be produced in an indirect way. The following may be helpful in this respect:

- *age and technology distribution*: the (generally available) time series on fleet evolution and annual new registrations can be used to derive estimates of appropriate scrappage rates. By combining the above with implementation dates of certain technologies, a relatively good picture of the fleet composition in specific years can be obtained;
- *mileage driven and mileage split*: energy/fuel consumption calculated on the basis of appropriate assumptions for annual mileage of the different vehicle categories can be balanced with available

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fuel statistics. By applying the abovementioned energy balance methodology, it is possible to reach acceptable estimates of mileage.

For the calculation of cold-start related emissions, the mean trip length is necessary. Table 3-35 provides the figures submitted by national experts in a previous COPERT exercise. Although these data refer to traffic conditions a decade ago, they can still be used with confidence because mean trip length is a highly aggregate value which little varies from year-to-year.

3.4.3 Emissions factors

The Tier 3 emission factors for non-catalyst petrol cars were developed by the Corinair Working Group (Eggleston et al., 1993), taking into account the results of comprehensive studies carried out in France, Germany, Greece, Italy, the Netherlands and the United Kingdom. In addition, some data measured in Austria, Sweden and Switzerland were incorporated. For petrol catalyst-equipped cars, improved diesel cars (91/441/EEC and later) and diesel heavy-duty vehicles, the emission factors are derived from the results of the Artemis project. The emission factors for light commercial vehicles originate from the MEET project, and those for L-category vehicles are taken from various DG Growth studies.

Table 3-35: Examples of average estimated trip length values- l_{trip} — as taken by COPERT 1990 updated run

Country	Trip length [km]	Country	Trip length [km]
Austria	12	Hungary	12
Belgium	12	Ireland	14
Denmark	9	Italy	12
Germany	14	Luxembourg	15
Spain	12	Netherlands	13.1
France	12	Portugal	10
Finland	17	UK	10
Greece	12		

Table 3-36: Coding used for the methodological approaches adopted for each vehicle category

Method	Hot Emissions	Cold Start Overemission	Evaporation Losses*
A	the total annual kilometres driven per vehicle the share of kilometres driven under the driving modes A1: the average speed of the vehicles under the driving modes A2: driving mode dependent emission factors	The average trip length per vehicle trip the average monthly temperature, trip length and catalyst technology dependent cold start correction factor	the fuel volatility (RVP) the average monthly temperature and temperature variation fuel volatility and temperature dependent emission factor
B	the total annual kilometres driven per vehicle the share of kilometres driven under the driving modes B1: the average speed of the vehicles under the driving modes B2: driving mode dependent emission factors	No Cold Start Overemission Calculations	the fuel volatility (RVP) the average monthly temperature and temperature variation fuel volatility and temperature dependent emission factor
C	the total annual kilometres driven per vehicle the share of kilometres driven under the driving modes	No Cold Start Overemission Calculations	No Evaporation Calculations

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	driving mode dependent emission factors		
D	the total annual fuel consumption of the vehicle category fuel consumption related emission factors	No Cold Start Overemission Calculations	No Evaporation Calculations

*Attributed only to NMVOC emissions from gasoline powered vehicles

The emission factors can be broadly separated into two classes according to the pollutant: those for which a detailed evaluation is necessary and possible, and those for which simpler 'bulk' emission factors or equations can be provided. The pollutants CO, VOCs and NO_x and PM (as well as energy consumption) are in the first category, whereas SO₂, NH₃, Pb, CO₂, N₂O and (partly) CH₄ are the second one.

The presentation of the emission factors firstly covers CO, VOCs, NO_x and PM (the pollutants which have been regulated in legislation), and energy consumption, for the individual SNAP activities. The 'bulk' emission factors for unregulated pollutants — SO₂, NH₃, Pb, CO₂, N₂O and CH₄ — are then addressed. Table 3-36 and Table 3-37 show the level of detail which is necessary for the calculation of emissions from each vehicle technology.

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Table 3-37: Summary of calculation methods applied for the different vehicle classes and pollutants

Vehicle category	NO _x	CO	NM VOC	CH ₄	PM	N ₂ O	NH ₃	SO ₂	CO ₂	Pb	HM	EC
Petrol passenger cars												
Pre-ECE	A1	A1	A1	A2	-	A2	A2	D	D	D	D	A1
ECE 15/00-01	A1	A1	A1	A2	-	A2	A2	D	D	D	D	A1
ECE 15/02	A1	A1	A1	A2	-	A2	A2	D	D	D	D	A1
ECE 15/03	A1	A1	A1	A2	-	A2	A2	D	D	D	D	A1
ECE 15/04	A1	A1	A1	A2	-	A2	A2	D	D	D	D	A1
Improved conventional	A1	A1	A1	A2	-	A2	A2	D	D	D	D	A1
Open loop	A1	A1	A1	A2	-	A2	A2	D	D	D	D	A1
Euro 1 to Euro 6	A1	A1	A1	A1	B2	A2	A2	D	D	D	D	A1
Diesel passenger cars												
Conventional	A1	A1	A1	A1	A1	C	C	D	D	D	D	A1
Euro 1 to Euro 6	A1	A1	A1	A1	A1	C	C	D	D	D	D	A1
LPG passenger cars												
	A1	A1	A1	A2	-	C	-	-	D	-	-	A1
2-stroke passenger cars												
	C	C	C	C	-	C	C	D	D	D	D	C
E85 passenger cars												
	A1	A1	A1	A1	-	A2	A2	D	D	D	D	A1
CNG passenger cars												
	A1	A1	A1	A1	-	A2	A2	D	D	D	D	A1
Light commercial vehicles												
Petrol < 3.5 t conventional	A1	A1	A1	A2	-	A2	A2	D	D	D	D	A1
Petrol < 3.5 t Euro 1 to Euro 6	A1	A1	A1	A1	B2	A2	A2	D	D	D	D	A1
Diesel < 3.5 t conventional	A1	A1	A1	A2	A1	A2	A2	D	D	D	D	A1
Diesel < 3.5 t Euro 1 to Euro 6	A1	A1	A1	A2	A1	A2	A2	D	D	D	D	A1
Heavy-duty vehicles > 3.5 t												
Petrol conventional	C	C	C	C	-	C	C	D	D	D	D	C
Diesel conventional	B1	B1	B1	C	B1	C	C	D	D	D	D	B1
Diesel Euro I to Euro VI	B1	B1	B1	C	B1	C	C	D	D	D	D	B1
Buses and coaches conventional	B1	B1	B1	C	B1	C	C	D	D	D	D	B1
Buses and coaches Euro I to VI	B1	B1	B1	C	B1	C	C	D	D	D	D	B1
L-category vehicles												
Mopeds < 50 cm ³	B2	B2	B2	C	B2	C	C	D	D	D	D	B2
Motorcycles 2-stroke > 50 cm ³	B1	B1	B1	C	B2	C	C	D	D	D	D	B1
Motorcycles 4-stroke 50–250 cm ³	B1	B1	B1	C	B2	C	C	D	D	D	D	B1
Motorcycles 4-stroke 250–750 cm ³	B1	B1	B1	C	B2	C	C	D	D	D	D	B1
Motorcycles 4-stroke > 750 cm ³	B1	B1	B1	C	B2	C	C	D	D	D	D	B1
Mini-cars	B1	B1	B1	C	B2	C	C	D	D	D	D	B1
ATVs	B1	B1	B1	C	B2	C	C	D	D	D	D	B1

Petrol passenger cars

Hot Emissions

Hot emission factors are speed dependant and are expressed in g/km. They differ by fuel, vehicle class and engine technology. In previous versions of this chapter a number of functions were provided to calculate hot emission factors for the different vehicle categories. All these functions are now consolidated into a single equation. Due to the large number of the equation coefficients required to calculate emissions for all the different vehicle categories, all relevant figures can be found in Appendix 4. The emissions covered by the methodology are CO, VOC, NO_x, PM and energy consumption.

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
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The following generic equation can be used to calculate the speed (V) dependant emission factors (EF) for all vehicle classes and pollutants. Where necessary a reduction factor (RF) is applied.

$$EF = (\text{Alpha} \times V^2 + \text{Beta} \times V + \text{Gamma} + \text{Delta} / V) / (\text{Epsilon} \times V^2 + \text{Zeta} \times V + \text{Eta}) \times (1 - \text{RF}) \quad (25)$$

Cold start emissions

Pre Euro 1 vehicles

Table 3-38 provides $e^{\text{COLD}}/e^{\text{HOT}}$ emission quotients for the pollutants in Group 1. The β -parameter is calculated by means of the equation provided in Table 3-39. The introduction of the values in equation (10), together with the hot emission factors quoted previously, provides estimates of cold-start emissions. Again, the quotients were produced during older COPERT versions.

Table 3-38: Cold-start emission quotient ($e^{\text{COLD}}/e^{\text{HOT}}$) for conventional petrol vehicles (temperature range of -10 °C to 30 °C)

Pollutant or EC	$e^{\text{COLD}} / e^{\text{HOT}}$
CO	3.7 - 0.09 t_a
NO _x	1.14 - 0.006 t_a
VOC	2.8 - 0.06 t_a
Energy consumption	1.47 - 0.009 t_a

Table 3-39: Cold mileage percentage β

Calculations based on	β -parameter (Beta parameter)
Estimated l_{trip}	$0.6474 - 0.02545 \times l_{\text{trip}} - (0.00974 - 0.000385 \times l_{\text{trip}}) \times t_a$

Euro 1 to Euro 5 vehicles**Table 3-40: Over-emission ratios $e^{\text{COLD}} / e^{\text{HOT}}$ for Euro 1 to Euro 5 petrol vehicles (V: speed in km/h, t_a : temperature in °C)**

Case	Category	Speed [km/h]	Temp [°C]	$e^{\text{COLD}}/e^{\text{HOT}} = A \times V + B \times t_a + C$		
				A	B	C
CO	Mini, Small	5-25	-20 : 15	0.156	-0.155	3.519
		26-45	-20 : 15	0.538	-0.373	-6.24
		5-45	> 15	8.032E-02	-0.444	9.826
	Medium	5-25	-20 : 15	0.121	-0.146	3.766
		26-45	-20 : 15	0.299	-0.286	-0.58
		5-45	> 15	5.03E-02	-0.363	8.604
	Large-SUV-Executive	5-25	-20 : 15	7.82E-02	-0.105	3.116
		26-45	-20 : 15	0.193	-0.194	0.305
		5-45	> 15	3.21E-02	-0.252	6.332
NOx	Mini, Small	5-25	> -20	4.61E-02	7.38E-03	0.755
		26-45	> -20	5.13E-02	2.34E-02	0.616
	Medium	5-25	> -20	4.58E-02	7.47E-03	0.764
		26-45	> -20	4.84E-02	2.28E-02	0.685
	Large-SUV-Executive	5-25	> -20	3.43E-02	5.66E-03	0.827
		26-45	> -20	3.75E-02	1.72E-02	0.728
VOC	Mini, Small	5-25	-20 : 15	0.154	-0.134	4.937
		26-45	-20 : 15	0.323	-0.240	0.301
		5-45	> 15	9.92E-02	-0.355	8.967
	Medium	5-25	-20 : 15	0.157	-0.207	7.009
		26-45	-20 : 15	0.282	-0.338	4.098
		5-45	> 15	4.76E-02	-0.477	13.44
	Large-SUV-Executive	5-25	-20 : 15	8.14E-02	-0.165	6.464
		26-45	-20 : 15	0.116	-0.229	5.739
		5-45	> 15	1.75E-02	-0.346	10.462
EC	All classes	-	-10 : 30	0	-0.009	1.47

Note: If the calculated value of $e^{\text{COLD}} / e^{\text{HOT}}$ is less than 1, a value of 1 should be used.

Emissions of catalyst-equipped vehicles during the warming-up phase are significantly higher than during stabilised thermal conditions due to the reduced efficiency of the catalytic converter at temperatures below the light-off. Therefore, the effect of cold start has to be modelled in detail for Euro 1 and later vehicles.

Table 3-40 provides $e^{\text{COLD}}/e^{\text{HOT}}$ emission quotients for three main pollutants and energy consumption. The values are a result of fitting the existing COPERT methodology to the results published by MEET, and are a function of ambient temperature and average trip speed. Two speed regions have been introduced (5-25 km/h and 25-45 km/h). As in the case of the hot emission factors, the value introduced for speed should correspond to the mean trip speed, and not to the instantaneous speed. The speed range proposed is sufficient to cover most applications because excess cold-start emissions are allocated to urban driving only.

For CO and VOCs, the excess cold-start emission occurs not only because of the low catalyst conversion efficiency, but also because of the fuel enrichment during cold start conditions which allows for better drivability of a cold engine. The enrichment depends on the engine temperature during cold start. Therefore, the excess emission of these pollutants during cold starts is not only higher than NO_x (which

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is generally not sensitive to fuel enrichment), but it also has a stronger dependence on temperature. This is why two different temperature ranges have to be defined for CO and VOCs.

Generally, the cold-start effect becomes negligible above 25 °C in the case of CO, and above 30 °C in the case of VOCs. This is not only because excess emission under such ambient conditions is small, but also because engines cool down more slowly and the actual engine start-up temperature can still be high after several hours of parking.

The mileage fraction driven during the warm-up phase is calculated by means of the formula provided in Table 3-39. After calculating the β -parameter and $e^{\text{COLD}}/e^{\text{HOT}}$, the application of equations (10) or (11) is straightforward.

Compared with Euro 1 vehicles, the emission reduction during the warm-up phase of post-Euro 1 vehicles is mainly due to the reduced time which is required for new catalytic systems to reach the light-off temperature. This time reduction is further reflected in a decrease in the distance travelled with a partially warm engine and/or exhaust aftertreatment devices. Therefore, reduced cold start emissions are modelled by decreasing the value of the β -parameter (i.e. the mileage fraction driven with a cold or partially warm engine). Table 3-41 provides the reduction factors ($bc_{i,k}$) to be applied to the β -parameter according to the pollutant and vehicle class.

Table 3-41: β -reduction factors ($bc_{i,k}$) for Euro 1 to Euro 5 petrol vehicles (relative to Euro 1)

Emission legislation	CO	NOx	VOC
Euro 2 — 94/12/EC	0.72	0.72	0.56
Euro 3 — 98/69/EC Stage 2000	0.62	0.32	0.32
Euro 4 and Euro 5	0.18	0.18	0.18

On the other hand, there is no evidence to support the use of different values of $e^{\text{COLD}}/e^{\text{HOT}}$ for different vehicle classes ⁽⁷⁾. This means that the $e^{\text{COLD}}/e^{\text{HOT}}$ values calculated for Euro 1 vehicles can be also applied to later vehicle classes without further reductions. Similarly, the hot emission factor used in the estimation of cold-start emissions should also be the Euro 1 value.

Therefore, in the case of post-Euro 1 vehicles, equation (10) becomes:

$$E_{\text{COLD};i,k} = bc_{i,k} \times \beta_{i,\text{Euro 1}} \times N_k \times M_k \times e_{\text{hot}, i, \text{Euro 1}} \times (e^{\text{COLD}} / e^{\text{HOT}} - 1) |_{i, \text{Euro 1}} \quad (26)$$

Similar modifications should also be brought into equation (11) in cases where $bc_{i,k} \times \beta_{i,\text{EURO 1}} > S_U$. Obviously, the corrected value should be applied to the mileage fraction during the warm-up phase.

Euro 6 vehicles

⁽⁷⁾ This statement probably fails to predict the additional emission reduction which might be brought by the cold start testing (-7 °C) for Euro III and later vehicles. Most probably, the mixture enrichment strategy has to change in order that such vehicles comply with this test. This by turn will lead to a reduction of the $e^{\text{COLD}}/e^{\text{HOT}}$ ratio. However the magnitude of the effect of such modification at higher temperatures is arguable. Because of this reason and in the absence of a more detailed analysis for the time being, it was decided to abandon any correction of $e^{\text{COLD}}/e^{\text{HOT}}$ ratio.

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Table 3-42

Case	Speed [km/h]	Temp [°C]	$e^{COLD}/e^{HOT} = A \times V + B \times t_a + C$		
			A	B	C
CO	5-45	< 0	-0.235	-1.306	19.882
	5-45	> 0	-0.110	0.000	17.461
NOx	5-45	< 0	0.097	-0.181	5.651
	5-45	> 0	0.089	0.000	7.257
VOC	5-45	< 0	0.317	-3.612	38.115
	5-45	> 0	0.166	0.000	43.859

Note: If the calculated value of e^{COLD}/e^{HOT} is less than 1, a value of 1 should be used. Table 3-42 provides e^{COLD}/e^{HOT} emission quotients for three main pollutants. The EC quotients for Euro 6 are the same from Euro 1 to Euro 5. The values are a result of fitting the existing COPERT methodology to the measurement data from Euro 6 passenger cars, and are a function of ambient temperature and average trip speed. Two temperature regions have been introduced below and above zero degrees. The cold overemission from the most recent Euro Standards is not affected by the temperature above 0°C, and as a result the temperature coefficient is considered 0.

The part of the l_{trip} driven in cold conditions is described by the parameter Beta. The most recent technologies reduce the distance in cold conditions and as a result a β -reduction factor is implemented.

Table 3-43 β -reduction factors ($b_{ci,k}$) for Euro 6 petrol vehicles

Pollutant	$b_{ci,k}$ (β -reduction factor)
CO	$0.1902 - 0.006 * l_{trip}$
NOx	$0.1573 - 0.005 * l_{trip}$
VOC	$0.2072 - 0.0066 * l_{trip}$

In case of Euro 6 vehicles the equation 10 becomes:

$$E_{COLD; i, j} = \beta_i, k \times b_{ci,k} N_k \times M_k \times e^{HOT; i, k} \times (e^{COLD} / e^{HOT} |_{i,k} - 1)$$

Diesel passenger cars

Hot emissions

Experimental data from measurements on diesel passenger cars < 2.5 tonnes (Hassel et al., 1987; Pattas et al., 1985; Rijkeboer et al., 1989; 1990) enabled a differentiation to be made between cylinder capacities for NO_x, and speed-dependent emission factors to be developed for conventional (pre Euro 1) vehicles. For later technologies it is worth noting that some manufacturers produced diesel cars equipped with DPFs even at the Euro 3 stage. These vehicles were not significantly different from 'conventional' Euro 3 vehicles in terms of emissions of NO_x, CO or HC, but did have lower PM emissions.

The emission factors to be introduced in equation (8) for the calculation of hot emissions from diesel passenger cars (all technologies from conventional to Euro 6) can be calculated by applying equation (25) and using the coefficients included in the accompanying Excel file.

Cold-start emissions

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

Pre Euro 1 to Euro 5 vehicles

Excess cold-start emissions from diesel vehicles are not very significant compared with those from petrol vehicles. Therefore, no distinction is made between the different diesel vehicle types. The β parameter is calculated for all vehicle classes using the formula given in Table 3-39 and the values of $e^{\text{COLD}}/e^{\text{HOT}}$ are given in Table 3-44. Based on these, equation (10) can be applied to calculate cold start emissions from diesel passenger cars.

Table 3-44: Values of $e^{\text{COLD}} / e^{\text{HOT}}$ for diesel passenger cars (temperature range -10 °C to 30 °C)

Pollutant or EC	$e^{\text{COLD}} / e^{\text{HOT}}$
CO	$1.9 - 0.03 t_a$
NO _x	$1.3 - 0.013 t_a$
VOC	$3.1 - 0.09 t_a^{(1)}$
PM	$3.1 - 0.1 t_a^{(2)}$
Energy consumption	$1.34 - 0.008 t_a$

Note: ⁽¹⁾ VOC: if $t_a > 29$ °C then $e^{\text{COLD}} / e^{\text{HOT}} = 0.5$; ⁽²⁾ PM: if $t_a > 26$ °C then $e^{\text{COLD}} / e^{\text{HOT}} = 0.5$

Euro 6 vehicles

Table 3-45 Over-emission ratios $e^{\text{COLD}} / e^{\text{HOT}}$ for Euro 6 diesel vehicles (V: speed in km/h, t_a : temperature in °C)

Case	Euro Standard	Speed [km/h]	Temp [°C]	$e^{\text{COLD}}/e^{\text{HOT}} = A \times V + B \times t_a + C$		
				A	B	C
CO	Euro 6 a/b/c	5-45	< 0	0.504	-4.197	7.588
		5-45	> 0	0.091	0.000	11.477
	Euro 6d-temp	5-45	< 0	0.820	-9.184	21.879
		5-45	> 0	0.147	0.000	25.089
	Euro 6d	5-45	< 0	0.897	-10.045	23.836
		5-45	> 0	0.161	0.000	27.347
NO _x	Euro 6 a/b/c	5-45	< 0	0.015	-0.236	2.264
		5-45	> 0	0.005	0.000	2.327
	Euro 6d-temp	5-45	< 0	0.121	-1.948	11.415
		5-45	> 0	0.038	0.000	11.929
	Euro 6d	5-45	< 0	0.151	-2.435	14.019
		5-45	> 0	0.048	0.000	14.661
VOC	All Euro Standards	5-45	< 0	-0.545	-0.970	22.280
		5-45	> 0	-0.286	0.000	18.445

Note: If the calculated value of $e^{\text{COLD}} / e^{\text{HOT}}$ is less than 1, a value of 1 should be used. Table 3-45 provides $e^{\text{COLD}}/e^{\text{HOT}}$ emission quotients for three main pollutants. The EC and PM quotients for Euro 6 are the same from Euro 1 to Euro 6. The values are a result of fitting the existing COPERT methodology to the measurement data from Euro 6 passenger cars, and are a function of ambient temperature and average trip speed. Two temperature regions have been introduced below and above zero degrees. The cold overemission from the most recent Euro Standards is not affected by the temperature above 0°C, and as a result the temperature coefficient is considered 0.

The part of the l_{trip} driven in cold conditions is described by the parameter Beta. The most recent technologies reduce the distance in cold conditions and as a result a β -reduction factor is implemented (Table 3-46).

Table 3-46 β -reduction factors (bci,k) for Euro 6 diesel vehicles

Pollutant	bc (β -reduction factor)
CO	0.2022 -0.0064 * ltrip
NOx	0.1719 -0.0055 * ltrip
VOC	0.2398 -0.0076 * ltrip

In case of Euro 6 vehicles the equation (10) becomes:

$$E_{\text{COLD}; i, j} = \beta_i, k \times b_{C_i, k} N_k \times M_k \times e^{\text{HOT}; i, k} \times (e^{\text{COLD}} / e^{\text{HOT}} |_{i, k} - 1)$$

LPG and CNG bi-fuel passenger cars

The methodology for petrol cars is also valid for LPG and CNG vehicles. However, it has to be stressed that the amount of data for LPG vehicles was very limited and therefore a large number of assumptions and extrapolations had to be made on the basis of existing information to provide a consistent set of emission factors for hot and cold-start emissions.

LPG (and CNG) cars have become quite widespread in an effort to benefit from the lower fuel price of gas fuels compared to petrol and diesel. There are two main types of such vehicles: The ones which are produced by OEMs to operate as bi-fuel vehicles, and conventional petrol vehicles later retrofitted by their owners to operate with LPG (and/or CNG). Bi-fuel vehicles may operate under LPG/CNG or petrol fuel. Total emissions are calculated by adding the emissions of both operating conditions and taking into account the vehicle activity driven with either fuel.

With respect to conventional pollutant emissions, there is a general feeling that such vehicles are cleaner than their petrol counterparts, as a result of the lighter fuel used compared to petrol. Technically this is not true. Spark-ignition vehicles have been optimized to operate on petrol and shifting to a different fuel should not a priori be expected to decrease emissions. Moreover, the main emission control in spark-ignition vehicles occurs in the catalytic converter and it has to be guaranteed that the new fuel continues to retain optimal conditions for the catalyst to operate efficiently.

Vonk et al. (2010) compared the emission levels of LPG (and CNG) cars of Euro 4 technology with conventional petrol Euro 4. The OEM bi-fuelled cars emitted NO_x and PM at the same level as their petrol counterparts. On the other hand, retrofitted LPG vehicles emitted, on average, more than twice as much NO_x and 2.5 times as much PM as the petrol vehicles. Retrofitted vehicles exceeded the petrol-based NO_x emission limit by 40%.

Retrofitted vehicles use simplified components to control emissions. The closed-loop controlled of the catalyst is either bypassed or is not as efficient as the OEM control. This results to higher emissions. Additionally, retrofitted vehicles need not be type-approved for their emission levels. A certificate for good installation is only issued by local authorities after the conversion and a simplified emission check (low and high idle) is performed. This is known to be able to detect large exceedances of CO and HC emission limits only.

Emissions from retrofitted cars may therefore become an air quality issue in areas where retrofits are frequent. Unfortunately, there are not many data available yet to develop detailed emission factors and activity data on retrofitted cars are sparse. It is recommended that LPG (and CNG) retrofit

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programmes are reviewed and numbers of retrofitted cars be monitored in order to track the extent of the problem.

Hot emissions

Equation (25) is used to calculate hot emissions for conventional, Euro 1 and Euro 2 LPG vehicles. Appendix 4 provides the values of the coefficients used to calculate the emission factors for those engine technologies. The former emission factors were developed in earlier COPERT exercises, and the latter in the MEET project. Post Euro 2 emission technologies use the same modelling and parameters as the equivalent technology step of medium petrol passenger cars.

CNG vehicles use the same modelling and parameters as the equivalent technology step of medium petrol passenger cars by applying a reduction factor for the energy consumption (difference in enthalpy of combustion). As a result, tailpipe CO₂ estimation is then computed using the calculated fuel consumption. VOC emissions also use the same concept.

Cold-start emissions

Very few data on cold-start emissions from conventional LPG vehicles are available (AQA, 1990; Hauger et al.; 1991). For consistency, however, and since LPG emission-control technology is similar to that of petrol vehicles, the methodology for calculating emissions from petrol vehicles is also applied here. Table 3-47 provides values of e^{COLD}/e^{HOT} which are valid for conventional LPG vehicles to be used in equations (10) and (11). For Euro 1 and later LPG vehicles, the identical methodology of petrol passenger cars is used (

Table 3-40). This is made on purpose. Both OEM and retrofitted LPG cars operate on petrol before the engine and the catalyst heat up. LPG is only used under fully warmed conditions. As a result, LPG and petrol car cold-start emissions are not expected to differ.

Table 3-47: Values of e^{COLD} / e^{HOT} for conventional LPG passenger cars (temperature range of -10°C to 30°C)

Pollutant or EC	e ^{COLD} / e ^{HOT}
CO	3.66 - 0.09 t _a
NO _x	0.98 - 0.006 t _a
VOC	2.24 - 0.06 t _a (1)
Energy consumption	1.47 - 0.009 t _a

Note: VOC: if t_a > 29 °C then e^{COLD} / e^{HOT} > 0.5.

CNG vehicles are categorised as Euro 4 or higher so their cold emissions are calculated using the methodology for Euro 1 and later petrol vehicles. For all emissions other than hydrocarbons, the same approach used for Euro 1 and later LPG vehicles is utilised; CNG vehicles use the same values (

Table 3-40) as the equivalent petrol size vehicles.

For the calculation of hydrocarbons, Table 3-48 provides the values of e^{COLD}/e^{HOT} for Euro 4/5/6 CNG vehicles to be used in equations (10) and (11).

Table 3-48 Over-emission ratios $e^{\text{COLD}} / e^{\text{HOT}}$ for Euro 4/5/6 CNG passenger cars compared to Euro 1 petrol vehicles (temperature range of -10°C to 30°C)

Case	Speed [km/h]	Temperature [$^{\circ}\text{C}$]	$e^{\text{COLD}}/e^{\text{HOT}} = A \times V + B \times t_a + C$		
			A	B	C
VOC	5- 25	-20 : 15	0.11856	-0.15633	5.53804
	26-45	-20 : 15	0.21296	-0.25526	3.33963
	5-45	> 15	0.03594	-0.36023	10.3947

Two-stroke passenger cars

Few emission measurements are available for two-stroke cars (Appel et al., 1989; Jileh, 1991; Pattas and Kyriakis, 1983). The available data were used to derive emission factors for urban, rural and highway driving for petrol cars in earlier COPERT exercises. Total emission factors (hot + cold) are given in Table 3-49. These are relevant mainly for some Eastern European countries (and to some extent for Germany). However, it should be noted that due to the limited knowledge of the authors about the actual driving behaviour in Eastern Europe (e.g. average speeds on urban and rural roads and on highways), and the limited number of test data, the emission factors are less reliable than, for example, those given for other petrol passenger cars.

Table 3-49: Emission factors for petrol two-stroke vehicles < 2.5 t

Driving mode	CO [g/km]	NO _x [g/km]	VOC [g/km]	Energy consumption [MJ/km]
Urban	20.7	0.30	15.4	4.88
Rural	7.50	1.0	7.20	2.89
Highway	8.70	0.75	5.90	2.49

Hybrid passenger cars

A limited database of emission measurements was used to derive emission factors for hybrid petrol cars in the Artemis project. Only Euro 4 'full' hybrids of less than < 1.6 l engine capacity were included. The term 'full' refers to hybrids that can start only powered by their electric motor. The methodology is similar to that for petrol cars, and equation (25) is used to calculate emission and consumption factors, expressed in g/km and MJ/km. Parameter values for equation (25) are given in Appendix 4.

Rechargeable vehicles

Plug-in hybrid electric vehicles (PHEVs) (or OVC-HEV: Off-Vehicle Charging Hybrid Electric Vehicle) use two energy sources for vehicle propulsion, an internal combustion engine (ICE) and a battery. The battery can be charged by plugging it into an external power source or on-board through the ICE and a generator. The operation of these vehicles can be divided into two main modes: charge-depleting (CD) mode and charge-sustaining (CS) mode. In CD mode the vehicle's operation is similar to a pure electric vehicle, as the energy for propulsion comes mainly from the electric motor, with the ICE switched off. In CS mode the state of charge (SOC) of the battery remains approximately the same and the main source of energy for propulsion is the ICE. The vehicle operates like a hybrid electric vehicle (HEV), as both the battery and the ICE are used. PHEVs can deliver significant reduction in the overall emissions of GHG and air pollutants. The exact reduction amounts largely depend on the utility factor, which is the ratio of the distance driven in CD mode (i.e. the electric driving) between two charge cycles (Hooftman et al., 2020).

Equation (25) can be applied and all relevant parameters can be found in Appendix 4.

For pure electric (or battery electric) vehicles exhaust emissions will be zero therefore these do not contribute to the road transport air pollutants inventory. All CO₂ emissions they implicitly produce will be due to electricity production, which is part of the power generation.

Petrol light commercial vehicles

Hot emissions

The emissions of these vehicles within EU countries were initially regulated in the different ECE steps. All such vehicles have been combined in a common 'conventional' class. However classes for Euro 1 and later light commercial vehicles have been introduced. A similar equation consolidation method as for the passenger cars has been used for the calculation of the speed dependant hot emission factors for petrol light commercial vehicles. Equation (25) can be applied and all relevant parameters can be found in Appendix 4. The emissions covered by the methodology are CO, VOC, NO_x, PM and energy consumption.

Cold start emissions

In the absence of more detailed data, the values of $e^{\text{COLD}}/e^{\text{HOT}}$ for Large-SUV petrol cars (> 2.0 l) are also applied to light commercial vehicles. Although this assumption used to be a very rough estimate for past vehicle classes, due to the very different emission standards of light commercial vehicles and passenger cars, it is now likely to be more robust since the technology used in current light commercial vehicles does not differ significantly from that used in cars. Therefore, the values of $e^{\text{COLD}}/e^{\text{HOT}}$ in Table 3-38 (pre-Euro 1) and

Table 3-40 (Euro 1 to Euro 5) are applied to light commercial vehicles. The values of Table 3-40 are also applied to Euro 6 light commercial vehicles. Furthermore, equations (10), (11) are also valid for pre-Euro 1 vehicles and equation (26) for Euro 1 and later vehicles, in conjunction with the β -parameter reduction factors given in Table 3-41.

Diesel light commercial vehicles

Hot Emissions

Diesel light commercial vehicles are treated as passenger cars. Speed-dependent hot emission factors were developed in earlier COPERT exercises (conventional vehicles) and in the MEET project (Euro 1 and later vehicles). To calculate hot emission factors Equation (25) can be applied and all relevant parameters can be found in Appendix 4. The emissions covered by the methodology are CO, VOC, NO_x, PM and energy consumption.

Cold-start emissions

Excess cold-start emissions for diesel light commercial vehicles are calculated using equation (10), with the $e^{\text{COLD}}/e^{\text{HOT}}$ values calculated for all vehicle technologies as shown on Table 3-44. The β -parameter is calculated for all vehicle classes using the formula given in Table 3-39.

Petrol heavy-duty vehicles

Only hot emissions are calculated for petrol heavy-duty vehicles. Emission factors — derived from an extrapolation of the data for smaller vehicles — can be found in Appendix 4.

Diesel heavy duty vehicles and buses

Hot emissions

Speed dependent emission factors for diesel heavy-duty vehicles (including urban buses and coaches) have been taken from HBEFA. The emission factors are provided for conventional vehicles and the Euro I to Euro VI emission standards. Due to the large number of data required to calculate emissions from these categories, all relevant information can be found in Appendix 4. The emissions covered by the methodology are CO, VOC, NO_x, PM and energy consumption. For information of BC fractions of PM, please refer to Annex 4.

Distinct emission functions parameters are provided for Euro V vehicles, depending on their emission control concept (EGR or SCR). In order to correctly estimate emissions, one needs to estimate the shares of the two technologies in the vehicle stock. For European Member States, it is estimated that approximately 75% of Euro V heavy duty vehicles are equipped with SCR, the rest being equipped with EGR.

Cold emissions

Measurement data from Euro V and Euro VI Diesel heavy duty and buses were fitted in the existing COPERT methodology for cold emissions from passenger cars in a simpler approach with the use of the following equation.

$$E_{\text{COLD};i,k} = \beta \times N_k \times M_k \times e^{\text{COLD}}_{i,k}$$

where,

$E_{\text{COLD}; i, k}$ = cold-start emissions of pollutant i (for the reference year), produced by vehicle technology k,

β = fraction of mileage driven with a cold engine,

N_k = number of vehicles [veh] of technology k in circulation,

M_k = total mileage per vehicle [km/veh] in vehicle technology k,

$e^{\text{COLD}}_{i, k}$ = cold emission factor for pollutant i and vehicles of k technology.

The beta parameter is calculated as a function of the l_{trip} with the assumption that the operating distance in cold conditions of a heavy duty vehicle is 8.25 km using the following equation.

$$\beta = 8.25 / l_{\text{trip}}$$

if $\beta > 1$ then $\beta = 1$

The cold emission factor is dependent on the temperature and vehicle speed and calculated with the use of following equation:

$$e^{\text{COLD}} = A \times V + B \times t_a + C$$

The coefficients A, B and C for all the different segments and temperature ranges are presented in the Emissions Annex (Annex 4).

Hybrid electric urban buses

Speed dependent fuel and energy consumption factors for hybrid electric urban buses have been derived through simulation. To this aim the energy performance of a plug-in series Hybrid Electric bus under various driving cycles representing realistic traffic conditions was simulated (Hooftman et al., 2020). All relevant information on the fuel and energy consumption factors can be found in Appendix 4.

Natural gas buses

Natural gas vehicles (NGVs) are now present in several urban captive fleets around Europe. France already has around 700 natural gas buses in operation, out of a total of 12 000, while 416 natural gas buses are in operation in Athens, in a fleet of 1 800 vehicles. Natural gas cannot be used as a fuel in a diesel engine or a petrol engine without modifications, because it has a high octane number (120–130) and a cetane number below 50, which makes it unsuitable for diesel combustion. Most commercial systems therefore utilise a spark plug to initiate natural gas combustion, and a higher compression ratio than conventional petrol engines to take advantage of the high octane rate and to increase efficiency. NGVs may also operate either in 'stoichiometric' mode for low emissions, or in 'lean' mode for higher efficiency. In addition, high-pressure storage bottles are required to store compressed natural gas (CNG), while liquid natural gas (LNG) stored at low temperature is not that common, mainly due to the higher complexity of storage on the bus. CNG powertrains are hence associated with more cost elements and higher maintenance costs than diesel engines.

Different CNG buses may have completely different combustion and after-treatment technologies, despite using the same fuel. Hence, their emission performance may significantly vary. Therefore, CNG buses also need to comply with a specific emission standard (Euro II, Euro III, etc.). Due to the low NO_x and PM emissions compared with diesel, an additional emission standard has been set for CNG vehicles, known as the standard for Enhanced Environmental Vehicles (EEV). The emission limits imposed for EEV are even below Euro V, and usually EEVs benefit from tax waivers and free entrance to low-emission zones. New stoichiometric buses are able to meet the EEV requirements, while older buses were usually registered as Euro II or Euro III.

Typical emission and fuel consumption factors for CNG buses, depending on their emission level can be found in the Appendix 4. More information on the derivation of these emission values is given in Ntziachristos et al. (2007).

Two-stroke and four-stroke mopeds < 50 cm³

Mopeds are mostly driven in urban areas, and therefore only urban emission factors are proposed. These emissions factors should be considered as bulk values which include the cold-start fraction. No distinction is made between hot and cold-start emissions. Even if single values are proposed the generic equation (25) can be used by applying the function parameters in Appendix 4 to calculate the emission factor.

Motorcycles > 50 cm³

The equation used to calculate the emission factor for conventional and Euro 1 motorcycles over 50 cm³ engine displacement is equation (25). The coefficients needed to calculate the emission factors are given in Appendix 4, for the different motorcycle categories. PM emissions from two-stroke vehicles are particularly important. The emission factors proposed correspond to a typical mix of

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mineral and synthetic lubricant used for two-stroke engines. Full synthetic oil use would lead to lower PM emission factors.

Mini-cars and All-Terrain Vehicles (ATVs)

The source of the data used to develop the emission factors was the “Effect study of the environmental step Euro 5 for L-category vehicles” (Ntziachristos et al., 2017) and the tests performed therein. The tests were conducted at the chassis dynamometer of the Vehicle Emissions Laboratory VELA 1, which is part of the Sustainable Transport Unit (STU), Directorate for Energy Transport and Climate (previously “Institute for Energy and Transport (IET)), Joint Research Centre (JRC), Ispra, Italy. The laboratory is able to perform emission tests in accordance with Regulation (EU) No 168/2013 and Regulation (EU) No 134/2014.

The calculation of the cold/hot start emissions produced by mini-cars and ATVs is based on the calculation algorithm reported by Ntziachristos et al. (2007). For each vehicle category k , and pollutant i ($i = \text{CO, HC, NO}_x, \text{FC and PM}$), the emission level is calculated from equations (12) and (13). This form is a reduced version of the form given by Ntziachristos et al. (2007), where only urban environment emissions are calculated for mini-cars, while urban and rural environment emissions are calculated for ATVs, based on the average speeds of the regulatory driving cycles that were examined in the input data. Mini-cars and ATVs are generally not driven in highways.

The cold/hot start emission factors ($e_{\text{COLD URBAN}} / e_{\text{HOT URBAN}}$) of the examined pollutants (CO, HC, NO_x, FC and PM) for both mini-cars and ATVs, after being averaged on all the examined driving cycles and cycles’ parts/laps, are given in Table 3-50.

Table 3-50. Cold/hot start emission factors for mini-cars and for ATVs

Category	Emission standard	EC [MJ/km]	NO _x [g/km]	HC [g/km]	PM2.5 [g/km]	CO [g/km]
Mini-cars diesel	Conventional	1.449	0.589	0.308	0.250	1.152
	Euro 1	1.262	0.814	0.161	0.150	0.935
	Euro 2	1.262	0.814	0.161	0.150	0.935
	Euro 3	1.262	0.814	0.161	0.150	0.935
	Euro 4	1.136	0.689	0.120	0.080	0.935
	Euro 5	1.136	0.060	0.078	0.001	0.935
ATVs	Conventional	2.072	0.047	16.670	0.200	33.540
	Euro 1	1.795	0.300	9.000	0.080	13.320
	Euro 2	1.795	0.300	2.320	0.040	7.770
	Euro 3	1.795	0.300	2.320	0.040	7.770
	Euro 4	1.742	0.187	0.603	0.010	1.794
	Euro 5	1.742	0.060	0.088	0.002	1.000

Emissions of non-regulated pollutants

Methane and NMVOCs

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
**Passenger cars, light commercial trucks, heavy-duty vehicles including
buses and motor cycles**

The emission legislation regulates total VOC emissions, with no distinction between methane and NMVOCs. The previous tables in this chapter have provided emission factors for VOCs. However, as CH₄ is a greenhouse gas, separate emission factors are required to calculate its contribution. In order to calculate hot CH₄ emissions, equation (8) can be applied with the values given in Table 3-51. Reduction factors for more recent technologies are given in Table 3-52. In reference to those tables it should be noted that cold-start emission factors apply only to passenger cars and light commercial vehicles. In Table 3-52 the reductions are relative to Euro 1 for passenger cars and Euro I for heavy-duty vehicles and buses. For two-wheel vehicles the reductions are relative to conventional technology. The methane emission factors were derived from the literature for all types of vehicles (Bailey et al., 1989; Volkswagen, 1989; OECD, 1991, Zajontz et al., 1991), and the data from the Artemis project. Additional research (Bach et al, 2010; Zervas and Panousi, 2010; Timmons. 2010, Vonk et al, 2010) led to updated CH₄ factors for Euro Petrol/E85 passenger cars and CNG methane emissions.

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

Table 3-51: Methane (CH₄) emission factors (mg/km)

Vehicle type	Fuel	Vehicle technology/class	Urban		Rural	Highway
			Cold	Hot		
Passenger cars	Petrol-Hybrid Petrol-PHEV	Conventional	201	131	86	41
		Euro 1	45	26	16	14
		Euro 2	94	17	13	11
		Euro 3	83	3	2	4
		Euro 4 and later	57	2.87	2.69	5.08
	Diesel-PHEV	Conventional	22	28	12	8
		Euro 1	18	11	9	3
		Euro 2	6	7	3	2
		Euro 3	3	3	0	0
		Euro 4	1.1	1.1	0	0
	LPG	All Technologies	80	80	35	25
E85		All Technologies	57	2.87	2.69	5.08
CNG	All Technologies	*	57.3	27.73	43.39	
Light commercial vehicles	Petrol	Conventional	201	131	86	41
		Euro 1	45	26	16	14
		Euro 2	94	17	13	11
		Euro 3	83	3	2	4
		Euro 4 and later	57	2	2	0
	Diesel	Conventional	22	28	12	8
		Euro 1	18	11	9	3
		Euro 2	6	7	3	2
		Euro 3	3	3	0	0
		Euro 4	1.1	1.1	0	0
		Euro 5 and later	0.0075	0.0075	0	0
Heavy-duty vehicles and buses	Petrol	All Technologies	-	140	110	70
	Diesel	GVW< 16t	-	85	23	20
		GVW> 16t	-	175	80	70
	Diesel-Biodiesel	Urban Buses and Coaches	-	175	80	70
		Hybrid Urban Buses	-	175	80	70
	CNG	Euro I	-	-	6800	-
		Euro II	-	-	4500	-
		Euro III	-	-	1280	-
EEV		-	-	980	-	
L-category	Petrol	< 50 cm ³ 2-stroke	-	219	219	219
		< 50 cm ³ 4-stroke	-	219	219	219
		> 50 cm ³ 2-stroke	-	150	150	150
		> 50 cm ³ 4-stroke	-	200	200	200
	Mini-cars Diesel	Conventional	22	28	12	8
		Euro 1	18	11	9	3
		Euro 2	6	7	3	2
		Euro 3	3	3	0	0
		Euro 4	1.1	1.1	0	0
	ATVs	Euro 5	0.075	0.075	0	0
		Conventional	-	200	200	200

* Methane cold emissions from CNG passenger cars are calculated as a ratio of VOC cold emissions:

$$\text{CH}_4 \text{ cold} = 0.620 \text{ VOC cold}$$

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

The NMVOC emission factors were calculated as the remainder of the subtraction of CH₄ emissions from total VOC emissions. Hence, after VOC and CH₄ have been calculated by equation (6), NMVOC emissions can also be calculated by:

$$E_{NMVOC} = E_{VOC} - E_{CH_4} \quad (27)$$

Table 3-52: Methane (CH₄) emission reduction factors (%). Reductions are over Euro 1 for passenger cars, Euro I for heavy-duty vehicles and buses and the conventional technology for two-wheel vehicles

Vehicle type	Fuel	Vehicle technology/class	CH ₄ Emission Reduction Factors (%)		
			Urban	Rural	Highway
Passenger cars	LPG	Euro 2	76	76	76
		Euro 3	96.25	94.28	84
		Euro 4	97.5	94.28	95
Heavy-duty vehicles	Diesel	Euro II	36	13	7
		Euro III	44	7	9
		Euro IV	97	93	94
		Euro V and later	97	93	94
Buses	Diesel Biodiesel	Euro II	35	35	35
		Euro III	41	41	41
		Euro IV	97	97	97
		Euro V and later	97	97	97
L-category	Petrol	2-stroke < 50 cm ³ — Euro 1	80	80	80
		2-stroke < 50 cm ³ — Euro 2	89	89	89
		2-stroke < 50 cm ³ — Euro 3 and later	91	91	91
		4-stroke < 50 cm ³ — Euro 1	80	80	80
		4-stroke < 50 cm ³ — Euro 2	89	89	89
		4-stroke < 50 cm ³ — Euro 3 and later	91	91	91
		2-stroke > 50 cm ³ — Euro 1	34	29	35
		2-stroke > 50 cm ³ — Euro 2	80	79	80
		2-stroke > 50 cm ³ — Euro 3 and later	92	91	92
		4-stroke < 250 cm ³ — Euro 1	29	28	34
		4-stroke < 250 cm ³ — Euro 2	32	54	54
		4-stroke < 250 cm ³ — Euro 3 and later	59	84	86
		4-stroke 250–750 cm ³ — Euro 1	26	13	22
		4-stroke 250–750 cm ³ — Euro 2	22	40	39
		4-stroke 250–750 cm ³ — Euro 3 and later	53	79	82
		4-stroke > 750 cm ³ — Euro 1	54	54	23
		4-stroke > 750 cm ³ — Euro 2	58	69	49
		4-stroke > 750 cm ³ — Euro 3 and later	75	89	85
	ATVs	Euro 1	54	54	23
		Euro 2	58	69	49
Euro 3 and later		75	89	85	

PM characteristics

New emission factors for PM characteristics have been developed on the basis of the Particulates project, and these are presented in the following tables. New metrics include the 'active surface area'

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

in (cm²/km), the 'total particle number' (in #/km), and the 'solid particle number' (in #/km) divided into three different size bands (< 50 nm, 50–100 nm, 100–1 000 nm). The total particle number emitted by vehicles is only indicative of the total emission flux, since vehicles emit both solid and volatile particles, and the number concentration of the latter depends on the ambient conditions (temperature, humidity, traffic conditions, etc.). The values given in the following Tables were obtained in the laboratory under conditions which were expected to maximise the concentrations, hence they should be considered to represent a near-maximum emission rate. More details on the sampling conditions and the relevance of these values is given by Samaras et al. (2005).

Table 3-53: PM characteristics of diesel passenger cars

Pollutant	Category	Fuel specifications	Emission factor		
			Urban	Rural	Highway
Active surface area [m ² /km]	PC diesel Euro 1	later than 2000	2.10E+01	1.91E+01	2.94E+01
	PC diesel Euro 2	2005–2009	1.68E+01	1.71E+01	2.78E+01
		2000			3.62E+01
	PC diesel Euro 3	2005–2009	1.53E+01	1.34E+01	1.85E+01
		2000			3.93E+01
	PC diesel Euro 3 DPF	2005–2009	1.21E-02	1.32E-02	2.20E-01
		2000			4.46E+01
	PC petrol Euro 1	later than 2000	6.82E-01	4.33E-01	4.98E-01
PC petrol Euro 3	later than 2000	2.38E-02	3.32E-02	7.43E-02	
PC petrol Euro 3 DISI	later than 2000	2.04E+00	1.77E+00	2.48E+00	
Total particle number [#/km]	PC diesel Euro 1	later than 2000	4.04E+14	3.00E+14	3.21E+14
	PC diesel Euro 2	2005–2009	2.12E+14	2.05E+14	4.35E+14
		2000			7.10E+14
	PC diesel Euro 3	2005–2009	1.64E+14	1.73E+14	2.82E+14
		2000			1.23E+15
	PC diesel Euro 3 DPF	2005–2009	6.71E+10	9.00E+12	1.79E+14
		2000			1.34E+15
	PC petrol Euro 1	later than 2000	8.76E+12	7.35E+12	1.81E+13
PC petrol Euro-	later than 2000	6.99E+11	5.26E+12	5.59E+12	
PC petrol Euro 3 DISI	later than 2000	1.47E+13	1.13E+13	9.02E+13	

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
**Passenger cars, light commercial trucks, heavy-duty vehicles including
buses and motor cycles**

Table 3-54: Solid particle number emission from diesel passenger cars (not affected by fuel sulphur content)

Pollutant metric	Category	Emission factor (#/km)		
		Urban	Rural	Highway
Number of solid particles < 50 nm	PC diesel Euro 1	8.5E+13	8.6E+13	7.2E+13
	PC diesel Euro 2	7.6E+13	7.6E+13	6.1E+13
	PC diesel Euro 3	7.9E+13	7.1E+13	5.8E+13
	PC diesel Euro 3 DPF	5.5E+10	4.0E+10	2.3E+11
	PC petrol Euro 1	3.2E+12	2.4E+12	8.6E+11
	PC petrol Euro 3	9.6E+10	1.1E+11	5.5E+10
	PC petrol Euro 3 DISI	8.1E+12	6.1E+12	2.8E+12
Number of solid particles 50-100 nm	PC diesel Euro 1	9.3E+13	7.8E+13	7.3E+13
	PC diesel Euro 2	8.8E+13	7.7E+13	7.2E+13
	PC diesel Euro 3	8.7E+13	6.8E+13	6.9E+13
	PC diesel Euro 3 DPF	2.3E+10	1.6E+10	9.4E+10
	PC petrol Euro 1	1.4E+12	1.0E+12	3.4E+11
	PC petrol Euro 3	4.4E+10	5.4E+10	2.8E+10
	PC petrol Euro 3 DISI	6.5E+12	3.6E+12	1.9E+12
Number of solid particles 100-1 000 nm	PC diesel Euro 1	5.4E+13	3.8E+13	4.0E+13
	PC diesel Euro 2	5.1E+13	3.6E+13	4.0E+13
	PC diesel Euro 3	4.5E+13	3.2E+13	3.5E+13
	PC diesel Euro 3 DPF	1.6E+10	1.2E+10	2.8E+10
	PC petrol Euro 1	5.2E+11	3.7E+11	1.2E+11
	PC petrol Euro 3	2.6E+10	3.4E+10	5.1E+10
	PC petrol Euro 3 GDI	4.1E+12	2.1E+12	1.5E+12

Table 3-55 to Table 3-59 include particle properties information for buses, coaches and heavy-duty vehicles, following the classification of Table 2-1. Further to the technology classification given in Table 2-3, some additional technologies are included in these Tables, just because of their large influence on PM emissions. These tables include Euro II and Euro III vehicles retrofitted with continuously regenerated particle filters (CRDPF) and selective catalytic reduction aftertreatment (SCR). They also include new emission technologies (Euro IV and Euro V) equipped with original equipment aftertreatment devices.

Note

Weight classes of heavy-duty vehicles correspond to Gross Vehicle Weight, i.e. the maximum allowable total weight of the vehicle when loaded, including fuel, passengers, cargo, and trailer tongue weight.

Heavy-duty vehicles are distinguished into rigid and articulated vehicles. An articulated vehicle is a tractor coupled to a semi-trailer. A rigid truck may also carry a trailer, but this is not considered an articulated vehicle.

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

Table 3-55: PM characteristics of buses

Pollutant metric	Emission standard	Speed range [km/h]	Emission factor		
			Urban	Rural	Highway
Active surface area [cm ² /km]	Euro II and III	10-110	5.65E+05	1.99E+05	2.57E+05
	Euro II and III + CRDPF	10-110	8.07E+04	1.77E+04	2.18E+04
	Euro II and III+SCR	10-110	9.13E+05	3.37E+05	3.93E+05
	Euro IV +CRDPF	10-110			
	Euro V + SCR	10-110			
Total particle number [# /km]	Euro II and III	10-110	6.88E+14	4.55E+14	1.12E+15
	Euro II and III + CRDPF	10-110	2.72E+14	4.77E+13	8.78E+13
	Euro II and III+SCR	10-110	7.66E+14	5.68E+14	1.28E+15
	Euro IV +CRDPF	10-110	5.93E+12	3.57E+12	2.93E+12
	Euro V + SCR	10-110	1.73E+13	1.09E+13	1.22E+13
Solid particle number < 50 nm [# /km]	Euro II and III	10-110	1.25E+14	5.08E+13	7.43E+13
	Euro II and III + CRDPF	10-110	3.87E+12	1.89E+12	4.18E+12
	Euro II and III+SCR	10-110	1.19E+14	5.26E+13	7.67E+13
	Euro IV +CRDPF	10-110	1.25E+10	6.43E+09	8.20E+09
	Euro V + SCR	10-110	7.98E+12	2.87E+12	2.04E+12
Solid particle number 50-100 nm [# /km]	Euro II and III	10-110	1.44E+14	5.44E+13	6.82E+13
	Euro II and III + CRDPF	10-110	3.31E+12	1.43E+12	2.54E+12
	Euro II and III+SCR	10-110	1.57E+14	6.14E+13	7.25E+13
	Euro IV +CRDPF	10-110	1.04E+10	4.14E+09	3.88E+09
	Euro V + SCR	10-110	9.13E+12	3.06E+12	2.10E+12
Solid particle number 100-1 000 nm [# /km]	Euro II and III	10-110	2.09E+14	7.25E+13	7.16E+13
	Euro II and III + CRDPF	10-110	2.29E+12	8.53E+11	1.12E+12
	Euro II and III+SCR	10-110	3.30E+14	1.21E+14	1.10E+14
	Euro IV +CRDPF	10-110	3.27E+10	9.48E+09	5.89E+09
	Euro V + SCR	10-110	1.57E+13	5.16E+12	3.36E+12

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Table 3-56: PM characteristics of coaches

Pollutant metric	Emission standard	Speed range [km/h]	Emission factor		
			Urban	Rural	Highway
Active surface area [cm ² /km]	Euro II and III	10-110	6.75E+05	2.23E+05	2.13E+05
	Euro II and III + CRDPF	10-110	9.65E+04	1.98E+04	1.81E+04
	Euro II and III+SCR	10-110	1.09E+06	3.77E+05	3.26E+05
	Euro IV +CRDPF	10-110			
	Euro V + SCR	10-110			
Total particle number [# /km]	Euro II and III	10-110	8.23E+14	5.09E+14	9.28E+14
	Euro II and III + CRDPF	10-110	3.25E+14	5.34E+13	7.28E+13
	Euro II and III+SCR	10-110	9.16E+14	6.35E+14	1.06E+15
	Euro IV +CRDPF	10-110	7.29E+12	4.03E+12	2.42E+12
	Euro V + SCR	10-110	2.15E+13	1.24E+13	1.01E+13
Solid particle number < 50 nm [# /km]	Euro II and III	10-110	1.49E+14	5.68E+13	6.16E+13
	Euro II and III + CRDPF	10-110	4.63E+12	2.11E+12	3.47E+12
	Euro II and III+SCR	10-110	1.43E+14	5.89E+13	6.36E+13
	Euro IV +CRDPF	10-110	1.53E+10	7.27E+09	6.76E+09
	Euro V + SCR	10-110	9.92E+12	3.27E+12	1.69E+12
Solid particle number 50-100 nm [# /km]	Euro II and III	10-110	1.72E+14	6.08E+13	5.65E+13
	Euro II and III + CRDPF	10-110	3.96E+12	1.60E+12	2.10E+12
	Euro II and III+SCR	10-110	1.88E+14	6.86E+13	6.01E+13
	Euro IV +CRDPF	10-110	1.28E+10	4.68E+09	3.19E+09
	Euro V + SCR	10-110	1.14E+13	3.49E+12	1.73E+12
Solid particle number 100-1 000 nm [# /km]	Euro II and III	10-110	2.49E+14	8.11E+13	5.94E+13
	Euro II and III + CRDPF	10-110	2.74E+12	9.54E+11	9.30E+11
	Euro II and III+SCR	10-110	3.95E+14	1.36E+14	9.13E+13
	Euro IV +CRDPF	10-110	4.02E+10	1.07E+10	4.85E+09
	Euro V + SCR	10-110	1.95E+13	5.89E+12	2.77E+12

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
 Passenger cars, light commercial trucks, heavy-duty vehicles including
 buses and motor cycles

Table 3-57: PM characteristics of HDVs 3.5–7.5 tonnes

Pollutant metric	Emission standard	Speed range [km/h]	Emission factor		
			Urban	Rural	Highway
Active surface area [cm ² /km]	Euro II and III	10–110	2.62E+05	1.19E+05	1.61E+05
	Euro II and III + CRDPF	10–110	3.74E+04	1.06E+04	1.36E+04
	Euro II and III+SCR	10–110	4.23E+05	2.02E+05	2.45E+05
	Euro IV +CRDPF	10–110			
	Euro V + SCR	10–110			
Total particle number [# /km]	Euro II and III	10–110	3.19E+14	2.72E+14	6.99E+14
	Euro II and III + CRDPF	10–110	1.26E+14	2.85E+13	5.48E+13
	Euro II and III+SCR	10–110	3.55E+14	3.40E+14	8.01E+14
	Euro IV +CRDPF	10–110	2.73E+12	2.12E+12	1.80E+12
	Euro V + SCR	10–110	7.96E+12	6.41E+12	7.44E+12
Solid particle number < 50 nm [# /km]	Euro II and III	10–110	5.79E+13	3.04E+13	4.64E+13
	Euro II and III + CRDPF	10–110	1.80E+12	1.13E+12	2.61E+12
	Euro II and III+SCR	10–110	5.52E+13	3.15E+13	4.79E+13
	Euro IV +CRDPF	10–110	5.75E+09	3.81E+09	5.04E+09
	Euro V + SCR	10–110	3.66E+12	1.69E+12	1.24E+12
Solid particle number 50–100 nm [# /km]	Euro II and III	10–110	6.68E+13	3.25E+13	4.26E+13
	Euro II and III + CRDPF	10–110	1.53E+12	8.56E+11	1.59E+12
	Euro II and III+SCR	10–110	7.27E+13	3.67E+13	4.53E+13
	Euro IV +CRDPF	10–110	4.78E+09	2.46E+09	2.38E+09
	Euro V + SCR	10–110	4.19E+12	1.81E+12	1.28E+12
Solid particle number 100–1 000 nm [# /km]	Euro II and III	10–110	9.66E+13	4.34E+13	4.47E+13
	Euro II and III + CRDPF	10–110	1.06E+12	5.10E+11	7.01E+11
	Euro II and III+SCR	10–110	1.53E+14	7.26E+13	6.88E+13
	Euro IV +CRDPF	10–110	1.51E+10	5.62E+09	3.62E+09
	Euro V + SCR	10–110	7.21E+12	3.05E+12	2.04E+12

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Table 3-58: PM characteristics of rigid HDVs 7.5-14 tonnes

Pollutant metric	Emission standard	Speed range [km/h]	Emission factor		
			Urban	Rural	Highway
Active surface area [cm ² /km]	Euro II and III	10-110	5.56E+05	2.19E+05	2.37E+05
	Euro II and III + CRDPF	10-110	7.95E+04	1.95E+04	2.00E+04
	Euro II and III+SCR	10-110	8.99E+05	3.70E+05	3.61E+05
	Euro IV +CRDPF	10-110			
	Euro V + SCR	10-110			
Total particle number [# /km]	Euro II and III	10-110	6.78E+14	5.00E+14	1.03E+15
	Euro II and III + CRDPF	10-110	2.68E+14	5.24E+13	8.07E+13
	Euro II and III+SCR	10-110	7.54E+14	6.23E+14	1.18E+15
	Euro IV +CRDPF	10-110	5.81E+12	3.90E+12	2.66E+12
	Euro V + SCR	10-110	1.69E+13	1.18E+13	1.10E+13
Solid particle number < 50 nm [# /km]	Euro II and III	10-110	1.23E+14	5.58E+13	6.83E+13
	Euro II and III + CRDPF	10-110	3.82E+12	2.07E+12	3.84E+12
	Euro II and III+SCR	10-110	1.17E+14	5.78E+13	7.05E+13
	Euro IV +CRDPF	10-110	1.22E+10	7.02E+09	7.44E+09
	Euro V + SCR	10-110	7.77E+12	3.12E+12	1.84E+12
Solid particle number 50-100 nm [# /km]	Euro II and III	10-110	1.42E+14	5.97E+13	6.27E+13
	Euro II and III + CRDPF	10-110	3.26E+12	1.57E+12	2.33E+12
	Euro II and III+SCR	10-110	1.55E+14	6.73E+13	6.66E+13
	Euro IV +CRDPF	10-110	1.02E+10	4.52E+09	3.52E+09
	Euro V + SCR	10-110	8.90E+12	3.33E+12	1.89E+12
Solid particle number 100-1 000 nm [# /km]	Euro II and III	10-110	2.05E+14	7.95E+13	6.58E+13
	Euro II and III + CRDPF	10-110	2.26E+12	9.36E+11	1.03E+12
	Euro II and III+SCR	10-110	3.25E+14	1.33E+14	1.01E+14
	Euro IV +CRDPF	10-110	3.20E+10	1.04E+10	5.35E+09
	Euro V + SCR	10-110	1.53E+13	5.62E+12	3.02E+12

Table 3-59: PM characteristics of rigid HDVs 14–32 tonnes, and truck trailer/articulated 14–34 tonnes

Pollutant metric	Emission standard	Speed range [km/h]	Emission factor		
			Urban	Rural	Highway
Active surface area [cm ² /km]	Euro II and III	10–110	8.68E+05	3.38E+05	3.14E+05
	Euro II and III + CRDPF	10–110	1.24E+05	3.01E+04	2.65E+04
	Euro II and III+SCR	10–110	1.40E+06	5.71E+05	4.79E+05
	Euro IV +CRDPF	10–110			
	Euro V + SCR	10–110			
Total particle number [# /km]	Euro II and III	10–110	1.06E+15	7.71E+14	1.36E+15
	Euro II and III + CRDPF	10–110	4.19E+14	8.08E+13	1.07E+14
	Euro II and III+SCR	10–110	1.18E+15	9.62E+14	1.56E+15
	Euro IV +CRDPF	10–110	9.07E+12	6.02E+12	3.54E+12
	Euro V + SCR	10–110	2.64E+13	1.83E+13	1.46E+13
Solid particle number < 50 nm [# /km]	Euro II and III	10–110	1.92E+14	8.61E+13	9.05E+13
	Euro II and III + CRDPF	10–110	5.96E+12	3.20E+12	5.09E+12
	Euro II and III+SCR	10–110	1.83E+14	8.92E+13	9.35E+13
	Euro IV +CRDPF	10–110	1.91E+10	1.09E+10	9.89E+09
	Euro V + SCR	10–110	1.22E+13	4.83E+12	2.45E+12
Solid particle number 50–100 nm [# /km]	Euro II and III	10–110	2.22E+14	9.22E+13	8.31E+13
	Euro II and III + CRDPF	10–110	5.09E+12	2.42E+12	3.09E+12
	Euro II and III+SCR	10–110	2.41E+14	1.04E+14	8.84E+13
	Euro IV +CRDPF	10–110	1.59E+10	6.99E+09	4.67E+09
	Euro V + SCR	10–110	1.39E+13	5.15E+12	2.52E+12
Solid particle number 100–1 000 nm [# /km]	Euro II and III	10–110	3.21E+14	1.23E+14	8.73E+13
	Euro II and III + CRDPF	10–110	3.52E+12	1.44E+12	1.37E+12
	Euro II and III+SCR	10–110	5.08E+14	2.06E+14	1.34E+14
	Euro IV +CRDPF	10–110	5.00E+10	1.60E+10	7.10E+09
	Euro V + SCR	10–110	2.39E+13	8.69E+12	4.02E+12

Solid Particle Number > 23 nm (SPN23)

Emission regulation from the European Union focuses on Solid Particle Number > 23 nm (SPN23) for all types of vehicles. In 2011 (Euro 5b) a solid particle number (SPN) limit with a size cut-off at 23 nm (SPN23) was brought into force for light-duty diesel vehicles and two years later for heavy-duty ones. High SPN23 emissions were also observed from gasoline light-duty vehicles equipped with a direct injection (GDI) engine thus PM and SPN23 limits were implemented in 2009 and 2014, respectively. The following tables contain emission factors collected from lab measurements and literature review. (Andersson et al. 2014, Giechaskiel et al. 2018, Giechaskiel et al. 2010, Valverde et al., Joint Research Centre 2018, Valverde et al. 2019, Vouitsis et al. 2017)

Passenger Cars

The engine size was not considered to have an impact on the particle emissions, thus the categories of same Euro cars were based on the aftertreatment technologies.

SPN23 emission factors [# /km] for older Euro standard categories (Euro 1 – 4) were based on a study (Vouitsis et al. 2017) that categorized these factors based on the driving condition (Urban, Rural, Highway).

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

For the most recent Euro standards (Euro 5 and 6) the impact of engine cold start in comparison to hot engine operation for the SPN23 was calculated. The mean emission factors for each type of petrol and diesel car were calculated for both cold and hot start in [# /km].

Table 3-60: Passenger car SPN23 emission factors for cold and hot start and Overemission

Passenger cars			Cold [# /km] Average	Confidence	Hot [# /km] Average	Confidence	[#] Overemission
Diesel	Euro 5	DPF	2.09E+11	1.53E+11	8.73E+10	7.53E+10	3.67E+12
Diesel	Euro 6	DPF	1.72E+11	9.05E+10	4.82E+10	2.86E+10	3.98E+12
Petrol	Euro 5	GDI	1.85E+12		7.65E+11		3.81E+13
Petrol	Euro 5	PFI	1.39E+12		6.10E+11		2.72E+13
Petrol	Euro 6	GDI	1.97E+12	4.27E+11	8.12E+11	3.08E+11	3.96E+13
Petrol	Euro 6	GDI+GPF	5.55E+11	1.77E+11	1.30E+11	7.28E+10	1.78E+13
Petrol	Euro 6	PFI	1.47E+12	5.37E+11	6.48E+11	4.19E+11	3.69E+13
CNG	Euro 6		5.04E+11	1.70E+11	2.63E+11	1.24E+11	6.01E+12

Table 3-61: SPN23 Urban, Rural and Highway emission factors for diesel passenger cars

Passenger cars		Urban [# /km]	Rural [# /km]	Highway [# /km]
Diesel	Euro 1	3.97E+14	2.52E+14	4.70E+14
Diesel	Euro 2	2.12E+14	2.05E+14	4.35E+14
Diesel	Euro 3	1.64E+14	1.73E+14	2.82E+14
Diesel	Euro 4	7.48E+13	5.52E+13	9.00E+13

Table 3-62: SPN23 Urban, Rural and Highway emission factors for petrol passenger cars

Passenger cars			Urban [# /km]	Rural [# /km]	Highway [# /km]
Petrol	Euro 1	PFI	8.76E+12	3.11E+12	1.81E+13
Petrol	Euro 2	PFI	6.16E+12	2.67E+12	1.18E+13
Petrol	Euro 3	PFI	3.07E+12	2.23E+12	5.60E+12
Petrol	Euro 4	PFI	9.00E+11	7.90E+11	8.40E+11
Petrol	Euro 4	GDI	9.50E+12	7.60E+12	6.06E+13

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

Table 3-63: SPN23 petrol passenger cars ratios over Euro 6 GDI

Passenger cars		SPN23 Cold [#/km]	Ratio /Euro 6 GDI
Euro 5	PFI	1.39E+12	0.70
Euro 6	GDI	1.97E+12	1
Euro 6	GDI+GPF	5.55E+11	0.28
Euro 6	PFI	1.47E+12	0.75

The diesel passenger cars equipped with Diesel Particulate Filter (DPF) appear to have significantly increased particle emissions during the Regeneration periods. It is important to estimate the duration and the frequency of the Regeneration in order to calculate the increased emissions.

Table 3-64: DPF Regeneration frequency and duration in diesel passenger cars

Passenger cars	Euro 5	Euro 6
Frequency [km]	500	400
Duration [km]	20	20
Out of Reg	0.96	0.95
In Reg	0.04	0.05

According to literature in both chassis dyno and PEMS tests, active regenerations appeared to increase PN by a factor of ~10. In the following table the regeneration values for Euro 6 Diesel are presented as well as a comparison to hot emission factors.

Table 3-65: DPF Regeneration Euro 6 Diesel passenger cars

SPN23 [#/km]		
Regeneration	Average	6.47E+11
Regeneration	Confidence	1.97E+11
Hot	Average	4.82E+10
Regeneration/Hot		13.44

Heavy Duty Vehicles

As with the passenger cars, the SPN23 emission factors for Euro Standards from I to V were split to Urban, Rural and Highway driving conditions as presented in the study by Voutsis et al. 2017.

Table 3-66: SPN23 Urban, Rural and Highway emission factors for Euro I - V heavy duty vehicles

Heavy Duty Vehicle	Urban [#kWh]	Rural [#kWh]	Highway [#kWh]
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Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

Euro I	7.34E+14	3.18E+14	3.28E+14
Euro II	5.13E+14	2.21E+14	2.30E+14
Euro III	5.13E+14	2.21E+14	2.30E+14
Euro IV	1.08E+14	5.54E+13	6.18E+13
Euro V	1.08E+14	5.54E+13	6.18E+13

Table 3-67: Heavy Duty vehicles Urban, Rural and Highway SPN23 emission factors Euro VI)

Heavy Duty Vehicles		Average [#/kWh]	Confidence
Euro VI	Urban	1.79E+11	1.12E+11
Euro VI	Rural	6.09E+10	1.64E+10
Euro VI	Highway	4.75E+10	1.07E+10

L-Category

The average SPN23 emission factor from 14 Euro 4 Petrol 4s Motor measurements was 8,45E+11 [#/#km] (confidence interval 2,78E+11).

Detailed information on SPN23 emission factors for all vehicles can be found in Appendix 4.

Nitrous oxide (N₂O) emissions

Nitrous oxide emission factors were developed in a LAT/AUTh study (Papathanasiou and Tzircas, 2005), based on data collected in studies around the world. The same methodology was used in a more recent study (Pastramas et al., 2014) in order to develop the emission factors for Euro 5 and 6 vehicles. N₂O emissions are particularly important for catalyst vehicles, and especially when the catalyst is under partially oxidising conditions. This may occur when the catalyst has not yet reached its light-off temperature or when the catalyst is aged. Because N₂O has increased in importance on account of its contribution to the greenhouse effect, a detailed calculation of N₂O needs to take vehicle age (cumulative mileage) into account. Moreover, aftertreatment ageing depends upon the fuel sulphur level. Hence, different emission factors need to be derived to allow for variation in fuel sulphur content. In order to take both these effects into account, N₂O emission factors are calculated according to equation (28), and the coefficients in Table 3-68 to Table 3-75 for different passenger cars and light commercial vehicles. These values differ according to the fuel sulphur level and the driving conditions (urban, rural, highway). With regard to Euro 5, Euro 6 and Euro 6 RDE emission standards, only one category of low sulphur level is given, since these technologies are not compatible with higher sulphur contents. In particular, cold-start and a hot-start emission factors are given for urban driving.

$$EF_{N_2O} = [a \times CMileage + b] \times EF_{BASE} \quad (28)$$

Note

The **CMileage** value in this calculation corresponds to the mean cumulative mileage of a particular vehicle type. This corresponds to the mean odometer reading of vehicles of a particular type. The cumulative mileage is a good indication of the vehicle operation history. This should not be confused with the annual mileage driven by a vehicle, which corresponds to the distance travelled in a period of a year and typically ranges between 8 000 and 20 000 km. The cumulative mileage could be expressed as annual mileage times the years of life of a vehicle.

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
 Passenger cars, light commercial trucks, heavy-duty vehicles including
 buses and motor cycles

Table 3-68: Parameters for equation(28) to calculate N₂O emission factors for petrol, CNG and E85 passenger cars under cold urban conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	10	0	1
Euro 1	0-30	17.5	5.60E-07	0.936
Euro 1	30-350	40.5	1.76E-06	0.839
Euro 1	> 350	57.6	7.24E-06	0.748
Euro 2	0-30	11.5	5.85E-07	0.978
Euro 2	30-350	24.4	4.61E-07	0.972
Euro 2	> 350	37.4	2.41E-06	0.918
Euro 3	0-30	7.9	5.68E-07	0.95
Euro 3	30-90	11.4	-2.54E-07	1.02
Euro 3	> 90	11.7	-5.61E-07	1.04
Euro 4	0-30	5.4	3.79E-07	0.96
Euro 4	30-90	6.4	4.46E-07	0.951
Euro 4	> 90	10.5	4.51E-07	0.95
Euro 5 and later	0-30	2.8	2.49E-06	0.559

Table 3-69: Parameters for equation (28) to calculate N₂O emission factors for petrol, CNG and E85 passenger cars under hot urban conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	10	0	1
Euro 1	0-350	23.2	8.81E-07	0.92
Euro 1	> 350	60.4	1.54E-05	0.255
Euro 2	0-350	11.1	9.21E-07	0.962
Euro 2	> 350	17.9	3.14E-06	0.93
Euro 3	0-30	1.3	1.85E-06	0.829
Euro 3	30-90	1.8	2.34E-06	0.801
Euro 3	> 90	3	-3.34E-07	1.03
Euro 4	0-30	1.9	6.61E-07	0.931
Euro 4	30-90	2.4	2.39E-06	0.738
Euro 4	> 90	4.2	8.65E-07	0.903
Euro 5 and later	0-30	2.4	7.83E-07	0.861

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
 Passenger cars, light commercial trucks, heavy-duty vehicles including
 buses and motor cycles

Table 3-70: Parameters for equation (28) to calculate N₂O emission factors for petrol, CNG and E85 passenger cars under hot rural conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	6.5	0	1
Euro 1	0-30	9.2	1.31E-06	0.851
Euro 1	30-350	18.5	2.90E-06	0.747
Euro 1	> 350	48.9	1.37E-05	0.227
Euro 2	0-30	4	1.45E-06	0.945
Euro 2	> 30	4.2	4.93E-06	0.799
Euro 3	0-30	0.3	1.35E-06	0.875
Euro 3	30-90	1.1	4.10E-06	0.539
Euro 3	> 90	2.2	4.20E-06	0.68
Euro 4	0-30	0.3	2.61E-06	0.726
Euro 4	30-90	1.1	4.09E-06	0.549
Euro 4	> 90	2.5	4.82E-07	0.946
Euro 5 and later	0-30	0.2	2.61E-06	0.726

Table 3-71: Parameters for equation (28) to calculate N₂O emission factors for petrol, CNG and E85 passenger cars under hot highway conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	6.5	0	1
Euro 1	0-30	4.7	1.30E-06	0.846
Euro 1	30-350	9.4	2.87E-06	0.739
Euro 1	> 350	24.7	1.33E-05	0.219
Euro 2	0-30	2.2	1.45E-06	0.944
Euro 2	> 30	2.3	4.92E-06	0.797
Euro 3	0-30	0.19	1.49E-06	0.967
Euro 3	30-90	0.61	6.32E-06	0.832
Euro 3	> 90	1.3	5.56E-06	0.9
Euro 4	0-30	0.17	3.30E-06	0.918
Euro 4	30-90	0.63	6.23E-06	0.838
Euro 4	> 90	1.4	5.03E-07	0.987
Euro 5 and later	0-30	1	3.30E-06	0.918

Table 3-72: Parameters for equation (28) to calculate N₂O emission factors for petrol LCVs under cold urban conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	10	0	1
Euro 1	0-350	46.5	3.30E-07	0.933
Euro 1	> 350	83.6	1.55E-05	0.686
Euro 2	All	67.7	2.13E-06	0.812
Euro 3	0-30	16.8	3.38E-07	0.957
Euro 3	30-90	20.5	-1.81E-07	1.02
Euro 3	> 90	32.9	-2.84E-07	1.02
Euro 4	0-30	13.7	1.14E-06	0.87
Euro 4	30-90	16.5	4.75E-07	0.946
Euro 4	> 90	23.2	1.27E-07	0.986
Euro 5 and later	0-30	2.8	2.49E-06	0.559

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
 Passenger cars, light commercial trucks, heavy-duty vehicles including
 buses and motor cycles

Table 3-73: Parameters for equation (28) to calculate N₂O emission factors for petrol LCVs under hot urban conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	10	0	1
Euro 1	0-350	41.5	2.33E-06	0.53
Euro 1	> 350	60.4	1.54E-05	0.255
Euro 2	0-350	23.9	2.40E-06	0.68
Euro 2	> 350	42.1	1.17E-05	0.56
Euro 3	0-30	7.4	2.81E-06	0.64
Euro 3	30-90	12.7	1.41E-06	0.83
Euro 3	> 90	36.7	1.44E-06	0.86
Euro 4	0-30	1.2	6.57E-07	0.925
Euro 4	30-90	0.85	5.72E-07	0.935
Euro 4	> 90	7.9	3.07E-07	0.965
Euro 5 and later	0-30	2.4	7.83E-07	0.861

Table 3-74: Parameters for equation (28) to calculate N₂O emission factors for petrol LCVs under hot rural conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	6.5	0	1
Euro 1	0-350	18.5	2.90E-06	0.747
Euro 1	> 350	26.3	2.96E-05	0.49
Euro 2	0-350	12.2	2.67E-06	0.76
Euro 2	> 350	21.1	1.92E-05	0.66
Euro 3	0-30	1.4	1.27E-06	0.837
Euro 3	30-90	6	1.88E-06	0.77
Euro 3	> 90	18.1	1.78E-06	0.83
Euro 4	0-30	0.3	6.33E-06	0.278
Euro 4	30-90	2.2	3.62E-06	0.587
Euro 4	> 90	8.7	2.03E-06	0.768
Euro 5 and later	0-30	0.2	2.61E-06	0.726

Table 3-75 Parameters for equation (28) to calculate N₂O emission factors for petrol LCVs under hot highway conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	> 0	6.5	0	1
Euro 1	0-350	9.4	2.87E-06	0.739
Euro 1	> 350	26.3	2.96E-05	0.49
Euro 2	0-350	7.7	2.50E-06	0.75
Euro 2	> 350	21.1	1.92E-05	0.66
Euro 3	0-30	1.4	1.27E-06	0.837
Euro 3	30-90	6	1.88E-06	0.77
Euro 3	> 90	18.1	1.78E-06	0.83
Euro 4	0-30	0.3	6.33E-06	0.278
Euro 4	30-90	2.2	3.62E-06	0.587
Euro 4	> 90	8.7	2.03E-06	0.768
Euro 5 and later	0-30	1	3.30E-06	0.918

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

Nitrous oxide emissions from diesel vehicles without deNOx aftertreatment and motorcycles are substantially lower than those from catalyst-equipped passenger cars, and are roughly estimated on the basis of the literature (Pringent et al., 1989; Perby, 1990; de Reydellet, 1990; Potter, 1990; OECD, 1991; Zajontz et al., 1991, and others) and the work of TNO (2002), Riemersma et al. (2003) and Pastramas et al., (2014). These data are shown in Table 3-76 and

Table 3-77. For motorcycles and heavy duty vehicles, there is no separate methodology for estimating excess cold-start emissions, but they are assumed to be already incorporated in the bulk emission factors.

Table 3-76: N₂O emission factors (mg/km) for diesel and LPG cars, diesel light commercial vehicles, and two-wheel vehicles.

Vehicle category	Urban cold	Urban hot	Rural	Highway
Diesel passenger cars and LCVs				
Conventional	0	0	0	0
Euro 1	0	2	4	4
Euro 2	3	4	6	6
Euro 3/4/5	15	9	4	4
Euro 6 up to 2016 / 2017-2019 / 2020+	9	11	4	4
LPG passenger cars				
Conventional	0	0	0	0
Euro 1	38	21	13	8
Euro 2	23	13	3	2
Euro 3	9	5	2	1
Euro 4	9	5	2	1
Euro 5	1.8	2.1	0.2	1
Euro 6	1.8	2.1	0.2	1
L-category				
< 50 cm ³	1		1	1
> 50 cm ³ 2-stroke	2		2	2
> 50 cm ³ 4-stroke	2		2	2

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

Table 3-77: N₂O emission factors (mg/km) for heavy duty vehicles

HDV Category	Technology	Urban (g/km)	Rural (g/km)	Highway (g/km)
Petrol > 3.5 t	Conventional	6	6	6
Rigid 7.5–12 t	Conventional	30	30	30
	HD Euro I	6	5	3
	HD Euro II	5	5	3
	HD Euro III	3	3	2
	HD Euro IV	6	7.2	5.8
	HD Euro V	15	19.8	17.2
Rigid and articulated 12–28 t and coaches (all types)	Conventional	30	30	30
	HD Euro I	11	9	7
	HD Euro II	11	9	6
	HD Euro III	5	5	4
	HD Euro IV	11.2	13.8	11.4
	HD Euro V	29.8	40.2	33.6
Rigid and articulated 28–34 t	Conventional	30	30	30
	HD Euro I	17	14	10
	HD Euro II	17	14	10
	HD Euro III	8	8	6
	HD Euro IV	17.4	21.4	17.4
	HD Euro V	45.6	61.6	51.6
Articulated > 34 t	Conventional	30	30	30
	HD Euro I	18	15	11
	HD Euro II	18	15	10
	HD Euro III	9	9	7
	HD Euro IV	19	23.4	19.2
	HD Euro V	49	66.6	55.8
Diesel urban busses (all types)	Conventional	30		
	HD Euro I	12		
	HD Euro II	12		
	HD Euro III	6		
	HD Euro IV	12.8		
	HD Euro V	33.2		
	HD Euro VI	41.5		

Values in

Table 3-77 already designate that N₂O emissions from diesel vehicles equipped with de-NO_x aftertreatment, such Euro V and Euro VI ones, may be substantially higher than vehicles without aftertreatment. Most of the Euro V/VI trucks achieve low NO_x emission with use of selective catalytic reduction (SCR) systems. In these, NO_x are reduced to N₂ by means of an ammonia carrier (urea) which acts as the reducing agent over an appropriate catalyst. In normal operation, SCR should lead to minimal N₂O production, as NO_x are effectively converted to N₂. However, there are at least two cases which can lead to excess N₂O emission. The SCR chemical mechanism forms N₂O as a by-product of the N₂ conversion. This can be stored under low-to-medium temperature conditions and can be later released when the temperature increases. The second, most important mechanism of N₂O formation

in SCR systems is by oxidation of the ammonia introduced into the system. Several SCR configurations include a secondary oxidation catalyst, downstream of the primary SCR one, which aims at oxidizing ammonia that has “slipped” the main catalyst. This ammonia slip may occur when more ammonia is injected than what is at minimum required to reduce NO_x. This is often the result of a miscalculation in the injected quantity or overshooting in urea injection, in an effort to make sure that no NO_x is emitted downstream of the SCR system. This slipped ammonia cannot be fully oxidized into N₂ in the oxidation catalyst and often is emitted as N₂O.

The values in

Table 3-77 should be representative of well-operating SCR systems, i.e. without (excessive) ammonia slip. In case this occurs, N₂O emissions may increase disproportionately. High values of ammonia slip may occur for an aged system or due to malfunctions. One such study in Japan identified N₂O emissions to amount to up to 20% of CO₂ equivalent in the exhaust of an SCR equipped vehicle (Suzuki et al., 2008). N₂O emissions from SCR vehicles need to be monitored to reveal how much this is a problem in real-world conditions.

SCR systems will expand to diesel passenger cars as well, starting in Euro 6. It cannot currently be predicted how these systems will behave. First, passenger cars are expected to utilize SCR at a lower relative rate than diesel trucks do. Second, it is not determined yet whether SCR will precede DPFs in the exhaust line, or vice versa. N₂O emissions may be drastically different in the two cases. Because of these unknowns, predicting the level and the trend of N₂O emission from SCR equipped passenger cars is currently not possible.

Ammonia (NH₃) emissions

Ammonia emissions from passenger cars and light commercial vehicles are estimated in a similar manner to N₂O emissions. The NH₃ emission factors are calculated according to equation (28) and the coefficients in Table 3-78 to

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

Table 3-85. As already mentioned, these values differ according to the fuel sulphur level and the driving conditions (urban, rural, highway). With regard to Euro 5 and later emission standards, only one category of sulphur level is given, as for N₂O.

Table 3-78: Parameters for equation (28) to calculate NH₃ emission factors for petrol, LPG, CNG and E85 passenger cars under cold urban conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	> 0	2	0	1
Euro 1	0-150	50	1.52E-06	0.765
Euro 1	> 150	11.7	2.92E-06	0.351
Euro 2	0-150	51	1.70E-06	0.853
Euro 2	> 150	14.6	3.89E-06	0.468
Euro 3	0-30	5.4	1.77E-06	0.819
Euro 3	> 30	4.8	4.33E-06	0.521
Euro 4	0-30	5.4	1.77E-06	0.819
Euro 4	> 30	4.8	4.33E-06	0.521
Euro 5 and later	> 0	13.8	3.23E-06	0.917

Table 3-79: Parameters for equation (28) to calculate NH₃ emission factors for petrol, LPG, CNG and E85 passenger cars under hot urban conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	> 0	2	0	1
Euro 1	> 0	70	0	1
Euro 2	> 0	143	1.47E-06	0.964
Euro 3	0-30	1.9	1.31E-06	0.862
Euro 3	> 30	1.6	4.18E-06	0.526
Euro 4	0-30	1.9	1.31E-06	0.862
Euro 4	> 30	1.6	4.18E-06	0.526
Euro 5 and later	> 0	4.1	1.73E-06	0.955

Table 3-80: Parameters for equation (28) to calculate NH₃ emission factors for petrol, LPG, CNG and E85 passenger cars under hot rural conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	> 0	2	0	1
Euro 1	0-150	131	5.94E-08	0.999
Euro 1	> 150	100	8.95E-07	0.978
Euro 2	0-150	148	5.95E-08	0.999
Euro 2	> 150	90.7	9.08E-07	0.992
Euro 3	0-30	29.5	5.90E-08	0.994
Euro 3	> 30	28.9	8.31E-07	0.908
Euro 4	0-30	29.5	5.90E-08	0.994
Euro 4	> 30	28.9	8.31E-07	0.908

Passenger cars, light commercial trucks, heavy-duty vehicles including
buses and motor cycles

Euro 5 and later	> 0	8	9.04E-07	0.977
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Table 3-81: Parameters for equation (28) to calculate NH₃ emission factors for petrol, LPG, CNG and E85 passenger cars under hot highway conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	> 0	2	0	1
Euro 1	0-150	73.3	5.94E-08	0.998
Euro 1	> 150	56.2	8.86E-07	0.968
Euro 2	0-150	83.3	5.94E-08	0.999
Euro 2	> 150	51	9.05E-07	0.988
Euro 3	0-30	64.6	5.95E-08	0.999
Euro 3	> 30	63.4	9.02E-07	0.985
Euro 4	0-30	64.6	5.95E-08	0.999
Euro 4	> 30	63.4	9.02E-07	0.985
Euro 5 and later	> 0	21.8	5.95E-08	0.999

Table 3-82: Parameters for equation (28) to calculate NH₃ emission factors for petrol LCVs under cold urban conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	> 0	2	0	1
Euro 1	0-150	50	1.52E-06	0.765
Euro 1	> 150	11.7	2.92E-06	0.351
Euro 2	0-150	51	1.70E-06	0.853
Euro 2	> 150	14.6	3.89E-06	0.468
Euro 3	0-30	5.4	1.77E-06	0.819
Euro 3	> 30	4.8	4.33E-06	0.521
Euro 4	0-30	5.4	1.77E-06	0.819
Euro 4	> 30	4.8	4.33E-06	0.521
Euro 5 and later	> 0	13.8	3.23E-06	0.917

Table 3-83: Parameters for equation (28) to calculate NH₃ emission factors for petrol LCVs under hot urban conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	> 0	2	0	1
Euro 1	> 0	70	0	1
Euro 2	> 0	143	1.47E-06	0.964
Euro 3	0-30	1.9	1.31E-06	0.862
Euro 3	> 30	1.6	4.18E-06	0.526
Euro 4	0-30	1.9	1.31E-06	0.862
Euro 4	> 30	1.6	4.18E-06	0.526
Euro 5 and later	> 0	4.1	1.73E-06	0.955

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
 Passenger cars, light commercial trucks, heavy-duty vehicles including
 buses and motor cycles

Table 3-84: Parameters for equation (28) to calculate NH₃ emission factors for petrol LCVs under hot rural conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	> 0	2	0	1
Euro 1	0-150	131	5.94E-08	0.999
Euro 1	> 150	100	8.95E-07	0.978
Euro 2	0-150	148	5.95E-08	0.999
Euro 2	> 150	90.7	9.08E-07	0.992
Euro 3	0-30	29.5	5.90E-08	0.994
Euro 3	> 30	28.9	8.31E-07	0.908
Euro 4	0-30	29.5	5.90E-08	0.994
Euro 4	> 30	28.9	8.31E-07	0.908
Euro 5 and later	> 0	8	9.04E-07	0.977

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
**Passenger cars, light commercial trucks, heavy-duty vehicles including
buses and motor cycles**

Table 3-85: Parameters for equation (28) to calculate NH₃ emission factors for petrol LCVs under hot highway conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	> 0	2	0	1
Euro 1	0-150	73.3	5.94E-08	0.998
Euro 1	> 150	56.2	8.86E-07	0.968
Euro 2	0-150	83.3	5.94E-08	0.999
Euro 2	> 150	51	9.05E-07	0.988
Euro 3	0-30	64.6	5.95E-08	0.999
Euro 3	> 30	63.4	9.02E-07	0.985
Euro 4	0-30	64.6	5.95E-08	0.999
Euro 4	> 30	63.4	9.02E-07	0.985
Euro 5 and later	> 0	21.8	5.95E-08	0.999

For all other vehicle classes, bulk ammonia emission factors are given in Table 3-86. No separate calculation is required for excess cold-start emissions. These emission factors are based solely on a literature review, and should be considered as broad estimates (de Reydellet, 1990; Volkswagen, 1989).

Table 3-86: Bulk (hot + cold) ammonia (NH₃) emission factors (mg/km)

Vehicle category	Urban	Rural	Highway
Passenger cars			
Diesel Euro 4 or earlier	1	1	1
Diesel Euro 5	1.9	1.9	1.9
Diesel Euro 6 and later	7	7	7
2-stroke	2	2	2
Light commercial vehicles			
Diesel Euro 4 or earlier	1	1	1
Diesel Euro 5 and later	Equal to Diesel PC		
Heavy-duty vehicles			
Petrol vehicle > 3.5 t	2	2	2
Diesel Euro IV or earlier	2,9	2,9	2,9
Diesel Euro V	11	11	11
Diesel Euro VI and later	9	9	9
Motorcycles			
< 50 cm ³	1	1	1
> 50 cm ³ 2-stroke	2	2	2
> 50 cm ³ 4-stroke	2	2	2

PAHs and POPs

Emission factors (in µg/km) for specific polycyclic aromatic hydrocarbons (PAHs) and persistent organic pollutants (POPs) are given in Table 3-87. Different vehicle categories are covered. A rough distinction is made between conventional (pre-Euro I) and closed-loop catalyst vehicles (Euro I and later). For diesel passenger cars and light commercial vehicles, different emission factors are given for direct injection (DI) and indirect injection (IDI) vehicles. Since statistical information on the distribution of vehicles according to their combustion concept is difficult to collect, it is proposed that the average (DI, IDI) emission factor is used to estimate emissions from diesel non-heavy-duty vehicles.

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
**Passenger cars, light commercial trucks, heavy-duty vehicles including
buses and motor cycles**

The methodology is applicable to the four PAHs relevant for the UNECE POPs protocol: indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(a)pyrene, and several others. These emission factors should be considered as bulk values, and no distinction is made between hot and cold-start emissions. They have been developed on the basis of a literature review, including the following sources: BUWAL (1994), TNO (1993b), Volkswagen (1989). The application of equation (8) to these emission factors provides total emissions of PAHs and POPs per vehicle class.

PAH and POP emissions from four-stroke motorcycles are estimated using the emission factors for conventional petrol cars. This approach will be modified as soon any data on emissions of these pollutants from motorcycles become available.

Dioxins and furans

Emission factors for dioxins and furans are given in

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

Table 3-88. These are provided separately to other POPs because an aggregate toxicity equivalent emission factor is provided. This emission factor takes into account the toxicity of different dioxin and furan compounds according to the NATO Committee on the Challenges of the Modern Society (NATO-CCMS). Actual emission factors for different dioxins and furans have been collected from the available literature (Umweltbundesamt, 1996) and from a relevant literature study (Pastramas et al. 2014). The final value is a bulk emission factor expressed in pg/km. Due to the limited available information, these emission factors need to be reconsidered when updated data become available, especially with regard to HCB and PCB, for which data from road vehicles are scarce or virtually non-existent. In order to ensure a consistent approach for all vehicle sources, dioxin and furan emissions from four-stroke motorcycles are calculated using the same toxicity equivalent emission factors as conventional petrol vehicles.

Table 3-87: PAHs and POPs bulk (hot + cold) emission factors

Species	Bulk emission factors (µg/km)					
	Petrol, E85, CNG PC & LCV		Diesel PC & LCV		HDV	LPG
	Convent.	Euro I & on	DI	IDI	DI	
indeno(1,2,3-cd)pyrene	1.03	0.39	0.70	2.54	1.40	0.01
benzo(k)fluoranthene	0.30	0.26	0.19	2.87	6.09	0.01
benzo(b)fluoranthene	0.88	0.36	0.60	3.30	5.45	
benzo(ghi)perylene	2.90	0.56	0.95	6.00	0.77	0.02
fluoranthene	18.22	2.80	18.00	38.32	21.39	1.36
benzo(a)pyrene	0.48	0.32	0.63	2.85	0.90	0.01
pyrene	5.78	1.80	12.30	38.96	31.59	1.06
perylene	0.11	0.11	0.47	0.41	0.20	
anthanthrene	0.07	0.01	0.07	0.17		
benzo(b)fluorene	4.08	0.42	24.00	5.21	10.58	0.71
benzo(e)pyrene	0.12	0.27	4.75	8.65	2.04	
triphenylene	7.18	0.36	11.80	5.25	0.96	0.48
benzo(j)fluoranthene	2.85	0.06	0.32	0.16	13.07	
dibenzo(a,j)anthracene	0.28	0.05	0.11	0.12		
dibenzo(a,l)pyrene	0.23	0.01		0.12		
3,6-dimethyl-phenanthrene	4.37	0.09	4.85	1.25		0.18
benzo(a)anthracene	0.84	0.43	3.30	2.71	2.39	0.05
acenaphthylene			25.92	25.92		
acenaphthene			34.65	34.65		
fluorene					39.99	
chrysene	0.43	0.53	2.40	7.53	16.24	
phenanthrene	61.72	4.68	85.50	27.63	23.00	4.91
naphthalene	11.20	610.19	2100	650.5	56.66	40.28
anthracene	7.66	0.80	3.40	1.37	8.65	0.38
coronene	0.90	0.05	0.06	0.05	0.15	
dibenzo(ah)anthracene	0.01	0.03	0.24	0.56	0.34	

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
 Passenger cars, light commercial trucks, heavy-duty vehicles including
 buses and motor cycles

Table 3-88: PCDD, PCDF and PCB emission factors for passenger cars and light duty vehicles

Vehicle Category	Emission Standard	PCDD [pg I-Teq/km]	PCDF [pg I-Teq/km]	PCB [pg/km]
Petrol PCs	pre-Euro	10.3	21.2	6.4
	Euro 1	13	19	6.4
	Euro 2	13	19	6.4
	Euro 3	2.7	4.1	1.36
	Euro 4	2.7	4.1	1.36
	Euro 5, 6, 6 RDE	2.7	4.1	1.36
Diesel PCs	pre-Euro	0.5	1.00	1.5
	Euro 1	24.5	36.5	12.2
	Euro 2	24.5	36.5	12.2
	Euro 3	24.5	36.5	12.2
	Euro 4	24.5	36.5	12.2
	Euro 5, 6, 6 RDE	0.3	0.44	0.15
Petrol LDVs	pre-Euro	10.3	21.2	31.5
	Euro 1	13	19	6.4
	Euro 2	13	19	6.4
	Euro 3	2.7	4.1	1.36
	Euro 4	2.7	4.1	1.36
	Euro 5, 6, 6 RDE	2.7	4.1	1.36
Diesel LDVs	pre-Euro	0.5	1.00	1.5
	Euro 1	24.5	36.5	12.2
	Euro 2	24.5	36.5	12.2
	Euro 3	24.5	36.5	12.2
	Euro 4	24.5	36.5	12.2
	Euro 5, 6, 6 RDE	0.3	0.44	0.15

Table 3-89: PCDD, PCDF and PCB emission factors for heavy duty diesel vehicles, motorcycles and mopeds

Vehicle Category	Emission Standard	PCDD [pg I-Teq/km]	PCDF [pg I-Teq/km]	PCB [pg/km]
Diesel Heavy Duty	pre-Euro	25	38	10.9
	Euro 1	25	38	12.6
	Euro 2	25	38	12.6
	Euro 3	25	38	12.6
	Euro 4	25	38	12.6
	Euro 5	0.31	0.45	0.15
	Euro 6	0.16	0.24	0.08
Motorcycles	pre-Euro	10.3	21.2	31.5
	Euro 1	13	19	6.4
	Euro 2	13	19	6.4
	Euro 3	2.7	4.1	1.36
	Euro 4	2.7	4.1	1.36
	Euro 5	2.7	4.1	1.36
	Euro 6	2.7	4.1	1.36
Mopeds	pre-Euro	10.3	21.2	31.5
	Euro 1	13	19	6.4
	Euro 2	13	19	6.4
	Euro 3	2.7	4.1	1.36
	Euro 4	2.7	4.1	1.36
	Euro 5	2.7	4.1	1.36
	Euro 6	2.7	4.1	1.36

With regard to HCB, emission factors are not given due to a complete lack of relevant data from road transport. An initial approach was to gather the emission factors from other sources (industrial, waste combustion, ship engines, etc.). However, due to the high variance of the emission factors from these sources, it was decided that more relevant testing is needed to develop emission factors that better represent road vehicles. When compared to the most similar source found, a ship's engine, it cannot be considered that a typical road vehicle's combustion is similar. In addition, the ambient air that a ship uses has a much higher concentration of chlorine than that of an average road vehicle, a factor that is connected to the formation of polychlorinated substances. It was therefore decided to suspend the development of emission factors for HCB from road vehicles until more relevant data have become available.

Fuel consumption dependant emission factors

Emissions of heavy metals are calculated by means of equation (21). Table 3-90 presents the apparent heavy metal emission factors. These values have been calculated by encompassing the impact of engine wear to the heavy metal emissions. Therefore, by multiplying these apparent factors with fuel consumption, it is expected that the combined emissions of fuel and engine wear are estimated.

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

Table 3-90: Heavy metal emission factors for all vehicle categories in ppm/wt fuel

Category	Pb	Cd	Cu	Cr	Ni	Se	Zn	Hg	As
Passenger cars, petrol	0.0016	0.0002	0.0045	0.0063	0.0023	0.0002	0.033	0.0087	0.0003
Passenger cars, diesel	0.0005	5 E-05	0.0057	0.0085	0.0002	0.0001	0.018	0.0053	0.0001
LCVs, petrol	0.0016	0.0002	0.0045	0.0063	0.0023	0.0002	0.033	0.0087	0.0003
LCVs, diesel	0.0005	5 E-05	0.0057	0.0085	0.0002	0.0001	0.018	0.0053	0.0001
HDVs, petrol	0.0016	0.0002	0.0045	0.0063	0.0023	0.0002	0.033	0.0087	0.0003
HDVs, diesel	0.0005	5 E-05	0.0057	0.0085	0.0002	0.0001	0.018	0.0053	0.0001
L-category	0.0016	0.0002	0.0045	0.0063	0.0023	0.0002	0.033	0.0087	0.0003

Lubricant consumption dependant emission factors

Emissions of heavy metals from lubricant consumption are calculated by means of equation (22). Table 3-91 presents the apparent heavy metal emission factors.

Table 3-91: Heavy metal emission factors for all vehicle categories in ppm/wt lubricant

Category	Pb	Cd	Cu	Cr	Ni	Se	Zn	Hg	As
Passenger cars, petrol	0.0332	4.56	778	19.2	31.89	4.54	450.2	0	0
Passenger cars, diesel	0.0332	4.56	778	19.2	31.89	4.54	450.2	0	0
LCVs, petrol	0.0332	4.56	778	19.2	31.89	4.54	450.2	0	0
LCVs, diesel	0.0332	4.56	778	19.2	31.89	4.54	450.2	0	0
HDVs, petrol	0.0332	4.56	778	19.2	31.89	4.54	450.2	0	0
HDVs, diesel	0.0332	4.56	778	19.2	31.89	4.54	450.2	0	0
L-category	0.0332	4.56	778	19.2	31.89	4.54	450.2	0	0

Emission degradation functions

Error! Reference source not found. and **Error! Reference source not found.** provide the degradation functions to be used for simulating the deterioration of emission performance of petrol passenger cars and light commercial vehicles equipped with three way catalysts.

Table 3-92 and Table 3-93 provide the Ad and Bd coefficients of the equation to determine the deterioration of emission performance of petrol and diesel passenger cars and light commercial vehicles.

Table 3-92 Deterioration coefficients for petrol passenger cars and light commercial vehicles

Euro Standard	Pollutant	A _M	B _M
Euro 1	CO	8.50E-06	0.575
	NOx	1.55E-05	0.225
	VOC	4.93E-06	0.753
Euro 2	CO	5.00E-06	0.750
	NOx	1.35E-05	0.325
	VOC	4.93E-06	0.753

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv

Passenger cars, light commercial trucks, heavy-duty vehicles including
buses and motor cycles

Euro 3	CO	1.00E-05	0.500
	NOx	1.27E-05	0.365
	VOC	8.10E-07	0.960
Euro 4	CO	5.00E-06	0.750
	NOx	5.00E-06	0.750
	VOC	8.10E-07	0.960
Euro 5	CO	7.00E-06	0.650
	VOC	3.86E-06	0.807
	NOx	1.50E-05	0.250
Euro 6	CO	1.28E-06	0.936
	NOx	2.08E-06	0.896
	VOC	3.86E-06	0.807

Table 3-93 Deterioration coefficients for diesel passenger cars and light commercial vehicles

Euro Standard	Pollutant	A _M	B _M
Euro 1	CO	0.00E+00	1.0000
	NOx	0.00E+00	1.0000
	VOC	7.12E-06	0.6440
Euro 2	CO	2.50E-06	0.8750
	NOx	2.50E-06	0.8750
	VOC	7.12E-06	0.6440
Euro 3	CO	1.50E-06	0.9250
	NOx	1.50E-06	0.9250
	VOC	7.12E-06	0.6440
Euro 4	CO	3.00E-07	0.9850
	NOx	3.00E-07	0.9850
	VOC	7.12E-06	0.6440
Euro 5	CO	3.00E-07	0.9850
	NOx	3.00E-07	0.9850
	VOC	7.12E-06	0.6440
Euro 6	CO	2.32E-05	-0.1596

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

	NOx	1.82E-06	0.9090
	VOC	7.12E-06	0.6440

Fuel effects

Table 3-94, Table 3-95 and Table 3-96 provide the correction functions required to estimate the effect of fuel properties on emissions, according to subsection 4.6.

The use of biodiesel as a blend with diesel may also lead to some change in emissions. The values proposed in Table 3-97 are differences in emissions caused by different blends with fossil diesel, and correspond to a Euro 3 vehicle/engine technology. The effect of biodiesel on other technologies may vary, but the extent of the variation is difficult to estimate in the absence of detailed data. With regard to NO_x, CO₂ and CO, any effect of technology should be negligible, given the marginal effect of biodiesel on these pollutants in general. The effect of biodiesel on PM for different technologies is more difficult to assess. For older diesel technologies with no advanced combustion concepts and aftertreatment systems, biodiesel may lead to a higher reduction than the one shown in Table 3-97, because the presence of a carbon-oxygen chemical bond reduces the PM formation by intervening on its chemical mechanism. For more recent technologies, with ultra-high-pressure combustion and aftertreatment, the biodiesel effect is difficult to predict. On one hand the chemical mechanism demotes PM formation. On the other hand, the different physical properties of the fuel (viscosity, surface tension, gum content, etc.) may change the flow characteristics and affect the in-cylinder spray development. This may lead to poor combustion and increase soot formation. Hence, the values proposed in Table 3-97 should be used with care for post Euro 3 diesel technologies.

Table 3-94: Relations between emissions and fuel properties for passenger cars and light commercial vehicles

Pollutant	Correction factor equation
CO	$F_{corr} = [2.459 - 0.05513 \times (E100) + 0.0005343 \times (E100)^2 + 0.009226 \times (ARO) - 0.0003101 \times (97-S)] \times [1 - 0.037 \times (O_2 - 1.75)] \times [1 - 0.008 \times (E150 - 90.2)]$
VOC	$F_{corr} = [0.1347 + 0.0005489 \times (ARO) + 25.7 \times (ARO) \times e^{(-0.2642(E100))} - 0.0000406 \times (97-S)] \times [1 - 0.004 \times (OLEFIN - 4.97)] \times [1 - 0.022 \times (O_2 - 1.75)] \times [1 - 0.01 \times (E150 - 90.2)]$
NO _x	$F_{corr} = [0.1884 - 0.001438 \times (ARO) + 0.00001959 \times (ARO) \times (E100) - 0.00005302 \times (97 - S)] \times [1 + 0.004 \times (OLEFIN - 4.97)] \times [1 + 0.001 \times (O_2 - 1.75)] \times [1 + 0.008 \times (E150 - 90.2)]$

Note: O₂ = Oxygenates in %, S = Sulphur content in ppm, ARO = Aromatics content in %, OLEFIN = Olefins content in %, E100 = Mid range volatility in %, E150 = Tail-end volatility in %

Table 3-95: Relations between emissions and fuel properties for diesel passenger cars and light commercial vehicles

Pollutant	Correction factor equation
CO	$F_{corr} = -1.3250726 + 0.003037 \times DEN - 0.0025643 \times PAH - 0.015856 \times CN + 0.0001706 \times T95$
VOC	$F_{corr} = -0.293192 + 0.0006759 \times DEN - 0.0007306 \times PAH - 0.0032733 \times CN - 0.000038 \times T95$
NOx	$F_{corr} = 1.0039726 - 0.0003113 \times DEN + 0.0027263 \times PAH - 0.0000883 \times CN - 0.0005805 \times T95$
PM	$F_{corr} = (-0.3879873 + 0.0004677 \times DEN + 0.0004488 \times PAH + 0.0004098 \times CN + 0.0000788 \times T95) \times [1 - 0.015 \times (450 - S)/100]$

Note: DEN = Density at 15 °C [kg/m³], S = Sulphur content in ppm, PAH = Polycyclic aromatics content in %, CN = Cetane number, T95 = Back end distillation in °C.

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

Table 3-96: Relations between emissions and fuel properties for diesel heavy-duty vehicles

Pollutant	Correction factor equation
CO	$F_{corr} = 2.24407 - 0.0011 \times DEN + 0.00007 \times PAH - 0.00768 \times CN - 0.00087 \times T95$
VOC	$F_{corr} = 1.61466 - 0.00123 \times DEN + 0.00133 \times PAH - 0.00181 \times CN - 0.00068 \times T95$
Nox	$F_{corr} = -1.75444 + 0.00906 \times DEN - 0.0163 \times PAH + 0.00493 \times CN + 0.00266 \times T95$
PM	$F_{corr} = [0.06959 + 0.00006 \times DEN + 0.00065 \times PAH - 0.00001 \times CN] \times [1 - 0.0086 \times (450 - S)/100]$

Note: DEN = Density at 15 °C [kg/m³], S = Sulphur content in ppm, PAH = Polycyclic aromatics content in %, CN = Cetane number, T₉₅ = Back end distillation in °C

Table 3-97: Effect of biodiesel blends on diesel vehicle emissions

Pollutant	Vehicle type	B10	B20	B100
CO ₂	Passenger cars	-1.5 %	-2.0 %	
	Light commercial vehicles	-0.7 %	-1.5 %	
	Heavy-duty vehicles	0.2 %	0.0 %	0.1 %
NO _x	Passenger cars	0.4 %	1.0 %	
	Light commercial vehicles	1.7 %	2.0 %	
	Heavy-duty vehicles	3.0 %	3.5 %	9.0 %
PM	Passenger cars	-13.0 %	-20.0 %	
	Light commercial vehicles	-15.0 %	-20.0 %	
	Heavy-duty vehicles	-10.0 %	-15.0 %	-47.0 %
CO	Passenger cars	0.0 %	-5.0 %	
	Light commercial vehicles	0.0 %	-6.0 %	
	Heavy-duty vehicles	-5.0 %	-9.0 %	-20.0 %
HC	Passenger cars	0.0 %	-10.0 %	
	Light commercial vehicles	-10.0 %	-15.0 %	
	Heavy-duty vehicles	-10.0 %	-15.0 %	-17.0 %

CO₂ correction

CO₂ emissions of new passenger cars registered in Europe are monitored in order to meet the objectives of Regulation EC 443/2009. Empirical models have been constructed to check how well measured in-use fuel consumption of passenger cars can be predicted on the basis of independent variables. The set of models based on type-approval fuel consumption, require vehicle mass and capacity to predict real-world fuel consumption. Moreover, this set of models does not distinguish between vehicle types and it is ideal to predict consumption of new car registrations because both vehicle mass and type-approval CO₂ are readily available from the CO₂ monitoring database⁸.

Recent studies have shown that the divergence between type-approval and in-use CO₂ emissions is growing over time (Kadijk et al., 2012; Ligterink et al., 2016; Ligterink and Eijk, 2014; Mock et al., 2014b; Tietge et al., 2015). A 2017 study (Tietge et al., 2017) has examined real-world fuel consumption data from more than 130.000 vehicles to identify and model the evolution of the divergence. A regression model has been developed considering the registration year as an additional variable to the currently used variables (mass and capacity of vehicle). The model equations are:

Petrol passenger cars:

$$FC_{InUse} \left[\frac{l}{100km} \right] = 0.06056 + 0.0004079 \times CC + 0.001214 \times m + 0.7551 \times FC_{TA} + Y_{RC} \quad (29)$$

⁸ <https://www.eea.europa.eu/data-and-maps/data/co2-cars-emission-13>

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Diesel passenger cars:

$$FC_{InUse} \left[\frac{l}{100km} \right] = -0.5682 + 0.0003539 \times CC + 0.001708 \times m + 0.6279 \times FC_{TA} + Y_{RC} \quad (30)$$

where FC_{TA} stands for type-approval fuel consumption (in l/100km), m stands for the vehicle reference mass (empty weight + 75 kg for driver and 20 kg for fuel), CC stands for the engine capacity in cm³ and Y_{RC} stands for the Year regression coefficient.

The average mass, engine capacity and type-approval CO₂ values per passenger car category are required as user input to enable the CO₂ correction option. The mean FC_{Sample} is calculated as the average fuel consumption of the vehicle sample used in developing COPERT emission factors over the three parts (Urban, Road and Motorway) of the Common Artemis Driving Cycles (CADC). The sum of fuel consumption of the three CADC parts was used, each weighted by a 1/3 factor. It is noted that this 'average' fuel consumption was computed using actual vehicle performance (measurements), not COPERT emission factors. The correction factor is then calculated as:

$$Correction = \frac{FC_{InUse}}{FC_{Sample}} \quad (31)$$

This correction coefficient is then used to calculate the modified fuel consumption and respective CO₂ emission factors for hot emissions only.

Table 3-98. COPERT Sample mean FC (CADC 1/3 mix)

Subsector	FC sample in g/km (COPERT)
G < 0.8l	47.02
G 0.8 - 1.4l	59.48
G 1.4-2l	66.22
G >2l	72.84
D <1.4l	38.77
D 1.4-2l	54.43
D >2l	67.76

Table 3-99. Regression coefficients (YRC) for Petrol and Diesel vehicles

Year	Petrol	Diesel
2002	0.06109	0.01423
2003	0.07502	0.09597
2004	0.21420	0.14220
2005	0.27260	0.20380
2006	0.30680	0.21990
2007	0.37350	0.21190
2008	0.47190	0.23600
2009	0.49580	0.21270
2010	0.53240	0.24680
2011	0.65210	0.35810
2012	0.67840	0.43610

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
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2013	0.81580	0.53210
2014	1.00100	0.77140

The CO₂ correction concerns petrol and diesel passenger cars that conform to Euro 4 and later emission standards.

Species profiles

VOC Speciation

The separation of NMVOCs into different compounds is given in Table 3-100a and Table 3-100b. The proposed fractions have been obtained from the literature (BUWAL, 1994; TNO, 1993; Volkswagen, 1989; Umweltbundesamt, 1996). The fractions in the Tables are applied to the total NMVOC emissions from conventional (pre Euro 1) or closed-loop-catalyst (Euro 1 and later) petrol passenger cars and light commercial vehicles, diesel passenger cars and light commercial vehicles, diesel heavy-duty vehicles and LPG passenger cars. A common speciation is proposed for diesel passenger cars and light commercial vehicles, regardless of the combustion concept (DI or IDI).

The NMVOC speciation for four-stroke motorcycles is estimated using fractions derived from conventional petrol vehicles, as in the case of PAHs and POPs. This approach needs to be reconsidered when more complete data become available.

The last row of Table 3-100b shows the total sum of these fractions. It is assumed that the remaining fraction consists of PAHs and POPs.

Table 3-100a: Composition of NMVOC in exhaust emissions (alkanes, cycloalkanes, alkenes, alkynes)

Group	Species	NMVOC Fraction (% wt.)					
		Petrol 4 stroke		Diesel PC & LCV		HDV	LPG
		Convent.	Euro I & on	IDI & DI			
ALKANES	ethane	1.65	3.19	0.33	0.03	2.34	
	propane	0.47	0.65	0.11	0.10	49.85	
	butane	2.90	5.24	0.11	0.15	15.50	
	isobutane	1.29	1.59	0.07	0.14	6.95	
	pentane	1.78	2.15	0.04	0.06	0.35	
	isopentane	4.86	6.81	0.52		1.26	
	hexane	1.29	1.61		0.30	0.18	
	heptane	0.36	0.74	0.20		0.18	
	octane	0.56	0.53	0.25		0.04	
	2-methylhexane	0.80	1.48	0.45	0.63	0.25	
	nonane	0.06	0.16	0.67		0.01	
	2-methylheptane		0.57	0.12	0.21	0.09	
	3-methylhexane	0.56	1.14	0.22	0.35	0.19	
	decane	0.22	0.19	1.18	1.79		
	3-methylheptane	0.40	0.54	0.20	0.27	0.08	
Alkanes C10-C12	0.03	1.76	2.15		0.01		
Alkanes C>13	0.06	1.45	17.91	27.50			
CYCLOALKANES	All	0.88	1.14	0.65	1.16	0.10	
ALKENES	ethylene	8.71	7.30	10.97	7.01	5.20	
	propylene	4.87	3.82	3.60	1.32	5.19	
	propadiene		0.05				
	1-butene	0.50	0.73				
	isobutene	4.21	2.22	1.11	1.70	0.63	
	2-butene	1.27	1.42	0.52		0.53	
	1,3-butadiene	1.42	0.91	0.97	3.30	0.15	
	1-pentene	0.09	0.11				
	2-pentene	0.23	0.34				
	1-hexene		0.17				
	dimethylhexene		0.15				
ALKYNES	1-butine	0.05	0.21				
	propine	0.76	0.08				
	acetylene	5.50	2.81	2.34	1.05	1.28	

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
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Table 3-100b: Composition of NMVOC in exhaust emissions (aldehydes, ketones, aromatics)

Group	Species	NMVOC Fraction (% wt.)				
		Petrol 4 stroke		Diesel PC & LCV	HDV	LPG
		Convent.	Euro I & on	IDI & DI		
ALDEHYDES	formaldehyde	2.08	1.70	12.00	8.40	1.56
	acetaldehyde	0.59	0.75	6.47	4.57	1.81
	acrolein	0.16	0.19	3.58	1.77	0.59
	benzaldehyde	0.60	0.22	0.86	1.37	0.03
	crotonaldehyde	0.02	0.04	1.10	1.48	0.36
	methacrolein		0.05	0.77	0.86	0.10
	butyraldehyde		0.05	0.85	0.88	0.11
	isobutanaldehyde			2.09	0.59	
	propionaldehyde	0.11	0.05	1.77	1.25	0.70
	hexanal			0.16	1.42	
	i-valeraldehyde			0.11	0.09	0.01
	valeraldehyde		0.01	0.41	0.40	
	o-tolualdehyde	0.19	0.07	0.24	0.80	
	m-tolualdehyde	0.38	0.13	0.34	0.59	
	p-tolualdehyde	0.19	0.06	0.35		
KETONES	acetone	0.21	0.61	2.94		0.78
	methylethylketone	0.11	0.05	1.20		
AROMATICS	toluene	12.84	10.98	0.69	0.01	1.22
	ethylbenzene	4.78	1.89	0.29		0.24
	m,p-xylene	6.66	5.43	0.61	0.98	0.75
	o-xylene	4.52	2.26	0.27	0.40	0.26
	1,2,3 trimethylbenzene	0.59	0.86	0.25	0.30	0.05
	1,2,4 trimethylbenzene	2.53	4.21	0.57	0.86	0.25
	1,3,5 trimethylbenzene	1.11	1.42	0.31	0.45	0.08
	styrene	0.57	1.01	0.37	0.56	0.02
	benzene	6.83	5.61	1.98	0.07	0.63
	C9	3.12	4.21	0.78	1.17	0.25
	C10		3.07			
	C>13	6.01	3.46	13.37	20.37	
	TOTALS (all NMVOC species)		99.98	99.65	99.42	96.71

NO_x speciation

Nitrogen oxides (NO_x) in vehicle exhausts mainly consist of NO and NO₂. The NO₂ mass fraction of total NO_x (primary NO₂) is of particular importance due to the higher toxicity of NO₂ compared to NO. This mass fraction is quoted as f-NO₂, in consistency to the AQEG (2006) report.

Table 3-101 provides the range of f-NO₂ values (expressed as a percentage) developed in the framework of two relevant studies in Europe. The AEAT (2007) study was performed on behalf of DG Environment within a project aiming at assessing air quality targets for the future. The TNO study refers to national data used for the NO₂ emission assessment in the Netherlands (Smit, 2007). The same Table includes the values suggested for use. These values correspond to the AEAT study for Euro 4 and previous vehicle technologies. In general, the TNO and AEAT studies do not differ significantly for older vehicle technologies. It could be considered that the difference is lower than the expected uncertainty in any of the values proposed, given the limited sample of measurements available and the measurement uncertainty for NO₂. The AEAT study was considered more up-to-date, given the detailed discussion within UK concerning primary NO₂ emission rates (AQEG, 2006) and the NO₂/NO_x data provided to AEAT by LAT. The ranges proposed in the AEAT study for passenger cars have also been transferred to light commercial vehicles.

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv

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Table 3-101: Mass fraction of NO₂ in NO_x emissions (f-NO₂)

Category	Emission standard	f-NO ₂ (%)		
		AEAT Study	TNO Study	Suggested Value
Petrol PCs	pre-Euro	4	5	4
	Euro 1 — Euro 2	4	5	4
	Euro 3 — Euro 4	3	5	3
	Euro 5	3	5	3
	Euro 6 a/b/c	-	-	2
	Euro 6 d-temp	-	-	2
Diesel PCs	pre-Euro	11	20	15
	Euro 1 — Euro 2	11	20	13
	Euro 3	25	40	27
	Euro 3 with DPF	-	-	51
	Euro 4	55	40-70	46
	Euro 5	55	70	40
	Euro 6 a/b/c	-	-	30
	Euro 6 d-temp	-	-	20
LPG PCs	pre-Euro	5	5	5
	Euro 1 — Euro 3		5	5
	Euro 4		5	5
	Euro 5		-	5
	Euro 6		-	5
E85 PCs	Euro 4	-	-	3
	Euro 5	-	-	3
	Euro 6	-	-	2
CNG PCs	Euro 4	-	-	3
	Euro 5	-	-	3
	Euro 6	-	-	2
Petrol LCVs	pre-Euro	-	5	4
	Euro 1 — Euro 2	-	5	4
	Euro 3 — Euro 4	-	5	3
	Euro 5	-	5	3
	Euro 6 a/b/c	-	-	2
	Euro 6 d-temp	-	-	2
Diesel LCVs	pre-Euro	-	20	15
	Euro 1 — Euro 2	-	20	13
	Euro 3	-	40	27
	Euro 4	-	40-70	46
	Euro 5	-	70	33
	Euro 6 a/b/c	-	-	30
	Euro 6 d-temp	-	-	20
	Euro 6 d	-	-	20
HDVs (ETC)	pre-Euro	11	10	11
	Euro I — Euro II	11	10	11
	Euro III	14	10	14
	Euro IV	10	10	14
	Euro V	-	10	10
	Euro VI	-	-	10
Euro III+CRT	35	-	35	

With regard to Euro 5 and, in particular, Euro 6 diesel passenger cars, the exact configuration of the exhaust after-treatment system is a decisive factor in the f-NO₂ values. Use of an LNT may lead to f-NO₂ values of above 40%, while use of SCR limits f-NO₂ to a moderate 10-20% in real world conditions. However, if a catalysed DPF follows the SCR, then this could increase f-NO₂ to levels up to 50%. A Euro 6 diesel passenger car without any deNO_x aftertreatment has demonstrated f-NO₂ values that are at petrol car levels (2.5%). This concept is not considered to be really popular between the individual manufacturers. Thus, a wide range of possible values for f-NO₂ exists for diesel Euro 6 cars, and the actual average value will depend on the share of each aftertreatment configuration to the total vehicle fleet. The suggested value in

Table 3-101 assumes SCR to be the dominant de-NO_x technology with some 70% of SCRs preceding the DPF and 30% of SCRs following the DPF.

With regard to petrol passenger cars, current evidence suggests that the NO₂ emissions from late vehicle technologies will remain minimal. The efficiency of the three-way catalyst has led to a reduction in NO_x emissions over the consecutive Euro level vehicles, and at the same time kept f-NO₂ levels low, at 3%.

The f-NO₂ values for Euro V and Euro VI trucks remain relatively low. In all commercial applications, the SCR is installed downstream of the DPF, so NO remains well controlled. A special case is also presented in

Table 3-101 for those earlier heavy duty vehicles (Euro III) retrofitted with continuous regeneration particle filters (CRT). The DPF installed in this case disproportionately increases the f-NO₂.

PM speciation and black carbon

Exhaust PM mainly consists of elemental carbon (EC), organic carbon (OC) and inorganic components including metallic ash and ions. The PM speciation is important both because this affects the health and environmental impacts of the emitted particles but also because this is necessary input to atmospheric modelling studies. Therefore, different literature values have been collected and average EC and OC values have been proposed (Ntziachristos et al., 2007).

The variability of the data collected from tunnel, roadway and dynamometer studies, and the uncertainties in the measurement of, in particular, organic carbon (OC), indicate that exhaust PM speciation is bound to be highly uncertain. Because of this uncertainty, mean EC and black carbon (BC) values are considered practically equal in this chapter (e.g. Battye & Boyer; May et al., 2010; Flanner et al., 2007). Although it is known that EC and BC definitions and determination methods differ, this is considered to be of inferior importance compared to the overall uncertainty in determining either of them per vehicle emission control technology.

Despite overall uncertainties, reliable BC/OC ratios can be developed, because there is a general agreement in the measurements from tunnel and laboratory studies with regard to the emission characteristics of diesel and petrol vehicles. The effect of different technologies (e.g. oxidation catalyst, diesel particle filter) on emissions is also rather predictable.

Table 3-102 suggests ratios between organic material (OM) and black carbon (OM/BC) and BC/PM_{2.5} (both expressed as percentages) that can be applied to the exhaust PM emissions for different vehicle technologies. 'Organic material' is the mass of organic carbon corrected for the hydrogen content of the compounds collected. The sources of these data, and the methodology followed to estimate these values, is given in Ntziachristos et al. (2007). An uncertainty range is also proposed, based upon the values in the literature. The uncertainty is in percentage units, and is given as a range for both ratios

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proposed. For example, if the OM/EC ratio for a particular technology is 50 % and the uncertainty is 20 %, this would mean that the OM/EC ratio is expected to range from 40 % to 60 %. This is the uncertainty expected on fleet-average emissions, and not on an individual vehicle basis; Individual vehicles in a specific category may exceed this uncertainty range. The ratios also correspond to average driving conditions, with no distinction between driving modes or hot and cold-start operation.

Table 3-102: Split of PM in elemental (BC) and organic mass (OM)

Category	Euro standard	BC/PM _{2.5} (%)	OM/BC (%)	Uncertainty (%)
Petrol PC and LCV	PRE-ECE	2	4900	50
	ECE 15 00/01	5	1900	50
	ECE 15 02/03	5	1900	50
	ECE 15 04	20	400	50
	Open loop	30	233	30
	Euro 1	25	250	30
	Euro 2	25	250	30
	Euro 3	15	300	30
	Euro 4	15	300	30
Diesel PC and LCV	Conventional	55	70	10
	Euro 1	70	40	10
	Euro 2	80	23	10
	Euro 3	85	15	5
	Euro 4	87	13	5
	Euro 3, Euro 4, Euro 5 Equipped with DPF and fuel additive	10	500	50
	Euro 3, Euro 4, Euro 5 equipped with a catalyzed DPF	20	200	50
Diesel HDV	Conventional	50	80	20
	Euro I	65	40	20
	Euro II	65	40	20
	Euro III	70	30	20
	Euro IV	75	25	20
	Euro IV	75	25	20
	Euro VI	15	300	30
L-category	Conventional 2 stroke	10	900	50
	Euro 1 2 stroke	20	400	50
	Euro 2 2 stroke	20	400	50
	Conventional 4 stroke	15	560	50
	Euro 1 4 stroke	25	300	50
	Euro 2 4 stroke	25	300	50
	Euro 3 4 stroke	25	250	50

The values in Table 3-102 originate from available data in the literature and engineering estimates of the effects of specific technologies (catalysts, DPFs, etc.) on emissions. The estimates are also based on the assumption that low-sulphur fuels (< 50 ppm t. S) are used. Hence, the contribution of sulphate to PM emissions is generally low. In cases where advanced aftertreatment is used (such as catalysed DPFs), then EC and OM does not add up to 100 %. The remaining fraction is assumed to be ash, nitrates, sulphates, water and ammonium salts.

4 Data quality

4.1 Completeness

It should be considered that all significant exhaust emissions from road transport must have been addressed by following the methodology described in the preceding sections. Non-exhaust emissions induced by vehicles' operation (fuel evaporation and PM from the wear of components) are addressed in separate chapters.

4.2 Avoiding double counting with other sectors

Petrol and, in particular, diesel fuel sold by gas stations may also be used for off-road machinery (e.g. agriculture tractors). Attention should be given so that the fuel consumption reported for road transport does not include sales for off-road use.

In addition, care should be given not to include CO₂ emissions produced by the combustion of biofuels (bioethanol, biodiesel, and biogas). Section 0.C explains how the calculation of total Greenhouse gas emissions should be reported when biofuels are blended to fossil fuels. According to the IPCC 2006 Guidelines, CO₂ emissions from the production of biofuels is reported in the Land Use, Land-Use Change and Forestry sector, while CO₂ from the combustion of biofuels should not be reported. This does not apply to other greenhouse gases produced when combusting biofuels (CH₄, N₂O). These should be included in the reporting of greenhouse gas emissions from road transport.

Finally double-counting may occur in countries where gas used in CNG or LPG processes results from coal gasification. Also in this case, coal-derived CO₂ are part of industrial procedures and the resulting CO₂ from the combustion of the derived gas should not be counted in road transport totals.

4.3 Verification

A few remarks on the verification of road transport emission inventories are presented in the following paragraphs. For a complementary discussion of these issues, refer to the chapter on 'Inventory management, improvement and QA/QC' in this Guidebook and the studies referenced therein. In general, these approaches can be categorised as either 'soft' or 'ground truth' verification methods. Some detail of methods applied to verify emission inventorying models is provided by Smit et al. (2010).

Soft verification: This mainly refers to a *comparison of alternative estimates*: alternative estimates can be compared with each other to infer the validity of the data, based on the degree of agreement. This process can help to homogenise the data collected with different methods. For example, comparison of an inventory produced by a Tier 2 method (distance driven based) with an inventory produced by a Tier 1 method (fuel consumed based) can provide two alternative methods of estimating the same inventory. These two can be used to verify the calculations of either method. Depending on the reliability of the source of data, one may need to correct either the reported fuel consumption or the distance travelled.

Ground truth verification: This mainly refers to alternative scientific methods that can be used to physically verify the model calculations. These methods may be applied to verify either the complete inventory or the emission factors used to develop the inventory. For the verification of the emission factors, the following methods are most common:

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- *Remote sensing studies*: In such studies, measurement devices are setup in specific areas (junctions, ramps to highways, ...) and determine pollutant concentrations directly in the exhaust plume of the passing-by vehicles. Concentrations are converted to pollutant emission per unit of fuel consumed, using the CO₂ concentration in the exhaust and the carbon balance between engine inlet and exhaust. This technique has the advantage of producing results referring to several vehicles (a day-long sampling period may correspond to a few thousand of vehicle samples for dense traffic conditions), including a representative portion of high and ultra emitters. However, momentary concentrations of pollutants are only measured, which are specific to particular vehicle operation in the sampling area. In addition, it is often cumbersome to know the emission control technology of passing-by vehicles and therefore to establish a link between emission levels and emission control technologies.
- *Tunnel studies*: In these studies, road tunnels are used as laboratories to study emissions of vehicles in the tunnel. The difference in pollutant concentration between the inlet and the outlet of the tunnel is measured and is converted to emission levels by combining with the air flowrate through the tunnel. This is associated to the flow of vehicles through the tunnel and emission factors are calculated. Tunnels offer a longer sampling period than remote sensing and provide average emission factors over this period. However, speed in tunnels is usually constant, therefore emission factors may not be representative of actual vehicle operation. In addition, emissions are a mix from vehicles of different fuel and emission control technology, hence it is not straightforward to distinguish between the different vehicle types. Tunnel verification usually provides emission factors for specific vehicle categories (e.g. petrol passenger cars) but not technologies (e.g. Euro 1, 2, ...).
- *On-board and laboratory measurements*: These are the two methods that are primarily used to develop, rather than verify, emission factors. However, these can be also used for verification. In a laboratory, vehicles are driven over a predetermined driving pattern and emissions are measured with analyzers. This provides a detailed measurement of emissions of a known vehicle over a specific driving cycle. This represents high quality data to develop emission factors, as all conditions are known. On the other hand, these measurements are expensive and time consuming and a relatively small dataset becomes available in this way. With on-board measurements, vehicles are equipped with on-board instrumentation and are driven on a road network. This can provide a detailed picture of emissions under real-world vehicle operation. On the other hand, equipping a vehicle with all instrumentation and data-logging is technically demanding. Also, some measurement problems still exist for such systems. However, these two methods result to the most detailed recording of emissions for single vehicles. Both methods can be used to verify emission factors. However, it should be noted that the emission factors used in this Guidebook correspond to the average emission value of a large number of cars. Single cars may significantly deviate from this average, even for the same technology level. It is recommended that emission factors are verified using the average values of a sufficient vehicle sample (at least 4-5 cars).

Different methods can be used for the verification of complete inventories, i.e. verifying both the emission factors and the activity data. In general, the difficulty in verifying a complete inventory increases with the area covered by the inventory. That is, it is almost impossible to verify a complete national inventory by ground truth methods. However, the principles of different methods may be used at varying degree of success to attempt an independent verification. Methods that can be used for complete inventory verification include:

- *Inverse air quality modelling*: In these studies, ambient concentrations (mg/m³) are converted back to emissions by taking into account the meteorological conditions and the physical location of the

measuring station, the emission source(s) and the level of activity. This method has the advantage of being based on actual pollutant concentrations. Disadvantages include the mathematical complication of the problem and the uncertainty introduced by the contribution of emissions not taking place in the area being studied. For example, this method can be used to verify an emissions inventory for a road network in a city, with concentrations not only being affected by the particular roads but also by nearby domestic or industrial sources.

- *Mass-balance techniques.* In these studies emission fluxes (kg/h) are determined through measurement of ambient pollutant concentrations upwind and downwind of specific areas, where particular activity is taking place (i.e. upwind and downwind of a busy highway). These can be conducted at different heights and emissions over a differential volume can be calculated. The advantage of the technique is that emissions of other sources are, to a certain extent, corrected for by taking into account the upwind concentrations. However, some uncertainty is introduced by the wind flow conditions which cannot be exactly determined through this differential volume section.

There is an extensive scientific literature which deals with the verification of the emission factors and the methodology proposed in the Tier 3 method of this Guidebook chapter. Examples of such verification studies include the study of Broderick and O'Donoghue (2007), Librando et al. (2009), Johansson C et al. (2009), Beddows and Harrison (2008) and several others.

4.4 Bottom-up vs. top-down inventories

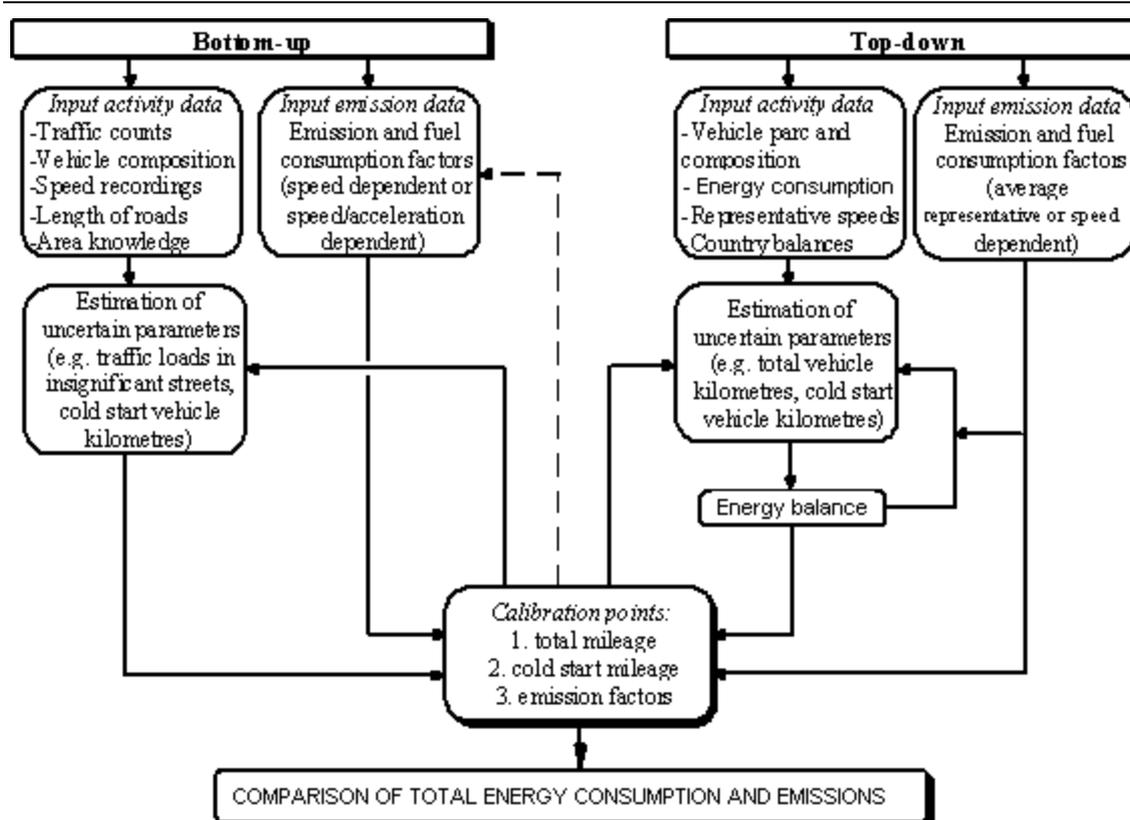
Spatially and temporally disaggregated emission inventories are necessary for reliable and accurate air quality predictions. For example, the ambient concentration of emissions in an urban hot-spot cannot be calculated using year-long average data, since concentrations depend both to the profile of emission rate and the meteorological conditions (temperature wind speed, direction). These follow a temporal profile. In addition, the concentration depends primarily on emissions produced in the nearby area and not the nation-wide or the city-wide emissions. Traffic conditions may differ in various parts of the city given the hour of the day, because they may serve different transportation needs. Therefore, the spatial and temporal resolution of road transport emissions is particularly important in relation to air pollution assessments. This temporal profile may require a bottom-up rather than a top-down approach in order to address it.

Moreover, bottom-up inventories are important when trying to allocate national emissions to individual territories in the country. This is done most of the time by using proxies of transport activity to allocate aggregated emissions, such as the citizens' population to different areas, the length of roads, etc. However, this approach may lead to higher or lower emissions for particular regions as such proxies are not always representative of real traffic activity. For example, the permanent population in the industrial district of a city may be very limited but traffic may be very dense. Moreover, industrial areas are linked to the activity of heavy commercial vehicles which are not present in the more domestic parts of the city. Using the citizens' population as a proxy to estimate road transport activity in the industrial area would therefore significantly underestimate emissions. In such cases, bottom up inventories need to be built in the different territories and any aggregated results (top-down) should be allocated in proportion to the bottom-up inventory calculations. Figure 4-1 illustrates a methodological approach that can be followed in order to make maximum use of both approaches in the creation of an emission inventory. In principle, the top-down and bottom-up estimates of motor vehicle emissions are carried out independently. In each case the most reliable information (such as traffic counts, statistics of vehicle registrations and measured emission factors) form the basis of the calculation. Uncertain parameters are then assessed according to relevant knowledge and reasonable assumptions. After the independent estimates have been carried out, the

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estimated activity and emission data of the two approaches (in terms of calculated total annual vehicle kilometres, annual cold-start vehicle kilometres, and emission factors) are compared, and any discrepancies which are identified are resolved. This reconciliation procedure leads to a re-estimation of the most uncertain parameters of each approach. After the activity and emission data have been reconciled, the next step is to calculate total energy consumption and emissions with both approaches, and to compare the aggregated results. The calculated and statistical energy consumption should not greatly vary, otherwise corrections may be necessary in one or both of the approaches.

Figure 4-1: Proposed reconciliation method in applying bottom-up and top-down approaches when building an urban emission inventory



The scheme shown in Figure 4-1 gives an overview of the required information for such an approach. Evidently, several of the required data are available in most European countries. An aspect that should not be overlooked, however, is the knowledge of the area and its traffic patterns, so that appropriate assumptions can be conducted. It is therefore necessary to create inventories with the close co-operation of local experts.

It should be evident that national emission inventories are difficult to compile in a bottom-up approach. The reason is that this would require an immense amount of data which can be hardly found and be reconciled for a complete country. It would also not offer a better calculation at this aggregated level. An exception to these are relatively small countries (e.g. Cyprus, Luxembourg) where the necessary data is easier to collect. However, if a country-wide road transport inventory should be developed with a bottom-up approach, then the following steps would have to be followed:

1. First, urban inventories should be compiled for the major cities (e.g. cities > 20000 inhabitants).

2. Second, emission inventories for the highway network should be developed. Traffic in highways is monitored both with respect to average speed and traffic counts during the day. This is input that can be directly used to calculate emissions with a high temporal profile.
3. Emissions over rural areas are more difficult to assess. These would require origin-destination matrices for different rural areas (city-village, village-village, ...) and an estimate of the rural vehicle stock, which is not the same as the urban vehicle stock (different proportion of two wheelers and busses, older car technologies, etc.). An approach would be to determine length of roads according to service (e.g. major road connecting city with village, secondary paved road, secondary unpaved road, etc.) and estimate vehicle road per service class. This can be used to estimate total activity in the rural network..

The amount of information given in this report (statistical data and calculated values) is suitable for the compilation of national emission inventories. The application of the methodology at higher spatial resolution can be undertaken only when more detailed data are available to the user. As a general guideline, it can be proposed that the smallest area of application should be the one for which it can be considered that the fuel sold and energy consumed in the region (statistical consumption) equals the actual consumption of the vehicles operating in the region. Zachariadis and Samaras (1997) and Moussiopoulos et al. (1996) have shown that the proposed methodology can be used with a sufficient degree of certainty at such high resolution (i.e. for the compilation of urban emission inventories with a spatial resolution of $1 \times 1 \text{ km}^2$ and a temporal resolution of 1 hour).

One specific point is that the methodology provided as Tier 3 can be used to calculate cold-start emissions on a monthly basis (providing already a temporal resolution). However, special attention should be paid to the allocation of excess cold-start emissions to sub-national areas. In such a calculation, one should independently adjust the beta value (cold-start mileage) and not be based on the I_{trip} value discussed in section 0.B. This I_{trip} value and the beta equation quoted in Table 3-39 should only be used for national inventories because they are calibrated to I_{trip} distribution at a national and not a city level.

4.5 Uncertainty assessment

4.5.1 Uncertainty of emission factors

The Tier 1 and Tier 2 emission factors have been calculated from detailed emission factors and activity data using the Tier 3 method. The Tier 1 and Tier 2 emission factors will therefore have a higher level of uncertainty than those for Tier 3.

The Tier 1 emission factors have been derived from the Tier 3 methodology using 1995 fleet data for the EU-15. The upper limits of the stated ranges in the emission factors correspond to a typical uncontrolled (pre-Euro) technology fleet, and the lower limit of the range corresponds to an average EU-15 fleet in 2005. The suitability of these emission factors for a particular country and year depends on the similarity between the national fleet and the assumptions used to derive the Tier 1 emission factors.

The Tier 2 emission factors have been calculated based on average driving and temperature conditions for the EU-15 in 2005. These emission factors assume average urban, rural and highway driving mileage shares and speeds for the EU-15. Again, the suitability of these emission factors depends on the similarity between the national driving conditions and the average of EU-15.

The Tier 3 emission factors have been derived from experimental (measured) data collected in a range of scientific programmes. The emission factors for old-technology passenger cars and light commercial vehicles were taken from earlier COPERT/CORINAIR activities (Eggleston et al., 1989), whilst the emissions from more recent vehicles are calculated on the basis of data from the Artemis project. (Boulter and Barlow, 2005; Boulter and McCrae, 2007). The emission factors for mopeds and motorcycles are derived from the a study on impact assessment of two-wheel emissions (Ntziachristos et al., 2004). Also, the emission factors of Euro 4 diesel passenger cars originate from an ad-hoc analysis of the Artemis dataset, enriched with more measurements (Ntziachristos et al., 2007).

Emission factors proposed for the Tier 3 methodology are functions of the vehicle type (emission standard, fuel, capacity or weight) and travelling speed. These have been deduced on the basis of a large number of experimental data, i.e. individual vehicles which have been measured over different laboratories in Europe and their emission performance has been summarised in a database. Emission factors per speed class are average emission levels of the individual vehicles. As a result, the uncertainty of the emission factor depends on the variability of the individual vehicle measurements for the particular speed class. This uncertainty has been characterized in the report of Kouridis et al. (2009) for each type of vehicle, pollutant, and speed classes. The tables are not repeated in this report due to their size. In general, the variability of the emission factors depends on the pollutant, the vehicle type, and the speed class considered. The standard deviations range from a few percentage units of the mean value to more than two times the emission factor value for some speed classes with limited emission information.

The distribution of individual values around the mean emission factor for a particular speed class is considered to follow a log-normal size distribution. This is because negative emission factor values are not possible and the log-normal distribution can only lead to positive values. Also, the lognormal distribution is highly skewed with a much higher probability allocated to values lower than the mean and a long tail that reaches high emission values. This very well represents the contribution of high and ultra emitters.

It follows that because of the large range of data utilised, and the processing involved, different limitations/restrictions are associated with the emission factors for different vehicle classes. However, a number of general rules should be followed when applying the methodology:

- the emission factors should only applied within the speed ranges given in the respective Tables. These ranges have been defined according to the availability of the experimental data. Extrapolation of the proposed formulae to lower or higher speeds is therefore not advisable.
- the proposed formulae should only be used with average travelling speed, and by no means can be they considered to be accurate when only 'spot' or constant speed values are available.
- the emission factors can be considered representative of emission performance with constant speed only at high velocities (> 100 km/h) when, in general, speed fluctuation is relatively low.
- the emission factors should not be applied in situations where the driving pattern differs substantially from the 'norm' (e.g. in areas with traffic calming).

4.5.2 Uncertainty of the emission inventory

In all cases of the application of the estimation methodologies, the results obtained are subject to uncertainties. Since the true emissions are unknown, it is impossible to calculate the accuracy of the estimates. However, one can obtain an estimate of their precision. This estimate also provides an impression of the accuracy, as long as the methodology used for estimating road traffic emissions

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represents a reliable image of reality. Errors when compiling an inventory may originate from two major sources:

1. Systematic errors of the emission calculation methodology. These may include errors in the determination of the emission factors and other emission-related elements (e.g. cold start modelling, default values of metals, etc.)
2. Errors in the input data provided by the inventory compiler. These refer to the activity data (vehicle parc, annual mileage, etc), fuel properties, and environmental conditions.

The uncertainty of the emission factors has been discussed in section 4.5.1. This has been mathematically determined based on the available experimental data. The most significant data input errors include:

- erroneous assumptions of vehicle usage. In many countries the actual vehicle usage is not known. In others, data from only a few statistical investigations are available. Most important are errors in total kilometres travelled, the decrease of mileage with age, and the average trip length.
- erroneous estimates of the vehicle parc. The Tier 3 methodology proposes emission factors for 241 individual vehicle types. Detailed statistics for all the vehicle types are not available in all countries and sometimes they have to be estimated. For example, assessing the number of petrol and diesel vehicles > 2.5 t which belong to the category 'light commercial vehicles' and those which belong to the category 'heavy-duty vehicles' involves much uncertainty, since the exact numbers are not available. The same may hold true for splitting a certain category into different age and technology groups, as the real numbers are again not always known.

Table 4-1 provides qualitative indications of the 'precision' which can be allocated to the calculation of the different pollutants

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Table 4-1: Precision indicators of the emission estimate for the different vehicle categories and pollutants

Vehicle Category	Pollutant							
	NO _x	CO	NMVOG	CH ₄	PM	N ₂ O	NH ₃	CO ₂
Petrol passenger cars								
Without catalyst	A	A	A	A	-	C	C	A
With catalyst	A	A	A	A	-	A	A	A
Diesel passenger cars								
All technologies	A	A	A	A	A	B	B	A
LPG passenger cars								
Without catalyst	A	A	A	-	-	--	-	A
With catalyst	A	A	A	A	D	C	C	A
With catalyst	D	D	D	D	D	D	D	A
2-stroke passenger cars	B	B	B	D	-	D	D	B
Light commercial vehicles								
Petrol	B	B	B	C	-	B	B	A
Diesel	B	B	B	C	A	B	B	A
Heavy-duty vehicles								
Petrol	D	D	D	D	-	D	D	D
Diesel	A	A	A	B	A	B	B	A
Two-wheel vehicles								
< 50 cm ³	A	A	A	B	-	B	B	A
> 50 cm ³ 2-stroke	A	A	A	B	-	B	B	A
> 50 cm ³ 4-stroke	A	A	A	B	-	B	B	A
Cold-start emissions								
Pass. Cars conventional	B	B	B	-	-	-	-	B
Pass. Cars Euro 1 and later	B	B	B	A	-	-	-	A
Pass. Cars diesel Conv.	C	C	C	-	C	-	-	B
Pass. Cars diesel Euro I	A	A	A	A	A	-	-	A
Pass. Cars LPG	C	C	C	-	-	-	-	B
Gas. Light commercial vehicles	D	D	D	-	-	-	-	D
Diesel light commercial vehicles	D	D	D	-	D	-	-	D

Note: A: Statistically significant emission factors based on sufficiently large set of measured and evaluated data; B: Emission factors non statistically significant based on a small set of measured re-evaluated data; C: Emission factors estimated on the basis of available literature; D: Emission factors estimated applying similarity considerations and/or extrapolation.

In order to assess the uncertainty of a complete emission inventory, Kouridis et al. (2009) performed an uncertainty characterisation study of the Tier 3 emission methodology, using the COPERT 4 emission model which encompasses this methodology. Global sensitivity and uncertainty analysis was performed by characterising the uncertainty of the emission factors and the input data and by performing Monte Carlo simulations. The report of Kouridis et al. (2009) presents in detail the steps followed in this process. It is not the intention to repeat here the methodology followed in that study. However, some key points and recommendations may prove useful in quantifying and, more significantly, reducing the uncertainty of road transport inventories.

The study quantified the uncertainty of the 2005 road transport inventory in two countries. These two countries were selected as examples of a country in the southern Europe with good knowledge of the stock and activity data and one country in northern Europe with poor statistics on the stock description. The difference in the territories selected (north vs south) affects the environmental conditions considered in each case.

For the compilation of the uncertainty and sensitivity analysis, the uncertainty of the input data was assessed based on available information and justified assumptions in case of no data. The uncertainty in the effect of vehicle age on the annual mileage driven and was assessed by collecting information from different countries. The variability in other input data (fuel properties, temperatures, trip distance distributions, etc.) was quantified based on justified assumptions. In total, the variability of 51 individual variables and parameters was assessed. Some of these parameters were multi-dimensional.

As a first step of the uncertainty characterisation methodology, a screening test was performed. This screened the significant variables and parameters and separated them from the non significant ones. 'Significant' in this case means that the expected variance of the particular variable affects the variance of the result by a significant amount. The significant variables in the case of the two countries are given in Table 4-2. It is evident from the table that there is a certain overlap of variables which are significant in both cases (hot emission factors, mean trip distance etc) but there are also other variables which are important only to each of the countries. For example, the country with good stock statistics has a very large number of two wheelers. As a result, even a small uncertainty in their mileage or total stock will significantly add to the uncertainty of the final result. This is not the case in the country with the weak stock statistics where two wheelers are relatively fewer. In contrast, this second country has only a rough knowledge of the allocation of vehicles to different technologies and this shows up as a significant variable.

The 16 variables in the case of the country with good statistics can explain from 78% (CO₂) to 91% (VOC) of the total uncertainty. This means that the remaining 35 variables can only explain ~10% of the remaining uncertainty of the result. In the country with poor statistics, the 17 variables can explain from 77% (CH₄) to 96% (NO_x) of the total uncertainty. This means that even by zeroing the uncertainty of the remaining 34 variables, the uncertainty in the case of that country would be reduced by less than 15% of its current value. Evidently, an effort should be made to reduce the uncertainty of the variables shown in Table 4-2. Reducing the uncertainty of other variables would have limited effect on the end result.

Some examples can be given to identify differences between the two countries examined:

In the country with good statistics, the uncertainty in NO_x emissions is dominated by the uncertainty in the emission factor, which explains 76% of the total model uncertainty. This means that even if that country had perfect input data of zero uncertainty, the NO_x calculation would not be more than 24% less uncertain than the current calculation. In this instance, the variable that individually explains most of the uncertainty of the inventory is the hot emission factor, followed by either the heavy duty vehicles mileage or the cold-start overemission. Other variables that are affected by the user (motorcycle and moped mileage, l_{trip} , speeds, etc.) affect the total uncertainty by 10-25%. This means that this country is an example where the uncertainty in the calculation of total emissions depends mostly on the inherent uncertainty of the model (emission factors) rather than on the uncertainty of the data provided by the inventory compiler.

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Table 4-2: Variables significant for the quantification of the total emission inventory uncertainty (not by order of significance)

Variable	Significant for country with good stock statistics	Significant for country with weak stock statistics
Hot emission factor	☑	☑
Cold overemission	☑	☑
Mean trip distance	☑	☑
Oxygen to carbon ratio in the fuel	☑	☑
Population of passenger cars	☑	-
Population of light commercial vehicles	☑	☑
Population of heavy duty vehicles	☑	☑
Population of mopeds	☑	-
Annual mileage of passenger cars	☑	☑
Annual mileage of light commercial vehicles	☑	☑
Annual mileage of heavy duty vehicles	☑	☑
Annual mileage of urban busses	-	☑
Annual mileage of mopeds/motorcycles	☑	-
Urban passenger car speed	☑	☑
Highway passenger car speed	☑	-
Rural passenger car speed	☑	-
Urban speed of light commercial vehicles	☑	-
Urban share of passenger cars	☑	-
Urban speed of light commercial vehicles	-	☑
Urban speed of busses	-	☑
Annual mileage of vehicles at the year of their registration	-	☑
The split between diesel and petrol cars	-	☑
The split of vehicles to capacity and weight classes	-	☑
The allocation of vehicles to different technology classes	-	☑

In the case of the country with poor stock statistics, the situation is quite different. In this case, the uncertainty was estimated using all available information and building submodels to estimate the distribution of vehicles to classes and technologies. This is because the allocation of vehicles to different fuels and technology classes is hardly known in this case. The uncertainty of the emission factors still remains as one of the most important variables in estimating the total uncertainty. However, other variables, such as the initial vehicle mileage and the distribution of vehicles to different types are equally important. For example, the hot and cold-start emission factor uncertainty explains only ~30% of the total VOC and CO uncertainty. The remainder is determined by values introduced by the inventory compiler. This is also true to a lesser extent also for the other pollutants. As a result, the quality of the inventory can significantly improve by collecting more detailed input data and by reducing their uncertainty.

The uncertainty analysis conducted in the study of Kouridis et al. (2009) also made possible to quantify the total uncertainty of the calculation. Table 4-3 shows the coefficient of variation (standard deviation over mean) for the different pollutants, for the two countries. In the table, pollutant CO_{2e} represents the equivalent CO₂ emission, when aggregating the greenhouse gases (CO₂, CH₄, and N₂O) weighted by their corresponding 100-year GHG GWPs. Two different uncertainty ranges are given per country. The first (w/o EC), is the uncertainty calculated without trying to respect the statistical energy consumption. This means that the calculated energy consumption can obtain any value, regardless of the statistical one. The second calculation (w. EC) filters the calculation to keep only these runs that

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provide energy consumption values which are within plus minus one standard deviation (7% for the country with good statistics, 11% for the country of poor statistics) of the statistical energy consumption. This is considered a reasonable filtering, as an inventory calculation which would lead to a very high or very low energy consumption value would have been rejected as non valid.

Table 4-3: Summary of coefficients of variation Two cases are shown, one w/o correction for energy consumption, and one with correction for energy consumption.

Case	CO	VOC	CH ₄	NO _x	N ₂ O	PM _{2.5}	PM ₁₀	PM _{exh}	FC	CO ₂	CO _{2e}
Good statistics w/o EC	30	18	44	15	33	13	13	14	7	7	7
Good statistics w. EC	19	12	34	10	26	9	8	9	3	4	4
Poor statistics w/o EC	20	18	57	17	28	18	17	19	11	11	12
Poor statistics w. EC	17	15	54	12	24	13	12	14	8	8	8

The following remarks can be made by comparing the values in Table 4-3:

1. the most uncertain emissions calculations are for CH₄ and N₂O followed by CO. For CH₄ and N₂O it is either the hot or the cold emission factor variance which explains most of the uncertainty. However, in all cases, the initial mileage value considered for each technology class is a significant user-defined parameter, that explains much of the variance. Definition of mileage functions of age is therefore significant to reduce the uncertainty in the calculation of those pollutants.
2. CO₂ is calculated with the least uncertainty, as it directly depends on fuel consumption. It is followed by NO_x and PM_{2.5} which are calculated with a coefficient of variance of less than 15%. The reason is that these pollutants are dominated by diesel vehicles, with emission factors which are less variable than petrol ones.
3. the correction for energy consumption within plus/minus one standard deviation of the official value is very critical as it significantly reduces the uncertainty of the calculation in all pollutants. Therefore, good knowledge of the statistical energy consumption (per fuel type) and comparison with the calculated energy consumption is necessary to improve the quality of the inventories. Particular attention should be given when dealing with the black market of fuel and road transport fuel used for other uses (e.g. off-road applications).
4. the relative level of variance in the country with poor stock statistics appears lower than the country with good stock statistics in some pollutants (CO, N₂O), despite the allocation to vehicle technologies in the former being not well known. This is for three reasons, (a) the stock in the country with poor statistics is older and the variance of the emission factors of older technologies was smaller than new technologies, (b) the colder conditions in the former country make the cold-start of older technologies to be dominant, (c) partially this is an artefact of the method as the variance of some emission factors of old technologies was not possible to quantify. As a result, the uncertainty of the old fleet calculation may have been artificially reduced.
5. despite the relatively larger uncertainty in CH₄ and N₂O emissions, the uncertainty in total greenhouse gas emissions (CO_{2e}) is dominated by CO₂ emissions in both

countries. Therefore, improving the emission factors of N₂O and CH₄ would not offer a substantially improved calculation of total GHG emissions. This may change in the future as CO₂ emissions from road transportation decrease.

4.6 Gridding

Gridding of national road transport inventories is required when trying to assess local air quality or to have a better allocation of national emissions to particular areas. The gridding of road transport emissions data basically means to allocate national emissions to sub-national level. In other words, starting from an aggregated inventory, move in a top-down fashion to allocate emissions at a higher spatial level. The discussion and guidance provided in streamlining top-down and bottom-up approaches in section 4.4 is useful in such a process. Some additional points that need to be clarified in such a procedure are:

- urban emissions should be allocated to urban areas only, e.g. by geographically localising all cities with more than 20 000 inhabitants, and allocating the emissions via the population living in each of the cities. A list of these cities, including their geographical co-ordinates, can be provided by Eurostat.
- rural emissions should be spread all over the country, but only outside urban areas, e.g. by taking the non-urban population density of a country.
- highway emissions should be allocated to highways only, in other words all roads on which vehicles are driven in accordance with the 'highway' driving pattern, not necessarily what is termed 'autobahnen' in Germany, 'autoroutes' in France, 'autostrade' in Italy, and so on. As a simple distribution key, the length of such roads in the territorial unit can be taken.

Some of the statistical data needed for carrying out the allocation of emissions can be found in Eurostat publications, but in general the national statistics are more detailed.

4.7 Weakest aspects/priority area for improvement in current methodology

The improvement of the emission factors for road transport is an ongoing task. The most important issues that need to be improved are considered to be:

- cold-start modelling, in particular for new vehicle technologies;
- improving emission factors for light commercial vehicles and LPG passenger cars;
- better assessment of energy consumption from new vehicle concepts, to better describe CO₂ emissions;
- introduction of alternative fuel and vehicle concepts into the methodology, such as different types of hybrids;
- speciation of NMVOC.

Furthermore, it should be mentioned that the estimation of emissions from road traffic might be considered a task which requires more frequent reviewing and updating than in the case of other inventory source categories. This is due to the relatively large and rapid changes in this sector over short time periods — the turnover of fleets is rather short, legislation changes quickly, the number of vehicles increases steadily, and so on. These changes not only require the continuation of the work on emission factors and activity data, but also the continual adaptation of the methodology.

5 Glossary

5.1 List of abbreviations

Artemis	Assessment and Reliability of Transport Emission Models and Inventory Systems
BC	Western Balkan countries: AL, BA, HR, MK, ME, RS
BEV	Battery Electric Vehicles
CAI	Controlled auto-ignition
CC (cc)	Cylinder capacity of the engine
CH ₄	Methane
CNG	Compressed natural gas
CO	Carbon monoxide
CO ₂	Carbon dioxide
COPERT	Computer programme to calculate emissions from road transport
CRDPF	Continuously regenerating diesel particle filter
CVS	Constant volume sampler
DI	Direct injection
DPF	Diesel particulate filter
E85	An ethanol fuel blend of up to 85% denatured ethanol fuel and petrol by volume
EC	Elemental carbon
EEA-32	Member countries of the European Environment Agency (EU+EFTA4+TR)
EFTA-4	European Free Trade Association Countries (CH, IS, LI, NO)
ETBE	Ethyl tert-butyl ether
FC	Fuel consumption
EC	Energy consumption
GDI	Gasoline direct injection
GVW	Gross vehicle weight
HCCI	Homogeneous charge compression ignition
HDV	Heavy-duty vehicle
I&M	Inspection and maintenance
IDI	Indirect injection
IRF	International Road Federation
JRC	DG Joint Research Centre of the European Commission
LC	Lubricant consumption
LCV	Light commercial vehicle
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MEET	Methodologies to Estimate Emissions from Transport
MTBE	Methyl tert-butyl ether
N ₂ O	Nitrous oxide
NATO-CCMS	NATO Committee on the Challenges to Modern Society
NGV	Natural gas vehicle
NH ₃	Ammonia

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NIS	Newly Independent States (AM, AZ, BY, EE, GE, KZ, KG, LV, LT, MD, RU, TJ, TM, UA, UZ)
NMVOCs	Non-methane volatile organic compounds
NO _x	Nitrogen oxides (sum of NO and NO ₂)
NUTS	Nomenclature of Territorial Units for Statistics (0 to III). According to the EU definition, NUTS 0 is the territory of individual Member States
OBD	On-board diagnostics
OC	Organic carbon
OM	Organic matter
Pb	Lead
PC	Passenger car
PHEV	Plug-in Hybrid Electric Vehicle
RDE	Real Driving Emissions
SCR	Selective catalyst reduction
SNAP	Selective nomenclature for air pollution
THC	Total hydrocarbons
SO _x	Sulphur oxides
VOC	Volatile organic compounds
WMTC	World motorcycle test cycle

5.2 List of symbols

A ^M	emission performance degradation per kilometre
B ^M	relative emission level of brand new vehicles
bc	correction coefficient for the β-parameter for improved catalyst vehicles
E _{HOT}	total emissions during thermally stabilised (hot) engine and exhaust aftertreatment conditions
E ^{CALC}	emission of a fuel-dependent pollutant (CO ₂ , SO ₂ , Pb, HM), estimated on the basis of the calculated fuel consumption
E ^{CORR}	corrected emission of a fuel dependent pollutant (CO ₂ , SO ₂ , Pb, HM) on the basis of the statistical fuel consumption
e ^{COLD} /e ^{HOT}	ratio of emissions of cold to hot engines
e _{HOT}	average fleet representative baseline emission factor in [g/km] for thermally stabilised (hot) engine and exhaust aftertreatment conditions
EF	fuel consumption specific emission factor
ES	emission standard according to the legislation
e(V)	mathematical expression of the speed dependency of e _{HOT}
f(V)	equation (e.g. formula of 'best fit' curve) of the frequency distribution of the mean speeds which corresponds to the driving patterns of vehicles on road classes 'rural', 'urban' and 'highway'
FC ^{CALC}	calculated fuel consumption
EC ^{CALC}	calculated energy consumption
Fce _{HOT}	hot emission factor corrected for the use of improved fuel
Fcorr	emission correction for the use of conventional or improved fuel
FC ^{STAT}	statistical (true) fuel consumption
EC ^{STAT}	statistical (true) energy consumption
FC ^{BIO}	statistical fuel consumption of biofuel

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k	weight related content of any component in the fuel [kg/kg fuel]
LP	the actual vehicle load factor (expressed as a percentage of the maximum load. i.e., LP = 0 denotes an unloaded vehicle and LP = 100 represents a totally laden one)
l_{trip}	average trip length [km]
M	average mileage in [km]
M_{CEHOT}	hot emission factor corrected for degraded vehicle performance due to mileage
M_{corr}	correction coefficient for emission performance degradation due to mileage
M^{MEAN}	mean fleet mileage [km]
N	number of vehicles [veh.]
$r_{\text{H:C}}$	ratio of hydrogen to carbon atoms in fuel
RF	reduction factor for emissions of pollutant of a class over a reference class
S	share of mileage driven in different road types
t	ambient temperature [°C]
V	vehicle mean travelling speed in [km/h]
β	fraction of mileage driven with cold engines

5.3 List of indices

a	monthly mean
Base	referred to the base fuel quality
c	cycle (c= UDC, EUDC)
C	correction
COLD	referring to cold start over-emissions
Fuel	referred to improved fuel quality
HIGHWAY	referring to highway driving conditions
HOT	referring to thermally stabilised engine conditions
I	pollutant index
j	vehicle category
k	vehicle technology
m	fuel type
Pb	lead content in fuel
r	road type (urban, rural, highway)
RURAL	referring to rural driving conditions
S	sulphur content in fuel
TOT	referring to total calculations
URBAN	referring to urban driving conditions

6 Supplementary documents, references and bibliography

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7 Point of enquiry

Enquiries concerning this chapter should be directed to the relevant leader(s) of the Task Force on Emission Inventories and Projection's expert panel on Transport. Please refer to the TFEIP website (www.tfeip-secretariat.org/) for the contact details of the current expert panel leaders.

Appendix 1 Bulk Tier 1 emission factors for selected European countries

The Tier 1 approach uses general emission factors which are averaged over a number of key parameters. A more detailed alternative would be to use data at a national level. This has been achieved by *a priori* introducing a large number of data and estimates to come up with aggregated emission factors. The production of these emission factors has been performed using the activity data from EC4MACS (www.ec4macs.eu) and the methodology of COPERT 4 v8.0 (<http://www.emisia.com/copert>).

In principle, for the Tier 1 method any energy consumption-related figure can substitute $FC_{j,m}$ value in equation (1). One may choose to use total vehicle-kilometres or passenger-kilometres, etc. However, we have chosen fuel consumption because it is a widely reported figure, and one which even the occasional user of the methodology has an understanding of. We also propose to group the vehicle categories in

Table 2-1 to come up with simplified emission factors. The split adopted is shown in Table A1-0-1, together with the range of SNAP codes included for each vehicle category j . The simplified methodology does not deal with LPG vehicles, two-stroke cars, and petrol heavy-duty vehicles because of their small contribution to a national inventory.

Table A1-0-2 to

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

Table A1-0-31 provide fuel consumption-specific emission factors for the main pollutants for a number of countries, and also for countries classified as CC4, BC and NIS. These emission factors should be combined with fuel consumption data by vehicle category to provide total emission estimates. In particular for CO₂, the emission factor corresponds to the exhaust emission and not ultimate CO₂. For definitions and a conversion between the two, refer to subsection 0. The emission factor production is based on a large number of assumptions concerning vehicle technology mix (e.g. share of passenger cars in different ECE and Euro classes), driving conditions (travelling speeds, etc.) and even climatic conditions (temperature). Such assumptions, as well as the methodology to produce vehicle fleet compositions, is described in detail in relevant literature (e.g. Zachariadis et al., 2001). There are a number of clarifications which need to be made for the relevance and range of application of these emission factors; most of the shortcomings are thoroughly discussed by Ntziachristos et. al. (2002):

- they have not been calculated strictly on the basis of national submitted data, but following a uniform methodology across all countries (EC4MACS). Hence, combination with the activity data also proposed in this chapter should not be expected to provide consistent results with the official data reported by countries;
- they correspond to a fleet composition in 2005. Their accuracy deteriorates forward from this point because new technologies appear and the contribution of older technologies decreases;
- they correspond to national applications, including mixed driving conditions (urban congestion to free flow highway).

Their range of application can include:

- simplified inventories, where rough estimate of the transport contribution is required;
- calculation of emissions when a particular vehicle type is 'artificially' promoted or discouraged from circulation (e.g. dieselisation, promotion of two-wheel vehicles in urban areas, etc);
- demonstration of the emission reduction potential when shifting the balance with other modes of transport.

Table A1-0-1: Vehicle categories for application of the simplified methodology and respective SNAP-like ranges from Table 2-1.

Vehicle category — j	SNAP-like code ranges included from Table 2-1
Petrol passenger cars < 2.5 t	07 01 01 01–07 01 03 03
Diesel passenger cars < 2.5 t	07 01 04 01–07 01 05 03
Petrol light commercial vehicles < 3.5 t	07 02 01 01–07 02 01 03
Diesel light commercial vehicles < 3.5 t	07 02 02 01–07 02 02 03
Diesel heavy-duty vehicles > 7.5 t	07 03 02 01–07 03 05 03
Buses	07 03 06 00
Coaches	07 03 07 01–07 03 07 03
Two-wheel vehicles	07 04 01 00–07 05 05 03

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
 Passenger cars, light commercial trucks, heavy-duty vehicles including
 buses and motor cycles

Table A1-0-2: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Austria, year 2005

Category	Austria						
	CO	NOx	NMVOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	68.7	6.44	7.43	0.64	0.03	8.89	3.16
Diesel PC	3.02	13.1	0.61	0.07	0.99	8.78	3.17
Petrol LCV	193	18.1	15.9	0.96	0.02	6.44	3.16
Diesel LCV	7.42	14.4	1.51	0.07	1.54	6.01	3.17
Diesel HDV	7.00	31.2	1.58	0.20	0.79	2.51	3.17
Buses	8.18	35.5	2.44	0.26	1.15	3.22	3.17
Mopeds	664	1.51	268	4.65	4.71	118	3.16
Motorcycles	421	9.91	67.2	4.52	1.17	31.8	3.16

Table A1-0-3: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Belgium, year 2005

Category	Belgium						
	CO	NOx	NMVOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	91.4	13.26	12.05	0.97	0.03	8.98	3.16
Diesel PC	2.54	13.1	0.68	0.06	1.07	8.27	3.17
Petrol LCV	197	16.7	14.8	0.83	0.02	5.79	3.16
Diesel LCV	7.11	13.4	1.29	0.05	1.37	6.37	3.17
Diesel HDV	7.13	32.5	1.49	0.19	0.88	2.02	3.17
Buses	8.09	33.9	2.03	0.24	0.96	4.12	3.17
Mopeds	593	1.75	389	6.39	6.45	158	3.16
Motorcycles	528	7.40	61.6	4.84	0.91	53.7	3.16

Table A1-0-4: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Bulgaria, year 2005

Category	Bulgaria						
	CO	NOx	NMVOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	266	19.5	33.9	1.75	0.03	8.27	3.16
Diesel PC	5.94	12.4	1.66	0.15	1.86	8.01	3.17
Petrol LCV	238	16.2	23.0	1.06	0.02	6.14	3.16
Diesel LCV	9.55	16.8	1.67	0.12	2.21	5.54	3.17
Diesel HDV	9.98	38.0	3.58	0.29	1.48	2.15	3.17
Buses	12.4	39.2	4.37	0.33	1.84	3.69	3.17
Mopeds	536	4.39	307	4.80	5.93	111	3.16
Motorcycles	513	6.35	143	5.42	2.32	16.4	3.16

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
 Passenger cars, light commercial trucks, heavy-duty vehicles including
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Table A1-0-5: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Cyprus, year 2005.

Category	Cyprus						
	CO	NO _x	NMVOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	49.0	5.34	7.46	0.60	0.03	7.96	3.16
Diesel PC	6.91	11.2	1.68	0.19	1.52	8.33	3.17
Petrol LCV	179	16.1	22.8	0.98	0.02	5.96	3.16
Diesel LCV	8.91	16.8	1.41	0.13	1.82	6.80	3.17
Diesel HDV	9.16	36.7	3.24	0.28	1.31	2.24	3.17
Buses	10.4	35.6	3.62	0.38	1.41	4.41	3.17
Mopeds	382	4.98	339	5.51	5.86	157	3.16
Motorcycles	435	6.02	154	5.25	2.49	39.0	3.16

Table A1-0-6: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Czech Republic, year 2005.

Category	Czech Republic						
	CO	NO _x	NMVOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	175	14.7	20.2	1.30	0.03	9.50	3.16
Diesel PC	7.67	11.8	1.83	0.25	2.64	10.3	3.17
Petrol LCV	146	12.6	16.3	0.83	0.02	5.92	3.16
Diesel LCV	11.7	18.4	1.72	0.19	2.99	6.84	3.17
Diesel HDV	8.93	35.6	3.07	0.27	1.27	2.72	3.17
Buses	10.4	39.5	3.19	0.33	1.57	4.70	3.17
Mopeds	683	1.44	297	5.05	6.30	145	3.16
Motorcycles	471	3.83	332	6.92	4.90	101	3.16

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
 Passenger cars, light commercial trucks, heavy-duty vehicles including
 buses and motor cycles

Table A1-0-7: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Denmark, year 2005.

Category	Denmark						
	CO	NOx	NMVOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	92.3	9.18	10.47	0.87	0.03	9.44	3.16
Diesel PC	4.43	12.8	0.77	0.15	1.28	10.31	3.17
Petrol LCV	69	4.3	3.9	0.46	0.02	5.79	3.16
Diesel LCV	6.39	15.0	1.75	0.09	1.35	7.48	3.17
Diesel HDV	6.93	32.5	1.48	0.21	0.78	2.16	3.17
Buses	8.82	36.2	2.34	0.27	1.14	4.57	3.17
Mopeds	575	2.42	279	4.71	5.15	126	3.16
Motorcycles	404	7.62	83.0	4.98	1.32	31.0	3.16

Table A1-0-8: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Estonia, year 2005.

Category	Estonia						
	CO	NOx	NMVOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	132.9	20.07	16.05	1.38	0.03	9.44	3.16
Diesel PC	5.51	12.5	1.32	0.22	2.07	10.05	3.17
Petrol LCV	164	18.8	11.7	1.09	0.02	6.99	3.16
Diesel LCV	8.90	15.0	1.75	0.14	2.27	6.98	3.17
Diesel HDV	7.69	36.9	2.16	0.29	1.10	2.63	3.17
Buses	9.16	38.2	2.64	0.39	1.46	3.22	3.17
Mopeds							
Motorcycles	665	8.88	30.0	6.10	0.64	12.5	3.16

Table A1-0-9: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Finland, year 2005.

Category	Finland						
	CO	NOx	NMVOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	108	11.6	13.3	0.97	0.03	8.50	3.16
Diesel PC	4.45	12.1	1.20	0.13	1.47	8.63	3.17
Petrol LCV	137	9.8	10.6	0.68	0.02	5.57	3.16
Diesel LCV	9.18	15.1	1.70	0.12	2.34	6.66	3.17
Diesel HDV	8.81	35.1	2.33	0.18	1.24	1.67	3.17
Buses	8.98	34.7	2.54	0.34	1.11	3.72	3.17
Mopeds	606	3.03	257	4.36	4.88	122	3.16
Motorcycles	444	7.82	75.3	4.74	1.20	33.8	3.16

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
 Passenger cars, light commercial trucks, heavy-duty vehicles including
 buses and motor cycles

Table A1-0-10: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for France, year 2005.

Category	France						
	CO	NOx	NMVOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	85.5	10.43	11.11	0.93	0.03	9.71	3.16
Diesel PC	3.68	13.0	0.76	0.10	1.15	8.94	3.17
Petrol LCV	125	12.6	12.7	0.77	0.02	6.27	3.16
Diesel LCV	6.96	14.5	1.51	0.08	1.39	6.62	3.17
Diesel HDV	7.21	32.2	1.66	0.20	0.79	2.15	3.17
Buses	9.81	34.3	2.75	0.32	1.08	4.28	3.17
Mopeds	579	2.98	292	4.90	5.17	122	3.16
Motorcycles	411	9.43	85.7	4.62	1.40	31.5	3.16

Table A1-0-11: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Germany, year 2005.

Category	Germany						
	CO	NOx	NMVOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	54.7	5.73	6.38	0.58	0.02	7.83	3.16
Diesel PC	2.34	12.2	0.63	0.05	0.89	8.01	3.17
Petrol LCV	98	5.5	5.8	0.46	0.02	5.29	3.16
Diesel LCV	7.57	15.3	1.68	0.10	1.62	6.35	3.17
Diesel HDV	6.98	32.9	1.45	0.17	0.85	2.35	3.17
Buses	8.44	34.6	2.16	0.25	0.99	3.57	3.17
Mopeds	561	1.75	344	5.75	5.62	125	3.16
Motorcycles	462	6.60	92.6	5.06	1.40	26.2	3.16

Table A1-0-12: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Greece, year 2005.

Category	Greece						
	CO	NOx	NMVOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	69.4	6.99	10.53	0.75	0.03	8.30	3.16
Diesel PC	5.03	12.2	0.85	0.12	0.92	8.42	3.17
Petrol LCV	214	19.1	26.1	1.13	0.02	6.26	3.16
Diesel LCV	8.54	16.2	1.38	0.11	1.73	6.57	3.17
Diesel HDV	8.49	35.6	2.80	0.26	1.24	2.32	3.17
Buses	8.32	34.2	2.26	0.35	1.05	3.71	3.17
Mopeds	450	1.80	298	4.92	4.97	147	3.16
Motorcycles	500	5.67	130.5	5.78	1.99	37.7	3.16

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
 Passenger cars, light commercial trucks, heavy-duty vehicles including
 buses and motor cycles

Table A1-0-13: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Hungary, year 2005.

Category	Hungary						
	CO	NOx	NM VOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	104	12.5	13.1	1.24	0.04	9.89	3.16
Diesel PC	6.60	11.9	1.37	0.22	1.98	10.21	3.17
Petrol LCV	205	24.7	23.6	1.42	0.03	7.26	3.16
Diesel LCV	9.22	16.8	1.73	0.15	2.16	6.97	3.17
Diesel HDV	9.00	37.9	2.98	0.30	1.31	2.34	3.17
Buses	9.30	36.7	2.86	0.33	1.21	4.44	3.17
Mopeds	599	1.04	377	6.29	6.80	164	3.16
Motorcycles	511	2.80	321	7.06	4.94	65.0	3.16

Table A1-0-14: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Ireland, year 2005.

Category	Ireland						
	CO	NOx	NM VOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	63.8	5.34	7.10	0.64	0.03	9.14	3.16
Diesel PC	4.47	12.1	0.88	0.12	1.26	9.23	3.17
Petrol LCV	85	3.2	11.1	0.33	0.02	4.76	3.16
Diesel LCV	7.40	15.3	1.57	0.11	1.52	6.32	3.17
Diesel HDV	4.90	26.6	1.15	0.07	0.54	3.37	3.17
Buses	7.49	32.0	1.71	0.27	0.76	3.13	3.17
Mopeds	492	0.82	464	7.60	7.11	126	3.16
Motorcycles	628	5.93	67.7	5.59	0.98	15.8	3.16

Table A1-0-15: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Italy, year 2005.

Category	Italy						
	CO	NOx	NM VOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	85.2	8.77	11.66	0.90	0.03	9.44	3.16
Diesel PC	2.88	13.3	0.62	0.06	1.06	8.77	3.17
Petrol LCV	134	13.0	13.0	0.76	0.02	6.26	3.16
Diesel LCV	8.83	15.5	1.54	0.13	2.01	7.15	3.17
Diesel HDV	8.05	35.7	2.39	0.20	1.08	2.43	3.17
Buses	8.24	36.4	2.26	0.29	1.17	2.90	3.17
Mopeds	437	2.68	395	6.45	6.46	143	3.16
Motorcycles	534	7.38	94.7	5.66	1.56	23.7	3.16

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
 Passenger cars, light commercial trucks, heavy-duty vehicles including
 buses and motor cycles

Table A1-0-16: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Latvia, year 2005.

Category	Latvia						
	CO	NOx	NM VOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	163	20.6	21.7	1.44	0.03	8.99	3.16
Diesel PC	8.19	12.0	1.88	0.29	2.63	10.8	3.17
Petrol LCV	93.7	8.00	7.17	0.61	0.02	6.00	3.16
Diesel LCV	7.67	15.5	1.96	0.13	1.89	7.72	3.17
Diesel HDV	6.89	33.6	1.76	0.25	0.90	2.22	3.17
Buses	8.69	35.0	2.87	0.30	1.32	3.99	3.17
Mopeds	469	2.44	458	7.47	6.93	148	3.16
Motorcycles	642	6.36	88.6	6.56	1.44	21.9	3.16

Table A1-0-17: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Lithuania, year 2005.

Category	Lithuania						
	CO	NOx	NM VOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	225	29.9	29.7	1.89	0.03	9.45	3.16
Diesel PC	7.30	11.6	1.61	0.23	2.08	9.82	3.17
Petrol LCV	213	14.0	17.5	0.91	0.02	5.56	3.16
Diesel LCV	10.1	18.2	1.93	0.18	2.50	6.65	3.17
Diesel HDV	8.31	37.9	2.52	0.27	1.34	2.19	3.17
Buses	8.68	35.4	2.56	0.28	1.28	1.82	3.17
Mopeds							
Motorcycles	640	7.50	33.0	5.82	0.62	12.1	3.16

Table A1-0-18: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Luxembourg, year 2005.

Category	Luxembourg						
	CO	NOx	NM VOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	77.3	8.59	8.94	0.72	0.03	8.05	3.16
Diesel PC	2.45	13.6	0.68	0.05	1.00	8.05	3.17
Petrol LCV	184	13.7	12.4	0.72	0.02	6.00	3.16
Diesel LCV	7.06	13.9	1.55	0.06	1.40	5.77	3.17
Diesel HDV	6.85	32.0	1.46	0.20	0.78	2.38	3.17
Buses	7.55	33.2	1.86	0.26	0.79	2.17	3.17
Mopeds	379	5.41	342	5.59	5.87	133	3.16
Motorcycles	346	8.02	126	4.11	2.11	33.5	3.16

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
 Passenger cars, light commercial trucks, heavy-duty vehicles including
 buses and motor cycles

Table A1-0-19: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Malta, year 2005.

Category	Malta						
	CO	NOx	NMVOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	50.5	5.97	6.13	0.70	0.04	9.62	3.16
Diesel PC	3.80	13.1	0.60	0.11	0.80	9.27	3.17
Petrol LCV	178	18.2	19.3	1.18	0.02	6.31	3.16
Diesel LCV	6.37	15.3	1.44	0.09	1.10	6.66	3.17
Diesel HDV	8.70	34.0	3.00	0.28	1.11	2.89	3.17
Buses	12.56	37.4	4.99	0.26	1.81	5.95	3.17
Mopeds	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Motorcycles	455	6.82	40.6	5.11	0.55	10.9	3.16

Table A1-0-20: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Netherlands, year 2005.

Category	Netherlands						
	CO	NOx	NMVOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	78.7	9.63	9.60	0.76	0.03	8.33	3.16
Diesel PC	2.71	13.9	0.66	0.07	1.29	8.23	3.17
Petrol LCV	211	16.0	16.4	0.86	0.02	5.81	3.16
Diesel LCV	6.84	13.7	1.47	0.05	1.29	5.41	3.17
Diesel HDV	6.87	31.6	1.49	0.18	0.80	2.30	3.17
Buses	7.60	32.9	1.91	0.22	0.89	3.73	3.17
Mopeds	421	5.08	316	5.16	5.44	101	3.16
Motorcycles	327	8.10	59.0	3.66	0.91	17.2	3.16

Table A1-0-21: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Norway, year 2005.

Category	Norway						
	CO	NOx	NMVOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	73.3	8.76	9.50	0.64	0.03	7.88	3.16
Diesel PC	2.78	12.0	0.62	0.05	0.85	8.90	3.17
Petrol LCV	110.3	11.89	8.06	0.26	0.02	5.58	3.16
Diesel LCV	8.67	16.1	1.91	0.09	2.16	6.99	3.17
Diesel HDV	6.50	31.8	0.90	0.24	0.78	2.32	3.17
Buses	10.95	38.0	3.61	0.45	1.61	4.17	3.17
Mopeds	402	3.27	347	6.51	6.26	124	3.16
Motorcycles	479	8.55	32.6	5.70	0.60	31.5	3.16

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
 Passenger cars, light commercial trucks, heavy-duty vehicles including
 buses and motor cycles

Table A1-0-22: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Poland, year 2005.

Category	Poland						
	CO	NOx	NM VOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	190	16.4	22.7	1.49	0.04	9.74	3.16
Diesel PC	5.26	12.6	0.88	0.16	1.13	9.94	3.17
Petrol LCV	130	10.3	11.0	0.78	0.02	5.79	3.16
Diesel LCV	8.00	16.3	1.91	0.13	1.81	6.88	3.17
Diesel HDV	8.84	37.4	2.90	0.25	1.29	2.35	3.17
Buses	9.48	36.5	2.58	0.29	1.23	4.92	3.17
Mopeds	619	1.85	259	4.49	5.39	146	3.16
Motorcycles	447	6.72	108	5.40	1.85	81.2	3.16

Table A1-0-23: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Portugal, year 2005.

Category	Portugal						
	CO	NOx	NM VOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	70.1	11.7	10.3	0.80	0.03	9.86	3.16
Diesel PC	3.36	13.5	0.47	0.08	0.89	11.31	3.17
Petrol LCV	226	25.5	19.7	1.05	0.02	7.28	3.16
Diesel LCV	6.77	15.1	1.47	0.09	1.21	6.01	3.17
Diesel HDV	7.44	34.7	2.10	0.23	1.00	2.71	3.17
Buses	8.20	36.1	2.21	0.33	1.10	3.52	3.17
Mopeds	530	1.40	418	6.87	6.58	154	3.16
Motorcycles	515	4.44	284	6.35	4.28	50.4	3.16

Table A1-0-24: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Romania, year 2005.

Category	Romania						
	CO	NOx	NM VOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	270	19.8	34.4	1.77	0.03	9.00	3.16
Diesel PC	5.99	12.4	1.67	0.15	1.87	8.31	3.17
Petrol LCV	238	16.5	23.2	1.07	0.02	5.83	3.16
Diesel LCV	9.20	16.5	1.66	0.11	2.09	6.35	3.17
Diesel HDV	9.91	37.8	3.51	0.29	1.47	2.01	3.17
Buses	13.1	39.9	4.82	0.34	1.99	4.37	3.17
Mopeds	522	5.15	282	4.40	5.71	160	3.16
Motorcycles	503	7.03	115	5.12	2.00	53.8	3.16

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
 Passenger cars, light commercial trucks, heavy-duty vehicles including
 buses and motor cycles

Table A1-0-25: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Slovakia, year 2005.

Category	Slovakia						
	CO	NOx	NM VOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	134	12.5	15.7	1.09	0.03	9.61	3.16
Diesel PC	6.81	12.0	1.52	0.23	2.29	10.4	3.17
Petrol LCV	105	9.0	13.4	0.65	0.02	5.78	3.16
Diesel LCV	10.5	17.1	1.61	0.16	2.57	6.90	3.17
Diesel HDV	9.24	36.0	3.34	0.27	1.31	2.82	3.17
Buses	9.80	38.7	2.86	0.33	1.44	4.54	3.17
Mopeds	622	1.43	323	5.48	5.93	155	3.16
Motorcycles	488	2.70	418	7.59	6.14	89.5	3.16

Table A1-0-26: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Slovenia, year 2005.

Category	Slovenia						
	CO	NOx	NM VOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	85.2	8.82	9.81	0.82	0.03	9.18	3.16
Diesel PC	3.23	13.1	0.71	0.08	1.17	8.67	3.17
Petrol LCV	102	6.7	6.7	0.53	0.02	5.58	3.16
Diesel LCV	6.51	14.1	1.57	0.06	1.30	6.44	3.17
Diesel HDV	6.77	29.8	1.66	0.20	0.78	3.18	3.17
Buses	7.17	33.3	1.83	0.22	0.84	3.66	3.17
Mopeds	720	1.75	254	4.48	6.04	111	3.16
Motorcycles	454	11.03	28.3	4.59	0.58	13.8	3.16

Table A1-0-27: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Spain, year 2005.

Category	Spain						
	CO	NOx	NM VOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	89.0	14.98	12.70	0.89	0.03	9.42	3.16
Diesel PC	3.94	13.4	0.61	0.08	1.04	8.67	3.17
Petrol LCV	226	25.5	19.7	1.05	0.02	7.28	3.16
Diesel LCV	7.16	15.1	1.44	0.09	1.34	5.74	3.17
Diesel HDV	6.49	30.8	1.51	0.14	0.79	2.50	3.17
Buses	7.82	32.1	1.81	0.29	0.85	3.30	3.17
Mopeds	615	3.76	243	3.96	4.88	134	3.16
Motorcycles	498	9.45	78.6	4.44	1.32	58.6	3.16

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
 Passenger cars, light commercial trucks, heavy-duty vehicles including
 buses and motor cycles

Table A1-0-28: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Sweden, year 2005.

Category	Sweden						
	CO	NOx	NMVOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	73.0	8.59	8.13	0.85	0.03	7.88	3.16
Diesel PC	3.57	11.2	0.95	0.13	1.13	8.90	3.17
Petrol LCV	82	4.5	4.8	0.42	0.02	5.58	3.16
Diesel LCV	7.64	15.0	1.81	0.11	1.81	6.99	3.17
Diesel HDV	6.83	32.1	1.56	0.25	0.80	2.32	3.17
Buses	7.79	33.5	1.77	0.35	0.90	4.17	3.17
Mopeds	587	4.11	202	3.54	4.04	124	3.16
Motorcycles	399	9.48	56.6	4.36	1.05	31.5	3.16

Table A1-0-29: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for Switzerland, year 2005

Category	Switzerland						
	CO	NOx	NMVOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	42.4	6.38	4.71	0.55	0.02	7.83	3.16
Diesel PC	1.81	11.6	0.47	0.03	0.68	8.01	3.17
Petrol LCV	61.5	5.93	3.12	0.17	0.02	5.29	3.16
Diesel LCV	7.33	14.6	1.39	0.05	1.45	6.35	3.17
Diesel HDV	6.31	31.3	0.76	0.26	0.67	2.35	3.17
Buses	8.61	31.2	2.31	0.41	1.06	3.57	3.17
Mopeds	387	4.90	351	6.41	6.17	125	3.16
Motorcycles	532	9.63	66.7	4.65	1.50	26.2	3.16

Table A1-0-30: Bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for UK, year 2005.

Category	UK						
	CO	NOx	NMVOC	CH ₄	PM	CO ₂ from lubricants g/kg fuel	CO ₂ kg/kg fuel
Petrol PC	72.1	4.48	5.55	0.61	0.03	8.90	3.16
Diesel PC	2.05	13.1	0.41	0.06	0.89	8.94	3.17
Petrol LCV	76	5.2	4.0	0.47	0.02	5.81	3.16
Diesel LCV	6.62	14.2	1.50	0.06	1.32	6.44	3.17
Diesel HDV	6.59	30.7	1.18	0.17	0.67	2.46	3.17
Buses	9.02	33.9	2.15	0.22	0.86	2.86	3.17
Mopeds	590	2.39	215	3.75	4.06	116	3.16
Motorcycles	393	9.26	35.2	4.49	0.67	21.8	3.16

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv
 Passenger cars, light commercial trucks, heavy-duty vehicles including
 buses and motor cycles

Table A1-0-31: Suggested bulk emission factors (g/kg fuel) (for CO₂ kg/kg fuel) for BC, NIS and CC4 countries, year 2002. Calculated with rough fleet composition estimations.

Category	BC, NIS and CC4 countries					
	CO	NO _x	NM VOC	CH ₄	PM	CO ₂ [kg/kg fuel]
Petrol PC	221.70	28.39	34.41	1.99	0.00	2.72
Diesel PC	12.66	11.68	3.73	0.12	4.95	3.09
Petrol LCV	305.63	26.58	32.61	1.51	0.00	2.59
Diesel LCV	15.94	20.06	2.08	0.08	4.67	3.09
Diesel HDV	11.54	38.34	6.05	0.34	2.64	3.09
Buses	15.71	49.18	4.13	0.51	2.15	3.09
Coaches	10.61	42.02	5.75	0.44	2.24	3.09
Mopeds	600.00	1.20	357.70	8.76	0.00	1.07
Motorcycles	691.76	4.82	114.71	5.26	0.00	1.71

Appendix 2 History of the development of the road transport chapter

This chapter presents the latest update of the initial methodology used in the Corinair 1985 emissions inventory (Eggleston et al., 1989), and firstly updated in 1991 for the Corinair 1990 inventory (Eggleston et al., 1993). The Corinair 1990 methodology was used in the first version of the Emission Inventory Guidebook. The second update of the methodology (Ahlvik et al., 1997) was introduced in the software tool COPERT II (**C**omputer **P**rogramme to calculate **E**missions from **R**oad **T**ransport) and a further update of the Guidebook was prepared. The next methodology was fully embodied in the COPERT III tool (Ntziachristos and Samaras, 2000a). The present methodology is the most recent revision (version 2008) of the methodology fully incorporated in the software tool COPERT 4, which is available at <http://www.emisia.com/copert>. Several methodological issues were introduced in the 2006 revision and have been retained in this version (hot emission factors for post Euro 1 vehicles, PM emission information, emission factors for two-wheel vehicles). Some of these have been corrected, and new items have been included to cover new emission technologies and pollutants.

The fundamental elements date back to the first version, and several emission factors from older vehicles still remain unmodified since this first version. The previous versions of this chapter introduced several methodological revisions, including extended vehicle classification and pollutant coverage, emission factors and corrections for road gradient and vehicle load, etc, as well as new PM, N₂O, NH₃ emission information and new emission factors for passenger cars including hybrids, heavy-duty vehicles and two-wheel vehicles. These mainly originated from the European Commission (DG Transport) projects Artemis (Assessment and Reliability of Transport Emission Models and Inventory Systems) and Particulates, a study of Euro 3 two-wheel vehicle emissions conducted on behalf of DG Enterprise, and specific Aristotle University studies on N₂O and NH₃ emissions. The present version includes additional refinements and new calculation elements across recent years. Those revisions and extensions mainly originate from the following sources:

- continuous work on the European Commission (DG Transport) Artemis project, which developed a new database of emission factors of gaseous pollutants from transport (www.trl.co.uk/artemis);
- aristotle University studies and literature reviews, aiming at developing new information for the PM split in elemental carbon and organic carbon, NO_x split in NO and NO₂, emission factors for CNG buses, emission with the use of biodiesel, etc. These dedicated studies were funded by the European Topic Centre (2007 Budget);
- the European Topic Centre on Air Pollution and Climate Change Mitigation of the European Environment Agency work relating to the assessment of the local contribution to air pollution at urban hotspots;
- the European Commission research project (DG Environment) on the further improvement and application of the transport and environment Tremove model;
- the joint EUCAR/JRC ⁽⁹⁾/Concawe programme on the effects of Petrol vapour pressure and ethanol content on evaporative emissions from modern cars.

⁽⁹⁾ DG Joint Research Centre of the European Commission

Appendix 3 Controls

Legislation classes for petrol passenger cars

The production year of vehicles in this category has been taken into account by introducing different classes, which either reflect legislative steps ('ECE', 'Euro') or technology steps ('Improved conventional', 'Open loop').

Between 1970 and 1985 all EC Member States followed the UNECE Regulation 15 amendments as regards the emissions of pollutants from vehicles lighter than 3.5 tonnes GVW. According to the relevant EC Directives, the approximate implementation dates — which varied from one Member State to another — of these regulations were as follows:

- pre ECE vehicles up to 1971
- ECE-15.00 and ECE 15.01 1972 to 1977
- ECE-15.02 1978 to 1980
- ECE-15.03 1981 to 1985
- ECE-15.04 1985 to 1992

The regulations were applicable to vehicles registered in each Member State — either produced in the Member State or imported from elsewhere in the world.

During the period 1985–1990, two intermediate technologies appeared in some countries for passenger cars < 2.0 l engine capacity. The two technologies were:

for petrol passenger cars < 1.4 l

- 'Improved conventional', which took into account German (Anl.XXIVC — effective date: 1.7.1985) and Dutch (NLG 850 — effective date: 1.1.1986) incentive programmes. The emission standards called for improved engine technology, but without the use of aftertreatment. This type of emission control technology also started to appear in Denmark from 1.1.1988.
- 'Open loop', which took into account German, Danish, Greek and Dutch incentive programmes in which the required emission standards were met by applying open-loop, three-way catalysts. Effective dates: Denmark 1.1.1989, Germany 1.7.1985, Greece 1.1.1990, the Netherlands 1.1.1987.

for petrol passenger cars 1.4–2.0 l

- 'Improved conventional', which took into account vehicles which met the limit values of Directive 88/76/EEC by means of open loop catalysts. In practice, relevant only for national incentive programmes. Effective dates of implementation were: Denmark 1.1.1987, Germany 1.7.1985, the Netherlands 1.1.1987.
- 'Open loop', which took into account vehicles which met the limit values of Directive 88/76/EEC by means of open-loop catalysts (three-way, but no lambda control). In practice, these were only relevant to the national incentive programmes. Effective dates: Denmark 1.1.1987, Germany 1.7.1985, Greece 1.1.1990, the Netherlands 1.1.1986.

After 1992, the so-called 'Euro' standards became mandatory in all Member States, and a new type-approval test was introduced. In some countries, again based on national incentives, the new standards were introduced earlier than their official implementation date. The following paragraphs provide a summary of the various stages, and the associated vehicle technology.

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

- Euro 1: these vehicles were officially introduced by Directive 91/441/EEC in July 1992, and were the first to be equipped with a closed-loop, three-way catalyst. They also necessitated the use of unleaded fuel. Euro 1 vehicles were introduced earlier in some countries by means of incentives. These included the voluntary programmes in Germany, introduced after 1.7.1985, which called for compliance with the US 83 limits for cars < 2.0 l. For cars with engines larger than 2.0 l, some additional voluntary measures were introduced. These were Directive 88/76/EEC (relevant for all countries), with implementation date for new vehicles 1.1.1990 and US 83 (only relevant for Denmark, Germany, Greece, the Netherlands) with the following implementation dates: Denmark 1.1.1987, Germany 1.7.1985, Greece 1.1.1989, and the Netherlands 1.1.1987.
- Euro 2: these vehicles had improved, closed-loop, three-way catalyst control, and complied with lower emission limits compared with Euro 1 (30 % and 55 % reduction in CO and HC+NO_x respectively, relative to Euro 1). They were introduced by Directive 94/12/EC in all Member States in 1996.
- Euro 3: this emission standard was introduced with Directive 98/69/EC (Step 1) in January 2000, and introduced a new type-approval test (the New European Driving Cycle) and reduced emission levels compared with Euro 2 (30 %, 40 % and 40 % for CO, HC and NO_x respectively). The same Directive also introduced the need for On-Board Diagnostics (OBD) and some additional requirements (aftertreatment durability, in-use compliance, etc.). Euro 3 vehicles were equipped with twin lambda sensors to comply with emission limits.
- Euro 4: this has been introduced by Directive 98/69/EC (Step 2) in January 2005. It required additional reductions of 57 % for CO and 47 % for HC and NO_x compared with Euro 3, by means of better fuelling and aftertreatment monitoring and control.
- Euro 5 and 6: the European Council adopted the Euro 5 and 6 emission standards proposed by the European Commission in May 2007. Euro 5, that came into effect in January 2010 (September 2009 for new type approvals), leads to further NO_x reductions of 25 % compared with Euro 4, and a PM mass emission limit for GDI cars which is similar to that for diesel cars. No further reductions for petrol vehicles have been proposed for the Euro 6 legislation. Euro 6 vehicles have been further split based on their year of registration: Euro 6 registered up to 2016, Euro 6 registered between 2017-2019 and Euro 6 registered from 2020 onwards. These coincide with the individual steps in Euro 6 regulation, namely Euro 6c, Euro 6d-temp and Euro 6d, which correspond to the same emission limits but increasingly stringent emission control procedure.

Legislation classes for diesel passenger cars

Diesel vehicles of pre-1992 production are all grouped together under the 'conventional' vehicle class. This includes non-regulated vehicles launched prior to 1985, and vehicles complying with Directive ECE 15/04 (up to 1992). Diesel vehicles in this class are equipped with indirect injection engines. In 1992, the 'Consolidated Emissions Directive' (91/441/EEC) introduced Euro standards for diesel cars.

The Euro standards of diesel cars correspond to those for petrol cars. These include Directives 91/441/EEC (Euro 1, 1992-1996), 94/12/EC (Euro 2, valid from 1996 for indirect injection and 1997 for direct injection up to 2000), regulation 98/69/EC Stage 2000 (Euro 3), and the current regulation 98/69/EC Stage 2005 (Euro 4). Euro 1 vehicles were the first to be regulated for all four main pollutants CO, HC, NO_x and PM. Few of the vehicles were equipped with oxidation catalysts. Directive 94/12/EC required reductions of 68 % for CO, 38 % for HC+NO_x and 55 % for PM relative to Euro 1, and oxidation catalysts were used in almost all vehicles. Euro 3 required further reductions relative to Euro 2: 40 %, 60 %, 14 % and 37.5 % for CO, NO_x, HC and PM respectively. These reductions were achieved with

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

exhaust gas recirculation (NO_x reduction) and optimisation of fuel injection with use of common-rail systems (PM reduction). Refinements to the fuel (mainly a reduction in sulphur content) also played an important role in reducing PM emissions. In addition, due to national incentives and competition between manufacturers, some Euro 3 vehicles were equipped with a diesel particle filter to reduce the PM emissions to levels well below the emission standard. Therefore, a special PM emission factor is required for these vehicles. The Euro 4 standard required vehicles to emit 22 % less CO and 50 % less HC, NO_x and PM than the Euro 3 standard. Further to the voluntary introduction particle filters, such significant reductions have been made possible with advanced engine technology and aftertreatment measures, such as cooled EGR, and NO_x reduction - PM oxidation techniques.

As in the case of petrol vehicles, a Euro 5 proposal was put in place in 2010. Euro 6 became effective for new types of vehicles in September 2014, with full implementation for all type approvals starting January 2015. For diesel vehicles, reductions in NO_x emissions relative to Euro 4 of 28 % and 68 % are required for Euro 5 and Euro 6 respectively. However, the most important reduction will be for PM: 88 % relative to Euro 4. A particle number emission limit has also been agreed ($5 \times 10^{11} \text{ km}^{-1}$) which makes mandatory the use of a diesel particle filter.

Euro 5 diesel vehicles have been found to be very high emitters of NO_x under real-world driving, many times above their type-approval emission levels. This has been the result of tunable emission control systems which may alter their performance depending on operation conditions. In order to limit such practices, regulators have introduced an additional package of rules to the Euro 6 limits, the so-called real driving emissions (RDE) regulation. Euro 6 RDE-approved vehicles will need to comply with emission limits with a conformity factor when tested on the road using portable emissions measurement systems (PEMS). The RDE emission limits will be introduced in two steps. The first should apply from September 2017 for new models and from September 2019 for new vehicles and the second one from January 2020 for new models and from January 2021 for new vehicles. The second step comprises a lower conformity factor and additional provisions for testing conditions. Whereas the original Euro 6 regulation (EU) 715/2007 only introduced more strict limits compared to Euro 5, Euro 6 RDE (Regulation (EU) 646/2016) is expected to lead to some significant NO_x emissions reductions for diesel passenger cars and light commercial vehicles. Due to these developments, Euro 6 vehicles have been further split based on their year of registration: Euro 6 registered up to 2016, Euro 6 registered between 2017-2019 and Euro 6 registered from 2020 onwards. Similar to petrol cars, these correspond to three individual steps within the Euro 6 regulation (Euro 6c, Euro 6d-temp, Euro 6d).

Legislation classes for LPG and CNG passenger cars

LPG and CNG vehicles constitute a small fraction of the European fleet. LPG cars which were compliant with the legislation prior to 91/441/EEC are grouped together as 'conventional'. Otherwise, the same Euro classes as those relating to petrol and diesel cars are used. For CNG cars only Euro classes 4, 5, and 6 have been introduced in the methodology as they were not relevant for earlier emission control levels.

Legislation classes for two-stroke passenger cars

This type of vehicles is today disappearing and may be only relevant for some Eastern European countries. Very few vehicles are still in circulation, and no emission standards are applicable. Therefore, all such vehicles are grouped in a common 'conventional' class.

Legislation classes for petrol-hybrid vehicles

Petrol-hybrid vehicles offered today by manufacturers comply with the Euro 6 emission limits. Due to their advanced technology, some hybrid vehicles (HEV) may have actual emission levels which are actually much lower than the Euro 6 limits. Specific emission and energy consumption values are therefore provided for hybrid cars in this chapter. The emission factors are appropriate for the so-called 'full' hybrid vehicles, i.e. vehicles that can be started solely with their electric motor, as opposed to 'mild' hybrids, i.e. vehicles where the electric motor is only complementary to the internal combustion engine.

Legislation classes for rechargeable vehicles

There are three vehicle concepts, offered already in the market today, which can be recharged by power from the electrical grid. These are the plug-in hybrid vehicle (PHEV), the electric vehicle with range-extender (EREV) and the battery electric vehicle (BEV). All three vehicle types can be connected to the electrical grid and recharge their on-board batteries with electrical power, which they then use for propulsion. These vehicles types should not be confused with a full or mild hybrid vehicle. The hybrid vehicle cannot be recharged from the grid; only its own engine may recharge its batteries. A hybrid vehicle therefore uses fuel as the only power source. On the contrary, the PHEV and the EREV use two power sources (fuel and electricity from the grid) while the BEV uses only electricity from the grid for propulsion.

In a battery electric vehicle, electricity from the grid is stored in on-board batteries. The batteries power an electrical motor which provides propulsion. PHEV and EREV vehicles are equipped both with an electrical motor and an internal combustion engine. In a PHEV, power to the wheels is provided both by the electrical motor and the engine. In an EREV, power to the wheels is provided only by the electrical motor. The engine is only used to recharge the batteries through an electrical generator, when the batteries are depleted. This significantly extends the range of these vehicles (hence their name).

All electric vehicles are considered to comply with the petrol Euro 6 emission limits. However, they differ with respect to their carbon dioxide emissions.

Legislation classes for petrol light commercial vehicles < 3.5 t

In the EU, the emissions of these vehicles were covered by the various ECE steps up to 1993, and all such vehicles are again termed 'conventional'. From 1993 to 1997, Euro standards were applicable. Directive 93/59/EEC (Euro 1) required catalytic converters on petrol vehicles. In 1997, Directive 96/69/EC (Euro 2) introduced stricter emission standards for light commercial vehicles. Euro 2 was valid up to 2001. Two more legislation steps have subsequently been introduced: Directive 98/69/EC (Euro 3, valid 2001–2006) and Directive 98/69/EC (Euro 4, valid from 2006 onwards). These introduced even stricter emission limits. The Euro 5, Euro 6 and Euro 6 RDE proposals for passenger cars also covers this vehicle category, although the actual limits vary according to the vehicle weight. The emission-control technology used in light commercial vehicles generally follows the technology of passenger cars with a delay of 1–2 years. Euro 6 vehicles have been further split based on their year of registration, Euro 6 up to 2017, Euro 6 registered between 2018-2020 and Euro 6 registered from 2021 onwards.

Legislation classes for diesel light commercial vehicles < 3.5 t

The legislation classes for petrol light commercial vehicles are also applicable to diesel light commercial vehicles (with different values, of course, plus a PM emission standard). Again, the engine technologies used in diesel light commercial vehicles tend to follow those used in diesel cars with 1–2 year delay. Specifically for the Euro 6 and Euro 6 RDE steps there is a one year delay compared to diesel passenger cars (Euro 6 up to 2017, Euro 6 2018-2020 and Euro 6 2021+).

Legislation classes for petrol heavy-duty vehicles > 3.5 t

Heavy-duty petrol vehicles > 3.5 t play a negligible role in European emissions from road traffic. Any such vehicles are included in the 'conventional' class. There is no legislative distinction as no specific emission standards have been set for such vehicles.

Legislation classes for diesel heavy-duty vehicles > 3.5 t

Emissions from diesel engines used in vehicles of GVW over 3.5 t were first regulated in 1988 with the introduction of the original ECE 49 Regulation. Vehicles (or, rather, engines) complying with ECE 49 and earlier are all classified as 'conventional'. Directive 91/542/EEC, implemented in two stages, brought two sets of reduced emission limits, valid from 1992 to 1995 (Stage 1 — Euro I) and from 1996 to 2000 (Stage 2 — Euro II). Directive 1999/96/EC Step 1 (Euro III) was valid from 2000, and introduced a 30 % reduction of all pollutants relative to Euro II. The same Directive included an intermediate step in 2005 (Euro IV), and a final step in 2008 (Euro V). The Euro V standards are very strict, requiring a reduction in NO_x of more than 70 % and a reduction in PM of more than 85 % compared with the Euro II standards. This will be achieved with engine tuning and oxidation catalysts for PM control, and selective catalytic reduction (SCR) for NO_x control.

Latest emission limits at a Euro VI level have enforced since the 2013/14 period. These call for 50 % reduction in PM and a further 80 % reduction in NO_x over Euro V, with the addition of a cold start cycle. This will necessitate the use of diesel particle filters, engine tuning and EGR for low engine-out NO_x, and specific NO_x exhaust aftertreatment to meet the regulations.

Legislation classes for two-stroke and four-stroke mopeds < 50 cm³

In June 1999, multi-directive 97/24/EC (Step 1 — Euro 1) introduced emission standards which, in the case of mopeds < 50 cm³, were equal to CO of 6 g/km and HC+NO_x at 3 g/km. An additional stage of the legislation came into force in June 2002 (Euro 2) with emission limits of 1 g/km CO and 1.2 g/km HC+NO_x. New Euro 3 emission standards for such small vehicles were prepared by the European Commission in 2013. The limit values are the same as those for Euro 2, but a new type of certification test will be introduced. This will be conducted with an engine start at the ambient temperature, as opposed to the hot engine start currently defined for Euro 2. Due to the strict emission limits, it is expected that few two-stroke mopeds will survive into the Euro 3 limits, and those that will conform with the regulations will have to be equipped with precise air-fuel metering devices, and possibly direct injection and secondary air injection in the exhaust line. In addition, Euro 4 levels have been regulated for the 2017/18 period and Euro 5 levels for the 2020/21 period. These new levels will lead to a further substantial decrease of emissions and are associated with additional measures, including evaporation control and durability requirements.

Legislation classes for two-stroke and four-stroke motorcycles > 50 cm³

Emissions regulations for two- and four-stroke motorcycles > 50 cm³ were first introduced in June 1999 (Euro 1), when Directive 97/24/EC came into force. The Directive imposed different emission standards for two- and four-stroke vehicles respectively, and separate limits were set for HC and NO_x to allow for a better distinction between different technologies (two-stroke: CO 8 g/km, HC 4 g/km, NO_x 0.1 g/km; four-stroke : CO 13 g/km, HC 3 g/km, NO_x 0.3 g/km). In 2002, Regulation 2002/51/EC introduced the Euro 2 (2003) and the Euro 3 (2006) standards for motorcycles, with differentiated limits depending on the engine size. Regulation 168/2013 introduced Euro 4 and Euro 5 limits for motorcycles that gradually lead their emission levels to become similar to passenger cars. This Regulation also mandates evaporation control, durability requirements, OBD requirements, and CO₂ measurement. Possible additional future steps include in-use compliance, offcycle emission control and particle emission number control for direct injection vehicles.

Appendix 4 Accompanying files

The accompanying hot emission function parameters and the cold emission parameters for diesel Euro V and Euro VI heavy-duty vehicles and buses files are available as an electronic annex alongside the main Guidebook files at <http://eea.europa.eu/emep-eea-guidebook>.

Appendix 5 HDV correspondence

Correspondence between the previous Corinair classification for HDVs and buses, and the new system of classification (Boulter and Barlow, 2005)

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