Road Transport

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 (SNAP code 0706) and component attrition (SNAP code 0707). Table 1.1 provides all the 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. Also, fuel (energy) consumption figures can be calculated. For NMVOC, a speciation to 68 substances is provided.

The methodology presented the third 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 present methodology is fully incorporated in the software tool COPERT III (Ntziachristos and Samaras, 2000a) which is available on http://vergina.eng.auth.gr/mech/lat/copert/copert.htm.

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 version 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. The present version introduces both additional refinements and new calculation elements. Those revisions and extensions mainly originate from the following sources:

- finalisation of the COST 319 action on the Estimation of Emissions from Transport, (Joumard R. (ed.), 1999),
- completion of the MEET (Methodologies to Estimate Emissions from Transport); a European Commission (Directorate for Transport) sponsored project in the framework of the 4th Framework Programme in the area of Transport (MEET, 1999),
- European Commission’s Auto Oil II programme (Ntziachristos and Samaras, 1999),
- the Inspection and Maintenance project (LAT/AUTh, 1998); a European Commission (Directorate Generals for Environment DGXI ,Transport DGVII, and Energy DGXVII) sponsored project,
- the EPEFE project; a programme conducted by the Association of European Automotive Manufacturers (ACEA) and the European Petroleum Industry Association (EUROPIA) (ACEA and EUROPIA, 1996).

Table 1.1: Activities covered in this chapter according to EMEP/CORINAIR nomenclature

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

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 >1.4 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 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

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

- Updated hot emission factors and consumption factors for Euro I gasoline and diesel passenger cars and light duty vehicles.
- Revised cold start over-emission ratios for Euro I gasoline vehicles.
- Modelling of the effect of vehicle age (mileage) on emissions and the effect of an enhanced Inspection and Maintenance scheme on fleet emissions.
- Revised vehicle category split, including future emission technologies for different classes and updated, representative emission reduction factors over existing vehicle technologies.
- The effect of the use of improved fuels on the emissions of present and future vehicle technologies.
- Extended NMVOC species profile, providing values for 68 different components.
- Emission factors for 23 PAHs and POPs and additional toxicity equivalent emission factors for Dioxins and Furans.
- Revisited emission factors of non regulated pollutants.

2 CONTRIBUTION TO TOTAL EMISSION

Road transport poses significant environmental pressures (EEA, 2002). 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 1999, road transport contributed to about 24% of total CO_2 emissions in EU and 47% of total NO_x emissions. However the trends in those two pollutants are opposite, with ~15% increase and ~20% decrease of CO_2 and NO_x in 1999 respectively, compared to 1990 levels. Tables 2.1a and 2.1b show the contribution of road transport to total anthropogenic emissions of main pollutants in EU.

Table 2.1a: Contribution of road transport to national totals of anthropogenic emissions for main pollutants.

Country	Road transport emissions - Year 1999									
	CO_2 (Mt)	CH_4 (kt)	N_2O (kt)	NO_x (kt)	CO (kt)	NMVOC (kt)	SO_2 (kt)	NH_3 (kt)	Pb (t)	PM_{10} (kt)
Austria	17.2	2.0		75.0	235.0	38.0	3.0	2.0		5.9
Belgium		4.0		141.0	542.0	87.0	6.0	2.0	45.0	10.3
Germany	174.0	19.0		833.0	2625.0	336.0	26.0	10.0		54.3
Denmark	11.4	3.0	1.0	81.0	345.0	50.0	1.0	2.0		4.3
Spain				550.0	1667.0	379.0	25.0		569.0	36.6
Finland	10.9	2.0		113.0	265.0	52.0				3.5
France	126.0	14.0		780.0	3000.0	546.0	36.0	10.0	523.0	50.8
UK				716.0	3290.0	474.0	14.0	12.0	331.0	30.1
Italy	110.0	42.0	9.0	748.0	4141.0	803.0	30.0	14.0		47.1
Luxembourg	1.3			7.0	32.0	6.0	1.0		1.0	0.5
Netherlands	29.1	4.0		177.0	430.0	105.0	5.0		3.0	9.5
Sweden	17.8	13.0		120.0	523.0	94.0	1.0	4.0		5.9

Notes: Data presented used for official data submission to UNFCC, CLRTAP by member states in 1999 and synthesised by ETC/ACC. Data for PM10 are unofficial data obtained from the CEPMEIP* activity (EMEP, 2001). National totals [kT] from road transport.

Table 2.1b: Contribution of road transport [%] to national total emissions. Data sources as indicated in Table 2.1a.

Country	Road transport contribution [%] to total emissions - Year 1999									
	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2	NH_3	Pb	PM_{10}
Austria	29.6	0.4		40.8	24.2	9.9	7.1	2.8		12.8
Belgium		0.7		48.8	53.3	30.3	3.3	2.0	31.3	12.2
Germany	20.3	0.6		50.9	53.0	20.4	3.1	1.6		16.1
Denmark	20.3	0.5	3.2	36.8	56.0	34.2	1.9	1.9		13.0
Spain				39.9	53.8	15.2	1.5		69.0	16.1
Finland	17.5	1.1		45.9	48.6	31.7				11.7
France	38.5	0.5		51.4	41.5	25.5	4.9	1.3	72.2	11.3
UK				44.6	69.7	26.7	1.2	3.8	60.4	11.5
Italy	24.9	2.1	6.9	50.3	68.1	43.6	1.0	3.1		14.7
Luxembourg	25.5	0.0		43.8	64.0	37.5	25.0		50.0	8.8
Netherlands	16.7	0.4		41.8	60.5	36.0	4.9		8.6	14.7
Sweden	31.0	4.3		44.9	57.5	21.8	1.9	7.1		13.9

The relevant contribution of each vehicle category to total emissions of each of the main pollutants is shown in Table 2.2. It is shown that relevant share is pollutant specific.

Table 2.2: 1990 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 2002)

Categor	CO	NOx	NMVO	CH_4	PM	FC	CO_2
Gasoline	79.15 (90.8 -	28.23 (44.5 -	58.69 (78.2 -	77.29 (87.8 -	0.00 (0.0 -	46.61 (65.4 -	45.43 (64.7 -
Diesel	1.00 (3.9 -	6.20 (20.0 -	1.86 (5.8 -	1.34 (4.6 -	17.89 (35.7 -	8.37 (23.6 -	8.68 (24.2 -
Gasoline	9.57 (27.8 -	3.84 (9.6 -	7.72 (23.2 -	4.32 (11.3 -	0.00 (0.0 -	3.55 (8.6 -	3.26 (8.1 -
Diesel	1.17 (3.9 -	7.65 (19.7 -	1.54 (5.7 -	0.73 (2.3 -	21.65 (45.9 -	7.51 (20.5 -	7.81 (21.0 -
Diesel	3.75 (7.6 -	47.07 (71.4 -	16.81 (30.8 -	8.94 (15.7 -	55.83 (76.7 -	30.46 (48.1 -	31.56 (49.4 -
Buses	0.43 (0.9 -	6.70 (12.2 -	1.18 (2.5 -	1.19 (2.5 -	5.39 (12.6 -	2.80 (6.4 -	2.91 (6.6 -
Coache	0.04 (0.1 -	0.85 (1.5 -	0.18 (0.3 -	0.16 (0.3 -	0.69 (1.4 -	0.49 (1.0 -	0.52 (1.0 -
Moped	1.91 (6.9 -	0.02 (0.1 -	8.80 (26.0 -	2.76 (11.4 -	0.00 (0.0 -	0.37 (1.6 -	0.20 (0.8 -
Motrocycle	3.69 (11.2 -	0.20 (0.7 -	3.86 (10.8 -	3.61 (13.5 -	0.00 (0.0 -	0.57 (2.3 -	0.38 (1.5 -

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

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.

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, …). 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 install aftertreatment devices, such as catalytic converters, to suppress by-product emission. However, such devices may also produce small quantities of pollutants such as NH_3 and N_2O.

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 output and more refined operation. For very small vehicles (mopeds and motorcycles), two stroke engines are favourable 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. This is an outcome of the technology improvements adopted for diesel engines which increase the power output density for given size and refine engine operation (systems such as common rail fuel injection, electronic engine control, etc.).

There are currently new technologies emerging, which aim at decreasing both energy consumption and pollutant emissions. Those technologies include new combustion processes for internal combustion engines (Gasoline Direct Injection, 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, calculation of emissions from road vehicles is a complicated and demanding procedure. The methodology presented in this chapter is only applicable for vehicles equipped with conventional internal combustion engines (spark ignition or compression ignition). There is a lack of experimental data to support an emission methodology development for alternative powertrains. The only possible extrapolation allowed for application of the present methodology regards GDI-equipped vehicles. One may assume that such vehicles perform as conventional spark-ignition ones when equipped with three way catalytic converter systems. However, one should also expect lower fuel consumption and higher PM emissions than conventional spark-ignition vehicles.

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). A detailed NMVOC split is also included to distinguish hydrocarbon emissions as alkanes, alkenes, alkines, aldehydes, ketones and aromatics.

According to the detail of information available and the approach adopted by the methodology to calculate emissions, the above mentioned pollutants can be arbitrarily 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
Particulate Matter (PM)	Given as the mass collected on a filter below 52°C in dilution tunnel measurements

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
Ammonia (NH_3)	Given as NH_3
Nitrous Oxide (N_2O)	Given as N_2O
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 an order of magnitude cleaner than vehicles two decades ago as regards conventional pollutants (CO, NO_x, VOC). Emission legislation becomes increasingly stringent and it is expected that further improvement of the emission levels will be established as an outcome.

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

The above implementation dates correspond to an "average" for the EU 15 member states. They are 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 the vehicles registered in the member state - either produced in the member state or imported from elsewhere in the world.

After 1985, new technologies appeared, imposed by the EC legislation and national schemes applying to vehicles <2.5 t. Those technologies are described in the following paragraphs.

<u>Gasoline Passenger Cars <1.4l</u>

a. Improved Conventional: It takes into account German and Dutch incentive programmes:

Anl.XXIVC (relevant for Germany). Effective date: 1.7.1985

NLG 850 (relevant for the Netherlands). Effective date: 1.1.1986

It is assumed that the required emission standards can be met by applying improved but conventional engine technology, that is without the use of a catalytic converter. This type of emission control technology also started to appear in Denmark from 1.1.1988.

b. Open Loop: It takes into account German, Danish, Greek and Dutch incentive programmes. It is assumed that the required emission standards can be 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.

c. Euro I: As early Euro I vehicles are considered those complying to (e.g. voluntary programmes in Germany carried out after 1.7.1985), where compliance with US 83 limits is required. However, directive 91/441/EEC introduced this emission standard at a European level for all vehicles introduced in the market for the period 1992 to 1996. This was also the first emission legislation which required unleaded fuel use.

<u>Gasoline Passenger Cars 1.4-2.0 l</u>

a. Improved conventional. It takes into account vehicles which meet 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 are: Denmark 1.1.1987, Germany 1.7.1985, the Netherlands 1.1.1987.

b. Open Loop. It takes 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 are: Denmark 1.1.1987, Germany 1.7.1985, Greece 1.1.1990, the Netherlands 1.1.1986.

c. Euro I: Similar to < 1.4 l, It takes into account national incentive programmes where compliance with US 83 limits is required. However, directive 91/441/EEC introduced this emission standard for all vehicles sold between 1992 and 1996. The use of unleaded fuel was mandatory.

<u>Gasoline Passenger Cars >2.0 l</u>

a. Euro I. It takes into account EC legislation and national incentive programmes:
88/76/EEC (relevant for all countries). Effective date for new vehicles: 1.1.1990.
US 83 (only relevant for Denmark, Germany, Greece, the Netherlands). Effective date: Denmark 1.1.1987, Germany 1.7.1985, Greece 1.1.1989, the Netherlands 1.1.1987. It is assumed that the required emission standards can be met by applying closed loop three way catalysts. Directive 91/441/EEC introduced this emission standard for all vehicles launched in the market between 1992 and 1996.

<u>Recent, current and future legislation steps</u>

After Euro I emission standards, all member states adopted directive 94/12/EC (Euro II) for type approval in the period 1996 - 2000. Compared to 91/441/EEC, 94/12/EC imposed a 30% and 55% reduction in CO and HC+NOx respectively. Current legislation (Directive 98/69/EC implemented in Stage 2000 - Euro III and Stage 2005 - Euro IV) imposes reductions of 30%, 40% and 40% respectively for CO, HC and NO_x over Euro II for the implementation step of year 2000. For the 2005 step, additional reductions reach 57% for CO and 47% for HC and NO_x. Such reductions bring emission levels of 2005 vehicles to the 1/5 of what it used to be in 1995. This is achieved with the use of closed-loop three way catalytic converters and additional measures such as installation of oxidation pre-catalysts, accurate control of the lambda value, use of on-board diagnostics systems and even the installation of NO_x-storage systems. Currently (2002) there are only discussions of how a Euro V emission standard (year

2010) should be formulated. Because those discussions have not yet reached a sufficient level of maturity, the present methodology only covers vehicles up to Euro IV.

3.5.2 Legislation classes of diesel passenger cars

Conventional vehicles

The "Conventional" vehicle class applies to diesel passenger cars of all capacities and includes vehicles prior to the introduction of the "Consolidated Emissions Directive" 91/441/EEC. Therefore, cases included are non regulated vehicles launched prior to 1985 and vehicles complying with directive ECE 15/04 (up to 1992). In principle diesel vehicles of this class are equipped with indirect injection engines and no exhaust aftertreatment.

Current and future diesel technologies

Improved diesel technologies include vehicles complying with directives 91/441/EEC (Euro I, 1992-1996), 94/12/EC (Euro II, valid from 1996 for indirect injection and 1997 for direct injection up to 2000) and the new regulations 98/69/EC Stage 2000 (Euro III) and 98/69/EC Stage 2005 (Euro IV). Euro I 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. Current Euro III vehicles target 40%, 60%, 14% and 37.5% less CO, NOx, HCs and PM than Euro II vehicles. The significant reductions have been achieved with exhaust gas recirculation (NOx reduction) and optimisation of fuel injection with use of common rail systems (PM reduction). Also fuel refinements (mainly sulphur content reduction) have played an important role in PM emission improvement. Euro IV vehicles are expected to further improve emission levels by 22% on CO and 50% to all other pollutants. Such significant reductions will only be made possible with advanced engine technology and aftertreatment measures, such as cooled EGRs, particulate traps and NOx reduction - PM oxidation techniques. As in the case of gasoline vehicles, Euro V standard is still under consideration and the present methodology reaches up to Euro IV.

3.5.3 Legislation classes of LPG passenger cars

LPG vehicles constitute a small and constantly decreasing 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 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 new emission standards have been applied (Euro I - Directive 93/59/EEC), which ask for catalytic converters on gasoline powered vehicles. Directive 96/69/EC (Euro II) 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 III - 98/69/EC (valid 2001-2006) and Euro IV - 98/69/EC (valid 2006 onwards) which introduce even stricter 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.

3.5.6 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.

3.5.7 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.

3.5.8 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) and 1996 up to 2000 (Stage 2). Currently, directive 1999/96/EC Step 1 (Euro III) is valid since 2000 and aims at a 30% reduction of all pollutants over the Euro II case. This directive includes an intermediate step in 2005 (Euro IV) and a final step in 2008 (Euro V). Standards for 2008 are very strict, targeting an over 70% reduction of NOx and over 85% decrease of PM compared to 1996 standards. Because such targets will necessitate advanced aftertreatment systems (selective catalyst reduction, constant regeneration traps, etc.) which are sensitive to fuel sulphur content, the feasibility of the final targets (esp. NO_x) are still under negotiation.

3.5.9 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. Since June 1999, multi-directive 97/24/EC has introduced emission standards, which for the case of two-stroke mopeds <50cm³, are applied to CO (6 g/km) and $HC+NO_x$ (3 g/km). An additional stage of the legislation has come into force very lately (June 2002) aiming at 1 g/km CO and 1.2 g/km $HC+NO_x$.

3.5.10 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 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).

3.5.11 Future emission standards

At present, there are only discussions how future emission standards (post Euro IV for vehicles <3.5 t and post Euro V for HDVs) should formulate and whether current form of measuring and controlling emissions will be applicable for the very low emission levels of future vehicles. Hence, the discussion is mainly widened in scope to include parameters such as emission levels durability, on-board diagnostics and measurement systems and alternative fuels production. The discussion is expected to generate useful results after 2005 when the efficiency of present measures to relax environmental pressures will have been examined.

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	PRE ECE
		ECE 15/00-01
		ECE 15/02
		ECE 15/03
		ECE 15/04
		Improved Conventional
		Open Loop
		Euro I - 91/441/EEC
		Euro II - 94/12/EC
		Euro III - 98/69/EC Stage 2000
		Euro IV - 98/69/EC Stage 2005
	Gasoline 1.4 - 2.0l	PRE ECE
		ECE 15/00-01
		ECE 15/02
		ECE 15/03
		ECE 15/04
		Improved Conventional
		Open Loop
		Euro I - 91/441/EEC
		Euro II - 94/12/EC
		Euro III - 98/69/EC Stage 2000
		Euro IV - 98/69/EC Stage 2005
	Gasoline >2.0l	PRE ECE
		ECE 15/00-01
		ECE 15/02
		ECE 15/03
		ECE 15/04
		Euro I - 91/441/EEC
		Euro II - 94/12/EC
		Euro III - 98/69/EC Stage 2000
		Euro IV - 98/69/EC Stage 2005
	Diesel <2.0l	Conventional
		Euro I - 91/441/EEC
		Euro II - 94/12/EC
		Euro III - 98/69/EC Stage 2000
		Euro IV - 98/69/EC Stage 2005
	Diesel >2.0l	Conventional
		Euro I - 91/441/EEC
		Euro II - 94/12/EC
		Euro III - 98/69/EC Stage 2000
		Euro IV - 98/69/EC Stage 2005
	LPG	Conventional
		Euro I - 91/441/EEC
		Euro II - 94/12/EC
		Euro III - 98/69/EC Stage 2000
		Euro IV - 98/69/EC Stage 2005
	2 Stroke	Conventional
Light Duty Vehicles	Gasoline <3.5t	Conventional
		Euro I - 93/59/EEC
		Euro II - 96/69/EC
		Euro III - 98/69/EC Stage 2000
		Euro IV - 98/69/EC Stage 2005

Vehicle Type	Class	Legislation
Light Duty Vehicles	Diesel <3.5t	Conventional
		Euro I - 93/59/EEC
		Euro II - 96/69/EC
		Euro III - 98/69/EC Stage 2000
		Euro IV - 98/69/EC Stage 2005
Heavy Duty Vehicles	Gasoline >3.5t	Conventional
	Diesel <7.5t	Conventional
		Euro I - 91/542/EEC Step I
		Euro II - 91/542/EEC Step II
		Euro III - 1999/96/EC Step I
		Euro IV – 1999/96/EC Step II
		Euro V – 1999/96/EC Step III
	Diesel 7.5 - 16t	Conventional
		Euro I - 91/542/EEC Step I
		Euro II - 91/542/EEC Step II
		Euro III - 1999/96/EC Step I
		Euro IV – 1999/96/EC Step II
		Euro V – 1999/96/EC Step III
	Diesel 16-32t	Conventional
		Euro I - 91/542/EEC Step I
		Euro II - 91/542/EEC Step II
		Euro III - 1999/96/EC Step I
		Euro IV – 1999/96/EC Step II
		Euro V – 1999/96/EC Step III
	Diesel >32t	Conventional
		Euro I - 91/542/EEC Step I
		Euro II - 91/542/EEC Step II
		Euro III - 1999/96/EC Step I
		Euro IV – 1999/96/EC Step II
		Euro V – 1999/96/EC Step III
Buses	Urban Buses	Conventional
		Euro I - 91/542/EEC Step I
		Euro II - 91/542/EEC Step II
		Euro III - 1999/96/EC Step I
		Euro IV – 1999/96/EC Step II
		Euro V – 1999/96/EC Step III
	Coaches	Conventional
		Euro I - 91/542/EEC Step I
		Euro II - 91/542/EEC Step II
		Euro III - 1999/96/EC Step I
		Euro IV – 1999/96/EC Step II
		Euro V – 1999/96/EC Step III
Mopeds	<50cm^3	Conventional
		97/24/EC Stage I
		97/24/EC Stage II
Motorcycles	2 Stroke >50cm^3	Conventional
		97/24/EC
	4 stroke 50 - 250cm^3	Conventional
		97/24/EC
	4 stroke 250 - 750cm^3	Conventional
		97/24/EC
	4 stroke >750cm^3	Conventional
		97/24/EC

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.

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

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

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.

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

Tables 4.2 to 4.16 provide fuel consumption specific emission factors for main pollutants and for each EU-15 country. These emission factors should be combined with fuel consumption for specific vehicle category to provide total emission estimates. 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. 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 2002. 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 estimates of the road transport contribution are 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 4.2: Bulk emission factors (g/kg fuel) for Austria, year 2002.

Category	Austria					
	CO	NOx	NMVOC	CH_4	PM	CO_2 [kg/kg fuel]
Gasoline PC	131.64	10.69	9.61	1.68	0.00	2.94
Diesel PC	7.98	11.80	1.82	0.14	2.36	3.12
Gasoline LDV	257.94	20.36	24.70	1.18	0.00	2.70
Diesel LDV	12.17	18.67	2.03	0.08	3.45	3.11
Diesel HDV	7.27	28.69	3.68	0.27	1.76	3.11
Buses	14.15	43.72	4.44	0.42	1.93	3.10
Coaches	7.39	32.98	3.95	0.32	1.54	3.11
Mopeds	500.80	1.20	310.80	7.60	0.00	1.38
Motorcycles	628.75	5.46	94.33	5.76	0.00	1.88

Table 4.3: Bulk emission factors (g/kg fuel) for Belgium, year 2002.

Category	Belgium					
	CO	NOx	NMVOC	CH4	PM	CO_2 [kg/kg fuel]
Gasoline PC	109.37	6.81	7.86	1.31	0.00	3.01
Diesel PC	9.24	12.84	1.77	0.13	1.86	3.12
Gasoline LDV	202.93	18.27	20.75	0.99	0.00	2.78
Diesel LDV	10.77	16.87	1.81	0.07	2.93	3.11
Diesel HDV	7.72	19.14	4.51	0.18	1.44	3.10
Buses	13.65	42.53	4.36	0.42	1.87	3.10
Coaches	7.17	31.95	3.87	0.31	0.00	3.11
Mopeds	535.60	1.20	328.00	8.00	0.00	1.27
Motorcycles	636.64	6.37	56.72	6.07	0.00	2.00

Table 4.4: Bulk emission factors (g/kg fuel) for Denmark, year 2002.

Category	Denmark					
	CO	NOx	NMVOC	CH4	PM	CO_2 [kg/kg fuel]
Gasoline PC	116.72	11.47	13.13	1.50	0.00	2.93
Diesel PC	7.06	11.07	1.62	0.12	1.94	3.12
Gasoline LDV	226.08	15.50	22.11	1.14	0.00	2.79
Diesel LDV	10.45	18.33	2.03	0.08	2.76	3.11
Diesel HDV	7.21	24.29	4.03	0.25	1.56	3.11
Buses	10.79	36.02	3.93	0.38	1.52	3.11
Coaches	6.13	26.07	3.38	0.28	1.14	3.12
Mopeds	306.80	0.84	210.00	5.20	0.00	2.02
Motorcycles	470.12	6.07	80.98	5.76	0.00	2.10

Table 4.5: Bulk emission factors (g/kg fuel) for Finland, year 2002.

Category	Finland					
	CO	NOx	NMVOC	CH_4	PM	CO_2 [kg/kg fuel]
Gasoline PC	138.78	12.99	12.20	1.41	0.00	2.92
Diesel PC	7.93	12.05	1.90	0.14	2.41	3.12
Gasoline LDV	219.47	18.54	22.74	1.05	0.00	2.76
Diesel LDV	11.53	18.74	2.10	0.08	3.31	3.11
Diesel HDV	10.63	27.37	6.33	0.27	2.17	3.10
Buses	13.63	42.52	4.36	0.42	1.87	3.10
Coaches	7.20	31.92	3.86	0.31	1.47	3.11
Mopeds	273.60	0.80	188.00	4.40	0.00	2.14
Motorcycles	542.80	4.76	142.66	5.77	0.00	1.86

Table 4.6: Bulk emission factors (g/kg fuel) for France, year 2002.

Category	France					
	CO	NOx	NMVOC	CH4	PM	CO_2 [kg/kg fuel]
Gasoline PC	146.75	13.01	17.31	1.66	0.00	2.93
Diesel PC	9.27	12.57	1.99	0.13	2.16	3.12
Gasoline LDV	267.54	18.87	30.11	1.31	0.00	2.72
Diesel LDV	12.81	20.87	2.19	0.08	3.38	3.11
Diesel HDV	11.25	24.32	6.78	0.26	1.97	3.09
Buses	12.94	40.84	4.25	0.41	1.78	3.10
Coaches	6.93	30.46	3.74	0.30	1.39	3.11
Mopeds	289.60	0.80	199.60	4.80	0.00	2.08
Motorcycles	486.41	7.47	69.63	6.79	0.00	2.23

Table 4.7: Bulk emission factors (g/kg fuel) for Germany, year 2002.

Category	Germany					
	CO	NOx	NMVOC	CH4	PM	CO_2 [kg/kg fuel]
Gasoline PC	190.86	11.76	13.54	2.29	0.00	2.90
Diesel PC	9.76	13.95	2.32	0.19	3.14	3.12
Gasoline LDV	257.77	24.03	22.12	1.52	0.00	2.69
Diesel LDV	13.82	18.87	2.40	0.10	4.60	3.11
Diesel HDV	10.99	23.81	6.54	0.24	1.99	3.09
Buses	14.36	44.37	4.48	0.43	1.97	3.10
Coaches	7.47	33.47	3.99	0.32	1.57	3.11
Mopeds	569.60	1.20	344.00	8.80	0.00	1.17
Motorcycles	750.34	7.13	62.50	6.79	0.00	1.97

Table 4.8: Bulk emission factors (g/kg fuel) for Greece, year 2002.

Category	Greece					
	CO	NOx	NMVOC	CH4	PM	CO_2 [kg/kg fuel]
Gasoline PC	172.92	14.51	23.91	1.33	0.00	2.83
Diesel PC	11.46	11.43	2.53	0.08	2.56	3.11
Gasoline LDV	216.89	21.38	28.92	1.00	0.00	2.75
Diesel LDV	11.97	20.24	1.62	0.06	2.90	3.11
Diesel HDV	9.69	30.04	5.27	0.28	2.18	3.10
Buses	13.16	41.61	4.30	0.41	1.82	3.10
Coaches	7.02	30.98	3.79	0.31	1.43	3.11
Mopeds	438.80	1.20	280.40	6.80	0.00	1.58
Motorcycles	585.22	5.90	98.42	5.90	0.00	1.93

Table 4.9: Bulk emission factors (g/kg fuel) for Ireland, year 2002.

Category	Ireland					
	CO	NOx	NMVOC	CH4	PM	CO_2 [kg/kg fuel]
Gasoline PC	115.53	11.63	18.20	1.14	0.00	2.91
Diesel PC	6.25	8.59	1.36	0.08	1.46	3.12
Gasoline LDV	224.34	19.64	29.04	1.03	0.00	2.73
Diesel LDV	11.30	18.40	1.82	0.07	3.03	3.11
Diesel HDV	7.81	25.31	4.05	0.24	1.62	3.11
Buses	12.91	41.00	4.26	0.41	1.79	3.10
Coaches	6.93	30.46	3.74	0.30	1.40	3.11
Mopeds	337.60	0.80	231.20	5.20	0.00	1.90
Motorcycles	476.56	7.14	56.50	6.21	0.00	2.22

Table 4.10: Bulk emission factors (g/kg fuel) for Italy, year 2002.

Category	Italy					
	CO	NOx	NMVOC	CH4	PM	CO_2 [kg/kg fuel]
Gasoline PC	155.50	13.77	18.97	1.32	0.00	2.86
Diesel PC	6.27	9.16	1.35	0.11	1.77	3.12
Gasoline LDV	225.26	18.46	23.45	1.03	0.00	2.76
Diesel LDV	11.13	18.18	1.79	0.07	2.90	3.11
Diesel HDV	8.72	22.59	5.02	0.23	1.64	3.10
Buses	12.83	40.67	4.24	0.41	1.77	3.10
Coaches	6.90	30.26	3.73	0.30	1.38	3.11
Mopeds	456.00	1.04	286.00	7.20	0.00	1.54
Motorcycles	573.73	6.83	54.64	6.21	0.00	2.11

Table 4.11: Bulk emission factors (g/kg fuel) for Luxembourg, year 2002.

Category	Luxembourg					
	CO	NOx	NMVOC	CH_4	PM	CO_2 [kg/kg fuel]
Gasoline PC	120.39	3.70	6.21	1.45	0.00	2.97
Diesel PC	7.33	11.41	1.77	0.14	1.55	3.12
Gasoline LDV	208.28	22.85	18.59	1.39	0.00	2.79
Diesel LDV	11.78	15.80	2.30	0.11	4.00	3.11
Diesel HDV	8.46	25.25	4.63	0.24	1.65	3.11
Buses	11.50	37.59	4.04	0.39	1.60	3.11
Coaches	6.40	27.52	3.50	0.28	1.22	3.12
Mopeds	375.20	0.80	241.60	6.00	0.00	1.81
Motorcycles	597.79	4.56	152.62	5.56	0.00	1.74

Table 4.12: Bulk emission factors (g/kg fuel) for Netherlands, year 2002.

Category	Netherlands					
	CO	NOx	NMVOC	CH4	PM	CO_2 [kg/kg fuel]
Gasoline PC	155.82	7.37	10.65	2.01	0.00	2.92
Diesel PC	11.74	13.88	2.93	0.16	3.13	3.11
Gasoline LDV	315.75	18.49	23.72	1.63	0.00	2.73
Diesel LDV	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Diesel HDV	8.60	27.42	4.87	0.26	1.84	3.11
Buses	10.85	36.19	3.94	0.38	1.53	3.11
Coaches	6.15	26.19	3.39	0.28	1.15	3.12
Mopeds	376.80	1.20	231.20	5.60	0.00	1.84
Motorcycles	508.95	6.83	71.59	6.18	0.00	2.15

Table 4.13: Bulk emission factors (g/kg fuel) for Portugal, year 2002.

Category	Portugal					
	CO	NOx	NMVOC	CH4	PM	CO_2 [kg/kg fuel]
Gasoline PC	165.17	11.51	16.09	1.86	0.00	2.85
Diesel PC	8.68	11.69	2.43	0.15	2.66	3.12
Gasoline LDV	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Diesel LDV	14.02	16.92	2.56	0.11	4.68	3.11
Diesel HDV	10.24	20.38	5.95	0.20	1.74	3.09
Buses	12.92	41.01	4.26	0.41	1.79	3.10
Coaches	6.93	30.48	3.75	0.30	1.40	3.11
Mopeds	422.40	1.04	259.60	6.40	0.00	1.67
Motorcycles	613.08	4.07	168.56	5.53	0.00	1.66

Table 4.14: Bulk emission factors (g/kg fuel) for Spain, year 2002.

Category	Spain					
	CO	NOx	NMVOC	CH_4	PM	CO_2 [kg/kg fuel]
Gasoline PC	220.75	13.01	22.12	2.01	0.00	2.76
Diesel PC	12.60	12.17	3.32	0.12	3.38	3.11
Gasoline LDV	301.60	16.83	24.86	1.37	0.00	2.63
Diesel LDV	11.82	22.23	2.39	0.08	3.29	3.11
Diesel HDV	10.99	26.58	6.55	0.28	2.02	3.10
Buses	13.31	41.80	4.31	0.41	1.83	3.10
Coaches	7.08	31.25	3.81	0.31	1.44	3.11
Mopeds	357.20	1.20	220.40	5.60	0.00	1.90
Motorcycles	592.76	3.76	178.00	5.81	0.00	1.67

Table 4.15: Bulk emission factors (g/kg fuel) for Sweden, year 2002.

Category	Sweden					
	CO	NOx	NMVOC	CH4	PM	CO_2 [kg/kg fuel]
Gasoline PC	175.65	10.89	16.01	2.12	0.00	2.89
Diesel PC	8.90	10.43	2.34	0.12	2.65	3.11
Gasoline LDV	269.36	17.72	24.40	1.27	0.00	2.65
Diesel LDV	10.81	16.54	2.09	0.08	3.37	3.11
Diesel HDV	10.26	27.66	5.89	0.26	2.07	3.10
Buses	14.04	43.30	4.42	0.42	1.91	3.10
Coaches	7.35	32.72	3.92	0.32	1.51	3.11
Mopeds	418.00	0.80	264.80	6.40	0.00	1.66
Motorcycles	604.37	7.52	54.32	6.83	0.00	2.15

Table 4.16: Bulk emission factors (g/kg fuel) for UK, year 2002.

Category	UK					
	CO	NOx	NMVOC	CH4	PM	CO_2 [kg/kg fuel]
Gasoline PC	167.87	9.44	15.78	1.85	0.00	2.90
Diesel PC	9.02	10.72	2.18	0.13	2.34	3.11
Gasoline LDV	212.31	11.12	17.07	1.22	0.00	2.80
Diesel LDV	8.92	15.55	2.11	0.08	2.57	3.11
Diesel HDV	8.47	25.70	5.17	0.25	1.74	3.11
Buses	9.63	33.37	3.76	0.36	1.38	3.11
Coaches	5.70	23.68	3.19	0.26	1.00	3.12
Mopeds	274.80	0.80	193.60	4.80	0.00	2.12
Motorcycles	482.75	7.52	77.55	6.49	0.00	2.21

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 trimmed, 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:

$$E_{TOTAL} = E_{HOT} + E_{COLD} \quad (1)$$

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:

$$E_{TOTAL} = E_{URBAN} + E_{RURAL} + E_{HIGHWAY} \quad (2)$$

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.

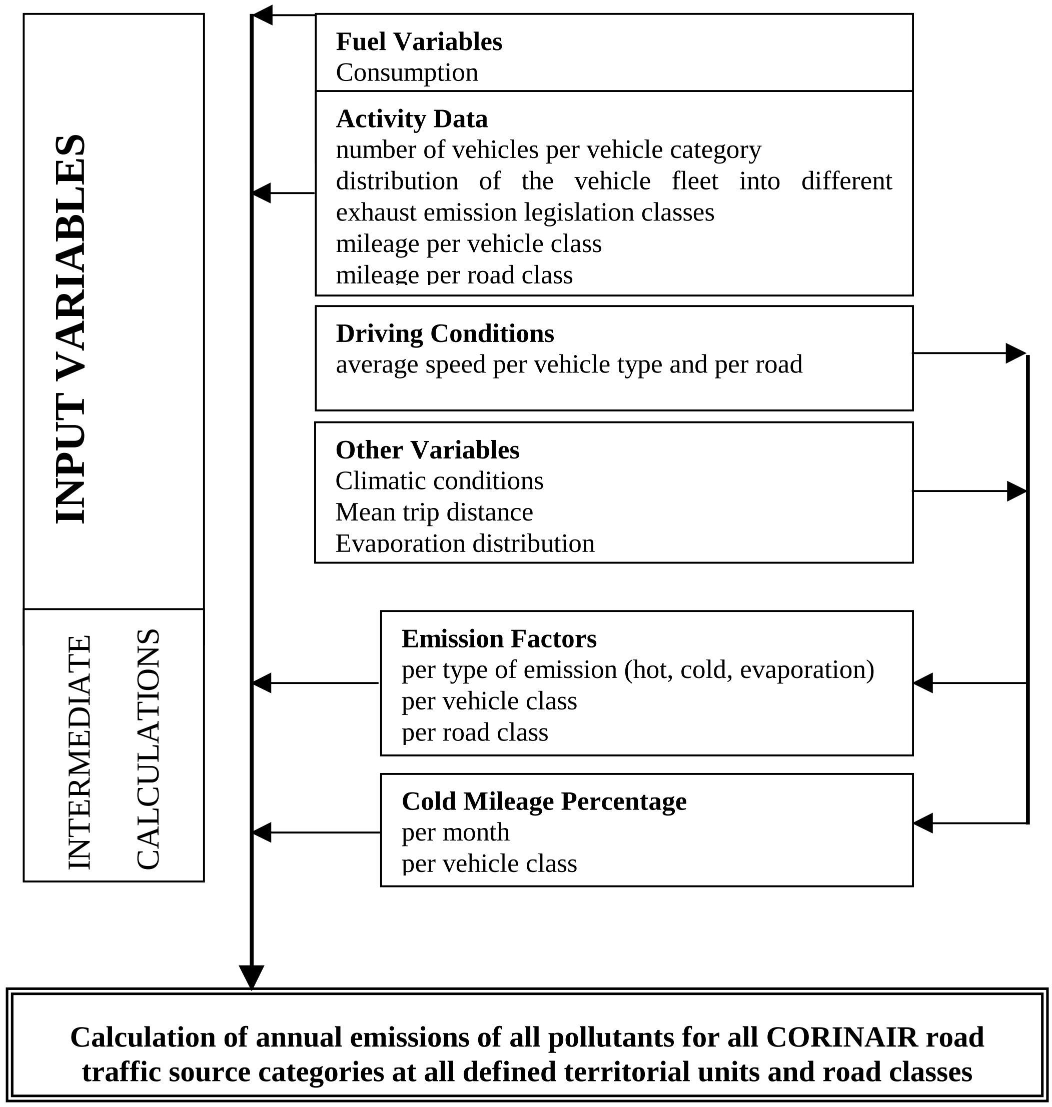

Figure 5.1: Flow chart of the application of the baseline methodology

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:

Emissions per Period of Time [g] = Emission Factor [g/km] × Number of Vehicles [veh.]×
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.)

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):

$$E_{HOT;\, i,\, j,\, k} = N_j \times M_{j,k} \times e_{HOT;\, i,\, j,\, k} \qquad (3)$$

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): 1-105 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.

$$e_{HOT;\, i,\, j,\, k} = \int [e(V) \times f_{j,\, k}(V)]\, dV \qquad (4)$$

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:

$$E_{COLD; i, j} = \beta_{i, j} \times N_j \times M_j \times e_{HOT; i, j} \times (e^{COLD} / e^{HOT}|_{i,j} - 1) \qquad (5)$$

where,
$E_{COLD; i, j}$: cold start emissions of the pollutant i (for the reference year), caused by vehicle class j,
$\beta_{i, j}$: fraction of mileage driven with cold engines or catalyst operated below the light-off temperature,
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 of pollutant i emissions, 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 8.11 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, new over-emission ratios have been introduced for catalyst equipped gasoline vehicles. The new ratios are based on a more detailed and accurate method which has been developed in the framework of MEET (MEET, 1999), which accounts for data and methods produced in a number of national programmes. However, the proposed approach did not fully comply with the flexibility required for application in different cases. Therefore, an intermediate step has been decided which accommodates the findings of the revised methodology on the existing approach.

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 5, which then yields:

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

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

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

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 6 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 6. This is because total cold start related emissions should not be differentiated according to place of emission.

It is important to note that VOC values proposed for the β-parameter and the e^{COLD}/e^{HOT} over-emission ratio are applied to calculate over-emissions of both NMVOC and CH_4 during cold start.

5.6 Fuel consumption dependent emissions

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:

$$E_{i,jm}^{CORR} = E_{i,jm}^{CALC} \times \frac{FC_m^{STAT}}{\sum_{jm} FC_{jm}^{CALC}} \qquad (7)$$

where,

j_m: class j from Table 3.6 operating on fuel type m,

$E_{i,jm}^{CORR}$: the corrected emission of fuel dependent pollutant i (CO_2, SO_2, Pb, HM) for vehicle class j_m,

$E_{i,jm}^{CALC}$: the emission of fuel dependent pollutant i estimated on the basis of the calculated fuel consumption of vehicle class j_m,

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

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

In that respect, total emission estimates for any emission dependent pollutant equals that derived by the statistical fuel consumption while there is still information provided for the allocation of emissions to different vehicle classes. The calculation of value $E^{CALC}_{i,jm}$ 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**.** The following formula should be applied:

$$E_{CO_2,j}^{CALC} = 44.011 \times \frac{FC_{jm}^{CALC}}{12.011 + 1.008 r_{H:C,m}} \qquad (8)$$

where,

$r_{H:C,m}$ the ratio of hydrogen to carbon atoms in the fuel (~1.8 for gasoline and ~2.0 for diesel).

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

$$E^{CALC}_{CO_2,j} = 44.011 \times \left(\frac{FC^{CALC}_{jm}}{12.011 + 1.008 r_{H:C,m}} - \frac{E^{CO}_{jm}}{28.011} - \frac{E^{VOC}_{jm}}{13.85} - \frac{E^{PM}_{jm}}{12.011} \right) \qquad (9)$$

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:

$$E^{CALC}_{SO_2,j} = 2 \times k_{S,m} \times FC^{CALC}_{jm} \qquad (10)$$

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:

$$E^{CALC}_{Pb,j} = 0{,}75 \times k_{Pb,m} \times FC^{CALC}_{jm} \qquad (11)$$

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 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:

$$E^{CALC}_{i,j} = k_{i,m} \times FC^{CALC}_{jm} \qquad (12)$$

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 (eq. 2 – 3), 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 2 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. Enhanced Inspection and Maintenance scheme. Current European standards on in-service emission testing have been introduced with Directive 92/55/EEC which seeks for emission compliance at two idle conditions (low and high idling). This testing, with only minor modifications is today applied by all Member States. In case that an enhanced Inspection and Maintenance scheme has been introduced (e.g. transient testing) then lower average emission levels would be reached from aged fleets. This effect can be simulated with correction of the degradation factors proposed. However, such correction has to be seen only as a relevant future scenario and should not be applied for a baseline national inventory.

c. 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.

d. Road gradient on heavy duty vehicles emissions. Corrections need to be applied 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.

e. Heavy duty vehicle load. 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 emission correction load factors.

5.7.1 Emission degradation due to vehicle age and effect of I&M schemes

Euro I gasoline passenger cars and light duty vehicles

The degradation of the emission reduction system efficiency with mileage for gasoline Euro I vehicles has been modelled in MEET. The degradation lines have been developed on the basis of emission measurements over the Urban and the Extra Urban part of the European

Driving Cycle respectively. Table 8.38 provides the mileage functions used for the estimation of the effect of mileage on emissions from Euro I gasoline passenger cars of three different capacity classes over the two driving cycles (UDC, EUDC). The mileage correction, for a given average fleet mileage and specific cycle is given by means of:

$$MC_{C,i} = A^M \times M^{MEAN} + B^M \qquad (13)$$

where,

M^{MEAN}: the mean fleet mileage of vehicles for which correction is applied

$MC_{C,i}$: the mileage correction for a given mileage (M_{av}), pollutant i and a specific cycle (C: UDC, EUDC)

A^M, B^M: coefficients to be selected from Tables 8.38 and 8.39.

The coefficient A^M corresponds to the degradation of the emission performance per kilometre. The correction factor at 0 km (B^M coefficient) reflects the emission level of a fleet of brand new vehicles. It is lower than 1 because emission functions proposed have been derived on the basis of an in-use vehicle sample of a specific average mileage (~30-50 Mm). Therefore, brand new vehicles are expected to emit less than the sample vehicles.

It was found that sample emissions tend to stabilise at the higher mileage region (above ~120 Mm). Therefore, it is assumed that emissions do not further degrade above this limit and a constant degradation value is applied on the base emission factor to calculate the emission level of older vehicles (this value is shown in the last Table 8.38 column).

The effect of speed on emission degradation is taken into account by combining the observed degradation lines over the two cycles. The actual emission degradation proposed for a speed different than that of the cycles is shown in Table 5.1. It is assumed that for speeds outside the region defined by the average speed over UDC (19 km/h) and EUDC (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 5.1: Euro I emission degradation functions of speed

Speed - V [km/h]	**Mileage Correction - MCorr [-]**
<=19	MC_{UDC}
>=63	MC_{EUDC}
>19 and <63	$MC_{UDC} + \frac{(V-19)\cdot(MC_{EUDC} - MC_{UDC})}{44}$

Finally, the mileage corrected emission factor is calculated by means of the equation:

$$MCe_{HOT;\, i,\, EURO\, I,\, k} = MCorr_{i,\, EURO\, I}(speed, mileage) \times e_{HOT;\, i,\, EURO\, I,\, k} \qquad (14)$$

where,

$MCe_{HOT;\, i,\, EURO\, I,\, k}$: hot emission factor corrected for degraded vehicle performance due to mileage

$MCorr_{i, EURO I}$: the mileage correction as proposed in Table 5.1 for a specific speed and mileage
$e_{HOT; i, EURO I, k}$: the speed dependent hot emission factor

The degradation proposed has been obtained from the emission performance of vehicles complying with Directive 92/55/EEC in what concerns their emission control system performance[1]. The improvement of an enhanced Inspection and Maintenance scheme which would include, e.g. testing of vehicles on a dynamometer, would most probably have an effect on the emission level of aged vehicles. The I&M project (LAT/AUTh et al., 1998) resulted in reductions of the emissions of catalyst passenger cars which would appear if an enhanced I&M scheme were in place. Those reductions are quoted in Table 5.2.

Table 5.2: Emission reduction with the introduction of an enhanced I&M scheme for Euro I vehicle fleet

Pollutant	Reduction (%)
CO	16
NOx	15
HC	15

According to those reductions, new degradation lines are applied in case of an enhanced & scheme (Table 8.39). Emissions again are assumed to stabilise at the same level as of the 92/55/EEC corresponding ones. Although a reduction on the stabilisation level is also probable with an enhanced I&M scheme, the new stabilisation level cannot be established with the available measurement data. Therefore, the stabilisation mileage is also quoted in the last column of Table 8.39.

The stabilisation of degradation is achieved in most cases within the interval of 200 Mm, which is a reasonable figure. However, for EUDC CO and large vehicles (capacity >2.0 l), the stabilisation is achieved at very high mileage. This has no physical meaning but it is rather an artefact of the applied correction methodology. On the other hand, this introduces no actual error to the calculations because the fleet fraction at this high mileage region is very limited. It is therefore proposed, for the sake of consistency, to keep the proposed I&M correction. Again, the emission degradation is modelled by application of equations 13 and 14 with coefficients A, B selected from Table 8.39.

It has to be stressed that these degradation lines are applicable on the hot emission factors only
and therefore cold-start overemission remains unaffected by degradation. This assumption is based on the fact that degradation is mainly induced from catalyst ageing which in any case does not affect substantially the cold start overemission. Therefore, equation 3 in case that mileage degradation correction has been applied for Euro I vehicles, yields:

$$E_{HOT; i, EURO I, k} = N_j \times M_{j,k} \times MCorr_{i, EURO I} \times e_{HOT; i, EURO I, k} \quad (15)$$

[1] Most of the vehicles of the data base originate from countries who have adopted 92/55/EEC or some kind of equivalent legislation. In addition, the I&M project showed that the application of the provisions of the above Directive on roadworthiness will have marginal effects on the emissions of in-use cars.

While equations 5 and 6, for the calculation of cold start over-emission remain unmodified.

Euro II gasoline passenger cars and light duty vehicles

No further requirements have been set by the legislation on the emission performance degradation of Euro II vehicles, compared to Euro I ones. It is thus assumed that the same mileage degradation applied to Euro I vehicles should also hold for Euro II vehicles. Therefore the emission degradation for Euro II vehicles is given by the functions of Table 8.38 in the case of the I&M scheme defined by 92/55/EEC or by the functions of Table 8.39 in case an enhanced I&M project is introduced. However, equation 15 should be applied with the hot emission factor corresponding to Euro II vehicles.

Euro III and IV gasoline passenger cars and light duty vehicles

The control of emissions on in-use Euro III and newer vehicles will be achieved by extended catalyst durability and the introduction of OBD systems. It is reasonable therefore to assume that the emission degradation with mileage of such vehicles will be reduced compared to Euro I vehicles. Moreover, it is believed that not only hot emissions but cold start extra emissions may also be affected by the degradation of the catalyst and the engine control measures, especially in the case of the advanced catalyst controls of Euro IV.

However, due to absence of experimental data, one may assume that the degradation of Euro III & IV vehicles, irrespective of the valid I&M scheme, will be approached by the degradation observed for Euro I vehicles in the case of an enhanced I&M scheme. In other words, we assume that on board engine "inspection" achieved by an OBD system will have the same results with an enhanced I&M scheme. For that reason, it is proposed to apply the degradation functions given in Table 8.39 for Euro III and IV vehicles, irrespective of I&M scheme used and to calculate degradation according to equations 13 and 15.

Conventional gasoline passenger cars and light duty vehicles

No initial degradation due to mileage is given for conventional vehicles because of limited available data. However, enhanced inspection and maintenance may also have an effect on the emission behaviour of conventional, non-catalyst vehicles. Therefore, it is proposed to apply the reduction factors of Table 5.3 on conventional vehicles, irrespective of their total mileage, in case an improved 92/55/EEC I&M scheme is introduced (e.g. a tightening of the CO standard and introduction of an additional HC standard, as suggested by the I&M project).

Table 5.3: Emission reduction with the introduction of an improved I&M scheme for conventional, non-three-way catalyst equipped vehicles

Pollutant	Reduction (%)
CO	15
NOx	8
HC	8

Diesel passenger cars and light duty vehicles

The findings of the I&M project indicate that - as expected - the diesel cars were found to be high polluters only in the case of particulate emissions. CO, HC and NO_x emissions were always found to be well below the emission standards. Therefore, in case an enhanced I&M scheme is introduced (e.g. continuous opacity measurement over a transient dynamometer test), then the possible effect on PM emissions should be in the order of a 10% reduction with respect to the baseline emissions (i.e. vehicles complying with emission standards up to Euro II) irrespective of the mileage of the vehicles. This level of reduction potential is in line with the basic assumptions of Auto Oil I programme. No reduction is proposed for post-Euro II vehicles.

Diesel heavy duty vehicles

In view of the absence of any experimental data, the same approach as in the case of Diesel passenger cars is adopted, i.e. 10% overall PM emission reduction up to Euro II in case that an enhanced I&M scheme is in place.

Two wheelers

The absence of experimental data in simulating the effect of mileage and inspection and maintenance on the emissions of two-wheelers, together with the different technology applied in such vehicles, compared to passenger cars, prohibits the application of any correction.

5.7.2 Fuel effects

Fuels of improved specifications become mandatory in Europe in two steps, January 2000 (Fuel 2000[2]) and January 2005 (Fuel 2005) respectively. The specifications of those fuels are displayed in Table 5.4 (Gasoline) and Table 5.5 (Diesel). Because of their improved properties, the fuels result in lower emissions from vehicles. Therefore, the stringent emission standards of Euro III technology (introduced ~2000) are achieved with fuel quality "Fuel 2000" and the more stringent emission standards of Euro IV and V with fuel quality "Fuel 2005". Table 5.6 shows the base emission fuel considered for each vehicle class.

Table 5.4: 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

[2] By convention

Table 5.5: Diesel fuel specifications

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

Table 5.6: Base fuels for each vehicle class

Vehicle Class	Base Fuel	Available Improved Fuel Qualities
Pre- Euro III	1996 Base Fuel	Fuel 2000 , Fuel 2005
Euro III	Fuel 2000	Fuel 2005
Euro IV	Fuel 2005	-

However use of such fuels results in reduced emissions also from pre-Euro III vehicle technologies, for which the 1996 market average fuel is considered as a basis (Table 5.6). 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. Tables 8.40, 8.41 and 8.42 display the equations for different vehicle categories and classes.

The hot emission factors are corrected according to the equation:

$$FCe_{HOT;\,I,\,j,\,k} = FCorr_{i,\,j,\,Fuel} / FCorr_{i,\,j,\,Base} \times e_{HOT;\,i,\,j,\,k} \qquad (16)$$

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 Tables 8.40, 8.41, 8.42 for the available improved fuel qualities (Table 5.6)

$FCorr_{i,\,j,\,Base}$: the fuel correction for pollutant i, vehicle category j, calculated with equations given in Tables 8.40, 8.41, 8.42 for the base fuel quality of vehicle class j (Table 5.6)

It is mentioned that equation 16 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 IV vehicles by inversion of FC coefficients). The emission factor calculated via equation 16 should be introduced in equations 3 and 5 or 6 respectively to estimate hot and cold start emissions.

5.7.3 Road slope effect

The gradient of a road has the effect of increasing or decreasing the resistance of a vehicle to traction, as the power employed during the driving operation is the decisive parameter for the emissions of a vehicle. Even in the case of large-scale considerations, however, it cannot be assumed that - for example - the extra emission when travelling uphill is compensated by correspondingly reduced emission when travelling downhill.

In principle the emissions and fuel consumption of both light and heavy duty vehicles are affected by road gradient. Nevertheless, the overall gradient effect on the behaviour of light duty vehicles (passenger cars and light duty trucks) was found to be very small (e.g. Keller et al., 1995), lying in the range of uncertainty of the basic emission factors. However, because of their higher masses, the gradient influence is much more significant in the case of heavy duty vehicles. Therefore it was decided to incorporate in the methodology only the gradient effect on the emissions of heavy duty vehicles. The method adopted is the one developed in MEET (MEET, 1999), which is largely based on the results of a Swiss/German test programme (Hassel et al., 1993; Keller et al. 1995).

Special gradient factors have been introduced for each heavy duty vehicle weight class. Those emission correction factors are considered to be a function of :

- The vehicle mass
- The road gradient
- The pollutant or consumption
- The mean speed of the vehicle

Heavy duty vehicles of different mass behave differently during uphill or downhill driving due to the different load of the engine. For each heavy duty vehicle class special equations have been provided to calculate the gradient factors.

Is obvious that the effect of the slope on emissions and consumption will be highly dependant on the road gradient. In order to represent the actual conditions, four road gradient classes have been introduced. These classes are presented in Table 5.7. Positive road gradient corresponds to uphill driving and vice versa. Gradient factors apply to all major pollutants (CO, VOC, NO_x, PM) as well as fuel consumption.

Table 5.7: Road gradient classes

Driving Conditions	Road Gradient
Uphill	0… 4%
Steep uphill	4… 6%
Downhill	-4… 0%
Steep downhill	-6… -4%

For each vehicle weight category, gradient and pollutant, the gradient factor can be calculated as a polynomial function of the vehicle's mean speed:

$$GCorr_{i,j,k} = A_{6i,j,k}V^6 + A_{5i,j,k}V^5 + A_{4i,j,k}V^4 + A_{3i,j,k}V^3 + A_{2i,j,k}V^2 + A_{1i,j,k}V + A_{0i,j,k} \quad (17)$$

where,

$GCorr_{i,j,k}$: the emission correction factor for the effect of road gradient
V: the mean speed
$A_{0;\,i,j,k}$... $A_{6;\,i,j,k}$: constants for each pollutant, weight and gradient class (Tables 8.43 to 8.48)

It is proposed to correct the emission factor calculated for vehicle's use on a flat road according to the following equation, in order to incorporate the influence of the road gradient:

$$GCe_{HOT;i,j,k} = GCorr_{i,j,k} \times e_{hot,i,j,k} \quad (18)$$

where,

$GCe_{HOT;i,j,k}$: corrected emission factor of the pollutant i in [g/km] of vehicle class j driven on roads of type k with hot engines
$GCorr_{i,j,k}$: gradient correction factor of the pollutant i in [g/km] of vehicle class j driven on roads of type k.

The corrected hot emission factor calculated with the help of equation 18 is then introduced in equation 3 to calculated total (hot) emissions from heavy duty vehicles.

5.7.4 Vehicle load effect

The emission and consumption factors used for heavy duty vehicles are representative only for a partially loaded vehicle, that is load factor of 50% is taken into account. For the same road pattern, the engine needs to operate under different loads for increased or decreased total vehicle weight. It is obvious that the lower the vehicle weight, the less load is demanded from the engine and vice versa. As a result, the consumption as well as the emission rate of the engine change in accordance to the vehicle weight.

The same applies to all vehicles carrying different load. The methodology though is only valid for heavy duty vehicles, because a high load fluctuation is expected in this vehicle category, depending on the different vehicle use. For smaller vehicles, a load factor of 50% seems to be in accordance with the actual fleet average and thus, load effect is neglected.

To compensate for the different load, the emission factor of heavy duty vehicles which is calculated for a load of 50%, is corrected with use of the following formula:

$$LCe_{HOT;\,i,\,j,\,k} = e_{HOT;\,i,\,j,\,k} \times [1 + 2 \times LCorr_i \times (LP - 50) / 100] \quad (19)$$

where,

$LCe_{HOT;\,i,\,j,\,k}$: load corrected emission factor of the pollutant i in [g/km] of the vehicle of category j
LP: the actual 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)

$LCorr_i$: load correction factor of the pollutant i (Table 5.8).

Table 5.8: Load correction factors ($LCorr_i$) applied to heavy duty vehicles

Pollutant	**Load Factor**
CO	0.21
NOx	0.18
VOC	0.00
PM	0.08
Fuel Consumption	0.18

As in the case of road gradient, the corrected hot emission factor calculated with the help of equation 19 is introduced in equation 3 to calculated total (hot) emissions from heavy duty vehicles.

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.

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

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 6.3: 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 catalyst equipped and improved diesel passenger cars (91/441/EEC and on), light duty vehicles, diesel heavy duty vehicles and power two wheelers, the emission factors incorporated are the outcome of the MEET project. Emission and consumption factors for passenger cars and light duty vehicles originate from a large number of measurements conducted in several European countries (Samaras et al., 1998). The emission factors proposed in a joint German - Swiss research project (Keller et al., 1995) were adopted for diesel heavy duty vehicles and 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.

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 8.1: 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

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	-	C	C	D	D	D	D	A1
ECE 15/00-01	A1	A1	A1	A2	-	C	C	D	D	D	D	A1
ECE 15/02	A1	A1	A1	A2	-	C	C	D	D	D	D	A1
ECE 15/03	A1	A1	A1	A2	-	C	C	D	D	D	D	A1
ECE 15/04	A1	A1	A1	A2	-	C	C	D	D	D	D	A1
Improved Conventional	A1	A1	A1	A2	-	C	C	D	D	D	D	A1
Open Loop	A1	A1	A1	A2	-	C	C	D	D	D	D	A1
Euro I to Euro IV	A1	A1	A1	A1	-	C	C	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 IV	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	-	C	C	D	D	D	D	A1
Gasoline <3.5t Euro I to Euro IV	A1	A1	A1	A1	-	C	C	D	D	D	D	A1
Diesel <3.5t Conventional	A1	A1	A1	A2	A1	C	C	D	D	D	D	A1
Diesel <3.5t Euro I to Euro IV	A1	A1	A1	A2	A1	C	C	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 I – "Conventional"

<u>Hot Emissions</u>
Hot emission factors for conventional vehicles are given in Tables 8.3, 8.4, and 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.

Cold start emissions

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 5, 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 8.3: 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	CC < 1.4 l	10-130	$14.577 - 0.294V + 0.002478V^2$	0.781
Conventional	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
Euro I	CC < 1.4 l	5-130	$9.846 - 0.2867V + 0.0022V^2$	0.133
	1.4 l < CC < 2.0 l	5-130	$9.617 - 0.245V + 0.0017285V^2$	0.145
	CC > 2.0 l	5-130	$12.826- 0.2955V +0.00177V^2$	0.159

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
Euro I	CC < 1.4 l	5-130	$0.628 - 0.01377V + 8.52E\text{-}05V^2$	0.207
	1.4 l < CC < 2.0 l	5-130	$0.4494 - 0.00888V + 5.21E\text{-}05V^2$	0.197
	CC > 2.0 l	5-130	$0.5086 - 0.00723V + 3.3E\text{-}05V^2$	0.0433

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 ECE 15-00/01	CC < 1.4 l	10-130	$1.173 + 0.0225V - 0.00014V^2$	0.916
	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
Euro I	CC < 1.4 l	5-130	$0.5595 - 0.01047V + 10.8E\text{-}05V^2$	0.122
	1.4 l < CC < 2.0 l	5-130	$0.526 - 0.0085V + 8.54E\text{-}05V^2$	0.0772
	CC > 2.0 l	5-130	$0.666 - 0.009V + 7.55E\text{-}05V^2$	0.0141

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
ECE 15-04	CC < 1.4 l	10-25	296.7 - 80.21ln(V)	0.518
		25-130	$81.1 - 1.014V + 0.0068V^2$	0.760
	1.4 l < CC < 2.0 l	10-60	$606.1V^{-0.667}$	0.907
		60-130	$102.5 - 1.364V + 0.0086V^2$	0.927
	CC > 2.0 l	10-60	$819.9V^{-0.663}$	0.966
		60-130	$41.7 + 0.122V + 0.0016V^2$	0.650
Improved Conventional	CC < 1.4 l	10-130	$80.52 - 1.41V + 0.013V^2$	0.954
	1.4 l < CC < 2.0 l	10-130	$111.0 - 2.031V + 0.017V^2$	0.994
Open Loop	CC < 1.4 l	10-130	$85.55 - 1.383V + 0.0117V^2$	0.997
	1.4 l < CC < 2.0 l	10-130	$109.6 - 1.98V + 0.0168V^2$	0.997
Euro I and onwards	CC < 1.4 l	5-12.3	$329.451 - 39.093V + 1.531V^2$	0.958
		12.3-130	$98.336 - 1.604V + 0.0106V^2$	0.790
	1.4 l < CC < 2.0 l	5-13.1	$428.06 - 46.696V + 1.697V^2$	0.989
		13.1-130	$135.44 - 2.314V + 0.0144V^2$	0.777
	CC > 2.0 l	5-12.7	$605.57- 70.09V +2.645V^2$	0.976
		12.7-130	$181.85- 3.398V +0.0209V^2$	0.865

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 I

Hot Emissions

Hot emission factors of this vehicle class have been developed in the framework of MEET and are also quoted in Tables 8.3 to 8.5 (fuel consumption factors in Table 8.6). Equations provided hold for the range 5-130 km/h with no further distinction to speed classes. However, there is a distinction to different engine capacity classes. The low correlation coefficients provided are an indication of the highly scattered individual values about the estimated value. A detailed analysis of those effects are thoroughly discussed in various publications (Ntziachristos and Samaras, 1999; 2000b).

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 vehicles. Table 8.9 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.

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.

Table 8.9: Over-emission ratios e^{COLD} / e^{HOT} for Euro I 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

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 5 or 6 is straightforward.

8.1.3 Post Euro I

<u>Hot emissions</u>

Hot emissions estimates for post-Euro I vehicles are calculated on the basis of reductions brought in the emission factors of Euro I vehicles due to the lack of experimental data. The reduction factors development has been conducted in the framework of the Auto Oil II exercise. It is based on the assumption that for any pollutant, the ratio of emission factor of any post-Euro I class over a reference class would be equal to the ratio of the respective emission standards. By taking Euro I vehicles as the reference, this assumption can be mathematically expressed as:

$$\frac{e_{TOT_i}^{\,j}}{e_{TOT_i}^{\,EURO\ I}} = \frac{ES_i^j}{ES_i^{EURO\ I, COP}} \qquad (20)$$

where,

$e_{TOT_i}^{\,j}$: total emission factor of pollutant i for vehicle class j (j = Euro II, Euro III, Euro IV)

$e_{TOT_i}^{\,EURO\ I}$: total emission factor of pollutant i of Euro I vehicles

ES_i^j: the emission standard of pollutant i for vehicle class j (j = Euro II, III, IV)

$ES_i^{EURO\ I, COP}$: the conformity of production emission standard for pollutant i of Euro I vehicles

Table 8.10: Emission reduction percentage for improved and future gasoline & LPG passenger cars, applied to vehicles complying with directive 91/441/EEC (Euro I)

Engine Capacity	Gasoline & LPG Passenger Cars	CO [%]	NOx [%]	VOC[%]
CC < 1.4 l	Euro II - 94/12/EC	32	64	79
	Euro III - 98/69/EC Stage 2000	44	76	85
	Euro IV - 98/69/EC Stage 2005	66	87	97
1.4 l < CC < 2.0 l	Euro II - 94/12/EC	32	64	79
	Euro III - 98/69/EC Stage 2000	44	76	86
	Euro IV - 98/69/EC Stage 2005	66	87	97
CC > 2.0 l	Euro II - 94/12/EC	32	64	76
	Euro III - 98/69/EC Stage 2000	44	76	84
	Euro IV - 98/69/EC Stage 2005	65	87	95

Note: The VOC reduction percentage has to be equally applied to the VOC emission factors (Table 8.4) and to the CH_4 emission factors (Table 8.32)

One has to note that reductions cannot be solely brought to hot emissions because emission standards also include a cold start fraction. Therefore a part of the reduction is attributed to cold emissions. Representative reduction factors of hot emissions are given in Table 8.10 for all pollutants in Group 1. Therefore, in the case of post-Euro I vehicles, the calculation of hot emissions is made by means of equation 3, where $e_{HOT;\,i,\,j,\,k}$ should be replaced with:

$$e_{HOT;\,i,\,j,\,k} = (100 - RF_{i,j}) / 100 \times e_{HOT;\,i,\,EURO\ I,\,k} \qquad (21)$$

where,

$RF_{i,j}$ the reduction factor as given by Table 8.10 for class j and pollutant i,

$e_{HOT;\ i,\ EURO\ I,\ k}$: the hot emission factor of Euro I vehicles (Tables 8.3 to 8.5) calculated for the average speed corresponding to vehicles of class j driven on roads of type k.

A clarification should be made for methane reduction factors. Current evidence suggests that the percentage of methane in the total VOC fraction increases in late catalyst vehicles because of its slower oxidation in the catalytic converter, compared to larger molecule hydrocarbons. However, the quantification of the increase is not possible with the available experimental data. The application of the methodology therefore assumes that the percentage of methane does not depend on the vehicle emission reduction technology. As a result the reduction factor assumed for VOC emissions (Table 8.10) to estimate emissions of post-Euro I vehicles needs to be equally applied to the NMVOC and CH_4 emission factors of Euro I vehicles.

Cold start emissions

Emission reduction compared to Euro I during the warming up phase of recent and future 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 8.11 provides reduction factors ($bc_{i,j}$) to be applied on the β-parameter according to pollutant and vehicle class. The different reduction factors proposed for each pollutant are due to the particularities of the application of equation 20 rather than the different time required to reach light off conditions (this should very little differ for CO, NO_x and VOC).

Table 8.11: β-parameter reduction factors (bc) in case of post-Euro I gasoline vehicles for three main pollutants

Emission legislation	CO	NO_x	VOC
Euro II - 94/12/EC	0.72	0.72	0.56
Euro III - 98/69/EC Stage 2000	0.62	0.32	0.32
Euro IV - 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[3]. This means that the e^{COLD}/e^{HOT} value calculated for Euro I vehicles can be also applied in the case of later vehicle classes without further

[3] 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.

reductions. In the same respect, even the hot emission factor involved in the equation of cold start over-emission of post-Euro I vehicles should keep the Euro I 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 I vehicle classes.

Therefore, equation 5 in the case of post-Euro I vehicle classes yields:

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

Respective modifications should also be brought in equation 6 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 I and Euro I

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 I) vehicles. Emission factors to be introduced in equation 3 for the calculation of hot emissions from conventional diesel passenger cars are given in Table 8.12.

Table 8.12: 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

From a methodological point of view, calculation of hot emissions from Euro I vehicles does not differ from conventional ones. Table 8.13 provides emission factors for pollutants of Group 1. In the case of Euro I vehicles, engine capacity does not seem relevant to characterise emissions and thus no distinction is made to different engine capacity classes.

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 I vehicles.

e^{COLD}/e^{HOT} ratios for calculating cold start over-emissions for those vehicles are quoted in Table 8.14.

Table 8.13: Speed dependency of emission and consumption factors for diesel passenger cars <2.5 t, complying with directive 91/441/EEC

Pollutant	Engine Capacity	Speed Range [km/h]	Emission Factor [g/km]	R^2
CO	All capacities	10-120	$1.4497 – 0.03385V + 21E-05V^2$	0.550
NO_x	All capacities	10-120	$1.4335 – 0.026V + 17.85E-05V^2$	0.262
VOC	All capacities	10-130	$0.1978 – 0.003925V +2.24E-05V^2$	0.342
PM	All capacities	10-130	$0.1804 - 0.004415V + 3.33E-05V^2$	0.294
Fuel Consumption	All capacities	10-130	$91.106 – 1.308V + 0.00871V^2$	0.526

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	$– 0.008\ t_a$

(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 Post Euro I

Hot emissions
Emissions of post-Euro I vehicle classes are calculated by introducing proper reduction factors to the emission factors of the Euro I class. In principle, the approach introduced by equation 20 holds also in the case of diesel vehicles. However, the initial low values of the emission factors compared to the emission standards of Euro I vehicles brings no additional reductions of Euro II vehicles compared to Euro I. Especially in the case of CO, it is proposed that emission factors of Euro I vehicles should not reduced even up to Euro IV vehicles. Therefore, hot emission factors of post-Euro I diesel passenger cars are calculated by application of equation 21 by introducing the relevant reduction factors given in Table 8.15.

Table 8.15: Emission reduction percentage for improved and future diesel passenger cars applied to vehicles complying with directive 91/441/EEC

Diesel Passenger Cars	CO [%]	NOx [%]	VOC [%]	PM [%]
Euro II - 94/12/EC	0	0	0	0
Euro III - 98/69/EC Stage 2000	0	23	15	28
Euro IV - 98/69/EC Stage 2005	0	47	31	55

Note: The VOC reduction percentage has to be equally applied to the VOC emission factors (Table 8.13) and to the CH_4 emission factors (Table 8.32).

Cold start emissions

Reduction factors proposed for hot emissions are also applicable for cold start over-emissions from diesel passenger cars. The β-parameter is calculated by the formula given in Table 8.8 for all classes. e^{COLD}/e^{HOT} ratios are quoted in Table 8.14 and are the same as in the case of conventional and Euro I diesel vehicles. Therefore, application of equation 5 in this case yields:

$$E_{COLD;i,j} = \beta_{i,j} \times N_j \times M_j \times (100\text{-}RF_{i,j}) / 100 \times e_{HOT;\, i,\, EURO\ I} \times (e^{COLD} / e^{HOT}|_{i,EURO\ I} - 1) \qquad (23)$$

Again, a similar transformation needs to be made in the case of equation 6.

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 3 is applied to calculate hot emissions for conventional and Euro I LPG vehicles. Table 8.16 provides hot emission factors for conventional passenger cars and Table 8.17 for those complying with 91/441/EEC (Euro I). 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). In respect with current and future vehicle classes (post-Euro I) of LPG vehicles and in the absence of more updated data, it is proposed to introduce reductions proposed for gasoline vehicles (Table 8.10) in equation 21.

Table 8.16: 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	- - -

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 8.18 provides over-emission ratios which are valid for all emission classes of LPG vehicles. Equations 5, 6 are applied up to Euro I vehicles while equation 22 is applied to post-Euro I ones. Reduction factors for the β-parameter equal those of gasoline vehicles (Table 8.11).

Table 8.17: 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 8.18: 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 $e^{COLD} / e^{HOT} > 0.5$

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.

Table 8.19: 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

Total emission factors (hot + cold) are given in Table 8.19. 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.

8.5 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 8.20. Emission factors of Euro I vehicles can also be found in the same Table. Hot emission factors of post-Euro I vehicles are calculated by application of equation 21 by introducing the reduction factors given in Table 8.21. Those reduction factors have been based on the rationale introduced by equation 20.

Table 8.20: 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 I	10-120	$0.0037V^2 - 0.5215V + 19.127$	0.394
NO_x	Conventional	10-110	$0.0179V + 1.9547$	0.142
	EURO I	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 I	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 I	10-120	$0.0195V^2 – 3.09V + 188.85$	0.723

Note: Due to limited available data, the function in the case of NO_x Euro I Gasoline is a mere copy of this applied in the case of gasoline passenger cars >2.0l Euro I. However, it seems to be in good compliance with both the measured data and the emission standards.

Table 8.21: Emission reduction percentage for future gasoline light duty vehicles applied to vehicles complying with directive 93/59/EEC (Euro I)

Gasoline Light Duty Vehicles	CO [%]	NOx [%]	VOC [%]
Euro II - 96/69/EC	39	66	76
Euro III - 98/69/EC Stage 2000	48	79	86
Euro IV - 98/69/EC Stage 2005	72	90	94

Note: The VOC reduction percentage has to be equally applied to the VOC emission factors (Table 8.20) and to the CH_4 emission factors (Table 8.32)

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 Tables 8.7 (pre-Euro I) and Table 8.9 (Euro I and on) are applied in the case of light duty vehicles. Furthermore, equations 5, 6 are valid for pre-Euro I vehicles and equation 22 for Euro I and later ones in conjunction with the β-parameter reduction factors given in Table 8.11.

8.6 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 8.22 for pollutants of Group 1. Cold start over-emissions up to Euro I are calculated by equation 5, where e^{COLD}/e^{HOT} ratios are selected from Table 8.14. Emission factors of post-Euro I vehicle classes are calculated by the functions corresponding to Euro I vehicles by introducing the reduction factors given in Table 8.23 both for hot and cold start emissions (equations 3, 20 and 22 respectively).

Table 8.22: 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	$20E-05V^2 - 0.0256V + 1.8281$	0.136
	EURO I	10-110	$22.3E-05V^2 - 0.026V + 1.076$	0.301
NOx	Conventional	10-110	$81.6E-05V^2 - 0.1189V + 5.1234$	0.402
	EURO I	10-110	$24.1E-05V^2 - 0.03181V + 2.0247$	0.0723
VOC	Conventional	10-110	$1.75E-05V^2 - 0.00284V + 0.2162$	0.0373
	EURO I	10-110	$1.75E-05V^2 - 0.00284V + 0.2162$	0.0373
PM	Conventional	10-110	$1.25E-05V^2 - 0.000577V + 0.288$	0.0230
	EURO I	10-110	$4.5E-05V^2 - 0.004885V + 0.1932$	0.224
Fuel Consumption	Conventional	10-110	$0.02113V^2 - 2.65V + 148.91$	0.486
	EURO I	10-110	$0.0198V^2 - 2.506V + 137.42$	0.422

Note: Due to limited available data, the same VOC emission factor function has been used in both Conventional and Euro I vehicles.

Table 8.23: 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 II - 96/69/EC	0	0	0	0
Euro III - 98/69/EC Stage 2000	18	16	38	33
Euro IV - 98/69/EC Stage 2005	35	32	77	65

Note: The VOC reduction percentage has to be equally applied to the VOC emission factors (Table 8.22) and to the CH_4 emission factors (Table 8.32)

8.7 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 8.24 and are distinguished only to the three driving modes (urban, rural, highway). Total emission estimates are therefore calculated by application only of equation 3.

Table 8.24: 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

Table 8.25: Speed dependency of emission and consumption factors for diesel heavy duty vehicles >3.5 t

Pollutant	Weight Class	Speed Range [km/h]	Emission Factor [g/km]	R^2
CO	All Weight Categories	0-100	$37.280V^{-0.6945}$	0.880
NOx	Weight<7.5t	0 - 46.7	$50.305V^{-0.7708}$	0.902
		46.7 - 100	$0.0014V^2 - 0.1737V + 7.5506$	0.260
	7.5<Weight<16t	0 - 58.8	$92.584V^{-0.7393}$	0.940
		58.8 - 100	$0.0006V^2 - 0.0941V + 7.7785$	0.440
	16<Weight<32t	0 - 100	$108.36V^{-0.6061}$	0.650
	Weight>32t	0 - 100	$132.88V^{-0.5581}$	0.894
VOC	All Weight Categories	0-100	$40.120V^{-0.8774}$	0.976
PM	Weight<7.5t	0 - 100	$4.5563V^{-0.7070}$	0.944
	7.5<Weight<16t	0 - 100	$9.6037V^{-0.7259}$	0.974
	16<Weight<32t	0 - 100	$10.890V^{-0.7105}$	0.946
	Weight>32t	0 - 100	$11.028V^{-0.6960}$	0.961
Fuel Consumption	Weight<7.5t	0 - 47	$1425.2V^{-0.7593}$	0.990
		47 - 100	$0.0082V^2 - 0.0430V + 60.12$	0.798
	7.5<Weight<16t	0 - 59	$1068.4V^{-0.4905}$	0.628
		59 - 100	$0.0126V^2 - 0.6589V + 141.18$	0.037
	16<Weight<32t	0 - 59	$1595.1V^{-0.4744}$	0.628
		59 - 100	$0.0382V^2 - 5.1630V + 399.3$	0.037
	Weight>32t	0 - 58	$1855.7V^{-0.4367}$	0.914
		58 - 100	$0.0765V^2 - 11.414V + 720.9$	0.187

8.8 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 German/Swiss Handbook (Keller et al., 1995) and are quoted in Table 8.25. Similarly, Table 8.26 provides hot emission factors for urban busses and coaches. The emission factors proposed correspond only to Conventional (pre 91/542/EEC Directive) vehicles. Estimation of emissions from improved vehicles is made by introducing the reduction factors given in Table 8.27 for different weight classes of heavy-duty vehicles, busses and coaches. Those factors are in principle based on application of equation 20 with the emission standards imposed by Stage 1 and 2 of 91/542/EEC or the different Proposals.

Table 8.26: Speed dependency of emission and consumption factors for conventional diesel urban busses and coaches

Pollutant	**Vehicle Class**	**Speed Range [km/h]**	**Emission Factor [g/km]**	**R^2**
CO	Urban Buses	0 - 50	$59.003\ V^{-0.7447}$	0.895
	Coaches	0 - 120	$63.791\ V^{-0.8393}$	0.978
NOx	Urban Buses	0 - 50	$89.174\ V^{-0.5185}$	0.534
	Coaches	0 – 58.8	$125.87\ V^{-0.6562}$	0.848
		58.8 – 120	$0.0010\ V^2 - 0.1608\ V + 14.308$	0.073
VOC	Urban Buses	0 - 50	$43.647\ V^{-1.0301}$	0.992
	Coaches	0 - 120	$44.217\ V^{-0.8870}$	0.993
PM	Urban Buses	0 - 50	$7.8609\ V^{-0.7360}$	0.920
	Coaches	0 - 120	$9.2934\ V^{-0.7373}$	0.975
Fuel Consumption	Urban Buses	0 - 50	$1371.6\ V^{-0.4318}$	0.502
	Coaches	0 -59	$1919.0\ V^{-0.5396}$	0.786
		59 - 120	$0.0447\ V^2 - 7.072\ V + 478$	0.026

Table 8.27: Emission reduction percentage for improved diesel heavy-duty vehicles applied to conventional ones (U: urban, R: rural, H: highway)

Veh. Class	Weight Class	CO			NO_x			VOC			PM		
		U	R	H	U	R	H	U	R	H	U	R	H
Euro I	Weight<7.5t	50.0	40.0	45.0	30.0	30.0	10.0	25.0	25.0	25.0	35.0	35.0	35.0
	7.5<Weight<16t	50.0	40.0	45.0	30.0	30.0	10.0	25.0	25.0	25.0	35.0	35.0	35.0
	16<Weight<32t	45.0	40.0	35.0	45.0	40.0	45.0	50.0	35.0	25.0	35.0	35.0	35.0
	Weight>32t	45.0	40.0	35.0	45.0	40.0	45.0	50.0	35.0	25.0	35.0	35.0	35.0
Euro II	Weight<7.5t	60.0	45.0	50.0	50.0	45.0	35.0	30.0	30.0	30.0	60.0	60.0	60.0
	7.5<Weight<16t	60.0	45.0	50.0	50.0	45.0	35.0	30.0	30.0	30.0	60.0	60.0	60.0
	16<Weight<32t	55.0	50.0	35.0	60.0	55.0	55.0	55.0	40.0	35.0	75.0	75.0	75.0
	Weight>32t	55.0	50.0	35.0	60.0	55.0	55.0	55.0	40.0	35.0	75.0	75.0	75.0
Euro III	Weight<7.5t	72.0	61.5	65.0	65.0	61.5	54.5	51.0	51.0	51.0	72.0	72.0	72.0
	7.5<Weight<16t	72.0	61.5	65.0	65.0	61.5	54.5	51.0	51.0	51.0	72.0	72.0	72.0
	16<Weight<32t	68.5	65.0	54.5	72.0	68.5	68.5	68.5	58.0	54.5	82.5	82.5	82.5
	Weight>32t	68.5	65.0	54.5	72.0	68.5	68.5	68.5	58.0	54.5	82.5	82.5	82.5
Euro IV	Weight<7.5t	79.6	71.9	74.5	75.5	73.1	68.2	65.7	65.7	65.7	94.7	94.7	94.7
	7.5<Weight<16t	79.6	71.9	74.5	75.5	73.1	68.2	65.7	65.7	65.7	94.7	94.7	94.7
	16<Weight<32t	77.0	74.5	66.8	80.4	78.0	78.0	78.0	70.6	68.2	96.7	96.7	96.7
	Weight>32t	77.0	74.5	66.8	80.4	78.0	78.0	78.0	70.6	68.2	96.7	96.7	96.7
Euro V	Weight<7.5t	79.6	71.9	74.5	86.0	84.6	81.8	65.7	65.7	65.7	94.7	94.7	94.7
	7.5<Weight<16t	79.6	71.9	74.5	86.0	84.6	81.8	65.7	65.7	65.7	94.7	94.7	94.7
	16<Weight<32t	77.0	74.5	66.8	88.8	87.4	87.4	78.0	70.6	68.2	96.7	96.7	96.7
	Weight>32t	77.0	74.5	66.8	88.8	87.4	87.4	78.0	70.6	68.2	96.7	96.7	96.7
Euro I	Urban Busses	50.0	40.0	45.0	30.0	30.0	10.0	25.0	25.0	25.0	35.0	35.0	35.0
	Coaches	45.0	40.0	35.0	45.0	40.0	45.0	50.0	35.0	25.0	35.0	35.0	35.0
Euro II	Urban Busses	60.0	45.0	50.0	50.0	45.0	35.0	30.0	30.0	30.0	60.0	60.0	60.0
	Coaches	55.0	50.0	35.0	60.0	55.0	55.0	55.0	40.0	35.0	75.0	75.0	75.0
Euro III	Urban Busses	72.0	61.5	65.0	65.0	61.5	54.5	51.0	51.0	51.0	72.0	72.0	72.0
	Coaches	68.5	65.0	54.5	72.0	68.5	68.5	68.5	58.0	54.5	82.5	82.5	82.5
Euro IV	Urban Busses	79.6	71.9	74.5	75.5	73.1	68.2	65.7	65.7	65.7	94.7	94.7	94.7
	Coaches	77.0	74.5	66.8	80.4	78.0	78.0	78.0	70.6	68.2	96.7	96.7	96.7
Euro V	Urban Busses	79.6	71.9	74.5	86.0	84.6	81.8	65.7	65.7	65.7	94.7	94.7	94.7
	Coaches	77.0	74.5	66.8	88.8	87.4	87.4	78.0	70.6	68.2	96.7	96.7	96.7

Note: The VOC reduction percentage has to be equally applied to the VOC emission factors (Table 8.25 and Table 8.26) and to the CH_4 emission factors (Table 8.32)

8.9 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 8.28. Reduction factors for improved moped technologies are given in Table 8.29. 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

Table 8.28: Emission and consumption factors for conventional mopeds (corresponding to urban driving conditions)

Mopeds	CO [g/km]	NOx [g/km]	VOC [g/km]	Fuel Consumption [g/km]
< 50 cm³	15.0	0.03	9.00	25.0

Table 8.29: Emission and consumption reduction percentage for improved mopeds applied to conventional ones

Mopeds <50 cm³	Road Classes	CO [%]	NOx [%]	VOC [%]	FC [%]
97/24/EC Stage I	All	50	0	55	40
97/24/EC Stage II	All	90	67	78	56

Note: The VOC reduction percentage has to be equally applied to the VOC emission factors (Table 8.28) and to the CH_4 emission factors (Table 8.32)

Table 8.30: Speed dependency of emission and consumption factors for 2 stroke motorcycles of engine displacement over 50 cm³

Pollutant	Vehicle Class	Speed Range [km/h]	Emission Factor [g/km]
CO	Conventional	10 - 60	-0.00100 V² + 0.1720 V + 18.10
		60 - 110	0.00010 V² + 0.0500 V + 21.50
	97/24/EC	10 - 60	-0.00630 V² + 0.7150 V - 6.900
		60 - 110	0.00070 V² + 0.1570 V + 6.000
NOx	Conventional	10 - 60	0.00003 V² - 0.0020 V + 0.064
		60 - 110	-0.00002 V² + 0.0049 V - 0.157
	97/24/EC	10 - 60	0.00002 V² - 0.0010 V + 0.032
		60 - 110	-0.00002 V² + 0.0041 V - 0.152
VOC	Conventional	10 - 60	0.00350 V² - 0.4090 V + 20.10
		60 - 110	0.00030 V² - 0.0524 V + 10.60
	97/24/EC	10 - 60	-0.00100 V² + 0.0970 V + 3.900
		60 - 110	-0.00030 V² + 0.0325 V + 5.200
Fuel Consumption	Conventional	10 - 60	0.006300 V² - 0.6028 V + 44.40
		60 - 110	-0.00050 V² + 0.2375 V + 18.20
	97/24/EC	10 - 60	-0.00110 V² + 0.2008 V + 17.80
		60 - 110	-0.00100 V² + 0.2425 V + 14.60

8.10 Motorcycles >50 cm³

As far as motorcycles are concerned, an inventory made by Swiss and German institutes and published by the Swiss BUWAL (Keller et al., 1995) provides more information. In total 24 motorcycles (including motor scooters) were measured, of which 15 four-stroke and 9 two-stroke, and of which 8 (6 four-stroke and 2 two-stroke) had to comply with the stricter Swiss legislation. The vehicles were measured over the European UDC, the European EUDC, the American US-FTP (divided into the first and second part), the American Highway Cycle and the German Motorway Cycle. This allowed a speed dependency to be established.

Table 8.31: Speed dependency of emission and consumption factors for 4 stroke motorcycles of engine displacement over 50cm³

Pollutant	Cylinder Capacity	Speed Range [km/h]	Emission Factor [g/km]
CO	Conventional $<250cm^3$	10 - 60	$0.01930V^2 - 1.9200V + 68.30$
		60 - 110	$0.00170V^2 + 0.1210V + 9.500$
	Conventional $250<cc<750cm^3$	10 - 60	$0.01390V^2 - 1.4200V + 55.00$
		60 - 110	$0.00090V^2 - 0.0099V + 17.80$
	Conventional $>750cm^3$	10 - 60	$0.01230V^2 - 1.1900V + 42.80$
		60 - 110	$0.00050V^2 + 0.1240V + 6.900$
	97/24/EC All Capacities	10 - 60	$0.00760V^2 - 0.7300V + 23.50$
		60 - 110	$0.00100V^2 + 0.0510V + 0.800$
NOx	Conventional $<250cm^3$	10 - 60	$0.00005V^2 - 0.0010V + 0.090$
		60 - 110	$0.00002V^2 + 0.0006V + 0.102$
	Conventional $250<cc<750cm^3$	10 - 60	$0.00005V^2 - 0.0009V + 0.092$
		60 - 110	$0.00002V^2 + 0.0007V + 0.104$
	Conventional $>750cm^3$	10 - 60	$0.00005V^2 - 0.0008V + 0.100$
		60 - 110	$0.00002V^2 + 0.0008V + 0.112$
	97/24/EC All Capacities	10 - 60	$0.00005V^2 -0.0007V + 0.137$
		60 - 110	$0.00002V^2 + 0.001V + 0.143$
VOC	Conventional $<250cm^3$	10 - 60	$0.00190V^2 - 0.2110V + 6.950$
		60 - 110	$0.00090V^2 - 0.1410V + 6.420$
	Conventional $250<cc<750cm^3$	10 - 60	$0.00150V^2 - 0.1640V + 5.510$
		60 - 110	$0.00001V^2 + 0.0005V + 0.860$
	Conventional $>750cm^3$	10 - 60	$0.00220V^2 - 0.2570V + 9.280$
		60 - 110	$0.00010V^2 - 0.0310V + 3.290$
	97/24/EC All Capacities	10 - 60	$0.00070V^2 - 0.0755V + 2.630$
		60 - 110	$0.00007V^2 - 0.0152V + 1.190$
Fuel Consumption	Conventional $<250cm^3$	10 - 60	$0.01890V^2 - 1.8740V + 67.90$
		60 - 110	$0.00080V^2 + 0.1614V + 11.50$
	Conventional $250<cc<750cm^3$	10 - 60	$0.02730V^2 - 2.8490V + 98.90$
		60 - 110	$0.00210V^2 - 0.1550V + 29.20$
	Conventional $>750cm^3$	10 - 60	$0.02870V^2 - 3.1080V + 115.9$
		60 - 110	$0.00180V^2 - 0.1638V + 37.00$
	97/24/EC All Capacities	10 - 60	$0.02000V^2 - 2.0750V + 77.10$
		60 - 110	$0.00130V^2 - 0.0391V + 23.50$

Tables 8.30 displays the bulk (hot + cold) emission factors proposed for 2-sroke motorcycles and Table 8.31 for respective 4-stroke ones.

8.11 Emissions of non-regulated pollutants

8.11.1 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 3 can be applied with the values given in

Table 8.32. 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).

Table 8.32: Methane (CH_4) emission factors (mg/km) for stabilised (hot) thermal conditions

Vehicle technology	Speed Range [km/h]	Urban	Rural	Highway
Passenger Cars				
Gasoline Conventional	10 - 130	$0.0331V^2 - 5.73V + 268$		
Gas. Euro I CC < 1.4 l	10 - 130	$0.012969V^2 - 2.1098V + 101.995$		
Gas. Euro I 1.4 l<CC<2.0 l	10 - 130	$0.011176V^2 - 1.9573V + 99.652$		
Gas. Euro I CC > 2.0 l	10 - 130	$0.0093945V^2 - 1.8118V + 97.488$		
Diesel CC < 2.0 l	10 - 130	$0.0019V^2 - 0.1775V + 7.9936$		
Diesel CC > 2.0 l	10 - 130	$0.0019V^2 - 0.1775V + 7.9936$		
LPG		80	35	25
2 - stroke		150	40	25
Light Duty Vehicles				
Gasoline Conventional		150	40	25
Gasoline Euro I and on	10 - 130	$0.012969V^2 - 2.1098V + 101.995$		
Diesel		5	5	5
Heavy Duty Vehicles				
Gasoline > 3.5 t		140	110	70
Diesel < 7.5 t		85	23	20
Diesel 7.5 t < W < 16 t		85	23	20
Diesel 16 t < W < 32 t		175	80	70
Diesel W > 32 t		175	80	70
Urban Buses		175	-	-
Coaches		175	80	70
Mopeds and Motorcycles				
< 50 cm³		219	219	219
> 50 cm³ 2 stroke		150	150	150
> 50 cm³ 4 stroke		200	200	200

Note: Emission factors for later vehicle technologies should be derived according to the reduction factors of Tables 8.10, 8.15, 8.21, 8.23, 8.27 and 8.29 for different vehicle types.

Cold start emissions of CH_4 are calculated by means of equations 5 or 6 with use of the hot emission factors determined in Table 8.32 and overemission functions corresponding to VOC (i.e. Tables 8.7, 8.9, 8.14, 8.18 depending on vehicle category).

Finally, NMVOC emission are deduced as the remainder of the subtraction of CH_4 total emissions from VOC total emissions, as calculated by equation 1. Hence, if VOC and CH_4 have been calculated by equation 1, NMVOC emissions can also be calculated by:

$$E_{NMVOC} = E_{VOC} - E_{CH4} \quad (24)$$

8.11.2 Nitrous oxide (N_2O) emissions

Emission factors for N_2O are roughly estimated on the basis of literature review for all vehicle categories (Pringent et al., 1989; Perby, 1990; de Reydellet, 1990; Potter, 1990; OECD, 1991; Zajontz et al., 1991 and others). Again these data are still quite unreliable and need further confirmation by measurements. There is no separate methodology for estimating cold start over-emissions but they are assumed to be already incorporated in the bulk emission factors. Therefore total emissions estimates for nitrous oxide are made by application of equation 3, substituting $e_{HOT;\ i,j,k}$ with the total emission factors provided in Table 8.33 for each vehicle category.

Table 8.33: Bulk (hot + cold) nitrous oxide (N_2O) emission factors (mg/km)

Vehicle category	Urban	Rural	Highway
Passenger Cars			
Gasoline Conventional	5	5	5
Gasoline Euro I and on	53	16	35
Diesel CC < 2.0 l	27	27	27
Diesel CC > 2.0 l	27	27	27
LPG	15	15	15
2 - stroke	5	5	5
Light Duty Vehicles			
Gasoline Conventional	6	6	6
Gasoline Euro I and on	53	16	35
Diesel	17	17	17
Heavy Duty Vehicles			
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

8.11.3 Ammonia (NH_3) emissions

For estimating ammonia emissions average emission factors are given for conventional and three way catalyst gasoline passenger cars, light duty vehicles, diesel passenger cars and light duty vehicles, related to the total annual kilometres driven. Again, no separate calculation is made for cold start over-emissions. Application of equation 3 provides total ammonia estimates by using emission factors provided in Table 8.34.

These emission factors are based on literature review only and should be considered as broad estimates (de Reydellet, 1990; Volkswagen, 1989).

Table 8.34: Bulk (hot + cold) ammonia (NH_3) emission factors (mg/km)

Vehicle category	**Urban**	**Rural**	**Highway**
Passenger Cars			
Gasoline Conventional	2	2	2
Gasoline Euro I and on	70	100	100
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			
Gasoline Conventional	2	2	2
Gasoline Euro I and on	70	100	100
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 cm^3	1	1	1
> 50 cm^3 2 stroke	2	2	2
> 50 cm^3 4 stroke	2	2	2

8.11.4 PAHs and POPs

Emission factors (in [g/km]) for polycyclic aromatic hydrocarbons (PAHs) and persistent organic pollutants (POPs) are given in Table 8.35 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 3 with those emission factors provides total emissions of PAHs and POPs per vehicle class.

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.

Table 8.35: PAHs and POPs bulk (hot + cold) emission factors

Species	Bulk emission factors (•g/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	

8.11.5 Dioxins and furans

Emission factors of Dioxins and Furans are given in Table 8.36 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 8.36: 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

8.12 Fuel consumption dependant emission factors

Emissions of heavy metals are calculated by means of equation 12. Table 8.37 provides emission factors of heavy metals for different vehicle categories.

Table 8.37: 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 < $50cm^3$	0.01	1.7	0.05	0.07	0.01	1
Motorcycles > $50cm^3$	0.01	1.7	0.05	0.07	0.01	1

8.13 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 8.38: 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_{UDC})			
CO - MC_{UDC}	≤1.4	29057	1.523E-05	0.557	2.39
	1.4-2.0	39837	1.148E-05	0.543	1.92
	>2.0	47028	9.243E-06	0.565	1.67
NO_x - MC_{UDC}	ALL	44931	1.598E-05	0.282	2.20
HC - MC_{UDC}	≤1.4	29057	1.215E-05	0.647	2.10
	1.4-2.0	39837	1.232E-05	0.509	1.99
	>2.0	47028	1.208E-05	0.432	1.88
		Correction for V>63 km/h (MC_{EUDC})			
CO - MC_{EUDC}	≤1.4	29057	1.689E-05	0.509	2.54
	1.4-2.0	39837	9.607E-06	0.617	1.77
	>2.0	47028	2.704E-06	0.873	1.20
NO_x - MC_{EUDC}	ALL	47186	1.220E-05	0.424	1.89
HC - MC_{EUDC}	≤1.4	29057	6.570E-06	0.809	1.60
	1.4-2.0	39837	9.815E-06	0.609	1.79
	>2.0	47028	6.224E-06	0.707	1.45

Table 8.39: 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]	A^M	B^M (Value at 0 km)	Value at 120000 km	Stabilisation Mileage [km]
		Correction for V<19 km/h (MC_{UDC})			
CO - MC_{UDC}	<1.4	1.146E-05	0.557	1.93	159,488
	1.4-2.0	8.346E-06	0.543	1.54	165,085
	>2.0	6.411E-06	0.565	1.33	173,001
NOx - MC_{UDC}	ALL	1.295E-05	0.282	1.84	148,071
HC - MC_{UDC}	<1.4	8.872E-06	0.647	1.71	164,278
	1.4-2.0	9.332E-06	0.509	1.63	158,456
	>2.0	9.301E-06	0.432	1.55	155,881
		Correction for V>63 km/h (MC_{EUDC})			
CO - MC_{EUDC}	<1.4	1.297E-05	0.509	2.07	156,273
	1.4-2.0	6.592E-06	0.617	1.41	174,868
	>2.0	1.823E-07	0.873	0.89	*1,779,775*
NOx - MC_{EUDC}	ALL	9.421E-06	0.424	1.55	155,436
HC - MC_{EUDC}	<1.4	3.770E-06	0.809	1.26	209,152
	1.4-2.0	6.977E-06	0.609	1.45	168,823
	>2.0	3.703E-06	0.707	1.15	201,667

8.14 Fuel effects functions

Tables 8.40, 8.41 and 8.42 provide the correction functions required to estimate the effect of fuel properties on emissions according to section 5.7.2.

Table 8.40: Relations between emissions and fuel properties for passenger cars and light duty vehicles

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

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 8.41: Relations between emissions and fuel properties for Diesel passenger cars and light duty vehicles

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

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 8.42: 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 ^{o}C

8.15 Road slope correction for HDVs

The tables following present the coefficients of equation 12, used to correct the emission and consumption of heavy duty vehicles due to gradient effects. The correction factors depend on the gross weight class of the vehicle, the pollutant under consideration and the slope of the road. The columns v_{min} and v_{max} give respectively the minimum and maximum vehicle speeds for which the equations are applicable. Use of the equation outside that speed region might lead to significant overestimation of the slope effect and therefore should be avoided. The slope column consists of classes as given in Table 5.1.

Table 8.43: Road gradient correction factors for heavy duty vehicles <7.5 t

A6	A5	A4	A3	A2	A1	A0	case	slope *[%]*	v_{min} *[km/h]*	v_{max} *[km/h]*
0.00E+00	-4.33E-09	1.40E-06	-1.53E-04	6.22E-03	-1.01E-01	1.63E+00	VOC	4… 6	13.0	39.3
0.00E+00	-5.14E-08	9.90E-06	-7.17E-04	2.39E-02	-3.57E-01	2.95E+00	VOC	-6… -4	13.5	49.9
0.00E+00	-2.05E-08	4.25E-06	-3.30E-04	1.18E-02	-1.92E-01	2.16E+00	VOC	0… 4	15.1	69.9
0.00E+00	4.02E-09	-9.36E-07	8.39E-05	-3.66E-03	7.99E-02	3.98E-01	VOC	-4… 0	15.1	86.2
0.00E+00	1.51E-07	-1.93E-05	9.26E-04	-2.11E-02	2.57E-01	6.58E-02	CO	4… 6	13.0	39.3
0.00E+00	-7.00E-08	1.25E-05	-8.51E-04	2.71E-02	-3.96E-01	2.86E+00	CO	-6… -4	13.5	49.9
0.00E+00	-1.18E-08	2.49E-06	-1.95E-04	6.78E-03	-9.28E-02	1.52E+00	CO	0… 4	15.1	69.9
0.00E+00	-5.54E-10	1.80E-07	-1.82E-05	6.42E-04	-5.54E-03	8.14E-01	CO	-4… 0	15.1	86.2
0.00E+00	1.82E-08	-1.85E-06	3.32E-05	1.28E-03	-4.14E-03	1.43E+00	NOx	4… 6	13.0	39.3
0.00E+00	-7.94E-08	1.37E-05	-9.08E-04	2.83E-02	-4.13E-01	2.78E+00	NOx	-6… -4	13.5	49.9
0.00E+00	-6.87E-09	1.37E-06	-1.06E-04	3.74E-03	-4.19E-02	1.23E+00	NOx	0… 4	15.1	69.9
0.00E+00	-3.00E-10	8.69E-08	-7.87E-06	2.26E-04	-2.07E-03	7.03E-01	NOx	-4… 0	15.1	86.2
0.00E+00	4.27E-07	-5.74E-05	2.97E-03	-7.43E-02	9.35E-01	-3.03E+00	FC	4… 6	13.0	39.3
0.00E+00	-7.74E-08	1.33E-05	-8.78E-04	2.72E-02	-3.93E-01	2.65E+00	FC	-6… -4	13.5	49.9
0.00E+00	-3.01E-09	5.73E-07	-4.13E-05	1.13E-03	8.13E-03	9.14E-01	FC	0… 4	15.1	69.9
0.00E+00	-1.39E-10	5.03E-08	-4.18E-06	1.95E-05	3.68E-03	6.69E-01	FC	-4… 0	15.1	86.2
0.00E+00	-2.54E-07	3.58E-05	-1.99E-03	5.42E-02	-6.89E-01	4.54E+00	PM	4… 6	13.0	39.3
0.00E+00	-5.34E-08	9.97E-06	-7.05E-04	2.32E-02	-3.48E-01	2.71E+00	PM	-6… -4	13.5	49.9
0.00E+00	-1.96E-08	4.11E-06	-3.22E-04	1.16E-02	-1.83E-01	2.08E+00	PM	0… 4	15.1	69.9
0.00E+00	-1.89E-10	8.23E-08	-9.49E-06	3.25E-04	-2.54E-04	8.21E-01	PM	-4… 0	15.1	86.2

vmin and vmax: Speed range in which the correction is applicable

Table 8.44: Road gradient correction factors for heavy duty vehicles 7.5 - 16 t

A6	A5	A4	A3	A2	A1	A0	case	slope *[%]*	v_{min} *[km/h]*	v_{max} *[km/h]*
0.00E+00	1.28E-07	-1.65E-05	7.96E-04	-1.82E-02	2.04E-01	3.24E-01	VOC	4… 6	13.1	39.5
0.00E+00	-4.01E-08	8.12E-06	-6.01E-04	2.01E-02	-3.01E-01	2.76E+00	VOC	-6… -4	13.5	49.9
0.00E+00	-1.82E-08	3.70E-06	-2.78E-04	9.60E-03	-1.51E-01	1.94E+00	VOC	0… 4	15.1	70.3
0.00E+00	1.10E-09	-3.38E-07	3.94E-05	-2.13E-03	5.25E-02	6.52E-01	VOC	-4… 0	15.1	86.4
0.00E+00	3.28E-07	-4.35E-05	2.21E-03	-5.46E-02	6.73E-01	-1.88E+00	CO	4… 6	13.1	39.5
0.00E+00	-6.79E-08	1.21E-05	-8.24E-04	2.58E-02	-3.67E-01	2.89E+00	CO	-6… -4	13.5	49.9
0.00E+00	-1.09E-08	2.16E-06	-1.56E-04	4.85E-03	-5.79E-02	1.34E+00	CO	0… 4	15.1	70.3
0.00E+00	-1.11E-10	-3.21E-08	1.19E-05	-1.09E-03	3.34E-02	6.97E-01	CO	-4… 0	15.1	86.4
0.00E+00	-2.42E-07	3.49E-05	-1.96E-03	5.28E-02	-6.52E-01	4.60E+00	NOx	4… 6	13.1	39.5
0.00E+00	-9.71E-08	1.70E-05	-1.14E-03	3.57E-02	-5.30E-01	3.81E+00	NOx	-6… -4	13.5	49.9
0.00E+00	-1.21E-08	2.39E-06	-1.77E-04	6.00E-03	-8.29E-02	1.56E+00	NOx	0… 4	15.1	70.3
0.00E+00	-8.49E-11	1.17E-08	3.94E-07	-1.38E-04	2.18E-03	9.09E-01	NOx	-4… 0	15.1	86.4
0.00E+00	3.21E-07	-4.29E-05	2.23E-03	-5.75E-02	7.62E-01	-1.98E+00	FC	4… 6	13.1	39.5
0.00E+00	-1.24E-07	2.08E-05	-1.33E-03	4.00E-02	-5.65E-01	3.57E+00	FC	-6… -4	13.5	49.9
0.00E+00	-9.78E-10	-2.01E-09	1.91E-05	-1.63E-03	5.91E-02	7.70E-01	FC	0… 4	15.1	70.3
0.00E+00	-6.04E-11	-2.36E-08	7.76E-06	-6.83E-04	1.79E-02	6.12E-01	FC	-4… 0	15.1	86.4
0.00E+00	8.06E-09	3.61E-07	-1.27E-04	5.99E-03	-8.25E-02	1.76E+00	PM	4… 6	13.1	39.5
0.00E+00	-5.44E-08	1.01E-05	-7.06E-04	2.28E-02	-3.38E-01	2.86E+00	PM	-6… -4	13.5	49.9
0.00E+00	-1.61E-08	3.27E-06	-2.45E-04	8.30E-03	-1.18E-01	1.72E+00	PM	0… 4	15.1	70.3
0.00E+00	-7.69E-10	1.50E-07	-7.72E-06	-8.94E-05	1.04E-02	8.95E-01	PM	-4… 0	15.1	86.4

v_{min} and v_{max}: Speed range in which the correction is applicable

Table 8.45: Road gradient correction factors for heavy duty vehicles 16 - 32 t

A6	A5	A4	A3	A2	A1	A0	case	slope *[%]*	v_{min} *[km/h]*	v_{max} *[km/h]*
0.00E+00	0.00E+00	6.18E-06	-6.51E-04	2.39E-02	-3.66E-01	3.24E+00	VOC	4… 6	12.5	36.5
0.00E+00	-4.96E-08	9.03E-06	-6.37E-04	2.11E-02	-3.22E-01	3.08E+00	VOC	-6… -4	13.5	49.9
0.00E+00	-2.11E-08	4.32E-06	-3.30E-04	1.17E-02	-1.91E-01	2.25E+00	VOC	0… 4	14.9	64.7
0.00E+00	3.21E-09	-7.41E-07	6.58E-05	-2.82E-03	5.69E-02	7.55E-01	VOC	-4… 0	15.1	86.1
0.00E+00	0.00E+00	-1.50E-05	1.43E-03	-4.92E-02	7.32E-01	-2.31E+00	CO	4… 6	12.5	36.5
0.00E+00	-7.70E-08	1.30E-05	-8.51E-04	2.62E-02	-3.80E-01	3.15E+00	CO	-6… -4	13.5	49.9
0.00E+00	-2.46E-08	4.79E-06	-3.44E-04	1.13E-02	-1.66E-01	2.12E+00	CO	0… 4	14.9	64.7
0.00E+00	1.44E-09	-3.32E-07	3.06E-05	-1.45E-03	2.91E-02	8.76E-01	CO	-4… 0	15.1	86.1
0.00E+00	0.00E+00	2.30E-06	-2.49E-04	9.39E-03	-1.26E-01	2.51E+00	NOx	4… 6	12.5	36.5
0.00E+00	-1.09E-07	1.84E-05	-1.20E-03	3.70E-02	-5.49E-01	3.83E+00	NOx	-6… -4	13.5	49.9
0.00E+00	-2.00E-08	3.87E-06	-2.81E-04	9.57E-03	-1.43E-01	2.08E+00	NOx	0… 4	14.9	64.7
0.00E+00	5.72E-11	1.59E-08	-4.09E-06	2.73E-04	-1.18E-02	9.79E-01	NOx	-4… 0	15.1	86.1
0.00E+00	0.00E+00	-6.69E-06	6.55E-04	-2.31E-02	3.69E-01	1.07E-01	FC	4… 6	12.5	36.5
0.00E+00	-1.22E-07	2.03E-05	-1.30E-03	3.94E-02	-5.70E-01	3.75E+00	FC	-6… -4	13.5	49.9
0.00E+00	-5.25E-09	9.93E-07	-6.74E-05	2.06E-03	-1.96E-02	1.45E+00	FC	0… 4	14.9	64.7
0.00E+00	-8.24E-11	2.91E-08	-2.58E-06	5.76E-05	-4.74E-03	8.55E-01	FC	-4… 0	15.1	86.1
0.00E+00	0.00E+00	-1.05E-05	9.88E-04	-3.35E-02	5.10E-01	-1.09E+00	PM	4… 6	12.5	36.5
0.00E+00	-6.72E-08	1.16E-05	-7.82E-04	2.50E-02	-3.79E-01	3.23E+00	PM	-6… -4	13.5	49.9
0.00E+00	-3.60E-08	7.00E-06	-5.07E-04	1.69E-02	-2.49E-01	2.59E+00	PM	0… 4	14.9	64.7
0.00E+00	2.40E-11	3.95E-08	-6.78E-06	3.25E-04	-9.46E-03	1.12E+00	PM	-4… 0	15.1	86.1

v_{min} and v_{max}: Speed range in which the correction is applicable

Table 8.46: Road gradient correction factors for heavy duty vehicles >32 t

A6	A5	A4	A3	A2	A1	A0	case	slope *[%]*	v_{min} *[km/h]*	v_{max} *[km/h]*
0.00E+00	5.68E-08	-5.40E-06	1.24E-04	1.11E-03	-6.09E-02	1.80E+00	VOC	4… 6	12.4	35.0
0.00E+00	-2.50E-08	5.91E-06	-4.88E-04	1.79E-02	-2.98E-01	3.08E+00	VOC	-6… -4	13.5	49.9
0.00E+00	-2.02E-08	4.10E-06	-3.11E-04	1.09E-02	-1.76E-01	2.18E+00	VOC	0… 4	14.8	66.3
0.00E+00	1.95E-09	-4.68E-07	4.26E-05	-1.84E-03	3.52E-02	9.32E-01	VOC	-4… 0	15.1	86.3
0.00E+00	1.43E-06	-1.75E-04	8.27E-03	-1.89E-01	2.09E+00	-7.12E+00	CO	4… 6	12.4	35.0
0.00E+00	-6.48E-08	1.17E-05	-7.95E-04	2.51E-02	-3.71E-01	3.10E+00	CO	-6… -4	13.5	49.9
0.00E+00	-8.63E-09	1.50E-06	-9.50E-05	2.65E-03	-2.44E-02	1.35E+00	CO	0… 4	14.8	66.3
0.00E+00	1.28E-09	-3.07E-07	2.99E-05	-1.48E-03	3.00E-02	8.54E-01	CO	-4… 0	15.1	86.3
0.00E+00	2.42E-08	3.11E-06	-4.50E-04	1.79E-02	-2.70E-01	3.56E+00	NOx	4… 6	12.4	35.0
0.00E+00	-9.96E-08	1.73E-05	-1.15E-03	3.63E-02	-5.48E-01	3.85E+00	NOx	-6… -4	13.5	49.9
0.00E+00	-1.31E-08	2.49E-06	-1.82E-04	6.46E-03	-1.01E-01	1.94E+00	NOx	0… 4	14.8	66.3
0.00E+00	-7.69E-10	2.13E-07	-2.19E-05	1.06E-03	-2.84E-02	1.08E+00	NOx	-4… 0	15.1	86.3
0.00E+00	5.88E-07	-7.24E-05	3.45E-03	-7.86E-02	8.63E-01	-9.76E-01	FC	4… 6	12.4	35.0
0.00E+00	-1.18E-07	2.00E-05	-1.29E-03	3.96E-02	-5.78E-01	3.72E+00	FC	-6… -4	13.5	49.9
0.00E+00	-2.04E-09	4.35E-07	-3.69E-05	1.69E-03	-3.16E-02	1.77E+00	FC	0… 4	14.8	66.3
0.00E+00	-1.10E-09	2.69E-07	-2.38E-05	9.51E-04	-2.24E-02	9.16E-01	FC	-4… 0	15.1	86.3
0.00E+00	-3.23E-07	3.70E-05	-1.70E-03	3.89E-02	-4.15E-01	3.36E+00	PM	4… 6	12.4	35.0
0.00E+00	-4.37E-08	8.63E-06	-6.36E-04	2.17E-02	-3.46E-01	3.17E+00	PM	-6… -4	13.5	49.9
0.00E+00	-1.83E-08	3.60E-06	-2.65E-04	8.95E-03	-1.30E-01	1.92E+00	PM	0… 4	14.8	66.3
0.00E+00	4.10E-10	-7.06E-08	4.33E-06	-1.28E-04	-1.87E-03	1.11E+00	PM	-4… 0	15.1	86.3

v_{min} and v_{max}: Speed range in which the correction is applicable

Table 8.47 gives the gradient correction factors for urban buses and Table 8.48 for coaches. One has to be aware of the fact that the equation for urban buses in only applicable in the range of 5 to 50 km/h since those vehicles only seldom exceed this speed.

Table 8.47: Gradient factor functions for urban buses

A6	A5	A4	A3	A2	A1	A0	case	slope *[%]*	v_{min} *[km/h]*	v_{max} *[km/h]*
0.00E+00	-2.12E-06	2.15E-04	-8.50E-03	1.62E-01	-1.49E+00	6.19E+00	VOC	4… 6	11.4	31.2
0.00E+00	-3.13E-07	3.32E-05	-1.37E-03	2.70E-02	-2.45E-01	1.72E+00	VOC	-6… -4	11.7	35.3
0.00E+00	1.75E-08	-4.51E-06	3.08E-04	-8.79E-03	1.11E-01	5.33E-01	VOC	0… 4	13.1	37.5
0.00E+00	4.15E-07	-5.26E-05	2.59E-03	-6.16E-02	7.06E-01	-2.13E+00	VOC	-4… 0	13.2	39.5
0.00E+00	-1.59E-06	1.57E-04	-6.04E-03	1.14E-01	-1.03E+00	4.91E+00	CO	4… 6	11.4	31.2
0.00E+00	-3.26E-07	3.80E-05	-1.71E-03	3.64E-02	-3.61E-01	2.05E+00	CO	-6… -4	11.7	35.3
0.00E+00	-3.21E-07	3.94E-05	-1.92E-03	4.65E-02	-5.57E-01	3.78E+00	CO	0… 4	13.1	37.5
0.00E+00	2.75E-07	-3.56E-05	1.79E-03	-4.36E-02	5.09E-01	-1.46E+00	CO	-4… 0	13.2	39.5
0.00E+00	7.96E-07	-9.09E-05	3.83E-03	-7.42E-02	6.63E-01	-2.96E-01	NOx	4… 6	11.4	31.2
0.00E+00	-3.27E-07	4.10E-05	-2.00E-03	4.65E-02	-5.18E-01	2.99E+00	NOx	-6… -4	11.7	35.3
0.00E+00	1.85E-07	-2.28E-05	1.08E-03	-2.47E-02	2.79E-01	9.98E-02	NOx	0… 4	13.1	37.5
0.00E+00	4.52E-08	-5.67E-06	2.75E-04	-6.43E-03	6.72E-02	5.15E-01	NOx	-4… 0	13.2	39.5
0.00E+00	1.25E-07	-1.82E-05	7.87E-04	-1.32E-02	7.18E-02	2.07E+00	FC	4… 6	11.4	31.2
0.00E+00	-3.77E-07	4.59E-05	-2.16E-03	4.83E-02	-5.14E-01	2.76E+00	FC	-6… -4	11.7	35.3
0.00E+00	8.21E-08	-9.61E-06	4.20E-04	-8.55E-03	8.22E-02	1.05E+00	FC	0… 4	13.1	37.5
0.00E+00	2.13E-07	-2.78E-05	1.41E-03	-3.45E-02	4.00E-01	-1.06E+00	FC	-4… 0	13.2	39.5
0.00E+00	-7.39E-07	5.92E-05	-1.83E-03	2.80E-02	-2.18E-01	1.78E+00	PM	4… 6	11.4	31.2
0.00E+00	2.54E-07	-2.61E-05	1.01E-03	-1.81E-02	1.54E-01	3.83E-01	PM	-6… -4	11.7	35.3
0.00E+00	1.39E-07	-1.87E-05	9.46E-04	-2.26E-02	2.60E-01	-1.14E-01	PM	0… 4	13.1	37.5
0.00E+00	2.02E-07	-2.43E-05	1.14E-03	-2.60E-02	2.86E-01	-3.34E-01	PM	-4… 0	13.2	39.5

v_{min} and v_{max}: Speed range in which the correction is applicable

Table 8.48: Gradient factor functions for coaches

A6	A5	A4	A3	A2	A1	A0	case	slope *[%]*	v_{min} *[km/h]*	v_{max} *[km/h]*
0.00E+00	0.00E+00	4.15E-06	-5.14E-04	2.17E-02	-3.76E-01	3.43E+00	VOC	4… 6	9.7	34.8
0.00E+00	0.00E+00	3.03E-06	-4.09E-04	1.94E-02	-3.75E-01	3.98E+00	VOC	-6… -4	11.7	49.9
2.49E-10	-8.50E-08	1.14E-05	-7.66E-04	2.65E-02	-4.41E-01	3.80E+00	VOC	0… 4	13.1	95.3
1.42E-10	-5.47E-08	8.20E-06	-6.05E-04	2.27E-02	-4.01E-01	3.89E+00	VOC	-4… 0	13.1	102.9
0.00E+00	0.00E+00	5.20E-06	-6.07E-04	2.51E-02	-4.28E-01	3.56E+00	CO	4… 6	9.7	34.8
0.00E+00	0.00E+00	2.24E-06	-3.21E-04	1.61E-02	-3.30E-01	3.25E+00	CO	-6… -4	11.7	49.9
2.22E-10	-7.88E-08	1.10E-05	-7.63E-04	2.73E-02	-4.69E-01	3.99E+00	CO	0… 4	13.1	95.3
1.09E-10	-4.42E-08	6.93E-06	-5.33E-04	2.09E-02	-3.87E-01	3.60E+00	CO	-4… 0	13.1	102.9
0.00E+00	0.00E+00	-1.15E-05	9.84E-04	-3.02E-02	3.89E-01	7.29E-01	NOx	4… 6	9.7	34.8
1.65E-08	-3.13E-06	2.39E-04	-9.44E-03	2.02E-01	-2.22E+00	1.04E+01	NOx	-6… -4	11.7	49.9
2.97E-10	-9.51E-08	1.18E-05	-7.16E-04	2.18E-02	-3.07E-01	3.21E+00	NOx	0… 4	13.1	95.3
1.27E-10	-4.61E-08	6.56E-06	-4.66E-04	1.71E-02	-3.00E-01	2.75E+00	NOx	-4… 0	13.1	102.9
0.00E+00	0.00E+00	-1.34E-05	1.12E-03	-3.31E-02	4.00E-01	9.84E-01	FC	4… 6	9.7	34.8
1.61E-08	-3.07E-06	2.37E-04	-9.43E-03	2.04E-01	-2.25E+00	1.04E+01	FC	-6… -4	11.7	49.9
1.99E-10	-6.52E-08	8.32E-06	-5.20E-04	1.65E-02	-2.43E-01	3.02E+00	FC	0… 4	13.1	95.3
1.15E-10	-4.23E-08	6.16E-06	-4.48E-04	1.69E-02	-3.05E-01	2.70E+00	FC	-4… 0	13.1	102.9
0.00E+00	0.00E+00	4.91E-07	-1.88E-04	1.17E-02	-2.47E-01	3.11E+00	PM	4… 6	9.7	34.8
-3.03E-09	4.76E-07	-2.59E-05	4.46E-04	6.68E-03	-2.90E-01	3.25E+00	PM	-6… -4	11.7	49.9
2.83E-10	-9.69E-08	1.30E-05	-8.68E-04	2.97E-02	-4.88E-01	4.21E+00	PM	0… 4	13.1	95.3
1.40E-10	-5.29E-08	7.85E-06	-5.78E-04	2.18E-02	-3.91E-01	3.54E+00	PM	-4… 0	13.1	102.9

v_{min} and v_{max}: Speed range in which the correction is applicable

8.16 Examples of methodology application

A number of corrections and reduction factors have been proposed for different vehicle classes and types of emissions (hot, cold start evaporation). The following present two examples on the application of the methodology to demonstrate the synergistic effect of the various correction factors.

8.16.1 Emissions from Euro II gasoline passenger cars

The case is treated where urban hot and cold start total emission CO estimates need to be made for Euro II gasoline passenger cars <1.4 l. We also assume that a number of corrections need to be made, including degradation of emissions in case of an enhanced I&M scheme and use of Fuel 2000.

<u>Input Variables:</u>

- Number of vehicles - N
- Mileage driven for the specific time period - M
- Mean urban travelling speed - V
- Mean trip distance - l_{trip}
- Average temperature for given time period - t_a
- Mean fleet mileage - M_{av}
- Fuel 2000 specifications (optional)

Calculation scheme

- V is introduced into the equation of Table 8.3 corresponding to Euro I vehicles and $e_{HOT;EUROI}$ is calculated
- The RF value is selected from Table 8.10 (RF = 32)
- $FCorr_{BASE}$ is calculated by means of the first equation given in Table 8.40 by introducing the fuel specifications given Table 5.4 under the title "1996 Base Fuel"
- $FCorr_{FUEL}$ is calculated by means of the first equation given in Table 8.40 by introducing the fuel specifications given Table 5.4 under the title "Fuel 2000" or by other values provided by the user
- MC_{UDC}, MC_{EUDC} values are calculated by the equation given in Table 8.39 (enhanced I&M) by introducing the M_{av} value into the respective equations
- MCorr is calculated by the algorithm of Table 5.1 according to the urban speed V
- The β-parameter is given by the equation of Table 8.8, introducing variables l_{trip} and t_a
- bc is selected from Table 8.11 (bc = 0.72)
- e^{COLD}/e^{HOT} ratio is calculated by equation in Table 8.9 according to urban speed V and mean temperature t_a

Finally combination of equations 3, 13, 14, 16, 21 and 22 provides the total hot and cold start emissions:

$$E_{TOT,\ URBAN} = N \times M \times FCorr_{FUEL} / FCorr_{BASE} \times$$
$$[(100\text{-}RF) / 100 \times e_{HOT;EURO\ I} \times MCorr + bc \times \beta \times e_{HOT;EURO\ I} \times (e^{COLD}/e^{HOT} - 1)]$$

8.16.2 Emissions from Euro III heavy duty vehicles

In this case it is assumed that total NO_x emissions from Euro III heavy duty vehicles 16-32 t need to be calculated. It is further assumed that vehicles operate with a load factor of 80% on roads of 3% positive gradient.

Input Parameters and Variables

- Number of vehicles - N
- Mileage driven for the specific time period - M
- Mean travelling speed for urban, rural and highway driving- V_U, V_R, V_H
- Mileage share to different driving modes S_{URBAN}, S_{RURAL}, $S_{HIGHWAY}$
- Road gradient class
- Load factor – LP

<u>Calculation scheme</u>

- The three speeds are introduced in the appropriate equation of Table 8.25 and three emission factors for each driving mode are calculated ($e_{TOT,U}$, $e_{TOT,R}$, $e_{TOT,H}$)
- Three reduction factors are selected from Table 8.27 (RF_{URBAN} = 72, RF_{RURAL} = 68.5, $RF_{HIGHWAY}$ = 68.5)
- Coefficients A_0 to A_6, corresponding to NOx 0…4 % slope are selected from Table 8.45 and are introduced in equation 17. Three correction factors are then calculated ($GCorr_{URBAN}$, $GCorr_{RURAL}$, $GCorr_{HIGHWAY}$). It is mentioned that in case that a speed is outside the V_{min} and V_{max} limits given in Table 8.45 then the correction factors are calculated with the respective speed limit.
- The LCorr value is selected from Table 5.8 (LCorr = 0.18)
-

Finally combination of equations 2, 3, 18, 19 and 21 provides the total emission estimates (U: Urban, R: Rural, H: Highway):

$$E_{TOT} = N \times M \times [1 + 2 \times LCorr \times (LP - 50) / 100] \times [e_{TOT,U} \times (100 - RF_U)/100 \times GCorr_U + e_{TOT,R} \times (100 - RF_R)/100 \times GCorr_R + e_{TOT,H} \times (100 - RF_H)/100 \times GCorr_H]$$

9 SPECIES PROFILES

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.

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
	methyl ethyl ketone	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**

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.

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

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.

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

<u>Legend</u>: 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 I	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 I		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 I		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. Presently the work of revising the existing methodology has been taken over by the ARTEMIS and PARTICULATES consortia. The points which are the main focus for revision are:

i) Emission factors for late vehicle technologies, including alternative powertrain systems (hybrids, advanced aftertreatment systems)
ii) Cold start modelling including the improvement brought with the new emissions test at –7°C.
iii) Improvement of precision of emission factors in emission factors of increasing significance (benzene, N_2O, …).
iv) Enhancement of the methodology related to CO_2 emission, considering bio-fuels, CO_2-neutral fuels, etc.
v) Improvement of the expression of emission factors, including some metric of driving behaviour (except of speed) as an independent variable.
vi) Independent estimations, e.g. nation-wide surveys, of total annual mileage driven on the three road classes by each of the vehicle categories.
vii) Methodology and statistical input for estimating the spatial allocation of vehicle emissions;

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.

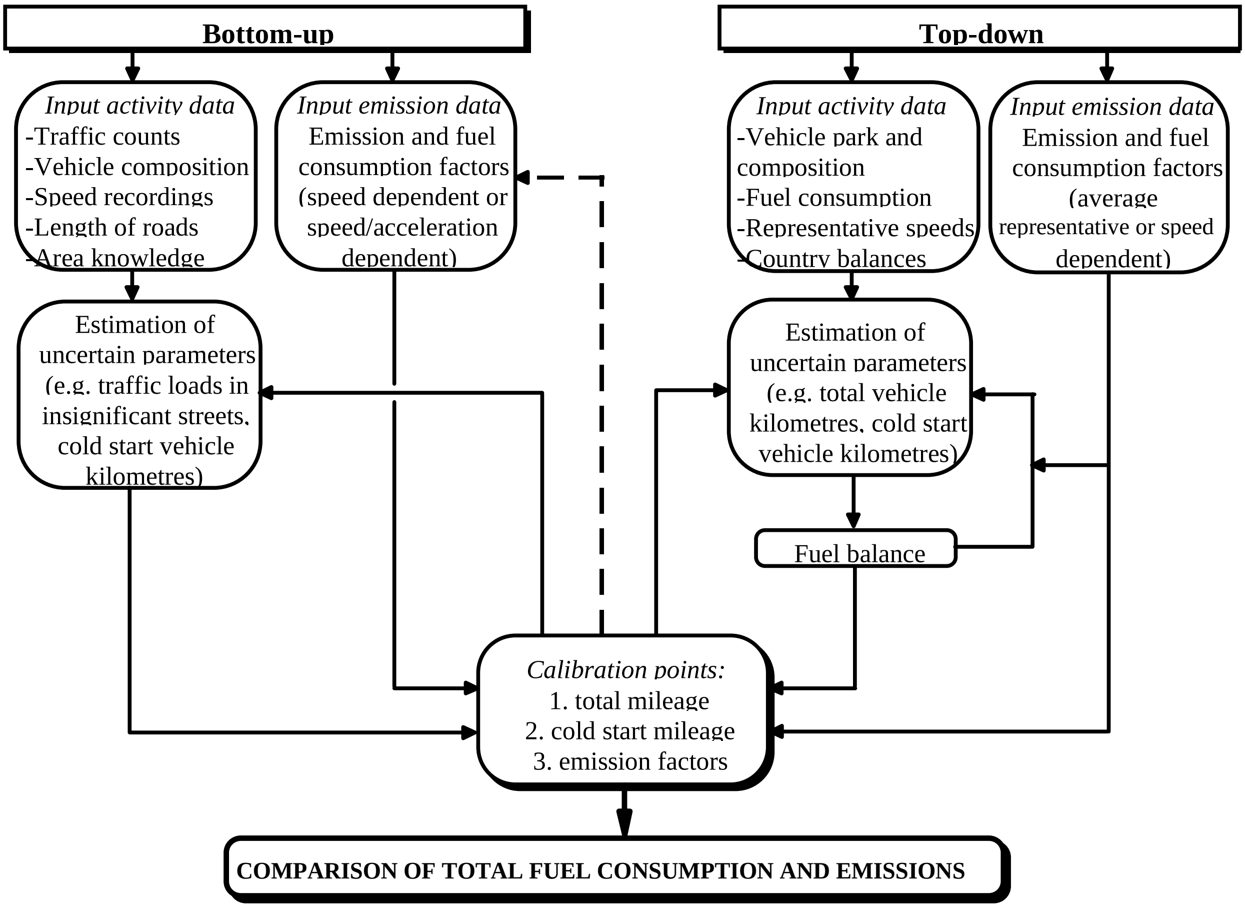

Figure 13.1: Proposed reconciliation method in applying bottom-up and top-down approaches when building an urban emission inventory

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 have been translated into a computer programme, called COPERT III (**Co**mputer **P**rogramme to Calculate **E**missions from **R**oad **T**raffic), which substantially facilitates the practical application of the methodology (see Ntziachristos and Samaras, 2000). This program is officially used by several countries for reporting emissions of road transport.

The update of Copert III will come via the work conducted in ARTEMIS project which aims at both producing new emissions factors and synthesising detailed and aggregated methodologies for producing results consistent at a national and more detailed spatial resolution.

15 SUPPLEMENTARY DOCUMENTS

Eggleston S., D. Gaudioso, N. Gorißen, R. Joumard, R.C. Rijkeboer, Z. Samaras and K.-H. Zierock (1993) CORINAIR Working Group on Emissions Factors for Calculating 1990 Emissions from Road Traffic. Volume 1: Methodology and Emission Factors. Final Report, Document of the European Commission ISBN 92-826-5571-X

Andrias A., Z. Samaras, D. Zafiris and K.-H. Zierock (1993) CORINAIR Working Group on Emission Factors for Calculating 1990 Emissions from Road Traffic. Volume 2: COPERT - Computer Programme to Calculate Emissions from Road Traffic - User's Manual. Final Report, Document of the European Commission ISBN 92-826-5572-X

Ahlvik P., S. Eggleston, N. Gorissen, D. Hassel, A.-J. Hickman, R. Joumard, L. Ntziachristos, R. Rijkeboer, Z. Samaras and K.-H. Zierock, (1997) COPERTII Methodology and Emission Factors, Draft Final Report, European Environment Agency, European Topic Center on Air Emissions.

Ntziachristos L., Samaras Z., (1997) COPERT II - Computer Programme to Calculate Emissions from Road Transport, User’s Manual - European Environmental Agency, European Topic Center on Air Emissions.

Ntziachristos L. and Samaras Z. (2000) COPERT III Methodology and emission factors (Version 2.1), Technical Report 49, European Environment Agency, Copenhagen, Denmark, p.86.

Kouridis, Ch., Ntziachristos L. and Samaras Z. (2000) COPERT III User's manual (Version 2.1), Technical Report 50, European Environment Agency, Technical Report 49, Copenhagen, Denmark, p.46.

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.

17 REFERENCES

ACEA and EUROPIA (1996) European Programme on Emissions, Fuels and Engine Technologies, Final Report, Brussels.

Ahlvik P., S. Eggleston, N. Gorissen, D. Hassel, A.-J. Hickman, R. Joumard, L. Ntziachristos, R. Rijkeboer, Z. Samaras and K.-H. Zierock, (1997) COPERTII Methodology and Emission Factors, Technical Report No. 6, ETC/AEM, European Environment Agency, http://themes.eea.eu.int/binary/t/tech06.pdf, p.85.

André M., J.P. Roumegoux, J. Delsey, J.P. Guitton and R. Vidon (1987) Etude expérimentale sur les utilisations réelles des véhicules (EUREV), Rapport INRETS No. 48, Bron, France.

André M., U. Hammarström and I. Reynaud (1998), Driving statistics for the assessment of air pollutant emissions from road transport, INRETS report, LEN9730, Bron, France, p. 186.

Appel H. and Stendel D. (1989), Abgasemissionen von Wartburg und Trabant. Veröffentlichung der Senatsverwaltung für Stadtentwicklung und Umweltschutz, Berlin.

AQA (1990), Final Report, Convention SPP 88248, Paris, p. 20.

Bailey J.C. and B. Schmidl (1989), A Survey of Hydrocarbons Emitted in Vehicle Exhaust Gases, over a Range of Driving Speeds and Conditions from a Representative Sample of the 86/87 UK Vehicle Fleet, Warren Spring Laboratory, Report LR673(AP)M, Stevenage, UK.

BUWAL (1994), Emissionfaktoren ausgewaehlter nichtlimitierter Schadstoffe des Strassenverkehrs, CD Data Version 2.2.

Committee of Common Market Automobile Constructors (CCMC) (1989), CCMC ECE/EUDC Test Programme, Ref. AE/11/89 VE/CCMC/29, Brussels.

EEA (2002) Environmental signals 2002 – benchmarking the Millennium, Environmental assessment report No.9, European Environmental Agency, Copenhagen, Denmark, p.149.

Eggleston S., N. Gorißen, R. Joumard, R.C. Rijkeboer, Z. Samaras and K.-H. Zierock (1989), CORINAIR Working Group on Emissions Factors for Calculating 1985 Emissions from Road Traffic. Volume 1: Methodology and Emission Factors, Final Report Contract No. 88/6611/0067, EUR 12260 EN.

Eggleston S., D. Gaudioso, N. Gorißen, R. Joumard, R.C. Rijkeboer, Z. Samaras and K.-H. Zierock (1993), CORINAIR Working Group on Emissions Factors for Calculating 1990 Emissions from Road Traffic. Volume 1: Methodology and Emission Factors. Final Report, Document of the European Commission ISBN 92-826-5571-X.

EMEP (2001), Transboundary particulate matter in Europe. 2001 status report. A joint CCC, MSW & CIAM report, EMEP Report 4/2001, Norway, p.85.

Hassel D., P. Jost, F. Dursbeck, J. Brosthaus and K.S. Sonnborn (1987), Das Abgas-Emissionsverhalten von Personenkraftwagen in der Bundesrepublik Deutschland im Bezugsjahr 1985. UBA Bericht 7/87. Erich Schmidt Verlag, Berlin.

Hassel D., P. Jost, F.-J. Weber, F. Dursbeck, K.-S. Sonnborn and D. Plettau (1993), Exhaust Emission Factors for Motor Vehicles in the Federal Republic of Germany for the Reference Year 1990, Final Report of a Study Carried Out on Behalf of the Federal Environmental

Protection Agency, UFOPLAN Nr. 104 05 152 und 104 05 509, UBA-FB 91-042, TÜV Rheinland (English Translation made by COST319).

Hauger A. and R. Joumard (1991), LPG pollutant emissions. Use of Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG) and Liquefied Petroleum Gas (LPG) as fuel for internal combustion engines, UN-ECE Symposium, Kiev, Ukraine.

Jileh P. (1991), Data of the Ministry of the Environment of the Czech. Republic supplied to Mr. Bouscaren (Citepa).

Keller M., R. Evéquoz, J. Heldstab and H. Kessler (1995), Luftschadstoffemissionen des Straßenverkehrs 1950-2010, Schriftenreihe Umwelt Nr. 255 des BUWAL - Bundesamt für Umwelt, Wald und Landschaft, 3003 Bern (in German, also available in French).

LAT/AUTh, INRETS, TNO, TÜV, TRL (1998), The inspection of in-use cars in order to attain minimum emissions of pollutants and optimum energy efficiency, Main Report, Project Funded by the European Commission, Directorate Generals for Environment (DG XI), Transport (DG VII) and Energy (DG XVII), http://europa.eu.int/comm/dg11/pollutants/index.htm, p.94, Thessaloniki, Greece.

Mobley J.D.and M. Saeger (1994): Concepts for Emissions Inventory Verification, US EPA, Draft Final Report.

Moussiopoulos N., Sahm P., Papalexiou S., Samaras Z. and Tsilingiridis G. (1996), The Importance of Using Accurate Emission Input Data for Performing Reliable Air Quality Simulations, EUROTRAC Annual Report, Computational Mechanics Publications, pp. 655-659.

Ntziachristos L. and Z. Samaras (1999), Amendment of COPERT II for the compilation of the ACEA Forecasts in the Framework of Auto Oil II Programme, Final report to the ACEA, Thessaloniki, Greece.

Ntziachristos L. and Samaras Z. (2000a) COPERT III Computer programme to calculate emissions from road transport, Technical Report 49, European Environment Agency, Copenhagen, Denmark, p.86.

Ntziachristos L. and Samaras Z. (2000b), Speed Dependent Representative Emission Factors of Catalyst Passenger Cars and Influencing Parameters, Atmospheric Environment, Vol. 34, pp.4611 - 4619.

Ntziachristos L. and Samaras Z (2001) An empirical method for predicting exhaust emissions of regulated pollutants from future vehicle technologies, Atmospheric Environment, Vol. 35, pp. 1985 – 1999.

Ntziachristos L., Tourlou P.M., Samaras Z., Geivanidis S., Andrias A. (2002) National and central estimates for air emissions from road transport, Technical Report 74, European Environment Agency, Copenhagen, Denmark, p.60.

Organisation for Economic Co-operation and Development -OECD (1991), Estimation of Greenhouse Gas Emissions and Sinks, Final Report, prepared for the Intergovernmental Panel on Climate Change.

Pattas K. and N. Kyriakis (1983), Exhaust Gas Emission Study of Current Vehicle Fleet in Athens (Phase I). Final Report to PERPA/ EEC, Thessaloniki, Greece.

Pattas K., N. Kyriakis and Z. Samaras (1985), Exhaust Gas Emission Study of Current Vehicle Fleet in Athens (PHASE II). Volumes I, II, III, Final Report to PERPA/EEC, Thessaloniki, Greece.

Perby H. (1990), Lustgasemission fran vågtrafik. Swedish Road and Traffic Research Institute, Report 629, Linköping, Sweden.

Potter D. and C. Savage (1983), A survey of gaseous pollutant emissions from tuned in-service gasoline engined cars over a range of road operating conditions. WSL Report, LR 447 (AP) M, Stevenage.

Potter D. (1990), Lustgasemission fran Katalysatorbilar, Department of Inorganic Chemistry, Chalmers University of Technology and University of Goeteborg, Report OOK 90:02, Sweden.

Pringent M. and G. De Soete (1989), Nitrous Oxide N_2O in Engines Exhaust Gases - A First Appraisal of Catalyst Impact. SAE Paper 890492.

de Reydellet. A. (1990), Gaz a effet de serre Methane CH_4 et protoxyde d'azote N_2O, Facteurs d'emission. Recherche bibliographique, IFE, Paris.

Rijkeboer R.C., P. Van Sloten and P. Schmal (1989), Steekproef-controleprogramma, onderzoek naar luchtverontreininging door voertuigen in het verkeer, Jaarrapport 1988/89. Nr. Lucht 87, IWT-TNO, Delft, the Netherlands.

Rijkeboer R.C., M.F. Van der Haagen and P. Van Sloten (1990), Results of Project on In-use Compliance Testing of Vehicles. TNO report 733039000, Delft, the Netherlands.

Rijkeboer R.C. (1997), Emission factors for mopeds and motorcycles, TNO report, n°97.OR.VM.31.1/RR, Delft, The Netherlands, p.16.

Samaras Z. and L. Ntziachristos (1998), Average Hot Emission Factors for Passenger Cars and Light Duty Vehicles, Task 1.2 / Deliverable 7 of the MEET project, LAT Report No 9811, Thessaloniki, Greece, http://www.inrets.fr/infos/cost319/index.html.

TNO (1993), Regulated and Unregulated Exhaust Components from LD Vehicles on Petrol, Diesel, LPG and CNG, Delft, The Netherlands.

Umweltbundesamt (1996), Determination of Requirements to Limit Emissions of Dioxins and Furans, Texte 58/95, ISSN 0722-186X.

Volkswagen AG (1989), Nicht limitierte Automobil-Abgaskomponenten, Wolfsburg, Germany.

Zachariadis T. and Z. Samaras (1997), Comparative Assessment of European Tools to Estimate Traffic International Journal of Vehicle Design, Vol. 18, Nos 3/4, pp. 312-325.

Zachariadis Th., Ntziachristos L., Samaras Z. (2001) The effect of age and technological change on motor vehicle emissions, Transportation Research Part D, Volume 6, pp. 221-227.

Zajontz J., V. Frey and C. Gutknecht (1991), Emission of unregulated Exhaust Gas Components of Otto Engines equipped with Catalytic Converters. Institute for Chemical Technology and Fuel Techniques, Technical University of Clausthal, Interim Status Report of 03/05/1991, Germany.

18 BIBLIOGRAPHY

Joumard, R. (ed.) (1999) COST 319 Estimation of pollutant emissions from transport, Final report of the action, Directorate General Transport, Office for official publications of the European communities, Luxembourg, p.174.

MEET (1999) Methodology for calculating transport emissions and energy consumption, DG VII, Office for official publications of the European communities, Luxembourg, p.362.

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
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
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
GCorr	emission correction factor for the effect of road gradient
$\mathbf{GCe_{HOT}}$	corrected hot emission factor for road gradient
k	weight related content of any component in the fuel [kg/kg fuel]
$\mathbf{LCe_{HOT}}$	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)
$\mathbf{l_{trip}}$	average trip length [km]
M	average mileage in [km]
$\mathbf{MCe_{HOT}}$	hot emission factor corrected for degraded vehicle performance due to mileage
MCorr	**c**orrection coefficient for emission performance degradation due to mileage
$\mathbf{M^{MEAN}}$	mean fleet mileage [km]
N	number of vehicles [veh.]
$\mathbf{r_{H:C}}$	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 = 1-105)
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

Version : 4.0

Date : August 2002

Updated by: Leonidas Ntziachristos
Aristotle University Thessaloniki
Lab of Applied Thermodynamics
Greece

Original authors: Zissis Samaras
Aristotle University
Greece

Karl-Heinz Zierock
EnviCon
Wiesbadenerstr. 13
Germany

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Leonidas Ntziachristos

Laboratory of Applied Thermodynamics
Aristotle University Thessaloniki
GR-54124 Thessaloniki
Greece

Tel: +30 310 996202
Fax: +30 310 996019
Email: leon@eng.auth.gr

SNAP CODE: **070600**

SOURCE ACTIVITY TITLE: **GASOLINE EVAPORATION FROM VEHICLES**

NOSE CODE: **201.06**

NFR CODE: **1 A 3 b v**

1 ACTIVITIES INCLUDED

Evaporative emissions occur in significant quantities for gasoline vehicles in the form of NMVOC emissions. For some vehicle classes and some pollutants, the different types of emissions are lumped together into one emission factor, for some others, individual emission factors are proposed. It should be noted that also refuelling losses exist. These are not included in this chapter as they are emitted at petrol stations.

2 CONTRIBUTIONS TO TOTAL EMISSIONS

Evaporative losses contribute substantially to total road transport related VOC emissions. On the basis of the results of CORINAIR 90 exercise, evaporative losses account for about 25% of total VOC emissions from road transport in the EU, as Table 2.1 shows.

Table 2.1: 1990 Total Evaporative Emissions as Percentage of the National and EU Total VOC of Road Transport

B	34.2
DK	34.9
D	22.1
F	30.1
GR	28.2
IRL	44.8
I	23.9
L	41.9
NL	n.a.
P	33.0
E	27.1
UK	14.5
EU 12	23.7

n.a.: not available

3 GENERAL

3.1 Description

There are three primary sources of evaporative emissions from vehicles[(1)] :

i) diurnal (daily) emissions;
ii) hot soak emissions; and
iii) running losses.

These are estimated separately. Again they are affected by factors that vary from country to country.

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 tank 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. At night, when the temperature drops, vapour contracts and fresh air is drawn into the gasoline tank through the vent. This lowers the concentration of hydrocarbons in the vapour space above the liquid gasoline, which subsequently leads to additional evaporation.

3.1.2 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 particularly significant source of hot soak emissions.

3.1.3 Running losses

Running losses are the result of vapour generated in gasoline tanks during vehicle operation. Running losses are most significant during periods of high ambient temperatures. The combined effect of high ambient temperature and exhaust system heat can generate a significant amount of vapour in the gasoline tank.

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.

[(1)] In US literature there is a fourth source mentioned: "Resting Loss Emissions" which result from vapour permeating parts of the evaporative control system. However, they are not taken into account explicitly in this paper.

3.2 Emissions

Evaporative VOC emissions from gasoline fuelled vehicles add to total NMVOC emissions. For evaporating emissions tank breathing is reported as $CH_{2,33}$ and hot soak as $CH_{2,20}$. 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 the EFTA countries which have adopted the US EPA SHED test procedure. Since 1993 the EC adopted equivalent emission standards as well (Directive 91/441/EEC). In order to comply with these requirements the application of an on board carbon canister is necessary, which adsorbs gasoline vapours and desorbs them to the engine under appropriate conditions. The overall efficiency of these canisters is of the order of 90%. Currently a step further is under consideration (namely introduction of the "large canister").

4 SIMPLER METHODOLOGY

No simple methodology is proposed here, because in principle all countries are in the position to apply the detailed methodology.

5 DETAILED METHODOLOGY

The main equation for estimating the evaporative emissions is (Gorißen 1988):

$$E_{eva,voc,j} = 365 \cdot a_j \,(e^d + S^c + S^{fi}) + R \qquad (1)$$

where:

$E_{eva,voc,j}$ = VOC emissions due to evaporative losses caused by vehicle category j

a_j = number of gasoline vehicles of category j

e^d = mean emission factor for diurnal losses of gasoline powered vehicles equipped with metal tanks, depending on average monthly ambient temperature, temperature variation, and fuel volatility (RVP)

S^c = average hot and warm soak emission factor of gasoline powered vehicles equipped with carburettor

S^{fi} = average hot and warm soak emission factor of gasoline powered vehicles equipped with fuel injection

R = hot and warm running losses

and

$$S^c = (l\text{-}q)\,(p \cdot x \cdot e^{s,hot} + w \cdot x \cdot e^{s,warm}) \qquad (2)$$

$$S^{fi} = q \cdot e^{fi} \cdot x \qquad (3)$$

$$R = m_j\,(p \cdot e^{r,\,hot} + w \cdot e^{r,\,warm}) \qquad (4)$$

where:

q	=	fraction of gasoline powered vehicles equipped with fuel injection
p	=	fraction of trips finished with hot engine (dependent on the average monthly ambient temperature)
w	=	fraction of trips finished with cold or warm engine[(1)] (shorter trips) or with catalyst below its light-off temperature
x	=	mean number of trips of a vehicle per day, average over the year $x = v_j / (365 \cdot l_{trip})$ (5)
$e^{s,hot}$	=	mean emission factor for hot soak emissions (which is dependent on fuel volatility RVP)
$e^{s,warm}$	=	mean emission factor for cold and warm soak emissions (which is dependent on fuel volatility RVP and average monthly ambient temperature)
e^{fi}	=	mean emission factor for hot and warm soak emissions of gasoline powered vehicles equipped with fuel injection
$e^{r,hot}$	=	average emission factor for hot running losses of gasoline powered vehicles (which is dependent on fuel volatility RVP and average monthly ambient temperature)
$e^{r,warm}$	=	average emission factor for warm running losses of gasoline powered vehicles (which is dependent on fuel volatility RVP and average monthly ambient temperature)
m_j	=	total annual mileage of gasoline powered vehicles of category j

The fraction of trips finished with cold and warm engine, w, is connected with the parameter β 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 w and β is:

$w \sim \beta$

Parameter β 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.

With reference to the application of the baseline calculation scheme outlined in chapter B710 Table 5.1, Table 5.1 summarises the methods proposed for application for the calculation of evaporation losses.

(1) Engines are defined as "cold" or "warm" if the water temperature is below 70^{o}C

Table 5.1: Summary of Calculation Methods applied for Calculation of Evaporation Losses (cf. chapter B710, Table 5.1)

Evaporation	NMVOC
Pass. Cars Conventional	A
Pass. Cars Closed Loop	A
Light Duty Vehicles	C
Two Wheelers <50 cm³	D
Two Wheelers >50 cm³	D

6 RELEVANT ACTIVITY STATISTICS

Apart from 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, i, w and x. Table 6.1 shows an example from the data base of CORINAIR85 exercise. These data can be found only in detailed national statistics, or can be produced via surveys.

Table 6.1: Examples of Statistical Input Data Relevant for Estimating Evaporative Emissions as used by EC Member States in COPERT 85

Country	Vehicle Category	Vehicles equipped with fuel injection [%]
B	< 1.4 l	0.0
	1.4 - 2.0 l	3.1
	> 2.0 l	1.8
D	< 1.4 l	8.4
	1.4 - 2.0 l	8.4
	> 2.0 l	8.4
DK	< 1.4 l	0.0
	1.4 - 2.0 l	0.0
	> 2.0 l	0.0
E	< 1.4 l	4.9
	1.4 - 2.0 l	4.9
	> 2.0 l	4.9
F	< 1.4 l	0.0
	1.4 - 2.0 l	4.2
	> 2.0 l	15.5
GR	< 1.4 l	1.0
	1.4 - 2.0 l	1.0
	> 2.0 l	1.0
I	< 1.4 l	5.0
	1.4 - 2.0 l	5.0
	> 2.0 l	5.0
IRL	< 1.4 l	0.0
	1.4 - 2.0 l	0.0
	> 2.0 l	0.0
L	< 1.4 l	5.0
	1.4 - 2.0 l	10.0
	> 2.0 l	15.0
NL	< 1.4 l	0.0
	1.4 - 2.0 l	0.0
	> 2.0 l	10.0
P	< 1.4 l	0.0
	1.4 - 2.0 l	10.0
	> 2.0 l	30.0
UK	< 1.4 l	0.0
	1.4 - 2.0 l	0.0
	> 2.0 l	0.0

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

Due to the lack of data, evaporative emissions can be estimated only for gasoline passenger cars, gasoline light duty vehicles and two wheelers. However, the methodology can only be fully applied for gasoline passenger cars. For the other two vehicle categories simplifications have to be made. Since evaporative emissions are very sensitive to temperature, the estimates are made on a monthly basis.

8.1 Gasoline Passenger Cars

The evaporative losses depend on the technology used, the fuel properties and the average ambient temperatures. The basic emission factors, which are necessary to apply the methodology, are listed in Table 8.1 for uncontrolled and controlled vehicles (based mainly on Concawe 1987, 1990, Eggleston 1991, Heine 1987, US EPA 1990). However, it should be mentioned that the working group considers the data base as still far too small, so that the reliability of the estimates obtained when using the emission factors is not very satisfactory.

Table 8.1: Summary of Emission Factors for Estimating Evaporative Emissions of Gasoline Powered Vehicles (all RVP in kPa, all temperatures in ^{o}C)

Emission factor (units)	Uncontrolled vehicle	Small carbon canister controlled vehicle
Diurnal (g/day)	$9.1 \cdot \exp(0.0158\,(RVP-61.2) + 0.0574\,(t_{a,min} - 22.5) + 0.0614 \cdot (t_{a,rise} - 11.7))$	$0.2 \cdot$ uncontrolled
warm soak (g/procedure)	$\exp(-1.644 + 0.01993\,RVP + 0.07521\,t_a)$	$0.2 \cdot \exp(-2.41 + 0.02302\,RVP + 0.09408\,t_a)$
hot soak (g/procedure)	$3.0042 \cdot \exp(0.02\,RVP)$	$0.3 \cdot \exp(-2.41 + 0.02302\,RVP + 0.09408\,t_a)$
warm and hot soak For fuel injected vehicles (g/procedure)	0.7	none
warm running losses (g/km)	$0.1 \cdot \exp(-5.967 + 0.04259\,RVP + 0.1773\,t_a)$	$0.1 \cdot$ uncontrolled
hot running losses (g/km)	$0.136 \cdot \exp(-5.967 + 0.04259\,RVP + 0.1773\,t_a)$	$0.1 \cdot$ uncontrolled

The application of the proposed methodology requires detailed knowledge of driving behaviour and vehicle park composition.

8.2 Light Duty Vehicles

For estimating evaporative emissions of this category, all vehicles are treated like uncontrolled gasoline passenger cars with regard to emission factors and driving pattern. As in the case of cold start emissions, this is a drastic simplification, because it implies the assumption that light duty vehicles are used in the same way as passenger cars.

8.3 Motorcycles

For estimating evaporative emissions of two wheelers, the latter are treated like uncontrolled gasoline passenger cars with regard to the driving pattern. Due to the smaller fuel tanks of two wheelers, it is assumed that the emissions are 0.2 times those of passenger cars for motor cycles <50 cc and 0.4 times those of passenger cars for motor cycles >50 cc. Again this approach has to be considered as a drastic simplification, which has been chosen only because the required data are not available.

9 SPECIES PROFILES

See the discussion in section 9 of Chapter B710 on road transport.

10 UNCERTAINTY ESTIMATES

Using the indicators introduced in Chapter B710 Table 8.24, 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 (cf. Chapter B710 Table 8.24)

Evaporation	NMVOC
Pass. Cars Conventional	C
Pass. Cars Closed Loop	C
Light Duty Vehicles	D
Two Wheelers <50 cm^3	D
Two Wheelers >50 cm^3 2 str.	D
Two Wheelers >50 cm^3 4 str.	D

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

In general, the estimation of evaporative emissions from gasoline vehicles involves still a large number of uncertainties which can not be solved without carrying out further measurements. Therefore the methodology cannot overcome many of the problems, but can try only to improve on some specific aspects. It should be strongly underlined that the authors see a need to improve the proposed methodology further, in particular in order to take into account better the temperature and RVP dependencies of evaporative emissions for the different vehicle categories. In addition the following points require further attention:

i) evaporative emission factors for all vehicle categories, and

ii) quantitative determination of parameters relevant to evaporative emissions, e.g. fuel properties (Reid vapour pressure);

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

- **Diurnal losses and Soak losses**: The calculation scheme proposed can be applied for finer temporal resolution (e.g. during a diurnal cycle)
- **Running losses**: The temporal variation of these emissions depends (as outlined in Chapter B710 on road transport) on the availability of traffic data (e.g. traffic counts).

14 ADDITIONAL COMMENTS

The evaporation losses calculation scheme presented above, is fully integrated into COPERT II (**Co**mputer **P**rogramme to Calculate **E**missions from **R**oad **T**raffic), which substantially facilitates the practical application of the methodology (see Ntziachristos et al. 1997).

15 SUPPLEMENTARY DOCUMENTS

Eggleston S., D. Gaudioso, N. Gorißen, R. Joumard, R.C. Rijkeboer, Z. Samaras and K.-H. Zierock (1993): CORINAIR Working Group on Emissions Factors for Calculating 1990 Emissions from Road Traffic. Volume 1: Methodology and Emission Factors. Final Report, Document of the European Commission ISBN 92-826-5571-X

Andrias A., Z. Samaras, D. Zafiris and K.-H. Zierock (1993): CORINAIR Working Group on Emission Factors for Calculating 1990 Emissions from Road Traffic. Volume 2: COPERT - Computer Programme to Calculate Emissions from Road Traffic - User's Manual. Final Report, Document of the European Commission ISBN 92-826-5572-X

Ntziachristos L., Samaras Z., (1997), COPERT II - Computer Programme to Calculate Emissions from Road Transport, User's Manual - European Environmental Agency

16 VERIFICATION PROCEDURES

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

17 REFERENCES

CONCAWE (1987): An investigation onto evaporative hydrocarbon emissions from European vehicles. Report N° 87/60

CONCAWE (1990): The effects of temperature and fuel volatility on vehicle evaporative emissions. Report N° 90/51

Eggleston S. (1991): Data on evaporative emissions of gasoline passenger cars submitted to the CORINAIR Working Group on Emission Factors for Calculating 1990 Emissions from Road Traffic. Brussels 7 and 8/10/1991

Gorißen N. (1988): Evaporative Emissions of Gasoline Powered Vehicles. Paper contributed to the CORINAIR working group on Emission from Road Traffic, unpublished. Umweltbundesamt, Berlin

Heine P. and Baretti A. (1987): Emissionsfaktoren für die Verdampfungsemissionen von Kraftfahrzeugen mit Ottomotoren. Im Auftrag des Umweltbundesamtes Berlin, November 1988

Mobley J.D. and M. Saeger (1994): Concepts for Emissions Inventory Verification, US EPA Draft Final Report.

U.S. Environmental Protection Agency (1990): Volatile Organic Compounds from On-Road Vehicles - Sources and Control Options. Draft Report

18 BIBLIOGRAPHY

U.S. Environmental Protection Agency; *Supplement A to Compilation of Air Pollutant Emission Factors (AP-42) - Volume II: Mobile Sources*, Test and Evaluation Branch, Office of Air and Radiation, January 1991.

U.S. Environmental Protection Agency; *User's Guide to MOBILE5*, Test and Evaluation Branch, Office of Air and Radiation, Draft 4a, December 3, 1992.

Organisation for Economic Co-operation and Development (OECD); *Estimation of Greenhouse Gas Emissions and Sinks*, Final Report, prepared for the Intergovernmental Panel on Climate Change, revised August 1991.

List of Abbreviations

CH_4:	Methane
NMVOC:	Non-Methane Volatile Organic Compounds
RVP:	Reid Vapour Pressure (standardised vapour pressure measurement, conducted at 38 ^{o}C, with a vapour: liquid ratio 4:1)
VOC:	Volatile Organic Compounds

List of Symbols

a_j	=	number of gasoline vehicles of category j, operated in 1990
e^d	=	mean emission factor for diurnal losses of gasoline powered vehicles equipped with metal tanks, depending on average monthly weighted temperature, temperature variation and fuel volatility (RVP)
$e^{s,hot}$	=	mean emission factor for hot soak emissions
$e^{s,warm}$	=	mean emission factor for cold and warm soak emissions
e^{fi}	=	mean emission factor for hot and warm soak emissions of gasoline powered vehicles equipped with fuel injection
$e^{r,hot}$	=	average emission factor for hot running losses of gasoline powered vehicles
$e^{r,warm}$	=	average emission factor for warm running losses of gasoline powered vehicles
l_{trip}	=	average trip length
p	=	fraction of trips, finished with hot engine (depending on the average monthly ambient temperature)
q	=	fraction of gasoline powered vehicles equipped with fuel injection
t_a	=	monthly mean ambient temperature in [^{o}C]
$t_{a,min}$	=	monthly mean minimum ambient temperature in [^{o}C]
$t_{a,rise}$	=	monthly mean of the daily ambient temperature rise in [^{o}C]

w	=	fraction of trips, finished with cold or warm engine
x	=	mean number of trips of a vehicle per day, average over the year
y	=	total number of trips of a vehicle per day
β_j	=	fraction of mileage driven with cold engines
$E_{eva,VOC,j}$	=	VOC emissions due to evaporative losses, caused by vehicles of category j under urban driving conditions
R	=	hot and warm running losses
S^c	=	average hot and warm soak emission factor of gasoline powered vehicles equipped with carburettor
S^{fi}	=	average hot and warm soak emission factor of gasoline powered vehicles equipped with fuel injection

19 RELEASE VERSION, DATE AND SOURCE

Version : 3.1

Date : 2 February 1999

Updated by: Zissis Samaras, Leonidas Ntziachristos
Aristotle University
Greece

Original authors: Zissis Samaras
Aristotle University
Greece

Karl-Heinz Zierock
EnviCon
Germany

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Zissis Samaras

Department of Mechanical Engineering
Aristotle University
GR-54006 Thessaloniki
Greece

Tel: +30 31 996 014
Fax:
Email: zisis@vergina.eng.auth.gr

SNAP CODE: **070700**

SOURCE ACTIVITY TITLE: **AUTOMOBILE TYRE AND BRAKE WEAR**

NOSE CODE:

NFR CODE: **1 A 3 b vi**

A specific methodology for this activity has not been prepared because the contribution to total national emissions is thought to be currently insignificant, i.e. less than 1% of national emissions of any pollutant.

If you have information contrary to this please contact the expert panel leaders.

Leaders of Transport Expert Panel

Riccardo De Lauretis
ANPA (National Environmental Protection Agency),
via Vitaliano Brancati 48,
00144 Rome, Italy,
Tel: +39 06 50072928,
Fax: +39 06 50072986,
Email: riccardo.delauretis@anpa.it

Zissis Samaras
Aristotle University,
Department of Mechanical Engineering,
GR-54006 Thessaloniki, Greece
Tel: 30 31 996 014
Email: zisis@vergina.eng.auth.gr

SNAP CODE: **070800**

SOURCE ACTIVITY TITLE: **AUTOMOBILE ROAD ABRASION**

NOSE CODE:

NFR CODE: **1 A 3 b vii**

A specific methodology for this activity has not been prepared because the contribution to total national emissions is thought to be currently insignificant, i.e. less than 1% of national emissions of any pollutant.

If you have information contrary to this please contact the expert panel leaders.

Leaders of Transport Expert Panel

Riccardo De Lauretis
ANPA (National Environmental Protection Agency),
via Vitaliano Brancati 48,
00144 Rome, Italy,
Tel: +39 06 50072928,
Fax: +39 06 50072986,
Email: riccardo.delauretis@anpa.it

Zissis Samaras
Aristotle University,
Department of Mechanical Engineering,
GR-54006 Thessaloniki, Greece
Tel: 30 31 996 014
Email: zisis@vergina.eng.auth.gr