SNAP CODES: **070100**
070200
070300
070400
070500

SOURCE ACTIVITY TITLE: **ROAD TRANSPORT**
Passenger Cars
Light Duty Vehicles < 3.5t
Heavy Duty Vehicles > 3.5t and buses
Mopeds and Motorcycles < 50cm^3
Motorcycles > 50cm^3

NOSE CODES: **201.01**
201.02
201.03
201.04
201.05

NFR CODES: **1 A 3 b i**
1 A 3 b ii
1 A 3 b iii
1 A 3 b iv

1 ACTIVITIES INCLUDED

This chapter provides the methodology, emission factors and relevant activity data to calculate emissions produced by the exhaust systems of road vehicles (SNAP codes 0701 to 0705). It does not cover non-exhaust emissions such as fuel evaporation from vehicles (SNAP code 0706) and component attrition (SNAP code 0707). Table 1-1 provides all the NFR and SNAP codes included in this chapter according to the EMEP/CORINAIR nomenclature.

The vehicle category split presented in Table 1-1 may serve as a basis to report emissions from road transport to international bodies. However, from a technical point of view, it does not provide the level of detail considered necessary to collect emissions from road vehicles in a systematic way. This is because road vehicle powertrains make use of a great range of fuels, engine technologies and aftertreatment devices. Thus, a more detailed vehicle category split is necessary and has been developed, as quoted in Table 1-2. On the one hand, this vehicle split attempts to introduce the level of detail necessary for vehicle technology distinction and on the other to preserve the spatial resolution for the three major driving classes (urban, rural and highway).

Pollutants covered include all major emission contributions from road transportation: Ozone precursors (CO, NO_x, NMVOC), greenhouse gases (CO_2, CH_4, N_2O), acidifying substances (NH_3, SO_2), particulate matter (PM), carcinogenic species (PAHs & POPs), toxic substances (dioxins and furans) and heavy metals. PM information is also distinguished to different particle sizes and further to mass, the particle number and surface concentrations are reported. All PM emission factors reported in this chapter refer to $PM_{2.5}$, as the coarse fraction ($PM_{2.5-10}$) is negligible in vehicle exhaust. Also, fuel (energy) consumption figures can be calculated. For NMVOC, a speciation to 68 substances is provided.

Table 1-1: Activities covered in this chapter according to EMEP/CORINAIR nomenclature

SNAP	2002 NFR	Name of SNAP/CORINAIR Activity
0701	1A3b i	PASSENGER CARS
070101 070102 070103		Highway Driving Rural Driving Urban Driving
0702	1A3b ii	LIGHT DUTY VEHICLES <3.5 t
070201 070202 070203		Highway Driving Rural Driving Urban Driving
0703	1A3b iii	HEAVY DUTY VEHICLES >3.5 t and buses
070301 070302 070303		Highway Driving Rural Driving Urban Driving
0704	1A3b iv	MOPEDS & MOTORCYCLES < 50 cm³
0705		MOTORCYCLES > 50 cm³
070501 070502 070503		Highway Driving Rural Driving Urban Driving

The methodology presented is the fifth update of the initial attempt for the CORINAIR 1985 emissions inventory (Eggleston et al., 1989) and firstly updated in 1991 for the CORINAIR 1990 inventory (Eggleston et al., 1993). This was included 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 (Ntziachristos and Samaras, 1997) and a further update of the Guidebook was prepared. The next methodology version was fully embodied in the COPERT III tool (Ntziachristos and Samaras, 2000). The present methodology is the most recent revision (version 2007) of the methodology fully incorporated in the software tool COPERT 4 which is available at http://lat.eng.auth.gr/copert/. Several methodological issues were introduced in the 2006 revision and have been carried along in this version (hot emission factors for post Euro 1 vehicles, PM emission information, two wheelers' emission values). Some of these have been corrected and new items have been included to cover new emission technologies and pollutants.

Several sources have been used as input to the methodology presented. 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 power two wheelers. These mainly originated from the European Commission (DG Transport) *Artemis* and *Particulates* projects, a study on Euro 3 power two wheeler emissions on behalf of DG Enterprise and Aristotle University specific 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 was funded to develop a new database of emission factors of gaseous pollutants from transport (http://www.trl.co.uk/artemis)

- Aristotle University specific 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 busses, 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 of the 2007 workplan related 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/CONCAWE programme on the effects of gasoline vapour pressure and ethanol content on evaporative emissions from modern cars.

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 trucks
- Estimates on the metal content of exhaust PM, originating from the fuel and lubricant oil metal contents and engine attrition

Table 1-2: Vehicle category split adopted for description of road transportation

SNAP-like code	Activity	Driving Mode		
		Highway	**Rural**	**Urban**
07 01	PASSENGER CARS			
07 01 01	Gasoline <1.4 l	07 01 01 01	07 01 01 02	07 01 01 03
07 01 02	Gasoline 1.4 – 2.0l	07 01 02 01	07 01 02 02	07 01 02 03
07 01 03	Gasoline >2.0 l	07 01 03 01	07 01 03 02	07 01 03 03
07 01 04	Diesel <2.0 l	07 01 04 01	07 01 04 02	07 01 04 03
07 01 05	Diesel >2.0 l	07 01 05 01	07 01 05 02	07 01 05 03
07 01 06	LPG	07 01 06 01	07 01 06 02	07 01 06 03
07 01 07	Two Stroke Gasoline	07 01 07 01	07 01 07 02	07 01 07 03
07 01 08	Hybrids	07 01 08 01	07 01 08 02	07 01 08 03
07 02	LIGHT DUTY VEHICLES <3.5 t			
07 02 01	Gasoline	07 02 01 01	07 02 01 02	07 02 01 03
07 02 02	Diesel	07 02 02 01	07 02 02 02	07 02 02 03
07 03	HEAVY DUTY VEHICLES			
07 03 01	Gasoline	07 03 01 01	07 03 01 02	07 03 01 03
07 03 02	Diesel <7.5 t	07 03 02 01	07 03 02 02	07 03 02 03
07 03 03	Diesel 7.5 – 16 t	07 03 03 01	07 03 03 02	07 03 03 03
07 03 04	Diesel 16 – 32 t	07 03 04 01	07 03 04 02	07 03 04 03
07 03 05	Diesel >32 t	07 03 05 01	07 03 05 02	07 03 05 03
07 03 06	Urban Buses	-	-	07 03 06 00
07 03 07	Coaches	07 03 07 01	07 03 07 02	07 03 07 03
07 04	MOPEDS & MOTORCYCLES < 50cm³	-	-	07 04 01 00
07 05	MOTORCYCLES			
07 05 01	Two stroke >50 cm³	07 05 01 01	07 05 01 02	07 05 01 03
07 05 02	Four stroke >50 cm³	07 05 02 01	07 05 02 02	07 05 02 03
07 05 03	Four stroke 50 – 250 cm³	07 05 03 01	07 05 03 02	07 05 03 03
07 05 04	Four stroke 250 – 750 cm³	07 05 04 01	07 05 04 02	07 05 04 03
07 05 05	Four stroke >750 cm³	07 05 05 01	07 05 05 02	07 05 05 03

2 CONTRIBUTION TO TOTAL EMISSIONS

Road transport poses significant environmental pressures (EEA, 2006). Until lately, air quality was the major issue of concern for road transport emissions but significant technology improvements have effectively alleviated the risks. Today, greenhouse gases (and energy consumption) from road vehicles arise as the main concern for sustainable road transport development. Available data show that in 2005, transport (excluding international aviation and maritime transport) contributed to about 21% of total GHG emissions in EU-15 and 56% of total NO_x. However the trends in those two pollutants are opposite, with ~23% increase and ~40% decrease of CO_2 and NO_x in 2005 respectively, compared to 1990 levels. Road transport is the main source of these shares, with a contribution of over 70% to GHG gases and 75% to NO_x. Table 2-1 and Table 2-2 show the contribution of road transport to total anthropogenic emissions of main pollutants in different European territories.

Table 2-1: Contribution of road transport to national total (ETC/ACC, 2005)

Country Group	Road transport emissions - Year 2003								
	CO_2 (Mt)	CH_4 (kt)	N_2O (kt)	NO_x (kt)	CO (kt)	NMVOC (kt)	SO_2 (kt)	NH_3 (kt)	PM_{10} (kt)
AC2 & CC2	24.3	4.2	0.75	529	2092	401	90.4	0.72	0.53
BC				22	76.3		1.0		0
EEA32	971	138	90.1	5069	16455	2964	201	87.5	343
EFTA4	29.9	4.2	3.2	96.6	523	67	1.96	3.39	8.42
EU10	76.4	14.2	7.7	581	1790	619	48.8	3.87	48.1
EU15	845	117	79.0	3890	12200	1902	65.6	80.0	287
EU25	922	131	86.7	4472	13990	2521	114	83.9	335
NIS				1226	10975	2148	407	0.55	0.43

Note: Country group definitions, as used by the European Environment Agency (http://www.eea.europa.eu)

Table 2-2: Contribution of road transport [%] to national total (ETC/ACC, 2005).

Country	Road transport contribution [%] to total emissions - Year 2003								
	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2	NH_3	PM_{10}
AC2 & CC2	12.9	0.24	1.38	33.5	34.8	28.4	2.8	0.2	7.2
BC				21.6	55.0		0.18		
EEA32	22.4	0.65	6.8	39.8	42.7	26.0	1.81	2.1	16.2
EFTA4	33.0	0.96	11.2	28.6	56.8	15.9	2.89	4.5	10.2
EU10	12.3	0.41	4.5	36.0	30.4	47.8	1.94	0.6	10.0
EU15	24.5	0.74	7.3	41.9	46.9	22.8	1.21	2.4	18.4
EU25	22.6	0.68	6.92	41.0	43.8	26.2	1.44	2.1	16.4
NIS				37.4	71.8	62.0	11.4	0.05	4.6

The relevant contribution of each vehicle category to total emissions of each of the main pollutants is shown in Table 2-3. It is shown that the relevant share is pollutant specific.

Table 2-3: Emissions of different vehicle categories as percentage of the EU Totals for road transport. In parentheses the range of dispersion of the countries (Estimates for Year 2005)

Category	CO (%)	NOx (%)	NMVOC (%)	CH4 (%)	PM (%)	CO2 (%)
Gasoline PC	73,57 (46,11 - 90,8)	23,11 (3,05 - 42,01)	48,84 (14,28 - 85,35)	64,5 (30,71 - 83,88)	1,94 (0,81 - 6,38)	44,26 (20,75 - 71,48)
Diesel PC	1,29 (0,19 - 7,42)	15,6 (2,47 - 33,66)	1,68 (0,17 - 11,99)	2,31 (0,28 - 6,56)	31,06 (6,53 - 59,51)	21,49 (3,95 - 45,11)
Gasoline LDV	3,6 (0,19 - 20,54)	1,52 (0,06 - 3,94)	1,65 (0,13 - 12,53)	0,92 (0,04 - 3,8)	0,06 (0 - 0,22)	1,72 (0,08 - 8,42)
Diesel LDV	1,08 (0,05 - 4,58)	5,77 (0,36 - 11,61)	1,36 (0,06 - 6,38)	1,06 (0,02 - 2,76)	19,28 (1,57 - 35,94)	6 (0,27 - 12,34)
Diesel HDV	3,31 (1,05 - 12,67)	47,23 (28,17 - 67,18)	2,92 (0,67 - 13,9)	11,68 (3,41 - 28,61)	32,39 (18,76 - 53)	22,29 (10,88 - 38,77)
Buses	0,58 (0,18 - 2,17)	6,16 (2,96 - 19,81)	1,15 (0,25 - 5,42)	2,18 (0,55 - 6,54)	6,47 (2,72 - 22,76)	2,69 (1,06 - 9,56)
Mopeds	5,93 (0,28 - 18,73)	0,12 (0,02 - 0,6)	36,06 (1,99 - 69,13)	8,1 (0,32 - 32,57)	7,26 (0,44 - 34,13)	0,63 (0,04 - 3,88)
Motorcycles	10,64 (2,26 - 30,62)	0,5 (0,05 - 2,07)	6,34 (1,28 - 18,5)	9,24 (2,26 - 26,84)	1,53 (0,4 - 12,02)	0,93 (0,17 - 5,97)

3 GENERAL

3.1 Description

In order to help identifying the vehicle categories, Table 3-1 gives the classification of vehicles according to the UN-ECE. The main vehicle categories can be allocated to the UN-ECE classification as follows:

Passenger Cars	M1
Light Duty Vehicles	N1
Heavy Duty Vehicles	N2, N3
Urban Buses & Coaches	M2, M3
Two Wheelers	L1, L2, L3, L4, L5

3.2 Definitions

Significant definitions will be described and explained in the relevant chapters.

3.3 Techniques

Traditionally, road vehicles have been powered by internal combustion engines which operate on fossil fuels combustion (gasoline, diesel, LPG, CNG, etc.). The combustion process produces CO_2 and harmless H_2O as the main products. Unfortunately, combustion also produces several by-products which either originate from incomplete fuel oxidation (CO, hydrocarbons, particulate matter) 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 been installing aftertreatment devices, such as catalytic converters and diesel particle filters, to suppress byproduct emission. However, such devices may also produce small quantities of pollutants such as NH_3 and N_2O.

Table 3-1: Vehicle classification categories according to UN-ECE

Category L:	Motor vehicles with less than four wheels
Category L1:	Two-wheeled vehicles with an engine cylinder capacity not exceeding 50 cm^3 and a maximum design speed not exceeding 40 km/h.
Category L2:	Three-wheeled vehicles with an engine cylinder capacity not exceeding 50 cm^3 and a maximum design speed not exceeding 40 km/h.
Category L3:	Two-wheeled vehicles with an engine cylinder capacity exceeding 50 cm^3 or a design speed exceeding 40 km/h.
Category 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).
Category 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).
Category M:	Power driven vehicles having at least four wheels or having three wheels when the maximum weight exceeds 1 metric ton, and used for the carriage of passengers
Category M1:	Vehicles used for the carriage of passengers and comprising not more than eight seats in addition to the driver's seat.
Category 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 metric tonnes.
Category 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 metric tonnes.
Category N:	Power-driven vehicles having at least four wheels or having three wheels when the maximum weight exceeds 1 metric ton, and used for the carriage of goods
Category N1:	Vehicles used for the carriage of goods and having a maximum weight not exceeding 3.5 metric tonnes.
Category N2:	Vehicles used for the carriage of goods and having a maximum weight exceeding 3.5 but not exceeding 12 metric tonnes.
Category N3:	Vehicles used for the carriage of goods and having a maximum weight exceeding 12 metric tonnes.

Gasoline powered (also spark-ignition) engines are used in small vehicles (up to 3.5 t GVW) because of their superior power/weight ratio and their wider operation range compared to diesel engines. Some less important reasons have also been responsible for this, such as lower noise and more refined operation. For very small vehicles (mopeds and motorcycles), two stroke engines have been favourable, especially in the past, because they provide the highest power/size ratio of all concepts. Diesel engines (also compression-ignition) on the other hand dominate in large vehicle applications because of their improved fuel efficiency and torque characteristics over gasoline engines. Lately though, an increasing shift to diesel engines is observed also for passenger cars, which now correspond to the highest share of new passenger car registrations in several European countries. The ACEA (2006) statistics show that 48.3% of passenger cars sold in Europe in 2005 were diesel ones, with shares reaching as high as 70% for countries like Austria, Belgium and France. This is an outcome of the higher fuel efficiency of diesel engines and technology improvements which increase the power output density for given engine size.

There are currently new technologies available, which aim at decreasing both energy consumption and pollutant emissions. Those technologies include new combustion processes for internal combustion engines (Gasoline Direct Injection (GDI), Controlled Auto-Ignition, Homogeneous Charge Compression Ignition), new fuels (CNG, Reformulated grades, eventually H_2) and alternative powertrains (hybrids – meaning a combination of internal combustion engine and electric motor, fuel cell vehicles, etc.). Some of these technologies (e.g. GDI, hybrids) become quite popular nowadays while others 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 availability of good quality activity data and emission rates. This report aims at covering emissions from all widespread technologies today in a systematic manner that will allow the production of high quality emission inventories.

3.4 Emissions

The methodology covers exhaust emissions of CO, NO_x, NMVOC, CH_4, CO_2, N_2O, NH_3, SO_x, diesel exhaust particulates (PM), PAHs and POPs, Dioxins and Furans and heavy metals contained in the fuel (Lead, Cadmium, Copper, Chromium, Nickel, Selenium and Zinc). NO_x emissions are further split to NO and NO_2 emissions. PM is also split to elemental and organic carbon as a function of the technology. A detailed NMVOC split is also included to distinguish hydrocarbon emissions as alkanes, alkenes, alkines, aldehydes, ketones and aromatics. Particulate emissions in the vehicle exhaust mainly fall in the $PM_{2.5}$ size range. Therefore, all PM mass emission factors correspond to $PM_{2.5}$. Also PM emissions are distinguished in different particle sizes.

According to the detail of information available and the approach adopted by the methodology to calculate emissions, the above mentioned pollutants can be distinguished into four groups:

Group 1: Pollutants for which a detailed methodology exists, based on specific emission factors and covering different traffic situations and engine conditions. The pollutants included in this group are given in Table 3-2.

Group 2: Emissions dependent on fuel consumption. Fuel consumption is calculated with specific consumption factors and calculations are of the same quality as of pollutants of Group 1. Emissions of pollutants of this Group are produced as a fraction of fuel consumption. These substances are quoted in Table 3-3.

Group 3: Pollutants for which a simplified methodology is applied mainly due to the absence of detailed data. This Group contains the pollutants given in Table 3-4.

Group 4: NMVOC profiles which are derived as a fraction of total NMVOC emissions. A small fraction of NMVOC remaining is considered to be PAHs. Speciation includes the categories given in Table 3-5.

Table 3-2: Pollutants included in Group 1 and methodology equivalencies

Pollutant	Equivalent
Carbon Monoxide (CO)	Given as CO
Nitrogen Oxides (NO_x: NO and NO_2)	Given as NO_2 equivalent
Volatile Organic Compounds (VOC)	Given as $CH_{1,85}$ equivalent (Also given as HC in emission standards)
Methane (CH_4)	Given as CH_4
Non Methane VOC (NMVOC)	Given as the remainder of VOC minus CH_4
Nitrous Oxide (N_2O)	Given as N_2O
Ammonia (NH_3)	Given as NH_3
Particulate Matter (PM)	Given as the mass of collected on a filter below 52°C in CVS-type of measurements. This corresponds to $PM_{2.5}$. Coarse exhaust PM is considered negligible, hence $PM_{2.5}$=PM_{10}.
PM Number and Surface	Given as particle number and particle active surface per kilometre, respectively

Table 3-3: Pollutants included in Group 2 and methodology equivalencies

Pollutant	Equivalent
Carbon Dioxide (CO_2)	Given as CO_2
Sulphur Dioxide (SO_2)	Given as SO_2
Lead (Pb)	Given as Pb
Cadmium (Cd)	Given as Cd
Chromium (Cr)	Given as Cr
Copper (Cu)	Given as Cu
Nickel (Ni)	Given as Ni
Selenium (Se)	Given as Se
Zinc (Zn)	Given as Zn

Table 3-4: Pollutants included in Group 3 and methodology equivalencies

Pollutant	Equivalent
Polyaromatic Hydrocarbons (PAHs) and Persistent Organic Pollutants (POPs)	Detailed speciation including indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, fluoranthene, benzo(a)pyrene
Polychlorinated Dibenzo Dioxins (PCDDs) and Polychlorinated Dibenzo Furans (PCDFs)	Given as Dioxins and Furans respectively

Table 3-5: Pollutants included in Group 4 and methodology equivalencies

Pollutant	**Equivalent**
Alkanes (C_nH_{2n+2}):	Given in Alkanes speciation
Alkenes (C_nH_{2n}):	Given in Alkenes speciation
Alkines (C_nH_{2n-2}):	Given in Alkines 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
Aromatics	Given in Aromatics speciation

3.5 Controls

The control of emissions from vehicles has been the target of relevant European legislation since the 70s. In order to fulfil those requirements, vehicle manufacturers have been improving the technology of their engines and introducing emission control systems. As a result, today's vehicles are more than an order of magnitude cleaner than vehicles two decades ago with regard to conventional pollutants (CO, NO_x, VOC). Emission legislation becomes increasingly stringent and, as a result, further improvement of the emission levels are being established.

The classification of vehicles according to their emission control technologies is made on the basis of the legislation they comply with which, by turn, consists a critical point in the application of the present methodology. The following paragraphs discuss the relevant legislation for each vehicle category.

3.5.1 Legislation classes of 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").

From 1970 and until 1985 all EC member states followed the UN ECE R15 (United Nations Economic Committee for Europe Regulation 15) amendments as regards the emissions of pollutants from vehicles lighter than 3.5 tonnes (gross vehicle weight – GVW). According to the relevant EC Directives, the implementation dates of these regulations were as follows:

pre ECE vehicles	up to 1971
ECE 15 00 & 01	1972 to 1977
ECE 15 02	1978 to 1980
ECE 15 03	1981 to 1985
ECE 15 04	1985 to 1992

These implementation dates correspond to an average estimate for the EU 15 member states. They were somewhat different from one member state to another as the directives had to be ratified by the national parliaments. Even more important, these regulations were applicable on vehicles registered in each member state - either produced in the member state or imported from elsewhere in the world.

In the period ~1985-1990, two intermediate steps appeared in some countries for passenger cars <2.0 l of engine capacity. The two technologies were:

For gasoline Passenger Cars <1.4 l

a. Improved Conventional, which took into account a German (Anl.XXIVC - Effective date: 1.7.1985) and a 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.
b. Open Loop, which took into account German, Danish, Greek and Dutch incentive programmes where 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

a. 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.
b. Open Loop, which took into account vehicles which meet the limit values of Directive 88/76/EEC by means of open loop catalysts (three-way but no lambda controlled catalytic converters). In practice relevant only to the national incentive programmes. Effective dates of implementation were: Denmark 1.1.1987, Germany 1.7.1985, Greece 1.1.1990, the Netherlands 1.1.1986.

After 1992, Euro-related standards became mandatory in all European member states and a new type-approval test was introduced. In some cases, again based on national incentives, some of the new emission standards were introduced earlier than their official implementation date. The following paragraphs provide a summary of the Euro steps and the associated technology of these vehicles.

a. Euro 1: These passenger cars were officially introduced by directive 91/441/EEC in July 1992 and were the first vehicles to be equipped with 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 larger that 2.0 l in engine capacity, 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 implementation dates for Denmark 1.1.1987, Germany 1.7.1985, Greece 1.1.1989, the Netherlands 1.1.1987.

b. Euro 2: These cars were improved closed-loop three way catalyst equipped ones and complied with lower emission limits compared to Euro 1 (30% and 55% reduction in CO and HC+NO_x over Euro 1 respectively). They were introduced by Directive 94/12/EC in all member states in 1996.
c. Euro 3: This emission standard was introduced with directive 98/69/EC Step 1 in January 2000 for all cars and introduced a new type-approval test (the New European Driving Cycle) and reduced emission levels compared to Euro 2 (30%, 40% and 40%, respectively, for CO, HC and NO_x respectively over Euro 2). 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 have been equipped with twin lambda sensors to comply with emission limits.
d. Euro 4: This is the current legislation introduced by directive 98/69/EC Step 2 in January 2005. It brought additional reductions of 57% for CO and 47% for HC and NO_x over Euro 3 by means of better fuelling and aftertreatment monitoring and control.
e. Euro 5 and 6: The European Council adopted the proposals of Euro 5 and 6 emission standards proposed by the European Commission in May 2007. Euro 5, to become effective from January 2010 (September 2009 for new type approvals) leads to further NO_x reductions of 25% compared to Euro 4 and a PM mass emission limit for direct injection cars, similar to the diesel ones. No further reductions for gasoline vehicles have been proposed at a Euro 6 level.

3.5.2 Legislation classes of diesel passenger cars

Diesel vehicles of pre-1992 production are all lumped 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 of this class are equipped with indirect injection engines. In 1992 the introduction of the "Consolidated Emissions Directive" 91/441/EEC introduced the Euro standards for diesel cars.

The Euro emission standards of diesel cars follow their gasoline counterparts. These include vehicles complying with 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 were the first vehicles to be regulated for all four main pollutants CO, HC+NOx and PM. Few of those vehicles were equipped with oxidation catalysts. Directive 94/12/EC brought reductions over the former Directive of 68% for CO, 38% for HC+NOx and 55% for PM and oxidation catalysts were used in almost all vehicles. Euro 3 vehicles targeted an additional 40%, 60%, 14% and 37.5% less CO, NOx, HCs and PM than Euro 2 vehicles. The significant reductions were achieved with exhaust gas recirculation (NO_x reduction) and optimisation of fuel injection with use of common rail systems (PM reduction). Also fuel refinements (mainly sulphur content reduction) played an important role in PM emission improvement. In addition, due to national incentives and manufacturers’ competition, some Euro 3 vehicles were equipped with original diesel particle filters to reduce the PM emissions to levels much below the emission standard. Therefore, a special PM emission factor needs to be provided for these vehicles. The current Euro 4 vehicles further improve emission levels by 22% on CO and 50% to all other pollutants. Further to the voluntary introduction of the particle filter to some vehicles, such significant reductions have been made possible with advanced engine technology and aftertreatment measures, such as cooled EGRs, and NOx reduction - PM oxidation techniques.

As in the case of gasoline vehicles, a Euro 5 and 6 proposal has been recently adopted. For diesel vehicles NOx emissions decrease by 28% and 68% at the Euro 5 and 6 levels, respectively over Euro 4. However, the most important reduction is brought for PM, which equals 88% over Euro 4. In parallel a number emission limit has been decided, at 5×10^{11} km^{-1}, which necessitates the use of diesel particle filters for compliance.

3.5.3 Legislation classes of LPG passenger cars

LPG vehicles constitute a small fraction of the European fleet. Legislation classes provided for LPG passenger cars, as in the case of diesel passenger ones, include a "Conventional" class where vehicles up to 91/441/EEC are grouped together. After this, legislation classes are introduced according to the Directives as adopted in the case of gasoline and diesel passenger cars.

3.5.4 Legislation classes of 2-stroke passenger cars

This type of vehicles is relevant mainly for some Eastern European countries (and to some extent for Germany). A very limited fleet of such vehicles is still in circulation and no particular emission standards are applicable. Therefore all such vehicles are grouped in a common "Conventional" class.

3.5.5 Legislation classes of hybrid vehicles

Current hybrid vehicles in circulation in Europe comply with the Euro 4 emission limits. Due to their advanced technology, some hybrid types may emit even below the expected Euro 5 emission levels. Specific emission and fuel consumption values are given for hybrid cards.

3.5.6 Legislation classes of gasoline light duty vehicles <3.5 t

In EU, the emissions of these vehicles were covered by the different ECE steps up to 1993 and all such vehicles are covered by the term "Conventional". From 1993 to 1997 Euro-type of emission standards have been applied (Euro 1 - Directive 93/59/EEC), which ask for catalytic converters on gasoline powered vehicles. Directive 96/69/EC (Euro 2) introduced stricter emission standards for light duty trucks in 1997 and was valid up to 2001. Two more legislation steps have been introduced since then, namely Euro 3 - 98/69/EC (valid 2001-2006) and Euro 4 - 98/69/EC (valid 2006 onwards) which introduce even stricter emission standards. Finally, the Euro 5 proposal of passenger cars covers this vehicle category as well, with somehow differentiated emission standards. It is expected that the emission control technology of light duty vehicles generally follows the technology of passenger cars with a delay of 1-2 years.

3.5.7 Legislation classes of diesel light duty vehicles <3.5 t

Legislation classes valid for gasoline light duty vehicles are also applicable in the case of diesel ones (with different emission standards level plus PM emission standard). In general, engine technology of diesel light duty vehicles follows the one of respective diesel passenger cars with 1-2 years delay.

3.5.8 Legislation classes of 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 without further distinction to legislation steps because no specific emission standards have been set for such vehicles.

3.5.9 Legislation classes of diesel heavy duty vehicles >3.5 t

Emissions from diesel engines used in vehicles of gross weight over 3.5 t were first regulated in 1988 with the introduction of the original ECE 49 Regulation. Vehicles (or, better, engines) complying with ECE 49 and earlier are all classified as "Conventional". Directive 91/542/EEC, implemented in two stages, brought two standards of reduced emission limits valid from 1992 to 1995 (Stage 1 – Euro I) and 1996 up to 2000 (Stage 2 – Euro II). Directive 1999/96/EC Step 1 (Euro III) was valid since 2000 and introduced a 30% reduction of all pollutants over the Euro II case. The same directive included an intermediate step in 2005 (Euro IV) and a final step in 2008 (Euro V). Standards for 2009 are very strict, targeting an over 70% reduction of NOx and over 85% decrease of PM compared to 1996 standards. This will be achieved with engine tuning and oxidation catalyst for PM control and Selective Catalyst 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 is not known yet. However, it is expected that Euro VI emission standards will necessitate both SCR and diesel particle filter for NO_x control.

3.5.10 Legislation classes for 2 stroke mopeds <50 cm³

No EU-wide emission standards were agreed until lately for emissions of two wheelers but 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 for the case of two-stroke mopeds <50cm³, were 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 levels of 1 g/km CO and 1.2 g/km $HC+NO_x$. New Euro 3 emission standards for such small vehicles are currently under preparation in the European Commission to be proposed to the European Council, which will not introduce arithmetic differences to the Euro 2 emission step, but will introduce a certification test initiated from ambient temperature conditions (as opposed to hot engine start currently in the regulations). Due to the very strict emission limits, it is expected that very few 2-stroke mopeds will be available after the new step becomes mandatory (possibly 2008) and those that will conform with the regulations will need to be equipped with precise air-fuel metering devices, possible direct injection and secondary air injection in the exhaust line.

3.5.11 Legislation classes for 2-stroke and 4-stroke motorcycles >50 cm³

Emissions from 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 imposes different emission standards for two and four stroke vehicles respectively, and separate limits are set for HC and NO_x to allow for a better distinction in the different technologies (2-stroke : CO 8 g/km, HC

4 g/km, NO_x 0.1 g/km; 4-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) steps for motorcycles with differentiated emission standards depending on the engine size. No other emission standards have been planned for the future. However, it is soon expected that the World Motorcycle Test Cycle (WMTC) will be used worldwide as a certification test and this may bring some changes in the emission standards.

3.5.12 Summary of vehicle technologies / control measures utilised

Table 3-6 provides a summary of all vehicle categories and technologies (emission standards) covered by the present methodology.

Table 3-6: Summary of all vehicle classes covered by the methodology

Vehicle Type	Class	Legislation
Passenger Cars	Gasoline <1.4l 1.4 - 2.0l >2.0l	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 <2.0l >2.0l	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
	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
	2 Stroke	Conventional
	Hybrids <1.6l	Euro 4 - 98/69/EC Stage 2005

table continues in next page

Table 3-6(cont.): Summary of all vehicle classes covered by the methodology

Vehicle Type	Class	Legislation
Light Duty Vehicles	Gasoline <3.5t	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 <3.5t	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
Heavy Duty Vehicles	Gasoline >3.5t	Conventional
	Rigid <=7.5t	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 – No proposal yet
	Rigid 7.5-12t	
	Rigid 12-14t	
	Rigid 14-20t	
	Rigid 20-26t	
	Rigid 26-28t	
	Rigid 28-32t	
	Rigid >32t	
	Articulated 14-20t	
	Articulated 20-28t	
	Articulated 28-34t	
	Articulated 34-40t	
	Articulated 40-50t	
	Articulated 50-60t	
Buses	Urban <=15t	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 – No proposal yet
	Urban 15-18t	
	Urban >18t	
	Coaches standard <=18t	
	Coaches articulated >18t	
	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

Table 3-6(cont.): Summary of all vehicle classes covered by the methodology

Vehicle Type	Class	Legislation
Mopeds	<50cm³	Conventional 97/24/EC Stage I – Euro 1 97/24/EC Stage II – Euro 2 Euro 3 proposal
Motorcycles	2 Stroke >50cm³	Conventional
	4 stroke 50 - 250cm³	97/24/EC – Euro 1
	4 stroke 250 - 750cm³	2002/51/EC Stage I – Euro 2
	4 stroke >750cm³	2002/51/EC Stage II – Euro 3

Due to the technological developments that occurred for heavy duty engines, but also their use in a wide range of vehicle types, in order to cover as many uses as possible, a more detailed classification of Heavy Duty Vehicles and Busses is required, than the one presented in Table 1-2. Table 3-6 includes this new categorization. In order however not to deviate with the CORINAIR classification, Figure 4-1 shows the correspondence of the more detailed HDV classes with the old ones.

4 SIMPLER METHODOLOGY

The methodology proposed in the following paragraphs is actually the application of the detailed methodology presented in next section at a national level (NUTS 0), followed by derivation of relevant emission factors. This means that we have a-priori introduced a large number of data and estimates required to apply the methodology for calculating emissions and we have come up with aggregated emission factors. The production of these emission factors has been performed using the activity data from Tremove v2.5 and the methodology of Copert 4, v3.0.

Based on this approach, total emission estimates for a country can be calculated using the simple equation:

$$E_{i,j} = \Sigma_j(FC_j \times EF_{i,j}) \quad (1)$$

where,

$E_{i,j}$: emission of pollutant i from vehicles of category j [g pollutant],

FC_j : fuel consumption of vehicle category j [kg fuel],

$EF_{i,j}$: fuel consumption specific emission factor of pollutant i for vehicle category j [g/kg fuel].

In principle, any energy consumption related figure can substitute FC_j value. 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 a perception of. Also, we propose to lump vehicle categories of Table 1-2 to come up with simplified emission factors. The split adopted is seen in Table 4-1 together with the range of SNAP-like codes included in each vehicle category j. The simplified methodology does not deal with LPGs, 2-stroke and gasoline heavy-duty vehicles because of their small contribution to a national inventory.

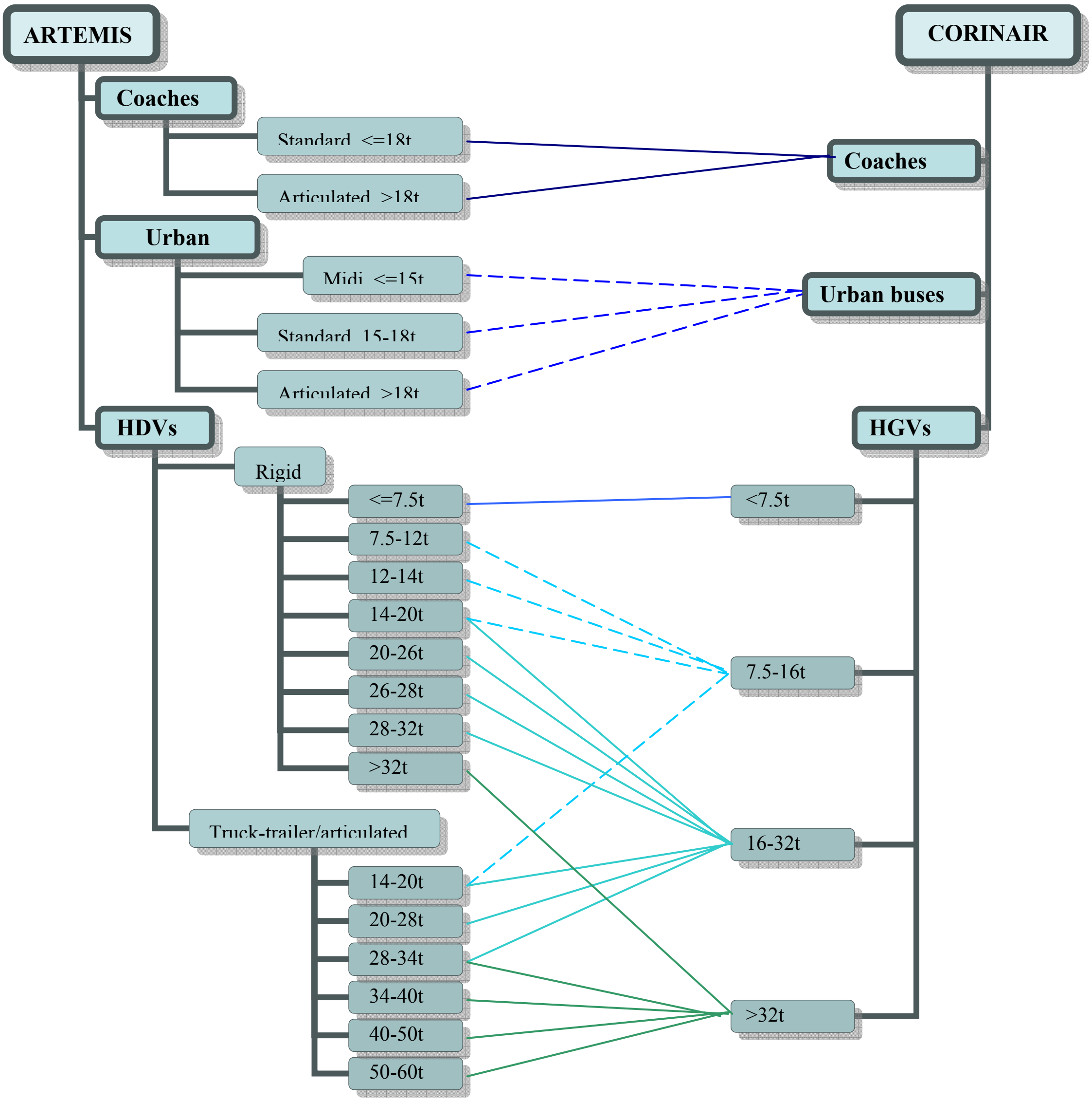

Figure 4-1: Correspondence between the CORINAIR and new HDV and Bus categorization, adopted in the framework of the ARTEMIS (2006) project

Table 4-2 to Table 4-22 provide fuel consumption specific emission factors for main pollutants and for each EU-15 country and countries classified as CC4, BC and NIS. These emission factors should be combined with fuel consumption for specific vehicle category to provide total emission estimates. In particular for CO_2, the emission factor corresponds to the end-of-pipe and not ultimate CO_2 emissions. For definition and conversion between the two, refer to section 5.6.1. The emission factor production is based on a large number of assumptions concerning vehicle technology mix (e.g. share of passenger cars to different ECE and Euro standards), 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 those emission factors (most of these shortcomings are thoroughly discussed by Ntziachristos et. al. (2002):

- They have not been calculated on the basis of national submitted data but following a uniform methodology across all countries (TREMOVE v2.5). Hence, combination with the activity data proposed also in this report (section 6) should not be expected to necessarily provide consistent results with the official data presented in Table 2-1.
- They correspond to a fleet composition estimated for year 2005. Their accuracy deteriorates as time distance increases from this point because new technologies appear and the contribution of older technologies decreases.
- They correspond to national-wide applications including mixed conditions driving (urban congestion to free flow highway).

Their range of application can cover:

- 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, 2-wheelers promotions in urban areas, etc).
- Demonstrations of the emission reduction potential when shifting the balance with other modes of transport

Table 4-1: Vehicle categories for application of the simplified methodology and respective SNAP-like ranges from Table 1-2.

Vehicle category - j	SNAP-like code ranges included from Table 1-2
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
Powered two-wheeled vehicles	07 04 01 00 – 07 05 05 03

Table 4-2: Bulk emission factors (g/kg fuel) for Austria (AT), year 2005.

Category	Austria					
	CO	NOx	NMVOC	CH4	PM	CO2
Gasoline PC	72.40	7.74	6.46	0.41	0.03	3.18
Diesel PC	2.93	11.60	0.59	0.04	0.91	3.14
Gasoline LDV	133.79	15.80	11.40	0.34	0.02	3.18
Diesel LDV	8.60	16.24	1.92	0.11	2.07	3.14
Diesel HDV	6.75	33.15	0.96	0.25	0.87	3.14
Buses	10.43	36.68	3.40	0.38	1.51	3.14
Mopeds	409.82	4.80	401.75	6.67	6.52	3.18
Motorcycles	535.03	9.69	51.89	4.61	1.12	3.18

Table 4-3: Bulk emission factors (g/kg fuel) for Belgium (BE), year 2005.

Category	Belgium					
	CO	NOx	NMVOC	CH4	PM	CO2
Gasoline PC	38.92	5.04	4.31	0.86	0.02	3.18
Diesel PC	2.38	11.21	0.53	0.05	0.78	3.14
Gasoline LDV	82.57	6.01	4.22	0.38	0.02	3.18
Diesel LDV	6.44	14.48	1.50	0.11	1.16	3.14
Diesel HDV	6.25	30.37	0.69	0.30	0.60	3.14
Buses	7.85	29.03	1.65	0.46	0.87	3.14
Mopeds	418.44	3.01	395.47	6.40	6.70	3.18
Motorcycles	400.66	8.27	29.18	5.19	0.53	3.18

Table 4-4: Bulk emission factors (g/kg fuel) for Switzerland (CH), year 2005.

Category	CH					
	CO	NOx	NMVOC	CH_4	PM	CO_2
Gasoline PC	42.44	6.38	4.71	0.55	0.02	3.18
Diesel PC	1.81	11.62	0.47	0.03	0.68	3.14
Gasoline LDV	61.45	5.93	3.12	0.17	0.02	3.18
Diesel LDV	7.33	14.63	1.39	0.05	1.45	3.14
Diesel HDV	6.31	31.26	0.76	0.26	0.67	3.14
Buses	8.61	31.16	2.31	0.41	1.06	3.14
Mopeds	386.95	4.90	350.95	6.41	6.17	3.18
Motorcycles	531.50	9.63	66.74	4.65	1.50	3.18

Table 4-5: Bulk emission factors (g/kg fuel) for Czech Republic (CZ), year 2005.

Category	Czech Republic					
	CO	NOx	NMVOC	CH_4	PM	CO_2
Gasoline PC	129.21	10.21	11.02	0.51	0.02	3.18
Diesel PC	2.53	12.20	0.55	0.05	0.99	3.14
Gasoline LDV	79.80	19.57	6.93	0.28	0.02	3.18
Diesel LDV	6.89	14.85	1.67	0.06	1.55	3.14
Diesel HDV	6.76	33.52	1.06	0.26	0.87	3.14
Buses	10.66	40.35	3.47	0.39	1.57	3.14
Mopeds	461.49	2.62	470.82	7.18	7.15	3.18
Motorcycles	755.41	9.88	28.84	6.12	0.62	3.18

Table 4-6: Bulk emission factors (g/kg fuel) for Denmark, year 2005.

Category	Denmark					
	CO	NOx	NMVOC	CH_4	PM	CO_2
Gasoline PC	68.46	7.38	7.37	0.46	0.03	3.18
Diesel PC	3.39	11.72	0.66	0.05	0.88	3.14
Gasoline LDV	78.66	7.06	4.90	0.22	0.02	3.18
Diesel LDV	7.35	16.17	1.85	0.09	1.60	3.14
Diesel HDV	6.50	32.18	0.84	0.30	0.77	3.14
Buses	9.72	32.58	2.84	0.41	1.29	3.14
Mopeds	341.83	4.72	241.19	5.88	5.44	3.18
Motorcycles	445.13	7.96	62.43	5.40	1.24	3.18

Table 4-7: Bulk emission factors (g/kg fuel) for Finland, year 2005.

Category	Finland					
	CO	NOx	NMVOC	CH_4	PM	CO_2
Gasoline PC	73.84	6.77	7.68	0.54	0.02	3.18
Diesel PC	4.92	10.58	1.03	0.08	1.28	3.14
Gasoline LDV	214.81	25.56	21.24	0.41	0.02	3.18
Diesel LDV	9.02	16.64	2.17	0.09	2.35	3.14
Diesel HDV	7.26	33.77	1.14	0.23	1.07	3.14
Buses	11.17	37.62	3.67	0.39	1.69	3.14
Mopeds	337.11	5.78	234.54	6.15	5.27	3.18
Motorcycles	504.99	5.20	132.07	5.91	2.50	3.18

Table 4-8: Bulk emission factors (g/kg fuel) for France, year 2005.

Category	France					
	CO	NOx	NMVOC	CH_4	PM	CO_2
Gasoline PC	59.58	9.20	7.46	0.87	0.03	3.18
Diesel PC	2.04	11.76	0.44	0.06	0.75	3.14
Gasoline LDV	79.38	12.76	4.77	0.26	0.02	3.18
Diesel LDV	8.35	14.49	1.55	0.08	1.97	3.14
Diesel HDV	6.54	33.31	0.82	0.30	0.74	3.14
Buses	9.25	37.44	2.76	0.52	1.33	3.14
Mopeds	259.96	10.97	197.77	5.19	4.70	3.18
Motorcycles	362.44	11.31	28.68	5.62	0.62	3.18

Table 4-9: Bulk emission factors (g/kg fuel) for Germany, year 2005.

Category	Germany					
	CO	NOx	NMVOC	CH_4	PM	CO_2
Gasoline PC	57.45	7.51	6.01	0.69	0.03	3.18
Diesel PC	2.23	11.39	0.56	0.06	0.91	3.14
Gasoline LDV	142.42	26.07	8.80	0.35	0.02	3.18
Diesel LDV	9.81	14.25	1.55	0.08	2.54	3.14
Diesel HDV	7.04	36.27	1.05	0.29	1.00	3.14
Buses	9.90	39.31	2.95	0.48	1.45	3.14
Mopeds	460.63	1.47	442.12	7.12	7.03	3.18
Motorcycles	613.77	9.70	28.05	5.39	0.61	3.18

Table 4-10: Bulk emission factors (g/kg fuel) for Greece, year 2005.

Category	Greece					
	CO	NOx	NMVOC	CH_4	PM	CO_2
Gasoline PC	92.45	10.88	13.99	1.09	0.03	3.18
Diesel PC	5.72	10.09	1.18	0.10	1.48	3.14
Gasoline LDV	64.79	6.43	4.56	0.24	0.02	3.18
Diesel LDV	13.35	19.89	1.57	0.13	3.30	3.14
Diesel HDV	6.72	33.13	1.03	0.25	0.85	3.14
Buses	11.78	37.75	4.02	0.36	1.75	3.14
Mopeds	427.74	2.97	400.55	6.80	6.64	3.18
Motorcycles	514.58	5.43	80.03	5.39	1.52	3.18

Table 4-11: Bulk emission factors (g/kg fuel) for Hungary, year 2005.

Category	Hungary					
	CO	NOx	NMVOC	CH_4	PM	CO_2
Gasoline PC	100.70	8.28	9.10	0.62	0.02	3.18
Diesel PC	3.63	11.57	0.79	0.06	1.26	3.14
Gasoline LDV	108.78	24.02	11.07	0.39	0.03	3.18
Diesel LDV	7.96	15.71	1.85	0.10	1.94	3.14
Diesel HDV	6.76	33.89	0.96	0.25	0.93	3.14
Buses	10.94	40.70	3.66	0.38	1.63	3.14
Mopeds	465.06	2.35	473.02	7.21	7.18	3.18
Motorcycles	695.02	10.56	31.21	5.61	0.60	3.18

Table 4-12: Bulk emission factors (g/kg fuel) for Ireland, year 2005.

Category	Ireland					
	CO	NOx	NMVOC	CH_4	PM	CO_2
Gasoline PC	59.33	6.59	8.34	0.86	0.03	3.18
Diesel PC	3.85	11.20	0.73	0.06	0.91	3.14
Gasoline LDV	80.79	7.16	5.80	0.22	0.02	3.18
Diesel LDV	7.42	16.52	1.93	0.09	1.63	3.14
Diesel HDV	6.58	32.41	0.99	0.24	0.81	3.14
Buses	11.13	37.95	3.79	0.38	1.66	3.14
Mopeds	310.63	7.76	240.50	5.64	5.21	3.18
Motorcycles	367.32	7.99	29.18	6.13	0.55	3.18

Table 4-13: Bulk emission factors (g/kg fuel) for Italy, year 2005.

Category	Italy					
	CO	NOx	NMVOC	CH_4	PM	CO_2
Gasoline PC	151.00	11.46	12.07	0.86	0.02	3.16
Diesel PC	3.43	11.13	0.65	0.05	0.86	3.14
Gasoline LDV	103.35	11.09	7.52	0.24	0.02	3.18
Diesel LDV	7.86	16.50	1.74	0.10	1.65	3.14
Diesel HDV	6.80	32.96	0.90	0.26	0.89	3.14
Buses	10.36	35.03	3.34	0.36	1.46	3.14
Mopeds	438.04	2.47	412.91	6.90	6.76	3.18
Motorcycles	533.37	8.55	34.51	5.05	0.55	3.18

Table 4-14: Bulk emission factors (g/kg fuel) for Luxembourg, year 2005.

Category	Luxemburg					
	CO	NOx	NMVOC	CH_4	PM	CO_2
Gasoline PC	30.69	2.39	1.07	0.92	0.02	3.18
Diesel PC	1.77	12.01	0.42	0.05	0.62	3.14
Gasoline LDV	67.18	8.79	4.60	0.33	0.02	3.18
Diesel LDV	7.53	15.73	1.77	0.13	1.74	3.14
Diesel HDV	6.42	32.18	0.79	0.39	0.74	3.14
Buses	9.32	34.75	2.61	0.51	1.27	3.14
Mopeds	362.48	6.20	324.40	6.18	5.90	3.18
Motorcycles	534.66	6.66	111.46	5.37	2.43	3.18

Table 4-15: Bulk emission factors (g/kg fuel) for Netherlands, year 2005.

Category	Netherlands					
	CO	NOx	NMVOC	CH_4	PM	CO_2
Gasoline PC	49.99	4.96	3.84	0.52	0.02	3.16
Diesel PC	3.01	11.26	0.58	0.04	0.77	3.14
Gasoline LDV	81.07	8.99	4.96	0.18	0.02	3.18
Diesel LDV						
Diesel HDV	6.44	31.90	0.85	0.24	0.75	3.14
Buses	9.17	31.87	2.64	0.37	1.21	3.14
Mopeds	425.58	2.89	393.71	6.77	6.60	3.18
Motorcycles	554.13	8.53	56.89	5.16	1.20	3.18

Table 4-16: Bulk emission factors (g/kg fuel) for Norway, year 2005.

Category	Norway					
	CO	NOx	NMVOC	CH_4	PM	CO_2
Gasoline PC	73.32	8.76	9.50	0.64	0.03	3.18
Diesel PC	2.78	11.97	0.62	0.05	0.85	3.14
Gasoline LDV	110.27	11.89	8.06	0.26	0.02	3.18
Diesel LDV	8.67	16.13	1.91	0.09	2.16	3.14
Diesel HDV	6.50	31.84	0.90	0.24	0.78	3.14
Buses	10.95	38.00	3.61	0.45	1.61	3.14
Mopeds	401.73	3.27	346.92	6.51	6.26	3.18
Motorcycles	479.18	8.55	32.59	5.70	0.60	3.18

Table 4-17: Bulk emission factors (g/kg fuel) for Poland, year 2005.

Category	Poland					
	CO	NOx	NMVOC	CH_4	PM	CO_2
Gasoline PC	100.02	8.55	8.11	0.60	0.02	3.15
Diesel PC	2.84	11.72	0.67	0.05	1.03	3.14
Gasoline LDV	78.68	20.47	7.64	0.30	0.02	3.18
Diesel LDV	8.12	14.87	1.70	0.07	2.04	3.14
Diesel HDV	6.73	32.99	1.01	0.26	0.86	3.14
Buses	10.81	41.56	3.59	0.41	1.65	3.14
Mopeds	464.28	2.32	470.37	7.20	7.16	3.18
Motorcycles	423.00	8.22	74.00	5.32	1.82	3.18

Table 4-18: Bulk emission factors (g/kg fuel) for Portugal, year 2005.

Category	Portugal					
	CO	NOx	NMVOC	CH_4	PM	CO_2
Gasoline PC	61.56	9.18	8.50	0.71	0.03	3.18
Diesel PC	3.20	11.28	0.57	0.04	0.72	3.14
Gasoline LDV						
Diesel LDV	9.39	17.91	1.72	0.11	2.05	3.14
Diesel HDV	7.14	34.09	1.14	0.24	1.04	3.14
Buses	11.88	40.75	4.18	0.31	1.85	3.14
Mopeds	403.89	3.62	360.25	6.55	6.32	3.18
Motorcycles	590.71	5.89	128.94	4.57	2.80	3.18

Table 4-19: Bulk emission factors (g/kg fuel) for Slovenia, year 2005.

Category	Slovenia					
	CO	NOx	NMVOC	CH_4	PM	CO_2
Gasoline PC	104.52	8.21	10.89	0.61	0.02	3.18
Diesel PC	4.23	10.72	0.87	0.05	1.21	3.14
Gasoline LDV	82.55	9.24	6.75	0.16	0.02	3.18
Diesel LDV	8.62	17.11	1.84	0.08	2.03	3.14
Diesel HDV	6.92	32.83	1.13	0.22	0.87	3.14
Buses	10.97	38.02	3.77	0.31	1.65	3.14
Mopeds	423.26	2.47	377.99	6.73	6.53	3.18
Motorcycles	558.55	11.35	25.53	4.88	0.55	3.18

Table 4-20: Bulk emission factors (g/kg fuel) for Spain, year 2005.

Category	Spain					
	CO	NOx	NMVOC	CH_4	PM	CO_2
Gasoline PC	75.99	10.89	13.44	1.19	0.03	3.18
Diesel PC	3.77	11.12	0.61	0.07	0.80	3.14
Gasoline LDV	87.35	10.64	6.85	0.26	0.02	3.18
Diesel LDV	8.41	16.62	1.57	0.10	1.80	3.14
Diesel HDV	6.62	32.67	0.99	0.24	0.81	3.14
Buses	9.82	34.84	3.06	0.38	1.34	3.14
Mopeds	427.54	3.32	408.41	6.81	6.67	3.18
Motorcycles	577.51	3.63	165.71	5.12	3.68	3.18

Table 4-21: Bulk emission factors (g/kg fuel) for Sweden, year 2005.

Category	Sweden					
	CO	NOx	NMVOC	CH_4	PM	CO_2
Gasoline PC	57.37	6.58	6.59	0.61	0.02	3.18
Diesel PC	3.84	10.43	0.85	0.07	0.95	3.14
Gasoline LDV	167.35	23.89	15.07	0.37	0.02	3.18
Diesel LDV	6.75	15.31	1.80	0.08	1.38	3.14
Diesel HDV	6.73	32.66	1.00	0.24	0.87	3.14
Buses	10.42	35.95	3.25	0.46	1.45	3.14
Mopeds	352.94	6.54	310.35	6.08	5.78	3.18
Motorcycles	414.68	9.14	28.56	5.76	0.52	3.18

Table 4-22: Bulk emission factors (g/kg fuel) for UK, year 2005.

Category	UK					
	CO	NOx	NMVOC	CH_4	PM	CO_2
Gasoline PC	51.43	6.79	5.40	0.87	0.03	3.18
Diesel PC	1.91	11.96	0.44	0.06	0.77	3.14
Gasoline LDV	99.40	16.29	6.55	0.38	0.02	3.18
Diesel LDV	6.65	14.84	1.55	0.11	1.33	3.14
Diesel HDV	6.22	31.65	0.65	0.34	0.60	3.14
Buses	6.14	31.08	1.48	0.54	0.79	3.14
Mopeds	258.50	11.09	197.15	5.17	4.68	3.18
Motorcycles	378.98	11.07	35.83	5.52	0.75	3.18

Table 4-23: Suggested bulk emission factors (g/kg fuel) for BC, NIS and CC4 countries, year 2002. Calculated with rough fleet composition estimations (not by TREMOVE).

Category	BC, NIS and CC4 countries					
	CO	NOx	NMVOC	CH4	PM	CO2 [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

5 DETAILED METHODOLOGY

Total emission estimates are calculated with combination of firm technical data (e.g. emission factors) and activity data (e.g. total vehicle kilometres). All technical data depend on control variables which may be tuned, to provide an accurate estimate depending on the type of application of the methodology.

5.1 Types of emission

In principle, total emissions are calculated by summing emissions from three different sources, namely the thermally stabilised engine operation (hot), the warming-up phase (cold start) and due to evaporation. Evaporation is dealt with in the next chapter. It is also clarified that the word "engine" is used in place of the actual "engine and any exhaust aftertreatment devices". Distinction in emissions during the stabilised and warming-up phase is necessary because of the substantial difference in vehicle emission performance during those two conditions. Concentrations of most pollutants during the warming-up period are many times higher than during hot operation and a different methodological approach is required to estimate over-emissions during this period. In that respect, total emissions can be calculated by means of the equation:

$$E_{TOTAL} = E_{HOT} + E_{COLD} \qquad (2)$$

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).

5.2 Emissions under different driving conditions

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 that respect, a distinction is made in urban, rural and highway driving to account for variations in driving performance.

As will be later demonstrated, different activity data and emission factors are attributed to each driving situation. Also, by definition, cold start emissions are attributed to urban driving because the assumption is made that the large majority of vehicles starts any trip in urban areas. Therefore, as far as driving conditions are concerned (spatial desegregation), total emissions can be calculated by means of the equation:

$$E_{TOTAL} = E_{URBAN} + E_{RURAL} + E_{HIGHWAY} \quad (3)$$

where,
E_{URBAN}, E_{RURAL}, $E_{HIGHWAY}$: total emissions (g) of any pollutant for the respective driving situation.

5.3 Calculation outline

Calculation of total emissions is made by combining activity data for each vehicle category with appropriate emission factors. Those emission factors vary according to input data (driving situations, climatic conditions). Also, information on fuel consumption and specifications is required to maintain a fuel balance between user provided figures and calculations. A summary of the variables required and the intermediate calculated values is given in the flow chart of Figure 5.1.

5.4 Hot emissions

By "Hot Emissions" we mean by convention the emissions occurring under thermally stabilised engine and exhaust aftertreatment conditions. These emissions depend on a variety of factors including the distance that each vehicle travels, its speed (or road type), its age, engine size and weight. As will be later explained, many countries do not have solid estimates of these data. Therefore a method to estimate the emissions from available solid data has been proposed. However, it is important that each country uses the best data they have available. This is an issue to be resolved by each individual country.

The basic formula for estimating hot emissions, using experimentally obtained emission factors is:

$$\text{Emissions per Period of Time [g]} = \text{Emission Factor [g/km]} \times \text{Number of Vehicles [veh.]} \times \text{Mileage per Vehicle per Period of Time [km/veh.]}$$

Different emission factors, number of vehicles and mileage per vehicle need to be introduced for each vehicle category and class. The assumption is made that hot emission factors, i.e. emission factors corresponding to thermally stabilised engine operation, depend only on average speed. The dependency of hot emission factors with speed is given by the functions quoted in tables of section 8 of this chapter for each vehicle category and class. The period of time depends on the application (month, year, etc.)

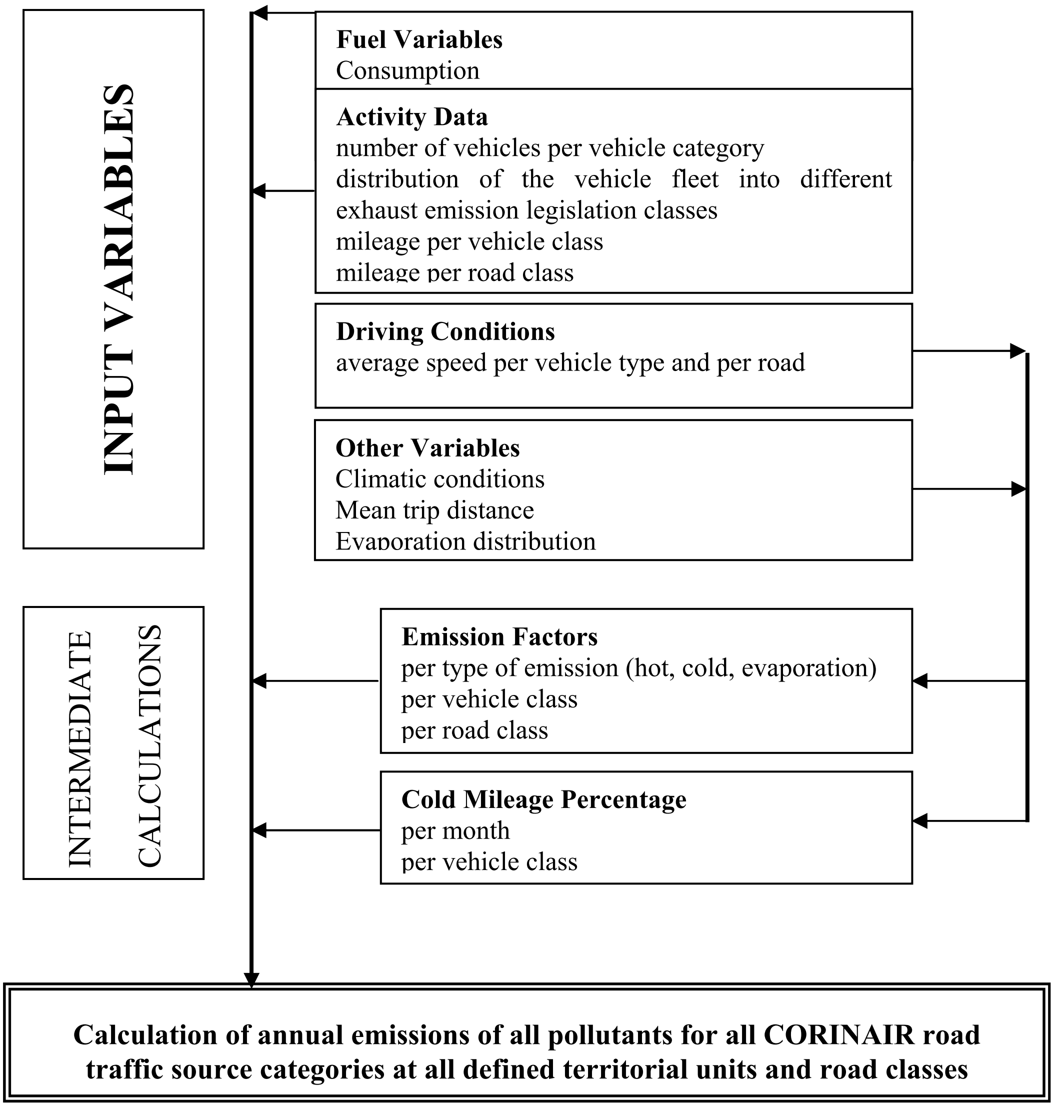

Figure 5.1: Flow chart of the application of the baseline methodology

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

$$E_{HOT;\, i,\, j,\, k} = N_j \times M_{j,k} \times e_{HOT;\, i,\, j,\, k} \qquad (4)$$

where,

$E_{HOT;\, i,\, j,\, k}$: emissions of the pollutant i in [g], produced in the reference year by vehicles of class j driven on roads of type k with thermally stabilised engine and exhaust aftertreatment system

N_j: number of vehicles [veh.] of class j in circulation at the reference year

$M_{j,k}$: mileage per vehicle [km/veh.] driven on roads of type k by vehicles of class j

$e_{HOT;\,i,\,j,\,k}$: average fleet representative baseline emission factor in [g/km] for the pollutant i, relevant for the vehicle class j, operated on roads of type k, with thermally stabilised engine and exhaust aftertreatment system

and,

i (pollutants): 1-36 for the pollutants of Group 1 and Group 3 (Section 3.4)

j (vehicle class): 1-230 for the vehicle classes defined in the vehicle split (Table 3-6)

k (road class): 1-3 for "urban", "rural", and "highway" driving.

5.4.1 Accounting for vehicle speed

Vehicle speed, which is introduced into the calculation via the three driving modes, has a major influence on the emissions of the vehicles. Different approaches have been developed to take into account the driving patterns. With the emission factors presented in this chapter, the authors propose two alternative methods:

to select one single average speed, 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 factors taken from the graphs or calculated with the help of the equations, or to define mean speed distribution curves $f_{j,\,k}(V)$ and to integrate over the emission curves, i.e.

$$e_{HOT;\,i,\,j,\,k} = \int [e(V) \times f_{j,\,k}(V)]\, dV \tag{5}$$

where,

V: speed of vehicles on road classes "rural", "urban", "highway",

e(V): mathematical expression of the speed-dependency of $e_{HOT;\,i,\,j,\,k}$

$f_{j,\,k}(V)$: 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". $f_{j,k}(V)$ depends on vehicle class j and road type k.

It is evident that the first approach mentioned above is much easier and most likely the one to be chosen by most of the countries. Additionally, given the uncertainty in the estimation of the emission factors (see section 11), the improvement brought by the second approach cannot really be substantiated.

5.5 Cold start emissions

Cold starts, compared with the "hot emissions", result in additional emissions. They take place under all three driving conditions, however, they seem to be most likely for urban driving. In principle they occur for all vehicle categories. However, emission factors are only available or can be reasonably estimated for gasoline, diesel and LPG passenger cars and - assuming that these vehicles behave like passenger cars - light duty vehicles, so that just these categories are covered by the methodology. Moreover, they are considered not to be a function of vehicle age.

These 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 used and applied to the fraction of kilometres driven with cold engines. This factor varies from country to country. Driving behaviour (varying trip lengths), as well as climate conditions affect the time required to warm up the engine and/or the catalyst and hence the fraction of a trip driven with cold engine. These factors can be taken into account, but again information may not be available to do this thoroughly in all countries, so that estimates have to close identified gaps.

The cold emissions are introduced into the calculation as additional emissions per km by using the following formula:

$$E_{COLD;\,i,\,j} = \beta_{i,\,j} \times N_j \times M_j \times e_{HOT;\,i,\,j} \times (e^{COLD} / e^{HOT}|_{i,j} - 1) \qquad (6)$$

where,

$E_{COLD;\,i,\,j}$: cold start emissions of pollutant *i* (for the reference year), produced by vehicle class *j*,

$\beta_{i,\,j}$: fraction of mileage driven with cold engines or catalyst operated below the light-off temperature for pollutant *i* and vehicle category *j*

N_j : number of vehicles [veh.] of class *j* in circulation,

M_j : total mileage per vehicle [km/veh.] in vehicle class *j*,

$e^{COLD} / e^{HOT}|_{i,j}$: cold over hot ratio for pollutant *i*, relevant to vehicles of class *j*.

The β-parameter depends on ambient temperature t_a (for practical reasons the average monthly temperature is proposed to be used) and 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 available statistical data (André et al., 1998) a European value of 12.4 km has been established for the l_{trip} value. Moreover, according to a relevant analysis, the value of l_{trip} for annual vehicle circulation should be found in the range of 8 to 15 km. Therefore it is proposed to use the value of 12.4 km unless firm national estimates are available. Table 6-3 presents the l_{trip} values used in the COPERT 1990 inventories by different member states.

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 to less mileage driven under warming-up conditions. Therefore, the β-parameter is also a function of the level of legislation conformity for gasoline catalyst vehicles. Table 8-12 presents the fraction of the original β-parameter to be used for current and future catalyst vehicles and for the main pollutants.

The over-emission ratio e^{COLD}/e^{HOT} also depends on the ambient temperature and pollutant 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 over-emission ratios were introduced for catalyst equipped gasoline vehicles in the previous update of this chapter. These ratios were based on the MEET project (MEET, 1999. However, the proposed approach still cannot fully describe the cold-start emission behaviour of recent vehicle technologies and a revision is scheduled for the next update of this chapter.

As has already been discussed, cold start over-emission is attributed to urban driving only because the valid assumption is made that the majority of trips start in urban areas. However, a portion of cold start over-emissions may also be attributed to rural conditions, in cases where the mileage fraction driven with non-thermally stabilised engine conditions (β-parameter) exceeds the mileage share attributed to urban conditions (S_{URBAN}). This case requires a transformation of equation (6), which then yields:

If $\beta_{i,j} > S_{URBAN}$

$$E_{COLD\ URBAN;\ i,j} = S_{URBAN;\ i,j} \times N_j \times M_j \times e_{HOT\ URBAN;\ i,j} \times (e^{COLD} / e^{HOT}|_{i,j} - 1)$$
$$E_{COLD\ RURAL;\ i,j} = (\beta_{i,j} - S_{URBAN;\ I,j}) \times N_j \times M_j \times e_{HOT\ URBAN;\ i,j} \times (e^{COLD} / e^{HOT}|_{i,j} - 1) \qquad (7)$$

In this case, it is considered that the total mileage driven under urban conditions corresponds to warming-up conditions, while the remaining over-emissions are attributed to urban conditions. The case demonstrated by equation (7) 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 (7). This is because total cold start related 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, and hot urban, rural and highway emissions. The following paragraphs present the calculation algorithm that is used in order to calculate these emissions. In particular for methane, the estimation is of importance because NMVOC emissions are calculated as the difference between VOC and CH_4.

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

If $\beta_{i,\,j} > S_{URBAN;\ j}$ (8)

$$E_{COLD\ URBAN;\ i,\,j} = \beta_{i,j} \times N_j \times M_j \times e_{COLD\ URBAN;\ i,\,j} \qquad (a)$$

$$E_{COLD\ RURAL;\ i,\,j} = 0 \qquad (b)$$

$$E_{HOT\ URBAN;\ i,\,j} = 0 \qquad (c)$$

$$E_{HOT\ RURAL;\ i,\,j} = [S_{RURAL;\ j} - (\beta_{i,j} - S_{URBAN;\ j})] \times N_j \times M_j \times e_{HOT\ RURAL;\ i,\,j} \qquad (d)$$

$$E_{HOT\ HIGHWAY;\ i,\,j} = S_{HIGHWAY;\ j} \times N_j \times M_j \times e_{HOT\ HIGHWAY;\ i,\,j} \qquad (e)$$

Else if $\beta_{i,j} <= S_{URBAN;j}$ (9)

$$E_{COLD\ URBAN;i,j} = \beta_{i,j} \times N_j \times M_j \times e_{COLD\ URBAN;i,j} \quad (a)$$

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

$$E_{HOT\ URBAN;i,j} = (S_{URBAN;j} - \beta_{i,j}) \times N_j \times M_j \times e_{HOT\ URBAN;i,j} \quad (c)$$

$$E_{HOT\ RURAL;i,j} = S_{RURAL;j} \times N_j \times M_j \times e_{HOT\ RURAL;i,j} \quad (d)$$

$$E_{HOT\ HIGHWAY;i,j} = S_{HIGHWAY;j} \times N_j \times M_j \times e_{HOT\ HIGHWAY;i,j} \quad (e)$$

where,

$S_{URBAN;j}$: the mileage share attributed to urban conditions for vehicle class *j*,

$S_{RURAL;j}$: the mileage share attributed to rural conditions for vehicle class *j*,

$S_{HIGHWAY;j}$: the mileage share attributed to highway conditions for vehicle class *j*,

$e_{COLD\ URBAN;i,j}$: cold start emission factor of the pollutant i (for the reference year), caused by vehicle class *j* under urban conditions,

$e_{HOT\ URBAN;i,j}$: hot emission factor of the pollutant *i* (for the reference year), caused by vehicle class *j* under urban conditions,

$e_{HOT\ RURAL;i,j}$: hot emission factor of the pollutant *i* (for the reference year), caused by vehicle class *j* under rural conditions,

$e_{HOT\ HIGHWAY;i,j}$: hot emission factor of the pollutant *i* (for the reference year), caused by vehicle class *j* under highway conditions.

5.6 Fuel consumption dependent emissions (excluding CO_2)

In principle, total emission estimates for pollutants depending on fuel consumption should be derived on the basis of the statistical (true) fuel consumption which is generally known by statistical sources. However, the necessity to allocate emissions to different vehicle categories (and classes) cannot be covered solely by means of the statistical consumption which is not separately provided for each vehicle class. In order to achieve both aims, first fuel dependent pollutants should be calculated on the basis of the calculated fuel consumption (per vehicle class) and then a correction should be applied based on the true consumption. In mathematical terms, this correction can be expressed:

$$E^{CORR}_{i,j,m} = E^{CALC}_{i,j,m} \times \frac{FC^{STAT}_{m}}{\sum_j FC^{CALC}_{j,m}} \quad (10)$$

where,

$E^{CORR}_{i,j,m}$: the corrected emission of fuel dependent pollutant i (SO_2, Pb, HM) emitted from vehicles in category j operating on fuel m

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

FC_{m}^{STAT} : the statistical (true) total consumption of fuel type m (m= leaded gasoline unleaded gasoline, diesel, LPG, CNG)

$\sum_{j} FC_{j,m}^{CALC}$: the total calculated fuel consumption of all vehicle classes operating on fuel type m.

In this respect, total emission estimates for any emission dependent pollutant equals that derived by the statistical fuel consumption (except of CO_2 due to the use of biofuels, see section 5.6.1) while there is still information provided for the allocation of emissions to different vehicle classes. The calculation of value $E^{CALC}_{i,j,m}$ is demonstrated in the following paragraphs.

5.6.1 Carbon dioxide (CO_2) emissions

Ultimate CO_2 emissions are estimated on the basis of fuel consumption only, assuming that the carbon content of the fuel is fully oxidised into CO_2**.**

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:

$$r_{H:C} = \frac{y}{x} \qquad r_{O:C} = \frac{z}{x} \tag{11}$$

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 correspondingly, 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:

$$r_{H:C} = 11.916\frac{h}{c} \qquad r_{O:C} = 0.7507\frac{o}{c} \tag{12}$$

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

$$E^{CALC}_{CO_2,j,m} = 44.011 \times \frac{FC^{CALC}_{j,m}}{12.011 + 1.008 r_{H:C,m} + 16.000 r_{O:C,m}} \tag{13}$$

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

If **end-of-pipe CO_2** emissions are to be calculated, then other emissions of C atoms in the form of CO, VOC, elemental carbon (EC) and organic mass (OM) in particulate emissions have to be taken into account. Then the following formula is applied:

$$E^{CALC}_{CO2,j,m} = 44.011 \times \left(\frac{FC^{CALC}_{j,m}}{12.011 + 1.008 r_{H:C,m} + 16.000 r_{O:C,m}} - \frac{E^{CO}_{j,m}}{28.011} - \frac{E^{VOC}_{j,m}}{13.85} - \frac{E^{EC}_{j,m}}{12.011} - \frac{E^{OM}_{j,m}}{13.85} \right) \quad (14)$$

Table 5-1 presents relevant hydrogen to carbon and oxygen to carbon ratios for different fuel types.

Oxygen in the fuel may be contained due to blending with bio-fuels (e.g. biodiesel in diesel or bioethanol in gasoline) or in additives not derived by biomass (e.g. MTBE or ETBE). Since biofuel derived CO_2 should not be reported as road-transport CO_2, in case of biodiesel blend, only the mass of fossil fuel should be used in the calculation of CO_2 emissions. In all calculations (fuel balance, SO_2 and HM emissions, etc.) the statistical fuel consumption should include both the biofuel and the fossil fuel mass according to eq. (10). In the calculation of CO_2 emissions though, only the fossil fuel statistical consumption should be taken into account in the calculation. This is consistent to 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. Hence, for reporting, the CO_2 calculated per vehicle category should be corrected according to equation :

$$E^{CORR}_{CO_2,j,m} = E^{CALC}_{CO_2,j,m} \times \frac{FC^{STAT}_{m} - FC^{BIO}_{m}}{\sum_j FC^{CALC}_{j,m}} \quad (15)$$

In equation (15), the calculated CO_2 emission should be derived from eq. (13), without considering the oxygen content of the biofuel part. In the same equation FC^{BIO} is the mass of biofuel blended in the total fuel of type *m* sold.

Table 5-1: 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
Natural Gas	CH_4 (95%)- C_2H_6 (5%)	$r_{H:C}$=3.90	$r_{O:C}$=0.0
	CH_4 (85%)- C_2H_6 (15%)	$r_{H:C}$=3.74	$r_{O:C}$=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

5.6.2 Sulphur dioxide (SO_2) emissions

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

$$E^{CALC}_{SO_2,j} = 2 \times k_{S,m} \times FC^{CALC}_{jm} \qquad (16)$$

where,

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

5.6.3 Lead (Pb) and other heavy metals emissions

Emissions of lead are estimated by assuming that 75% of lead contained in the fuel is emitted into air (Hassel et al., 1987). The formula used is:

$$E^{CALC}_{Pb,j} = 0.75 \times k_{Pb,m} \times FC^{CALC}_{jm} \qquad (17)$$

where,

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

With regard to the emission of other heavy metal species, emission factors provided correspond both to fuel and lubricant content and engine wear. Therefore it is considered that the total quantity is emitted to the atmosphere (no losses in the engine). Therefore, emissions of heavy metals included in Group 2 are calculated by means of:

$$E^{CALC}_{i,j} = k_{i,m} \times FC^{CALC}_{jm} \qquad (18)$$

where,

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

Values are proposed for fuel content in heavy metals, as provided by the Expert Panel on Heavy Metals and POPs of the UNECE Task Force on Emission Inventories. However, these emission factors have to be considered as preliminary estimates only. More measurements are needed in order to confirm these values.

5.7 Emission corrections

Corrections can be applied to the emission methodology, as it has been described by the baseline equations (4) - (5), to accommodate variation of emissions according to various environmental and technology effects. Specifically, the effect on emissions of the following parameters can be tackled:

a. Vehicle age (mileage). Baseline emission factors to be used in equation (4) correspond to a fleet of average mileage (30-60 Mm) and an inherent degradation factor is implemented. Further emission degradation due to increased mileage should be modelled by 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 young fleet age. However, when inventories and forecasts for future years need to be made, it is advised to correct emission factors according to mileage to introduce the effect of vehicle age in the calculations.

b. Improved fuels. Improved fuel qualities have become mandatory in the European Union since year 2000. The effect on the emissions of current and older vehicles can be quantified again by means of relevant correction factors. Those corrections should only be applied in inventories compiled for years after the introduction of the improved fuels.

c. Road gradient and vehicle load on heavy duty vehicles emissions. Corrections need to be made to heavy duty vehicles emissions in cases of driving on non-flat roads. 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 brought by means of respective emission factors functions.

5.7.1 Emission degradation due to vehicle age

Correction factors need to be applied to the baseline emission factor to account for different vehicle age. This correction factor which is given by equation:

$$MC_{C,i} = A_M \times M_{MEAN} + B_M \qquad (19)$$

where,
M_{MEAN}: the mean fleet mileage of vehicles for which correction is applied
$MC_{C,i}$: the mileage correction factor for a given mileage (M_{av}), pollutant i and a specific cycle
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 vehicles. It is assumed that emissions do not further degrade above 120,000 km for Euro I and II vehicles and 160,000 km for Euro III and IV 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, road). It is assumed that for speeds outside the region defined by the average speed of urban driving (19 km/h) and road 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. Table 8-69 presents the methodology parameters and the application of the scheme that are being discussed later on this document.

5.7.2 Fuel effects

Fuels of improved specifications become mandatory in Europe in two steps, January 2000 (Fuel 2000) and January 2005 (Fuel 2005) respectively. The specifications of those fuels are displayed in Table 5-2 (Gasoline) and Table 5-3 (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 quality

"Fuel 2000" and the more stringent emission standards of Euro 4 and 5 with fuel quality "Fuel 2005". Table 5-4 shows the base emission fuel considered for each vehicle class.

However use of such fuels results in reduced emissions also from pre-Euro 3 vehicle technologies, for which the 1996 market average fuel is considered as a basis (Table 5-4). Those reductions are equally applied to hot and cold start emissions. To correct the hot emission factors proposed, equations derived in the framework of the EPEFE programme (ACEA and EUROPIA, 1996) are applied. Table 8-70, Table 8-71 and Table 8-72 display the equations for different vehicle categories and classes.

Table 5-2: 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	0.003	0.003

Table 5-3: Diesel fuel specifications

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

Table 5-4: 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:

$$FCe_{HOT;\,I,\,j,\,k} = FCorr_{i,\,j,\,Fuel} \,/\, FCorr_{i,\,j,\,Base} \times e_{HOT;\,i,\,j,\,k} \qquad (20)$$

where,

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

$FCorr_{i,\,j,\,Fuel}$: the fuel correction for pollutant *i*, vehicle category *j*, calculated with equations given in Table 8-70, Table 8-71 and Table 8-72 for the available improved fuel qualities (Table 5-4)

$FCorr_{i, j, Base}$: the fuel correction for pollutant *i*, vehicle category *j*, calculated with equations given in Table 8-70, Table 8-71 and Table 8-72 for the base fuel quality of vehicle class *j* (Table 5-4)

It is mentioned that equation (20) should not be used to provide the deterioration of emissions in case that 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 (20) should be introduced in equations (4) and (6) or (7) respectively to estimate hot and cold start emissions.

6 RELEVANT ACTIVITY STATISTICS

In principle, vehicle statistics are readily available in the national statistical offices of all countries and in international statistical organisations and institutes (e.g. EUROSTAT, International Road Federation - IRF). However, it must be stressed that these statistics are almost exclusively vehicle oriented (i.e. comprising fleet data), with information about general aggregate categories only (e.g. passenger cars, trucks, buses, motorcycles). In addition, only little information referring to age and technology distribution can be found in a consistent form, while very little information is available as regards activity data (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.

Despite the lack of direct data in the national and international statistics as regards transport activity, and age and technology distribution of the vehicles, such data can be produced in an indirect way. The following hints may be helpful:

- *Age and technology distribution*: The (generally available) time series on fleet evolution and annual new registrations can be used in order to come up with estimates of appropriate scrappage rates. By combining the above with implementation dates of certain technologies, a relatively good picture of the fleet composition at specific years can be reached.
- *Mileage driven and mileage split*: Calculated fuel consumption on the basis of appropriate assumptions for annual mileage of the different vehicle categories can be balanced with available fuel statistics, following the methodology presented in chapter 5.1, using representative fuel consumption factors. By applying a trial-and-error approach, it is possible to reach acceptable estimates of mileage activity data.

Activity statistics presented in this methodology correspond to the central estimates provided by EEA in their relevant report (Ntziachristos et al., 2002). They have been produced with application of an approach as the one mentioned before to older official data. Table 6-1 provides the European fleet per vehicle category and Table 6-2 the mean mileage driven by each vehicle in each category.

For the calculation of cold –start related emissions, the mean trip length is necessary. Table 6-3 provides the figures submitted by national experts in a previous COPERT exercise. Despite these data refer to a decade ago circulation conditions, they can still be rather safely used because mean trip is a highly aggregate value which little varies from year to year.

Table 6-1: 2002 Vehicle fleet in the EU 15 countries

Country	Gasoline PC	Diesel PC	Gasoline LDV	Diesel LDV	Diesel HDV	Buses & Coaches	Two Wheelers
Austria	3 152 165	941 556	30 055	73 154	243 316	10 477	566 232
Belgium	3 207 878	1 468 450	88 760	172 729	188 435	14 090	444 676
Denmark	1 722 938	85 361	71 295	118 507	146 989	14 314	136 908
Finland	2 211 212	194 109	71 630	194 300	65 606	8 805	114 087
France	21 403 436	4 683 885	1 030 207	2 557 828	700 509	86 088	1 486 539
Germany	40 382 437	6 339 589	518 270	1 251 392	1 458 545	96 811	4 694 988
Greece	2 729 040	38 277	425 712	385 195	202 764	27 459	1 312 322
Ireland	906 757	138 014	11 334	66 404	112 920	5 737	16 980
Italy	30 688 296	4 892 337	503 066	1 633 541	1 290 050	84 616	7 137 278
Luxembourg	225 394	47 886	2 265	974	12 209	960	28 243
Netherlands	5 136 112	687 316	5 702	n.a.	674 734	13 089	368 959
Portugal	2 807 226	311 914	n.a.	613 933	552 177	17 003	794 687
Spain	13 418 202	3 379 900	862 828	2 142 255	586 696	48 976	2 074 002
Sweden	4 004 703	119 605	253 971	40 436	103 520	14 636	280 384
UK	24 342 193	1 999 321	1 238 713	1 120 819	589 992	72 178	644 677

Table 6-2: 2002 Mileage driven by each vehicle category in EU15 countries

Country	Gasoline PC	Diesel PC	Gasoline LDV	Diesel LDV	Diesel HDV	Buses & Coaches	Two Wheelers
Austria	16 641	18 156	25 000	25 000	67 891	41 573	4 881
Belgium	14 319	22 774	20 000	35 000	63 275	23 210	7 800
Denmark	20 410	21 413	18 253	15 000	38 714	60 040	3 846
Finland	19 256	31 165	8 500	16 000	55 000	70 000	3 260
France	9 950	15 059	16 500	25 000	59 719	39 550	4 359
Germany	11 596	15 353	17 500	22 000	70 340	47 000	2 420
Greece	16 689	16 054	13 000	20 000	40 225	16 904	5 975
Ireland	20 388	14 977	25 000	27 000	35 989	48 136	11 955
Italy	9 273	15 760	20 000	17 000	38 742	41 000	5 088
Luxembourg	13 920	20 174	40 000	40 000	40 000	47 730	2 189
Netherlands	10 841	15 087	35 000	n.a.	26 180	35 000	3 980
Portugal	12 267	12 267	n.a.	15 000	26 683	30 220	477
Spain	9 578	14 362	22 500	30 000	60 281	28 000	2 428
Sweden	15 005	23 579	20 000	35 000	56 930	60 000	5 995
UK	13 729	15 644	17 000	16 500	60 000	60 000	3 815

n.a.: not available

Table 6-3: 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		

7 POINT SOURCE CRITERIA

There are no relevant point sources, which fall under the source activities dealt within this chapter.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

Emission factors corresponding to non-catalyst gasoline passenger cars were jointly worked out by the members of 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 passenger cars (91/441/EEC and on) and diesel heavy duty vehicles the emission factors incorporated are the outcome of the Artemis project. Light duty vehicle emission factors originate from the MEET project. Power two wheeler emission factors originate from DG Enterprise studies on the regulation of power two wheelers.

The emission factors proposed can be distinguished into two classes: those for which detailed evaluations are necessary and possible, and those for which more simple "bulk" emission factors or equations can be provided. The pollutants CO, VOC and NO_x, PM together with fuel consumption factors fall under the first category, while SO_2, NH_3, Pb, CO_2, N_2O and partly CH_4 fall under the second one. Therefore this chapter is organised as follows:

First the exhaust emission factors of CO, VOC and NO_x, PM (called "regulated" pollutants because they have been regulated by relevant legislation) as well as fuel consumption factors of the individual SNAP activities are presented and discussed.

Secondly the "bulk" emission factors for SO_2, NH_3, Pb, CO_2, N_2O and CH_4 follow.

Table 8-1: Coding explanation used for the methodological approaches adopted for each vehicle category

Method	Hot Emissions	Cold Start Overemission	Evaporation Losses*
A	the total annual kilometres driven per vehicle the share of kilometres driven under the driving modes '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	the fuel volatility (RVP) the average monthly temperature and temperature variation fuel volatility and temperature dependent emission factor
B	the total annual kilometres driven per vehicle the share of kilometres driven under the driving modes '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*	the fuel volatility (RVP) the average monthly temperature and temperature variation fuel volatility and temperature dependent emission factor
C	the total annual kilometres driven per vehicle the share of kilometres driven under the driving modes 'urban', 'rural', 'highway' driving mode dependent emission factors	*No Cold Start Overemission Calculations*	*No Evaporation Calculations*
D	the total annual fuel consumption of the vehicle category fuel consumption related emission factors	*No Cold Start Overemission Calculations*	*No Evaporation Calculations*

*Attributed only to NMVOC emissions from gasoline powered vehicles

Analytical description of the methodology application for each vehicle category follows. However, Table 8-1 and Table 8-2 show the level of detail which is necessary for the calculation of emissions from each vehicle technology.

Table 8-2: 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 I 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 <3.5t Conv.	A1	A1	A1	A2	-	A2	A2	D	D	D	D	A1
Gasoline <3.5t Euro 1 to Euro 4	A1	A1	A1	A1	-	A2	A2	D	D	D	D	A1
Diesel <3.5t Conventional	A1	A1	A1	A2	A1	A2	A2	D	D	D	D	A1
Diesel <3.5t 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 & Coaches Conventional	B1	B1	B1	C	B1	C	C	D	D	D	D	B1
Buses & Coaches Euro I to Euro V	B1	B1	B1	C	B1	C	C	D	D	D	D	B1
Two Wheelers												
Mopeds <50cm³	B2	B2	B2	C	-	C	C	D	D	D	D	B2
Motorcycles 2-st >50cm³	B1	B1	B1	C	-	C	C	D	D	D	D	B1
Motorcycles 4-st 50-250 cm³	B1	B1	B1	C	-	C	C	D	D	D	D	B1
Motorcycles 4-st 250-750cm³	B1	B1	B1	C	-	C	C	D	D	D	D	B1
Motorcycles 4-st >750cm³	B1	B1	B1	C	-	C	C	D	D	D	D	B1

8.1 Gasoline passenger cars

8.1.1 Pre Euro – "Conventional"

Hot Emissions

Hot emission factors for conventional vehicles are given in Table 8-3, Table 8-4 and Table 8-5 for different pollutants and Table 8-6 provides fuel consumption factors for the same vehicles. Those emission factors have been developed in the framework of older COPERT exercises (Eggleston et al., 1989). Separate equations are valid for different speed ranges and engine capacity classes.

Table 8-3: 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 8-4: 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

<u>Cold start emissions</u>

Table 8-7 provides e^{COLD}/e^{HOT} over-emission ratios for pollutants of Group 1. The β-parameter is calculated by means of equation provided in Table 8-8. Introduction of those values in equation (6), together with the hot emission factors quoted previously provides estimates of cold start emissions. Again, those ratios have been produced during older COPERT versions.

Table 8-5: 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 8-6: Speed dependency of fuel consumption factors for gasoline passenger cars

Vehicle Class	Cylinder Capacity	Speed Range (km/h)	Fuel Consumption Factor (g/km)	R^2
PRE ECE	CC < 1.4 l	10-60	$521V^{-0.554}$	0.941
		60-80	55	-
		80-130	$0.386V + 24.143$	-
	1.4 l < CC < 2.0 l	10-60	$681V^{-0.583}$	0.936
		60-80	67	-
		80-130	$0.471V + 29.286$	-
	CC > 2.0 l	10-60	$979V^{-0.628}$	0.918
		60-80	80	-
		80-130	$0.414V + 46.867$	-
ECE 15-00/01	CC < 1.4 l	10-60	$595V^{-0.63}$	0.951
		60-130	$95 - 1.324V + 0.0086V^2$	0.289
	1.4 l < CC < 2.0 l	10-60	$864V^{-0.69}$	0.974
		60-130	$59 - 0.407V + 0.0042V^2$	0.647
	CC > 2.0 l	10-60	$1236V^{-0.764}$	0.976
		60-130	$65 - 0.407V + 0.0042V^2$	-
ECE 15-02/03	CC < 1.4 l	10-50	$544V^{-0.63}$	0.929
		50-130	$85 - 1.108V + 0.0077V^2$	0.641
	1.4 l < CC < 2.0 l	10-50	$879V^{-0.72}$	0.950
		50-130	$71 - 0.7032V + 0.0059V^2$	0.830
	CC > 2.0 l	10-50	$1224V^{-0.756}$	0.961
		50-130	$111 - 1.333V + 0.0093V^2$	0.847

table continues in next page

Table 8-6(cont.): Speed dependency of fuel consumption factors for gasoline passenger cars

Vehicle Class	**Cylinder Capacity**	**Speed Range (km/h)**	**Fuel Consumption Factor (g/km)**	**R^2**
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 8-7: Over-emission ratios e^{COLD} / e^{HOT} for conventional gasoline vehicles (temperature range of –10°C to 30°C)

Conventional Gasoline Powered Vehicles	**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 8-8: Cold mileage percentage β

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

8.1.2 Euro 1 and later

Hot emissions

Hot emissions estimates for Euro 2 and post-Euro 1 gasoline passenger cars are calculated as a function of speed. They have been developed in the framework of the *Artemis* project. Table 8-9 provides the factors of the function used to calculate the emission factors. The generic function used in this case is:

$$EF = (a + c \times V + e \times V^2)/(1 + b \times V + d \times V^2) \quad (21)$$

Table 8-9: Values for eq.(21) 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 8-10 also presents simplified emission factors to be used for PM emission calculation from gasoline passenger cars of Euro 1 and later technologies. A separate emission factor is proposed for direct injection gasoline vehicles (GDI) due to the different combustion process of these engines.

Table 8-10: 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 & 2	2000-2009	3.22E-03	1.84E-03	1.90E-03
	Euro 3 & 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

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 in the case of Euro I and later vehicles. Table 8-11 provides e^{COLD}/e^{HOT} over-emission ratios for three main pollutants (and fuel consumption). The values proposed are a result of fitting the existing COPERT methodology to the results published by MEET and are a function of ambient temperature and average travelling speed. Two speed regions have been introduced (5-25 km/h and 25-45 km/h). As in the case of hot emission factors, the value introduced for speed should correspond to the mean speed during travelling and not to the instantaneous speed. The speed range proposed is sufficient to cover most applications because cold start over-emissions are in principle allocated to urban driving only.

Table 8-11: 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: e^{COLD} /e^{HOT} should be replaced with unit when it is calculated less than unit within the temperature and speed application limits

In the cases of CO and VOC over-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, over-emission of those 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 distinguished for those pollutants.

The proposed functions receive values less than unit at relatively high temperatures. Results should be replaced by unit in this case. Generally, cold start effect becomes negligible in the region of 25°C in the case of CO and 30°C in the case of VOC. This is not only because over-emission under such ambient conditions is limited but also because actual engine start-up temperature can still be high after several hours of parking at these high ambient temperatures.

The mileage fraction driven during the warming up phase is calculated by means of the formula provided in Table 8-8. After calculating the β-parameter and the e^{COLD}/e^{HOT} over-emission ratios, the application of equations (6) or (7) is straightforward.

Emission reduction compared to Euro 1 during the warming up phase of post-Euro 1 vehicle technologies mainly comes from the reduced time which is required from new catalytic systems to reach the light-off temperature. This time reduction is further reflected to a decrease in the distance travelled with a partial warmed engine and/or exhaust aftertreatment devices. Therefore, reduced cold start emissions are simulated with a respective decrease of the β-parameter, which stands for the mileage fraction driven with a cold or partially warmed engine. Table 8-12 provides reduction factors ($bc_{i,j}$) to be applied on the β-parameter according to pollutant and vehicle class.

Table 8-12: β-parameter reduction factors (bc) in case of post-Euro 1 gasoline vehicles for three main pollutants

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 particular reason for over-emission rate (i.e. emission in g/s) differentiation between vehicle classes[1]. This means that the e^{COLD}/e^{HOT} value calculated for Euro 1 vehicles can be also applied in the case of later vehicle classes without further reductions. In the same respect, even the hot emission factor involved in the equation of cold start over-emission of post-Euro 1 vehicles should keep the Euro 1 calculated value. This is valid because, as mentioned before, there is no evidence for significant reduction of the rate of over-emission for later than Euro 1 vehicle classes.

Therefore, equation (6) in the case of post-Euro 1 vehicle classes yields:

$$E_{COLD;i,j} = bc_{i,j} \times \beta_{i,\text{Euro 1}} \times N_j \text{ x } M_j \times e_{hot,\, i,\, \text{Euro 1}} \times (e^{COLD} / e^{HOT} - 1)|_{I,\, \text{Euro 1}} \qquad (22)$$

[1] 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.

Respective modifications should also be brought in equation (7) in cases where $bc_{i,j} \times \beta_{i,EURO\ I} > S_U$. It is obvious that the corrected value should be used for the mileage fraction during the warming up phase.

8.2 Diesel passenger cars

8.2.1 Pre Euro 1

Hot emissions

Based on a relatively large number of measured data on emissions of diesel passenger cars <2.5 tonnes (Hassel et al., 1987; Pattas et al., 1985; Rijkeboer et al., 1989; 1990) enabled to differentiate between cylinder capacities and to come up with speed dependent emission factors for conventional (pre Euro 1) vehicles. Emission factors to be introduced in equation (4) for the calculation of hot emissions from conventional diesel passenger cars are given in Table 8-13.

Table 8-13: Speed dependency of emission and consumption factors for conventional diesel vehicles <2.5 t

Pollutant	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 < 2.0l	10-130	$0.918 - 0.014V + 0.000101V^2$	0.949
	CC > 2.0l	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

Cold start over-emissions from diesel vehicles are not very significant compared to gasoline vehicles. Therefore, no distinction is made between conventional and Euro 1 vehicles. e^{COLD}/e^{HOT} ratios for calculating cold start over-emissions for those vehicles are quoted in Table 8-14.

Table 8-14: Over-emission ratios e^{COLD} / e^{HOT} for diesel passenger cars (temperature range -10°C to 30°C)

Pollutant	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	$1.34 - 0.008\ t_a$

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

8.2.2 Euro 1 and post-Euro 1

Hot emissions

Hot emissions estimates for Euro 1 and post-Euro 1 vehicles are calculated as a function of speed. They have been developed in the framework of the *Artemis* project. Table 8-15 provides the factors of the function used to calculate the emission factors. The generic function used in this case is:

$$EF = (a + c \times V + e \times V^2)/(1 + b \times V + d \times V^2) + f/V \tag{23}$$

Some manufacturers launched, already at Euro 3 emission standard, diesel passenger cars equipped with diesel particle filters. Those vehicle types that became popular did not significantly differ with 'conventional' Euro 3 vehicles in NOx (and secondarily) CO or HC emissions but only in PM. Table 8-16 presents PM specific emission factors for these vehicles. These emission factors assume the use of fuel fulfilling the EN590:2005 standards.

Table 8-15: Values for eq.(23) to calculate emissions from Euro 1 and later diesel passenger cars

Pollutant	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	1.10E+00
	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	0
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	0
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 $CO = 17.5E-3 + 86.42\left[1 + e^{-\frac{V+117.67}{-21.99}}\right]^{-1}$

Cold start emissions
In order to calculate cold-start emissions of Euro 1 and later diesel passenger cars, the β-parameter is calculated by the formula given in Table 8-8 for all classes, while e^{COLD}/e^{HOT} ratios are quoted in Table 8-14 and are the same as in the case of conventional vehicles. However, some additional reductions need to be applied for vehicle technologies post-Euro 1 (RFij), which are given in Table 8-17. Based, on these, application of equation (6) in this case yields:

$$E_{COLD;i,j} = \beta_{i,j} \times N_j \times M_j \times (100-RF_{i,j}) / 100 \times e_{HOT;\, i,\, Euro\, 1} \times (e^{COLD} / e^{HOT}|_{i,Euro\, 1} - 1) \qquad (24)$$

A similar transformation needs to be made in the case of equation (7).

Table 8-16: Emission factors of PM from Euro 3 diesel passenger cars equipped with diesel particle filters (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

Table 8-17: 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

8.3 LPG passenger cars

The methodology introduced in the case of gasoline passenger cars is valid also in the case of LPG vehicles. However, it has to be stressed that the amount of data in the case of 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 to calculate hot and cold start emissions.

Hot emissions
Equation (4) is applied to calculate hot emissions for conventional and Euro 1 LPG vehicles. Table 8-18 provides hot emission factors for conventional passenger cars and Table 8-19 for those complying with 91/441/EEC (Euro 1). The former emission factors have been developed in the framework of earlier COPERT exercises and the latter ones in the framework of MEET (Samaras and Ntziachristos, 1997). With respect to post-Euro 1 LPG vehicles and in the absence of more updated data, reduction factors over Euro 1 emission factors are proposed. These can be introduced by means of equation (25), while the reduction factors are given in Table 8-20:

$$e_{HOT;\, i,\, j,\, k} = (100-RF_{i,j}) / 100 \times e_{HOT;\, i,\, Euro\, 1,\, k} \qquad (25)$$

Cold start emissions

Very few data on cold start over-emission from LPG vehicles are available (AQA, 1990; Hauger et al.; 1991). For consistency however and since LPG emission limitation technology is similar to that of gasoline vehicles, the methodology applied to calculate emissions from gasoline vehicles is also applied here. Table 8-21 provides over-emission ratios which are valid for all emission classes of LPG vehicles. Equations (6) and (7) are applied up to Euro 1 vehicles while equation (24) is applied to post-Euro 1 ones. Reduction factors for the β-parameter equal those of gasoline vehicles (Table 8-12).

Table 8-18: Speed Dependency of Emission Factors for LPG Vehicles <2.5 t

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	- - -

8.4 Two-stroke passenger cars

Few measured data are available (Appel et al., 1989; Jileh, 1991; Pattas et al., 1983) which have been used to derive emission factors for urban, rural and highway driving for two-stroke gasoline powered cars in the framework of older COPERT exercises. Total emission factors (hot + cold) are given in Table 8-22. They 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 speed 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 8-19: Speed dependency of emission and consumption factors for LPG vehicles <2.5t, complying with directive 91/441/EEC

Pollutant	Cylinder 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	$0.00720V^2 - 0.9250V + 74.625$

Table 8-20: Emission reduction percentage for post Euro 1 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	79
	Euro 3 - 98/69/EC Stage 2000	44	76	85
	Euro 4 - 98/69/EC Stage 2005	66	87	97
1.4 l < CC < 2.0 l	Euro 2 - 94/12/EC	32	64	79
	Euro 3 - 98/69/EC Stage 2000	44	76	86
	Euro 4 - 98/69/EC Stage 2005	66	87	97
CC > 2.0 l	Euro 2 - 94/12/EC	32	64	76
	Euro 3 - 98/69/EC Stage 2000	44	76	84
	Euro 4 - 98/69/EC Stage 2005	65	87	95

Table 8-21: Over-emission ratios e^{COLD} / e^{HOT} for LPG passenger cars (temperature range of –10°C to 30°C)

Pollutant	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	$1.47 - 0.009\ t_a$

(1) VOC: if ta > 29°C then e^{COLD} / e^{HOT} > 0.5

Table 8-22: 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

8.5 Hybrid passenger cars <1.6l

Few measured data are available which have been used to derive emission factors hybrid gasoline powered cars in the framework of new *Artemis* exercises. Only Euro 4 vehicles less than <1.6 of engine capacity were used in the measurements. The methodology is similar to gasoline passenger cars and the equation used to calculate the emission factors is:

$$EF = a + c \times V + e \times V^2 \qquad (26)$$

The factors used in the equation can be found in Table 8-23.

Table 8-23: Values for eq.(26) 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	1.95E-04	3.80E-05	-2.64E-07
HC		All capacities	10-130	1	5.50E-04	-8.54E-06	4.94E-08
NO_x		All capacities	10-130	1	1.48E-02	-4.20E-04	4.29E-06
FC		All capacities	10-130	1	1.94E+01	6.06E-02	7.54E-04

8.6 Gasoline light duty vehicles

Hot emissions

The emissions of these vehicles within EU countries were covered by the different ECE steps. All those vehicle classes have been introduced in a common "Conventional" class and emission factors for pollutants of Group 1 are given in Table 8-24. Emission factors of Euro 1 vehicles can also be found in the same Table. Hot emission factors of post-Euro 1 vehicles are calculated by application of equation (25) by introducing the reduction factors given in Table 8-25.

Table 8-24: Speed dependency of emission and consumption factors for gasoline light duty vehicles <3.5 t

Pollutant	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 8-25: 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

PM emissions from gasoline light duty vehicles can be considered similar to passenger cars (Table 8-10).

Cold start emissions

The same over-emission ratios applied in the case of gasoline passenger cars of engine capacity >2.0 l are also applied in the case of light duty vehicles in the absence of more detailed data. 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 tends to be a reality today since the technology introduced nowadays in light duty vehicles does not significantly differ from respective passenger cars. Therefore the over-emission ratios proposed in Table 8-7 (pre-Euro 1) and Table 8-11 (Euro 1 and on) are applied in the case of light duty vehicles. Furthermore, equations (6), (7) are valid for pre-Euro 1 vehicles and equation (24) for Euro 1 and later ones in conjunction with the β-parameter reduction factors given in Table 8-12.

8.7 Diesel light duty vehicles

Diesel light duty vehicles are treated as passenger cars. Hot emission factor speed dependencies have been developed in the framework of older COPERT exercises (Conventional vehicles) and in the MEET project (Euro I and later vehicles) and are quoted in Table 8-26 for pollutants of Group 1. Cold start over-emissions up to Euro 1 are calculated by equation (6), where e^{COLD}/e^{HOT} ratios are selected from Table 8-14. Emission factors of post-Euro 1 vehicle classes are calculated by the functions corresponding to Euro I vehicles by introducing the reduction factors given in Table 8-27 both for hot and cold start emissions (equations (25) and (24), respectively).

8.8 Gasoline heavy duty vehicles

Only hot emissions are calculated for gasoline heavy duty vehicles. Emission factors derived from an extrapolation of results from smaller vehicles are presented in Table 8-28 and are distinguished only to the three driving modes (urban, rural, highway). Total emission estimates are therefore calculated by application only of equation (4).

Table 8-26: Speed dependency of emission and consumption factors for diesel light duty vehicles <3.5 t

Pollutant	Vehicle Class	Speed Range [km/h]	Emission Factor [g/km]	R^2
CO	Conventional	10-110	$20E\text{-}05V^2 - 0.0256V + 1.8281$	0.136
	Euro 1	10-110	$22.3E\text{-}05V^2 - 0.026V + 1.076$	0.301
NOx	Conventional	10-110	$81.6E\text{-}05V^2 - 0.1189V + 5.1234$	0.402
	Euro 1	10-110	$24.1E\text{-}05V^2 - 0.03181V + 2.0247$	0.0723
VOC	Conventional	10-110	$1.75E\text{-}05V^2 - 0.00284V + 0.2162$	0.0373
	Euro 1	10-110	$1.75E\text{-}05V^2 - 0.00284V + 0.2162$	0.0373
PM	Conventional	10-110	$1.25E\text{-}05V^2 - 0.000577V + 0.288$	0.0230
	Euro 1	10-110	$4.5E\text{-}05V^2 - 0.004885V + 0.1932$	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 8-27: 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

Table 8-28: 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

8.9 Diesel heavy duty vehicles and busses

Speed dependencies of emission factors for diesel heavy duty vehicles have been built on the results provided by the *Artemis* Project. Similarly, the methodology provides hot emission factors for urban busses and coaches. The emission factors are provided for conventional, Euro I to Euro V standards. Due to the large number of data required to calculate emissions from those categories, all relevant information can be found as an Annex to this guidebook chapter The emissions covered by the methodology are CO, VOC, NOx, PM and Fuel Consumption (FC).

Equations (27) to (36) represent the main equations used to calculate the emission factors, while the Annex contains the necessary parameters in a specific structure. The name of the files in the Annex is "EFs_GXX%_LYYY%.xls", where XX is the road gradient and YYY is the load factor of the vehicle. The sheet names correspond to the emission factors described in the file, namely CO, THC (VOC), NOx, and PM.

For each sheet, column G describes the function while columns I to M contain the factors used in the equation. As an example, file "EFs_G00%_L050%.xls" contains the emission factors for a road gradient 0% and a load factor of 50%. Sheet "FC" describes the fuel consumption emission functions. The equation for Euro 1, <15t midi Urban Buses is:

$EF = 1 / (((c \times (V^2)) + (b \times V)) + a)$
where *EF* is the emission factor, *V* is the vehicle speed and the different parameters are found in the columns I to M in the *Annex* file, namely: a= 0.00094 – b= 0.00017 – c= -0.000001.

Equations (27) to (36), describe all the different equations that are potentially used in the *Annex* to calculate heavy duty vehicle and bus emission factors.

$$EF = (a + (b \times V))+(((c - b) \times (1-\exp(((-1) \times d) \times V))) / d) \tag{27}$$

$$EF = (e + (a \times \exp(((-1) \times b) \times V))) + (c \times \exp(((-1) \times d) \times V)) \tag{28}$$

$$EF = 1 / (((c \times (V^2)) + (b \times V)) + a) \tag{29}$$

$$EF = 1 / (a + (b \times (V^c))) \tag{30}$$

$$EF = 1 / (a + (b \times V)) \tag{31}$$

$$EF = a - (b \times \exp(((-1) \times c) \times (V^d))) \tag{32}$$

$$EF = a + (b / (1+\exp((((-1) \times c) + (d \times \ln(x))) + (e \times V)))) \tag{33}$$

$$EF = c + (a \times \exp(((-1) \times b) \times V)) \tag{34}$$

$$EF = c + (a \times \exp(b \times V)) \tag{35}$$

$$EF = \exp(a + (b / V)) + (c \times \ln(V)) \tag{36}$$

8.10 Natural gas busses

Natural gas vehicles (NGVs) are nowadays present in several urban captive fleets around Europe. France has already some 700 NG busses in operation, out of a total of 12000 while 416 NG busses are in operation in Athens, in a fleet of 1800 vehicles. NG as a fuel can neither be used on a diesel engine nor on a gasoline one without modifications because it has a high octane number (120-130) and a lower than 50 cetane number which makes it unsuitable for diesel combustion. Most commercial systems therefore utilize 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 on stoichiometric mode for low emissions or on lean-mode for higher efficiency. In addition, high pressure storage bottles are required to store Compressed NG (CNG) while liquid NG (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.

CNG busses may have completely different combustion and aftertreatment technology, despite using the same fuel. Hence, their emission performance may significantly vary. Therefore, CNG busses also need to fulfil a specific emission standard (Euro II, Euro III, etc.). Due to the low NO_x and PM performance compared to 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 are benefited from taxation waivers and free entrance to low emission zones. New stoichiometric buses are able to fulfil the EEV requirements, while older busses were usually registered as Euro II or Euro III. **Table 8-29** provides typical emission and consumption factors that can be used to estimate the emission contribution of CNG busses, depending on their emission level. More information on the derivation of these emission values is given in Ntziachristos et al. (2007).

Table 8-29: Proposed emission and consumption factors for urban CNG busses in typical urban driving conditions

Emission Standard	**CO (g/km)**	**THC (g/km)**	**NOx (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

8.11 Two-stroke mopeds <50 cm³

Mopeds are mostly driven under "urban" driving conditions and therefore only an urban emission factor value is proposed in Table 8-30 and
Table 8-31. Emissions factors should be considered as bulk values which include the cold start fraction, therefore no distinction is made to hot and cold start emissions.

8.12 Motorcycles >50 cm³

The equation used to calculate the emission factor of Euro Conventional and Euro 1 motorcycles over 50 cm³ engine displacement is eq. (26). The coefficients to calculate these emission factors up to the Euro I emission standard are given in Table 8-32 for 2-stroke vehicles and Table 8-34 for 4-stroke ones. For more recent vehicle technologies, reduction factors over the Euro 1 emission factor are proposed for 2-stroke ones, which should be applied according to Table 8-33. Urban, rural and highway emission factors are proposed for 4-stroke motorcycles of improved technology in Table 8-35.

Table 8-30: Emission and consumption factors for mopeds (corresponding to urban driving conditions)

Category	Emission Standard	CO [g/km]	NOx [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 8-31: PM emission factors for conventional and post Euro mopeds (corresponding to 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

Table 8-32: Speed dependency of emission and consumption factors for conventional and Euro 1 2 stroke motorcycles of engine displacement over 50 cm³

Pollutant	Emission Standard	Speed Range [km/h]	Coefficients		
			e	c	a
CO	Conventional	10 - 60	-1.000E-03	1.720E-01	1.810E+01
		60 - 110	1.000E-04	5.000E-02	2.150E+01
	Euro 1	10 - 60	-6.300E-03	7.150E-01	-6.900E+00
		60 - 110	-7.000E-04	1.570E-01	6.000E+00
NOx	Conventional	10 - 60	3.000E-05	-2.000E-03	6.400E-02
		60 - 110	-2.000E-05	4.900E-03	-1.570E-01
	Euro 1	10 - 60	2.000E-05	-1.000E-03	3.200E-02
		60 - 110	-2.000E-05	4.100E-03	-1.520E-01
HC	Conventional	10 - 60	3.500E-03	-4.090E-01	2.010E+01
		60 - 110	3.000E-04	-5.240E-02	1.060E+01
	Euro 1	10 - 60	-1.000E-03	9.700E-02	3.900E+00
		60 - 110	-3.000E-04	3.250E-02	5.200E+00
Fuel Consumption	Conventional	10 - 60	6.300E-03	-6.028E-01	4.440E+01
		60 - 110	-5.000E-04	2.375E-01	1.820E+01
	Euro 1	10 - 60	-1.100E-03	2.008E-01	1.780E+01
		60 - 110	-1.000E-03	2.425E-01	1.460E+01

Table 8-33: Emission correction factors for Euro 2 and later 2 stroke motorcycles of engine displacement over 50 cm³ over Euro 1

Pollutant	Emission Standard	Speed Range [km/h]	Equation	Correction Factor CF
CO	Euro 2	10 - 110	$EF_{Euro\ 1} \times CF$	6.88E-01
	Euro 3	10 - 110		1.67E-01
NOx	Euro 2	10 - 110		3.70E+00
	Euro 3	10 - 110		1.00E+01
HC	Euro 2	10 - 110		3.00E-01
	Euro 3	10 - 110		1.20E-01
Fuel Consumption	Euro 2	10 - 110		9.10E-01
	Euro 3	10 - 110		7.00E-01

Table 8-34: Speed dependency of emission and consumption factors for 4 stroke conventional and Euro 1 motorcycles of engine displacement over 50cm³

Pollutant	Cylinder Capacity	Emission Standard	Speed Range [km/h]	Coefficients		
				e	c	a
CO	<250cm³	Conventional	10 - 60	1.93E-02	-1.92E+00	6.83E+01
			60 - 110	1.70E-03	1.21E-01	9.50E+00
		Euro 1	10 - 60	-4.68E-04	1.08E-01	9.33E+00
			60 - 110	-4.68E-04	1.08E-01	9.33E+00
	250<cc<750cm³	Conventional	10 - 60	1.39E-02	-1.42E+00	5.50E+01
			60 - 110	9.00E-04	-9.90E-03	1.78E+01
		Euro 1	10 - 60	1.51E-03	-4.02E-02	8.73E+00
			60 - 110	1.51E-03	-4.02E-02	8.73E+00
	>750cm³	Conventional	10 - 60	1.23E-02	-1.19E+00	4.28E+01
			60 - 110	5.00E-04	1.24E-01	6.90E+00
		Euro 1	10 - 60	2.79E-03	-3.42E-01	1.71E+01
NOx	<250cm³	Conventional	10 - 60	5.00E-05	-1.00E-03	9.00E-02
			60 - 110	2.00E-05	6.00E-04	1.02E-01
		Euro 1	10 - 60	7.66E-05	-2.73E-03	2.32E-01
			60 - 110	7.66E-05	-2.73E-03	2.32E-01
	250<cc<750cm³	Conventional	10 - 60	5.00E-05	-9.00E-04	9.20E-02
			60 - 110	2.00E-05	7.00E-04	1.04E-01
		Euro 1	10 - 60	5.23E-05	4.30E-04	1.91E-01
			60 - 110	5.23E-05	4.30E-04	1.91E-01
	>750cm³	Conventional	10 - 60	5.00E-05	-8.00E-04	1.00E-01
			60 - 110	2.00E-05	8.00E-04	1.12E-01
		Euro 1	10 - 60	1.43E-04	-5.32E-03	1.94E-01
			60 - 110	1.43E-04	-5.32E-03	1.94E-01

Table continues in next page

Table 8-34(cont.): Speed dependency of emission and consumption factors for 4 stroke conventional and Euro 1 motorcycles of engine displacement over 50cm³

Pollutant	Cylinder Capacity	Emission Standard	Speed Range [km/h]	Coefficients		
				e	c	a
HC	<250cm^3	Conventional	10 - 60	1.90E-03	-2.11E-01	6.95E+00
			60 - 110	9.00E-04	-1.41E-01	6.42E+00
		Euro 1	10 - 60	-1.53E-04	3.44E-03	1.21E+00
			60 - 110	0.00E+00	0.00E+00	8.70E-01
	250<cc<750cm^3	Conventional	10 - 60	1.50E-03	-1.64E-01	5.51E+00
			60 - 110	1.00E-05	5.00E-04	8.60E-01
		Euro 1	10 - 60	1.59E-04	-2.58E-02	1.78E+00
			60 - 110	1.59E-04	-2.58E-02	1.78E+00
	>750cm^3	Conventional	10 - 60	2.20E-03	-2.57E-01	9.28E+00
			60 - 110	1.00E-04	-3.10E-02	3.29E+00
		Euro 1	10 - 60	3.36E-04	-5.12E-02	2.68E+00
			60 - 110	3.36E-04	-5.12E-02	2.68E+00
Fuel Consumption	<250cm^3	Conventional	10 - 60	1.89E-02	-1.87E+00	6.79E+01
			60 - 110	8.00E-04	1.61E-01	1.15E+01
		Euro 1	10 - 60	8.40E-03	-6.77E-01	3.57E+01
			60 - 110	8.40E-03	-6.77E-01	3.57E+01
	250<cc<750cm^3	Conventional	10 - 60	2.73E-02	-2.85E+00	9.89E+01
			60 - 110	2.10E-03	-1.55E-01	2.92E+01
		Euro 1	10 - 60	6.44E-03	-6.96E-01	4.65E+01
			60 - 110	6.44E-03	-6.96E-01	4.65E+01
	>750cm^3	Conventional	10 - 60	2.87E-02	-3.11E+00	1.16E+02
			60 - 110	1.80E-03	-1.64E-01	3.70E+01
		Euro 1	10 - 60	7.22E-03	-1.08E+00	7.66E+01
			60 - 110	7.22E-03	-1.08E+00	7.66E+01

Table 8-35: Emission and consumption factors for 4 stroke Euro 2 and Euro 3 motorcycles of engine displacement over 50cm³

Pollutant	Cylinder Capacity	Emission Standard	Speed Range [km/h]	Emission Factor [g/km]		
				Urban	Rural	Highway
CO	All Categories	Euro 2	10 - 110	6.472	5.947	9.309
	All Categories	Euro 3	10 - 110	4.705	1.581	2.241
NOx	All Categories	Euro 2	10 - 110	0.195	0.265	0.531
	All Categories	Euro 3	10 - 110	0.126	0.150	0.329
HC	All Categories	Euro 2	10 - 110	1.053	0.557	0.612
	All Categories	Euro 3	10 - 110	0.628	0.193	0.179
Fuel Consumption	All Categories	Euro 2	10 - 110	Equal to Euro 1		
	All Categories	Euro 3	10 - 110			

Table 8-36 also includes PM emission factors from power two wheelers, which are particularly important for 2-stroke vehicles. These emission factors correspond to a mix of mineral and synthetic lubricant used for 2-stroke engines.

Table 8-36: PM Emission factors for 2 and 4 stroke conventional and post Euro motorcycles of engine displacement over 50cm³

Pollutant	Cylinder Capacity	Emission Standard	Speed Range [km/h]	Emission Factor [gr/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
	<250cm3	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<750cm3	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
	>750cm3	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

8.13 Emissions of non-regulated pollutants

8.13.1 Distinction to methane / non methane VOC emissions

Legislation regulates total VOC emissions with no distinction to methane / non-methane split. Hence, previous tables have provided emission factors for VOC emissions. However, since CH_4 is a greenhouse gas, we need different emission factors to calculate its contribution. In order to calculate hot CH_4 emissions, equation (4) can be applied with the values given in Table 8-37. Reduction factors for more recent technologies are given in Table 8-38. In reference to those tables it should be noted that cold emission factors are applied only for passenger cars and light duty vehicles. In Table 8-38 the reductions are over Euro 1 for passenger cars and over Euro I for heavy duty vehicles and buses. For power two wheelers the reductions are over conventional technology.

Methane emission factors have been derived from the literature for all types of vehicles (Bailey et al. 1989, Volkswagen 1989, OECD 1991, Zajontz et al. 1991, Artemis data).

NMVOC emission are deduced as the remainder of the subtraction of CH_4 total emissions from VOC total emissions, as calculated by equation (37). Hence, after VOC and CH_4 have been calculated by equation (2), NMVOC emissions can also be calculated by:

$$E_{NMVOC} = E_{VOC} - E_{CH4} \tag{37}$$

Table 8-37: Methane (CH_4) emission factors (mg/km)

Vehicle Type	Fuel	Vehicle Technology/Class	CH_4 Emission Factors (mg/km)			
			Urban		Rural	Highway
			Cold	Hot		
Passenger Car	Gasoline	pre-Euro	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	pre-Euro	22	28	12	8
		Euro 1	18	11	9	3
		Euro 2	6	7	3	2
		Euro 3	3	3	0	0
		Euro 4	0	0	0	0
	LPG	pre-ECE	80	80	35	25
		Euro 1				
		Euro 2				
		Euro 3 and later				
Light Duty Vehicles	Gasoline	pre-Euro	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	pre-Euro	22	28	12	8
		Euro 1	18	11	9	3
		Euro 2	6	7	3	2
		Euro 3	3	3	0	0
		Euro 4	0	0	0	0
Heavy Duty Vehicles & Busses	Gasoline	All Technologies	-	140	110	70
	Diesel	GVW<16t	-	85	23	20
		GVW>16t	-	175	80	70
		Urban Busses & Coaches	-	175	80	70
	CNG	Euro I	-	6800		
		Euro II	-	4500		
		Euro III	-	1280		
		EEV	-	980		
Power Two Wheelers	Gasoline	<50 cm^3	-	219	219	219
		>50 cm^3 2-stroke	-	150	150	150
		>50 cm^3 4-stroke	-	200	200	200

Table 8-38: Methane (CH_4) emission reduction factors (%). Reductions are over Euro 1 for passenger cars, Euro I for heavy duty vehicles and busses and the Conventional technology for power two wheelers.

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
Power Two Wheelers	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

8.13.2 PM characteristics

New emission factors for PM characteristics have been developed on the basis of the *Particulates* project and are presented in the following tables. These include the “Active Surface Area” in cm^2/km, the “Total Particle Number” in #/km, and the “Solid Particle Number” in #/km , differentiated in three different classes (< 50 nm, 50-100 nm, 100-1000 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 have been obtained in the laboratory under conditions expected to maximize the concentration of these particles, hence they should be considered to represent a close to maximum emission rate. More details on the sampling conditions and the relevance of these values is given by Samaras et al. (2005).

Table 8-39: PM characteristics of Diesel Passenger Cars

Pollutant	Category	Fuel sulphur content	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 8-40: Solid particle number emission from Diesel Passenger Cars (not affected by fuel sulphur content)

Pollutant	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 100-1000 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 8-41 to Table 8-45 include particle properties information for busses and heavy duty vehicles, following the classification of Table 1-2. Further to the technology classification given in Table 3-6, 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.

Table 8-41: PM characteristics of Buses

Pollutant	Emission Standard	Speed Range [km/h]	Emission Factor		
			Urban	Rural	Highway
Active Surface Area [cm²/km]	Euro II & III	10 - 110	5.65E+05	1.99E+05	2.57E+05
	Euro II & III + CRDPF	10 - 110	8.07E+04	1.77E+04	2.18E+04
	Euro II & 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 & III	10 - 110	6.88E+14	4.55E+14	1.12E+15
	Euro II & III + CRDPF	10 - 110	2.72E+14	4.77E+13	8.78E+13
	Euro II & 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 & III	10 - 110	1.25E+14	5.08E+13	7.43E+13
	Euro II & III + CRDPF	10 - 110	3.87E+12	1.89E+12	4.18E+12
	Euro II & 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
olid Particle Number 50-100 nm [#/km]	Euro II & III	10 - 110	1.44E+14	5.44E+13	6.82E+13
	Euro II & III + CRDPF	10 - 110	3.31E+12	1.43E+12	2.54E+12
	Euro II & 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 100-1000 nm [#/km]	Euro II & III	10 - 110	2.09E+14	7.25E+13	7.16E+13
	Euro II & III + CRDPF	10 - 110	2.29E+12	8.53E+11	1.12E+12
	Euro II & 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 8-42: PM characteristics of Coaches

Pollutant	Emission Standard	Speed Range [km/h]	Emission Factor		
			Urban	Rural	Highway
Active Surface Area [cm²/km]	Euro II & III	10 - 110	6.75E+05	2.23E+05	2.13E+05
	Euro II & III + CRDPF	10 - 110	9.65E+04	1.98E+04	1.81E+04
	Euro II & 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 & III	10 - 110	8.23E+14	5.09E+14	9.28E+14
	Euro II & III + CRDPF	10 - 110	3.25E+14	5.34E+13	7.28E+13
	Euro II & 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 & III	10 - 110	1.49E+14	5.68E+13	6.16E+13
	Euro II & III + CRDPF	10 - 110	4.63E+12	2.11E+12	3.47E+12
	Euro II & 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 & III	10 - 110	1.72E+14	6.08E+13	5.65E+13
	Euro II & III + CRDPF	10 - 110	3.96E+12	1.60E+12	2.10E+12
	Euro II & 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 100-1000 nm [#/km]	Euro II & III	10 - 110	2.49E+14	8.11E+13	5.94E+13
	Euro II & III + CRDPF	10 - 110	2.74E+12	9.54E+11	9.30E+11
	Euro II & 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 8-43: PM characteristics of HDVs 3.5-7.5 tn

HDVs 3.5-7.5 tn					
Pollutant	**Emission Standard**	**Speed Range [km/h]**	**Emission Factor**		
			Urban	**Rural**	**Highway**
Active Surface Area [cm²/km]	Euro II & III	10 - 110	2.62E+05	1.19E+05	1.61E+05
	Euro II & III + CRDPF	10 - 110	3.74E+04	1.06E+04	1.36E+04
	Euro II & 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 & III	10 - 110	3.19E+14	2.72E+14	6.99E+14
	Euro II & III + CRDPF	10 - 110	1.26E+14	2.85E+13	5.48E+13
	Euro II & 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 & III	10 - 110	5.79E+13	3.04E+13	4.64E+13
	Euro II & III + CRDPF	10 - 110	1.80E+12	1.13E+12	2.61E+12
	Euro II & 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 & III	10 - 110	6.68E+13	3.25E+13	4.26E+13
	Euro II & III + CRDPF	10 - 110	1.53E+12	8.56E+11	1.59E+12
	Euro II & 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 100-1000 nm [#/km]	Euro II & III	10 - 110	9.66E+13	4.34E+13	4.47E+13
	Euro II & III + CRDPF	10 - 110	1.06E+12	5.10E+11	7.01E+11
	Euro II & 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 8-44: PM characteristics of rigid HDVs 7.5-14 tn

HDVs 7.5-16 tn					
Pollutant	**Emission Standard**	**Speed Range [km/h]**	**Emission Factor**		
			Urban	**Rural**	**Highway**
Active Surface Area [cm2/km]	Euro II & III	10 - 110	5.56E+05	2.19E+05	2.37E+05
	Euro II & III + CRDPF	10 - 110	7.95E+04	1.95E+04	2.00E+04
	Euro II & 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 & III	10 - 110	6.78E+14	5.00E+14	1.03E+15
	Euro II & III + CRDPF	10 - 110	2.68E+14	5.24E+13	8.07E+13
	Euro II & 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 & III	10 - 110	1.23E+14	5.58E+13	6.83E+13
	Euro II & III + CRDPF	10 - 110	3.82E+12	2.07E+12	3.84E+12
	Euro II & 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 & III	10 - 110	1.42E+14	5.97E+13	6.27E+13
	Euro II & III + CRDPF	10 - 110	3.26E+12	1.57E+12	2.33E+12
	Euro II & 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 100-1000 nm [#/km]	Euro II & III	10 - 110	2.05E+14	7.95E+13	6.58E+13
	Euro II & III + CRDPF	10 - 110	2.26E+12	9.36E+11	1.03E+12
	Euro II & 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 8-45: PM characteristics of rigid HDVs 14-32 t and truck trailer/articulated 14-34t

HDVs 16-32 tn					
Pollutant	**Emission Standard**	**Speed Range [km/h]**	**Emission Factor**		
			Urban	**Rural**	**Highway**
Active Surface Area [cm2/km]	Euro II & III	10 - 110	8.68E+05	3.38E+05	3.14E+05
	Euro II & III + CRDPF	10 - 110	1.24E+05	3.01E+04	2.65E+04
	Euro II & 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 & III	10 - 110	1.06E+15	7.71E+14	1.36E+15
	Euro II & III + CRDPF	10 - 110	4.19E+14	8.08E+13	1.07E+14
	Euro II & 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 & III	10 - 110	1.92E+14	8.61E+13	9.05E+13
	Euro II & III + CRDPF	10 - 110	5.96E+12	3.20E+12	5.09E+12
	Euro II & 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 & III	10 - 110	2.22E+14	9.22E+13	8.31E+13
	Euro II & III + CRDPF	10 - 110	5.09E+12	2.42E+12	3.09E+12
	Euro II & 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 100-1000 nm [#/km]	Euro II & III	10 - 110	3.21E+14	1.23E+14	8.73E+13
	Euro II & III + CRDPF	10 - 110	3.52E+12	1.44E+12	1.37E+12
	Euro II & 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

8.13.3 Nitrous oxide (N_2O) emissions

Nitrous oxide emission factors have been developed on the basis of an LAT/AUTh study (Papathanasiou and Tzirgas, 2005), based on literature data collected in studies around the world. N_2O emission factors are particularly important for catalyst vehicles, and especially under conditions that the catalyst is under partial oxidizing behaviour. This may occur wither when the catalyst has not yet reached its light-off temperature or when the catalyst is aged. Just because the emission of N_2O received increased importance lately, due to its contribution to the greenhouse effect, a detailed calculation of N_2O needs to take vehicle age (mileage) into account. In parallel, the aftertreatment ageing depends on the fuel sulphur level. Hence different emission factors need to be derived depending on the fuel sulphur content. In order to take both these effects into account, N_2O emission factors are calculated according to eq. (38), with its parameters receiving values from Table 8-46 to Table 8-53 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, the urban emission factor is distinguished between a cold-start and a hot-start one.

$$EF_{N2O} = [a \times \text{Mileage} + b] \times EF_{BASE} \quad (38)$$

<u>Passenger Cars</u>

Table 8-46: Parameters for eq.(38) 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 8-47: Parameters for eq. (38) 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 8-48: Parameters for eq. (38) 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 8-49: Parameters for eq. (38) 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

Light Duty vehicles

Table 8-50: Parameters for eq. (38) 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 8-51: Parameters for eq. (38) 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 8-52: Parameters for eq. (38) 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 8-53 Parameters for eq. (38) 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 emission factors for diesel vehicles and motorcycles are not that important compared to catalyst equipped passenger cars and are more roughly estimated on the basis of earlier literature review (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). These data are shown in Table 8-54. For heavy duty vehicles and motorcycles, there is no separate methodology for estimating cold start over-emissions but they are assumed to be already incorporated in the bulk emission factors, as shown in Table 8-54.

Table 8-54: Bulk (hot + cold) nitrous oxide (N_2O) emission factors (mg/km)

Vehicle category	Urban Cold	Urban Hot	Rural	Highway
Diesel Passenger Cars				
Conventional	0	0	0	0
Euro 1	0	2	4	4
Euro 2	3	4	6	6
Euro 3	15	9	4	4
Euro 4	15	9	4	4
LPG Passenger Cars				
Conventional	0	0	0	0
Euro 1	38	21	13	8
Euro 2	23	13	3	2
Euro 3	9	5	2	1
Euro 4	9	5	2	1
Diesel Light Duty Vehicles				
Conventional	0	0	0	0
Euro 1	0	2	4	4
Euro 2	3	4	6	6
Euro 3	15	9	4	
Euro 4	15	9	4	4
Heavy Duty Vehicles	**Urban**		**Rural**	**Highwat**
Gasoline > 3.5 t	6		6	6
Diesel < 7.5 t	30		30	30
Diesel 7.5 t < W < 16 t	30		30	30
Diesel 16 t < W < 32 t	30		30	30
Diesel W > 32 t	30		30	30
Urban Buses	30		-	-
Coaches	30		30	30
Motorcycles				
< 50 cm³	1		1	1
> 50 cm³ 2 stroke	2		2	2
> 50 cm³ 4 stroke	2		2	2

8.13.4 Ammonia (NH_3) emissions

Ammonia emissions from passenger cars and light duty vehicles are estimated on a similar manner to N_2O emissions, presented in the previous section. NH_3 emission factors are calculated according to eq. (38), with its parameters receiving values from Table 8-55 to Table 8-62. As already mentioned, these values differ according to the fuel sulphur level and the driving conditions (urban, rural, highway).

Passenger Cars

Table 8-55: Parameters for eq. (38) 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 8-56: Parameters for eq. (38) 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 8-57: Parameters for eq. (38) 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 8-58: Parameters for eq. (38) 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

Light Duty vehicles

Table 8-59: Parameters for eq. (38) 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 8-60: Parameters for eq. (38) 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 8-61: Parameters for eq. (38) 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 8-62: Parameters for eq. (38) 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 8-63. No separate calculation is made for cold start over-emissions. These emission factors are based on literature review only and should be considered as broad estimates (de Reydellet, 1990; Volkswagen, 1989).

8.13.5 PAHs and POPs

Emission factors (in [μg/km]) for polycyclic aromatic hydrocarbons (PAHs) and persistent organic pollutants (POPs) are given in Table 8-64 for different species and vehicle categories. A rough distinction is made to conventional (pre Euro I) and closed loop catalyst equipped vehicles (Euro I and on). For diesel passenger cars and light duty vehicles, different emission factors are quoted for direct injection and indirect injection vehicles. Since statistical information on the distribution of fleet vehicles according to their combustion concept is difficult to collect, it is proposed to use the average (DI, IDI) emission factor to estimate emissions from diesel non heavy duty vehicles.

Methodoloy is applicable for the six protocol pollutants (indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, fluoranthene, benzo(a)pyrene) and several others. Those emission factors should be considered as bulk values and no distinction is made to hot and cold start emissions. They have been developed on the basis of literature review including the following sources: BUWAL, 1994; TNO, 1993b; Volkswagen, 1989. Application of equation (4) with those emission factors provides total emissions of PAHs and POPs per vehicle class.

Table 8-63: 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 Veh. > 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

Although this introduces just another simplification, PAHs and POPs emissions from 4 stroke motorcycles are estimated with the same emission factors used for conventional gasoline passenger cars. This approach is due to modification as soon any results on emissions of such species from motorcycles become available.

8.13.6 Dioxins and furans

Emission factors of Dioxins and Furans are given in Table 8-65 separately to other POPs because an aggregate toxicity equivalent emission factor is provided in this case. This emission factor takes into account the toxicity of different Dioxin and Furan species according to the NATO - Committee on the Challenges of the Modern Society (NATO-CCMS). Actual emission rates of different Dioxin and Furan species have been collected from the available literature sources (Umweltbundesamt, 1996). The final value is a bulk emission factor expressed in [pg/km]. Due to the limited available information, emission factors provided need to be reconsidered when updated data become available. In order to keep a consistent approach for all vehicle sources, Dioxin and Furan emissions from 4 stroke motorcycles are calculated with the same toxicity equivalent emission factors as of conventional gasoline vehicles.

Table 8-64: 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 8-65: Dioxins and Furans toxicity equivalence emission factors

	Toxicity Equivalent Emission Factors [pg/km]		
Polychlorinated Dibenzo Dioxins	**PC Gasoline Conventional**	**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

8.14 Fuel consumption dependant emission factors

Emissions of heavy metals are calculated by means of equation (17). Table 8-66 provides emission factors of heavy metals for different vehicle categories.

Table 8-66: Heavy metal emission factors for all vehicle categories in mg/kg fuel

Category	Cadmium	Copper	Chromium	Nickel	Selenium	Zinc
Passenger cars, gasoline	0.01	1.7	0.05	0.07	0.01	1
Passenger cars, gasoline catalyst	0.01	1.7	0.05	0.07	0.01	1
Passenger cars, diesel	0.01	1.7	0.05	0.07	0.01	1
Passenger cars, LPG	0.0	0.0	0.0	0.0	0.0	0.0
Light duty vehicles, gasoline	0.01	1.7	0.05	0.07	0.01	1
Light duty vehicles, gasoline catalyst	0.01	1.7	0.05	0.07	0.01	1
Light duty vehicles, diesel	0.01	1.7	0.05	0.07	0.01	1
Heavy duty vehicles, gasoline	0.01	1.7	0.05	0.07	0.01	1
Heavy duty vehicles, diesel	0.01	1.7	0.05	0.07	0.01	1
Motorcycles < 50cm³	0.01	1.7	0.05	0.07	0.01	1
Motorcycles > 50cm³	0.01	1.7	0.05	0.07	0.01	1

8.15 Emission degradation functions

Tables 8.38 and 8.39 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. Relevant methodology given in section 5.7.1

Table 8-67: Emission degradation due to vehicle age for Euro I and Euro II 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 ≥ 120000 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 8-68: Emission degradation due to vehicle age for Euro III and Euro IV gasoline passenger cars and light duty vehicles (and Euro I & II vehicles in case of an enhanced I&M 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 ≥ 160000 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 8-69: 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	$MC_{URBAN} + \frac{(V-19)\cdot(MC_{ROAD}-MC_{URBAN})}{44}$

8.16 Fuel effects functions

Table 8-70, Table 8-71 and Table 8-72 provide the correction functions required to estimate the effect of fuel properties on emissions according to section 5.7.2.

Use of biodiesel as a blend with diesel may also lead to some change in emissions. The values proposed in Table 8-73 are differences in emissions caused by different fuel blends on 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 literature 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 8-73 because the presence of a carbon-atom 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 the 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 in the soot formation potent. Hence, the proposed values of Table 8-73 should be used with care for post Euro 3 diesel technologies

Table 8-70: 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)]
NOx	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)]

Legend: 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 8-71: Relations between emissions and fuel properties for Diesel passenger cars and light duty vehicles

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

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

Table 8-72: Relations between emissions and fuel properties for Diesel heavy duty vehicles

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

Legend: DEN = Density at 15°C [kg/m³]
S = Sulphur content in ppm
PAH = Polycyclic aromatics content in %
CN = Cetane number
T_{95} = Back end distillation in °C

Table 8-73: 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%

9 SPECIES PROFILES

9.1.1 VOC Speciation

The content of non methane VOCs in different species is given in Table 9-1a and Table 9-1b. Proposed fractions have been obtained by results published in the literature (BUWAL, 1994; TNO, 1993; Volkswagen, 1989; Umweltbundesamt, 1996). Fractions quoted in those Tables are applied to the total NMVOC emissions from vehicle classes classified as conventional (pre Euro I) or closed loop catalyst equipped (Euro I and on) 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).

NMVOC speciation from four stroke motorcycles is estimated with 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 9-1b shows the total that these fractions sum to. It is assumed that the remaining fraction consists of PAHs and POPs.

Table 9-1a: Composition of NMVOC in exhaust emissions (alkanes, cycloalkanes, alkenes, alkines)

Group	Species	NMVOC Fraction (% wt.)				
		Gasoline 4 stroke		Diesel PC & LDV	HDV	LPG
		Convent.	Euro I & on	IDI & DI		
ALKANES	ethane	1.65	3.19	0.33	0.03	2.34
	propane	0.47	0.65	0.11	0.10	49.85
	butane	2.90	5.24	0.11	0.15	15.50
	isobutane	1.29	1.59	0.07	0.14	6.95
	pentane	1.78	2.15	0.04	0.06	0.35
	isopentane	4.86	6.81	0.52		1.26
	hexane	1.29	1.61			
	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			
ALKINES	1-butine	0.05	0.21			
	propine	0.76	0.08			
	acetylene	5.50	2.81	2.34	1.05	1.28

Table 9-1b: 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 trimethylbenzen	0.59	0.86	0.25	0.30	0.05
	1,2,4 trimethylbenzen	2.53	4.21	0.57	0.86	0.25
	1,3,5 trimethylbenzen	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**

9.1.2 NOx Speciation

Table 9-2 provides the range of NO_2/NO_x values developed in the framework of two relevant studies in Europe. The AEAT (2007) study has been 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 significantly differ 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 relevant to NO_2

emission determination. The AEAT study was considered more up-to-date given the detailed discussion within UK concerning primary NO_2 emission rates (AQEG, 2006) and NO_2/NOx data provided to AEAT by LAT. The ranges proposed in the AEAT study for passenger cars have been transferred to light duty vehicles as well.

Table 9-2: Mass fraction of NO_2 in NO_x emissions

Category	Emission Standard	NO2/NOx primary mass ratio (%)		
		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 NO_2/NO_x ratios for upcoming vehicle and engine technologies (post Euro 4). Therefore, some estimates need to be conducted based on the expected technology. Due to the spread of the urea network and the heavy investments of manufacturers on SCR technology, it is expected that SCR will become more popular on diesel cars and trucks in the future. Also, due to the better engine calibration and fuel efficiency that it provides, SCR may also become more frequent in gasoline cars. Additionally, SCR systems may assist the promotion of lean-burn GDI gasoline concepts. SCR, when properly calibrated leads to negligible NO_2 emissions (Mayer et al., 2007), as NO_2 efficiently reacts with ammonia to produce nitrogen and water.

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

With regard to diesel passenger cars, SCR would ideally zero tailpipe NO_2 emissions. However, deviations from ideal in urea dosing over transients may lead to NO_2 slip. This could lead to an estimated increase of NO_2 up to 20%. Furthermore the need for high efficiency over cold start may lead manufacturers to place SCR close to the engine outlet, followed by a catalyzed diesel particle filter. In this case, the oxidative environment inside the filter may lead to high NO_2 ratios. Hence, for Euro 5 and 6 passenger cars, the NO_2/NO_x ratio will strongly depend on the concept desired and the whole range of 5-70% seems possible.

In the case of heavy duty vehicles the evolution of NO_2/NO_x ratio for future technologies is more predictable than 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 mode of operation of heavy duty engines also means reduced NO_2 slip compared to passenger cars. As a result, the SCR will effectively reduce the tailpipe NO_2 emission levels. A NO_2/NO_x ratio of 10% is proposed just to account for any non-idealities in SCR calibration in real-world operation.

9.1.3 PM Speciation in elemental and organic carbon

The range of data collected from tunnel, roadway and dynamometer studies and the uncertainties in the experimental determination of, in particular, organic carbon (OC) indicate that the determination of exhaust PM speciation is bound to large uncertainties. However, this does not mean that the task of deriving such ratios is impossible, because there is a general agreement in measurements conducted in tunnels and in laboratory studies, with regard to the emission characteristics of diesel and gasoline vehicles. Also, the effect of different technologies (e.g. oxidation catalyst, diesel particle filter, etc.) on emissions is also predictable.

Table 9-3 suggests ratios of organic material (OM) over elemental carbon (OM/EC) and $EC/PM_{2.5}$ that can be used on the exhaust PM emissions calculated from Copert and similar models for different vehicle technologies. Organic material is the mass of organic carbon corrected for the hydrogen content of the organic species 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 according to literature values. 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 (e.g. emissions from individual vehicles falling in a specific category may exceed this uncertainty range). The ratios suggested correspond to average driving conditions with no distinction between driving modes or cold-start operation.

Table 9-3: Split of PM in elemental (EC) and organic mass (OM)

Category	Euro Standard	EC/PM2.5 (%)	OM/EC (%)	Uncertainty (%)
Gasoline PC and LDT	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 LDT	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	10	500	50
	Euro 3, Euro 4, Euro 5	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
Power Two Wheelers	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 proposed originate from available literature data and engineering estimates of the effect of technological solutions (catalysts, DPFs, etc.) on emissions. The available literature data of OM have been scaled down in cases where EC and OM exceeded 100% of the collected mass (due to the positive artefact discussed before). Also, the table assumes low sulphur fuels (<50 ppm wt. S), currently available in Europe. Hence, the contribution of sulphate on PM emissions is generally low. In cases where advanced aftertreatment is used (such as catalysed DPFs) then the EC and OM does not sum up to 100%. The remaining fraction is assumed to be ash, nitrates, sulphates, water and ammonium, that can be a significant fraction of total PM.

10 UNCERTAINTY ESTIMATES

10.1 Fuel consumption balance

Several input data in applying the methodology can obviously be only estimates. Such data include total annual mileage, share of mileage to different driving modes (urban, rural, highway), mean travelling speeds, etc. There is a certain degree of uncertainty in estimating these data. A firm checkpoint in estimating the accuracy of calculations is that the total calculated fuel consumption per fuel type should equal the consumption statistics for the level of activity considered. If however the calculated value does not match the true one, the "soft" input variables should be modified. "Soft" in this case denotes those variables associated with large uncertainty. Since the availability of statistical data differs from one country to another, it is up to national experts to make the appropriate modifications. However, the authors have the impression that the distribution of mileage in driving conditions (urban, rural, highway) and the respective average travelling speeds are those variables for which most attention should be given in most of the cases.

10.2 Unleaded fuel allocation

This method is only relevant for calculations corresponding to pre-2000 runs when unleaded fuel was available. In such cases, even if fuel balance has provided close values for calculated and statistical fuel consumption for each vehicle type, a similar situation may be observed when actual consumption of unleaded fuel exceeds the calculated one. However, it was known that drivers of conventional (non-catalyst) vehicles sporadically refuelled their vehicles with unleaded gasoline to benefit from the lower prices due to lower taxation. Therefore, statistical values provided for unleaded fuel consumption cannot be solely used to check the quality of calculations via an unleaded fuel balance because of the failure to identify the exact use of this fuel type. In this case, an alternative approach is proposed.

It is assumed that passenger cars originally considered to use leaded gasoline, have also the potential to operate on unleaded fuel, in cases where the statistical value provided for unleaded fuel exceeds the respective calculated one. To account for this, it is proposed that one or more vehicle classes should be shifted to the use of unleaded fuel, until the calculated consumption of unleaded fuel equals or just exceeds the statistical one. This change should start from the most recent leaded gasoline class ("Improved Conventional" vehicles) and should reach up to "PRE ECE" ones in cases where a large positive deviation exists between the statistical and the calculated value. Preferably, consumption of vehicles of large engine capacity is corrected first. Table 10-1 provides the exact sorting of vehicle classes proposed for allocating unleaded fuel.

However, in actual inventories corrections should not exceed a few vehicle classes. In cases where a large number of classes need to be shifted from leaded to unleaded fuel use, input data should be checked and probably corrected. Moreover, the ban of unleaded fuel that took place in 2000 in most Member States (and by 2002 to all MSs), renders this discussion obsolete for post 2000 runs.

Table 10-1: Sorting order of vehicle classes originally operating on leaded gasoline and participating in the unleaded fuel allocation algorithm (classes appearing first in the table are the ones for which leaded to unleaded shift occurs first)

Sort Order	Legislation Class	Subsector
1	Improved Conventional	Gasoline 1.4 - 2.0 l
2	Improved Conventional	Gasoline <1.4 l
3	ECE 15/04	Gasoline >2.0 l
4	ECE 15/04	Gasoline 1.4 - 2.0 l
5	ECE 15/04	Gasoline <1.4 l
6	ECE 15/03	Gasoline >2.0 l
7	ECE 15/03	Gasoline 1.4 - 2.0 l
8	ECE 15/03	Gasoline <1.4 l
9	ECE 15/02	Gasoline >2.0 l
10	ECE 15/02	Gasoline 1.4 - 2.0 l
11	ECE 15/02	Gasoline <1.4 l
12	ECE 15/00-01	Gasoline >2.0 l
13	ECE 15/00-01	Gasoline 1.4 - 2.0 l
14	ECE 15/00-01	Gasoline <1.4 l
15	PRE ECE	Gasoline >2.0 l
16	PRE ECE	Gasoline 1.4 - 2.0 l
17	PRE ECE	Gasoline <1.4 l

10.3 Range of application of hot emission factors

Emission factors proposed by the methodology have been derived in the framework of different scientific programmes. Emission factors of former technology passenger cars and light duty vehicles have been developed in the frame of older COPERT/CORINAIR activities (Eggleston et al., 1989) while emissions from recent vehicles are calculated on the basis of the work conducted in the frame of MEET (Samaras and Ntziachristos, 1998). Emission factors for heavy-duty trucks, coaches and busses originate from the German/Swiss Handbook of emission factors (Keller et al., 1995). Also, emission factors for mopeds and motorcycles are derived from the same work with further processing by TNO (Rijkeboer R.C., 1997).

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

Application of the emission factors should only be made within the speed ranges given in the respective tables providing the emission factors. Those ranges have been defined according to the availability of the input data. Extrapolation of the proposed formulas to lower/higher speeds is therefore not advised, because this is not justified on the basis of the available experimental data.

The proposed formulas should only be used with average travelling speed and by no means can be considered an accurate approach when only instant speed values are available. 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 cases in which the driving pattern differs too much from what is common, e.g. in traffic calming areas.

The three road types (highway, urban, rural) are obviously synonyms for certain driving patterns which are to some extent typical, but not the same in all countries and cities, e.g. there are indications that highway driving in Germany takes place at a higher average speed than in Belgium, or urban driving in Athens takes place at a lower average speed than in Berlin, and so on. Moreover, it is possible that driving patterns depend on additional parameters, such as age of the vehicle or cylinder capacity. Such dependencies should only be taken into account if sound statistical data are available.

As in all cases of the application of 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, if the methodology used for estimating road traffic emissions represents a reliable image of reality. These uncertainties are the results of errors which can be divided into random and systematic ones.

Random errors are those caused by:

- the inaccuracy of the measurement devices and techniques,
- the lack of a sufficient number of representative measurements, e.g., for heavy duty vehicles, cold starts, and evaporative emissions,
- erroneous data with regard to vehicle usage.

In principle systematic errors may be distinguished into two categories:

- Errors concerning emission factors and measurements:
- Errors in the patterns used to simulate actual road traffic; this means that driving cycles may not be representative of real-life road traffic, e.g., typical speed and acceleration of real driving conditions may be considerably different from those used in off-road dynamometer tests, thus systematically underestimating vehicle emissions
- Errors in the emission factors used for the calculations. Sufficient emission measurements are not available in all countries; therefore, average values derived from measurements in other countries have to be used. This can lead to significant variations because in some countries vehicles are undergoing periodic emission tests, so measured emission factors may not be representative of the vehicle fleets of other countries; this can bias the emission factor measurements and the evaluation of the effects of Inspection/Maintenance programmes and degradation of emission control equipment.

Errors concerning assessment of vehicle park and usage:

- Erroneous assumptions of vehicle usage. In many countries the actual vehicle usage is not known, in some others, data from only a few statistical investigations are available. Most important are errors in total kilometres travelled and in the average trip length. However, the fuel balance (i.e., the comparison of the calculated fuel consumption with the statistically known one), is a valuable means to check the validity of the various assumptions made and to avoid major errors.

- Erroneous estimates of the vehicle park. Not all sub-categories of the methodology presented here appear in the statistics and, therefore, have to be estimated. To take an example, assessing the number of gasoline and diesel vehicles >2.5 t which belong to the category "Light Duty Trucks" 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 10-2 provides qualitative indications of the "precision" which can be allocated to the calculation of the individual emissions. In general, no emission measurements were available for post Euro I passenger cars and light duty vehicles. Therefore, a “D” index should be assigned to these vehicle technologies. However, despite the “D” indication, a sound engineering approach has been used to derive their emissions (see Ntziachristos and Samaras, 2001). Hence, it is expected that those emission factors should not much deviate from actual levels.

In order to illustrate the above evaluation, Table 10-3 presents as an example the estimate of the band of errors expressed as the coefficient of variation (CV = standard deviation / mean value) of the measured VOC emission factors and fuel consumption factors. It is interesting to note that the mean CV for measured VOC emission factors is 48.7% while the mean CV for fuel consumption factors is 12.1%. Moreover, measured data from older ECE classes (conventional cars) show lower variation than measurements of catalyst-equipped vehicles. This is probably because the emission level of catalyst vehicles is much dependant on the condition of the aftertreatment system (maintenance condition, thermal condition, etc.). Hence, even if their emission level is much below conventional vehicles, their variability is larger. Moreover, a fraction vehicles in the Euro I technology class are a collection of vehicles following different national standards and consecutively emission control techniques of different efficiency. Thirdly, a large number of driving cycles with different dynamic conditions has been utilised for the production of the emission factors and this increases the variability of the results.

Table 10-2: Precision Indicators of the Emission Estimate for the Different Vehicle Categories and Pollutants

Legend: 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. See text for later than Euro I vehicles.

Vehicle Category	Pollutants									
	NOx	CO	NMVOC	CH_4	PM	N_2O	NH_3	SO_2	CO_2	Pb	FC
Gasoline Passenger Cars											
Up to Open Loop	A	A	A	A	-	C	C	A	A	B	A
Euro I	A	A	A	A	-	B	B	A	A	A	A
Diesel Passenger Cars											
Up to Euro I	A	A	A	A	A	B	B	A	A	-	A
LPG Passenger Cars	A	A	A	-	-	--	-	-	A	-	A
2 Stroke Passenger Cars	B	B	B	D	-	D	D	A	B	B	B
Light Duty Vehicles											
Gasoline up to Euro I	A	A	A	B	-	B	B	A	A	A	A
Diesel up to Euro I	A	A	A	B	A	B	B	A	A	-	A
Heavy Duty Vehicles											
Gasoline	D	D	D	D	-	D	D	D	D	D	D
Diesel	A	A	A	B	A	B	B	A	A	-	A
Two Wheelers											
<50 cm³	A	A	A	B	-	B	B	A	A	A	A
> 50 cm³ 2 stroke	A	A	A	B	-	B	B	A	A	A	A
> 50 cm³ 4 stroke	A	A	A	B	-	B	B	A	A	A	A
Cold Start Emissions											
Pass. Cars Conventional	B	B	B	-	-	-	-	-	B	B	B
Pass. Cars Euro I	A	A	A	A	-	-	-	A	A	A	A
Pass. Cars Diesel Conv.	C	C	C	-	C	-	-	-	B	-	C
Pass. Cars Diesel Euro I	A	A	A	A	A	-	-	A	A	A	A
Pass. Cars LPG	C	C	C	-	-	-	-	-	B	-	C
Gas Light Duty Vehicles	D	D	D	-	-	-	-	-	D	D	D
Diesel Light Duty Veh.	D	D	D	-	D	-	-	-	D	-	D

Table 10-3: Estimated error of emission factors, according to the variance of measured data for Passenger Cars < 3.5 t

Emission Factor	Legislation / Technology	Cylinder Capacity	Mean CV [%]
	Gasoline Cars		
VOC	PRE ECE	All categories	16.5
	ECE 15-00/01	All categories	32.6
	ECE 15-02	All categories	32.7
	ECE 15-03	All categories	25.5
	ECE 15-04	All categories	32.8
	Improved Conventional	CC < 1.4 l	32.8
		1.4 l < CC < 2.0 l	39.9
	Open Loop	CC < 1.4 l	47.5
		1.4 l < CC < 2.0 l	49.2
	Euro 1	CC < 1.4 l	76.7
		1.4 l < CC < 2.0 l	87.5
		CC > 2.0 l	111.2
FC	PRE ECE	CC < 1.4 l	3.2
	ECE 15-00/01		11.4
	ECE 15-02		9.5
	ECE 15-03		10.3
	ECE 15-04		10.3
	Improved Conventional		15.9
	Open Loop		15.0
	Euro		10.6
	PRE ECE	1.4 l < CC < 2.0 l	3.1
	ECE 15-00/01		9.6
	ECE 15-02		10.7
	ECE 15-03		10.9
	ECE 15-04		25.8
	Improved Conventional		22.4
	Open Loop		20.7
	Euro 1		14.8
	PRE ECE	CC > 2.0 l	6.3
	ECE 15-00/01		12.2
	ECE 15-02		6.7
	ECE 15-03		8.6
	ECE 15-04		11.0
	Euro I		17.5
	Diesel Cars		
VOC		1.4 l < CC < 2.0 l	28.4
		CC > 2.0 l	54.5
FC		1.4 l < CC < 2.0 l	21.4
		CC > 2.0 l	21.6
	LPG Cars		
VOC		All categories	9.2
FC		All categories	20.0

CV: coefficient of variation (= standard deviation / mean value)

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The work on emission factors for traffic is a continuously improving task. The points which are the main focus for revision are:

i) Cold start modelling including the improvement brought with the new emissions test at –7°C
ii) Emission factors from light duty vehicles
iii) Estimate of the heavy metal content of exhaust emissions due to fuel, lubricant and engine attrition
iv) More capacity classes and better assessment of fuel consumption from new vehicle concepts to better describe CO_2 related emissions
v) Independent estimations, e.g. nation-wide surveys, of total annual mileage driven on the three road classes by each of the vehicle categories
vi) Methodology and statistical input for estimating the spatial allocation of vehicle emissions and trip statistics
vii) Statistical calculation of total uncertainties for the estimation of emissions, e.g. by Monte Carlo analysis

Moreover, it should be mentioned that the estimation of emissions from road traffic might be, more than in the case of other source categories, a task which requires permanent updating. This is due to the relatively large and rapid changes in this sector over short time periods, e.g. 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, but also the adaptation of the methodology.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

In order to meet the CORINAIR requirements, and in particular the one that data should be suitable for advanced long-range dispersion models, this information in principle should be available for the smallest territorial unit (NUTS 3 level).

For countries for which the required input data are not available at this low level, it seems to be more appropriate to start at NUTS level 0 (national level) and to allocate emissions to other NUTS levels with the help of available surrogate data. National particularities can be taken into account by this top-down approach via the composition of the vehicle parc, the driving conditions and the temperature dependency of some emission factors, and the influence of road gradient on heavy vehicle emissions. In such cases the following guidelines apply:

i) Urban emissions should be allocated to urban areas only, e.g. by localising geographically 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.

ii) 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.

iii) Highway emissions should be allocated to highways only, that means: all roads on which vehicles are driven in accordance with the "highway driving pattern", not necessarily what is called "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 national statistics are more detailed.

For countries which have the required input available at smaller NUTS level (including for example traffic counting) it is proposed to make use of this information and to apply a bottom-up approach, building the national total by summing up emissions from the smaller units. However, in such cases it is recommended to cross-check the total obtained in this way with the total calculated by using the top-down approach in order to balance possible deviations in the statistics. As already mentioned, it has been shown (Zachariadis and Samaras, 1997; Moussiopoulos et al., 1996) that the proposed methodology can be used with a sufficient degree of certainty at a higher resolution too, i.e. for the compilation of urban emission inventories with a spatial resolution of 1x1 km^2 and a temporal resolution of 1 hour.

However, the amount of information given in this report (statistical data and calculated values) is suitable for the compilation of national emission inventories. Application of the methodology at higher spatial resolution has to be done only when more detailed data are available from the user. As a general guideline, it can be proposed that the smaller area of application should be the one for which it can be considered that the fuel sold in this region (statistical consumption), equals the actual consumption of the vehicles operating in this region.

13 TEMPORAL DISAGGREGATION CRITERIA

The temporal resolution of road transport emissions is particularly important as input in mesoscale air quality models or for local air pollution assessment. In this case, the patterns of the traffic load, in conjunction with the variation over time of the average vehicle speed. should be used for the calculation of temporal variation of the emissions. This means that traffic counts and speed recordings (or estimates) should be available for the modelled area.

In principle, the two approaches (top down and bottom up) mentioned above for the spatial disaggregation apply here as well: In the top down approach total road traffic emissions are first spatially and then temporally disaggregated over the area, using traffic load and speed variation in a dimensionless form as the basic disaggregation pattern. In the bottom-up approach emissions are calculated on the basis of the available patterns and then summed up. Again, in such cases it is recommended to cross-check the total obtained in this way with the total calculated by using the top-down approach in order to balance possible deviations in the statistics.

According to the proposed methodology cold-start emissions are calculated on a monthly basis providing already a temporal resolution. However, special attention should be paid on the allocation of the cold-start extra emissions in urban areas. If solid data are lacking, then the following suggestion could be helpful: The urban area can be divided into three districts, a central business district, a residential district and an intermediate district. By coupling the districts with the trip patterns of the city, it is in principle possible to come up with a first approximation of temporal (and spatial) allocation of cold start emissions.

At this point it has to be recalled that spatial and temporal disaggregation of the emissions is coupled with a deterioration of the accuracy of the emission estimates. This is particularly true in the case of road transport emissions, because:

i) at high resolution the random character of transport activities dominates the emission estimates and
ii) the emission factors proposed are aggregated emission factors, averaged over a large number of driving cycles, therefore not necessarily representative of the instantaneous emissions of vehicles driven under actual conditions.

Emission Estimates for Urban areas

Spatially and temporally disaggregated emission inventories are necessary in order to make reliable air quality simulations and predict ambient concentration levels with reasonable accuracy. Several attempts to create a refined motor vehicle emission inventory have been made up to now, in particular for urban areas. These attempts can be distinguished in top-down (or macroscale) and bottom-up (or microscale) approaches. Evidently the bottom-up method attempts to simulate reality more accurately and requires more effort than the top-down method, although it is not yet clear whether such a degree of sophistication could bring more reliable emission estimates and consequently support better air quality simulations.

Figure 13.1 illustrates a methodological approach that can be followed in order to make maximum usage of both approaches in the creation of such an emission inventory. In the bottom-up approach motor vehicle emissions are calculated for each street or road of the area under simulation at an hourly basis; according to the top-down approach, the whole area is simulated on an annual basis. In principle, the top-down and bottom-up estimates of motor vehicle emissions are carried out independently. In each case the "hard facts", i.e. the most reliable information (such as traffic counts, statistics of vehicle registrations and measured emission factors) are the starting point; uncertain parameters are then assessed according to relevant knowledge and reasonable assumptions. In the top-down approach the fuel balance constitutes already an internal calibration point: calculated and statistical fuel consumption should not vary greatly.

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, cold start annual vehicle kilometres and emission factors) are compared, and it is attempted to resolve the discrepancies that may be identified. This reconciliation procedure leads to a re-estimation of the most uncertain parameters of each approach. At this point, emission factors are evidently a crucial parameter; more analytical microscale estimates apply modal emission factors which are expressed as a function of instantaneous vehicle speed and acceleration and therefore differ from average speed dependent emission factors that are regularly used in macroscale models. In that case the harmonisation of the two different sets of emission factors is required as well. The activity and emission data having been reconciled, the next step is to calculate total fuel consumption and emissions with both approaches and compare their aggregate results.

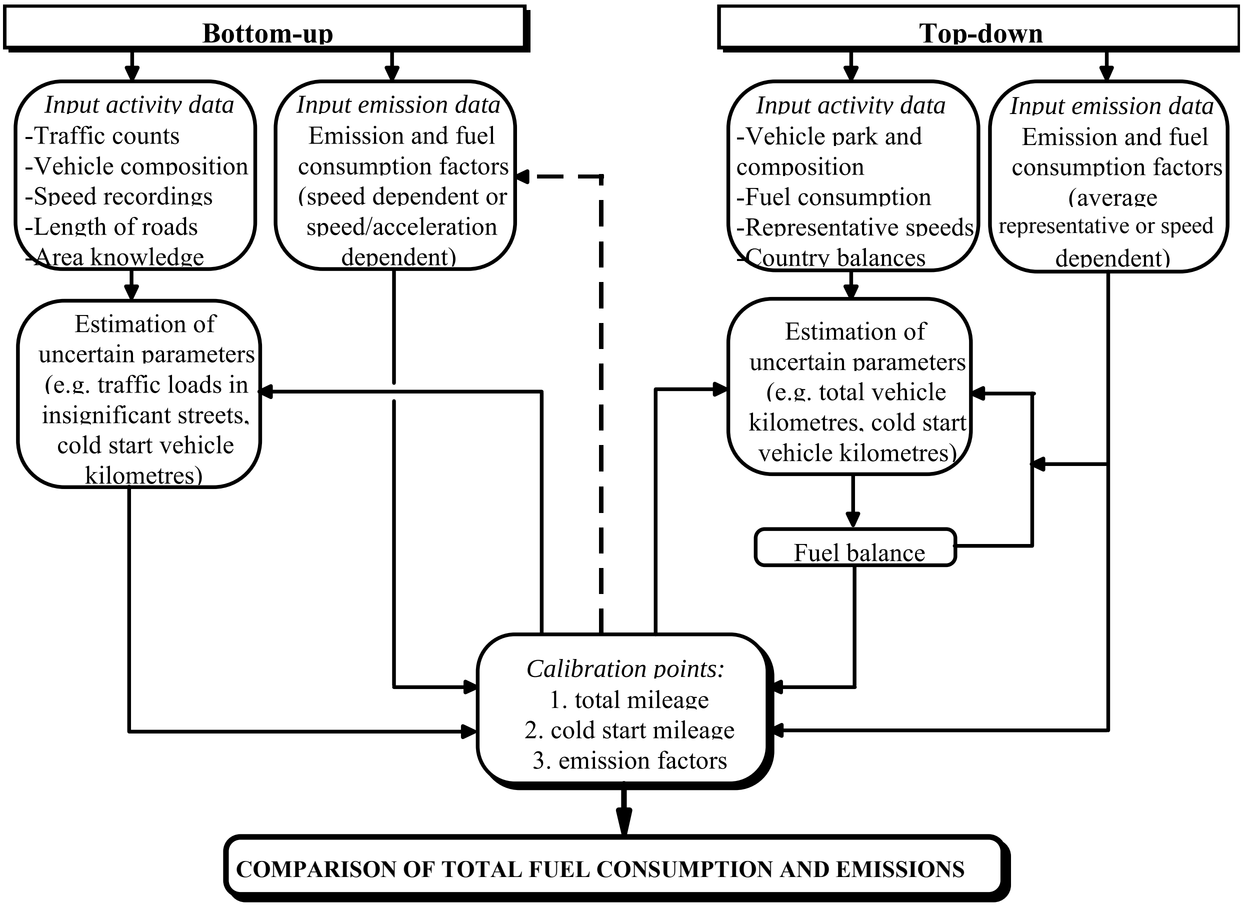

Figure 13.1: Proposed reconciliation method in applying bottom-up and top-down approaches when building an urban emission inventory

The scheme shown in Fig. 13.1 gives an overview of the required information for such an approach. Evidently most of these data are sufficiently available in most European cities. 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.

14 ADDITIONAL COMMENTS

As mentioned above the results of this work will be included into the fourth version of the COPERT (**Co**mputer **P**rogramme to Calculate **E**missions from **R**oad **T**raffic) computer programme (http://lat.eng.auth.gr/copert). This program is officially used by several countries for reporting emissions of road transport.

15 SUPPLEMENTARY DOCUMENTS

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16 VERIFICATION PROCEDURES

In the following only some concepts for emissions inventory verification are outlined, that are applicable in the case of road transport emission inventories. For a more detailed discussion on these issues, refer to Mobley et al. 1994 (see Chapter on "Procedures for Verification of Emission Inventories" in this Guidebook). In general these approaches can be categorised into soft and ground truth verification approaches. Specifically:

i) The first category comprises:

Comparison of alternate estimates: These estimates can be compared to each other to infer the validity of the data based on the degree of agreement among these estimates. Such a process can help to homogenise data developed through different approaches.

Quality Attribute Ratings: This approach involves the development of a semi-quantitative procedure that could assign a value for a component of an emissions inventory or to the collective emissions inventory. An example of such a technique (called the Data Attribute Rating System) is in development in US EPA. A numerical scale is used to rank a list of attributes in a relative priority against the set of criteria selected to represent the reliability of each attribute estimate.

ii) The second category comprises:
Survey Analyses: Some common methodologies for estimating emissions from area sources rely on a per capita or per area emission factor. The results of a statistical sampling based on these principles could be applied to develop regionally specific emission or allocation factors that depend on population density, economic demographics etc.

Indirect Source Sampling: These approaches can use remote measurement techniques (FTIR, Ultra Violet Spectrometry, Gas Radiometer). Specifically the Gas Filter Radiometer Emission Test System has been used to measure in use motor vehicle emissions.

Ambient Ratio Studies: Typically these measurement programmes include a rural measurement side, two or more sides in the downtown area and two or more sides in the downwind sector. Grid based and trajectory modelling approaches are used to simulate the urban area and model predictions are compared to the observed concentrations.

Tunnel Studies: Concentrations can be measured at both the upwind and downwind portals of the tunnel and the emissions rate can be calculated by the air difference. The measured concentrations data may be used to estimate the mass emissions rate for the sampling period.

Air Quality Modelling: This is a complex activity in which atmospheric processes are simulated through the solution of a series of mathematical expressions. All models involve simplifying assumptions to represent the process active in the atmosphere. The lack of understanding of all the atmospheric processes and the simplifying assumptions contribute to a significant uncertainty in model outputs.

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18.1 List of abbreviations

CC	Cylinder Capacity of the Engine
CH_4	Methane
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
EC	Elemental Carbon
FC	Fuel Consumption
GVW	Gross Vehicle Weight
HDV	Heavy Duty Vehicle
I&M	Inspection and Maintenance
LDV	Light Duty Vehicle
LPG	Liquid Petroleum Gas
NH_3	Ammonia
NMVOC	Non-Methane Volatile Organic Compounds
N_2O	Nitrous Oxide
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
SNAP	Selective Nomenclature for Air Pollution
SOx	Sulphur Oxides
VOC	Volatile Organic Compounds

18.2 List of symbols

$\mathbf{A_0 \ldots A_6}$	constants for the emission correction due to road gradient
$\mathbf{A^M}$	emission performance degradation per kilometre
$\mathbf{B^M}$	relative emission level of brand new vehicles
bc	correction coefficient for the β-parameter to be applied for improved catalyst vehicles
$\mathbf{E_{HOT}}$	total emissions during thermally stabilised (hot) engine and exhaust aftertreatment conditions
$\mathbf{E^{CALC}}$	emission of a fuel dependent pollutant (CO_2, SO_2, Pb, HM) estimated on the basis of the calculated fuel consumption
$\mathbf{E^{CORR}}$	corrected emission of a fuel dependent pollutant (CO_2, SO_2, Pb, HM) on the basis of the statistical fuel consumption
$\mathbf{e^{COLD}/e^{HOT}}$	ratio of emissions of cold to hot engines
$\mathbf{e_{HOT}}$	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"
$\mathbf{FC^{CALC}}$	calculated fuel consumption)
$\mathbf{FCe_{HOT}}$	hot emission factor corrected for the use of improved fuel
FCorr	emission correction for the use of conventional or improved fuel
$\mathbf{FC^{STAT}}$	statistical (true) total consumption
$\mathbf{FC^{BIO}}$	statistical fuel consumption of biofuel

GCorr	emission correction factor for the effect of road gradient
GCe_{HOT}	corrected hot emission factor for road gradient
k	weight related content of any component in the fuel [kg/kg fuel]
LCe_{HOT}	corrected hot emission factor for vehicle load
LCorr	vehicle load correction factor
LP	the actual vehicle load factor (expressed as a percentage of the maximum load. That is, **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

18.3 List of indices

a	monthly mean
Base	referred to the base fuel quality
c	cycle (c= UDC, EUDC)
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 (i = 1-36)
j	vehicle class (j = 1-230)
jm	vehicle class operating on fuel type m
k	road classes (k= urban, rural, highway)
m	fuel type (m= gasoline, diesel , LPG)
Pb	Lead content in fuel
RURAL	referring to rural driving conditions
S	Sulphur content in fuel
TOT	referring to total calculations
URBAN	referring to urban driving conditions

19 RELEASE VERSION, DATE AND SOURCE

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1 ACTIVITIES INCLUDED

This chapter provides the methodology, emission factors and relevant activity data to calculate evaporative NMVOC emissions from gasoline vehicles (SNAP code 0706). The term “evaporative emissions” refers to the sum of all NMVOC emissions not deriving from fuel combustion.

2 CONTRIBUTIONS TO TOTAL EMISSIONS

The contribution of evaporative losses to the total road transport related VOC emissions has been decreased considerably since the introduction of carbon canisters. The percentage contribution for various European countries in 2006 is shown in Table 2-1, based on the methodology presented in this chapter and the activity data and exhaust emissions calculated with TREMOVE v2.5.

Table 2-1: 2006 Total Evaporative Emissions as Percentage of the National Total VOC of Road Transport

Country	%	Country	%
AT	2.9	HU	4.4
BE	6.8	IE	12.7
CH	11.2	IT	8.5
CZ	5.0	LU	6.6
DE	11.5	NL	4.9
DK	6.1	NO	16.7
ES	9.0	PL	9.4
FI	5.1	PT	3.5
FR	10.5	SE	10.2
GR	8.8	SI	3.6
		UK	15.2

3 GENERAL

3.1 Description

Breathing losses through the tank vent and fuel permeation are in general the most important sources of evaporative emissions in a vehicle. Breathing losses are due to evaporation of gasoline in the tank during driving and parking, as a result of normal diurnal temperature variation. In current vehicles vapour emissions are controlled by means of an activated carbon canister connected to the fuel tank. Various studies, (e.g. CRC, 2004; Reuter et al., 1994), indicate that liquid fuel seepage and permeation through plastic and rubber components of the fuel and vapour control system contribute significantly to the total evaporative emissions. There are three main mechanisms causing evaporative emissions from gasoline powered vehicles, that is diurnal emissions, running losses and hot soak emissions.

3.1.1 Diurnal emissions

The evaporative emissions associated with the daily (diurnal) variation in ambient temperature result from the vapour expansion inside the gasoline that occurs as the ambient temperature rises during the daylight hours. Without an emission control system, some of the increasing volume of fuel vapour is vented to the atmosphere.

3.1.2 Running losses

Running losses are the result of vapour generated in gasoline tanks during vehicle operation. For older vehicles equipped with carburettor and/or fuel return systems, engine operation results in a significant temperature increase in the fuel tank and/or the carburettor (Morgan et al., 1993). For such vehicles, the combined effect of high ambient temperature and exhaust system heat can generate a significant amount of vapour in the gasoline tank. For gasoline vehicles with fuel injection and returnless fuel systems, the fuel temperature in the tank is not affected by engine operation and thus no fuel vapour is generated in the tank. The running losses of these vehicles are therefore very low and may be attributed to fuel permeation and/or leakage.

3.1.3 Hot soak emissions

Hot soak evaporative emissions are the emissions caused when a hot engine is turned off. Heat from the engine and exhaust system increases the temperature of the fuel in the system that is no longer flowing. Carburettor float bowls are a particularly significant source of hot soak emissions. For vehicles with fuel injection and returnless fuel systems, no fuel vapour is generated in the tank when a hot engine is turned off and thus hot soak emissions are mainly due to fuel permeation and/or leakage.

All three types of evaporative emissions are significantly affected by the volatility of the gasoline being used, the absolute ambient temperature and temperature changes, and vehicle design characteristics. For hot soak emissions and running losses the driving pattern is also of importance.

Fuel vapour loss also takes place during vehicle refuelling. However, this is not included in this chapter as it is considered part of loss during fuel delivery at the petrol stations.

3.2 Emissions

Evaporative VOC emissions from gasoline fuelled vehicles add to total NMVOC emissions. For evaporating emissions tank breathing is reported as $CH_{2.1}$. These are the units used to report test protocols.

3.3 Controls

Until 1993 evaporative losses of gasoline passenger cars were not controlled in Europe, with the exception of Austria, Denmark, Finland, Sweden and Switzerland which adopted the US EPA SHED test procedure. In the EU, a limit value of 2.0 g of HC per test was first introduced by Directive 91/441/EEC (Euro 1 and Euro 2 vehicles). In order to meet this emission limit, the installation of small on-board carbon canisters was necessary. Directive 91/441/EC was superseded by Directive 98/69/EC, applicable to Euro 3 and Euro 4 vehicles. According to this, the limit value for evaporative emissions remained at the same level, however the evaporative emissions testing procedure has been increased in severity. The introduction of larger carbon canisters is necessary to comply with these more stringent requirements.

4 SIMPLER METHODOLOGY

The main equation for estimating the evaporative emissions is:

$$E_{eva,voc,j} = 365 \times N_j \times (HS_j + e_{d,j} + RL_j) \quad (1)$$

where:

$E_{eva,voc,j}$: annual VOC emissions due to evaporative losses of vehicles in category j (g)

N_j: number of gasoline vehicles of category j

HS_j: average daily hot and warm soak emissions of vehicle category j (g/day)

$e_{d,j}$: average diurnal losses of vehicle category j (g/day)

RL_j: average daily hot and warm running losses of vehicle category j (g/day)

and

$$HS_j = x\ \{c\ [p\ \ e_{s,hot,c} + (1 - p)\ e_{s,warm,c}] + (1 - c)\ e_{s,hot,fi}\} \quad (2)$$

$$RL_j = x\ \{c\ [p\ e_{r,hot,c} + (1 - p)\ e_{r,warm,c}] + (1 - c)\ e_{r,hot,fi}\} \quad (3)$$

where:

x: mean number of trips per vehicle per day, average over the year (trips/day)

c: fraction of gasoline powered vehicles equipped with carburettor and/or fuel return systems

p: fraction of trips finished with hot engine, i.e. an engine that has reached its normal operating temperature and the catalyst its light-off temperature (dependent on the average monthly ambient temperature)

$e_{s,hot,c}$: mean hot soak emission factor of gasoline powered vehicles with carburettor and/or fuel return systems (dependent on fuel volatility and average monthly ambient temperature) (g/procedure)

$e_{s,warm,c}$: mean cold and warm soak emission factor of gasoline powered vehicles with carburettor and/or fuel return systems (dependent on fuel volatility and average monthly ambient temperature) (g/procedure)

$e_{s,hot,fi}$: mean hot soak emission factor of gasoline powered vehicles with fuel injection and returnless fuel systems (dependent on fuel volatility and average monthly ambient temperature) (g/procedure)

$e_{r,hot,c}$: mean emission factor for hot running losses of gasoline powered vehicles with carburettor and/or fuel return systems (dependent on fuel volatility and average monthly ambient temperature) (g/trip)

$e_{r,warm,c}$: mean emission factor for cold and warm running losses of gasoline powered vehicles with carburettor and/or fuel return systems (dependent on fuel volatility and average monthly ambient temperature) (g/trip)

$e_{r,hot,fi}$: mean emission factor for hot running losses of gasoline powered vehicles with fuel injection and returnless fuel systems (dependent on fuel volatility and average monthly ambient temperature) (g/trip)

The number of trips per day, if not known from statistical data, can be estimated by the expression:

$$x = \frac{M_j}{365 \times l_{trip}} \qquad (4)$$

where M_j is the total annual mileage of gasoline vehicles of category j.

The fraction of trips finished with cold and warm engine, (1-p), is linked to the parameter β, also used in the calculation of cold start emissions: both depend, inter alia, on ambient temperature. In the absence of better data, the assumed relation between (1-p) and β is $(1\text{-}p) \approx \beta$. Parameter β also depends on the average trip length l_{trip}. This indicates that, for the calculation of the cold start emissions and soak emissions, the average trip length is of great importance.

In order to apply equation (1), Table 4-1 provides emission factors for gasoline passenger cars in three different size classes and Table 4-2 for two wheelers. Emission factors are given for typical temperature ranges in winter and summer and typical fuel vapour pressures. For canister-equipped passenger cars, three different carbon canister sizes (small, medium, large) were considered, depending on vehicle engine size and technology as indicated in Table 6-4. Hence, the calculation of total evaporative emissions with this methodology is straightforward.

Table 4-1: Summary of simplified emission factors for estimating evaporative emissions of passenger cars for typical summer and winter conditions

	summer		winter		summer		winter		summer		winter	
T. variation (°C)	20−35	10−25	0−15	-5−10	20−35	10−25	0−15	-5−10	20−35	10−25	0−15	-5−10
Fuel DVPE (kPa)	60	70	90	90	60	70	90	90	60	70	90	90
	Gasoline passenger cars <1.4 l - uncontrolled				Gasoline passenger cars 1.4 - 2.0 l - uncontrolled				Gasoline passenger cars >2.0 l - uncontrolled			
e_d (g/day)	3.90	2.35	1.74	1.24	4.58	2.76	2.04	1.45	5.59	3.36	2.49	1.77
$e_{s,hot,fi}$ (g/proced.)	0.10	0.07	0.04	0.04	0.10	0.07	0.04	0.04	0.10	0.07	0.04	0.04
$e_{s,warm,c}$ (g/proced.)	8.48	5.09	3.75	2.63	10.01	6.01	4.42	3.10	12.29	7.38	5.43	3.80
$e_{s,hot,c}$ (g/proced.)	11.93	7.16	5.27	3.69	14.08	8.45	6.22	4.36	17.31	10.39	7.65	5.35
$e_{r,hot,fi}$ (g/trip)	0.13	0.08	0.06	0.04	0.13	0.08	0.06	0.04	0.13	0.08	0.06	0.04
$e_{r,warm,c}$ (g/trip)	1.84	1.11	0.81	0.53	2.15	1.30	0.95	0.67	2.62	1.58	1.15	0.81
$e_{r,hot,c}$ (g/trip)	10.05	6.03	4.44	3.11	11.85	7.12	5.24	3.67	14.56	8.74	6.43	4.50
	Gasoline passenger cars <1.4 l - small canister				Gasoline passenger cars 1.4 - 2.0 l - small canister				Gasoline passenger cars >2.0 l - small canister			
e_d (g/day)	0.61	0.15	0.11	0.10	0.95	0.17	0.11	0.10	1.57	0.21	0.11	0.10
$e_{s,hot,fi}$ (g/proced.)	0.10	0.07	0.04	0.04	0.10	0.07	0.04	0.04	0.10	0.07	0.04	0.04
$e_{s,warm,c}$ (g/proced.)	0.63	0.13	0.06	0.04	0.96	0.15	0.06	0.04	1.82	0.20	0.06	0.04
$e_{s,hot,c}$ (g/proced.)	1.74	0.20	0.06	0.04	2.87	0.26	0.07	0.05	4.92	0.43	0.09	0.05
$e_{r,hot,fi}$ (g/trip)	0.13	0.08	0.06	0.04	0.13	0.08	0.06	0.04	0.13	0.08	0.06	0.04
$e_{r,warm,c}$ (g/trip)	0.13	0.08	0.06	0.04	0.13	0.08	0.06	0.04	0.13	0.08	0.06	0.04
$e_{r,hot,c}$ (g/trip)	0.13	0.08	0.06	0.04	0.13	0.08	0.06	0.04	0.13	0.08	0.06	0.04
	Gasoline passenger cars <1.4 l - medium canister				Gasoline passenger cars 1.4 - 2.0 l - medium canister				Gasoline passenger cars >2.0 l - medium canister			
e_d (g/day)	0.24	0.13	0.10	0.10	0.26	0.13	0.10	0.10	0.32	0.14	0.10	0.10
$e_{s,hot,fi}$ (g/proced.)	0.10	0.07	0.04	0.04	0.10	0.07	0.04	0.04	0.10	0.07	0.04	0.04
$e_{s,warm,c}$ (g/proced.)	0.22	0.09	0.05	0.04	0.26	0.09	0.05	0.04	0.35	0.10	0.05	0.04
$e_{s,hot,c}$ (g/proced.)	0.35	0.10	0.05	0.04	0.45	0.11	0.05	0.04	0.70	0.13	0.06	0.04
$e_{r,hot,fi}$ (g/trip)	0.13	0.08	0.06	0.04	0.13	0.08	0.06	0.04	0.13	0.08	0.06	0.04
$e_{r,warm,c}$ (g/trip)	0.13	0.08	0.06	0.04	0.13	0.08	0.06	0.04	0.13	0.08	0.06	0.04
$e_{r,hot,c}$ (g/trip)	0.13	0.08	0.06	0.04	0.13	0.08	0.06	0.04	0.13	0.08	0.06	0.04
	Gasoline passenger cars <1.4 l - large canister				Gasoline passenger cars 1.4 - 2.0 l - large canister				Gasoline passenger cars >2.0 l - large canister			
e_d (g/day)	0.20	0.13	0.10	0.10	0.20	0.13	0.10	0.10	0.21	0.13	0.10	0.10
$e_{s,hot,fi}$ (g/proced.)	0.10	0.07	0.04	0.04	0.10	0.07	0.04	0.04	0.10	0.07	0.04	0.04
$e_{s,warm,c}$ (g/proced.)	0.15	0.07	0.05	0.04	0.16	0.08	0.05	0.04	0.17	0.08	0.05	0.04
$e_{s,hot,c}$ (g/proced.)	0.18	0.08	0.05	0.04	0.20	0.08	0.05	0.04	0.23	0.09	0.05	0.04
$e_{r,hot,fi}$ (g/trip)	0.13	0.08	0.06	0.04	0.13	0.08	0.06	0.04	0.13	0.08	0.06	0.04
$e_{r,warm,c}$ (g/trip)	0.13	0.08	0.06	0.04	0.13	0.08	0.06	0.04	0.13	0.08	0.06	0.04
$e_{r,hot,c}$ (g/trip)	0.13	0.08	0.06	0.04	0.13	0.08	0.06	0.04	0.13	0.08	0.06	0.04

Table 4-2: Summary of simplified emission factors for estimating evaporative emissions of two wheelers for typical summer and winter conditions

	summer		winter		summer		winter		summer		winter	
Temp variation (°C)	20−35	10−25	0−15	-5−10	20−35	10−25	0−15	-5−10	20−35	10−25	0−15	-5−10
Fuel DVPE (kPa)	60	70	90	90	60	70	90	90	60	70	90	90
	Mopeds <50 cm^3				Motorcycles 2-stroke >50 cm^3				Motorcycles 4-stroke <250 cm^3			
e_d (g/day)	0.59	0.37	0.28	0.22	0.79	0.49	0.37	0.28	0.93	0.57	0.43	0.33
$e_{s,hot,fi}$ (g/proced.)	0.27	0.16	0.12	0.08	0.41	0.25	0.18	0.13	0.50	0.30	0.22	0.15
$e_{s,hot,c}$ (g/proced.)	0.69	0.41	0.30	0.21	1.03	0.62	0.45	0.32	1.26	0.75	0.55	0.39
$e_{r,hot,fi}$ (g/trip)	0.19	0.11	0.08	0.06	0.28	0.17	0.12	0.09	0.34	0.21	0.15	0.11
$e_{r,hot,c}$ (g/trip)	0.49	0.30	0.22	0.15	0.74	0.44	0.33	0.23	0.90	0.54	0.40	0.28
	Motorcycles 4-stroke 250 – 750 cm^3				Motorcycles 4-stroke > 750 cm^3 – uncontrolled				Motorcycles 4-stroke > 750 cm^3 – small canister			
e_d (g/day)	1.47	0.89	0.67	0.49	1.60	0.97	0.73	0.53	0.22	0.13	0.10	0.10
$e_{s,hot,fi}$ (g/proced.)	0.86	0.52	0.38	0.27	0.95	0.57	0.42	0.29	0.02	0.00	0.00	0.00
$e_{s,hot,c}$ (g/proced.)	2.17	1.30	0.96	0.67	2.40	1.44	1.06	0.74	0.05	0.01	0.00	0.00
$e_{r,hot,fi}$ (g/trip)	0.59	0.35	0.26	0.18	0.65	0.39	0.29	0.20	0.01	0.00	0.00	0.00
$e_{r,hot,c}$ (g/trip)	1.56	0.94	0.69	0.48	1.73	1.03	0.76	0.53	0.03	0.01	0.00	0.00

5 DETAILED METHODOLOGY

Equation (1) can be also used to estimate evaporation emissions with the detailed methodology. In this case, detailed emission factors can be used depending on the temperature profile and the driving and parking pattern over the day.

5.1 Diurnal temperature variation

Diurnal losses take place during vehicle parking as the ambient temperature varies during the day. In order to calculate diurnal losses both the temperature variation and the parking distribution during the day need to be known.

The diurnal temperature variation may be simulated by a probability density function of a normal distribution between the minimum and the maximum ambient temperatures given by the following equation:

$$T = T_{min} + T_{rise}\ e^{-0.0247\,(t-14)^2} \qquad (5)$$

where

t: hour of the day (h)

T_{min}: minimum daily temperature (°C)

T_{max}: maximum daily temperature (°C)

T_{rise}: rise in the daily temperature, calculated as $T_{max} - T_{min}$ (°C)

The minimum and maximum temperatures need to be calculated over a complete parking period. A parking period can be defined from the end-time of the parking period and the parking duration t_{park}. In order to estimate diurnal losses in detail, the parking duration can be distributed into 24 time classes ranging from <0.5 to >11.5 h. Each combination of parking duration and parking end-time has a probability factor f_k as shown in Table 5-1. The sum of f_k values in Table 5-1 equals 1.

Table 5-1: Parking time distribution as a function of parking end-time

Parking end-time t_2 (hh:mm)	Parking duration t_{park} (h)				
	< 0.5	1	1.5	…	>11.5
0:00	f_1	f_2	f_3	…	f_{24}
1:00	f_{25}	f_{26}	f_{27}	…	f_{48}
2:00	f_{49}	f_{50}	f_{51}	…	f_{72}
…	…	…	…	…	…
23:00	f_{553}	f_{554}	f_{555}	…	f_{576}

The start time of parking may be calculated as $t_1 = t_2 - t_{park}$.

5.2 Fuel tank vapour generation

The vapour generation in the fuel tank (g) may be calculated as a function of fuel volatility, temperature variation, fuel tank size and fill level by the following equation (Reddy, 1989):

$$m_{tank}(T_{1,k}, T_{2,k}) = (1 - h/100)\, v_{tank} \left(0.025\, e^{0.0205\, vp}\left(e^{0.0716\, T_{2,k}} - e^{0.0716\, T_{1,k}}\right)\right) \quad (6)$$

where:

h: fuel tank fill level (%)

v_{tank}: fuel tank, fuel system and vapour control system volume (lt)

vp: fuel vapour pressure (DVPE) (kPa)

$T_{1,k}$: minimum tank temperature during parking period k (°C)

$T_{2,k}$: maximum tank temperature during parking period k (°C)

The above equation is valid only for the fraction of the parking period for which temperature increases. In the occasion of a continuous temperature decrease (e.g. after daily maximum value) there is no vapour generated in the fuel tank (m_{tank}=0).

5.3 Canister breakthrough emissions

Based on experimental work on carbon canisters (Mellios and Samaras, 2007) it was found that the canister weight gain during loading with fuel vapour is best described by the following equation:

$$m_{ads} = m_{load} - e^{(a + b \times s \times m_{load})} \quad (7)$$

and

$$a = -3.27861 - 0.01052\, vp + 0.0229\, T \quad (8)$$

$b = 0.03247 + 0.00054\ vp + 0.00056\ T$ (9)

where:

m_{ads}: cumulative fuel vapour adsorbed on the carbon canister during loading (g)

m_{load}: cumulative fuel vapour loaded to the carbon canister (g)

s: canister size (s=2 for small, s=1 for medium and s=0.5 for large canister)

The initial canister weight is determined from the cumulative mileage of the vehicle as:

$m_{ads,1} = 1/s\ [8.13\ \ln(M_{cum,j}) - 22.92]$ (10)

where $M_{cum,j}$ is the cumulative mileage of the vehicle category j.

An initial amount of vapour loaded to the canister $m_{load,1}$ is calculated by equations (7)-(9) for the vapour pressure and the initial temperature of the fuel in the tank. This vapour load corresponds to the amount of vapour needed to increase the canister weight from dry to its initial weight at the beginning of the parking period. The amount of fuel vapour generated over the parking period is calculated by equation (6), and it is then added to $m_{load,1}$ to give the final vapour load $m_{load,2}$. The canister breakthrough emissions (g) are then calculated as:

$$m_{break}(T_{1,k}, T_{2,k}) = e^{(a+b\times s\times m_{load,2})} - e^{(a+b\times s\times m_{load,1})} \quad (11)$$

Permeation and leakage emissions

The mean emission factor (g/h) is given by the following equation:

$m_{perm}(T) = e^{0.004\cdot vp} \times (6.1656\times10^{-6}\ T^{2.5} + 0.0206)$ (12)

The permeation emissions (g) over a parking period k are thus calculated as:

$$m_{perm}(T_{1,k}, T_{2,k}) = \sum_{T_{1,k}}^{T_{2,k}} e^{0.004\cdot vp}(6.1656\times10^{-6}T^{2.5} + 0.0206) \quad (13)$$

6 RELEVANT ACTIVITY STATISTICS

Further to the emission factors, the proposed methodology requires a number of statistical data which are most likely not available in many countries, e.g. the parameters p, c, x, t_{park}, t_{trip} and l_{trip}. These data can be found in detailed national statistics or various experimental studies (e.g. André et al., 1994). Examples for some countries are shown in Tables 4 and 5 below. Tables 6 and 7 suggest input data for the parking time distribution and vehicle design characteristics respectively.

Table 6-1: Average daily uses of vehicles

	Number of trips/day	Driving duration (min)	Daily distances (km)
Germany	5.8	75	66.0
France	4.8	60	36.8
UK	4.7	58	41.0
Average	5.1	64	46.4

Table 6-2: Average trip characteristics

	Average length (km)	Average duration (min)	Average speed (km/h)
Germany	10.6	12.3	51.4
France	7.6	12.4	36.8
UK	8.4	12.1	41.5
Average	8.9	12.3	43.4

Table 6-3: Parking time distribution

Parking end-time t_2 (hh:mm)	Parking duration t_{park} (h): 0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	
0:00	0.94%	0.31%	0.04%	0.11%	0.13%	0.04%	0.07%	0.03%	0.03%	0.02%	0.02%	0.01%	0.02%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.30%	**2.2%**
1:00	0.51%	0.17%	0.02%	0.06%	0.07%	0.02%	0.04%	0.02%	0.02%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.17%	**1.2%**
2:00	0.30%	0.10%	0.01%	0.04%	0.04%	0.01%	0.02%	0.01%	0.01%	0.01%	0.01%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.10%	**0.7%**
3:00	0.17%	0.06%	0.01%	0.02%	0.02%	0.01%	0.01%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.06%	**0.4%**
4:00	0.30%	0.10%	0.01%	0.04%	0.04%	0.01%	0.02%	0.01%	0.01%	0.01%	0.01%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.10%	**0.7%**
5:00	0.94%	0.31%	0.04%	0.11%	0.13%	0.04%	0.07%	0.03%	0.03%	0.02%	0.02%	0.01%	0.02%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.30%	**2.2%**
6:00	1.97%	0.64%	0.09%	0.23%	0.28%	0.09%	0.14%	0.07%	0.07%	0.05%	0.05%	0.02%	0.05%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.63%	**4.6%**
7:00	2.40%	0.78%	0.11%	0.28%	0.34%	0.11%	0.17%	0.08%	0.08%	0.06%	0.06%	0.03%	0.06%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.77%	**5.6%**
8:00	2.23%	0.72%	0.10%	0.26%	0.31%	0.10%	0.16%	0.08%	0.08%	0.05%	0.05%	0.03%	0.05%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.72%	**5.2%**
9:00	2.23%	0.72%	0.10%	0.26%	0.31%	0.10%	0.16%	0.08%	0.08%	0.05%	0.05%	0.03%	0.05%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.72%	**5.2%**
10:00	2.27%	0.74%	0.11%	0.27%	0.32%	0.11%	0.16%	0.08%	0.08%	0.05%	0.05%	0.03%	0.05%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.73%	**5.3%**
11:00	2.35%	0.76%	0.11%	0.28%	0.33%	0.11%	0.17%	0.08%	0.08%	0.06%	0.06%	0.03%	0.06%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.76%	**5.5%**
12:00	1.97%	0.64%	0.09%	0.23%	0.28%	0.09%	0.14%	0.07%	0.07%	0.05%	0.05%	0.02%	0.05%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.63%	**4.6%**
13:00	2.23%	0.72%	0.10%	0.26%	0.31%	0.10%	0.16%	0.08%	0.08%	0.05%	0.05%	0.03%	0.05%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.72%	**5.2%**
14:00	2.40%	0.78%	0.11%	0.28%	0.34%	0.11%	0.17%	0.08%	0.08%	0.06%	0.06%	0.03%	0.06%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.77%	**5.6%**
15:00	2.48%	0.81%	0.12%	0.29%	0.35%	0.12%	0.17%	0.09%	0.09%	0.06%	0.06%	0.03%	0.06%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.80%	**5.8%**
16:00	2.78%	0.90%	0.13%	0.33%	0.39%	0.13%	0.20%	0.10%	0.10%	0.07%	0.07%	0.03%	0.07%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.90%	**6.5%**
17:00	2.78%	0.90%	0.13%	0.33%	0.39%	0.13%	0.20%	0.10%	0.10%	0.07%	0.07%	0.03%	0.07%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.90%	**6.5%**
18:00	2.70%	0.88%	0.13%	0.32%	0.38%	0.13%	0.19%	0.09%	0.09%	0.06%	0.06%	0.03%	0.06%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.87%	**6.3%**
19:00	2.18%	0.71%	0.10%	0.26%	0.31%	0.10%	0.15%	0.08%	0.08%	0.05%	0.05%	0.03%	0.05%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	0.70%	**5.1%**
20:00	1.88%	0.61%	0.09%	0.22%	0.26%	0.09%	0.13%	0.07%	0.07%	0.04%	0.04%	0.02%	0.04%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.61%	**4.4%**
21:00	1.80%	0.58%	0.08%	0.21%	0.25%	0.08%	0.13%	0.06%	0.06%	0.04%	0.04%	0.02%	0.04%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.58%	**4.2%**
22:00	1.67%	0.54%	0.08%	0.20%	0.23%	0.08%	0.12%	0.06%	0.06%	0.04%	0.04%	0.02%	0.04%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.54%	**3.9%**
23:00	1.33%	0.43%	0.06%	0.16%	0.19%	0.06%	0.09%	0.05%	0.05%	0.03%	0.03%	0.02%	0.03%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.43%	**3.1%**
	43%	**14%**	**2.0%**	**5.0%**	**6.0%**	**2.0%**	**3.0%**	**1.5%**	**1.5%**	**1.0%**	**1.0%**	**0.5%**	**1.0%**	**0.5%**	**0.5%**	**0.5%**	**0.5%**	**0.5%**	**0.5%**	**0.5%**	**0.5%**	**0.5%**	**0.5%**	**14%**	**100%**

Table 6-4: Suggested fuel tank volumes and carbon canister sizes for the various COPERT categories

Sector	Subsector	Technology	Tank (lt)	Canister*
Passenger Cars	Gasoline <1,4 l	PRE ECE	50	NO
Passenger Cars	Gasoline <1,4 l	ECE 15/00-01	50	NO
Passenger Cars	Gasoline <1,4 l	ECE 15/02	50	NO
Passenger Cars	Gasoline <1,4 l	ECE 15/03	50	NO
Passenger Cars	Gasoline <1,4 l	ECE 15/04	50	NO
Passenger Cars	Gasoline <1,4 l	Improved Conventional	50	NO
Passenger Cars	Gasoline <1,4 l	Open Loop	50	NO
Passenger Cars	Gasoline <1,4 l	PC Euro 1 - 91/441/EEC	50	SC
Passenger Cars	Gasoline <1,4 l	PC Euro 2 - 94/12/EEC	50	SC
Passenger Cars	Gasoline <1,4 l	PC Euro 3 - 98/69/EC Stage2000	50	MC
Passenger Cars	Gasoline <1,4 l	PC Euro 4 - 98/69/EC Stage2005	50	MC
Passenger Cars	Gasoline <1,4 l	PC Euro 5 (post 2005)	50	MC
Passenger Cars	Gasoline 1,4 - 2,0 l	PRE ECE	60	NO
Passenger Cars	Gasoline 1,4 - 2,0 l	ECE 15/00-01	60	NO
Passenger Cars	Gasoline 1,4 - 2,0 l	ECE 15/02	60	NO
Passenger Cars	Gasoline 1,4 - 2,0 l	ECE 15/03	60	NO
Passenger Cars	Gasoline 1,4 - 2,0 l	ECE 15/04	60	NO
Passenger Cars	Gasoline 1,4 - 2,0 l	Improved Conventional	60	NO
Passenger Cars	Gasoline 1,4 - 2,0 l	Open Loop	60	NO
Passenger Cars	Gasoline 1,4 - 2,0 l	PC Euro 1 - 91/441/EEC	60	SC
Passenger Cars	Gasoline 1,4 - 2,0 l	PC Euro 2 - 94/12/EEC	60	SC
Passenger Cars	Gasoline 1,4 - 2,0 l	PC Euro 3 - 98/69/EC Stage2000	60	MC
Passenger Cars	Gasoline 1,4 - 2,0 l	PC Euro 4 - 98/69/EC Stage2005	60	MC
Passenger Cars	Gasoline 1,4 - 2,0 l	PC Euro 5 (post 2005)	60	MC
Passenger Cars	Gasoline >2,0 l	PRE ECE	75	NO
Passenger Cars	Gasoline >2,0 l	ECE 15/00-01	75	NO
Passenger Cars	Gasoline >2,0 l	ECE 15/02	75	NO
Passenger Cars	Gasoline >2,0 l	ECE 15/03	75	NO
Passenger Cars	Gasoline >2,0 l	ECE 15/04	75	NO
Passenger Cars	Gasoline >2,0 l	PC Euro 1 - 91/441/EEC	75	MC
Passenger Cars	Gasoline >2,0 l	PC Euro 2 - 94/12/EEC	75	MC
Passenger Cars	Gasoline >2,0 l	PC Euro 3 - 98/69/EC Stage2000	75	LC
Passenger Cars	Gasoline >2,0 l	PC Euro 4 - 98/69/EC Stage2005	75	LC
Passenger Cars	Gasoline >2,0 l	PC Euro 5 (post 2005)	75	LC
Passenger Cars	Hybrid Gasoline <1,4 l	PC Euro 4 - 98/69/EC Stage2005	50	MC
Passenger Cars	Hybrid Gasoline 1,4 - 2,0 l	PC Euro 4 - 98/69/EC Stage2005	60	MC
Passenger Cars	Hybrid Gasoline >2,0 l	PC Euro 4 - 98/69/EC Stage2005	75	LC
Light Duty Vehicles	Gasoline <3,5t	Conventional	60	NO
Light Duty Vehicles	Gasoline <3,5t	LD Euro 1 - 93/59/EEC	60	SC
Light Duty Vehicles	Gasoline <3,5t	LD Euro 2 - 96/69/EEC	60	SC
Light Duty Vehicles	Gasoline <3,5t	LD Euro 3 - 98/69/EC Stage2000	60	MC
Light Duty Vehicles	Gasoline <3,5t	LD Euro 4 - 98/69/EC Stage2005	60	MC
Light Duty Vehicles	Gasoline <3,5t	LD Euro 5 - 2008 Standards	60	MC
Mopeds	<50 cm³	Conventional	5	NO
Mopeds	<50 cm³	Mop - Euro 1	5	NO
Mopeds	<50 cm³	Mop - Euro 2	5	NO
Mopeds	<50 cm³	Mop - Euro 3	5	NO
Motorcycles	2-stroke >50 cm³	Conventional	8	NO
Motorcycles	2-stroke >50 cm³	Mot - Euro 1	8	NO
Motorcycles	2-stroke >50 cm³	Mot - Euro 2	8	NO
Motorcycles	2-stroke >50 cm³	Mot - Euro 3	8	NO
Motorcycles	4-stroke <250 cm³	Conventional	10	NO
Motorcycles	4-stroke <250 cm³	Mot - Euro 1	10	NO
Motorcycles	4-stroke <250 cm³	Mot - Euro 2	10	NO
Motorcycles	4-stroke <250 cm³	Mot - Euro 3	10	NO
Motorcycles	4-stroke 250 - 750 cm³	Conventional	18	NO
Motorcycles	4-stroke 250 - 750 cm³	Mot - Euro 1	18	NO
Motorcycles	4-stroke 250 - 750 cm³	Mot - Euro 2	18	NO
Motorcycles	4-stroke 250 - 750 cm³	Mot - Euro 3	18	NO
Motorcycles	4-stroke >750 cm³	Conventional	20	SC
Motorcycles	4-stroke >750 cm³	Mot - Euro 1	20	SC
Motorcycles	4-stroke >750 cm³	Mot - Euro 2	20	SC
Motorcycles	4-stroke >750 cm³	Mot - Euro 3	20	SC

* NO = no canister, SC = small canister, MC = medium canister, LC = large canister

7 POINT SOURCE CRITERIA

There are no relevant point sources which fall under the source activities dealt with in this chapter.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Gasoline Passenger Cars

8.1.1 Diurnal emissions

For any parking period k the vapour generated in the tank and the associated breakthrough emissions are calculated using equations (6)-(11) as described above. The permeation emissions are calculated by equation (13). The diurnal emissions for each parking period k (in g/parking) are thus calculated as:

$$m_{break}(T_{1,k}, T_{2,k}) + e_{perm}(T_{1,k}, T_{2,k}) \tag{14}$$

Taking into account all parking periods, the average diurnal emissions (in g/day) are calculated as:

$$e_d = \sum_k f_k \cdot \left(m_{break}(T_{1,k}, T_{2,k}) + m_{perm}(T_{1,k}, T_{2,k})\right) \tag{15}$$

For gasoline vehicles without carbon canister all vapour generated in the fuel tank is released in the atmosphere. Thus the mean emission factor for uncontrolled vehicles (in g/day) is given by the following equation:

$$e_d = \sum_k f_k \cdot \left(m_{tank}(T_{1,k}, T_{2,k}) + m_{perm}(T_{1,k}, T_{2,k})\right) \tag{16}$$

Hot soak emissions

For gasoline vehicles with fuel injection and returnless fuel systems, the fuel temperature in the tank is not affected by engine operation and thus no fuel vapour is generated in the tank when a hot engine is turned off. Hot soak emissions are mainly due to fuel permeation and/or leakage. Taking into account the increased temperature of the fuel circulating in the fuel system (from fuel tank to injectors), the mean hot soak emission factor for gasoline vehicles (both canister-equipped and uncontrolled) with fuel injection and returnless fuel systems (in g/procedure) is given by the following equation:

$$e_{s,hot,fi} = \sum_k f_k \cdot m_{perm}(T_{1,k} + 11) \tag{17}$$

For vehicles equipped with carburettor and/or fuel return systems, engine operation results in significant temperature increase in the fuel tank and/or the carburettor (Morgan et al., 1993). The additional fuel vapour that is generated loads the carbon canister causing breakthrough emissions which are calculated using equations (6)-(11) as described above. For the warm soak emissions a 4.5°C increase in the fuel temperature in the tank is used, while a 6°C increase is used for hot soak emissions. The mean warm and hot soak emission factors for canister-equipped gasoline vehicles with carburettor and/or fuel return systems (in g/procedure) are thus given by the following equations:

$$
\begin{aligned}
e_{s,hot,c} &= \sum_k f_k \cdot m_{break}(T_{1,k}, T_{1,k}+6) + e_{s,hot,fi} \\
e_{s,warm,c} &= \sum_k f_k \cdot m_{break}(T_{1,k}, T_{1,k}+4.5) + e_{s,hot,fi}
\end{aligned} \tag{18}
$$

For uncontrolled vehicles the above equations are rewritten as follows:

$$
\begin{aligned}
e_{s,hot,c} &= \sum_k f_k \cdot m_{tank}(T_{1,k}, T_{1,k}+6) + e_{s,hot,fi} \\
e_{s,warm,c} &= \sum_k f_k \cdot m_{tank}(T_{1,k}, T_{1,k}+4.5) + e_{s,hot,fi}
\end{aligned} \tag{19}
$$

8.1.2 Running losses

As mentioned above, for vehicles with fuel injection and returnless fuel systems the fuel temperature in the tank is not affected by engine operation and thus the running losses are attributed to fuel permeation and/or leakage. The mean running losses emission factor for gasoline vehicles (both canister-equipped and uncontrolled) with returnless fuel systems (in g/trip) is calculated as:

$$
e_{r,hot,fi} = t_{trip} \cdot \sum_k f_k \cdot m_{perm}(T_{2,k} + 15) \tag{20}
$$

where t_{trip} is the mean driving duration per trip, average over the year (h/trip).

For vehicles equipped with carburettor and/or fuel return systems, the additional fuel vapour that is generated in the fuel tank loads the carbon canister. However, the canister is being purged with air at certain time intervals and thus no significant breakthrough emissions are observed (except for long periods of idling when the purge valve, controlling the amount of air that is used for purging, remains shut). For canister-equipped vehicles with carburettor and/or fuel return systems, equation (20) can be used for calculating hot and warm running losses, i.e.:

$$
e_{r,hot,c} = e_{r,warm,c} = e_{r,hot,fi} \tag{21}
$$

For uncontrolled vehicles the fuel vapour generated in the tank due to temperature increase also contributes to the running losses. For the warm running losses a 1°C increase in the fuel temperature in the tank is used, while a 5°C increase is used for hot running losses. The mean warm and hot running losses factors for uncontrolled gasoline vehicles with fuel return systems (in g/trip) are thus given by the following equation:

$$
\begin{aligned}
e_{r,hot,c} &= \sum_k f_k \cdot m_{tank}(T_{2,k}, T_{2,k}+5) + e_{r,hot,fi} \\
e_{r,warm,c} &= \sum_k f_k \cdot m_{tank}(T_{2,k}, T_{2,k}+1) + e_{r,hot,fi}
\end{aligned} \tag{22}
$$

8.2 Light Duty Vehicles

The same emission factors as for passenger cars may be applied.

8.3 Two wheelers

Diurnal emissions for canister-equipped and uncontrolled two wheelers are calculated by equations (15) and (16) respectively.

The mean warm and hot soak emission factors for controlled motorcycles equipped with fuel injection and those equipped with carburettor (in g/procedure) are given by the following equations:

$$\begin{aligned} e_{s,hot,fi} &= \sum_k f_k \cdot m_{break}(T_{1,k}, T_{1,k} + 1.5) \\ e_{s,hot,c} &= \sum_k f_k \cdot m_{break}(T_{1,k}, T_{1,k} + 3.5) \end{aligned} \quad (23)$$

For uncontrolled mopeds and motorcycles equipped with fuel injection and those equipped with carburettor (in g/procedure) the mean warm and hot soak emission factors are:

$$\begin{aligned} e_{s,hot,fi} &= \sum_k f_k \cdot m_{tank}(T_{1,k}, T_{1,k} + 1.5) \\ e_{s,hot,c} &= \sum_k f_k \cdot m_{tank}(T_{1,k}, T_{1,k} + 3.5) \end{aligned} \quad (24)$$

The mean warm and hot running losses factors for controlled motorcycles equipped with fuel injection and those equipped with carburettor (in g/trip) are given by the following equations:

$$\begin{aligned} e_{r,hot,fi} &= \sum_k f_k \cdot m_{break}(T_{2,k}, T_{2,k} + 1) \\ e_{r,hot,c} &= \sum_k f_k \cdot m_{break}(T_{2,k}, T_{2,k} + 2.5) \end{aligned} \quad (25)$$

For uncontrolled mopeds and motorcycles equipped with fuel injection and those equipped with carburettor the mean warm and hot running losses factors (in g/trip) are:

$$\begin{aligned} e_{r,hot,fi} &= \sum_k f_k \cdot m_{tank}(T_{2,k}, T_{2,k} + 1) \\ e_{r,hot,c} &= \sum_k f_k \cdot m_{tank}(T_{2,k}, T_{2,k} + 2.5) \end{aligned} \quad (26)$$

8.4 Summary

The basic emission factors, which are necessary to apply the methodology, are listed in Table 8-1 for uncontrolled and controlled vehicles.

Table 8-1: Summary of emission factors for estimating evaporative emissions of passenger cars, light duty vehicles and two wheelers

Emission factor	Uncontrolled vehicle	Canister-equipped vehicle
Passenger cars and light duty vehicles		
e_d (g/day)	$\sum_k f_k \left(m_{tank}(T_{1,k}, T_{2,k}) + m_{perm}(T_{1,k}, T_{2,k})\right)$	$\sum_k f_k \left(m_{break}(T_{1,k}, T_{2,k}) + m_{perm}(T_{1,k}, T_{2,k})\right)$
$e_{s,hot,fi}$ (g/proced.)	$\sum_k f_k \cdot m_{perm}(T_{1,k} + 11)$	$\sum_k f_k \cdot m_{perm}(T_{1,k} + 11)$
$e_{s,warm,c}$ (g/proced.)	$\sum_k f_k m_{tank}(T_{1,k}, T_{1,k} + 4.5) + e_{s,hot,fi}$	$\sum_k f_k m_{break}(T_{1,k}, T_{1,k} + 4.5) + e_{s,hot,fi}$
$e_{s,hot,c}$ (g/proced.)	$\sum_k f_k \cdot m_{tank}(T_{1,k}, T_{1,k} + 6) + e_{s,hot,fi}$	$\sum_k f_k \cdot m_{break}(T_{1,k}, T_{1,k} + 6) + e_{s,hot,fi}$
$e_{r,hot,fi}$ (g/trip)	$t_{trip} \cdot \sum_k f_k \cdot m_{perm}(T_{2,k} + 15)$	$t_{trip} \cdot \sum_k f_k \cdot m_{perm}(T_{2,k} + 15)$
$e_{r,warm,c}$ (g/trip)	$\sum_k f_k \cdot m_{tank}(T_{2,k}, T_{2,k} + 1) + e_{r,hot,fi}$	$e_{r,hot,fi}$
$e_{r,hot,c}$ (g/trip)	$\sum_k f_k \cdot m_{tank}(T_{2,k}, T_{2,k} + 5) + e_{r,hot,fi}$	$e_{r,hot,fi}$
Two wheelers		
e_d (g/day)	$\sum_k f_k \cdot \left(m_{tank}(T_{1,k}, T_{2,k}) + m_{perm}(T_{1,k}, T_{2,k})\right)$	$\sum_k f_k \cdot \left(m_{break}(T_{1,k}, T_{2,k}) + m_{perm}(T_{1,k}, T_{2,k})\right)$
$e_{s,hot,fi}$ (g/procedure)	$\sum_k f_k \cdot m_{tank}(T_{1,k}, T_{1,k} + 1.5)$	$\sum_k f_k \cdot m_{break}(T_{1,k}, T_{1,k} + 1.5)$
$e_{s,hot,c}$ (g/procedure)	$\sum_k f_k \cdot m_{tank}(T_{1,k}, T_{1,k} + 3.5)$	$\sum_k f_k \cdot m_{break}(T_{1,k}, T_{1,k} + 3.5)$
$e_{r,hot,fi}$ (g/trip)	$\sum_k f_k \cdot m_{tank}(T_{2,k}, T_{2,k} + 1)$	$\sum_k f_k \cdot m_{break}(T_{2,k}, T_{2,k} + 1)$
$e_{r,hot,c}$ (g/trip)	$\sum_k f_k \cdot m_{tank}(T_{2,k}, T_{2,k} + 2.5)$	$\sum_k f_k \cdot m_{break}(T_{2,k}, T_{2,k} + 2.5)$

9 SPECIES PROFILES

The content of non-methane VOCs in different species is given in Table 9-1. The proposed fractions have been obtained by results from a European test programme on evaporative emissions from canister-equipped gasoline passenger cars (JRC, 2007). It should be noted that the speciation of evaporative emissions depends on the fuel composition. Light fuel components are easier to evaporate than heavy ones. Hence, the profile of species evaporating may be shifted to lighter components.

Table 9-1: Composition of NMVOC in evaporative emissions

Group	Species	NMVOC fraction (% wt)
Alkanes	ethane	0.30
	propane	5.15
	i-butane	4.38
	n-butane	5.86
	i-pentane	10.69
	n-pentane	7.72
	2-methylpentane	14.02
	3-methylpentane	25.14
	n-hexane	2.02
	n-heptane	1.65
Alkenes	ethene	0.05
	propene	0.28
	1-butene	0.72
	trans-2-butene	1.19
	isobutene	0.12
	cis-2-butene	1.05
	1,3 butadiene	0.00
	trans-2-pentene	1.60
	cis-2-pentene	0.75
	isoprene	0.00
Alkines	propyne	0.07
	acetylene	0.01
Aromatics	benzene	0.97
	toluene	3.94
	ethylbenzene	3.52
	m-xylene	5.79
	o-xylene	2.52
	1,2,4-trimethylbenzene	0.50
	1,3,5-trimethylbenzene	0.00
Totals (all NMVOC species)		100

10 UNCERTAINTY ESTIMATES

Using the indicators introduced in Chapter B710, Table 10-1 provides qualitative estimates of the precision which can be allocated to the calculation of evaporative losses.

Table 10-1: Summary of precision indicators of the evaporative emission estimates

Vehicle category	NMVOC
Passenger cars conventional	B
Passenger cars canister-equipped	A
Light duty vehicles conventional	D
Light duty vehicles canister-equipped	D
Two wheelers conventional	B
Two wheelers canister-equipped	B

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The proposed methodology has been based on results from a range of canister-equipped gasoline vehicles representative of current Euro 3-4 technology and typical summer and winter fuels and temperatures. Although a large number of hot soak and diurnal tests has been carried out, running losses were not measured and therefore the proposed emission factors need further improvement. Other areas requiring additional consideration include:

i) evaporative emission factors for light duty vehicles, and

ii) evaporative emission factors for fuels containing bio components (e.g. ethanol).

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Evidently the principles of the approaches outlined for exhaust emission spatial allocation apply equally to evaporative losses. In particular as regards the top down approach, the following hints may be useful:

- Diurnal losses: As diurnal losses occur at any time, their spatial allocation to urban/rural/highway conditions depends on the time spent by the vehicles on the different road classes. Therefore for those vehicles that are used by city inhabitants one can assume that 11/12 of their diurnal emissions occur in urban areas, the rest being split between rural and highway driving proportionally to the ratio of (rural mileage . highway speed) / (highway mileage . rural speed)
- Soak losses: The majority of these emissions occur in the area of residence of the car owner, as they are associated with short trips.
- Running losses: Running losses are proportional to the mileage driven by the vehicles. Therefore their allocation to urban areas - rural areas - highways has to follow the mileage split assumed for the calculation of the exhaust emissions.

13 TEMPORAL DISAGGREGATION CRITERIA

14 ADDITIONAL COMMENTS

The evaporation losses calculation scheme presented above, is fully integrated into COPERT 4 (Computer Programme to Calculate Emissions from Road Traffic), which substantially facilitates the practical application of the methodology (see Ntziachristos et al. 2000).

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16 VERIFICATION PROCEDURES

See the discussion in Chapter 16 of Chapter B710 on road transport.

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18 BIBLIOGRAPHY

List of abbreviations

DVPE: Dry Vapour Pressure Equivalent at a temperature of 37.8°C

NMVOC: Non-Methane Volatile Organic Compounds

VOC: Volatile Organic Compounds

List of symbols

c: fraction of gasoline powered vehicles equipped with carburettor and/or fuel return systems

e_d: average diurnal losses of vehicle category j (g/day)

$e_{r,hot,c}$: mean emission factor for hot running losses of gasoline powered vehicles with carburettor and/or fuel return systems (g/trip)

$e_{r,hot,fi}$: mean emission factor for hot running losses of gasoline powered vehicles with fuel injection and returnless fuel systems (g/trip)

$e_{r,warm,c}$: mean emission factor for cold and warm running losses of gasoline powered vehicles with carburettor and/or fuel return systems (g/trip)

$e_{s,hot,c}$: mean hot soak emission factor of gasoline powered vehicles with carburettor and/or fuel return systems (g/procedure)

$e_{s,hot,fi}$: mean hot soak emission factor of gasoline powered vehicles with fuel injection and returnless fuel systems (g/procedure)

$e_{s,warm,c}$: mean cold and warm soak emission factor of gasoline powered vehicles with carburettor and/or fuel return systems (g/procedure)

$E_{eva,voc,j}$: VOC emissions due to evaporative losses caused by vehicle category j (g)

f_k: probability factor for combination of parking duration and ending hour of parking

h: fuel tank fill level (%)

HS_j: average daily hot and warm soak emissions of vehicle category j (g/day)

l_{trip}: average trip length (km)

m_{ads}: cumulative fuel vapour adsorbed on the carbon canister during loading (g)

m_{load}: cumulative fuel vapour loaded to the carbon canister (g)

m_{tank}: fuel vapour generation (g)

m_{break}: canister breakthrough emissions (g)

m_{perm}: emissions due to fuel permeation and/or leakage (g)

M_j: total annual mileage of gasoline vehicles of category j

$M_{cum,j}$: total cumulative mileage of gasoline vehicles of category j

N_j: number of gasoline vehicles of category j

p: fraction of trips finished with hot engine, i.e. an engine that has reached its normal operating temperature and the catalyst its light-off temperature

RL_j: average daily hot and warm running losses of vehicle category j (g/day)

s: canister size (s=2 for small, s=1 for medium and s=0.5 for large canister)

t: hour of the day (h)

t_1: hour of the day at the beginning of a parking period (h)

t_2: hour of the day at the end of a parking period (h)

t_{park}: mean parking duration (h)

t_{trip}: mean driving duration per trip, average over the year (h/trip)

T: ambient temperature (°C)

$T_{1,k}$: minimum tank temperature during parking period k (°C)

$T_{2,k}$: maximum tank temperature during parking period k (°C)

T_{min}: minimum daily temperature (°C)

T_{max}: maximum daily temperature (°C)

T_{rise}: rise in the daily temperature, calculated as $T_{max} – T_{min}$ (°C)

v_{tank}: fuel tank, fuel system and vapour control system volume (lt)

vp: fuel vapour pressure (DVPE) (kPa)

x: mean number of trips per vehicle per day, average over the year (trips/day)

19 RELEASE VERSION, DATE AND SOURCE

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1 ACTIVITIES INCLUDED

This Chapter covers the emissions of airborne particulate matter (PM) from road transport which are due to vehicle tyre and brake wear (SNAP code 070700) and road surface wear (SNAP code 070800). PM emissions from vehicle exhaust are not included. The focus is on primary non-exhaust particles - in other words those particles emitted directly as a result of the wear of surfaces - and not those resulting from the resuspension of previously deposited material. The sources of such PM emissions are considered in relation to the general vehicle classes identified in the Road Transport Chapter of the Guidebook (SNAPS 0701-0705), these being passenger cars, light-duty trucks, heavy-duty vehicles and two-wheelers.

2 CONTRIBUTIONS TO TOTAL EMISSIONS

Table 1 presents total emissions of particulate matter (PM_{10}, $PM_{2.5}$ and TSP) in European Union countries (CEPMEIP, 2003). According to CEPMEIP, non-exhaust sources contribute 3.1% and 1.7% of total PM_{10} and $PM_{2.5}$ respectively at the EU15 level. The contribution of non-exhaust sources to TSP is much larger than the contributions to the finer particle fractions because CEPMEIP assumes that all tyre wear material becomes airborne PM. The validity of this assumption is examined later in this Chapter.

The estimation of the non-exhaust contribution to total PM emissions depends upon the emission factors selected for tyre wear, brake wear and road surface wear. However, the emission factors for these sources are rather uncertain, and the following brief discussion has been included here to justify *a priori* the large variability which has been reported for the contribution of non-exhaust sources to total PM in urban and national inventories.

In 1999 more than 54 million passenger car tyres were used in the UK, equating to a total weight of more than 430,000 tonnes (Used Tyre Working Group, 2000). A new passenger car tyre weighs around 8 kg, and loses roughly 1-1.5kg in weight during its service lifetime, which is typically around 3 years. Thus, between around 10% and 20% of the rubber which goes into a tyre will disappear before the tyre is ready to scrap (Environment Agency, 1998). Based on the upper estimate for rubber loss of 20%, a simple calculation reveals that around 90 kilotonnes (kt) of tyre material could have been lost to the UK environment during 1999, mainly as a result of in-service wear. The value can be compared with the estimated annual release of tyre debris in the US during the 1970s of 500 kt, and the 40 kt released in Italy in 1991 (Camatini *et al*., 2001).

Table 1: Total airborne particle emissions from CEPMEIP for EU15 Member States and grand average. Row 'Tyre & Brake & Road' corresponds to the non-exhaust particles sources covered in this Chapter, 'Road Transport' relates to both exhaust and non-exhaust emissions, and 'National Total' relates to all national sources, not covering international aviation and bunkers. Percentages are given as a fraction of the National Total.

Country	Source	PM10 [kt]	PM2.5 [kt]	TSP [kt]	%PM10	%PM2.5	%TSP
Austria	Tyre & Brake & Road	1.6	0.6	22.1	3.5	1.8	26.7
	Road Transport	7.5	6.5	28.0	16.3	19.5	33.8
	National Total	46.2	33.5	82.7			
Belgium	Tyre & Brake & Road	2.3	0.9	31.1	2.7	1.5	21.8
	Road Transport	12.6	11.2	41.4	14.9	19.5	29.0
	National Total	84.1	57.1	142.7			
Denmark	Tyre & Brake & Road	1.1	0.4	14.7	3.2	1.7	24.0
	Road Transport	5.4	4.7	19.0	16.2	20.1	31.0
	National Total	33.0	23.3	61.2			
Finland	Tyre & Brake & Road	0.7	0.3	10.3	2.5	1.3	20.5
	Road Transport	4.4	3.5	23.4	14.6	15.8	46.8
	National Total	30.0	22.0	50.0			
France	Tyre & Brake & Road	10.1	3.8	138.3	2.2	1.1	20.0
	Road Transport	60.9	54.6	189.1	13.5	15.6	27.3
	National Total	449.7	350.6	693.3			
Germany	Tyre & Brake & Road	14.7	5.6	202.3	4.4	2.6	29.5
	Road Transport	69.0	59.9	256.6	20.6	27.6	37.4
	National Total	335.3	217.1	685.8			
Greece	Tyre & Brake & Road	1.5	0.6	20.9	2.4	1.4	21.5
	Road Transport	9.2	8.2	28.6	14.7	19.6	29.4
	National Total	62.4	41.9	97.2			
Ireland	Tyre & Brake & Road	0.6	0.2	7.7	2.5	1.7	16.6
	Road Transport	2.5	2.2	9.7	11.2	17.1	20.8
	National Total	22.7	12.8	46.5			
Italy	Tyre & Brake & Road	10.1	3.8	139.4	3.2	1.7	26.9
	Road Transport	57.2	50.9	186.4	17.9	21.9	36.0
	National Total	319.3	232.3	518.3			
Luxembourg	Tyre & Brake & Road	0.1	0.0	1.6	2.3	1.6	18.3
	Road Transport	0.6	0.5	2.1	11.1	17.9	23.4
	National Total	5.2	2.8	9.0			
Netherlands	Tyre & Brake & Road	2.4	0.9	32.5	3.7	2.1	25.5
	Road Transport	11.9	10.4	42.1	18.5	25.2	33.0
	National Total	64.4	41.4	127.3			
Portugal	Tyre & Brake & Road	1.4	0.5	19.4	2.7	1.4	23.9
	Road	7.9	7.1	25.9	15.5	19.1	32.0
	National Total	51.0	37.0	81.0			
Spain	Tyre & Brake & Road	6.2	2.3	85.6	2.8	1.5	23.3
	Road	42.8	38.9	122.1	19.0	24.5	33.3
	National Total	225.6	158.5	366.5			
Sweden	Tyre & Brake & Road	1.6	0.6	22.0	3.8	2.0	28.6
	Road	7.5	6.5	27.9	17.8	21.9	36.2
	National Total	42.1	29.7	77.1			
UK	Tyre & Brake & Road	8.7	3.3	118.5	3.3	2.0	25.0
	Road	38.7	33.3	148.6	14.9	20.3	31.4
	All	259.6	164.4	473.4			
EU15	Tyre & Brake & Road	63.1	23.9	866.5	3.1	1.7	24.7
	Road Transport	338.1	298.4	1150.9	16.6	20.9	32.8
	Int. Total	2030.6	1424.4	3512.0			

It should be noted that these values relate to total dustfall debris, and not just respirable PM. In the UK National Atmospheric Emissions Inventory, it is estimated that over 80% of respirable PM in cities comes from road transport (Goodwin *et al*., 2002), although non-exhaust sources (tyre and brake wear) were responsible for the emission of just 5 kt of PM_{10} in UK in 2000, compared with the 26 kt from exhaust emissions, and represent just 3% of total PM_{10}. However, this relatively small contribution from non-exhaust sources to PM_{10} emissions has not been observed universally. For example, according to Rauterberg-Wulff (1999) tyre wear is responsible for annual PM_{10} emissions in Germany of 56-98 kt, whereas diesel exhaust emissions are responsible for around 76 kt of PM_{10}. This would suggest that non-exhaust sources may be as significant as exhaust sources. Such variation in estimated annual emissions is likely to be due to the use of different methodological approaches, emission factors, and assumptions. In this Chapter, a methodology is proposed which provides a common basis for calculating and comparing non-exhaust particle emissions in different countries.

Resuspended particulate matter also contributes to the PM concentrations recorded by ambient air samplers, though resuspension is not generally considered to be a primary particle emission source. On the other hand, the USEPA AP-42 model considers road slit loading as the predominant source for non-exhaust particle emissions, and assumes that most vehicle-related non-exhaust PM_{10} arises from re-suspension. However, this modelling approach has been criticised within US (Venkatram, 2000). Moreover, the UK Airborne Particle Expert Group (APEG, 1999) considers the model unsuitable for UK conditions and, to enable the model to be used in Berlin, Düring *et al*. (2002) had to fully recalibrate it on the basis of local experimental data.

3 SOURCE DESCRIPTION AND DEFINITION

Airborne particles are produced as a result of the interaction between a vehicle’s tyre and the road surface, and also when the brakes are applied to decelerate the vehicle. In both cases, the generation of shear forces by the relative movement of surfaces is the main mechanism for particle production. A secondary mechanism involves the evaporation of material from surfaces at the high temperatures developed during contact.

3.1 Tyre and road surface wear

A vehicle’s tyres carry the vehicle and passenger load, offer traction and steering, and absorb variations in the road surface to improve ride quality. Tyre material is a complex rubber blend, although the exact composition of the tyres on the market is not usually published for commercial reasons. As a rule of thumb, Camatini *et al*. (2001) quote 75% styrene butadiene rubber (SBR), 15% natural rubber and 10% polybutadiene for passenger car tyres. Metal and organic additives are also introduced to this blend to obtain the desired properties during the manufacturing process, and to give the required road performance. Zinc oxide (ZnO), which acts as a vulcanising agent, is one of the more significant additives. According to Smolders and Degryse (2002), the typical ZnO concentration in tyre tread is between 1.2% (cars) and 2.1% (trucks).

Tyre tread wear is a complex physio-chemical process which is driven by the frictional energy developed at the interface between the tread and the pavement aggregate particles.

Tyre wear particles and road surface wear particles are therefore inextricably linked. However, for the purpose of determining emission factors tyre wear and road surface wear must, at present, be treated as separate particle sources due to the lack of appropriate experimental data on the emission rates associated with different tyre-road surface combinations.

The actual rate of tyre wear rate depends on a large number of factors, including driving style, tyre position, vehicle traction configuration, bulk surface material properties, tyre and road condition, tyre age, road surface age, and the weather.

For example, driving pattern has a significant effect on wear rate. Even when a vehicle is being driven at a constant speed, there is a continuous micro-sliding of the tyre on the road surface - an effect which is responsible for traction. When driving dynamics (cornering, braking, accelerating) increase, sliding develops in response to the larger forces generated at the road surface-tyre interface, and this can cause additional wear of both the tyre and the road surface. Therefore, ‘smooth’ driving extends the lifetime of a tyre and, conversely, tyre lifetime reduces as the amount of harsh or transient vehicle operation increases. Urban driving has been found to be associated with a high wear rate per unit distance. For example, Stalnaker *et al*. (1996) compared urban driving with Motorway driving, and found out that the wear rate associated with the former may be as much as 30 times greater than the wear rate associated with the latter.

On a front-wheel drive (FWD) vehicle, the front wheels are used both for traction and steering, while the rear wheels are only responsible for rear axle control and load carriage. On a rear-wheel drive (RWD) vehicle, the front wheels serve primarily for steering, while traction is a rear-wheel responsibility. Due to these different roles, it is expected, and is experimentally verified, that front tyres show the higher wear rate on a FWD vehicle, and rear tyres on a RWD one. Warner *et al*. (2002) report that front tyres on a FWD vehicle accounted for 69-85% of total vehicle tyre wear while on a RWD vehicle there was an equal contribution from each axle. High wear rates may also occur due to steering system misalignment. The most common effect is high peripheral wear of low pressure tyres, and unbalanced wear caused by improper steering system setting (wheel toe-in, camber and caster).

The physical characteristics of the tyre tread material have a prominent effect on tyre wear rate. In general, high performance tyres, such as those used in superbikes and sports passenger cars have the highest wear rates because of their large frictional coefficient and use under more severe operational conditions. The lifetime for such tyres may be as little as 10,000 km. On the other hand, a typical car tyre has a lifetime of 50 – 60,000 km, during which time it loses about 10% of its total weight (UK Environment Agency, 1998; Kolioussis *et al*., 2000). The lifetime of truck tyres is estimated to be typically 100,000 km, depending on truck usage and load per tyre. Also, some tyres in this vehicle category are retreaded, whereby a new tread is fixed onto a worn tyre. Retreading prolongs the lifetime of the tyre, but it has led to concerns about safety (Dunn, 1993). Obviously, the total amount of material lost during a tyre’s lifetime is different for each individual vehicle, and may range from a few hundreds of grams for two wheelers to 1-1.5 kg for passenger cars and up to 10 kg for a truck or bus. Table 2 provides a list of wear rates collected from the literature.

Weather and road conditions may also affect the lifetime of a tyre. Wet conditions decrease friction, and hence should be expected to also decrease the wear rate. Similarly, new tarmac, although safer, is also harsher on the tyre than an older surface

Table 2: Tyre wear rates found in the literature

Remarks	Value / Range(1)	Source
Average tyre wear rate for FWD car (meas.)	79 mg/vkm	Warner *et al.* (2002)
Average tyre wear rate for RWD car (meas.)	193 mg/vkm	
Average tyre wear for a vehicle (meas.)	97 mg/vkm	
Front tyre for FWD vehicle (meas.)	28 mg/tyre/km	
Rear tyre for FWD vehicle (meas.)	8 mg/tyre/km	
Front tyre for RWD vehicle (meas.)	50 mg/tyre/km	
Rear tyre for RWD vehicle (meas.)	47 mg/tyre/km	
Tyre wear rate (est.)	30 mg/tyre/km	Gottle (1979)
Tyre wear rate (est.)	30 mg/tyre/km	Malmqvist (1983)
Tyre wear rate (est.)	60-90 mg/tyre/km	Dannis (1974)
Tyre wear rate (est.)	50 mg/tyre/km	Baekken (1993)
Tyre wear rate (est.)	16 mg/tyre/km	Lee *et al*. (1997)
Tyre wear rate for light vehicles (est.)	17 mg/tyre/km	Legret and Pagotto (1999)
Tyre wear rate for heavy vehicles (>3.5t) (est.)	34 mg/tyre/km	
Tyre wear rate	53 mg/vkm	Gebbe (1997)
Passenger car tyre wear rate	120 mg/vkm	CARB (1993)
Tyre wear for car <1400cc (meas.)	36 mg/vkm	Kolioussis and Pouftis (2000)
Tyre wear for car 1400-2000cc (meas.)	40 mg/vkm	
Tyre wear for car >2000cc (meas.)	46 mg/vkm	
Average estimated tyre wear (meas.)	40 mg/vkm	

(1) Note that ranges are stated either in mg/ vehicle-km or mg/ tyre-km. "Meas." is a direct measurement by weighing of tyres while "Est." is an estimation based on statistical data and manufacturer information.

As a vehicle moves, the road surface is also being worn at the tyre-road interface, and this wear material contributes to total particle emissions from road transport. A range of asphalt-based and concrete-based road surfacings are in use throughout Europe, with block paving being used in many urban areas. Concrete surfacings are composed of coarse aggregate, sand and cement. Asphalts are mixtures of mineral aggregate, sands, filler, and bitumen binder, though the composition can vary widely both from country to country and within countries. Generally, the stone content is around 90-95% and the bituminous binder around 5-10%. The properties of asphalt can be modified by additives such as adhesives, polymers, and different types of filler.

In areas where there is extensive use of studded tyres during winter, the wear of the road surface increases considerably. In Norway, the use of studded tyres is thought to be responsible for the wear of around 250,000 tonnes of asphalt per year (NILU, 1996).

3.2 Brake wear

Brakes are used to decelerate a vehicle. There are two main brake system configurations in current use: disc brakes, in which flat brake pads are forced against a rotating metal disc, and drum brakes, in which curved pads are forced against the inner surface of a rotating cylinder. Disc brakes tend to be used in smaller vehicles (passenger cars and motorcycles) and in the front wheels of light-duty trucks, whereas drum brakes tend to be used in heavier vehicles.

Linings generally consist of four main components – binders, fibres, fillers, and friction modifiers – which are stable at high temperatures. Various modified phenol-formaldehyde resins are used as the binders. Fibres can be classified as metallic, mineral, ceramic, or aramide, and include steel, copper, brass, potassium titanate, glass, asbestos, organic material, and Kevlar. Fillers tend to be low-cost materials such as barium and antimony sulphate, kaolinite clays, magnesium and chromium oxides, and metal powders. Friction modifiers can be of inorganic, organic, or metallic composition. Graphite is a major modifier used to influence friction, but other modifiers include cashew dust, ground rubber, and carbon black. In the past, brake pads included asbestos fibres, though these have now been totally removed from the European fleet.

The effect on wear rate of the relative position of brakes on a vehicle is even more important than it is for tyres. In passenger cars and motorcycles, the braking force is mainly developed in the front wheels, whilst braking in the rear axle is applied only for vehicle stability. As a result, the brake pads on the front axle are replaced more frequently (~30,000 km) than the pads on the rear axle (~50,000 km) (Kolioussis and Pouftis, 2000). With heavy trucks, the braking energy is more evenly distributed to different axles because of lower deceleration rates and the heavy load at the back of the vehicle. Wear rates also depend on brake actuation mechanism (pneumatic, electric), and hence it is more difficult to estimate pad lifetime. It is expected that for trucks and coaches, pad lifetime is of the order of 60,000 km. Table 3 provides a summary of brake wear rates found in the literature.

Table 3: Brake wear rates found in the literature

Remarks	Value	Method	Source
Brake wear of brake linings for passenger cars	20 mg/vkm	Estimation of wear for typical brake linings using manufacturer information	Legret and Pagotto (1999)
Brake wear of brake linings for light goods vehicles	29 mg/vkm		
Brake wear of brake linings for heavy lorries	47 mg/vkm		
Total brake wear for a small car	11 mg/vkm	Estimation of brake wear using the following data: (1) Average weight of brake's friction material, (2) lifetime of front and rear brakes under normal usage in km, (3) average percentage of mass loss, which is 80%.	Garg *et al.* (2000)
Total brake wear for a large car	17 mg/vkm		
Total brake wear for a pick-up truck	29 mg/vkm		
Average amount of brake material lost	8.8 mg/vkm	Gravimetric measurement of brake wear (brakes of 5 test vehicles -passenger cars- were weighed and mass loss was calculated)	Warner *et al.* (2002)
Material lost for passenger cars	17 mg/vkm	-	Westerlund, K-G (2001)
Material lost for heavy goods vehicles	84 mg/vkm		

3.3 Definitions

The following definitions are used in this Chapter in relation to airborne particulate matter:

- PM_x: Particulate matter which is collected by ambient samplers with a retention efficiency of 50% for particles of x µm aerodynamic diameter. For example, PM_{10} corresponds to all particles collected in an ambient sampler with a 50% cut-off at 10 µm. Particles smaller than PM_{10} comprise the "respirable" fraction which penetrates the nasal region.

- TSP: Total Suspended Particles. The definition of TSP is rather equivocal, since the residence time of particles in the atmosphere is a function of their size. Practically, particles larger than 50-100 µm have residence times of only seconds to minutes (depending on turbulence), and are generally considered as dustfall. Hence, only sizes up to 100 µm may generally be considered as TSP.

- Fine particles: Particles in the size range <2.5 µm ($PM_{2.5}$).

- Ultrafine particles: Particles in the size range <0.1 µm ($PM_{0.1}$).

- Nuclei mode (also Aitken mode): Particles in the size range 0.003-0.050 µm which form a distinct log-normal distribution. This mode usually forms by nucleation of condensable species.

- Accumulation mode: particle size range from 0.050 to 1 µm which also forms a distinct lognormal distribution. Such particles are usually solids which originate from combustion or very fine abrasion.

- Coarse mode: particle size range above 2.5 µm. Such particles may form from mechanical processes (abrasion, grinding, milling, etc.).

3.4 Techniques

This Section describes the techniques used to determine particle emission rates associated with tyre wear, brake wear and road surface wear. A discussion of the various techniques is important in order to explain the wide range of emission rates reported, and to aid the understanding of the uncertainties and difficulties associated with estimating PM contributions from non-exhaust sources.

Three main approaches have been used for estimating emission rates:

- The determination of particle emissions by direct measurement using a simulated wheel or brake operation in the laboratory.

- The sampling and analysis of particulate matter in ambient air followed by the application of source apportionment methods (receptor modelling).

- The combination of a size distribution profile with a measured wear rate to estimate emissions of given size ranges.

The real-world performance of a tyre is difficult to simulate in the laboratory, and therefore direct measurement of particle emissions is problematic. Early studies (Cardina, 1974; Dannis, 1974; Cadle and Williams, 1978) used laboratory-based techniques to identify particle characteristics, such as size distributions. More recently, Camatini *et al*. (2001) have used a rotating drum method to simulate tyre wear in order to study the morphology and speciation of emitted particles.

Receptor modelling is a more widely-used technique for determining particle emission rates for different vehicle-related sources, including tyre wear. With this technique, ambient aerosol samples are collected in specific locations (tunnels, street canyons, street junctions, etc.) and are apportioned to different sources using tracer species for identification. Traces used for tyre wear have included zinc or SBR (Fauser, 1999) or a typical tyre material profile (Rauterberg-Wulff, 1999; Abu-Allaban, 2002). This method is also termed chemical mass balance (CMB). Following well-structured statistical analyses (e.g. principal components analysis), the contribution from each primary source may be determined by comparing bulk material profiles with relevant contributions of the tracer species to the sample.

The third method is to record wear rates of particles by periodic weighing of tyres, and then to deduce an emission factor by assuming that a fraction of this wear is airborne (*e.g.* Luhana *et al*., 2002). Ranges for airborne fractions are mostly engineering judgements based on typical emission size profiles derived for tyre debris.

In principle, the same techniques are also used to determine emission factors for brake and road surface wear. In the case of brake particles, the simulation of brake operation in the laboratory is more straightforward, and brake-wear emission factors have been directly determined this way. For example, Garg *et al*. (2000) and Sanders *et al*. (2002) have utilised closed-chamber dynamometers to collect dustfall particles, with airborne particles being sampled using filters, impactors and aerosol analysis instrumentation.

There are inherent limitations to any of the techniques employed. Receptor modelling should generate accurate emission factors because samples are collected close to roadways. However, the samples obtained are a bulk average from different sources and different vehicles, and largely depend on environmental conditions (*e.g.* wind direction). Another significant problem with this method is that resuspended particles arising from vehicle-generated turbulence may be included as primary emissions during sampling. On the other hand, laboratory experiments may not fully reproduce real-world vehicle (*i.e.* tyre or brake) operation, and can only concentrate on a small sample of brake pads or tyre types. Also, the airborne fraction produced depends on the geometry of the dynamometer facility and the sampling conditions utilised.

Differences between these measurement techniques have contributed to the large ranges of particle emission rates reported in the literature.

3.5 Emissions

3.5.1 Particles from tyre wear

Tyre wear material is emitted across the whole size range for airborne particles. Camatini *et al*. (2001) collected debris from the road of a tyre proving ground. They found tyre debris agglomerated to particle sizes up to a few hundred micrometers. Such particles are not airborne and are of limited interest to air pollution, but they contribute the largest fraction by weight of total tyre wear. Although the samples were collected in the environment of a proving ground, where tyre wear may be extreme, similar observations were also made by Smolders and Degryse (2002), who found that roadside tyre debris <100 μm had a mean diameter of 65 μm for cars and 80 μm for trucks.

Significant research in the area of airborne particle size definition was conducted in the 1970s. Cadle and Williams (1979) reported a tyre wear particle size distribution in the range 0.01-30 μm. Other studies have indicated two separate size modes: one consisting of particles below 1 μm, the other consisting of coarse particles above 7 μm (Cardina, 1974; Dannis, 1974; Pierson and Brachaczek, 1974; Cadle and Williams, 1978). This observation has also been confirmed in a more recent study (Fauser, 1999). A plausible mechanism for the distinction is the volatilisation and subsequent condensation of material in the ultrafine particle mode, and normal wear for larger sizes (Cadle *et al*., 1978). However, this is by no means verified as yet.

The observed mass-weighted size distribution has varied in different studies, and it is not straightforward to draw firm general conclusions. Early studies indicated a small mass fraction below around 3 μm (Pierson and Brachaczek, 1974; Cadle and Williams, 1978). More recently, a study by TNO (1997) has suggested that PM_{10} is distributed as 70% $PM_{2.5}$, 10% PM_1 and 8% $PM_{0.1}$. Rauterberg-Wulff (1999) noted that tyre wear particles were only found in the coarse mode (>2.5 μm). On the other hand, Fauser (1999) reported size distributions with up to 90% of mass below 1 μm. Additionally, information from Miguel *et al*. (1999) may be used to estimate a TSP contribution from tyre wear. This investigation identified that 50-70 % of the airborne-sized road dust may be classified as PM_{10}. By extrapolation, this value may also be used to estimate an approximate TSP/PM_{10} ratio for tyre wear. A summary of the size-related studies is provided in Table 4.

Table 4: Summary of particle size information from tyre wear

Value / Range	Source
0.01μm to 30μm	Cadle and Williams (1979)
Smaller than 1μm or larger than ~7μm	Cardina (1974); Dannis (1974); Pierson and Brachaczek (1974); Cadle and Williams (1978); Fauser (1999)
Only 10% by mass of tyre wear particles are smaller than 3μm	Pierson and Brachaczek (1974)
Larger sizes of PM_{10} dominate the total mass	Cadle and Williams (1979)
90% by mass of tyre wear particles are PM_1	Fauser (1999)
Tyre wear particles were only found in the coarse mode fraction (2,5μm to 10μm)	Rauterberg-Wulff (1999)
70% by mass of tyre wear PM_{10} are $PM_{2.5}$, 10% are PM_1 and 8% are $PM_{0.1}$	USEPA (1995); TNO (1997)
50-70% of total airborne-sized road dust may be classified as PM_{10}	Miguel *et al.* (1999)

Unsurprisingly, tyre wear particles mainly consist of the compounds used to formulate tyre wear. According to Hildemann *et al*. (1991), tyre particles contain 29% elemental carbon and 58% organic material. With regard to metals, zinc is again the most abundant material.

3.5.2 Particles from brake wear

The ability to measure particle emission rates from brake wear in the laboratory has also provided valuable information on the characteristics of such particles. However, there is still a large amount of variation in the fraction of total wear mass that can be assumed to be airborne. USEPA (1995) and TNO (1997) indicate that 98% by mass of wear particles can be classified as PM_{10}. On the other extent, Garg *et al*. (2000) performed laboratory tests with a number of pad types and brake systems, and found out that the airborne fraction corresponds to 16-35% of total wear, with the percentage increasing as temperature decreases. Even more recently, Sanders *et al*. (2002) conducted detailed laboratory tests, and observed that 55-70% of the total wear material was in the form of airborne particles. In this study the collection efficiency for wear debris was 90-100% of the wear mass, and the investigators used a state-of-art experimental setup. The same study identified that 3-30% of brake debris falls on the road, 16-22% is retained on the wheel, and 8-25% is retained on the brake and steering and suspension equipment.

The size distribution of airborne brake wear particles is also rather uncertain. Sanders *et al*. (2002) quote earlier studies in which the average size of wear debris was in the 1-3 μm region. USEPA (1995) and TNO (1997) indicate that PM_{10} can be classified as 40% $PM_{2.5}$, 10% PM_1 and 8% $PM_{0.1}$. Garg *et al*. (2000) found a much higher fraction attributable to the ultrafine range, and noted that 88% of TSP can be classified as PM_{10}, 63% as $PM_{1.5}$ and 33% as $PM_{0.1}$. By sampling at the roadside and using chemical mass balance for receptor modelling, Abu-Allaban (2002) estimated that $PM_{2.5}$ share is only 5-17% of the total PM_{10} brake wear. The ranges reported also reveal the uncertainties of the different methods.

With regard to its chemical composition, brake wear material largely depends on the manufacturer, the application (car, truck, etc.) and the desired properties of the brake pads. Pads are expected to consist mainly of metals bound together with Si-based materials. Analyses by Legret and Pagotto (1999) and Hildemann *et al*. (1991) have shown a Fe contribution up to 46%, Cu content of up to 14%, organic material in the order of 13%, and then several other metals including Pb (~4%), Zn (~2%), Ca, Ba.

3.5.3 Particles from road surface wear

The wear rate of asphalt, at least in terms of airborne wear particles, is even more difficult to quantify than tyre and brake wear, partly because the chemical composition of bitumen is too complex for quantification with CMB, and partly because primary wear particles mix with road dust and resuspended material. Therefore, wear rates and particle emission rates for road surfaces are highly uncertain. Muschack (1990) reports an asphalt wear rate of 3.8 mg/km per vehicle kilometre. Work in Scandinavia suggests that studded winter tyres result in a much higher wear rate, producing 11-24 g/km of asphalt wear per vehicle in dry weather (Lindgren, 1996). According to Fauser (1999), around 70% by weight of airborne particles from bitumen range from 0.35 μm to 2.8 μm with a mean below 0.7 μm.

The problem of quantifying particle emissions arising from road surface wear has been also tackled by Lükewille *et al.* (2002), who propose preliminary emission factor values. These preliminary values have been adopted in this Chapter.

3.6 Controls

From 1999, European Directive 98/12/EC enforced asbestos-free brake pads for all road vehicles. This has had no direct effect on the emission rate of brake debris, only on the chemical composition of the associated particles. There is no other control legislation or method for tyre and brake wear. Currently, efforts are focussing on the development of low-friction tyres for fuel consumption and CO_2 benefits. Such tyres might also result to lower emissions of particles.

4 SIMPLE METHODOLOGY

In order to calculate PM_{10} emissions from brake and tyre wear and road surface wear, equation (1) can be used. This equation can be used to estimate emissions for a defined spatial and temporal resolution by selecting appropriate values for the fleet size and the activity rate (mileage). Emission factors are then a function of vehicle class alone. Total traffic-generated emissions can be estimated by summating the emissions from individual vehicle classes.

$$TE_{s,j} = N_j \times M_j \times EF_{s,j} \qquad (1)$$

Where,

TE... Total PM_{10} Emissions for the defined time period and spatial boundary[g]
N… Number of vehicles in defined class within the defined spatial boundary
M… Average mileage driven per vehicle in defined class during the defined time period [km]
EF… Mass emission factor [g/km]

while indices correspond to:

s… non exhaust source of particles (s = tyre, brake, road),
j… vehicle class (j = two-wheeler, passenger car, light-duty truck, heavy-duty vehicle).

Therefore, the user of this simple methodology need only determine activity rates in the form of the vehicle population (by class) and mileage driven per vehicle (by class) for the requested temporal and spatial resolution.

Relevant emission factors for use in equation (1) are given in section 8.1. For selection of the appropriate vehicle class it is considered that two wheelers correspond to mopeds and motorcycles which are more common in cities. Passenger cars are small or larger family cars mainly for the carriage of people. Light-duty trucks also include vans for the carriage of people or goods. Heavy-duty vehicles correspond to trucks, urban buses and coaches. More details on the vehicle classification and selection criteria can be found in Chapters 070100-070500 of this Guidebook.

5 DETAILED METHODOLOGY

5.1 Tyre wear particle emissions

In order to estimate particle emissions from tyre wear, equation 2 can be used. This equation refers to a single vehicle category for a defined temporal and spatial resolution. Also, different particle size classes are considered (TSP, PM_{10}, $PM_{2.5}$, PM_1, $PM_{0.1}$).

$$TE_{Ti,j} = N_j \cdot M_j \cdot (EF_T)_j \cdot f_{Ti} \cdot S_T(V) \qquad (2)$$

Where,

TE... Total Emissions for the defined time period and spatial boundary [g]
N… Number of vehicles in the defined class within the defined spatial boundary
M… Mileage driven by vehicles in the defined class during the defined time period [km]
EF_T… TSP mass emission factor from tyre wear [g/km]
f_{Ti}… Mass fraction of tyre-wear TSP that can be attributed to particle size class i
$S_T(V)$… Tyre-wear correction factor for a mean vehicle traveling speed V

and indices,
T… tyre
i… TSP, PM_{10}, $PM_{2.5}$, PM_1 and $PM_{0.1}$ size classes,
j… Vehicle class similar to eq.1.

The TSP emission factors for tyre wear are presented in Section 8.2.1.

Typical size profiles for TSP emitted by tyre wear have been obtained by combining information from the literature, as discussed in section 3.5.1. Based on this information, the mass fraction of TSP in the different particle size classes is shown in Table 5.

Table 5: Size distribution of tyre wear emitted particles

Particle size class (i)	**Mass fraction (f_T) of TSP**
TSP	1.000
PM_{10}	0.600
$PM_{2.5}$	0.420
PM_1	0.060
$PM_{0.1}$	0.048

A speed correction is required to account for the different wear rate of the tyre depending on the vehicle speed. Figure 1 shows the speed correction, based on the findings of Luhana *et al.* (2002). It should be noted that, as in the case of exhaust emission factors, vehicle speed corresponds to mean trip speed and not constant traveling speed. There is a decreasing pattern of emissions with increasing speed. This is in contrast to the usual perception that airborne particles increase in the wake of a vehicle as speed increases, because Figure 1 corresponds to primary particle emissions from the tyre and not resuspended dust. Tyre wear decreases as mean trip speed increases, because braking and cornering are more frequent in urban driving than in motorway driving.

The mathematical expression of Figure 1 is:

V < 40km/h:	$S_T(V) = 1.39$	
40km/h ≤ V ≤ 90km/h:	$S_T(V) = -0.00974 \cdot V + 1.78$	(3)
V > 90km/h:	$S_T(V) = 0.902$	

Note that $S_T(V) = 1$ when the mean trip speed is 80 km/h, and stabilizes below 40 km/h and above 90 km/h due to the absence of any experimental data. Also, although the proposed equation has been obtained from measurements on passenger cars, it is to be used for all vehicle categories.

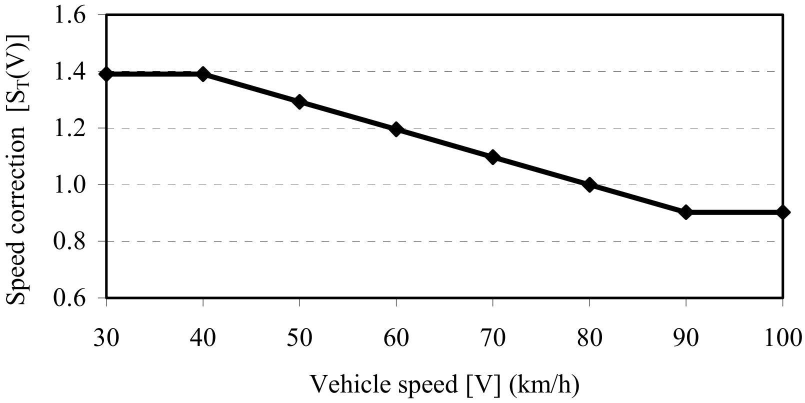

Figure 1: Speed correction factor for tyre wear particle emissions

5.2 Brake wear particle emissions

Similarly to tyre wear, brake wear emissions can be calculated by:

$$TE_{Bi,j} = N_j \cdot M_j \cdot (EF_B)_j \cdot f_{Bi} \cdot S_B(V) \qquad (4)$$

Where the nomenclature is similar to equation 2, but "B" corresponds to brake wear rather than tyre wear. The TSP emission factors for break wear are presented in Section 8.2.2.

The mass fraction of TSP in the different particle size classes is shown in Table 6.

Table 6: Size distribution of brake wear emitted particles

Particle size class (i)	Mass fraction (f_B) of TSP
TSP	1.000
PM_{10}	0.980
$PM_{2.5}$	0.390
PM_1	0.100
$PM_{0.1}$	0.080

The speed correction factor for the case of brake wear is given in Figure 2, and the mathematical expression of $S_B(V)$ is given in equation 5.

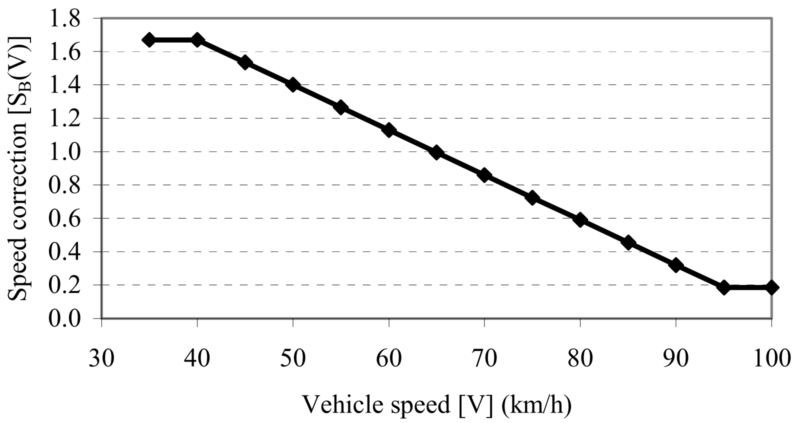

Figure 2: Speed correction factor for brake wear particle emissions

$$
\begin{array}{ll}
V < 40\text{km/h}: & S_B(V) = 1.67 \\
40\text{km/h} \leq V \leq 95\text{km/h}: & S_B(V) = -0.0270 \cdot V + 2.75 \\
V > 95\text{km/h}: & S_B(V) = 0.185
\end{array}
\qquad (5)
$$

In this case, the speed correction is normalised for a speed of 65 km/h, and the slope is generally larger than for tyre wear because brake wear is negligible at high motorway speeds when limited braking occurs. Again, although the proposed equation has been obtained from measurements on passenger cars, it is to be used for all vehicle categories.

5.3 Road surface wear emissions

There is very little information on airborne emission rates from asphalt wear (Section 3.4.3), and therefore the quality of the detailed methodology does not differ from the quality of the simple one. The detailed methodology only provides a mass-weighted size classification of road surface wear particles based on the work of Lükewille *et al.* (2002), according to the equation:

$$TE_{Ri,j} = N_j \cdot M_j \cdot (EF_R)_j \cdot f_{Ri} \qquad (6)$$

Where the nomenclature is similar to Equation 2, but "R" corresponds to road surface wear. The TSP emission factors for particles of road surface wear are presented in Section 8.2.3. The mass fraction of TSP in the different particle size classes is shown in Table 7.

Table 7: Size distribution of road surface wear emitted particles

Particle size class (i)	Mass fraction (f_R) of TSP
TSP	1.00
PM_{10}	0.50
$PM_{2.5}$	0.27

Due to the lack of appropriate experimental data, no emission factors are included for road surface wear associated with the use of studded tyres, although it is recognised that in some countries this may be an important particle source.

6 RELEVANT ACTIVITY STATISTICS

Information on activity statistics relevant to tyre, brake and road surface wear may be found in the Road Transport Chapter (SNAP Codes 070100 – 070500).

7 POINT SOURCE CRITERIA

There are no relevant point sources which fall under the source activities dealt within this Chapter.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Emission Factors for simple methodology

The emission factors quoted in Table 8 are only approximate estimates based on the wear rates and emission factors reported in the literature. The exhaust emission rates correspond to fleet average values in Europe for a typical year of the period 2000-2002, and are only quoted for comparison with non-exhaust sources. Application of the non-exhaust emission factors is only meant for calculation of indicative emission levels to the atmosphere. Based on the information used to derive these values, an expected range of -50% to +100% may be relevant, or even higher if individual vehicles and not traffic average emissions need to be studied.

Table 8: Non-exhaust PM_{10} emission factors to be used with the simple methodology and comparison with aggregated exhaust emission factors

Vehicle class (j)	**Particle source(s)**			
	Tyre wear (g/km)	**Brake Wear (g/km)**	**Road surface wear (g/km)**	**Exhaust emission rate (g/km)***
Two-wheelers	0.0028	0.0037	0.0030	0.060 (two-stroke)
Passenger cars	0.0064	0.0073	0.0075	0.060 (diesel)
Light duty trucks	0.0101	0.0115	0.0075	0.080 (diesel)
Heavy vehicles	0.0270	0.0320	0.0380	0.400

*For comparative purposes only.

8.2 Emission Factors of detailed methodology

8.2.1 Tyre wear

TSP Emission factors for different vehicle classes are given in Table 9. All emission factors are based on available experimental data. It should be noted that the TSP emission rates do not assume that all tyre wear material is transformed into suspended particulate, as a large fraction of tyre rubber may be produced as dustfall particles or larger shreds (e.g. under heavy braking). A value of 0.6 has been selected as the PM_{10}/TSP ratio for tyre wear in order to derive TSP values where only PM_{10} emission rates are available in the literature.

Table 9: TSP emission factors from tyre wear

Vehicle Class (j)	**Emission Factor (g/km)**	**Range (g/km)**	**Quality Code**
Two-wheelers	0.0046	0.0042 – 0.0053	B
Passenger cars	0.0107	0.0067 – 0.0162	B
Light-duty trucks	0.0169	0.0088 – 0.0217	B
Heavy-duty trucks	Eq.7	0.0227 – 0.0898	B-C

Quality codes:

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.

For the heavy-duty truck case, emission factor needs to take vehicle size into account. This is introduced by the equation:

$$\left(\mathrm{EF_T}\right)_{\mathrm{HDV}} = \frac{\mathrm{N_{axle}}}{2} \cdot \mathrm{LCF_T} \cdot \left(\mathrm{EF_T}\right)_{\mathrm{PC}} \qquad (7)$$

Where,

N_{axle}… number of truck axles,
LCF_T… a load correction factor,
$(EF_T)_{PC}$… the passenger car relevant TSP emission factor.

For heavy-duty trucks, the number of axles is a parameter which can be used to differentiate truck size. An additional parameter is a load correction factor, which accounts for the load carried by the truck or bus. The load correction factor can be estimated on the basis of equation 8 which has been derived by linear regression on experimental data:

$$LCF_T = 1.41 + 1.38 \cdot LF \qquad (8)$$

Where LF is the load factor for the truck, ranging from 0 for an empty truck to 1 for a fully laden one. The same equations can be used for urban busses and coaches.

8.2.2 Brake wear

TSP emission factors for brake wear particles are given in Table 10, together with the range and a quality code for the emission factor.

Table 10: TSP emission factors from brake wear. Emission factors coding as in Table 9.

Vehicle Class (j)	Emission Factor (g/km)	Range (g/km)	Quality Code
Two-wheelers	0.0037	0.0022 – 0.0050	D
Passenger Cars	0.0075	0.0044 – 0.0100	B
Light Duty Trucks	0.0117	0.0088 – 0.0145	B
Heavy Duty Trucks	Eq.9	0.0235 – 0.0420	B-C

The heavy-duty emission factor is calculated by adjusting the passenger car emission factor to fit heavy-duty vehicle experimental data:

$$\left(EF_B\right)_{HDV} = 3.13 \cdot LCF_B \cdot \left(EF_B\right)_{PC} \qquad (9)$$

In equation 9, 3.13 is an empirical factor derived from experimental data and LCF_B is defined in a similar way to LCF_T and can be determined again by linear regression on experimental data by the equation:

$$LCF_B = 1 + 0.79 \cdot LF \qquad (10)$$

LF again receives the value of 0 for an empty truck and 1 for a fully laden one. Equations 9 and 10 are also proposed for urban busses and coaches.

8.2.3 Road surface wear

Preliminary values for road surface wear TSP emissions are shown in Table 11. These TSP values should correspond to primary particles from road surface wear but they are based on limited information and are highly uncertain.

Table 11: TSP emission factors from road surface wear. Emission factors coding as in Table 9.

Vehicle Class (j)	Emission Factor (g/km)	Quality Code
Two-wheelers	0.0060	C-D
Passenger Cars	0.0150	C-D
Light Duty Trucks	0.0150	C-D
Heavy Duty Trucks	0.0760	C-D

9 SPECIES PROFILES

For a detailed list of organic compounds and PAHs, the reader should refer to the work of Rogge *et al*. (1993) which is, however, based on a single tyre type and a single brake pad. Instead of quoting the very extensive list of compounds we focus on the six protocol PAHs (Table 12).

Table 12: Brake and tyre debris-bound PAHs

Compound	Tyre Wear (ppm wt.)	Brake Wear (ppm wt.)
Fluoranthene	11.1	0.69
Benzo(a)pyrene	3.9	0.74
Benzo(b)fluoranthene	0	0.42
Benzo(k)fluoranthene	0	0.62
Indeno(1,2,3-cd)pyrene	-	-
Benzo(ghi)perylene	0	2.6

Table 13 provides the speciation of tyre and brake wear into different elements. Several sources have been used to provide this speciation and for this reason, a mean value and the minimum and maximum values are shown. In several instances a large range is reported. This is obviously due to the variety of materials and sources used to manufacture tyre tread and brake linings, and a larger sample of materials needs to be studied. At present, due to the absence of such information the "mean" value is a non-weighted average of values given in different reports. Sources for the ranges of Table 13 include Malmqvist, 1983; Hewitt and Rashed, 1990; Brewer, 1997; VROM, 1997; Legret and Pagotto, 1999; Westerlund, 2001 and Hildemann *et al*., 1991.

Table 13: Elemental speciation of tyre and brake wear (in ppm wt.)

Element	Elemental Speciation					
	Tyre			Break		
	Mean	Min	Max	Mean	Min	Max
Ag	0.1	0.1	0.1			
Al	324	81.0	470	2050	330	3770
As	0.8			10.0		
Ba	125.0	0.9	370.0	38520	2640	74400
Br	20.0			40.0		
Ca	892	113.0	2000	7700	1100	14300
Cd	2.6	0.3	5.0	13.2	2.7	29.9
Cl	520			1500		
Cl-	600			1500		
Co	12.8	0.9	24.8	6.4		
Cr	12.4	0.4	30.0	669	115	1200
Cu	174	1.8	490	51112	370	142000
EC	153000			26100		
Fe	1712	2.1	4600	209667	115000	399000
K	280	180.0	380	523.5	190	857
Li	1.3	0.2	2.3	55.6		
Mg2+	166	32.0	360	44570	6140	83000
Mn	51	2.0	100	2460	1700	3220
Mo	2.8			10000		
Na+	645	610.0	680	7740	80.0	15400
NH4+	190			30.0		
Ni	33.6	0.9	50	463	133	850
NO3-	1500			1600		
OC	360000			107000		
P						
Pb	107	1.0	160	3126	50.0	6594
Rb				50.0		
S	1100			12800		
Sb	2.0			10000		
Se	20.0			20.0		
Si	1800			67900		
SO4--	2500			33400		
Sn				7000		
Sr	14.4	0.2	40.0	520	81.4	740
Ti	378			3600		
V	1.0			660		
Zn	7434	430	13494	8676	270	21800

NB. EC = Elemental Carbon, OC = Organic Carbon.

10 UNCERTAINTY ESTIMATES

The emission factors provided in this Chapter have been developed on the basis of information collected by literature review, and on wear rate experiments. The experimental information required was obtained by three different methods:

1. By roadside receptor modelling at urban pollution hot-spots or in road-tunnels,
2. By airborne particle and wear rate determination in laboratory experiments,
3. By applying a size distribution to wear rates in order to derive the airborne fraction.

Obviously there is a significant uncertainty associated with each of these methods. In the case of receptor modelling, the profile used is of large importance, and artefacts from resuspension may significantly modify emission factors. For example, Abu-Allaban *et al*. (2002) identified no airborne particles from tyre wear, and up to 160 mg/km particulate mass from brake wear for heavy-duty vehicles. On the other hand, Rauterberg-Wulff (1999) determined up to 32 mg/km tyre wear particles from heavy-duty vehicles. The uncertainties are similar for the other methods. For example, Fauser (1999) reported that more than 90% of airborne tyre wear is less that 1 μm. In contrast, Rauterberg-Wulff (1999) found airborne tyre particles only above 2.5 μm. Several such diverse effects apply also to chemical speciation (Table 13). Of course, these are extreme examples, but they do provide a frame of reference for the uncertainty associated with the proposed methodology.

The emission factors used here are typical of the values in the available literature and uncertainty range is given next to each emission factor value (Tables 9-11). A solid point for cross-checking of the methodology is the wear rates for tyres and brakes which are rather well established values. Therefore, application of typical size profiles on these wear rate values (method 3 in the list above) may also provide a reasonable emission factor value for comparison. The emission factor values proposed in this Chapter have also been cross-checked with inventory activities (e.g. Flugsrud *et al*., 2000) and source apportionment investigations (e.g. Schauer *et al*., 2002). As a rule of thumb, an uncertainty in the order of ±50% is expected.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The following have been identified as weak aspects of the current methodology, and therefore areas for improvement:

- *Tyre wear – effects of different tyre and road surface combinations*
  The current methodology is based on experimental data based on a variety of tyre and road surface types. More detailed information is required on the relative effects of different tyre and road surface combinations, including unpaved roads.

- *Road surface wear - conventional tyres*
  The preliminary emission factor values for asphalt wear are highly uncertain. Again, additional experimental information is necessary to establish more precise values.

- *Road surface wear – studded tyres*
  In some countries the use of studded tyres results in a high rate of road surface wear, though the effects on airborne particle emissions are not well documented. Due to the lack of appropriate experimental data, no emission factors have been included for studded tyres, although it is recognised that this may be an important particle source.

- *Resuspended particles*
  A significant weak area is the contribution from the resuspension of road dust. In ambient and tunnel experiments it is not possible to distinguish freshly emitted tyre and brake wear aerosol from resuspended material from the same sources. Inherently, a part of resuspension is included in the proposed emission factors.

- *Weather conditions*
  The methodology and the emission factors provided in this Chapter have been derived from studies conducted on dry days with dry road conditions. It is obvious that a water layer on the road and a rainy day will result to significant reduction of airborne particle emissions, especially from brake and road surface wear, because such particles may be trapped by the water.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Since the emission factors presented in this Chapter are global, differentiated only for speed (and load for heavy duty vehicles), spatial disaggregation mainly refers to activity data. Such discussion is included in the road transport chapter (SNAPs 070100–070500).

13 TEMPORAL DISAGGREGATION CRITERIA

The same comment for spatial disaggregation criteria also applies here. However, one needs to take into account that, as temporal resolution increases, the effects of wet weather needs to be taken into account using some reasonable indicator.

14 ADDITIONAL COMMENTS

15 SUPPLEMENTARY DOCUMENTS

16 VERIFICATION PROCEDURES

The approaches which could be used to verify the emission factors and methodology in this Chapter are essentially those which have been used to determine the primary information. These include tunnel studies, receptor modelling, and direct laboratory-based measurement. There is currently a lack of on-road measurement data (i.e. using instrumented vehicles) under real-world driving conditions, and the collection of such data would also aid verification.

On simple verification approach would be to compare the results obtained using this method with those obtained in other inventories, and to determine whether the proportion of non-exhaust particles is consistent.

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