Category		**Exhaust emissions from road transport**
NFR:	**1.A.3.b.i** **1.A.3.b.ii** **1.A.3.b.iii** **1.A.3.b.iv**	**Passenger cars** **Light-duty trucks** **Heavy-duty vehicles including buses** **Motorcycles**
SNAP:	**0701** **0702** **0703** **0704** **0705**	**Passenger cars** **Light-duty vehicles < 3.5 t** **Heavy-duty vehicles > 3.5 t and buses** **Mopeds and motorcycles < 50 cm^3** **Motorcycles > 50 cm^3**
ISIC:		
Version	**Guidebook 2009**	
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Contents

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-duty 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 and motorcycles (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 ([3]);
- greenhouse gases (CO_2, CH_4, N_2O);
- acidifying substances (NH_3, SO_2);
- particulate matter mass (PM);
- carcinogenic species (PAHs ([4]) and POPs ([5]);
- toxic substances (dioxins and furans);
- heavy metals.

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 exhaust. Emission factors for particulate matter are presented in terms of particle number and surface area for different size ranges. Also, fuel (energy) consumption figures can be calculated. For NMVOCs, emission factors for 68 separate substances are provided.

1.2 Structure and origins of this chapter

The original Corinair 1985 emissions inventory (Eggleston et al, 1989) has been updated five times, with the most recent version having been published in August 2007 (Ntziachristos and Kouridis, 2007). As part of the European Environment Agency (EEA) Guidebook restructuring project, a new standardised tier-based structure has been adopted for all sectoral chapters. In the present chapter, the Tier 3 methodology is, in fact, a transfer of the ‘detailed’ methodology of the previous version of the Guidebook. Also, the Tier 1 and Tier 2 emission factors were calculated on the basis of the Tier 3 methodology, by applying some default values, by the team at Aristotle University, Thessaloniki. Annex 2 provides a brief history of the previous versions of this chapter.

([1]) LDVs

([2]) HDVs

([3]) NMVOCs = non-methane volatile organic compounds.

([4]) PAHs = polycyclic aromatic hydrocarbons.

([5]) POPs = persistant organic pollutants.

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 gasoline, 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 the red, exhaust emissions being those covered in this chapter, whilst the other sources of emissions from road vehicles are covered in other chapters.

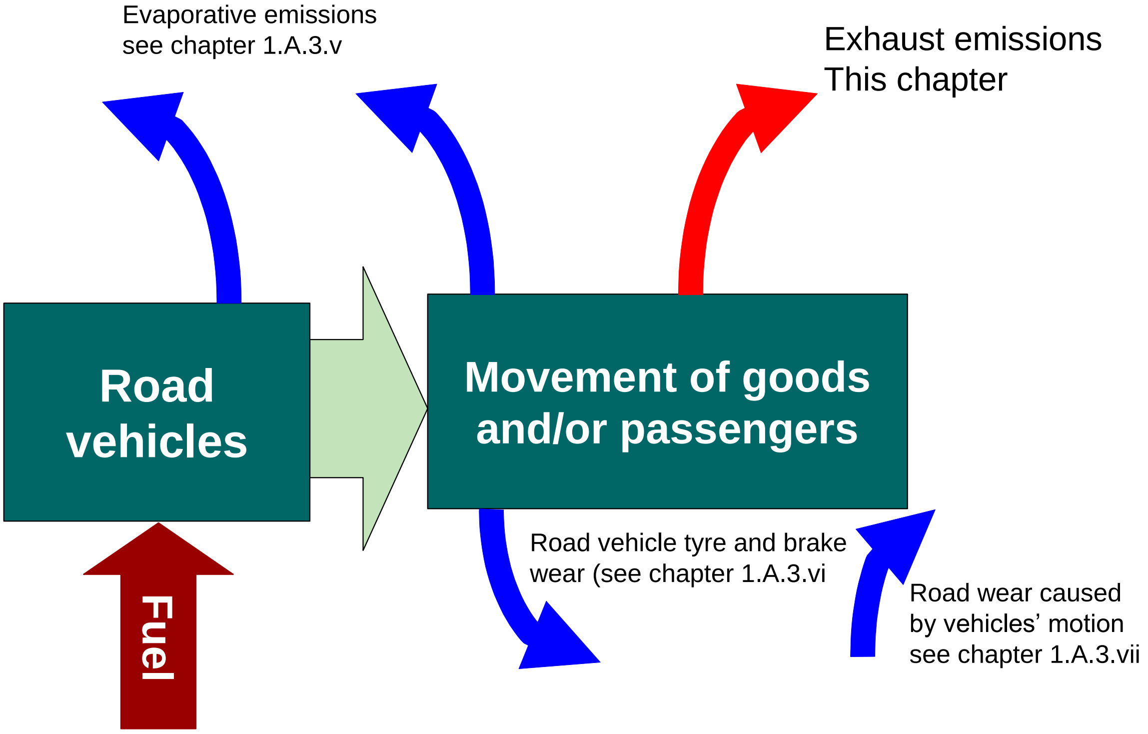

Figure 2-1 Flow diagram emissions from road transport.

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 the engine size, weight or technology level of the vehicle, giving a total of 23 vehicle categories. For certain pollutants, the emission factors for these vehicle categories 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	SNAP-like code	Vehicle category	UNECE Classification
1.A.3.b.i	07 01	PASSENGER CARS	**M1:** vehicles used for the carriage of passengers and comprising not more than eight seats in addition to the driver's seat.
	07 01 01	Gasoline < 1.4 l	
	07 01 02	Gasoline 1.4–2.0 l	
	07 01 03	Gasoline > 2.0 l	
	07 01 04	Diesel < 2.0 l	
	07 01 05	Diesel > 2.0 l	
	07 01 06	LPG	
	07 01 07	Two-stroke gasoline	
	07 01 08	Hybrids	
1.A.3.b.ii	07 02	LIGHT-DUTY VEHICLES < 3.5 t	**N1:** vehicles used for the carriage of goods and having a maximum weight not exceeding 3.5 tonnes.
	07 02 01	Gasoline	
	07 02 02	Diesel	
1.A.3.b.iii	07 03	HEAVY-DUTY VEHICLES	
	07 03 01	Gasoline	**N2:** vehicles used for the carriage of goods and having a maximum weight exceeding 3.5 tonnes but not exceeding 12 tonnes. **N3**: vehicles used for the carriage of goods and having a maximum weight exceeding 12 tonnes.
	07 03 02	Diesel < 7.5 t	
	07 03 03	Diesel 7.5–16 t	
	07 03 04	Diesel 16–32 t	
	07 03 05	Diesel > 32 t	
	07 03 06	Urban buses	**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.
	07 03 07	Coaches	**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.
1.A.3.b.iv	07 04	MOPEDS and MOTORCYCLES < 50 cm^3	**L1:** two-wheeled vehicles with an engine cylinder capacity not exceeding 50 cm^3 and a maximum design speed not exceeding 40 km/h. **L2:** three-wheeled vehicles with an engine cylinder capacity not exceeding 50 cm^3 and a maximum design speed not exceeding 40 km/h. **L3:** two-wheeled vehicles with an engine cylinder capacity exceeding 50 cm^3 or a design speed exceeding 40 km/h. **L4:** vehicles with three wheels asymmetrically arranged in relation to the longitudinal median axis, with an engine cylinder capacity exceeding 50 cm^3 or a design speed exceeding 40 km/h (motor cycles with sidecar). **L5:** vehicles with three wheels symmetrically arranged in relation to the longitudinal median axis, with a maximum weight not exceeding 1 000 kg and either an engine cylinder capacity exceeding 50 cm^3 or a design speed exceeding 40 km/h (motor cycles with sidecar).
	07 05	MOTORCYCLES	
	07 05 01	Two stroke > 50 cm^3	
	07 05 02	Four stroke > 50 cm^3	
	07 05 03	Four stroke 50–250 cm^3	
	07 05 04	Four stroke 250–750 cm^3	
	07 05 05	Four stroke > 750 cm^3	

Due to the technological developments that have occurred for heavy-duty engines, and also their use in a wide range of vehicle types, a more detailed classification of heavy-duty vehicles and buses is required than the one presented in Table 2-1. Table 2-2 includes this new categorisation. In this version of the exhaust emissions chapter, a detailed categorisation of HDVs in size-categories is included to allow for a more detailed calculation of their exhaust emissions. In order to maintain consistency with the Corinair classification, Figure 2-2 shows the correspondence between the new, more detailed HDV categories and the old ones.

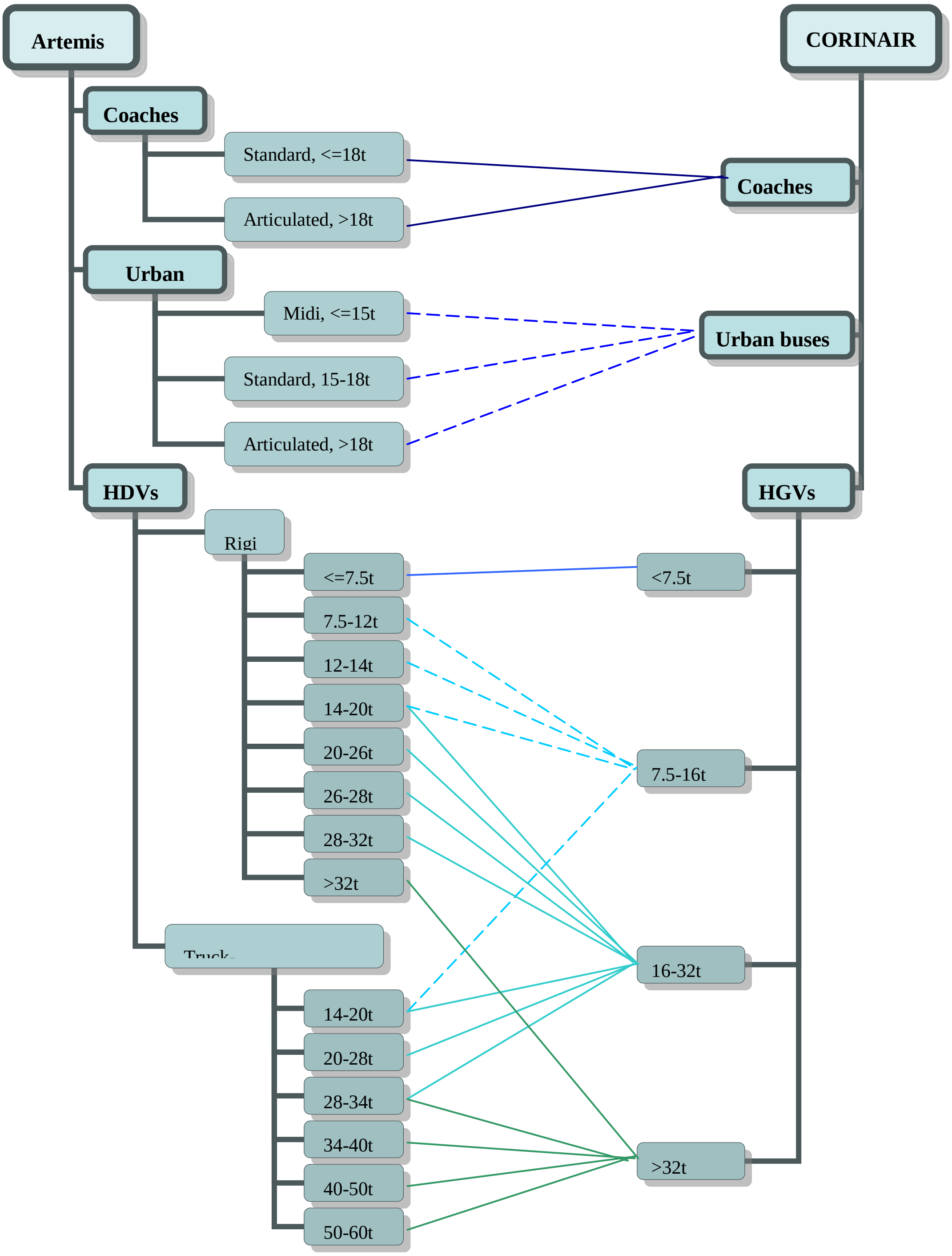

Figure 2-2: Correspondence between the previous Corinair classification for HDVs and buses, and the new system of classification (Boulter and Barlow, 2005)

2.2 Techniques

The combustion process produces CO_2 and H_2O 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 N_2 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 NH_3 and N_2O.

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 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 gasoline 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. Statistics published by the European Automobile Manufacturers' Association (ACEA, 2006) show that 48.3 % of passenger cars sold in Europe in 2005 were diesel, with shares reaching as high as 70 % for countries like Austria, Belgium and France. 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:

- 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, eleven 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 LDVs, HDVs and two-wheel vehicles. For LDVs and two-wheel vehicles Arabic numerals are used (e.g. Euro 1, Euro 2, etc.), whereas for HDVs roman numerals are used (e.g. Euro I, Euro IIetc.).

2.3.1 Legislation classes for gasoline 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 gasoline 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 gasoline 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.

- 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 gasoline vehicles have been proposed for the Euro 6 legislation.

2.3.2 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 gasoline 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 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 gasoline vehicles, a Euro 5 and 6 proposal has been recently adopted. For diesel vehicles, reductions in NO_x emissions relative to Euro 4 of 28 % and 68 % will be 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 (5×10^{11} km^{-1}) which will necessitate the use of a diesel particle filter.

2.3.3 Legislation classes for LPG passenger cars

LPG 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 gasoline and diesel cars are used.

2.3.4 Legislation classes for two-stroke passenger cars

This type of vehicles is relevant mainly for some Eastern European countries (and to some extent for Germany). Very few vehicles are still in circulation, and no emission standards are applicable. Therefore, all such vehicles are grouped in a common 'conventional' class.

2.3.5 Legislation classes for hybrid vehicles

Hybrid vehicles offered today by manufacturers comply with the Euro 5 emission limits. Due to their advanced technology, some hybrid vehicles (HEV) may have actual emission levels which are actually much lower than the Euro 5 limits. Specific emission and fuel 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.

2.3.6 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 (REV) and the full electric vehicle (EV). 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 REV use two power sources (fuel and electricity from the grid) and the EV uses only electricity from the grid for propulsion.

In a full electric vehicle, electricity from the grid is stored in on-board batteries. The batteries power an electrical motor which provides propulsion. PHEV and a REV 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 a REV 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 comply with the gasoline Euro 6 emission limits. However, they differ with respect to their carbon dioxide emissions.

2.3.7 Legislation classes for gasoline light-duty 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 gasoline vehicles. In 1997, Directive 96/69/EC (Euro 2) introduced stricter emission standards for light-duty 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 proposal 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-duty vehicles generally follows the technology of passenger cars with a delay of 1–2 years.

2.3.8 Legislation classes for diesel light-duty vehicles < 3.5 t

The legislation classes for gasoline light-duty vehicles are also applicable to diesel light-duty vehicles (with different values, of course, plus a PM emission standard). Again, the engine technologies used in diesel light-duty vehicles tend to follow those used in diesel cars with 1–2 year delay.

2.3.9 Legislation classes for gasoline heavy-duty vehicles > 3.5 t

Heavy-duty gasoline 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.

2.3.10 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.

A discussion is currently underway concerning the Euro VI emission standards, to be introduced in 2014. The European Commission proposal calls for 50 % reduction in PM and a further 80 % reduction in NO_x over Euro V. This will necessitate the use of diesel particle filters, engine tuning and EGR for low engine-out NOx, and NOx exhaust aftertreatment to meet the regulations. The Commission' approval is still pending approval by the Council.

2.3.11 Legislation classes for two-stroke mopeds < 50 cm³

Until recently, no EU-wide emission standards had been agreed for two-wheel vehicles, and only national legislation was valid in a few countries. In June 1999, multi-directive 97/24/EC (Step 1 — Euro 1) introduced emission standards which, in the case of two-stroke mopeds < 50 cm³, applied to CO (6 g/km) and HC+NO_x (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 are currently being prepared by the European Commission. The limit values will be 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 be available once Euro 3 becomes mandatory (possibly 2009), 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.

2.3.12 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. No further emission standards have been planned for the future. However, it is expected that the World Motorcycle Test Cycle (WMTC) will soon be used worldwide as a certification test, and this may bring some changes in the emission standards.

2.3.13 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 2-2: Summary of all vehicle classes covered by the methodology

Vehicle category	Type	Legislation/technology
Passenger cars	Gasoline < 1.4 l 1.4–2.0 l > 2.0 l	PRE ECE
		ECE 15/00-01 ECE 15/02 ECE 15/03 ECE 15/04 Improved conventional Open loop Euro 1 — 91/441/EEC Euro 2 — 94/12/EC Euro 3 — 98/69/EC Stage 2000 Euro 4 — 98/69/EC Stage 2005 Euro 5 — EC 715/2007 Euro 6 — EC 715/2007
	Diesel < 2.0 l > 2.0 l	Conventional Euro 1 — 91/441/EEC Euro 2 — 94/12/EC Euro 3 — 98/69/EC Stage 2000 Euro 4 — 98/69/EC Stage 2005 Euro 5 — EC 715/2007 Euro 6 — EC 715/2007

Vehicle category	Type	Legislation/technology
Passenger cars	LPG	Conventional Euro 1 — 91/441/EEC Euro 2 — 94/12/EC Euro 3 — 98/69/EC Stage 2000 Euro 4 — 98/69/EC Stage 2005
		Euro 5 — EC 715/2007
		Euro 6 — EC 715/2007
	2-stroke	Conventional
	Hybrids < 1.6 l	Euro 4 — 98/69/EC Stage 2005
Light-duty vehicles	Gasoline < 3.5 t	Conventional Euro 1 — 93/59/EEC Euro 2 — 96/69/EC Euro 3 — 98/69/EC Stage 2000 Euro 4 — 98/69/EC Stage 2005 Euro 5 — EC 715/2007 Euro 6 — EC 715/2007
	Diesel < 3.5 t	Conventional Euro 1 — 93/59/EEC Euro 2 — 96/69/EC Euro 3 — 98/69/EC Stage 2000 Euro 4 — 98/69/EC Stage 2005 Euro 5 — EC 715/2007 Euro 6 — EC 715/2007
		Continues in next page
Heavy-duty vehicles	Gasoline > 3.5 t	Conventional
	Rigid <= 7.5 t	Conventional Euro I — 91/542/EEC Stage I Euro II — 91/542/EEC Stage II Euro III — 1999/96/EC Stage I Euro IV — 1999/96/EC Stage II Euro V — 1999/96/EC Stage III Euro VI — COM (2007) 851
	Rigid 7.5–12 t	
	Rigid 12–14 t	
	Rigid 14–20 t	
	Rigid 20–26 t	
	Rigid 26–28 t	
	Rigid 28–32 t	
	Rigid > 32 t	
	Articulated 14–20 t	
	Articulated 20–28 t	
	Articulated 28–34 t	
	Articulated 34–40 t	
	Articulated 40–50 t	
	Articulated 50–60 t	
Buses	Urban <=15 t	Conventional Euro I — 91/542/EEC Stage I
	Urban 15–18 t	

Vehicle category	Type	Legislation/technology
	Urban > 18 t	Euro II — 91/542/EEC Stage II Euro III — 1999/96/EC Stage I Euro IV — 1999/96/EC Stage II Euro V — 1999/96/EC Stage III Euro VI — COM (2007) 851
	Coaches, standard <=18 t	
	Coaches, articulated > 18 t	
	CNG	Euro I — 91/542/EEC Stage I
		Euro II — 91/542/EEC Stage II
		Euro III — 1999/96/EC Stage I
		EEV — 1999/96/EC
Mopeds	< 50 cm³	Conventional 97/24/EC Stage I — Euro 1 97/24/EC Stage II — Euro 2 Euro 3 proposal
Motorcycles	2-stroke, > 50 cm³	Conventional
	4-stroke, 50–250 cm³	97/24/EC — Euro 1
	4-stroke, 250–750 cm³	2002/51/EC Stage I — Euro 2
	4-stroke, > 750 cm³	2002/51/EC Stage II — Euro 3

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, CH_4, CO_2, N_2O, NH_3, SO_x, exhaust PM, PAHs and POPs, dioxins and furans, and heavy metals contained in the fuel (lead, arsenic, cadmium, copper, chromium, mercury, nickel, selenium and zinc). NO_x emissions are further split into NO and NO_2. 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.

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_2O)	Given as N_2O
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 $PM_{2.5}$. 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

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

Pollutant	Equivalent
Alkanes (C_nH_{2n+2}):	Given in alkanes speciation
Alkenes (C_nH_{2n}):	Given in alkenes speciation
Alkynes (C_nH_{2n-2}):	Given in alkynes speciation
Aldehydes ($C_nH_{2n}O$)	Given in aldehydes speciation
Ketones ($C_nH_{2n}O$)	Given in ketones speciation
Cycloalkanes (C_nH_{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 the previous version 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 9-1 to Table 9-31 of section 9.

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.

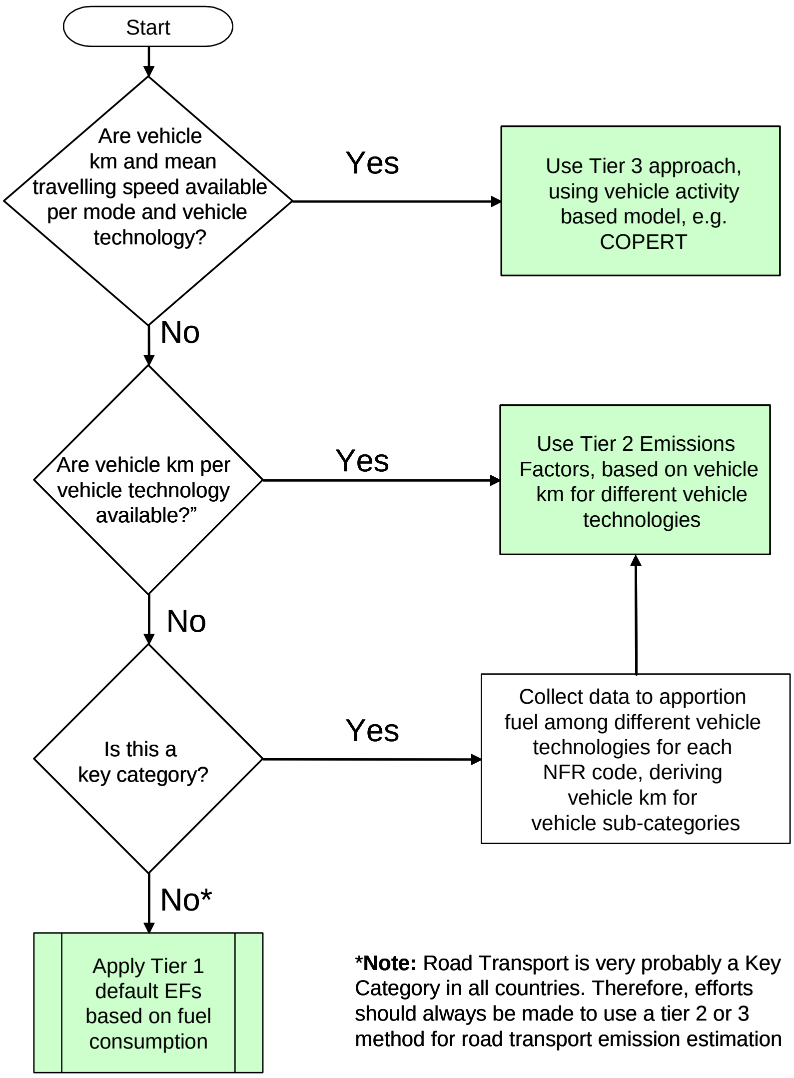

Figure 3-1 Decision tree for exhaust emissions from road transport

3.2 Tier 1 method

3.2.1 Algorithm

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

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

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-duty vehicles, heavy-duty vehicles, and motorcycles and mopeds. The fuels to be considered include gasoline, 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 (actually Copert 4 — http://www.emisia.com/copert), assuming a typical EU-15 fleet and activity data for 1995, taken from EC4MACS – 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 3-11. 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 3-5 Tier 1 emission factors for CO and NMVOCs

Category	Fuel	CO (g/kg fuel)			NMVOC (g/kg fuel)		
		Mean	Min	Max	Mean	Min	Max
PC	Gasoline	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
LDV	Gasoline	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
Two-wheel	Gasoline	497.7	331.2	664.5	131.4	30.0	364.8

Table 3-6 Tier 1 emission factors for NO_X and PM

Category	Fuel	NOx (g/kg fuel)			PM (g/kg fuel)		
		Mean	Min	Max	Mean	Min	Max
PC	Gasoline	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
LDV	Gasoline	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
Two-wheel	Gasoline	6.64	1.99	10.73	2.20	0.55	6.02

Table 3-7 Tier 1 emission factors for N_2O and NH_3

Category	Fuel	N_2O (g/kg fuel)			NH_3 (g/kg fuel)		
		Mean	Min	Max	Mean	Min	Max
PC	Gasoline	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
LDV	Gasoline	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
Two-wheel	Gasoline	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 (g/kg fuel)			B(k)F (g/kg fuel)		
		Mean	Min	Max	Mean	Min	Max
PCs	Gasoline	8.90E-06	1.33E-05	5.90E-06	3.90E-06	3.90E-06	3.90E-06
	Diesel	2.12E-05	4.05E-05	1.11E-05	1.18E-05	4.58E-05	3.00E-06
	LPG	2.00E-07	2.00E-07	2.00E-07	2.00E-07	2.00E-07	2.00E-07
LDVs	Gasoline	6.90E-06	1.21E-05	3.90E-06	3.00E-06	3.50E-06	2.60E-06
	Diesel	1.58E-05	2.84E-05	8.70E-06	8.70E-06	3.21E-05	2.40E-06
HDV	Diesel	7.90E-06	8.60E-06	7.30E-06	3.44E-05	3.72E-05	3.18E-05
	CNG (Buses)	n.a			n.a		
Two-wheel	Gasoline	1.02E-05	1.04E-05	1.00E-05	6.80E-06	7.00E-06	6.70E-06

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

Category	Fuel	B(b)F (g/kg fuel) Mean	Min	Max	B(a)P (g/kg fuel) Mean	Min	Max
PCs	Gasoline	7.90E-06	1.14E-05	5.40E-06	5.50E-06	6.20E-06	4.80E-06
	Diesel	2.24E-05	5.26E-05	9.60E-06	2.14E-05	4.55E-05	1.00E-05
	LPG	0.00E+00	0.00E+00	0.00E+00	2.00E-07	2.00E-07	2.00E-07
LDVs	Gasoline	6.10E-06	1.03E-05	3.60E-06	4.20E-06	5.60E-06	3.20E-06
	Diesel	1.66E-05	3.69E-05	7.50E-06	1.58E-05	3.19E-05	7.90E-06
HDV	Diesel	3.08E-05	3.33E-05	2.84E-05	5.10E-06	5.50E-06	4.70E-06
	CNG (Buses)	n.a			n.a		
Two-wheel	Gasoline	9.40E-06	9.60E-06	9.20E-06	8.40E-06	8.60E-06	8.20E-06

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

Category	Fuel	Pb (g/kg fuel) Mean	Min	Max
PCs	Gasoline	3.30E-05	1.70E-05	2.00E-04
	Diesel	5.20E-05	1.60E-05	1.94E-04
	LPG	n.a		
LDVs	Gasoline	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 (Busses)	n.a		
Two Wheel	Gasoline	3.30E-05	1.70E-05	2.00E-04

Table 3-11 Tier 1 CO_2 emission factors for different road transport fossil fuels

Subsector units	Fuel	$kgCO_2$ per kg of fuel[1]
All vehicle types	Gasoline	3.180
All vehicle types	Diesel	3.140
All vehicle types	LPG[2]	3.017
All vehicle types	CNG[3](or LNG)	2.750
All vehicle types	E5 [4]	3.125
All vehicle types	E10 [4]	3.061
All vehicle types	E85 [4]	2.104

Notes:

[1] CO_2 emission factors are based on an assumed 100% oxidation of the fuel carbon (ultimate CO_2).

[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 gasoline.

Table 3-12 Tier 1 CO_2 emission factors from combustion of lubricant oil[1]

Category	Fuel	CO2 from lubricant (g/kg fuel) Mean	Min	Max
PC	Gasoline	8.84	7.83	9.89
	Diesel	8.74	8.01	11.3
	LPG	8.84	7.83	9.89
LDV	Gasoline	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
Two-wheel	Gasoline	53.8	33.3	110

Note:
[1] These emission factors assume typical consumption and composition values for lubricant oil used in automotive applications. More information on the data used can be found in section 3.4.1.1

The emissions of SO_2 per fuel-type *m* are estimated by assuming that all sulphur in the fuel is transformed completely into SO_2, using the formula:

$$E_{SO_2,m} = 2 \times k_{S,m} \times FC_m \qquad (2)$$

where:

$E_{SO2,m}$ = emissions of SO_2 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 upcoming further regulation of diesel fuel sulphur to maximum 10 ppm by January 2009 (Fuel 2009). Again, typical emission factors for Tier 1 for a number of countries can be found in Annex 1.

Table 3-13 Tier 1 — Typical sulphur content of fuel (1 ppm = 10^{-6} g/g fuel)

	1996 Base fuel (Market average)	Fuel 2000	Fuel 2005	Fuel 2009
Gasoline	165 ppm	130 ppm	40 ppm	40 ppm
Diesel	400 ppm	300 ppm	40 ppm	8 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 (gasoline, 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.:

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

Table 3-14 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 3-14 Tier 1 — Typical fuel consumption figures, per km, by category of vehicle

Vehicle category (j)	Fuel	Typical fuel consumption (g/km)
Passenger cars	Gasoline	70
	Diesel	60
	LPG	57.5
LDVs	Gasoline	100
	Diesel	80
HDVs	Diesel	240
	CNG (buses)	500
Two-wheel vehicles	Gasoline	35

A more detailed approach for estimating the fuel consumption split by vehicle category is provided in Tier 3 subsection 0.

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 3-15).

Table 3-15: Summary of all vehicle classes covered by the Tier 2 methodology

Vehicle category (j)	Type	Legislation/technology (k)
Passenger cars	Gasoline < 1.4 l, 1.4–2.0 l > 2.0 l	PRE ECE, ECE 15/00-01 ECE 15/02, ECE 15/03, ECE 15/04 Improved Conventional (only for < 2.0 l), Open-Loop (only for < 2.0 l), Euro 1 Euro 2, Euro 3, Euro 4, Euro 5, Euro 6
	Diesel < 2.0 l, > 2.0 l	Conventional, Euro 1 Euro 2, Euro 3, Euro 4, Euro 5, Euro 6
	LPG	Conventional, Euro 1, Euro 2, Euro 3, Euro 4
	2-stroke	Conventional
	Hybrids < 1.6 l	Euro 4
Light-duty vehicles	Gasoline < 3.5 t	Conventional, Euro 1 Euro 2, Euro 3, Euro 4, Euro 5, Euro 6
	Diesel < 3.5 t	Conventional, Euro 1 Euro 2, Euro 3, Euro 4, Euro 5, Euro 6
Heavy-duty vehicles	Gasoline > 3.5 t	Conventional
	<=7.5 t, 7.5–16 t, 16–32 t, > 32 t	Conventional, Euro I, Euro II, Euro III, Euro IV, Euro V, Euro VI
Buses	Urban CNG buses	Euro I, Euro II, Euro III, EEV
	Urban buses standard	Conventional, Euro I, Euro II, Euro III, Euro IV, Euro V, Euro VI
	Coaches standard <=18 t	Conventional, Euro I, Euro II, Euro III, Euro IV, Euro V, Euro VI
Mopeds	< 50 cm³	Conventional, Euro 1, Euro 2, Euro 3
Motorcycles	2-stroke > 50 cm³	Conventional, Euro 1, Euro 2, Euro 3
	4-stroke 50–250 cm³	Conventional, Euro 1, Euro 2, Euro 3
	4-stroke 250–750 cm³	Conventional, Euro 1, Euro 2, Euro 3
	4-stroke > 750 cm³	Conventional, Euro 1, Euro 2, Euro 3

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:

$$E_{i,j} = \sum_k (\langle M_{j,k} \rangle \times EF_{i,j,k}) \tag{4}$$

or

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

where,

$\langle M_{j,k} \rangle$ = 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-duty vehicles, heavy-duty vehicles, and motorcycles and mopeds. The vehicle technologies *k* were given in Table 3-15.

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 3-15. 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, N_2O, NH_3, Pb, PM (considered to be $PM_{2.5}$), four PAHs, and CO2 from the combustion of lube oil. A figure for fuel consumption (g/km) is provided, derived from carbon balance, so that fuel-based pollutants (SO_2, 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 3-16 Tier 2 emission factors for passenger cars, NFR 1.A.3.b.i

Sector	Type	Technology	CO	NMVOC	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
Passenger Cars	Gasoline <1.4 l	PRE ECE	39.2	3.65	1.89	0.010	0.0025	2.58E-06	6.63E-01
Passenger Cars	Gasoline <1.4 l	ECE 15/00-01	30.5	3.05	1.89	0.010	0.0025	2.21E-06	6.63E-01
Passenger Cars	Gasoline <1.4 l	ECE 15/02	22.8	2.94	2.06	0.010	0.0025	2.12E-06	6.63E-01
Passenger Cars	Gasoline <1.4 l	ECE 15/03	23.2	2.94	2.23	0.010	0.0025	2.12E-06	6.63E-01
Passenger Cars	Gasoline <1.4 l	ECE 15/04	13.6	2.51	2.02	0.010	0.0025	1.88E-06	6.63E-01
Passenger Cars	Gasoline <1.4 l	Open Loop	11.9	2.22	1.49	0.010	0.0025	2.02E-06	6.63E-01
Passenger Cars	Gasoline <1.4 l	PC Euro 1 - 91/441/EEC	4.23	0.564	0.441	0.023	0.0731	1.82E-06	5.96E-01
Passenger Cars	Gasoline <1.4 l	PC Euro 2 - 94/12/EEC	2.39	0.301	0.242	0.012	0.0958	1.80E-06	5.30E-01
Passenger Cars	Gasoline <1.4 l	PC Euro 3 - 98/69/EC I	2.14	0.169	0.098	0.005	0.0276	1.84E-06	4.64E-01
Passenger Cars	Gasoline <1.4 l	PC Euro 4 - 98/69/EC II	0.710	0.123	0.062	0.005	0.0276	1.93E-06	3.98E-01
Passenger Cars	Gasoline 1.4 - 2.0 l	PRE ECE	39.2	3.80	2.47	0.010	0.0025	3.11E-06	6.63E-01
Passenger Cars	Gasoline 1.4 - 2.0 l	ECE 15/00-01	30.5	3.19	2.47	0.010	0.0025	2.60E-06	6.63E-01
Passenger Cars	Gasoline 1.4 - 2.0 l	ECE 15/02	22.8	3.081	2.33	0.010	0.0025	2.48E-06	6.63E-01
Passenger Cars	Gasoline 1.4 - 2.0 l	ECE 15/03	23.2	3.08	2.43	0.010	0.0025	2.48E-06	6.63E-01
Passenger Cars	Gasoline 1.4 - 2.0 l	ECE 15/04	13.8	2.66	2.58	0.010	0.0025	2.22E-06	6.63E-01
Passenger Cars	Gasoline 1.4 - 2.0 l	Open Loop	6.68	1.73	1.26	0.010	0.0025	2.44E-06	6.63E-01
Passenger Cars	Gasoline 1.4 - 2.0 l	PC Euro 1 - 91/441/EEC	3.93	0.645	0.441	0.023	0.0731	2.17E-06	5.96E-01
Passenger Cars	Gasoline 1.4 - 2.0 l	PC Euro 2 - 94/12/EEC	2.18	0.349	0.243	0.012	0.0958	2.13E-06	5.30E-01
Passenger Cars	Gasoline 1.4 - 2.0 l	PC Euro 3 - 98/69/EC I	1.96	0.193	0.098	0.005	0.0276	2.21E-06	4.64E-01
Passenger Cars	Gasoline 1.4 - 2.0 l	PC Euro 4 - 98/69/EC II	0.658	0.136	0.062	0.005	0.0276	2.26E-06	3.98E-01
Passenger Cars	Gasoline >2.0 l	PRE ECE	39.2	4.01	3.70	0.010	0.0025	3.76E-06	6.63E-01
Passenger Cars	Gasoline >2.0 l	ECE 15/00-01	30.5	3.41	3.70	0.010	0.0025	2.92E-06	6.63E-01
Passenger Cars	Gasoline >2.0 l	ECE 15/02	22.8	3.30	2.62	0.010	0.0025	3.08E-06	6.63E-01
Passenger Cars	Gasoline >2.0 l	ECE 15/03	23.2	3.30	3.44	0.010	0.0025	3.08E-06	6.63E-01
Passenger Cars	Gasoline >2.0 l	ECE 15/04	13.8	3.51	2.80	0.010	0.0025	2.80E-06	6.63E-01
Passenger Cars	Gasoline >2.0 l	PC Euro 1 - 91/441/EEC	3.33	0.520	0.419	0.023	0.0731	2.78E-06	5.96E-01
Passenger Cars	Gasoline >2.0 l	PC Euro 2 - 94/12/EEC	1.74	0.273	0.226	0.012	0.0958	2.90E-06	5.30E-01
Passenger Cars	Gasoline >2.0 l	PC Euro 3 - 98/69/EC I	1.58	0.157	0.091	0.005	0.0276	2.62E-06	4.64E-01
Passenger Cars	Gasoline >2.0 l	PC Euro 4 - 98/69/EC II	0.549	0.116	0.058	0.005	0.0276	3.09E-06	3.98E-01
Passenger Cars	Diesel <2.0 l	Conventional	0.713	0.162	0.561	0.000	0.0012	3.26E-06	6.63E-01
Passenger Cars	Diesel <2.0 l	PC Euro 1 - 91/441/EEC	0.449	0.051	0.691	0.003	0.0012	2.83E-06	5.96E-01
Passenger Cars	Diesel <2.0 l	PC Euro 2 - 94/12/EEC	0.333	0.036	0.726	0.006	0.0012	2.95E-06	5.30E-01
Passenger Cars	Diesel <2.0 l	PC Euro 3 - 98/69/EC I	0.097	0.020	0.780	0.010	0.0012	2.79E-06	4.64E-01
Passenger Cars	Diesel <2.0 l	PC Euro 4 - 98/69/EC II	0.097	0.016	0.601	0.010	0.0012	2.79E-06	3.98E-01
Passenger Cars	Diesel >2.0 l	Conventional	0.713	0.162	0.890	0.000	0.0012	3.26E-06	6.63E-01
Passenger Cars	Diesel >2.0 l	PC Euro 1 - 91/441/EEC	0.449	0.077	0.691	0.003	0.0012	3.82E-06	5.96E-01
Passenger Cars	Diesel >2.0 l	PC Euro 2 - 94/12/EEC	0.333	0.110	0.726	0.006	0.0012	3.82E-06	5.30E-01
Passenger Cars	Diesel >2.0 l	PC Euro 3 - 98/69/EC I	0.097	0.019	0.780	0.010	0.0012	3.82E-06	4.64E-01
Passenger Cars	Diesel >2.0 l	PC Euro 4 - 98/69/EC II	0.097	0.016	0.601	0.010	0.0012	3.82E-06	3.98E-01
Passenger Cars	LPG	Conventional	6.75	1.10	2.31	0.000	0.0100	n.a.	6.63E-01
Passenger Cars	LPG	PC Euro 1 - 91/441/EEC	3.80	0.771	0.444	0.024	0.0230	n.a.	5.96E-01
Passenger Cars	LPG	PC Euro 2 - 94/12/EEC	2.65	0.369	0.199	0.013	0.0120	n.a.	5.30E-01
Passenger Cars	LPG	PC Euro 3 - 98/69/EC I	2.22	0.206	0.115	0.005	0.0050	n.a.	4.64E-01
Passenger Cars	LPG	PC Euro 4 - 98/69/EC II	1.04	0.100	0.063	0.005	0.0050	n.a.	3.98E-01
Passenger Cars	2-Stroke	Conventional	13.1	10.0	0.642	0.008	0.0019	n.a.	n.a.
Passenger Cars	Hybrid Gas 1.4-2.0 l	PC Euro 4 - 98/69/EC II	0.001	0.021	0.009	0.005	0.0276	n.a.	3.98E-01

Table 3-17 Tier 2 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				
Gasoline <1.4 l	PRE ECE	0.0024	1.03E-06	3.00E-07	8.80E-07	4.80E-07
Gasoline <1.4 l	ECE 15/00-01	0.0024	1.03E-06	3.00E-07	8.80E-07	4.80E-07
Gasoline <1.4 l	ECE 15/02	0.0024	1.03E-06	3.00E-07	8.80E-07	4.80E-07
Gasoline <1.4 l	ECE 15/03	0.0024	1.03E-06	3.00E-07	8.80E-07	4.80E-07
Gasoline <1.4 l	ECE 15/04	0.0024	1.03E-06	3.00E-07	8.80E-07	4.80E-07
Gasoline <1.4 l	Open Loop	0.0024	3.90E-07	2.60E-07	3.60E-07	3.20E-07
Gasoline <1.4 l	PC Euro 1 - 91/441/EEC	0.0024	3.90E-07	2.60E-07	3.60E-07	3.20E-07
Gasoline <1.4 l	PC Euro 2 - 94/12/EEC	0.0024	3.90E-07	2.60E-07	3.60E-07	3.20E-07
Gasoline <1.4 l	PC Euro 3 - 98/69/EC I	0.0011	3.90E-07	2.60E-07	3.60E-07	3.20E-07
Gasoline <1.4 l	PC Euro 4 - 98/69/EC II	0.0011	3.90E-07	2.60E-07	3.60E-07	3.20E-07
Gasoline 1.4 - 2.0 l	PRE ECE	0.0024	1.03E-06	3.00E-07	8.80E-07	4.80E-07
Gasoline 1.4 - 2.0 l	ECE 15/00-01	0.0024	1.03E-06	3.00E-07	8.80E-07	4.80E-07
Gasoline 1.4 - 2.0 l	ECE 15/02	0.0024	1.03E-06	3.00E-07	8.80E-07	4.80E-07
Gasoline 1.4 - 2.0 l	ECE 15/03	0.0024	1.03E-06	3.00E-07	8.80E-07	4.80E-07
Gasoline 1.4 - 2.0 l	ECE 15/04	0.0024	1.03E-06	3.00E-07	8.80E-07	4.80E-07
Gasoline 1.4 - 2.0 l	Open Loop	0.0024	3.90E-07	2.60E-07	3.60E-07	3.20E-07
Gasoline 1.4 - 2.0 l	PC Euro 1 - 91/441/EEC	0.0024	3.90E-07	2.60E-07	3.60E-07	3.20E-07
Gasoline 1.4 - 2.0 l	PC Euro 2 - 94/12/EEC	0.0024	3.90E-07	2.60E-07	3.60E-07	3.20E-07
Gasoline 1.4 - 2.0 l	PC Euro 3 - 98/69/EC I	0.0011	3.90E-07	2.60E-07	3.60E-07	3.20E-07
Gasoline 1.4 - 2.0 l	PC Euro 4 - 98/69/EC II	0.0011	3.90E-07	2.60E-07	3.60E-07	3.20E-07
Gasoline >2.0 l	PRE ECE	0.0024	1.03E-06	3.00E-07	8.80E-07	4.80E-07
Gasoline >2.0 l	ECE 15/00-01	0.0024	1.03E-06	3.00E-07	8.80E-07	4.80E-07
Gasoline >2.0 l	ECE 15/02	0.0024	1.03E-06	3.00E-07	8.80E-07	4.80E-07
Gasoline >2.0 l	ECE 15/03	0.0024	1.03E-06	3.00E-07	8.80E-07	4.80E-07
Gasoline >2.0 l	ECE 15/04	0.0024	1.03E-06	3.00E-07	8.80E-07	4.80E-07
Gasoline >2.0 l	PC Euro 1 - 91/441/EEC	0.0024	3.90E-07	2.60E-07	3.60E-07	3.20E-07
Gasoline >2.0 l	PC Euro 2 - 94/12/EEC	0.0024	3.90E-07	2.60E-07	3.60E-07	3.20E-07
Gasoline >2.0 l	PC Euro 3 - 98/69/EC I	0.0011	3.90E-07	2.60E-07	3.60E-07	3.20E-07
Gasoline >2.0 l	PC Euro 4 - 98/69/EC II	0.0011	3.90E-07	2.60E-07	3.60E-07	3.20E-07
Diesel <2.0 l	Conventional	0.246	2.54E-06	2.87E-06	3.30E-06	2.85E-06
Diesel <2.0 l	PC Euro 1 - 91/441/EEC	0.0877	7.00E-07	1.90E-07	6.00E-07	6.30E-07
Diesel <2.0 l	PC Euro 2 - 94/12/EEC	0.0594	7.00E-07	1.90E-07	6.00E-07	6.30E-07
Diesel <2.0 l	PC Euro 3 - 98/69/EC I	0.0412	7.00E-07	1.90E-07	6.00E-07	6.30E-07
Diesel <2.0 l	PC Euro 4 - 98/69/EC II	0.0342	7.00E-07	1.90E-07	6.00E-07	6.30E-07
Diesel >2.0 l	Conventional	0.246	2.54E-06	2.87E-06	3.30E-06	2.85E-06
Diesel >2.0 l	PC Euro 1 - 91/441/EEC	0.0877	7.00E-07	1.90E-07	6.00E-07	6.30E-07
Diesel >2.0 l	PC Euro 2 - 94/12/EEC	0.0594	7.00E-07	1.90E-07	6.00E-07	6.30E-07
Diesel >2.0 l	PC Euro 3 - 98/69/EC I	0.0412	7.00E-07	1.90E-07	6.00E-07	6.30E-07
Diesel >2.0 l	PC Euro 4 - 98/69/EC II	0.0342	7.00E-07	1.90E-07	6.00E-07	6.30E-07
LPG	Conventional	n.a.	1.00E-08	1.00E-08	0.00E+00	1.00E-08
LPG	PC Euro 1 - 91/441/EEC	n.a.	1.00E-08	1.00E-08	0.00E+00	1.00E-08
LPG	PC Euro 2 - 94/12/EEC	n.a.	1.00E-08	1.00E-08	0.00E+00	1.00E-08
LPG	PC Euro 3 - 98/69/EC I	n.a.	1.00E-08	1.00E-08	0.00E+00	1.00E-08
LPG	PC Euro 4 - 98/69/EC II	n.a.	1.00E-08	1.00E-08	0.00E+00	1.00E-08
2-Stroke	Conventional	n.a.	n.a.	n.a.	n.a.	n.a.
Hybrid Gas 1.4-2.0 l	PC Euro 4 - 98/69/EC II	n.a.	n.a.	n.a.	n.a.	n.a.

Table 3-18 Tier 2 emission factors for light-duty vehicles, NFR 1.A.3.b.ii

Type	Technology	CO	NMVOC	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
Gasoline <3.5t	Conventional	25.5	3.44	3.09	0.010	0.0025	2.82E-06	6.63E-01
Gasoline <3.5t	LD Euro 1 - 93/ 59/ EEC	8.82	0.614	0.563	0.025	0.0758	3.31E-06	5.96E-01
Gasoline <3.5t	LD Euro 2 - 96/ 69/ EEC	5.89	0.304	0.230	0.025	0.0910	3.31E-06	5.30E-01
Gasoline <3.5t	PC Euro 3 - 98/ 69/ EC I	5.05	0.189	0.129	0.028	0.0302	3.31E-06	4.64E-01
Gasoline <3.5t	PC Euro 4 - 98/ 69/ EC II	2.01	0.128	0.064	0.013	0.0302	3.31E-06	3.98E-01
Diesel <3.5 t	Conventional	1.34	0.133	1.66	0.000	0.0012	4.65E-06	6.63E-01
Diesel <3.5 t	LD Euro 1 - 93/ 59/ EEC	0.577	0.141	1.22	0.003	0.0012	4.17E-06	5.96E-01
Diesel <3.5 t	LD Euro 2 - 96/ 69/ EEC	0.577	0.149	1.22	0.006	0.0012	4.17E-06	5.30E-01
Diesel <3.5 t	PC Euro 3 - 98/ 69/ EC I	0.473	0.094	1.03	0.009	0.0012	4.17E-06	4.64E-01
Diesel <3.5 t	PC Euro 4 - 98/ 69/ EC II	0.375	0.035	0.831	0.009	0.0012	4.17E-06	3.98E-01

Table 3-19 Tier 2 emission factors for light-duty 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				
Gasoline <3.5t	Conventional	0.0023	1.03E-06	3.00E-07	8.80E-07	4.80E-07
Gasoline <3.5t	LD Euro 1 - 93/59/EEC	0.0023	3.90E-07	2.60E-07	3.60E-07	3.20E-07
Gasoline <3.5t	LD Euro 2 - 96/69/EEC	0.0023	3.90E-07	2.60E-07	3.60E-07	3.20E-07
Gasoline <3.5t	PC Euro 3 - 98/69/EC I	0.0011	3.90E-07	2.60E-07	3.60E-07	3.20E-07
Gasoline <3.5t	PC Euro 4 - 98/69/EC II	0.0011	3.90E-07	2.60E-07	3.60E-07	3.20E-07
Diesel <3.5 t	Conventional	0.356	2.54E-06	2.87E-06	3.30E-06	2.85E-06
Diesel <3.5 t	LD Euro 1 - 93/59/EEC	0.117	7.00E-07	1.90E-07	6.00E-07	6.30E-07
Diesel <3.5 t	LD Euro 2 - 96/69/EEC	0.117	7.00E-07	1.90E-07	6.00E-07	6.30E-07
Diesel <3.5 t	PC Euro 3 - 98/69/EC I	0.0783	7.00E-07	1.90E-07	6.00E-07	6.30E-07
Diesel <3.5 t	PC Euro 4 - 98/69/EC II	0.0409	7.00E-07	1.90E-07	6.00E-07	6.30E-07

Table 3-20 Tier 2 emission factors for heavy-duty vehicles, NFR 1.A.3.b.iii

Type	Technology	CO	NMVOC	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
Gasoline >3.5 t	Conventional	59.5	5.25	6.60	0.006	0.0019	5.84E-06	1.99E+00
Rigid <=7.5 t	Conventional	1.85	1.07	4.70	0.029	0.0029	6.47E-06	4.86E-01
Rigid <=7.5 t	HD Euro I - 91/ 542/ EEC I	0.657	0.193	3.37	0.005	0.0029	5.43E-06	4.86E-01
Rigid <=7.5 t	HD Euro II - 91/ 542/ EEC II	0.537	0.123	3.49	0.004	0.0029	5.22E-06	4.86E-01
Rigid <=7.5 t	HD Euro III - 2000	0.584	0.115	2.63	0.003	0.0029	5.47E-06	4.86E-01
Rigid <=7.5 t	HD Euro IV - 2005	0.047	0.005	1.64	0.006	0.0029	5.17E-06	4.86E-01
Rigid <=7.5 t	HD Euro V - 2008	0.047	0.005	0.933	0.017	0.0029	5.17E-06	4.86E-01
Rigid <=7.5 t	HD Euro VI	0.047	0.005	0.180	0.017	0.0029	5.17E-06	4.86E-01
Rigid 12 - 14 t	Conventional	2.13	0.776	8.92	0.029	0.0029	9.48E-06	4.86E-01
Rigid 12 - 14 t	HD Euro I - 91/ 542/ EEC I	1.02	0.326	5.31	0.008	0.0029	8.36E-06	4.86E-01
Rigid 12 - 14 t	HD Euro II - 91/ 542/ EEC II	0.902	0.207	5.50	0.008	0.0029	8.05E-06	4.86E-01
Rigid 12 - 14 t	HD Euro III - 2000	0.972	0.189	4.30	0.004	0.0029	8.39E-06	4.86E-01
Rigid 12 - 14 t	HD Euro IV - 2005	0.071	0.008	2.65	0.012	0.0029	7.85E-06	4.86E-01
Rigid 12 - 14 t	HD Euro V - 2008	0.071	0.008	1.51	0.034	0.0029	7.85E-06	4.86E-01
Rigid 12 - 14 t	HD Euro VI	0.071	0.008	0.291	0.033	0.0029	7.85E-06	4.86E-01
Rigid 20 - 26 t	Conventional	1.93	0.486	10.7	0.029	0.0029	1.31E-05	4.86E-01
Rigid 20 - 26 t	HD Euro I - 91/ 542/ EEC I	1.55	0.449	7.52	0.008	0.0029	1.14E-05	4.86E-01
Rigid 20 - 26 t	HD Euro II - 91/ 542/ EEC II	1.38	0.29	7.91	0.007	0.0029	1.11E-05	4.86E-01
Rigid 20 - 26 t	HD Euro III - 2000	1.49	0.278	6.27	0.004	0.0029	1.13E-05	4.86E-01
Rigid 20 - 26 t	HD Euro IV - 2005	0.105	0.010	3.83	0.012	0.0029	1.06E-05	4.86E-01
Rigid 20 - 26 t	HD Euro V - 2008	0.105	0.010	2.18	0.034	0.0029	1.06E-05	4.86E-01
Rigid 20 - 26 t	HD Euro VI	0.105	0.010	0.422	0.032	0.0029	1.06E-05	4.86E-01
Rigid >32 t	Conventional	2.25	0.534	12.8	0.029	0.0029	1.54E-05	4.86E-01
Rigid >32 t	HD Euro I - 91/ 542/ EEC I	1.90	0.510	9.04	0.012	0.0029	1.36E-05	4.86E-01
Rigid >32 t	HD Euro II - 91/ 542/ EEC II	1.69	0.326	9.36	0.012	0.0029	1.33E-05	4.86E-01
Rigid >32 t	HD Euro III - 2000	1.79	0.308	7.43	0.007	0.0029	1.36E-05	4.86E-01
Rigid >32 t	HD Euro IV - 2005	0.121	0.012	4.61	0.018	0.0029	1.26E-05	4.86E-01
Rigid >32 t	HD Euro V - 2008	0.121	0.012	2.63	0.053	0.0029	1.26E-05	4.86E-01
Rigid >32 t	HD Euro VI	0.121	0.012	0.507	0.049	0.0029	1.26E-05	4.86E-01

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

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				
Gasoline >3.5 t	Conventional	0.000	1.03E-06	3.00E-07	8.80E-07	4.80E-07
Rigid <=7.5 t	Conventional	0.333	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid <=7.5 t	HD Euro I - 91/542/EEC I	0.129	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid <=7.5 t	HD Euro II - 91/542/EEC II	0.061	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid <=7.5 t	HD Euro III - 2000	0.0566	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid <=7.5 t	HD Euro IV - 2005	0.0106	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid <=7.5 t	HD Euro V - 2008	0.0106	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid <=7.5 t	HD Euro VI	0.0005	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid 12 - 14 t	Conventional	0.3344	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid 12 - 14 t	HD Euro I - 91/542/EEC I	0.201	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid 12 - 14 t	HD Euro II - 91/542/EEC II	0.104	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid 12 - 14 t	HD Euro III - 2000	0.0881	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid 12 - 14 t	HD Euro IV - 2005	0.0161	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid 12 - 14 t	HD Euro V - 2008	0.0161	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid 12 - 14 t	HD Euro VI	0.0008	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid 20 - 26 t	Conventional	0.418	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid 20 - 26 t	HD Euro I - 91/542/EEC I	0.297	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid 20 - 26 t	HD Euro II - 91/542/EEC II	0.155	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid 20 - 26 t	HD Euro III - 2000	0.13	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid 20 - 26 t	HD Euro IV - 2005	0.0239	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid 20 - 26 t	HD Euro V - 2008	0.0239	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid 20 - 26 t	HD Euro VI	0.0012	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid >32 t	Conventional	0.491	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid >32 t	HD Euro I - 91/542/EEC I	0.358	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid >32 t	HD Euro II - 91/542/EEC II	0.194	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid >32 t	HD Euro III - 2000	0.151	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid >32 t	HD Euro IV - 2005	0.0268	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid >32 t	HD Euro V - 2008	0.0268	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Rigid >32 t	HD Euro VI	0.0013	1.40E-06	6.09E-06	5.45E-06	9.00E-07

Table 3-22 Tier 2 emission factors for buses, NFR 1.A.3.b.iii

Type	Technology	CO	NMVOC	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
Urban CNG Buses	HD Euro I - 91/ 542/ EEC I	8.40	0.371	16.5	n.a.	n.a.	2.89E-05	1.86E+00
Urban CNG Buses	HD Euro II - 91/ 542/ EEC II	2.70	0.313	15.0	n.a.	n.a.	2.68E-05	1.59E+00
Urban CNG Buses	HD Euro III - 2000	1.00	0.052	10.0	n.a.	n.a.	2.37E-05	1.59E+00
Urban CNG Buses	EEV	1.00	0.045	2.50	n.a.	n.a.	2.37E-05	n.a.
Urban Buses Standa	Conventional	5.71	1.99	16.5	0.029	0.0029	1.90E-05	2.65E+00
Urban Buses Standa	HD Euro I - 91/ 542/ EEC I	2.71	0.706	10.1	0.012	0.0029	1.61E-05	2.05E+00
Urban Buses Standa	HD Euro II - 91/ 542/ EEC II	2.44	0.463	10.7	0.012	0.0029	1.55E-05	1.46E+00
Urban Buses Standa	HD Euro III - 2000	2.67	0.409	9.38	0.001	0.0029	1.62E-05	8.61E-01
Urban Buses Standa	HD Euro IV - 2005	0.223	0.022	5.42	0.012	0.0029	1.54E-05	2.65E-01
Urban Buses Standa	HD Euro V - 2008	0.223	0.022	3.09	0.032	0.0029	1.54E-05	2.65E-01
Urban Buses Standa	HD Euro VI	0.223	0.022	0.597	0.040	0.0029	1.54E-05	2.65E-01
Coaches Standard <	Conventional	2.27	0.661	10.6	0.029	0.0029	1.37E-05	6.63E-01
Coaches Standard <	HD Euro I - 91/ 542/ EEC I	1.85	0.624	8.10	0.009	0.0029	1.26E-05	6.30E-01
Coaches Standard <	HD Euro II - 91/ 542/ EEC II	1.60	0.416	8.95	0.008	0.0029	1.25E-05	5.96E-01
Coaches Standard <	HD Euro III - 2000	1.91	0.399	7.51	0.004	0.0029	1.35E-05	5.63E-01
Coaches Standard <	HD Euro IV - 2005	0.150	0.021	4.51	0.012	0.0029	1.28E-05	5.30E-01
Coaches Standard <	HD Euro V - 2008	0.150	0.021	2.57	0.034	0.0029	1.28E-05	5.30E-01
Coaches Standard <	HD Euro VI	0.150	0.021	0.496	0.033	0.0029	1.28E-05	5.30E-01

Table 3-23 Tier 2 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)P
Units		g/km	g/km	g/km	g/km	g/km
Notes		PM2.5=PM10 =TSP				
Urban CNG Buses	HD Euro I - 91/542/EEC I	0.02	n.a.	n.a.	n.a.	n.a.
Urban CNG Buses	HD Euro II - 91/542/EEC II	0.01	n.a.	n.a.	n.a.	n.a.
Urban CNG Buses	HD Euro III - 2000	0.01	3.00E-08	4.00E-08	8.00E-08	5.00E-08
Urban CNG Buses	EEV	0.005	1.00E-08	1.00E-08	1.00E-08	3.00E-08
Urban Buses Standa	Conventional	0.909	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Urban Buses Standa	HD Euro I - 91/542/EEC I	0.479	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Urban Buses Standa	HD Euro II - 91/542/EEC II	0.22	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Urban Buses Standa	HD Euro III - 2000	0.207	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Urban Buses Standa	HD Euro IV - 2005	0.0462	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Urban Buses Standa	HD Euro V - 2008	0.0462	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Urban Buses Standa	HD Euro VI	0.0023	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Coaches Standard <	Conventional	0.47	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Coaches Standard <	HD Euro I - 91/542/EEC I	0.362	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Coaches Standard <	HD Euro II - 91/542/EEC II	0.165	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Coaches Standard <	HD Euro III - 2000	0.178	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Coaches Standard <	HD Euro IV - 2005	0.0354	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Coaches Standard <	HD Euro V - 2008	0.0354	1.40E-06	6.09E-06	5.45E-06	9.00E-07
Coaches Standard <	HD Euro VI	0.0018	1.40E-06	6.09E-06	5.45E-06	9.00E-07

Table 3-24 Tier 2 emission factors for mopeds and motorcycles, NFR 1.A.3.b.iv

Type	Technology	CO	NMVOC	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
<50 cm^3	Conventional	13.8	13.8	0.020	0.001	0.0010	8.25E-07	4.24E+00
<50 cm^3	Mop - Euro I	5.60	2.82	0.020	0.001	0.0010	4.95E-07	3.53E+00
<50 cm^3	Mop - Euro II	1.30	1.66	0.260	0.001	0.0010	3.99E-07	2.83E+00
<50 cm^3	Mop - Euro III	1.00	1.31	0.260	0.001	0.0010	3.47E-07	2.12E+00
2-stroke >50 cm^3	Conventional	24.3	9.97	0.067	0.002	0.0019	1.10E-06	4.24E+00
2-stroke >50 cm^3	Mot - Euro I	16.3	5.82	0.028	0.002	0.0019	8.22E-07	3.53E+00
2-stroke >50 cm^3	Mot - Euro II	11.2	1.84	0.104	0.002	0.0019	7.49E-07	2.83E+00
2-stroke >50 cm^3	Mot - Euro III	2.73	0.806	0.280	0.002	0.0019	5.74E-07	2.12E+00
4-stroke <250 cm^3	Conventional	32.8	2.06	0.225	0.002	0.0019	1.06E-06	3.98E-01
4-stroke <250 cm^3	Mot - Euro I	13.6	1.08	0.445	0.002	0.0019	1.19E-06	3.09E-01
4-stroke <250 cm^3	Mot - Euro II	7.17	0.839	0.317	0.002	0.0019	1.19E-06	2.21E-01
4-stroke <250 cm^3	Mot - Euro III	3.03	0.465	0.194	0.002	0.0019	1.19E-06	1.33E-01
4-stroke 250 - 750 c	Conventional	25.7	1.68	0.233	0.002	0.0019	1.23E-06	3.98E-01
4-stroke 250 - 750 c	Mot - Euro I	13.8	1.19	0.477	0.002	0.0019	1.19E-06	3.09E-01
4-stroke 250 - 750 c	Mot - Euro II	7.17	0.918	0.317	0.002	0.0019	1.19E-06	2.21E-01
4-stroke 250 - 750 c	Mot - Euro III	3.03	0.541	0.194	0.002	0.0019	1.19E-06	1.33E-01
4-stroke >750 cm^3	Conventional	21.1	2.75	0.247	0.002	0.0019	1.48E-06	3.98E-01
4-stroke >750 cm^3	Mot - Euro I	10.1	1.50	0.579	0.002	0.0019	1.53E-06	3.09E-01
4-stroke >750 cm^3	Mot - Euro II	7.17	0.994	0.317	0.002	0.0019	1.53E-06	2.21E-01
4-stroke >750 cm^3	Mot - Euro III	3.03	0.587	0.194	0.002	0.0019	1.53E-06	1.33E-01

Table 3-25 Tier 2 emission factors for mopeds and motorcycles, 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=PM10 =TSP				
<50 cm^3	Conventional	0.188	n.a.	n.a.	n.a.	n.a.
<50 cm^3	Mop - Euro I	0.0755	n.a.	n.a.	n.a.	n.a.
<50 cm^3	Mop - Euro II	0.0376	n.a.	n.a.	n.a.	n.a.
<50 cm^3	Mop - Euro III	0.0114	n.a.	n.a.	n.a.	n.a.
2-stroke >50 cm^3	Conventional	0.16	n.a.	n.a.	n.a.	n.a.
2-stroke >50 cm^3	Mot - Euro I	0.064	n.a.	n.a.	n.a.	n.a.
2-stroke >50 cm^3	Mot - Euro II	0.032	n.a.	n.a.	n.a.	n.a.
2-stroke >50 cm^3	Mot - Euro III	0.0096	n.a.	n.a.	n.a.	n.a.
4-stroke <250 cm^3	Conventional	0.014	3.90E-07	2.60E-07	3.60E-07	3.20E-07
4-stroke <250 cm^3	Mot - Euro I	0.014	3.90E-07	2.60E-07	3.60E-07	3.20E-07
4-stroke <250 cm^3	Mot - Euro II	0.0035	3.90E-07	2.60E-07	3.60E-07	3.20E-07
4-stroke <250 cm^3	Mot - Euro III	0.0035	3.90E-07	2.60E-07	3.60E-07	3.20E-07
4-stroke 250 - 750 cr	Conventional	0.014	3.90E-07	2.60E-07	3.60E-07	3.20E-07
4-stroke 250 - 750 cr	Mot - Euro I	0.014	3.90E-07	2.60E-07	3.60E-07	3.20E-07
4-stroke 250 - 750 cr	Mot - Euro II	0.0035	3.90E-07	2.60E-07	3.60E-07	3.20E-07
4-stroke 250 - 750 cr	Mot - Euro III	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
4-stroke >750 cm^3	Mot - Euro I	0.014	3.90E-07	2.60E-07	3.60E-07	3.20E-07
4-stroke >750 cm^3	Mot - Euro II	0.0035	3.90E-07	2.60E-07	3.60E-07	3.20E-07
4-stroke >750 cm^3	Mot - Euro III	0.0035	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. SO_2 and heavy metals) originate directly from the fuel and lubricant combustion. Therefore, Table 3-26 provides the fuel 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 3-11 to Table 3-13) give the Tier 2 emission factors.

Table 3-26 Tier 2 average fuel consumption values

Vehicle category	Sub-category	Technology	FC (g/km)
Passenger cars	Gasoline < 1.4 l	PRE-ECE to open loop	65
Passenger cars	Gasoline < 1.4 l	Euro 1 and later	56
Passenger cars	Gasoline 1.4–2.0 l	PRE-ECE to open loop	77
Passenger cars	Gasoline 1.4–2.0 l	Euro 1 and later	66
Passenger cars	Gasoline > 2.0 l	PRE-ECE to open loop	95
Passenger cars	Gasoline > 2.0 l	Euro 1 and later	86
Passenger cars	Diesel < 2.0 l	Conventional	63
Passenger cars	Diesel < 2.0 l	Euro 1 and later	55
Passenger cars	Diesel > 2.0 l	Conventional	75
Passenger cars	Diesel > 2.0 l	Euro 1 and later	73
Passenger cars	LPG	Conventional	59
Passenger cars	LPG	Euro 1 and later	57
Passenger cars	2-stroke	Conventional	82
Passenger cars	Hybrid gasoline 1.4–2.0 l	Euro 1 and later	26
Light-duty vehicles	Gasoline < 3.5 t	Conventional	85
Light-duty vehicles	Gasoline < 3.5 t	Euro 1 and later	100
Light-duty vehicles	Diesel < 3.5 t	Conventional	89
Light-duty vehicles	Diesel < 3.5 t	Euro 1 and later	80
Heavy-duty trucks	Gasoline > 3.5 t	Conventional	177
Heavy-duty trucks	<=7.5 t	Conventional	125
Heavy-duty trucks	<=7.5 t	Euro I and later	101
Heavy-duty trucks	7.5-16 t	Conventional	182
Heavy-duty trucks	7.5-16 t	Euro I and later	155
Heavy-duty trucks	16-32 t	Conventional	251
Heavy-duty trucks	16-32 t	Euro I and later	210
Heavy-duty trucks	> 32 t	Conventional	297
Heavy-duty trucks	> 32 t	Euro I and later	251
Buses	Urban CNG buses	HD Euro I — 91/542/EEC Stage I	555
Buses	Urban CNG buses	HD Euro II — 91/542/EEC Stage II	515
Buses	Urban CNG buses	HD Euro III — 2000 Standards	455
Buses	Urban CNG buses	EEV	455
Buses	Urban buses, standard 15–18 t	Conventional	366
Buses	Urban buses, standard 15–18 t	Euro I and later	301
Buses	Coaches, standard <=18 t	Conventional	263
Buses	Coaches, standard <=18 t	Euro I and later	247
Mopeds	< 50 cm³	Conventional	25
Mopeds	< 50 cm³	Euro 1	15
Mopeds	< 50 cm³	Euro 2	12
Mopeds	< 50 cm³	Euro 3	11
Motorcycles	2-stroke > 50 cm³	Conventional	33
Motorcycles	2-stroke > 50 cm³	Euro 1	25
Motorcycles	2-stroke > 50 cm³	Euro 2	23
Motorcycles	2-stroke > 50 cm³	Euro 3	17
Motorcycles	4-stroke < 250 cm³	Conventional	32
Motorcycles	4-stroke < 250 cm³	Euro 1 and later	36
Motorcycles	4-stroke 250–750 cm³	Conventional	37
Motorcycles	4-stroke 250–750 cm³	Euro 1 and later	36
Motorcycles	4-stroke > 750 cm³	Conventional	45
Motorcycles	4-stroke > 750 cm³	Euro 1 and later	46

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-27 countries and CH, HR, NO, TR can be also found on the Copert website (http://www.emisia.com/copert), under the 'Data' menu item. 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.

For the annual distance driven per vehicle technology (typical values can be found also on the Copert website, as above), the fuel consumption calculated on the basis of appropriate assumptions for annual mileage of the different vehicle categories can be balanced with available fuel statistics. Then by applying a trial-and-error approach, it is possible to reach a good match between the calculated and the statistical fuel 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 4. 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:

$$E_{TOTAL} = E_{HOT} + E_{COLD} \tag{6}$$

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:

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

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). Also, information on fuel consumption and fuel specification is required to maintain a fuel balance between the figures provided by the user and the calculations. A summary of the variables required — and the intermediate calculated values — is given in the flow chart of Figure 3-2.

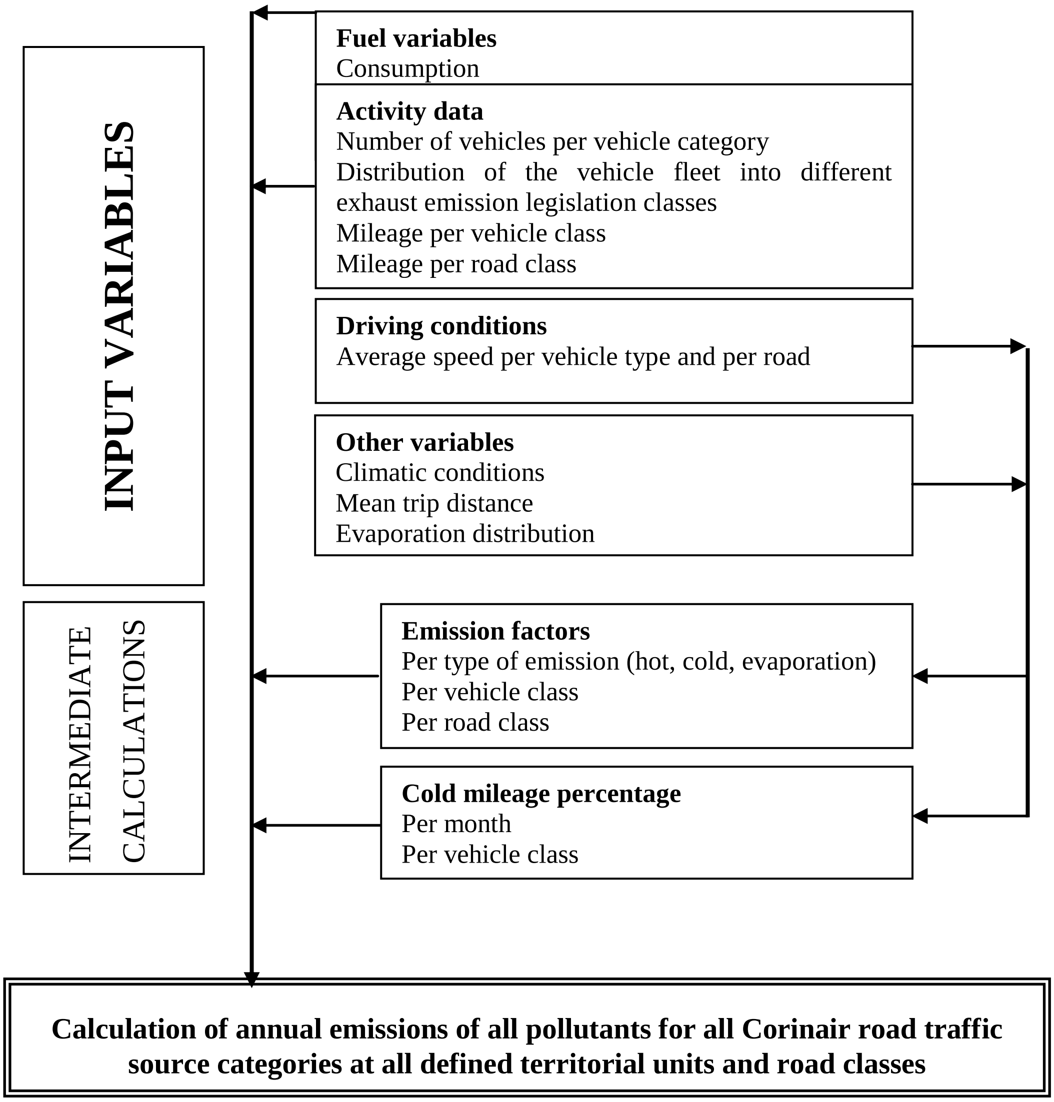

Figure 3-2: Flow chart of the application of the baseline methodology

3.4.1.1 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:

emission [g] = emission factor [g/km] × number of vehicles [veh]× 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.

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:

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

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 (section 3),

k vehicle technologies in Table 2-2,

r road class (‘urban’, ‘rural’, and ‘highway’).

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

Vehicle speed, which is introduced into the calculation via the three 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.:

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

where,

V = speed of vehicles on the road classes ‘rural’, ‘urban’, ‘highway’,

e(V) = expression of the speed-dependency of eHOT; 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 fk,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.

B. Cold-start emissions

Cold starts result in additional exhaust emissions. They take place under all three 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). In principle, they occur for all vehicle categories, but emission factors are only available, or can be reasonably estimated, for gasoline, diesel and LPG cars and — assuming that these vehicles behave like passenger cars — light-duty vehicles, 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:

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

where,

$E_{COLD;\, i,\, k}$	=	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*,
$e^{COLD} / e^{HOT}\|_{i,k}$	=	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 3-32 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 on 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 gasoline 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 gasoline catalyst vehicles. Table 3-44 presents factors to be used for calculating the reduction in the β-parameter for current and future catalyst vehicles and for the main pollutants.

The cold/hot emission quotient e^{COLD}/e^{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 gasoline vehicles in the previous update of this chapter. These quotients were based on the Methodologies to Estimate Emissions from Transport (MEET) project (MEET, 1999). However, the proposed approach still cannot fully describe the cold-start emission behaviour of recent vehicle technologies, and a further revision is scheduled for the next update of this chapter.

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

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

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

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 cases where a very small value has been provided for l_{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 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:

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

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

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

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

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

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

else if $\beta_{i,\ k} <= S_{URBAN;\ k}$ (13)

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

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

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

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

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

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

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) fuel 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, emissions of fuel-dependent pollutants should be firstly determined on the basis of the calculated fuel consumption (per vehicle class), and then a correction should be applied based on the true fuel consumption. In mathematical terms, this correction can be expressed as follows:

$$E^{CORR}_{i,k,m} = E^{CALC}_{i,k,m} \times \frac{FC^{STAT}_{m}}{\sum_{k} FC^{CALC}_{k,m}} \tag{14}$$

where,

$E^{CORR}_{i,k,m}$ = the corrected emission of fuel-dependent pollutant *i* (SO_2, Pb, heavy metals) emitted from vehicles of technology *k* operating on fuel *m*,

$E^{CALC}_{i,k,m}$ = the emission of fuel-dependent pollutant *i*, estimated on the basis of the calculated fuel consumption of vehicle class *k*, operating on fuel *m*,

FC^{STAT}_{m} = The statistical (true) total fuel consumption of fuel type m (*m* = leaded gasoline unleaded gasoline, diesel, LPG, CNG),

$\sum_{k} FC^{CALC}_{k,m}$ = the total calculated fuel consumption of all vehicle technologies operating on fuel type *m*.

In this respect, the total emission estimate for any fuel-dependent pollutant equals that derived by the statistical fuel consumption (except CO_2 due to the use of biofuels, see subsection 0) while there is still information provided for the allocation of emissions to different vehicle classes. The calculation of value $E^{CALC}{}_{i,k,m}$ is demonstrated in the following paragraphs.

C. Carbon dioxide emissions

Emissions of **ultimate CO_2** 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 CO_2. The following paragraphs describe the methodology to calculate CO_2 in each case.

CO_2 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:

$$r_{H:C} = \frac{y}{x} \qquad r_{O:C} = \frac{z}{x} \tag{15}$$

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:

$$r_{H:C} = 11.916\frac{h}{c} \qquad r_{O:C} = 0.7507\frac{o}{c} \tag{16}$$

With these ratios, the mass of CO_2 emitted by vehicles in technology k, combusting fuel m can be calculated as:

$$E^{CALC}_{CO_2,k,m} = 44.011 \times \frac{FC^{CALC}_{k,m}}{12.011 + 1.008 r_{H:C,m} + 16.000 r_{O:C,m}} \tag{17}$$

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

Table 3-27 gives hydrogen:carbon and oxygen:carbon ratios for different fuel types.

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). However, in petrol oxygen should be found through the blending of 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 reportingCO_2 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 and Forestry sector under IPCC. Hence, for reporting, the CO_2 calculated per vehicle category should be corrected according to equation:

$$E_{CO_2,k,m}^{CORR} = E_{CO_2,k,m}^{CALC} \times \frac{FC_m^{STAT,\,FOSSIL}}{\sum_k FC_{k,m}^{CALC}} \qquad (18)$$

In equation (18), the calculated CO_2 emission should be derived from equation (17), without considering the oxygen content of the biofuel part.

Table 3-27: Ratios of hydrogen to carbon and oxygen to carbon atoms for different fuel types

Fuel (*m*)	**Chemical formula**	**Ratio of hydrogen to carbon**	**Ratio of oxygen to carbon**
Gasoline	$[CH_{1.8}]_x$	$r_{H:C}$=1.80	$r_{O:C}$=0.0
Diesel	$[CH_2]_x$	$r_{H:C}$=2.00	$r_{O:C}$=0.0
Ethanol	C_2H_5OH	$r_{H:C}$=3.00	$r_{O:C}$=0.5
E5	$[CH_{1.8}]_x$ (95%) - C_2H_5OH (5%)	$r_{H:C}$=1.86	$r_{O:C}$=0.025
E10	$[CH_{1.8}]_x$ (90%) - C_2H_5OH (10%)	$r_{H:C}$=1.92	$r_{O:C}$=0.05
E85	$[CH_{1.8}]_x$ (15%) - C_2H_5OH (85%)	$r_{H:C}$=2.82	$r_{O:C}$=0.43
ETBE	$C_6H_{14}O$	$r_{H:C}$=2.33	$r_{O:C}$=0.17
Methanol	CH_3OH	$r_{H:C}$=4	$r_{O:C}$=1
MTBE	$C_5H_{12}O$	$r_{H:C}$=2.4	$r_{O:C}$=0.2
Natural Gas	CH_4 (95 %)- C_2H_6 (5 %) CH_4 (85 %)- C_2H_6 (15 %)	$r_{H:C}$=3.90 $r_{H:C}$=3.74	$r_{O:C}$=0.0 $r_{O:C}$=0.0
LPG Fuel A	C_3H_8 (50 %)-C_4H_{10} (50 %)	$r_{H:C}$=2.57	$r_{O:C}$=0.0
LPG Fuel B	C_3H_8 (85 %)-C_4H_{10} (15 %)	$r_{H:C}$=2.63	$r_{O:C}$=0.0

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 gasoline 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.

CO_2 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, the ones operating with 2-stroke engines, consume 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 CO_2 production and should be taken into account in the national totals for completeness.

Table 3-28 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 ~150000 for a passenger car).

Table 3-28: Lubricant oil consumption rate for different vehicle types, fuel and age in kg/10.000 km

Category	Fuel/engine category	Age	kg/10.000 km		
			Mean	Min	Max
PC	Gasoline	Old	1.45	0.85	2.13
	Gasoline	New	1.28	0.85	1.70
	Diesel	Old	1.49	0.85	2.13
	Diesel	New	1.28	0.43	2.13
LDV	Gasoline	Old	1.45	0.85	2.13
	Gasoline	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		
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		0.85

CO_2 emissions due to lube oil consumption can be calculated by means of equation (17), where fuel consumption should be replaced by the values of Table 3-28. This will lead to CO_2 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.

CO_2 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 duty vehicles as well. Urea has a chemical type of $(NH_2)_2CO$ and when it is injected upstream of a hydrolysis catalyst in the exhaust line, then the following reaction takes place:

$$(NH_2)_2CO + H_2O \rightarrow 2NH_3 + CO_2$$

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 CO_2 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/cm^3. If total commercial urea solution sales are known (UC in litres), then total ultimate CO_2 emissions (in kg) by the use of the additive can be calculated by means of the following equation:

$$E_{CO2,urea} = 0.26 \times UC \tag{19}$$

The coefficient 0.26 (kg CO_2/lt urea solution) takes into account the density of urea solution, the molecular masses of CO_2 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 CO_2/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, CO_2 emission can be calculated by applying equation (19).

D. Sulphur dioxide (SO2) emissions

Emissions of SO_2 are estimated by assuming that all the sulphur in the fuel is transformed completely into SO_2 using the formula:

$$E_k = 2 \times k_{S,m} \times FC_{k,m}^{CALC} \tag{20}$$

where,

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

E. Lead (Pb) and other heavy metals emissions

Emissions of lead have been significantly dropped in Europe, as a result of unleaded gasoline 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 leaded gasoline only, the total lead emitted to the atmosphere should be calculated according to:

$$E_{Pb,k}^{CALC} = 0.75 \times k_{Pb,m} \times FC_{k,m}^{CALC} \tag{21}$$

where,

$k_{Pb,m}$ = weight-related lead content of gasoline (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 gasoline, the fuel metal content factors provided (μg/kg) are assumed to include fuel and lubricant content and engine wear. Therefore, these are apparent fuel metal content which should provide equivalent heavy metal emissions to fuel, lube oil 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:

$$E_{i,k}^{CALC} = k_{i,m} \times FC_{k,m}^{CALC} \tag{22}$$

where,

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

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.

F. 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 gasoline cars and light-duty 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 gasoline cars and light-duty vehicles to account for different vehicle age. These correction factors are given by equation:

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

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.

B_M is lower than 1 because the correction factors are determined using vehicle fleets with mileages ranging from 16 000 to 50 000 km. Therefore, brand new vehicles are expected to emit less than the sample of vehicles upon which the emission factors are based. It is assumed that emissions do not further degrade above 120 000 km for Euro 1 and Euro 2 vehicles, and above 160 000 km for Euro 3 and Euro 4 vehicles.

The effect of average speed on emission degradation is taken into account by combining the observed degradation lines over the two driving modes (urban, rural). It is assumed that for speeds outside the region defined by the average speed of urban driving (19 km/h) and rural driving (63 km/h), the degradation is independent of speed. Linear interpolation between the two values provides the emission degradation in the intermediate speed region.

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 3-29 (gasoline) and Table 3-30 (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 3-31 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 3-31). 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 3-101, Table 3-102 and Table 3-103 display the equations for different vehicle categories and classes.

Table 3-29: Gasoline 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 3-30: Diesel fuel specifications

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

Table 3-31: 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	-

The hot emission factors are corrected according to the equation:

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

where,

$FCe_{HOT;\, i,\, k,\, r}$: = the hot emission factor, corrected for the use of improved fuel for pollutant *i* of vehicle technology *k* driven on road class *r*,

$FCorr_{i,\, k,\, Fuel}$: = the fuel correction for pollutant *i*, vehicle technology *k*, calculated with equations given in Table 3-101, Table 3-102 and Table 3-103 for the available improved fuel qualities (Table 3-31),

$FCorr_{i,\, k,\, Base}$: = the fuel correction for pollutant *i*, calculated with equations given in Table 3-101, Table 3-102 and Table 3-103 for the base fuel quality of vehicle technology *k* (Table 3-31).

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), under the 'Data' menu item. 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*: fuel consumption calculated on the basis of appropriate assumptions for annual mileage of the different vehicle categories can be balanced with available fuel statistics. By applying a trial-and-error approach, it is possible to reach acceptable estimates of mileage.

For the calculation of cold-start related emissions, the mean trip length is necessary. Table 3-32 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 gasoline 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 gasoline 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-duty vehicles originate from the MEET project, and those for two-wheel vehicles are taken from various DG Enterprise studies.

Table 3-32: 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 3-33: Coding used for the methodological approaches adopted for each vehicle category

Method	Hot Emissions	Cold Start Overemission
A	the total annual kilometres driven per vehicle the share of kilometres driven under the driving modes 'urban', 'rural', 'highway' A1: the average speed of the vehicles under the driving modes 'urban', 'rural', 'highway' A1: speed-dependent hot emission factors A2: driving mode dependent emission factors	the average trip length per vehicle trip the average monthly temperature temperature, trip length and catalyst technology dependent cold start correction factor
B	the total annual kilometres driven per vehicle the share of kilometres driven under the driving modes 'urban', 'rural', 'highway' B1: the average speed of the vehicles under the driving modes 'urban', 'rural', 'highway' B1: speed-dependent hot emission factors B2: driving mode dependent emission factors	*No Cold Start Overemission Calculations*
C	the total annual kilometres driven per vehicle the share of kilometres driven under the driving modes 'urban', 'rural', 'highway' driving mode dependent emission factors	*No Cold Start Overemission Calculations*
D	the total annual fuel consumption of the vehicle category fuel consumption related emission factors	*No Cold Start Overemission 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 fuel consumption) are in the first category, whereas SO_2, NH_3, Pb, CO_2, N_2O and (partly) CH_4 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 fuel consumption, for the individual SNAP activities. The ‘bulk’ emission factors for unregulated pollutants — SO_2, NH_3, Pb, CO_2, N_2O and CH_4 — are then addressed. Table 3-33 and Table 3-34 show the level of detail which is necessary for the calculation of emissions from each vehicle technology.

Table 3-34: Summary of calculation methods applied for the different vehicle classes and pollutants

Vehicle category	NO_x	CO	NMVOC	CH_4	PM	N_2O	NH_3	SO_2	CO_2	Pb	HM	FC
Gasoline 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 4	A1	A1	A1	A1	-	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 4	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
Light-duty vehicles												
Gasoline < 3.5 t conventional	A1	A1	A1	A2	-	A2	A2	D	D	D	D	A1
Gasoline < 3.5 t Euro 1 to Euro 4	A1	A1	A1	A1	-	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 4	A1	A1	A1	A2	A1	A2	A2	D	D	D	D	A1
Heavy-duty vehicles > 3.5 t												
Gasoline 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 V	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 V	B1	B1	B1	C	B1	C	C	D	D	D	D	B1
Two-wheel vehicles												
Mopeds < 50 cm³	B2	B2	B2	C	-	C	C	D	D	D	D	B2
Motorcycles 2-stroke > 50 cm³	B1	B1	B1	C	-	C	C	D	D	D	D	B1
Motorcycles 4-stroke 50–250 cm³	B1	B1	B1	C	-	C	C	D	D	D	D	B1
Motorcycles 4-stroke 250–750 cm³	B1	B1	B1	C	-	C	C	D	D	D	D	B1
Motorcycles 4-stroke > 750 cm³	B1	B1	B1	C	-	C	C	D	D	D	D	B1

3.4.3.1 Gasoline passenger cars

Pre Euro – 'Conventional'

Hot Emissions

Hot emission factors for conventional vehicles are given in Table 3-35, Table 3-36 and Table 3-37 for different pollutants, and Table 3-38 provides fuel consumption factors for the same vehicles.. The separate equations are valid for different speed ranges and engine capacity classes.

Table 3-35: Speed dependency of CO emission factors for gasoline passenger cars

Vehicle class	Engine capacity	Speed range (km/h)	CO emission factor (g/km)	R^2
PRE ECE	All capacities	10–100	$281V^{-0.630}$	0.924
	All capacities	100–130	$0.112V + 4.32$	-
ECE 15-00/01	All capacities	10–50	$313V^{-0.760}$	0.898
	All capacities	50–130	$27.22 - 0.406V + 0.0032V^2$	0.158
ECE 15-02	All capacities	10–60	$300V^{-0.797}$	0.747
	All capacities	60–130	$26.260 - 0.440V + 0.0026V^2$	0.102
ECE 15-03	All capacities	10–20	$161.36 - 45.62\ln(V)$	0.790
	All capacities	20–130	$37.92 - 0.680V + 0.00377V^2$	0.247
ECE 15-04	All capacities	10–60	$260.788 \cdot V^{-0.910}$	0.825
	All capacities	60–130	$14.653 - 0.220V + 0.001163V^2$	0.613
Improved conventional	cc < 1.4 l	10–130	$14.577 - 0.294V + 0.002478V^2$	0.781
	1.4 l < cc < 2.0 l	10–130	$8.273 - 0.151V + 0.000957V^2$	0.767
Open loop	cc < 1.4 l	10–130	$17.882 - 0.377V + 0.002825V^2$	0.656
	1.4 l < cc < 2.0 l	10–130	$9.446 - 0.230V + 0.002029V^2$	0.719

Table 3-36: Speed dependency of VOC emission factors for gasoline passenger cars

Vehicle class	Engine capacity	Speed range (km/h)	VOC emission factor (g/km)	R^2
PRE ECE	All capacities	10–100	$30.34V^{-0.693}$	0.980
	All capacities	100–130	1.247	-
ECE 15-00/01	All capacities	10–50	$24.99V^{-0.704}$	0.901
	All capacities	50–130	$4.85V^{-0.318}$	0.095
ECE 15-02/03	All capacities	10–60	$25.75V^{-0.714}$	0.895
	All capacities	60–130	$1.95 - 0.019V + 0.00009V^2$	0.198
ECE 15-04	All capacities	10–60	$19.079V^{-0.693}$	0.838
	All capacities	60–130	$2.608 - 0.037V + 0.000179V^2$	0.341
Improved conventional	cc < 1.4 l	10–130	$2.189 - 0.034V + 0.000201V^2$	0.766
	1.4 l < cc < 2.0 l	10–130	$1.999 - 0.034V + 0.000214V^2$	0.447
Open loop	cc < 1.4 l	10–130	$2.185 - 0.0423V + 0.000256V^2$	0.636
	1.4 l < cc < 2.0 l	10–130	$0.808 - 0.016V + 0.000099V^2$	0.49

Cold start emissions

Table 3-39 provides e^{COLD}/e^{HOT} emission quotients for the pollutants in Group 1. The β-parameter is calculated by means of the equation provided in Table 3-40. 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 3-37: Speed dependency of NO_x emission factors for gasoline passenger cars

Vehicle class	**Engine capacity**	**Speed range (km/h)**	**NO_x emission factor (g/km)**	**R^2**
PRE ECE	cc < 1.4 l	10–130	$1.173 + 0.0225V - 0.00014V^2$	0.916
ECE 15-00/01	1.4 l < cc < 2.0 l	10–130	$1.360 + 0.0217V - 0.00004V^2$	0.960
	cc > 2.0 l	10–130	$1.5 + 0.03V + 0.0001V^2$	0.972
ECE 15-02	cc < 1.4 l	10–130	$1.479 - 0.0037V + 0.00018V^2$	0.711
	1.4 l < cc < 2.0 l	10–130	$1.663 - 0.0038V + 0.00020V^2$	0.839
	cc > 2.0 l	10–130	$1.87 - 0.0039V + 0.00022V^2$	-
ECE 15-03	cc < 1.4 l	10–130	$1.616 - 0.0084V + 0.00025V^2$	0.844
	1.4 l < cc < 2.0 l	10–130	$1.29e^{0.0099V}$	0.798
	cc > 2.0 l	10–130	$2.784 - 0.0112V + 0.000294V^2$	0.577
ECE 15-04	cc < 1.4 l	10–130	$1.432 + 0.003V + 0.000097V^2$	0.669
	1.4 l < cc < 2.0 l	10–130	$1.484+0.013 \cdot V+0.000074V^2$	0.722
	cc > 2.0 l	10–130	$2.427 - 0.014V + 0.000266V^2$	0.803
Improved Conventional	cc < 1.4 l	10–130	$-0.926 + 0.719\ln(V)$	0.883
	1.4 l < cc < 2.0 l	10–130	$1.387 + 0.0014V + 0.000247V^2$	0.876
Open loop	cc < 1.4 l	10–130	$-0.921 + 0.616\ln(V)$	0.791
	1.4 l < cc < 2.0 l	10–130	$-0.761 + 0.515\ln(V)$	0.495

Table 3-38: Speed dependency of fuel consumption factors for gasoline passenger cars

Vehicle Class	Engine capacity	Speed range (km/h)	Fuel consumption factor (g/km)	R^2
PRE ECE	cc < 1.4 l	10–60 60–80 80–130	$521V^{-0.554}$ 55 0.386V + 24.143	0.941 - -
	1.4 l < cc < 2.0 l	10–60 60–80 80–130	$681V^{-0.583}$ 67 0.471V + 29.286	0.936 - -
	cc > 2.0 l	10–60 60–80 80–130	$979V^{-0.628}$ 80 0.414V + 46.867	0.918 - -
ECE 15-00/01	cc < 1.4 l	10–60 60–130	$595V^{-0.63}$ $95 - 1.324V + 0.0086V^2$	0.951 0.289
	1.4 l < cc < 2.0 l	10–60 60–130	$864V^{-0.69}$ $59 - 0.407V + 0.0042V^2$	0.974 0.647
	cc > 2.0 l	10–60 60–130	$1236V^{-0.764}$ $65 - 0.407V + 0.0042V^2$	0.976 -
ECE 15-02/03	cc < 1.4 l	10–50 50–130	$544V^{-0.63}$ $85 - 1.108V + 0.0077V^2$	0.929 0.641
	1.4 l < cc < 2.0 l	10–50 50–130	$879V^{-0.72}$ $71 - 0.7032V + 0.0059V^2$	0.950 0.830
	cc > 2.0 l	10–50 50–130	$1224V^{-0.756}$ $111 - 1.333V + 0.0093V^2$	0.961 0.847
ECE 15-04	cc < 1.4 l	10–17.9 17.9–130	296.7 - 80.21ln(V) $81.1 - 1.014V + 0.0068V^2$	0.518 0.760
	1.4 l < cc < 2.0 l	10–22.3 22.3–130	$606.1V^{-0.667}$ $102.5 - 1.364V + 0.0086V^2$	0.907 0.927
	cc > 2.0 l	10–60 60–130	$819.9V^{-0.663}$ $41.7 + 0.122V + 0.0016V^2$	0.966 0.650
Improved conventional	cc < 1.4 l 1.4 l < cc < 2.0 l	10–130 10–130	$80.52 - 1.41V + 0.013V^2$ $111.0 - 2.031V + 0.017V^2$	0.954 0.994
Open loop	cc < 1.4 l 1.4 l < cc < 2.0 l	10–130 10–130	$85.55 - 1.383V + 0.0117V^2$ $109.6 - 1.98V + 0.0168V^2$	0.997 0.997

Table 3-39: Cold-start emission quotient (e^{COLD}/e^{HOT}) for conventional gasoline vehicles (temperature range of –10 °C to 30 °C)

Pollutant or FC	e^{COLD} / e^{HOT}
CO	$3.7 - 0.09\ t_a$
NO_x	$1.14 - 0.006\ t_a$
VOC	$2.8 - 0.06\ t_a$
Fuel consumption	$1.47 - 0.009\ t_a$

Table 3-40: Cold mileage percentage β

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

Euro 1 and later

Hot emissions

Hot emissions for Euro 1 and later gasoline passenger cars are calculated as a function of speed. The emission factors were developed in the framework of the Artemis project. The generic function used in this case is:

$$EF = (a + c \times V + e \times V^2)/(1 + b \times V + d \times V^2) \quad (25)$$

Table 3-41 provides the values for the coefficients of the function.

Table 3-41: Values for equation(25) to calculate emissions from Euro 1 and later gasoline passenger cars

Pollutant	Emission Standard	Engine capacity	Speed Range (km/h)	R^2	a	b	c	d	e
CO	Euro 1	All capacities	10–130	0.87	1.12E+01	1.29E-01	-1.02E-01	-9.47E-04	6.77E-04
	Euro 2	All capacities	10–130	0.97	6.05E+01	3.50E+00	1.52E-01	-2.52E-02	-1.68E-04
	Euro 3	All capacities	10–130	0.97	7.17E+01	3.54E+01	1.14E+01	-2.48E-01	
	Euro 4	All capacities	10–130	0.93	1.36E-01	-1.41E-02	-8.91E-04	4.99E-05	
HC	Euro 1	All capacities	10–130	0.82	1.35E+00	1.78E-01	-6.77E-03	-1.27E-03	
	Euro 2	All capacities	10–130	0.95	4.11E+06	1.66E+06	-1.45E+04	-1.03E+04	
	Euro 3	All capacities	10–130	0.88	5.57E-02	3.65E-02	-1.10E-03	-1.88E-04	1.25E-05
	Euro 4	All capacities	10–130	0.10	1.18E-02		-3.47E-05		8.84E-07
NO_x	Euro 1	All capacities	10–130	0.86	5.25E-01		-1.00E-02		9.36E-05
	Euro 2	All capacities	10–130	0.52	2.84E-01	-2.34E-02	-8.69E-03	4.43E-04	1.14E-04
	Euro 3	All capacities	10–130	0.80	9.29E-02	-1.22E-02	-1.49E-03	3.97E-05	6.53E-06
	Euro 4	All capacities	10–130	0.71	1.06E-01		-1.58E-03		7.10E-06
FC	Euro 1	< 1.4	10–130	0.99	1.91E+02	1.29E-01	1.17E+00	-7.23E-04	
		1.4–2.0	10–130	0.98	1.99E+02	8.92E-02	3.46E-01	-5.38E-04	
		> 2.0	10–130	0.93	2.30E+02	6.94E-02	-4.26E-02	-4.46E-04	
	Euro 2	< 1.4	10–130	0.99	2.08E+02	1.07E-01	-5.65E-01	-5.00E-04	1.43E-02
		1.4–2.0	10–130	0.98	3.47E+02	2.17E-01	2.73E+00	-9.11E-04	4.28E-03
		> 2.0	10–130	0.98	1.54E+03	8.69E-01	1.91E+01	-3.63E-03	
	Euro 3	< 1.4	10–130	0.99	1.70E+02	9.28E-02	4.18E-01	-4.52E-04	4.99E-03
		1.4–2.0	10–130	0.99	2.17E+02	9.60E-02	2.53E-01	-4.21E-04	9.65E-03
		> 2.0	10–130	0.99	2.53E+02	9.02E-02	5.02E-01	-4.69E-04	
	Euro 4	< 1.4	10–130	0.95	1.36E+02	2.60E-02	-1.65E+00	2.28E-04	3.12E-02
		1.4–2.0	10–130	0.96	1.74E+02	6.85E-02	3.64E-01	-2.47E-04	8.74E-03
		> 2.0	10–130	0.98	2.85E+02	7.28E-02	-1.37E-01	-4.16E-04	

Table 3-42 gives simplified emission factors to be used to calculate PM emissions from gasoline passenger cars of Euro 1 and later technologies. A separate emission factor is proposed for GDI vehicles due to the different combustion process of these engines.

Table 3-42: PM emission factors for Euro 1 and later gasoline passenger cars

Pollutant	Emission standard	Fuel specs (EN590)	Urban [g/km]	Rural [g/km]	Highway [g/km]
PM	Euro 1 and 2	2000–2009	3.22E-03	1.84E-03	1.90E-03
	Euro 3 and 4	2000–2009	1.28E-03	8.36E-04	1.19E-03
	Euro 3 GDI	2000–2009	6.60E-03	2.96E-03	6.95E-03

Table 3-43: Over-emission ratios e^{COLD} / e^{HOT} for Euro 1 and later gasoline vehicles (*V*: speed in km/h, t_a: temperature in °C)

Case	Category	Speed [km/h]	Temp [°C]	$e^{COLD}/e^{HOT} = A \times V + B \times t_a + C$		
				A	B	C
CO	cc< 1.4 l	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
	1.4 l < cc < 2.0 l	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
	cc> 2.0 l	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	cc< 1.4 l	5–25	> -20	4.61E-02	7.38E-03	0.755
		26–45	> -20	5.13E-02	2.34E-02	0.616
	1.4 l < cc < 2.0 l	5–25	> -20	4.58E-02	7.47E-03	0.764
		26–45	> -20	4.84E-02	2.28E-02	0.685
	cc>2.0 l	5–25	> -20	3.43E-02	5.66E-03	0.827
		26–45	> -20	3.75E-02	1.72E-02	0.728
VOC	cc< 1.4 l	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
	1.4 l < cc < 2.0 l	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
	cc> 2.0 l	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
FC	All classes	-	-10 : 30	0	-0.009	1.47

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

Cold start emissions

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 3-43 provides e^{COLD}/e^{HOT} emission quotients for three main pollutants and fuel 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 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 3-40. After calculating the β-parameter and e^{COLD}/e^{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 3-44 provides the reduction factors ($bc_{i,k}$) to be applied to the β-parameter according to the pollutant and vehicle class.

Table 3-44: β-reduction factors ($bc_{i,k}$) for post-Euro 1 gasoline vehicles (relative to Euro 1)

Emission legislation	CO	NO_x	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 — 98/69/EC Stage 2005	0.18	0.18	0.18

On the other hand, there is no evidence to support the use of different values of e^{COLD}/e^{HOT} for different vehicle classes ([6]). This means that the e^{COLD}/e^{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.

([6]) However 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^{COLD}/e^{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^{COLD}/e^{HOT} ratio.

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

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

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

3.4.3.2 Diesel passenger cars

Pre Euro 1

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. The emission factors to be introduced in equation (8) for the calculation of hot emissions from conventional diesel passenger cars are given in Table 3-45.

Table 3-45: Speed dependency of emission and consumption factors for conventional diesel vehicles < 2.5 t

Pollutant or FC	Engine capacity	Speed range [km/h]	Emission factor [g/km]	R^2
CO	All capacities	10–130	$5.41301V^{-0.574}$	0.745
NO_x	cc < 2.0 l	10–130	$0.918 – 0.014V + 0.000101V^2$	0.949
	cc > 2.0 l	10–130	$1.331 – 0.018V + 0.000133V^2$	0.927
VOC	All capacities	10–130	$4.61\ V^{-0.937}$	0.794
PM	All capacities	10–130	$0.45 – 0.0086V + 0.000058V^2$	0.439
Fuel consumption	All capacities	10–130	$118.489 – 2.084V + 0.014V^2$	0.583

Cold-start emissions

Excess cold-start emissions from diesel vehicles are not very significant compared with those from gasoline vehicles. Therefore, no distinction is made between conventional vehicles and Euro 1 vehicles. The values of e^{COLD}/e^{HOT} for diesel cars are given in Table 3-46.

Table 3-46: Values of e^{COLD} / e^{HOT} for diesel passenger cars (temperature range -10 °C to 30 °C)

Pollutant or FC	e^{COLD} / e^{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)
Fuel consumption	$1.34 – 0.008\ t_a$

Note
(1) VOC: if ta > 29 °C then $e^{COLD} / e^{HOT} > 0.5$.
(2) PM: if ta > 26 °C then $e^{COLD} / e^{HOT} > 0.5$.

Euro 1 and post-Euro 1

Hot emissions

Hot emissions for Euro 1 and post-Euro 1 vehicles are calculated as a function of speed. The emission functions were developed in the Artemis project. The generic function used in this case is:

$$EF = (a + c \times V + e \times V^2)/(1 + b \times V + d \times V^2) + f/V \qquad (27)$$

Table 3-47 provides the values of the coefficients used to calculate the emission factors.

Even at the Euro 3 stage, some manufacturers produced diesel cars equipped with DPFs. 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. Table 3-48 presents PM-specific emission factors for these vehicles. These emission factors assume the use of fuel complying with the EN590:2005 standards.

Table 3-47: Values for equation (27) to calculate emissions from Euro 1 and later diesel passenger cars

Pollutant or FC	Emission standard	Engine capacity	Speed range (km/h)	R^2	a	b	c	D	e	f
CO	Euro 1	All capacities	10–130	0.94	9.96E-01		-1.88E-02		1.09E-04	
	Euro 2	All capacities	10–130	0.91	9.00E-01		-1.74E-02		8.77E-05	
	Euro 3	All capacities	10–130	0.95	1.69E-01		-2.92E-03		1.25E-05	1.1
	Euro 4	All capacities	10–130	See table footnote						
HC	Euro 1	< 2.0	10–130	0.93	1.42E-01	1.38E-02	-2.01E-03	-1.90E-05	1.15E-05	
		> 2.0	10–130	0.98	1.59E-01		-2.46E-03		1.21E-05	
	Euro 2	< 2.0	10–130	0.99	1.61E-01	7.46E-02	-1.21E-03	-3.35E-04	3.63E-06	
		> 2.0	10–130	0.98	5.01E+04	3.80E+04	8.03E+03	1.15E+03	-2.66E+01	
	Euro 3	< 2.0	10–130	0.99	9.65E-02	1.03E-01	-2.38E-04	-7.24E-05	1.93E-06	
		> 2.0	10–130	0.54	9.12E-02		-1.68E-03		8.94E-06	
	Euro 4	All capacities	10–130		3.47E-02	2.69E-02	-6.41E-04	1.59E-03	1.12E-05	
NO_x	Euro 1	All capacities	10–130	0.96	3.10E+00	1.41E-01	-6.18E-03	-5.03E-04	4.22E-04	
	Euro 2	All capacities	10–130	0.94	2.40E+00	7.67E-02	-1.16E-02	-5.00E-04	1.20E-04	
	Euro 3	All capacities	10–130	0.92	2.82E+00	1.98E-01	6.69E-02	-1.43E-03	-4.63E-04	
	Euro 4	All capacities	10–130		1.11E+00		-2.02E-02		1.48E-04	
PM	Euro 1	All capacities	10–130	0.70	1.14E-01		-2.33E-03		2.26E-05	
	Euro 2	All capacities	10–130	0.71	8.66E-02		-1.42E-03		1.06E-05	
	Euro 3	All capacities	10–130	0.81	5.15E-02		-8.80E-04		8.12E-06	
	Euro 4	All capacities	10–130		4.50E-02		-5.39E-04		3.48E-06	
FC	Euro 1	< 2.0	10–130	0.98	1.45E+02	6.73E-02	-1.88E-01	-3.17E-04	9.47E-03	
		> 2.0	10–130	0.96	1.95E+02	7.19E-02	1.87E-01	-3.32E-04	9.99E-03	
	Euro 2	< 2.0	10–130	0.97	1.42E+02	4.98E-02	-6.51E-01	-1.69E-04	1.32E-02	
		> 2.0	10–130	0.96	1.95E+02	7.19E-02	1.87E-01	-3.32E-04	9.99E-03	
	Euro 3	< 2.0	10–130	0.95	1.62E+02	1.23E-01	2.18E+00	-7.76E-04	-1.28E-02	
		> 2.0	10-130	0.96	1.95E+02	7.19E-02	1.87E-01	-3.32E-04	9.99E-03	

Note:

The Euro 4 CO emission factor is given by $CO = 17.5E\text{-}3 + 86.42\left[1 + e^{-\frac{V+117.67}{-21.99}}\right]^{-1}$

Table 3-48: Emission factors of PM from Euro 3 diesel passenger cars equipped with DPFs (EN590:2005 fuel considered)

Diesel passenger cars	Urban driving (g/km)	Rural driving (g/km)	Highway driving (g/km)
Euro 3 + DPF	0.002	0.002	0.002

Cold-start emissions

In order to calculate cold-start emissions of Euro 1 and later diesel passenger cars, the β-parameter is calculated for all vehicle classes using the formula given in Table 3-40, and the values of e^{COLD}/e^{HOT} are given in Table 3-46 (these are the same as those for conventional vehicles). However, some additional reductions need to be applied for post-Euro 4 vehicle technologies ($RF_{i,k}$), and these are given in Table 3-49. Based on these, equation (10) can be applied to diesel passenger cars up to Euro 4, but for post-Euro 4 vehicles it should be expressed as:

$$E_{COLD;i,k} = \beta_{i,k} \times N_k \times M_k \times (100\text{-}RF_{i,k}) / 100 \times e_{HOT;\,i,\,Euro\,4} \times (e^{COLD} / e^{HOT}|_{i,Euro\,1} - 1) \qquad (28)$$

A similar transformation needs to be made in the case of equation (11).

Table 3-49: Emission reduction percentage for Euro 5 and 6 diesel passenger cars applied to vehicles complying with Euro 4 standards.

Diesel passenger cars	CO [%]	NOx [%]	VOC [%]	PM [%]
Euro 5 — EC 715/2007 Stage I	0	28	0	95
Euro 6 — EC 715/2007 Stage II	0	68	0	95

3.4.3.3 LPG passenger cars

The methodology for gasoline cars is also valid for LPG 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 gasoline and diesel. There are two main types of such vehicles: The ones which are produced by OEMs to operate as bi-fuelled vehicles, and conventional gasoline vehicles later retrofitted by their owners to operate with LPG (and/or CNG).

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 gasoline. Technically this is not true. Spark-ignition vehicles have been optimized to operate on gasoline and shifting to a different fuel should not a priori 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 gasoline counterparts. On the other hand, retrofitted LPG vehicles emitted, on average, more than twice as much NOx and 2.5 times as much PM as the gasoline vehicles. Retrofitted vehicles exceeded the gasoline-based NOx 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 f 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 prorammes are reviewed and numbers of retrofitted cars be monitored in order to track the extent of the problem.

In the absence of detailed data, emission factors of post-Euro 3 LPG cars are based on the gasoline ones. This approach will have to be reviewed as soon as new reliable data become available. However, assuming that most of the LPG fuel is consumed by retrofitted cars (few options of bi-fuelled OEM vehicles available), this may lead to some underestimation of emissions from such vehicles. The data compiler should be awars of the fact and should expect that emission factors of these vehicles may increase in a future update of this chapter.

Hot emissions

Equation (8) is used to calculate hot emissions for conventional and Euro 1 LPG vehicles. Table 3-50 provides the hot emission factors for conventional cars, and Table 3-51 for Euro 1 cars. The former emission factors were developed in earlier Copert exercises, and the latter in the MEET project. With respect to Euro 2 LPG vehicles, and in the absence of more up-to-date data, emission-reduction factors (compared with Euro 1) are provided. These can be introduced by means of equation (29), and the values of the emission-reduction factors are given in Table 3-52. Post Euro 2 emission technologies use the same modelling and parameters as the equivalent technology step of gasoline passenger cars 1.4-2.0 l (Table 3-41).

$$e_{HOT;\, i,\, k,\, r} = (100 - RF_{i,k}) / 100 \times e_{HOT;\, i,\, Euro\, 1,\, r} \tag{29}$$

Table 3-50: Speed dependency of emission and consumption factors for conventional LPG cars

Pollutant	Engine Capacity	Speed Range	Emission Factor [g/km]	R^2
CO	All categories	10–130	$12.523-0.418 \cdot V+0.0039 \cdot V^2$	0.893
NOx	All categories	10–130	$0.77 \cdot V^{0.285}$	0.598
VOC	All categories	10–130	$26.3 \cdot V^{-0.865}$	0.967
Fuel consumption	All categories	Urban Rural Highway	59 45 54	- - -

Table 3-51: Speed dependency of emission and consumption factors for LPG cars, complying with Directive 91/441/EEC (Euro 1)

Pollutant	Engine Capacity	Speed range [km/h]	Emission factor [g/km]
CO	All categories	10–130	$0.00110V^2 - 0.1165V + 4.2098$
NO_x	All categories	10–130	$0.00004V^2 - 0.0063V + 0.5278$
VOC	All categories	10–130	$0.00010V^2 - 0.0166V + 0.7431$
Fuel Consumption	All categories	10–130	$0.00720V^2 - 0.9250V + 74.625$

Note: The fuel consumption function applies to all LPG car technologies up to Euro 6.

Table 3-52: Emission reduction percentage for Euro 2 LPG passenger cars, applied to vehicles complying with Directive 91/441/EEC (Euro 1)

Engine capacity	LPG passenger cars	CO [%]	NOx [%]	VOC[%]
cc < 1.4 l	Euro 2 — 94/12/EC	32	64	76

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 gasoline vehicles, the methodology for calculating emissions from gasoline vehicles is also applied here. Table 3-53 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 gasoline passenger cars is used (Table 3-43). This is made on on purpose. Both OEM and retrofitted LPG cars operate on gasoline before the engine and the catalyst heat up. LPG is only used under fully warmed conditions. As a result, LPG and gasoline car cold-start emissions are not expected to differ.

Table 3-53: Values of e^{COLD} / e^{HOT} for conventional LPG passenger cars (temperature range of –10°C to 30°C)

Pollutant or FC	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)
Fuel consumption	$1.47 - 0.009\ t_a$

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

3.4.3.4 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 gasoline cars in earlier Copert exercises. Total emission factors (hot + cold) are given in Table 3-54. 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 gasoline passenger cars.

Table 3-54: Emission factors for gasoline two-stroke vehicles < 2.5 t

Driving mode	CO [g/km]	NO_x [g/km]	VOC [g/km]	Fuel consumption [g/km]
Urban	20.7	0.30	15.4	111.5
Rural	7.50	1.0	7.20	66.0
Highway	8.70	0.75	5.90	56.9

3.4.3.5 Hybrid passenger cars < 1.6 l

A limited database of emission measurements was used to derive emission factors for hybrid gasoline 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 gasoline cars, and equation (30) is used to calculate emission and consumption factors (except for CO for which a different equation is given on Table 3-55), expressed in g/km. Parameter values for equation (30) are given on Table 3-55.

$$EF = a + c \times V + e \times V^2 \qquad (30)$$

Table 3-55: Values for equation(30) to calculate emissions from hybrid gasoline passenger cars

Pollutant	Emission standard	Engine capacity	Speed range (km/h)	R^2	a	c	e
CO	Euro 4	All capacities	10–130	1	CO = 3.293 × V^(-1.165)		
HC		All capacities	10–130	1	2.21E-03	-4.44E-05	3.00E-07
NO_x		All capacities	10–130	1	-1.00E-02	6.54E-04	-3.76E-06
FC		All capacities	10–130	1	3.8E+01	-2.95E-01	2.99E-03

3.4.3.6 Rechargeable vehicles

Emission and consumption factors for rechargeable vehicles have not been derived yet. For pure electric vehicles exhaust emissions will be zero therefore these do not contribute to the road transport air pollutants inventory. However, plug-in hybrids and electric with range extender ones will have a very low but non-zero emission rate. As the volume of these vehicles is currently very

low, their emissions can for the time being be neglected. However, emission factors will have to be developed in the future as their market numbers increase.
The contribution of these vehicles to total CO_2 emissions will also have to be assessed. Again, pure electric vehicles will have zero CO_2 emissions. All CO_2 emissions they implicitly produce will be due to electricity production, which is part of the power generation. However, plug-in vehicles and electric with range extender will also produce CO_2 emissions due to the combustion of fuel on-board the vehicle. Such vehicles are assumed to have a significant electric range, in the order of 40 to 60 km. Operation of the vehicles within their electric range and recharging will result to minimal CO_2 emissions from the combustion of fuel. Long trips without recharging will result to significant on-board CO_2 generation. The actual fuel consumption and CO_2 emission factor of such vehicles will therefore depend on their driving pattern (speed and trip distance distribution), As a general guidance, it may be expected that these two vehicle categories will behave similarly to hybrid passenger cars (Table 3-55), when they exceed their electric range.

3.4.3.7 Gasoline light-duty 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, and emission factors for pollutants in Group 1 are given in Table 3-56. The emission factors for Euro 1 vehicles can also be found in the same Table. Hot emission factors for post-Euro 1 vehicles are calculated by the application of equation (29) and the reduction factors given in Table 3-57. PM emissions from gasoline light-duty vehicles can be considered similar to passenger cars (Table 3-42).

Table 3-56: Speed dependency of emission and consumption factors for gasoline light-duty vehicles < 3.5 t

Pollutant or FC	Vehicle class	Speed range [km/h]	Emission factor [g/km]	R^2
CO	Conventional	10–110	$0.01104V^2 - 1.5132V + 57.789$	0.732
	Euro 1	10–120	$0.0037V^2 - 0.5215V + 19.127$	0.394
NO_x	Conventional	10–110	$0.0179V + 1.9547$	0.142
	Euro 1	10–120	$7.55E\text{-}05V^2 - 0.009V + 0.666$	0.0141
VOC	Conventional	10–110	$67.7E\text{-}05V^2 - 0.117V + 5.4734$	0.771
	Euro 1	10–120	$5.77E\text{-}05V^2 - 0.01047V +0.5462$	0.358
Fuel consumption	Conventional	10–110	$0.0167V^2 – 2.649V + 161.51$	0.787
	Euro 1	10–120	$0.0195V^2 – 3.09V + 188.85$	0.723

Table 3-57: Emission reduction percentage post-Euro 1 light-duty vehicles applied to vehicles complying with Directive 93/59/EEC (Euro 1)

Gasoline light-duty vehicles	CO [%]	NOx [%]	VOC [%]
Euro 2 — 96/69/EC	39	66	76
Euro 3 — 98/69/EC Stage 2000	48	79	86
Euro 4 — 98/69/EC Stage 2005	72	90	94
Euro 5 — EC 715/2007	72	92.5	94
Euro 6 — EC 715/2007	72	92.5	94

Cold start emissions

In the absence of more detailed data, the values of e^{COLD}/e^{HOT} for gasoline cars > 2.0 l are also applied to light-duty vehicles. Although this assumption used to be a very rough estimate for past vehicle classes, due to the very different emission standards of light-duty vehicles and passenger cars, it is now likely to be more robust since the technology used in current light-duty vehicles does not differ significantly from that used in cars. Therefore, the values of e^{COLD}/e^{HOT} in Table 3-39 (pre-Euro 1) and Table 3-43 (Euro 1 and later) are applied to light-duty vehicles. Furthermore, equations (10), (11) are also valid for pre-Euro 1 vehicles and equation (28) for Euro 1 and later vehicles, in conjunction with the β-parameter reduction factors given in Table 3-44.

3.4.3.8 Diesel light-duty vehicles

Diesel light-duty 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). These are given in Table 3-58 for pollutants in Group 1. Excess cold-start emissions up to Euro 1 are calculated using equation (10), with the e^{COLD}/e^{HOT} values being taken from Table 3-46. The emission factors for post-Euro 1 vehicles are calculated using the functions for Euro 1 vehicles and the reduction factors given in Table 3-59 both for hot and cold-start emissions (equations (29) and (28), respectively).

Table 3-58: Speed dependency of emission and consumption factors for diesel light-duty vehicles < 3.5 t

Pollutant or FC	Vehicle class	Speed range [km/h]	Emission factor [g/km]	R^2
CO	Conventional	10–110	$20E-05V^2 - 0.0256V + 1.8281$	0.136
	Euro 1	10–110	$22.3E-05V^2 - 0.026V + 1.076$	0.301
NO_x	Conventional	10–110	$81.6E-05V^2 - 0.1189V + 5.1234$	0.402
	Euro 1	10–110	$24.1E-05V^2 - 0.03181V + 2.0247$	0.0723
VOC	Conventional	10–110	$1.75E-05V^2 - 0.00284V + 0.2162$	0.0373
	Euro 1	10–110	$1.75E-05V^2 - 0.00284V + 0.2162$	0.0373
PM	Conventional	10–110	$1.25E-05V^2 - 0.000577V + 0.288$	0.0230
	Euro 1	10–110	$4.5E-05V^2 – 0.004885V + 0.1932$	0.224
Fuel consumption	Conventional	10–110	$0.02113V^2 - 2.65V + 148.91$	0.486
	Euro 1	10–110	$0.0198V^2 - 2.506V + 137.42$	0.422

Table 3-59: Emission reduction percentage for future diesel light-duty vehicles applied to vehicles complying with Directive 93/59/EEC

Emission Standard	CO [%]	NOx [%]	VOC [%]	PM [%]
Euro 2— 96/69/EC	0	0	0	0
Euro 3 — 98/69/EC Stage 2000	18	16	38	33
Euro 4 — 98/69/EC Stage 2005	35	32	77	65
Euro 5 — EC 715/2007	35	51	77	98.25
Euro 6 — EC715/2007	35	78	77	98.25

3.4.3.9 Gasoline heavy-duty vehicles

Only hot emissions are calculated for gasoline heavy-duty vehicles. Emission factors — derived from an extrapolation of the data for smaller vehicles — are presented in Table 3-60, and are defined only according to the three driving modes (urban, rural, highway). Total emission estimates are therefore calculated simply by application of equation (8).

Table 3-60: Emission factors for heavy-duty gasoline vehicles > 3.5 t

Driving Mode	CO [g/km]	NOx [g/km]	VOC [g/km]	Fuel consumption [g/km]
Urban	70	4.5	7.0	225
Rural	55	7.5	5.5	150
Highway	55	7.5	3.5	165

3.4.3.10 Diesel heavy-duty vehicles and buses

Speed dependent emission factors for diesel heavy-duty vehicles — including urban buses and coaches — have been taken from HBEFA v3.1. 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 as a separate Annex file accompanying this Guidebook chapter, also available from the EMEP EEA Guidebook website. The emissions covered by the methodology are CO, VOC, NO_x, PM and fuel consumption.

Equations (31) to (40) represent the main equations used to calculate the emission factors, and the accompanying file contains the necessary parameters. Distinct emission functions 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.

$$EF = (a + (b \times V))+(((c - b) \times (1-\exp(((-1) \times d) \times V))) / d) \quad (31)$$

$$EF = (e + (a \times \exp(((-1) \times b) \times V))) + (c \times \exp(((-1) \times d) \times V)) \quad (32)$$

$$EF = 1 / (((c \times (V^2)) + (b \times V)) + a) \quad (33)$$

$$EF = 1 / (a + (b \times (V^c))) \quad (34)$$

$$EF = 1 / (a + (b \times V)) \quad (35)$$

$$EF = a - (b \times \exp(((-1) \times c) \times (V^d))) \quad (36)$$

$$EF = a + (b / (1+\exp((((-1) \times c) + (d \times \ln(x))) + (e \times V)))) \quad (37)$$

$$EF = c + (a \times \exp(((-1) \times b) \times V)) \quad (38)$$

$$EF = c + (a \times \exp(b \times V)) \quad (39)$$

$$EF = \exp(a + (b / V)) + (c \times \ln(V)) \quad (40)$$

3.4.3.11 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 gasoline 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 gasoline 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.

Table 3-61 provides typical emission and fuel consumption factors for CNG buses, depending on their emission level. More information on the derivation of these emission values is given in Ntziachristos et al. (2007).

Table 3-61: Emission and fuel consumption factors for urban CNG buses.

Emission standard	CO (g/km)	THC (g/km)	NO_x (g/km)	PM (g/km)	Tailpipe CO_2 (g/km)	Derived FC_{CH4} (g/km)
Euro I	8.4	7.0	16.5	0.02	1400	555
Euro II	2.7	4.7	15.0	0.01	1400	515
Euro III	1.0	1.33	10.0	0.01	1250	455
EEV	1.0	1.0	2.5	0.005	1250	455

3.4.3.12 Two-stroke mopeds < 50 cm³

Mopeds are mostly driven in urban areas, and therefore only urban emission factors are proposed in Table 3-62 and Table 3-63. 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.

Table 3-62: Emission and fuel consumption factors for mopeds (urban driving conditions)

Category	Emission standard	CO [g/km]	NO_x [g/km]	VOC [g/km]	Fuel consumption [g/km]
Mopeds < 50 cm³	Conventional	13.80	0.02	13.91	25.00
	Euro 1	5.60	0.02	2.73	15.00
	Euro 2	1.30	0.26	1.56	12.08
	Euro 3	1.00	0.26	1.20	10.50

Table 3-63: PM emission factors for mopeds (urban driving conditions)

Category	Emission standard	Speed range [km/h]	PM [g/km]
Mopeds < 50 cm³	Conventional	10–110	1.88E-01
	Euro 1	10–110	7.55E-02
	Euro 2	10–110	3.76E-02
	Euro 3	10–110	1.14E-02

3.4.3.13 Motorcycles > 50 cm³

The equation used to calculate the emission factor for conventional and Euro 1 motorcycles over 50 cm³ engine displacement is equation (41). The coefficients a0 to a5 needed to calculate the emission factors are given in Table 3-64 to Table 3-65, for the different motorcycle categories.

$$EF = a0 + a1 \times V + a2 \times V^2 + a3 \times V^3 + a4 \times V^4 + a5 \times V^5 \tag{41}$$

Table 3-64: Speed dependency of emission and fuel consumption factors for two-stroke motorcycles of engine displacement over 50 cm^3

Pollutant or FC	Emission Standard	Speed Range [km/h]	Emission Factor Coefficients					
			a5	a4	a3	a2	a1	a0
CO	Conventional	0 - 100	-1.638E-08	5.164E-06	-6.478E-04	4.397E-02	-1.520E+00	3.597E+01
	Euro 1		-1.081E-08	3.409E-06	-4.276E-04	2.903E-02	-1.003E+00	2.373E+01
	Euro 2		-8.502E-09	2.680E-06	-3.362E-04	2.284E-02	-7.905E-01	1.875E+01
	Euro 3		-4.818E-09	1.520E-06	-1.904E-04	1.288E-02	-4.429E-01	1.040E+01
NOx	Conventional		-3.501E-10	1.003E-07	-1.073E-05	5.282E-04	-1.159E-02	1.134E-01
	Euro 1		-3.035E-11	7.962E-09	-8.279E-07	4.684E-05	-1.232E-03	5.042E-02
	Euro 2		-2.250E-10	6.639E-08	-7.398E-06	3.864E-04	-9.019E-03	1.171E-01
	Euro 3		-1.738E-11	1.090E-08	-1.873E-06	1.302E-04	-3.540E-03	4.970E-02
HC	Conventional		-1.375E-08	4.714E-06	-6.418E-04	4.568E-02	-1.747E+00	3.560E+01
	Euro 1		-3.150E-09	1.107E-06	-1.586E-04	1.246E-02	-5.223E-01	1.119E+01
	Euro 2		-1.578E-09	5.585E-07	-8.077E-05	6.432E-03	-2.728E-01	5.903E+00
	Euro 3		-1.098E-09	3.836E-07	-5.447E-05	4.227E-03	-1.752E-01	3.722E+00
FC	Conventional		-3.442E-08	1.152E-05	-1.543E-03	1.095E-01	-4.081E+00	8.794E+01
	Euro 1		-3.173E-08	1.062E-05	-1.423E-03	1.009E-01	-3.764E+00	8.114E+01
	Euro 2		-3.173E-08	1.062E-05	-1.423E-03	1.009E-01	-3.764E+00	8.114E+01
	Euro 3		-3.173E-08	1.062E-05	-1.423E-03	1.009E-01	-3.764E+00	8.114E+01

Table 3-65: Speed dependency of emission and fuel consumption factors for four-stroke motorcycles of engine displacement over 50 cm³

Pollutant or FC	Emission Standard	Speed Range [km/h]	Emission Factor Coefficients					
			a5	a4	a3	a2	a1	a0
4-Stroke <250 cm^3								
CO	Conventional	0 - 100	-1.373E-08	4.662E-06	-6.358E-04	4.690E-02	-1.792E+00	4.206E+01
	Euro 1		-1.389E-08	4.267E-06	-5.156E-04	3.455E-02	-1.190E+00	2.621E+01
	Euro 2		-7.281E-09	2.327E-06	-3.036E-04	2.126E-02	-7.278E-01	1.303E+01
	Euro 3		-4.016E-09	1.283E-06	-1.673E-04	1.172E-02	-4.012E-01	7.183E+00
NOx	Conventional		-4.597E-10	1.369E-07	-1.541E-05	8.232E-04	-1.696E-02	3.484E-01
	Euro 1		-7.075E-10	2.098E-07	-2.346E-05	1.235E-03	-2.633E-02	4.368E-01
	Euro 2		-3.892E-10	1.141E-07	-1.275E-05	7.340E-04	-1.897E-02	4.010E-01
	Euro 3		-1.953E-10	6.014E-08	-6.860E-06	4.080E-04	-1.090E-02	3.191E-01
HC	Conventional		-8.349E-10	3.320E-07	-5.391E-05	4.658E-03	-2.170E-01	5.155E+00
	Euro 1		-7.560E-10	2.837E-07	-4.286E-05	3.413E-03	-1.465E-01	3.535E+00
	Euro 2		-7.004E-10	2.350E-07	-3.116E-05	2.093E-03	-7.210E-02	1.455E+00
	Euro 3		-4.743E-10	1.596E-07	-2.115E-05	1.413E-03	-4.809E-02	9.394E-01
FC	Conventional		-4.675E-08	1.500E-05	-1.887E-03	1.205E-01	-3.859E+00	7.573E+01
	Euro 1		-3.844E-08	1.234E-05	-1.552E-03	9.912E-02	-3.173E+00	6.225E+01
	Euro 2		-3.416E-08	1.114E-05	-1.428E-03	9.274E-02	-3.052E+00	5.933E+01
	Euro 3		-3.416E-08	1.114E-05	-1.428E-03	9.274E-02	-3.052E+00	5.933E+01
4-Stroke 250-750 cm^3								
CO	Conventional	0 - 140	-9.989E-09	4.367E-06	-7.403E-04	6.304E-02	-2.679E+00	6.398E+01
	Euro 1		-1.217E-08	4.832E-06	-6.900E-04	4.577E-02	-1.486E+00	2.985E+01
	Euro 2		-2.022E-10	3.310E-07	-7.183E-05	7.733E-03	-4.020E-01	9.718E+00
	Euro 3		-1.189E-10	1.850E-07	-3.988E-05	4.275E-03	-2.217E-01	5.356E+00
NOx	Conventional		5.330E-10	-1.664E-07	1.911E-05	-9.296E-04	2.021E-02	8.537E-02
	Euro 1		6.455E-11	-1.738E-08	1.406E-06	1.981E-05	-1.793E-03	2.454E-01
	Euro 2		-9.295E-12	5.284E-09	-1.050E-06	1.386E-04	-6.921E-03	1.862E-01
	Euro 3		-1.930E-11	8.174E-09	-1.296E-06	1.181E-04	-4.823E-03	1.067E-01
HC	Conventional		-7.761E-10	3.622E-07	-6.487E-05	5.791E-03	-2.808E-01	7.660E+00
	Euro 1		-4.121E-10	1.882E-07	-3.282E-05	2.901E-03	-1.401E-01	3.949E+00
	Euro 2		-2.251E-10	1.012E-07	-1.686E-05	1.437E-03	-6.510E-02	1.746E+00
	Euro 3		-1.180E-10	5.438E-08	-9.250E-06	8.121E-04	-3.805E-02	1.062E+00
FC	Conventional		-1.595E-08	6.942E-06	-1.151E-03	9.545E-02	-3.983E+00	1.015E+02
	Euro 1		-1.226E-08	5.431E-06	-9.263E-04	8.063E-02	-3.517E+00	9.249E+01
	Euro 2		-1.225E-08	5.408E-06	-9.138E-04	7.818E-02	-3.332E+00	8.505E+01
	Euro 3		-1.225E-08	5.408E-06	-9.138E-04	7.818E-02	-3.332E+00	8.505E+01

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Table 3-65: Speed dependency of emission and fuel consumption factors for four-stroke motorcycles of engine displacement over 50 cm³ (cont.)

Pollutant or FC	Emission Standard	Speed Range [km/h]	Coefficients a5	a4	a3	a2	a1	a0
4-Stroke >750 cm^3								
CO	Conventional	0 - 140	-9.989E-09	4.367E-06	-7.403E-04	6.304E-02	-2.679E+00	6.398E+01
	Euro 1		-1.217E-08	4.832E-06	-6.900E-04	4.577E-02	-1.486E+00	2.985E+01
	Euro 2		-2.022E-10	3.310E-07	-7.183E-05	7.733E-03	-4.020E-01	9.718E+00
	Euro 3		-1.189E-10	1.850E-07	-3.988E-05	4.275E-03	-2.217E-01	5.356E+00
NOx	Conventional		1.348E-10	-5.133E-08	7.639E-06	-4.643E-04	1.142E-02	3.943E-02
	Euro 1		-3.488E-11	1.237E-08	-1.988E-06	2.357E-04	-1.104E-02	3.059E-01
	Euro 2		1.479E-11	-3.649E-09	2.877E-07	9.909E-05	-8.524E-03	2.754E-01
	Euro 3		2.880E-12	2.555E-10	-2.087E-07	7.753E-05	-5.274E-03	1.527E-01
HC	Conventional		-7.483E-10	3.297E-07	-5.680E-05	5.165E-03	-2.647E-01	7.687E+00
	Euro 1		-6.341E-10	2.944E-07	-5.145E-05	4.480E-03	-2.053E-01	4.737E+00
	Euro 2		-2.975E-10	1.460E-07	-2.592E-05	2.236E-03	-9.617E-02	1.969E+00
	Euro 3		-1.955E-10	9.428E-08	-1.652E-05	1.409E-03	-6.000E-02	1.221E+00
FC	Conventional		-1.819E-08	7.981E-06	-1.347E-03	1.139E-01	-4.820E+00	1.213E+02
	Euro 1		-1.775E-08	7.805E-06	-1.326E-03	1.129E-01	-4.871E+00	1.230E+02
	Euro 2		-1.833E-08	8.050E-06	-1.363E-03	1.157E-01	-4.939E+00	1.213E+02
	Euro 3		-1.833E-08	8.050E-06	-1.363E-03	1.157E-01	-4.939E+00	1.213E+02

Table 3-66 also includes PM emission factors for two-wheel vehicles. PM emissions are particularly important for two-stroke vehicles. These emission factors correspond to a mix of mineral and synthetic lubricant used for two-stroke engines.

Table 3-66: PM Emission factors for 2- and four-stroke conventional and post-Euro motorcycles of engine displacement over 50 cm³

Pollutant	Engine type/capacity	Emission standard	Speed range [km/h]	Emission factor [g/km]
PM	2-stroke	Conventional	10–110	2.0E-01
		Euro 1	10–110	8.0E-02
		Euro 2	10–110	4.0E-02
		Euro 3	10–110	1.2E-02
	< 250 cm3	Conventional	10–110	2.0E-02
		Euro 1	10–110	2.0E-02
		Euro 2	10–110	5.0E-03
		Euro 3	10–110	5.0E-03
	250< cc< 750 cm3	Conventional	10–110	2.0E-02
		Euro 1	10–110	2.0E-02
		Euro 2	10–110	5.0E-03
		Euro 3	10–110	5.0E-03
	> 750 cm3	Conventional	10–110	2.0E-02
		Euro 1	10–110	2.0E-02
		Euro 2	10–110	5.0E-03
		Euro 3	10–110	5.0E-03

3.4.3.14 Emissions of non-regulated pollutants

Methane and NMVOCs

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 CH_4 is a greenhouse gas, separate emission factors are required to calculate its contribution. In order to calculate hot CH_4 emissions, equation (8) can be applied with the values given in Table 3-67. Reduction factors for more recent technologies are given in Table 3-68. In reference to those tables it should be noted that cold-start emission factors apply only to passenger cars and light-duty vehicles. In Table 3-68 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.

Table 3-67: Methane (CH_4) emission factors (mg/km)

Vehicle type	Fuel	Vehicle technology/class	Urban		Rural	Highway
			Cold	Hot		
Passenger cars	Gasoline	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	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
	LPG	All Technologies	80	80	35	25
Light-duty vehicles	Gasoline	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	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
Heavy-duty vehicles and buses	Gasoline	All Technologies	-	140	110	70
	Diesel	GVW< 16t	-	85	23	20
		GVW> 16t	-	175	80	70
		Urban Buses and Coaches	-	175	80	70
	CNG	Euro I	-	6800		
		Euro II	-	4500		
		Euro III	-	1280		
		EEV	-	980		
Two-wheel vehicles	Gasoline	< 50 cm^3	-	219	219	219
		> 50 cm^3 2-stroke	-	150	150	150
		> 50 cm^3 4-stroke	-	200	200	200

The NMVOC emission factors were calculated as the remainder of the subtraction of CH_4 emissions from total VOC emissions. Hence, after VOC and CH_4 have been calculated by equation (6), NMVOC emissions can also be calculated by:

$$E_{NMVOC} = E_{VOC} - E_{CH4} \qquad (42)$$

Table 3-68: Methane (CH_4) 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	84	84	84
		Euro 4	95	95	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	Euro II	35	35	35
		Euro III	41	41	41
		Euro IV	97	97	97
		Euro V and later	97	97	97
Two-wheel vehicles	Gasoline	< 50 cm^3 — Euro 1	80	-	-
		< 50 cm^3 — Euro 2	89		
		< 50 cm^3 — Euro 3	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	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	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	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	75	89	85

PM characteristics

New emission factors for PM characteristics have been developed on the basis of the Paticulates project, and these are presented in the following tables. New metrics include the 'active surface area' 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 3-69: PM characteristics of diesel passenger cars

Pollutant	Category	Fuel specifications	Emission factor		
			Urban	Rural	Highway
Active surface area [m²/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		4.03E+00	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		1.67E+14	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

Table 3-70: 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 gasoline Euro 1	3.2E+12	2.4E+12	8.6E+11
	PC gasoline Euro 3	9.6E+10	1.1E+11	5.5E+10
	PC gasoline 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 gasoline Euro 1	1.4E+12	1.0E+12	3.4E+11
	PC gasoline Euro 3	4.4E+10	5.4E+10	2.8E+10
	PC gasoline 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 gasoline Euro 1	5.2E+11	3.7E+11	1.2E+11
	PC gasoline Euro 3	2.6E+10	3.4E+10	5.1E+10
	PC gasoline Euro 3 GDI	4.1E+12	2.1E+12	1.5E+12

Table 3-71 to Table 3-75 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 2-2, 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.

Table 3-71: PM characteristics of buses

Pollutant metric	Emission standard	Speed range [km/h]	Emission factor		
			Urban	Rural	Highway
Active surface area [cm²/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

Table 3-72: PM characteristics of coaches

Pollutant metric	Emission standard	Speed range [km/h]	Emission factor		
			Urban	Rural	Highway
Active surface area [cm²/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

Table 3-73: 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 [cm²/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

Table 3-74: PM characteristics of rigid HDVs 7.5-14 tonnes

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 3-75: PM characteristics of rigid HDVs 14–32 tonnes, and truck trailer/articulated 14–34 tonnes

HDVs 14-34 tn					
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

Nitrous oxide (N_2O) emissions

Nitrous oxide emission factors were developed in a LAT/AUTh study (Papathanasiou and Tzirgas, 2005), based on data collected in studies around the world. N_2O 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 N_2O has increased in importance on account of its contribution to the greenhouse effect, a detailed calculation of N_2O 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, N_2O emission factors are calculated according to equation (43), and the coefficients in Table 3-76 to Table 3-83 for different passenger cars and light-duty vehicles. These values differ according to the fuel sulphur level and the driving conditions (urban, rural, highway). In particular, cold-start and a hot-start emission factors are given for urban driving.

$$EF_{N2O} = [a \times CMileage + b] \times EF_{BASE} \quad (43)$$

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. is the total number of kilometres driven on average by a certain vehicle class over a calendar year. Typical values for passenger cars are between 10 and 20 thousand kilometres. 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. The cumulative mileage could be expressed as annual mileage times the years of life of a vehicle.

Table 3-76: Parameters for equation(43) to calculate N_2O emission factors for gasoline passenger cars under cold urban conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	A	b
pre-Euro	All	10	0.00E+00	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

Table 3-77: Parameters for equation (43) to calculate N_2O emission factors for gasoline passenger cars under hot urban conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	A	b
pre-Euro	All	10	0.00E+00	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

Table 3-78: Parameters for equation (43) to calculate N_2O emission factors for gasoline passenger cars under hot rural conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	A	b
pre-Euro	All	6.5	0.00E+00	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

Table 3-79: Parameters for equation (43) to calculate N_2O emission factors for gasoline passenger cars under hot highway conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	A	b
pre-Euro	All	6.5	0.00E+00	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

Table 3-80: Parameters for equation (43) to calculate N_2O emission factors for gasoline LDVs under cold urban conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	10	0.00E+00	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

Table 3-81: Parameters for equation (43) to calculate N_2O emission factors for gasoline LDVs under hot urban conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	10	0.00E+00	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

Table 3-82: Parameters for equation (43) to calculate N_2O emission factors for gasoline LDVs under hot rural conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	6.5	0.00E+00	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

Table 3-83 Parameters for equation (43) to calculate N_2O emission factors for gasoline LDVs under hot highway conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	> 0	6.5	0.00E+00	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

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) and Riemersma et al. (2003). These data are shown in Table 3-84 and Table 3-85. 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 3-84: N_2O emission factors (mg/km) for diesel and LPG cars, diesel light duty vehicles, and two-wheel vehicles

Vehicle category	Urban cold	Urban hot	Rural	Highway
Diesel passenger cars and LDVs				
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	t.b.d	t.b.d	t.b.d	t.b.d
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
Mopeds and motorcycles				
< 50 cm³	1		1	1
> 50 cm³ 2-stroke	2		2	2
> 50 cm³ 4-stroke	2		2	2

Table 3-85: N_2O emission factors (mg/km) for heavy duty vehicles

HDV Category	Technology	Urban (g/km)	Rural (g/km)	Highway (g/km)
Gasoline > 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
	HD Euro VI	18.5	19	15
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
	HD Euro VI	37	39	29
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
	HD Euro VI	56.5	59.5	44.5
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
	HD Euro VI	61	64	48
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 3-85 already designate that N_2O emissions from diesel vehicles equipped with deNOx 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 N_2 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 N_2O production, as NO_x are effectively converted to N_2. However, there are at least two cases which can lead to excess N_2O emission. The SCR chemical mechanism forms N_2O as a byproduct of the N_2 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 N_2O 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 than no NO_x is emitted downstream of the SCR system. This slipped ammonia can not be fully oxidized into N_2 in the oxidation catalyst and often is emitted as N_2O.

The values in Table 3-85 should be representative of well-operating SCR systems, i.e. without (excessive) ammonia slip. In case this occurs, N_2O emissions may increase disproportionally. High values of ammonia slip may occur for an aged system or due to malfunctions. One such study in Japan identified N_2O emissions to amount to up to 20% of CO_2 equivalent in the exhaust of an SCR equipped vehicle (Suzuki et al., 2008). N_2O emissions from SCR vehicles need to me 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 can not 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. N_2O emissions may be drastically different in the two cases. Because of these unknowns, predicting the level and the trend of N_2O emission from SCR equipped passenger cars is currently not possible.

Ammonia (NH_3) emissions

Ammonia emissions from passenger cars and light-duty vehicles are estimated in a similar manner to N_2O emissions. The NH_3 emission factors are calculated according to equation (43) and the coefficients in Table 3-86 to Table 3-93. As already mentioned, these values differ according to the fuel sulphur level and the driving conditions (urban, rural, highway).

Table 3-86: Parameters for equation (43) to calculate NH_3 emission factors for gasoline passenger cars under cold urban conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	2	0.00E+00	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

Table 3-87: Parameters for equation (43) to calculate NH_3 emission factors for gasoline passenger cars under hot urban conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	2	0.00E+00	1
Euro 1	All	70	0.00E+00	1
Euro 2	All	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

Table 3-88: Parameters for equation (43) to calculate NH_3 emission factors for gasoline passenger cars under hot rural conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	2	0.00E+00	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

Table 3-89: Parameters for equation (43) to calculate NH_3 emission factors for gasoline passenger cars under hot highway conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	2	0.00E+00	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

Table 3-90: Parameters for equation (43) to calculate NH_3 emission factors for gasoline LDVs under cold urban conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	> 0	2	0.00E+00	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

Table 3-91: Parameters for equation (43) to calculate NH_3 emission factors for gasoline LDVs under hot urban conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	> 0	2	0.00E+00	1
Euro 1	> 0	70	0.00E+00	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

Table 3-92: Parameters for equation (43) to calculate NH_3 emission factors for gasoline LDVs under hot rural conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	> 0	2	0.00E+00	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

Table 3-93: Parameters for equation (43) to calculate NH_3 emission factors for gasoline LDVs under hot highway conditions

Emission standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	2	0.00E+00	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

For all other vehicle classes, bulk ammonia emission factors are given in Table 3-94. 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 3-94: Bulk (hot + cold) ammonia (NH_3) emission factors (mg/km)

Vehicle category	Urban	Rural	Highway
Passenger cars			
Diesel cc < 2.0 l	1	1	1
Diesel cc > 2.0 l	1	1	1
LPG	nd	nd	nd
2-stroke	2	2	2
Light-duty vehicles			
Diesel	1	1	1
Heavy-duty vehicles			
Gasoline vehicle > 3.5 t	2	2	2
Diesel < 7.5 t	3	3	3
Diesel 7.5 t < W < 16 t	3	3	3
Diesel 16 t < W < 32 t	3	3	3
Diesel W > 32 t	3	3	3
Urban buses	3	-	-
Coaches	3	3	3
Motorcycles			
< 50 cm³	1	1	1
> 50 cm³ 2-stroke	2	2	2
> 50 cm³ 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 3-95. 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-duty 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.

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 gasoline 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 Table 3-96. 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). 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. 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 gasoline vehicles.

Table 3-95: PAHs and POPs bulk (hot + cold) emission factors

Species	Bulk emission factors (µg/km)					
	Gasoline PC & LDV		Diesel PC &LDV		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)anthacene	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		
acenapthene			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
napthalene	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	

Table 3-96: Dioxins and furans toxicity equivalence emission factors

	Toxicity equivalent emission factor [pg/km]		
Polychlorinated dibenzo dioxins	**PC gasoline conv.**	**PC diesel IDI**	**Heavy-duty diesel**
TeCDD.TOTAL	3.8	0.2	1.4
PeCDD.TOTAL	5.2	0.2	0.9
HxCDD. TOTAL	1.0	0.1	0.3
HpCDD.TOTAL	0.2	0.0	0.2
OCDD	0.1	0.0	0.2
Total dioxins	10.3	0.5	3.0
Polychlorinated dibenzo furans			
TeCDF.TOTAL	3.6	0.1	0.6
PeCDF.TOTAL	8.2	0.5	2.8
HxCDF.TOTAL	8.1	0.4	3.9
HpCDF.TOTAL	1.3	0.0	0.5
OCDF	0.0	0.0	0.1
Total furans	21.2	1.0	7.9

3.4.3.15 Fuel consumption dependant emission factors

Emissions of heavy metals are calculated by means of equation (21). Table 3-97 apparent fuel metal content heavy metal factors. These values have been calculated by encompassing the impact of engine wear and lube oil heavy metal content to the heavy metal emissions. Therefore, by multiplying these apparent factors with fuel consumption, it is expected that the combined emissions of fuel, lube oil, and engine wear are estimated. .

Table 3-97: Heavy metal emission factors for all vehicle categories in μg/kg fuel

Category	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Passenger cars, gasoline (unleaded gasoline)	0.30	10.8	16.0	42.0	8.7	13.0	33.2	0.2	2163
Passenger cars, diesel	0.10	8.7	30.0	21.2	5.3	8.8	52.1	0.1	1738
Passenger cars, LPG	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
LDVs, gasoline	0.30	10.8	16.0	42.0	8.7	13.0	33.2	0.2	2163
LDVs, diesel	0.10	8.7	30.0	21.2	5.3	8.8	52.1	0.1	1738
HDVs, gasoline	0.30	10.8	16.0	42.0	8.7	13.0	33.2	0.2	2163
HDVs, diesel	0.10	8.7	30.0	21.2	5.3	8.8	52.1	0.1	1738
HDVs, CNG	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Motorcycles > 50 cm³	0.30	10.8	16.0	42.0	8.7	13.0	33.2	0.2	2163

3.4.3.16 Emission degradation functions

Table 3-98 and Table 3-99 provide the degradation functions to be used for simulating the deterioration of emission performance of gasoline passenger cars and light-duty vehicles equipped with three way catalysts. The relevant methodology given in subsection 5.7.1.

Table 3-98: Emission degradation due to vehicle age for Euro 1 and Euro 2 gasoline passenger cars and light-duty vehicles

$MC = A^M \times M^{MEAN} + B^M$	Capacity class [l]	Average mileage [km]	A^M	B^M (Value at 0 km)	Value at ≥ 120 000 km
Correction for V< 19 km/h (MC_{URBAN})					
$CO – MC_{URBAN}$	≤ 1.4	29 057	1.523E-05	0.557	2.39
	1.4–2.0	39 837	1.148E-05	0.543	1.92
	> 2.0	47 028	9.243E-06	0.565	1.67
$NO_x – MC_{URBAN}$	ALL	44 931	1.598E-05	0.282	2.20
$HC – MC_{URBAN}$	≤ 1.4	29 057	1.215E-05	0.647	2.10
	1.4–2.0	39 837	1.232E-05	0.509	1.99
	> 2.0	47 028	1.208E-05	0.432	1.88
Correction for V> 63 km/h (MC_{ROAD})					
$CO – MC_{ROAD}$	≤ 1.4	29 057	1.689E-05	0.509	2.54
	1.4–2.0	39 837	9.607E-06	0.617	1.77
	> 2.0	47 028	2.704E-06	0.873	1.20
$NO_x – MC_{ROAD}$	ALL	47 186	1.220E-05	0.424	1.89
$HC – MC_{ROAD}$	≤ 1.4	29 057	6.570E-06	0.809	1.60
	1.4–2.0	39 837	9.815E-06	0.609	1.79
	> 2.0	47 028	6.224E-06	0.707	1.45

Table 3-99: Emission degradation due to vehicle age for Euro 3 and Euro 4 gasoline passenger cars and light-duty vehicles (and Euro 1 and 2 vehicles in case of an enhanced IandM scheme)

$MC = A^M \times M^{MEAN} + B^M$	Capacity class [l]	Average mileage [km]	A^M	B^M (Value at 0 km)	Value at ≥ 160,000 km
Correction for V< 19 km/h (MC_{URBAN})					
$CO – MC_{URBAN}$	≤ 1.4	32 407	7.129E-06	0.769	1.91
	> 1.4	16 993	2.670E-06	0.955	1.38
$NO_x – MC_{URBAN}$	≤ 1.4	31 313	0	1	1
	> 1.4	16 993	3.986E-06	0.932	1.57
$HC – MC_{URBAN}$	≤ 1.4	31 972	3.419E-06	0.891	1.44
	> 1.4	17 913	0	1	1
Correction for V> 63 km/h (MC_{ROAD})					
$CO – MC_{ROAD}$	≤ 1.4	30 123	1.502E-06	0.955	1.20
	> 1.4	26 150	0	1	1
$NO_x – MC_{ROAD}$	ALL	26 150	0	1	1
$HC – MC_{ROAD}$	ALL	28 042	0	1	1

Table 3-100: Emission degradation correction factor as a function of speed

Speed — V [km/h]	Mileage correction — Mcorr [-]
≤19	M_{URBAN}
≥63	M_{ROAD}
> 19 and < 63	$MC_{URBAN} + \frac{(V-19)\cdot(MC_{ROAD} - MC_{URBAN})}{44}$

3.4.3.17 Fuel effects

Table 3-101, Table 3-102 and Table 3-103 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 3-104 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, CO_2 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 3-104, 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 3-104 should be used with care for post Euro 3 diesel technologies.

Table 3-101: Relations between emissions and fuel properties for passenger cars and light-duty vehicles

Pollutant	Correction factor equation
CO	Fcorr = [2.459 – 0.05513 × (E100) + 0.0005343 × $(E100)^2$ + 0.009226 × (ARO)- 0.0003101 × (97-S)] × [1-0.037 × (O_2 – 1.75)] × [1-0.008 × (E150 – 90.2)]
VOC	Fcorr = [0.1347 + 0.0005489 × (ARO) + 25.7 × (ARO) × $e^{(-0.2642\ (E100))}$ – 0.0000406 × (97-S)] × [1-0.004 × (OLEFIN – 4.97)] × [1-0.022 × (O_2 – 1.75)] × [1-0.01 × (E150 – 90.2)]
NO_x	Fcorr = [0.1884 – 0.001438 × (ARO) + 0.00001959 × (ARO) × (E100) – 0.00005302 × (97 – S)] × [1+0.004 × (OLEFIN – 4.97)] × [1+0.001 × (O_2 – 1.75)] × [1+0.008 × (E150 – 90.2)]

Note:
O_2 = 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 3-102: Relations between emissions and fuel properties for diesel passenger cars and light-duty vehicles

Pollutant	Correction factor equation
CO	$Fcorr=-1.3250726 + 0.003037 \times DEN - 0.0025643 \times PAH - 0.015856 \times CN + 0.0001706 \times T_{95}$
VOC	$Fcorr=-0.293192 + 0.0006759 \times DEN - 0.0007306 \times PAH - 0.0032733 \times CN - 0.000038 \times T_{95}$
NO_x	$Fcorr=1.0039726 - 0.0003113 \times DEN + 0.0027263 \times PAH - 0.0000883 \times CN - 0.0005805 \times T_{95}$
PM	$Fcorr=(-0.3879873 + 0.0004677 \times DEN + 0.0004488 \times PAH + 0.0004098 \times CN + 0.0000788 \times T_{95}) \times [1 - 0.015 \cdot \times (450 - S)/100]$

Note:
DEN = Density at 15 °C [kg/m^3], S = Sulphur content in ppm, PAH = Polycyclic aromatics content in %, CN = Cetane number , T95 = Back end distillation in ^oC.

Table 3-103: Relations between emissions and fuel properties for diesel heavy-duty vehicles

Pollutant	Correction factor equation
CO	$Fcorr = 2.24407 - 0.0011 \times DEN + 0.00007 \times PAH - 0.00768 \times CN - 0.00087 \times T_{95}$
VOC	$Fcorr = 1.61466 - 0.00123 \times DEN + 0.00133 \times PAH - 0.00181 \times CN - 0.00068 \times T_{95}$
NO_x	$Fcorr = -1.75444 + 0.00906 \times DEN - 0.0163 \times PAH + 0.00493 \times CN + 0.00266 \times T_{95}$
PM	$Fcorr = [0.06959 + 0.00006 \times DEN + 0.00065 \times PAH - 0.00001 \times CN] \times [1-0.0086 \times (450 - S)/100]$

Note:
DEN = Density at 15 °C [kg/m^3], S = Sulphur content in ppm, PAH = Polycyclic aromatics content in %, CN = Cetane number , T_{95} = Back end distillation in ^oC

Table 3-104: Effect of biodiesel blends on diesel vehicle emissions

Pollutant	Vehicle type	B10	B20	B100
CO_2	Passenger cars	-1.5 %	-2.0 %	
	Light-duty vehicles	-0.7 %	-1.5 %	
	Heavy-duty vehicles	0.2 %	0.0 %	0.1 %
NO_x	Passenger cars	0.4 %	1.0 %	
	Light-duty vehicles	1.7 %	2.0 %	
	Heavy-duty vehicles	3.0 %	3.5 %	9.0 %
PM	Passenger cars	-13.0 %	-20.0 %	
	Light-duty vehicles	-15.0 %	-20.0 %	
	Heavy-duty vehicles	-10.0 %	-15.0 %	-47.0 %
CO	Passenger cars	0.0 %	-5.0 %	

	Light-duty vehicles	0.0 %	-6.0 %	
	Heavy-duty vehicles	-5.0 %	-9.0 %	-20.0 %
HC	Passenger cars	0.0 %	-10.0 %	
	Light-duty vehicles	-10.0 %	-15.0 %	
	Heavy-duty vehicles	-10.0 %	-15.0 %	-17.0 %

3.4.4 Species profiles

3.4.4.1 VOC Speciation

The separation of NMVOCs into different compounds is given in Table 3-105a and Table 3-105b. 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) gasoline passenger cars and light-duty vehicles, diesel passenger cars and light-duty vehicles, diesel heavy-duty vehicles and LPG passenger cars. A common speciation is proposed for diesel passenger cars and light-duty vehicles, regardless of the combustion concept (DI or IDI).

The NMVOC speciation for four-stroke motorcycles is estimated using fractions derived from conventional gasoline 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 3-105b shows the total sum of these fractions. It is assumed that the remaining fraction consists of PAHs and POPs.

Table 3-105a: Composition of NMVOC in exhaust emissions (alkanes, cycloalkanes, alkenes, alkynes)

Group	Species	NMVOC Fraction (% wt.)				
		Gasoline 4 stroke		Diesel PC & LDV	HDV	LPG
		Convent.	Euro 1 & 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			
	heptane	0.36	0.74	0.20	0.30	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-butyne	0.05	0.21			
	propyne	0.76	0.08			
	acetylene	5.50	2.81	2.34	1.05	1.28

Table 3-105b: Composition of NMVOC in exhaust emissions (aldehydes, ketones, aromatics)

Group	Species	NMVOC Fraction (% wt.)				
		Gasoline 4 stroke		Diesel PC & LDV	HDV	LPG
		Convent.	Euro I & on	IDI & DI		
ALDEHYDES	formaldehyde	2.08	1.70	12.00	8.40	1.56
	acetaldahyde	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
	methylethlketone	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**	**99.98**

3.4.5 *NO_x speciation*

Nitrogen oxides (NO_x) in vehicle exhausts mainly consist of NO and NO_2. The NO_2 mass fraction of total NO_x (primary NO_2) is of particular importance due to the higher toxicity of NO_2 compared to NO. This mass fraction is quoted as f-NO_2, in consistency to the AQEG (2006) report. Table 3-106 provides the range of f-NO_2 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 NO_2 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 NO_2. The AEAT study was considered more up-to-date, given the detailed discussion within UK concerning primary NO_2 emission rates (AQEG, 2006) and the

NO_2/NO_x data provided to AEAT by LAT. The ranges proposed in the AEAT study for passenger cars have also been transferred to light-duty vehicles.

Table 3-106: Mass fraction of NO_2 in NO_x emissions (f-NO_2)

Category	Emission standard	f-NO_2 (%)		
		AEAT Study	TNO Study	Suggested Value
Gasoline 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	-	-	2
Diesel PCs	pre-Euro	11	20	11
	Euro 1 — Euro 2	11	20	11
	Euro 3	25	40	25
	Euro 4	55	40-70	55
	Euro 5	55	70	5-70
	Euro 6			5-70
LPG PCs	pre-Euro	5	5	5
	Euro 1 — Euro 3		5	5
	Euro 4		5	5
	Euro 5		-	5
	Euro 6		-	5
Gasoline LDTs	pre-Euro	-	5	4
	Euro 1 — Euro 2	-	5	4
	Euro 3 — Euro 4	-	5	3
	Euro 5	-	5	3
	Euro 6	-		2
Diesel LDTs	pre-Euro	-	20	11
	Euro 1 — Euro 2	-	20	11
	Euro 3	-	40	25
	Euro 4	-	40-70	55
	Euro 5	-	70	5-70
	Euro 6	-	-	5-70
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

Neither the TNO nor the AEAT studies provide f-NO_2 values for upcoming vehicle and engine technologies (post Euro 4). Therefore, some estimates need to be conducted based on the expected technology. Due to the heavy investments of manufacturers in SCR technology, and the increase in the availability of urea in fuel stations all over Europe, it is expected that SCR will become more popular on diesel cars and trucks in the future. Due to the better engine calibration and fuel efficiency that it provides, SCR may also become more prevalent in gasoline cars. Additionally, SCR systems may assist the promotion of lean-burn GDI gasoline concepts. SCR, when properly calibrated leads to negligible f-NO_2 emissions (Mayer et al., 2007), as NO_2 efficiently reacts with ammonia to produce nitrogen and water.

For gasoline cars the use of SCR is expected to lead to zero exhaust emissions of NO_2. Considering that 30 % of gasoline passenger cars may be equipped with SCR, an average value of 2 % for NO_2/NO_x is proposed at the Euro 6 level.

With regard to diesel passenger cars, SCR would ideally lead to zero exhaust emissions of NO_2. However, deviations from the ideal urea dosing over transient cycles may lead to 'NO_2 slip'. This could result in an increase in f-NO_2 which may then reach up to 20 % of total NOx. Furthermore the need for high efficiency during cold start may lead manufacturers to place SCR close to the engine outlet, followed by a catalysed DPF. In this case, the oxidative environment inside the filter may lead to a high value of f-NO_2. Hence, for Euro 5 and 6 passenger cars, f-NO_2 will strongly depend on the actual concept, and the whole range of 5–70 % seems possible.

In the case of heavy-duty vehicles the evolution of f-NO_2 for future technologies is more predictable than for passenger cars. The reason is that all Euro V and VI will be equipped with SCR. The SCR will be installed downstream of any diesel particle filter (mandatory at Euro VI level) because there is no cold-start emission standard for heavy-duty engines. The less transient operation of heavy-duty engines will also result in less NO_2 slip compared with passenger cars. Consequently, the SCR will effectively reduce exhaust NO_2 emission levels. An f-NO_2 ratio of 10 % is proposed, simply to account for any non-ideal SCR calibration during real-world operation.

3.4.6 Separation of PM into elemental and organic carbon

Exhaust PM mainly consists of elemental carbon (EC) and organic carbon (OC). Their content in PM is important both because they affect the health and environmental effects of the emitted particles but also because this is useful input to atmospheric modelling studies. Therefore, different literature values have been collected and EC and OC values have been proposed. 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. However, this does not mean that developing EC/OC ratios is impossible, because there is a general agreement in the measurements from tunnel and laboratory studies with regard to the emission characteristics of diesel and gasoline vehicles. The effect of different technologies (e.g. oxidation catalyst, diesel particle filter) on emissions is also rather predictable.

Table 3-107 suggests ratios between organic material (OM) and elemental carbon (OM/EC) and $EC/PM_{2.5}$ (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 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 3-107: Split of PM in elemental (EC) and organic mass (OM)

Category	Euro standard	$EC/PM_{2.5}$ (%)	OM/EC (%)	Uncertainty (%)
Gasoline PC and LDV	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 LDV	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
Two-wheel vehicles	Conventional	10	900	50
	Euro 1	20	400	50
	Euro 2	20	400	50
	Conventional	15	560	50
	Euro 1	25	300	50
	Euro 2	25	300	50
	Euro 3	25	250	50

The values in Table 3-107 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

Gasoline 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 CO_2 emissions produced by the combustion of biofuels (bioethanol, biodiesel, and biogas). Section 3.4.1.1.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, CO_2 emissions from the production of biofuels is reported in the Land Use, Land-Use Change and Forestry sector, while CO_2 from the combustion of biofuels should not be reported. This does not apply to other greenhouse gases produced when combusting biofuels (CH_4, N_2O). 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 CO_2 are part of industrial procedures and the resulting CO_2 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:

- *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 CO_2 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. gasoline 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/m^3) 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 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 fuel consumption and emissions with both approaches, and to compare the aggregated results. The calculated and statistical fuel consumption should not greatly vary, otherwise corrections may be necessary in one or both of the approaches.

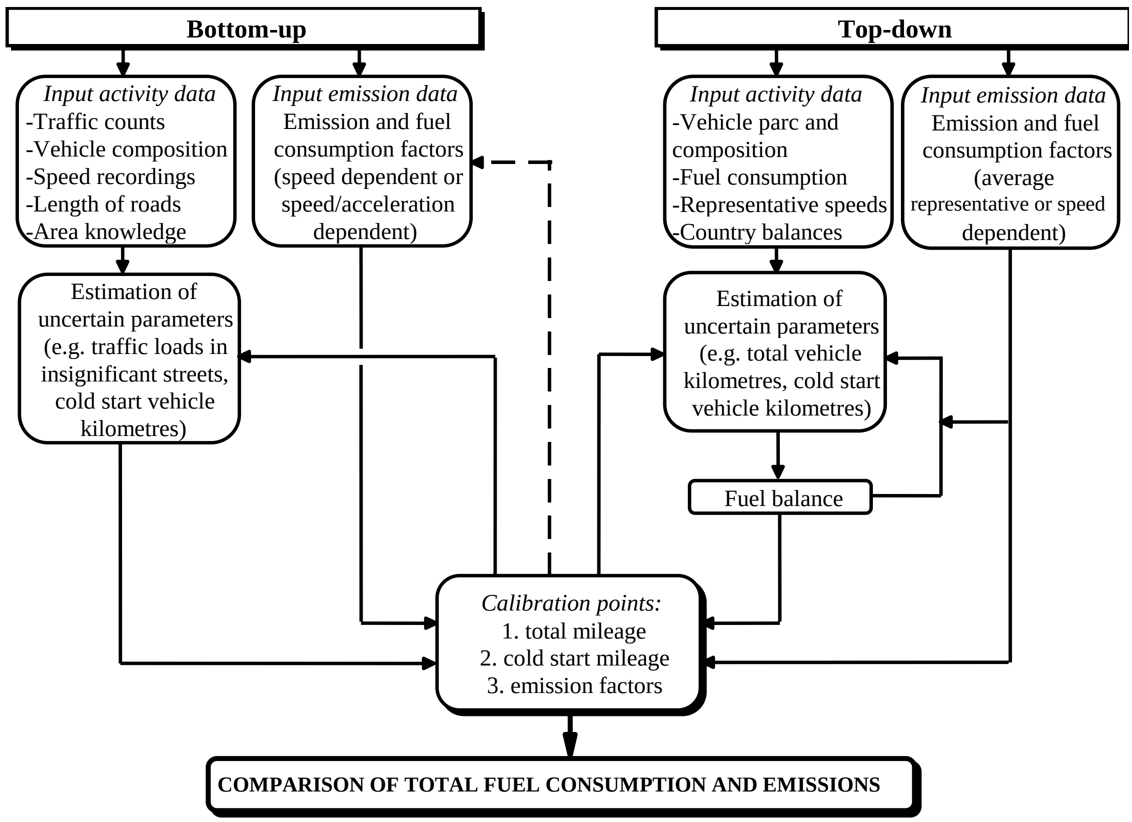

Figure 4-1: Proposed reconciliation method in applying bottom-up and top-down approaches when building an urban emission inventory

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 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 1×1 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 ltrip value discussed in section 3.4.1.1.B. This ltrip value and the beta equation quoted in Table 3-40 should only be used for national inventories because they are calibrated to ltrip 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-duty 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 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 gasoline and diesel vehicles > 2.5 t which belong to the category 'light-duty 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

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

Vehicle Category	Pollutant							
	NO_x	CO	NMVOC	CH_4	PM	N_2O	NH_3	CO_2
Gasoline 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	A	A	A	-	-	--	-	A
Without 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-duty vehicles								
Gasoline	B	B	B	C	-	B	B	A
Diesel	B	B	B	C	A	B	B	A
Heavy-duty vehicles								
Gasoline	D	D	D	D	-	D	D	D
Diesel	A	A	A	B	A	B	B	A
Two-wheel vehicles								
< 50 cm³	A	A	A	B	-	B	B	A
> 50 cm³ 2-stroke	A	A	A	B	-	B	B	A
> 50 cm³ 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-duty vehicles	D	D	D	-	-	-	-	D
Diesel light-duty 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% (CO_2) 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% (CH_4) 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 that 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.

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 duty vehicles	☑	☑
Population of heavy duty vehicles	☑	☑
Population of mopeds	☑	-
Annual mileage of passenger cars	☑	☑
Annual mileage of light duty 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 duty vehicles	☑	-
Urban share of passenger cars	☑	-
Urban speed of light duty vehicles	-	☑
Urban speed of busses	-	☑
Annual mileage of vehicles at the year of their registration	-	☑
The split between diesel and gasoline 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 conduced 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 CO_2 emission, when aggregating the greenhouse gases (CO_2, CH_4, and N_2O) weighted by their corresponding 100-year GHG GWPs. Two different uncertainty ranges are given per country. The first (w/o FC), is the uncertainty calculated without trying to respect the statistical fuel consumption. This means that the calculated fuel consumption can obtain any value, regardless of the statistical one. The second calculation (w. FC) filters the calculation to keep only these runs that provide fuel 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 fuel consumption. This is considered a reasonable filtering, as an inventory calculation which would lead to a very high or very low fuel 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 fuel consumption, and one with correction for fuel consumption.

Case	CO	VOC	CH_4	NO_x	N_2O	$PM_{2.5}$	PM_{10}	PM_{exh}	FC	CO_2	CO_{2e}
Good statistics w/o FC	30	18	44	15	33	13	13	14	7	7	7
Good statistics w. FC	19	12	34	10	26	9	8	9	3	4	4
Poor statistics w/o FC	20	18	57	17	28	18	17	19	11	11	12
Poor statistics w. FC	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 CH_4 and N_2O followed by CO. For CH_4 and N_2O 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. CO_2 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 gasoline ones.

3. the correction for fuel 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 fuel consumption (per fuel type) and comparison with the calculated fuel 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, N_2O), 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 CH_4 and N_2O emissions, the uncertainty in total greenhouse gas emissions (CO_{2e}) is dominated by CO_2 emissions in both countries. Therefore, improving the emission factors of N_2O and CH_4 would not offer a substantially improved calculation of total GHG emissions. This may change in the future as CO_2 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-duty vehicles and LPG passenger cars;
- estimates of the heavy metal content of exhaust emissions due to fuel, lubricant and engine attrition;
- better assessment of fuel consumption from new vehicle concepts, to better describe CO_2 emissions;
- introduction of alternative fuel and vehicle concepts into the methodology, such as different types of hybrids and CNG cars

Further more, 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
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
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
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
LDV	Light-duty vehicle
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MEET	Methodologies to Estimate Emissions from Transport
MTBE	Methyl tert-butyl ether
N_2O	Nitrous oxide
NATO-CCMS	NATO Committee on the Challenges to Modern Society
NGV	Natural gas vehicle
NH_3	Ammonia
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
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 t	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
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) total consumption
FC^{BIO}	statistical fuel consumption of biofuel
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]
Mce_{HOT}	hot emission factor corrected for degraded vehicle performance due to mileage
Mcorr	correction coefficient for emission performance degradation due to mileage
M^{MEAN}	mean fleet mileage [km]
N	number of vehicles [veh.]
$r_{H:C}$	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

6.1 Supplementary documents

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7 Additional comments

The Tier 3 method described in this chapter has been fully incorporated in version 5.1 (February 2008) of Copert 4 software. This program is officially used by several countries for reporting emissions of road transport and is available to download from http://lat.eng.auth.gr/copert.

8 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 expert panel’s website (http://transportpanel.jrc.it/) for the contact details of the current expert panel leaders.

9 Annex 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 9-1, 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 gasoline heavy-duty vehicles because of their small contribution to a national inventory.

Table 9-2 to Table 9-31 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 CO_2, the emission factor corresponds to the exhaust emission and not ultimate CO_2. 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 9-1: 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
Gasoline 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
Gasoline light-duty vehicles < 3.5 t	07 02 01 01–07 02 01 03
Diesel light-duty 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

Table 9-2: Bulk emission factors (g/kg fuel) (for CO_2 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
Gasoline 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
Gasoline LDV	193	18.1	15.9	0.96	0.02	6.44	3.16
Diesel LDV	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 9-3: Bulk emission factors (g/kg fuel) (for CO_2 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
Gasoline 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
Gasoline LDV	197	16.7	14.8	0.83	0.02	5.79	3.16
Diesel LDV	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 9-4: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Bulgaria, year 2005

Category	Bulgaria						
	CO	NOx	NMVOC	CH_5	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	238	16.2	23.0	1.06	0.02	6.14	3.16
Diesel LDV	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

Table 9-5: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Cyprus, year 2005.

Category	Cyprus						
	CO	NOx	NMVOC	CH_6	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	179	16.1	22.8	0.98	0.02	5.96	3.16
Diesel LDV	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 9-6: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Czech Republic, year 2005.

Category	Czech Republic						
	CO	NOx	NMVOC	CH_7	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	146	12.6	16.3	0.83	0.02	5.92	3.16
Diesel LDV	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

Table 9-7: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Denmark, year 2005.

Category	Denmark						
	CO	NOx	NMVOC	CH_9	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	69	4.3	3.9	0.46	0.02	5.79	3.16
Diesel LDV	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 9-8: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Estonia, year 2005.

Category	Estonia						
	CO	NOx	NMVOC	CH_{10}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	164	18.8	11.7	1.09	0.02	6.99	3.16
Diesel LDV	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 9-9: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Finland, year 2005.

Category	Finland						
	CO	NOx	NMVOC	CH_{12}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	137	9.8	10.6	0.68	0.02	5.57	3.16
Diesel LDV	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

Table 9-10: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for France, year 2005.

Category	France						
	CO	NOx	NMVOC	CH_{13}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	125	12.6	12.7	0.77	0.02	6.27	3.16
Diesel LDV	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 9-11: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Germany, year 2005.

Category	Germany						
	CO	NOx	NMVOC	CH_8	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	98	5.5	5.8	0.46	0.02	5.29	3.16
Diesel LDV	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 9-12: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Greece, year 2005.

Category	Greece						
	CO	NOx	NMVOC	CH_{14}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	214	19.1	26.1	1.13	0.02	6.26	3.16
Diesel LDV	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

Table 9-13: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Hungary, year 2005.

Category	Hungary						
	CO	NOx	NMVOC	CH_{28}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	205	24.7	23.6	1.42	0.03	7.26	3.16
Diesel LDV	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 9-14: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Ireland, year 2005.

Category	Ireland						
	CO	NOx	NMVOC	CH_{29}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	85	3.2	11.1	0.33	0.02	4.76	3.16
Diesel LDV	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 9-15: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Italy, year 2005.

Category	Italy						
	CO	NOx	NMVOC	CH_{15}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	134	13.0	13.0	0.76	0.02	6.26	3.16
Diesel LDV	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

Table 9-16: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Latvia, year 2005.

Category	Latvia						
	CO	NOx	NMVOC	CH_{18}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	93.7	8.00	7.17	0.61	0.02	6.00	3.16
Diesel LDV	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 9-17: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Lithuania, year 2005.

Category	Lithuania						
	CO	NOx	NMVOC	CH_{16}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	213	14.0	17.5	0.91	0.02	5.56	3.16
Diesel LDV	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 9-18: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Luxembourg, year 2005.

Category	Luxemburg						
	CO	NOx	NMVOC	CH_{17}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	184	13.7	12.4	0.72	0.02	6.00	3.16
Diesel LDV	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

Table 9-19: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Malta, year 2005.

Category	Malta						
	CO	NOx	NMVOC	CH_{19}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	178	18.2	19.3	1.18	0.02	6.31	3.16
Diesel LDV	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 9-20: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Netherlands, year 2005.

Category	Netherlands						
	CO	NOx	NMVOC	CH_{20}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	211	16.0	16.4	0.86	0.02	5.81	3.16
Diesel LDV	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 9-21: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Norway, year 2005.

Category	Norway						
	CO	NOx	NMVOC	CH_{31}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	110.3	11.89	8.06	0.26	0.02	5.58	3.16
Diesel LDV	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

Table 9-22: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Poland, year 2005.

Category	Poland						
	CO	NOx	NMVOC	CH_{21}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	130	10.3	11.0	0.78	0.02	5.79	3.16
Diesel LDV	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 9-23: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Portugal, year 2005.

Category	Portugal						
	CO	NOx	NMVOC	CH_{22}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	226	25.5	19.7	1.05	0.02	7.28	3.16
Diesel LDV	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 9-24: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Romania, year 2005.

Category	Romania						
	CO	NOx	NMVOC	CH_{23}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	238	16.5	23.2	1.07	0.02	5.83	3.16
Diesel LDV	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

Table 9-25: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Slovakia, year 2005.

Category	Slovakia						
	CO	NOx	NMVOC	CH_{26}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	105	9.0	13.4	0.65	0.02	5.78	3.16
Diesel LDV	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 9-26: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Slovenia, year 2005.

Category	Slovenia						
	CO	NOx	NMVOC	CH_{25}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	102	6.7	6.7	0.53	0.02	5.58	3.16
Diesel LDV	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 9-27: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Spain, year 2005.

Category	Spain						
	CO	NOx	NMVOC	CH_{11}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	226	25.5	19.7	1.05	0.02	7.28	3.16
Diesel LDV	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

Table 9-28: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Sweden, year 2005.

Category	Sweden						
	CO	NOx	NMVOC	CH_{24}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	82	4.5	4.8	0.42	0.02	5.58	3.16
Diesel LDV	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 9-29: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for Switzerland, year 2005

Category	Switzerland						
	CO	NOx	NMVOC	CH_{31}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	61.5	5.93	3.12	0.17	0.02	5.29	3.16
Diesel LDV	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 9-30: Bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for UK, year 2005.

Category	UK						
	CO	NOx	NMVOC	CH_{27}	PM	CO_2 from lubricants g/kg fuel	CO_2 kg/kg fuel
Gasoline 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
Gasoline LDV	76	5.2	4.0	0.47	0.02	5.81	3.16
Diesel LDV	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

Table 9-31: Suggested bulk emission factors (g/kg fuel) (for CO_2 kg/kg fuel) for BC, NIS and CC4 countries, year 2002. Calculated with rough fleet composition estimations.

Category	BC, NIS and CC4 countries					
	CO	NOx	NMVOC	CH_4	PM	CO_2 [kg/kg fuel]
Gasoline 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
Gasoline LDV	305.63	26.58	32.61	1.51	0.00	2.59
Diesel LDV	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

10 Annex 2: History of the development of the road transport chapter

This chapter presents the fifth 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 (**Co**mputer **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, N_2O, NH_3 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 N_2O and NH_3 emissions. The present version introduces both additional refinements and new calculation elements. 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 NO_2, 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 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 ([7])/Concawe programme on the effects of gasoline vapour pressure and ethanol content on evaporative emissions from modern cars.

([7]) DG Joint Research Centre of the European Commission

The following major revisions have been made since previous version of the methodology:

- new emission factors for diesel Euro 4 passenger cars;
- new reduction factors for Euro 5 and 6 (passenger cars and light-duty vehicles) and Euro V and VI (heavy-duty vehicles) emission standards;
- information on the elemental carbon and organic mass split of exhaust PM emissions;
- split of NO_x emissions to NO and NO_2 depending on vehicle technology;
- emission factors for urban CNG buses;
- effect of biodiesel blends on emissions from diesel cars and heavy-duty vehicles;
- revised CO_2 calculation to include the effect of oxygenated fuels;
- corrections to N_2O, NH_3 and CH_4 calculations.

The study team is also working on the following issues, which will soon be available and will be included in the Copert 4 software:

- a new cold-start calculation methodology, which includes more detailed calculations for late technology vehicles;
- revised emission factors for light-duty vehicles;