SNAP CODES :	**070100** **070200** **070300** **070400** **070500**
SOURCE SECTOR TITLES :	**Passenger Cars** **Light Duty Vehicles** **Heavy Duty Vehicles** **Mopeds and Motorcycles** **Motorcycles**

1. ACTIVITIES INCLUDED

The vehicle category split required for reporting in CORINAIR 1990 (Fontelle et al. 1992) does not meet all aspects of vehicle emissions considered important. Thus, a more detailed vehicle category split has been developed, presented in Table 7.1. With this vehicle split it is attempted on the one hand to introduce the technological changes which took effect in passenger cars (introduction of three way catalytic converters) and on the other to preserve the distinction between the three major driving classes (urban, rural and highway) for a more detailed spatial allocation of emissions.

However other important emission related parameters, in particular the age of vehicles (year of production) and the engine technology, are not sufficiently reflected in the proposed split. Major differences occur in the category passenger cars, where the different steps of international legal conformity have to be taken into account (ECE classes), as well as national legislation with the classes 'Improved Conventional' and 'Open Loop'. This report provides detailed emission factors for a number of technology classes, which are presented in Table 7.2 and which in a second step can be aggregated to match the proposed CORINAIR split. The category 'Buses' is not specifically differentiated, but it is covered by the category heavy duty vehicles >16t, because emission factors different from those of heavy duty vehicles could not be found.

The "CORINAIR Working Group on Emission Factors for Calculating Emissions from Road Traffic" initially developed a methodology, including appropriate emission factors, for the reference year 1985 (Eggleston et al. 1989). The methodology was transformed into a computer programme (Samaras et al. 1989a) and applied by many EC countries in the 1985 exercise (Samaras et al. 1989b). In 1991 the group was re-convened and proposed a revised set of emission factors to be used for the 1990 inventory, including, where necessary a revision of the underlying methodology used for estimating the emissions. This report is largely based on the methodology developed by the working group and proposes emission factors which are needed for its application (Eggleston et al. 1993). As in 1985, the results of this work have been translated into a menu-driven computer programme, called COPERT 90, which substantially facilitates the practical application of the methodology (see Andrias et al. 1993).

Due to the differences in the proposed calculation schemes, this part of the Emission Inventory Guidebook referring to Road Transport emissions is organised into two parts: Exhaust emissions (SNAP codes 07 01 to 07 05) are presented in this chapter, while Gasoline Evaporation from Cars (SNAP code 07 06) is dealt with separately in chapter B760.

Table 7.1: Vehicle Category Split

0701	PASSENGER CARS	
070101	Conventional Gasoline Passenger Cars	
	07 01 01 01	Highway Driving
	07 01 01 02	Rural Driving
	07 01 01 03	Urban Driving
070102	Catalyst Gasoline Gasoline Passenger Cars	
	07 01 02 01	Highway Driving
	07 01 02 02	Rural Driving
	07 01 02 03	Urban Driving
070103	Diesel Passenger Cars	
	07 01 03 01	Highway Driving
	07 01 03 02	Rural Driving
	07 01 03 03	Urban Driving
070104	L P G Passenger Cars	
	07 01 04 01	Highway Driving
	07 01 04 02	Rural Driving
	07 01 04 03	Urban Driving
070105	Two Stroke Gasoline Vehicles	
	07 01 05 01	Highway Driving
	07 01 05 02	Rural Driving
	07 01 05 03	Urban Driving
0702	LIGHT DUTY VEHICLES	
070201	Gasoline Light Duty Vehicles	
	07 02 01 01	Highway Driving
	07 02 01 02	Rural Driving
	07 02 01 03	Urban Driving
070202	Diesel Light Duty Vehicles	
	07 02 02 01	Highway Driving
	07 02 02 02	Rural Driving
	07 02 02 03	Urban Driving
0703	HEAVY DUTY VEHICLES	
070301	Gasoline Heavy Duty Vehicles	
	07 03 01 01	Highway Driving
	07 03 01 02	Rural Driving
	07 03 01 03	Urban Driving
070302	Diesel Heavy Duty Vehicles	
	07 03 02 01	Highway Driving
	07 03 02 02	Rural Driving
	07 03 02 03	Urban Driving
0704	MOPEDS & MOTORCYCLES < 50 cc	
	07 04 01	Rural Driving
	07 04 02	Urban Driving
0705	MOTORCYCLES > 50 cc	
	07 05 01	Highway Driving
	07 05 02	Rural Driving
	07 05 03	Urban Driving
0706	GASOLINE EVAPORATION FROM MOTOR VEHICLES	

Table 7.2: Detailed Vehicle Category Split Used in this Report

PASSENGER CARS
Gasoline < 1.4 l
PRE ECE
ECE 15/00-01
ECE 15/02
ECE 15/03
ECE 15/04
Improved Conventional
Open Loop
Closed Loop
Gasoline 1.4 - 2.0 l
PRE ECE
ECE 15/00-01
ECE 15/02
ECE 15/03
ECE 15/04
Improved Conventional
Open Loop
Closed Loop
Gasoline > 2.0 l
PRE ECE
ECE 15/00-01
ECE 15/02
ECE 15/03
ECE 15/04
Closed Loop
Diesel
Diesel <2.0l
Diesel >2.0l
L P G
Two Stroke Gasoline Vehicles
LIGHT DUTY VEHICLES
Gasoline
Diesel
HEAVY DUTY VEHICLES
Gasoline Veh. > 3.5 t
Diesel Veh. 3.5 - 16 t
Diesel Veh. > 16 t
MOTORCYCLES
< 50 cm^3
> 50 cm^3 2 stroke
> 50 cm^3 4 stroke

2. CONTRIBUTION TO TOTAL EMISSIONS

Road transport has been identified as a major source of air pollution, especially in urban areas. For example, the contribution of motor vehicles to total man-made NOx emissions of the European Community in 1990 is estimated to be about 44% and to total man-made NMVOC about 34% (see Table 7.3). In addition, Table 7.4 presents the contribution to total traffic related emissions of the main vehicle sub-categories, for the pollutants CO, NOx, VOC, CO_2, SO_2, Pb , particulates, N_2O and NH_3. Further details are also provided in chapter ACOR which provides full details of the CORINAIR results for 28 European countries. It is of interest to note that gasoline passenger cars are the main traffic emitters of CO, VOC and Pb, while heavy duty trucks are responsible for major parts of traffic related NOx, SO_2 and PM on average at EU level.

Table 7.3: Contribution of Road Transport to Total Man-made NOx and NMVOC emissions in [kt] and [%]. Estimates of CORINAIR 90

	NOx Emissions			NMVOC Emissions		
	Total kt	Road Traffic kt	%	Total kt	Road Traffic kt	%
B	343	190	55	394	189	48
DK	273	102	37	178	99	55
D	2424	1493	62	2484	810	33
FR	1590	1038	65	2866	1170	41
GR	544	114	21	718	137	19
IRL	116	44	38	197	62	32
I	2053	946	46	2549	954	37
L	23	9	40	20	10	50
NL	576	272	47	460	184	40
P	221	107	48	644	81	13
E	1257	512	41	1894	449	24
UK	2773	1383	50	2682	982	37
EU 12	12184	6210	51	15087	5127	34
D(GDR)	556	137	25	839	424	51
AUS	227	154	68	656	114	17
FI	269	119	44	457	73	16
SW	345	163	47	722	154	21
EVI5	13590	6782	50	17761	5893	33

Table 7.4: 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 of CORINAIR 90)

	CO	NO_x	NMVOC	CH_4	CO_2	SO_2	Pb	PM	N_2O	NH_3
Gasoline Passenger Cars	80.0 (62-94)	49.8 (29-90)	62.4 (45-85)	70.3 (13-84)	47.7 (32-65)	19.4 (8-43)	80.4 (63-87)		49.3 (22-70)	87.6 (56-97)
Diesel Passenger Cars	0.9 (0-2)	3.3 (0-8)	1.8 (0-5)	1.5 (0-15)	10.0 (0-25)	16.4 (0-37)		26.2 (11-43)	11.8 (7-30)	2.0 (2-17)
LPG Passenger Cars	0.6 (0-3)	0.9 (0-5)	1.0 (0-5)	1.1 (0-5)	0.8 (0-4)					
Light Duty Vehicles	9.3 (1-24)	8.0 (2-17)	8.4 (2-20)	6.5 (2-17)	12.4 (1-23)	17.2 (5-27)	12.7 (6-32)	16.6 (0-31)	13.6 (6-26)	4.5 (3-15)
Heavy Duty Vehicles	5.4 (2-14)	37.8 (0-59)	13.5 (4-20)	10.7 (3-32)	27.9 (18-60)	46.4 (27-76)	2.1 (0-7)	57.2 (44-89)	24.8 (12-63	4.9 (4-31)
Motorcycles	3.8 (0-10)	0.2 (0-1)	13.0 (1-25)	9.9 (1-37)	1.2 (0-3)	0.6 (0-1)	4.8 (1-8)		0.4 (0-2)	1.1 (0-24)

3. GENERAL

3.1 Description

In order to help identifying the vehicle categories, Table 7.5 gives the classification of vehicles according to the UN-ECE. The main CORINAIR categories can be allocated to the UN-ECE classification as follows:

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

Table 7.5: Classification of Vehicles 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 CC AND A MAXIMUM DESIGN SPEED NOT EXCEEDING 40 KM/H.
CATEGORY L2:	THREE-WHEELED VEHICLES WITH AN ENGINE CYLINDER CAPACITY NOT EXCEEDING 50 CC AND A MAXIMUM DESIGN SPEED NOT EXCEEDING 40 KM/H.
CATEGORY L3:	TWO-WHEELED VEHICLES WITH AN ENGINE CYLINDER CAPACITY EXCEEDING 50 CC 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 CC 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 CC 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 Emissions

The report contains emission factors for NOx, N_2O, SOx, VOC, CH_4, CO, CO_2, NH_3, diesel particulates and lead. The following definitions apply:

NOx (NO and NO_2) :	given as NO_2 equivalent
N_2O :	given as N_2O equivalent
SOx :	given as SO_2 equivalent
VOC :	given as $CH_{1.85}$ equivalent
CH_4 :	given as CH_4 equivalent
CO :	given as CO equivalent
CO_2 :	given as CO_2 equivalent
NH_3 :	given as NH_3 equivalent
Particulate matter :	given as mass equivalent of filter measurements
Lead :	given as Pb equivalent
NMVOC:	produced by deducting CH_4 from total VOC emissions

3.3 Controls

3.3.1 Gasoline passenger cars

This is the only vehicle category in which the production year of vehicles has been taken into account by introducing different sub-categories, which reflect legislative steps (ECE) or technology steps ("improved conventional", "open loop" and "closed loop"). The technology steps are of importance in particular for those countries which introduced emission limits in national legislation which are more stringent than the ECE 15/04 limits, or implemented special incentive programmes for the purchase of such vehicles.

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 less than 3.5 tonnes. 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

However, the above implementation dates are "average" for the EU 12 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 - either produced in the member state or imported from elsewhere in the world - registered in the member state.

After 1985, the following technologies appeared, imposed by the EC legislation and national schemes:

Gasoline Passenger Cars <1.4l

a. Improved Conventional. It takes into account

- German and Dutch incentive programmes:
  - Anl.XXIVC (only relevant for Germany). Effective date: 1.7.1985.
  - NLG 850 (only relevant for the Netherlands). Effective date: 1.1.1986

It is assumed that the required emission standards can be met by applying improved conventional technology. 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, F.R.Germany 1.7.1985, Greece 1.1.1990, The Netherlands 1.1.1987.

c. Closed Loop. It takes into account national incentive programmes (e.g. voluntary programmes in F.R.Germany carried out after 1.7.1985), where compliance with US 83 limits is required. In addition this category addresses the passenger cars complying with the Directive 91/441/EEC.

Gasoline Passenger Cars 1.4-2.0 l

a. Improved conventional. It takes into account vehicles which meet the limit values of the Directive 88/76/EEC (Commission 1988) by means of open loop catalysts. In practice relevant only for the national incentive programmes. Effective dates of implementation are: Denmark 1.1.1987, F.R.Germany 1.7.1985, The Netherlands 1.1.1987.

b. Open Loop. It takes into account vehicles which meet the limit values of the Directive 88/76/EEC by means of open loop catalysts. In practice relevant only to the national incentive programmes. Effective dates of implementation are ; Denmark 1.1.1987, F.R.Germany 1.7.1985, Greece 1.1.1990, The Netherlands 1.1.1986.

c. Closed Loop. It takes into account national incentive programmes where compliance with US 83 limits is required. In addition this category addresses the passenger cars complying with the Directive 91/441/EEC.

Gasoline Passenger Cars >2.0 l

a. Open Loop. It takes into account vehicles which meet the limit values of the Directive 88/76/EEC by means of open loop catalysts. In practice relevant only to the national incentive programmes. Effective dates of implementation are: Denmark 1.1.1987, F.R.Germany 1.7.1985.

b. Closed Loop. 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, F.R.Germany, Greece, The Netherlands). Effective date: Denmark 1.1.1987, F.R.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. In addition this category addresses the passenger cars complying with Directive 91/441/EEC.

It is of importance to note that new emission standards for passenger cars have been adopted in the EU to be effective 1996 (Directive 94/12/EEC). Compared to 91/441/EEC the new emission standards impose a 30% and 55% reduction in CO and HC+NOx respectively. In addition the 2000 emission standards are also under discussion: they aim at the introduction of early light-off three-way catalysts, complying with high durability requirements.

3.3.2 Other vehicle categories

Light Duty Trucks: In the EC the emissions of these vehicles were covered by the different ECE steps. From 1995 onwards new emission standards are applicable (Directive 93/59/EEC), which ask for catalytic converters on the gasoline powered vehicles and engine modifications on the diesel vehicles of this category. In addition, these emission standards for the first time address particulate emissions of diesel light duty trucks. Currently, an amendment of the above mentioned Directive is under discussion, aimed at the introduction of emission standards equivalent to those of 94/12/EEC to light duty trucks by 1998.

Heavy Duty Vehicles: In the EC, emission standards for the gaseous pollutants CO, HC and NOx have been promulgated since 1988, only for the diesel powered commercial vehicles >3.5 t GVW. However a 1991 Directive (91/542/EEC) adopted a two stage approach (effective 1994 and 1997) for a more stringent control of the emissions (in particular NOx and PM) of these vehicles. It is expected that the emission standards of both stages will be met with engine modifications (such as turbocharging and exhaust gas recirculation) and in some cases with oxidation catalysts.

Motorcycles: So far, emissions from these vehicles have been uncontrolled in the EC. Only some EFTA countries (e.g. Switzerland and Austria) have adopted stringent emission standards imposing the application of catalytic converters on two stroke engines. The EU is about to adopt legislation (COM(93)449), to be implemented from 1997 onwards.

4. SIMPLER METHODOLOGY

Several methods to calculate emissions can be foreseen. In all cases, emission estimates have to be based on a mixture of (some) hard facts and a (large) number of assumptions. It is, therefore, important to define a method to be used for the estimation work which builds upon as many hard facts as possible, reducing at the same time the number of assumptions. However, when searching for such a compromise method, one always has to keep in mind the objective of the work, i.e. the final data usage which, determines to a large extent the source category split requirements.

In principle the detailed methodology proposed in the following section is easily applicable. A simple methodology for estimating emissions is based on total fuel consumption or total mileage or energy consumption data which then have to be multiplied by appropriate bulk emission factors.

Therefore, the formula to be applied in this case is

$$E_i = FC \cdot EF_i$$

with

E_i = mass of emissions of pollutant i during inventory period
FC = fuel consumption or mileage or energy consumption
EF_i = average emissions of pollutant i per unit of fuel used or mileage or energy

Since the simple methodology outlined above averages over different types of engines, using different types of fuels, it can provide only broad estimates at best.

Tables 7.6 to 7.13 present bulk emission factors for the application of the simple methodology. These tables have been produced by averaging the data submitted by the different European countries to the CORINAIR90 inventory. In addition an attempt was made to classify the emissions factors to different technology classes (especially as regards gasoline passenger cars) following the IPCC nomenclature.

Table 7.6: Estimated Emission Factors for Gasoline Passenger Cars

	NOx	CH_4	VOC	CO	N_2O	CO_2
Uncontrolled: Assumed Fuel Economy 12.3 l/100 km						
Total g/km	1.89	0.08	5.13	50.2	0.005	295
Exhaust	1.89	0.08	3.75	50.2	0.005	295
Evaporative (*)			1.38			
g/kg fuel	20.4	0.91	55.5	542	0.057	3183
g/MJ	0.47	0.02	1.27	12.5	0.001	73.2
Early non-catalyst controls: Assumed Fuel Economy 9.5 l/100 km						
Total g/km	2.05	0.08	3.88	28.8	0.005	226
Exhaust	2.05	0.08	2.50	28.8	0.005	226
Evaporative (*)			1.38			
g/kg fuel	28.9	1.16	54.7	406	0.071	3183
g/MJ	0.66	0.03	1.26	9.33	0.002	73.2
Non-catalyst controls: Assumed Fuel Economy 8.4 l/100 km						
Total g/km	2.31	0.07	3.27	18.9	0.005	200
Exhaust	2.31	0.07	2.01	18.9	0.005	200
Evaporative (*)			1.26			
g/kg fuel	36.7	1.13	52.0	300	0.079	3183
g/MJ	0.84	0.03	1.19	6.89	0.002	73.2
Oxidation catalyst: Assumed Fuel Economy 8.1 l/100 km						
Total g/km	1.35	0.07	0.97	7.53	0.01	194
Exhaust	1.35	0.07	0.56	7.53	0.01	194
Evaporative (*)			0.41			
g/kg fuel	22.2	1.17	16.0	124	0.08	3183
g/MJ	0.51	0.03	0.37	2.83	0.002	73.2
Three-way catalyst: Assumed Fuel Economy 8.5 l/100 km						
Total g/km	0.52	0.02	0.38	2.86	0.050	204
Exhaust	0.52	0.02	0.32	2.86	0.050	204
Evaporative (*)			0.06			
g/kg fuel	8.05	0.31	5.97	44.6	0.780	3183
g/MJ	0.18	0.007	0.14	1.02	0.018	73.2
2 - stroke: Assumed Fuel Economy 11.2 l/100 km						
Total g/km	0.72	0.08	11.3	12.5	0.005	267
Exhaust	0.72	0.08	10,0	12.5	0.005	267
Evaporative (*)			1.30			
g/kg fuel	8.57	0.95	134	149	0.061	3183
g/MJ	0.20	0.02	3.08	3.42	0.001	73.2

(*) Including diurnal, soak and running losses

Table 7.7: Estimated Emission Factors for Diesel Passenger Cars

	NOx	CH_4	VOC	CO	N_2O	CO_2
Moderate Control: Assumed Fuel Economy 7.3 l/100 km						
Total g/km	0.67	0.005	0.19	0.71	0.010	190
g/kg fuel	11.0	0.083	3.08	11.7	0.165	3138
g/MJ	0.26	0.002	0.07	0.28	0.004	73.9

Table 7.8: Estimated Emission Factors for LPG Passenger Cars

	NOx	CH_4	VOC	CO	N_2O	CO_2
Moderate Control: Assumed Fuel Economy 11.3 l/100 km(*)						
Total g/km	2.16	0.06	1.51	7.17	-	178
g/kg fuel	36.8	0.96	25.7	122	-	3030
g/MJ	0.80	0.02	0.56	2.65	-	65.7

(*) under 5 bar pressure

Table 7.9: Estimated Emission Factors for Gasoline Light Duty Vehicles

	NOx	CH_4	VOC	CO	N_2O	CO_2
Moderate Control: Assumed Fuel Economy 13.7 l/100 km						
Total g/km	2.94	0.08	4.86	36.6	0.006	327
Exhaust	2.94	0.08	3.51	36.6	0.006	327
Evaporative *			1.35			
g/kg fuel	28.7	0.80	47.4	356	0.059	3183
g/MJ	0.66	0.02	1.09	8.20	0.001	73.2

Table 7.10: Estimated Emission Factors for Diesel Light Duty Vehicles

	NOx	CH_4	VOC	CO	N_2O	CO_2
Moderate Control: Assumed Fuel Economy 11.0 l/100 km						
Total g/km	1.44	0.005	0.42	1.58	0.017	284
g/kg fuel	15.9	0.055	4.64	17.5	0.188	3138
g/MJ	0.37	0.001	0.11	0.41	0.004	73.9

Table 7.11: Estimated Emission Factors for Gasoline Heavy Duty Vehicles

	NOx	CH_4	VOC	CO	N_2O	CO_2
Moderate Control: Assumed Fuel Economy 24.0 l/100 km						
Total g/km	6.75	0.11	5.13	58.4	0.006	553
Exhaust	6.75	0.11	5.13	58.4	0.006	553
g/kg fuel	37.5	0.64	28.5	324	0.035	3183
g/MJ	0.86	0.02	0.65	7.46	0.001	73.2

Table 7.12: Estimated Emission Factors for Diesel Heavy Duty Vehicles

	NOx	CH_4	VOC	CO	N_2O	CO_2
Moderate Control: Assumed Fuel Economy 30.8 l/100 km						
Total g/km	10.9	0.06	2.08	8.71	0.03	800
g/kg fuel	42.7	0.25	8.16	34.2	0.12	3138
g/MJ	1.01	0.006	0.19	0.80	0.003	73.9

Table 7.13: Estimated Emission Factors for Motorcycles

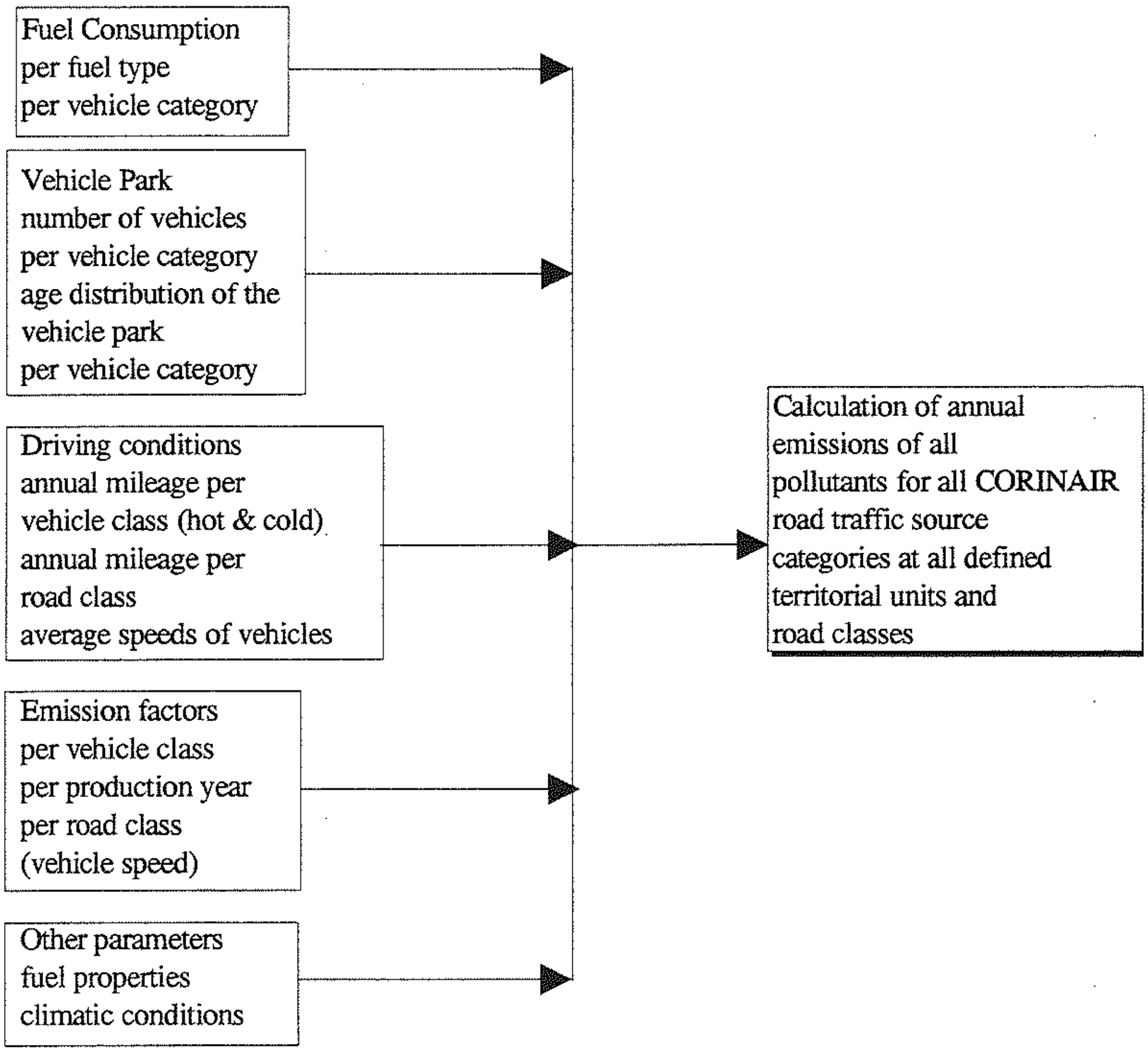
	NOx	CH_4	VOC	CO	N_2O	CO_2
MOTORCYCLES < 50 cc						
Uncontrolled: Assumed Fuel Economy 2.6 l/100 km						
Total g/km	0.05	0.10	6.19	10.0	0.001	57.3
Exhaust	0.05	0.10	5.89	10.0	0.001	57.3
Evaporative (*)			0.30			
g/kg fuel	2.56	5.55	317	510	0.056	3183
g/MJ	0.06	0.13	7.28	11.7	0.001	73.2
MOTORCYCLES > 50 cc 2 str						
Uncontrolled: Assumed Fuel Economy 4.1 l/100 km						
Total g/km	0.08	0.15	15.4	22.0	0.002	95.8
Exhaust	0.08	0.15	14.8	22.0	0.002	95.8
Evaporative (*)			0.6			
g/kg fuel	2.64	5.00	509	724	0.067	3183
g/MJ	0.06	0.12	11.7	16.7	0.002	73.2
MOTORCYCLES > 50 cc 4 str						
Uncontrolled: Assumed Fuel Economy 5.1 l/100 km						
Total g/km	0.30	0.20	3.36	20.0	0.002	121
Exhaust	0.30	0.20	2.80	20.0	0.002	121
Evaporative (*)			0.56			
g/kg fuel	7.89	5.26	88.3	526	0.053	3183
g/MJ	0.18	0.12	2.03	12.1	0.001	73.2

(*) Including diurnal, soak and running losses

5. DETAILED METHODOLOGY

The aim of the calculations described below is to estimate the emissions of NOx (sum of NO and NO_2), N_2O, NMVOC (total VOC minus methane), CH_4, CO, CO_2, SOx, NH_3, diesel particulates and lead from road traffic for the reference year, differentiated into ten different major categories and 39 sub-categories, most of them separated into three types of roads (urban, rural, highway), for each area, or territorial unit (NUTS III). The basic data is therefore the reference year emission of pollutant i, caused by vehicle category j at local area level (NUTS III) on roads of type k. In the ideal case, such information must be available for all pollutants, all categories at all territorial units and for all types of roads.

The methodology is defined in such a way that it uses the firm technical data and that national variations can be incorporated. The variations may include such things as composition of vehicle park, vehicle age, driving patterns, some fuel parameters and a few climatic parameters. Other variations which may exist, for example, variations in vehicle maintenance, are not accounted for because there is not enough data available to do so.



The calculation is based on five main types of input parameters:

- total fuel consumption
- vehicle park
- driving condition
- emission factors
- other parameters

For these main types of input parameters, additional information (e.g. on vehicle classes, production years etc.) is needed in order to carry out the calculations. The picture above shows the calculation scheme.

This information in principle should be available for the smallest territorial unit (NUTS level III). However, this is not the case in most countries, so that it seems to be more appropriate for these countries to start at NUTS level 0 (national level) and to allocate emissions to other NUTS levels with the help of available surrogate data. This implies that certain local particularities within a certain country, e.g. mountains or climatic differences, cannot be taken into account. An attempt to do so by applying all sorts of "corrections" introduced at a later stage of the calculation failed because no sound set of "correction factors" could be identified. However, national particularities can be taken into account by this top-down approach via the composition of the vehicle park, the driving conditions and the temperature dependency of some emission factors.

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. However, the model should not be used for NUTS much smaller than NUTS III because vehicle speeds and driving modes are average values themselves and may not fit to particular local circumstances. Finally, as it will be outlined in the next sections, some categories can be lumped together (e.g. without distinguishing among production years or road classes), so that the total calculation effort is substantially reduced.

Exhaust emissions from road transport are divided into two types. The first are the "hot emissions". These are the emissions from vehicles after they have warmed up to their normal operating temperature. The second are the so-called "cold-start extra emissions" which are the emissions from vehicles while they are warming up.

5.1 Hot Emissions

These emissions depend on a variety of factors including the distance that each vehicle travels, its speed (or road type), its age and engine size. As explained later, 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.

There are a number of other factors that may influence vehicle emissions, for example, state of maintenance, slope or altitude. However, there is so little data about the influence of these parameters on European vehicles that their influence cannot be taken into account.

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

$$\text{Emissions [g]} = \text{emission factor [g/km]} \cdot \text{vehicle kilometers per year [km]}$$

The emission factors and vehicle kilometers are in most cases split into certain classes of road types and vehicle categories.

However, for many countries the only data known with any certainty is the total fuel consumption of petrol, diesel and LPG, not vehicle kilometers. **It is therefore suggested that fuel**

consumption data are used to check vehicle mileage where they are known and to make a final fuel balance.

Since emission factors can be converted from [g/km] into [g/kg fuel], using consumption data for all vehicle classes and road types, the calculation can be carried out either on one or the other emission factor.

If fuel consumption is to be used, we have:

$$E_{hot;i,j,k} = g_{j,k,1} \cdot b_{j,1} \cdot e_{*,hot,year,i,j,k} \qquad (1)$$

where:

$E_{hot,i,j,k}$ = emissions of the pollutant i in [g], caused in the reference year by vehicles of category j driven on roads of type k with hot engines

$g_{j,k,1}$ = share of annual fuel consumption of type 1 used by vehicles of category j, driven on road type k

$b_{j,1}$ = total annual consumption of fuel type 1 in [kg] by vehicles of category j operated in the reference year

$e_{*,hot,year,i,j,k}$ = average fleet representative baseline emission factor in [g/kg fuel] for the pollutant i, relevant for the vehicle category j, operated on roads of type k with hot engines (please note: these factors have been derived from emission factors of individual cars which were grouped together according to the national car park).

and:

i (pollutants) = 1-10 for the pollutants covered

j (vehicle category) = 1-34 for the on-road categories defined in the vehicle category split (Tables 7.1 & 7.2)

k (road classes) = 1-3 for "urban", "rural", and "highway" driving (note that the road types imply certain speed patterns)

l (fuel type) = 1-3 for gasoline, diesel, LPG

The application of equation (1) requires statistical input data which are not available in several countries. Therefore, some data have to be estimated. It is proposed to apply as a principle for these estimations the rule that those parameters which are least known should be modified most. In practice this means to attribute uncertainties to parameters which are actually uncertain and to avoid modifications of parameters which are known somewhat more precisely. In the following, some practical explanations are given.

The factors $b_{j,1}$ and $g_{j,k,1}$ used in equation (1) cannot be introduced into the calculation from statistical data but have to be estimated with the help of other parameters. As outlined above, in most of the Member States the total fuel consumption is only known for different fuels, (e.g. gasoline, diesel, LPG) but not, as required, related to vehicle categories. In such a case it is proposed to distribute the total fuel figures to the vehicle categories in an iterating process, making assumptions concerning the average annual mileage driven per vehicle of a defined category and the distribution of the total annual mileage to different road types. The data on total fuel consumption of the different fuels, the number of vehicles in each category and the average fuel consumption for each vehicle category on the different road types remain the fixed points in this process. It is proposed to start with

$$m_j = h_j \cdot v_j \qquad (2)$$

where:

m_j = total annual mileage in [km] of vehicle category j

h_j = number of vehicles of category j

v_j = average annual mileage driven by each vehicle of category j

While h_j is considered as a well-known statistical figure, v_j, is not available as independent statistical data in many countries and has to be estimated.

In the next step, m_j is introduced into the formula:

$$m_{j,k} = m_j \cdot d_{j,k} \qquad (3)$$

where:

$m_{j,k}$ = total annual mileage in [km] of vehicle category j on road class k

$d_{j,k}$ = share of annual mileage driven on road class k by vehicle category j

The parameter $d_{j,k}$ is rarely available as independent statistical data in any European country and therefore has to be estimated. The parameter $m_{j,k}$ should then be introduced into the formula:

$$b_{j,1} = \sum_{k=1}^{3} m_{j,k} \cdot c_{j,k} \qquad (4)$$

where:

$b_{j,1}$ = total annual consumption of fuel of type 1 in [kg] by vehicles of category j -- operated in the reference year

$c_{j,k}$ = average fuel consumption in [g/km] of vehicle category j on road class k

The figure $c_{j,k}$ is a measured value (figures can be taken from Tables given in this chapter), so that the calculation can be carried out easily.

$$O_1 = \sum_j b_{j,1} \qquad (5)$$

where:

O_l = total annual consumption of fuel type l

As a rule, the calculated O_l should be equal to the consumption statistics(1). If now the calculated O_l does not match the true value, the "soft" input parameters should be modified. 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 in most of the cases the parameters $d_{j,k}$ and/or v_l are those to which most attention should be given .

The factor $g_{j,k}$ can be calculated as follows:

$$g_{j,urban} = c_{j,urban} \cdot m_{j,urban} / \sum_{k=1}^{3} c_{j,k} \cdot m_{j,k} \quad \text{for } k = \text{urban}$$

(1) However, it should be noted that in some countries there might be a difference between the fuel sold and the fuel actually consumed in this country due to vehicles in transit. The official statistics always correspond to the fuel sold in a country and therefore have to be corrected if there are clear indications for a substantial import or export of fuel.

$$g_{j,rural} = c_{j,rural} \cdot m_{j,rural} / \sum_{k=1}^{3} c_{j,k} \cdot m_{j,k} \quad \text{for } k = \text{rural} \qquad (6)$$

$$g_{j,highway} = c_{j,highway} \cdot m_{j,highway} / \sum_{k=1}^{3} c_{j,k} \cdot m_{j,k} \quad \text{for } k = \text{highway}$$

where:

$c_{j,k}$ = average fuel consumption in [g/km] of vehicle category j on road class k

$m_{j,k}$ = total annual mileage in [km] of vehicle category j on road class k

All elements of these equations are known, so that the calculation can be carried out directly.

Generally, the emission factor $e_{hot,year,i,j,k}$, expressed in [g/km] is known from measurements and should be converted into [g/kg fuel] as follows:

$$e_{*,hot,year,i,j,k} = e_{hot,year,i,j,k} / c_{j,k} \qquad (7)$$

where:

$e_{hot,year,i,j,k}$= average fleet representative baseline emission factor for the reference year in [g/km] for the pollutant i for the vehicle category j, operated on roads of type k with hot engines

$c_{j,k}$ = average fuel consumption in [g/km] of vehicle category j on road class k

5.1.1 Accounting for Vehicle Speed

Vehicle speed, which is introduced into the calculation via the three road types, 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 $f_k(z)$ and to integrate over the emission curves, i.e.:

$$e_{hot,i,j,k,g} = \int e(z)\, f_k(z) \qquad (8)$$

where:

$e_{hot,i,j,k,g}$ = emission factor in [g/km] for pollutant i, relevant for vehicle category j, operated on roads of type k with hot engines, valid for regulatory step g

z = speed of gasoline vehicles <2.5 tonnes on road classes "rural", "urban", "highway"

e(z) = mathematical expression (e.g. "best fit") of the speed-dependency of $e_{hot,i,j,g,z}$

$f_k(z)$ = equation (e.g. formula of "best fit" curve) of the frequency distribution of the mean speeds which corresponds to the driving patterns of gasoline vehicles <2.5 tonnes on road classes "rural", "urban" and "highway", $f_k(z)$ depends on road type k and also, possibly, on engine size.

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.

5.1.2 Accounting for Vehicle Age

The emissions of vehicles have changed over time, mainly due to regulatory requirements. The composition of the national fleets differs because the evolution of national fleets and their replacement rates vary from one country to another. Therefore, in a second step, it is proposed to use the following equation in order to calculate emission factors representative of the national fleet:

$$e_{hot,year,i,j,k} = \sum_{g} s_{j,g} \cdot e_{hot,i,j,k,g} \qquad (9)$$

with:

$$s_{j,g} = \frac{a_{j,g}}{\sum_{g} a_{j,g}} \qquad (10)$$

for periods of legal or of technological conformity g with:

$a_{j,g}$ = number of vehicles of category j produced within the period of legal or technological conformity g (only passenger cars)

The application of this equation requires detailed knowledge of the composition of the national fleet with regard to age and cylinder capacity.

As mentioned above, the study analysed with great care available emission data of individual vehicle tests. They were derived by grouping all available measurements carried out with on-road vehicles into periods of legal or technical conformity. In total, about 1,500 vehicles test data have been evaluated. As far as possible, only data obtained in transient mode test cycles were used. Only for high speed driving (80 km/h and more), data obtained under conditions of steady driving were taken into account as well.

5.2 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 factor, the ratio of cold to hot emissions, is used and applied to the fraction of kilometers driven with cold engines. These factors may vary from country to country. Different driving behaviour (varying trip lengths), as well as climate with varying time (and hence distance) required to warm up the engine and/or the catalyst affect the fraction of distance driven with cold engines. 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:

$$E_{cold;i,j} = \beta_j \cdot m_j \cdot e^{hot} \cdot (e^{cold} / e^{hot} - 1) \qquad (11)$$

with:

$E_{cold,i,j}$ = cold start emissions of the pollutant i (for the reference year), caused by vehicle category j (assumption: all cold start estimates are allocated to urban driving)

β_j = fraction of mileage driven with cold engines[1] or catalyst operated below the light-off temperature

m_j = total annual mileage of the vehicle category j

e^{cold}/e^{hot} = cold to hot ratio of emissions

The parameter β 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, some simplifications have been introduced for some vehicle categories.

The ratio e^{cold}/e^{hot} also depends on the ambient temperature and pollutant considered.

[1] "cold" engines are defined as those with a water temperature below $70^{o}C$

5.3 Application of the baseline methodology to the different vehicle categories and pollutants

Due to gaps in knowledge, the baseline methodology can not be applied in full and in the same way to all vehicle categories. Moreover, there are variations depending on the pollutant considered. In general, one can distinguish between four methods, as Table 7.14 presents.

Table 7.14: Summary of Calculation Methods applied for the different Vehicle Categories and Pollutants

Method A: Hot emissions are calculated based on
the total annual kilometers driven per vehicle;
the share of kilometers driven under the driving modes 'urban', 'rural', 'highway';
the average speed of the vehicles under the driving modes 'urban', 'rural', 'highway';
speed-dependent hot emission factors.

Cold start emissions are calculated based on
the average trip length per vehicle trip;
the average monthly temperature;
temperature and trip length dependent cold start correction factor.

Method B: The total annual emissions per vehicle are calculated based on
the total annual kilometers driven per vehicle;
the share of kilometers driven under the driving modes 'urban', 'rural', 'highway';
the average speed of the vehicles under the driving modes 'urban', 'rural', 'highway';
speed-dependent emission factors.

---

remark: for diesel passenger cars, cold start extra emissions for CO, NOx and NMVOC as well as extra fuel consumption are added using the method described under A. For LPG passenger cars a simplified method is used.

Method C: The total annual emissions per vehicle are calculated based on
the total annual kilometers driven per vehicles;
the share of kilometers driven under the driving modes 'urban', 'rural', 'highway';
driving mode dependent emissions factors.

---

remark: For gasoline and diesel light duty vehicle cold start extra emissions for CO, NOx and NMVOC as well as fuel consumption are added using the method described under A.

Method D: The total annual emissions per vehicle category are calculated based on
the total annual fuel consumption of the vehicle category and/or the total annual kilometers driven by the vehicle category;
fuel consumption and/or kilometer related emission factors.

These methods are applied to the different vehicle categories and the different pollutants as shown in Table 7.15

Table 7.15: Summary of Calculation Methods applied for the different Vehicle Categories and Pollutants

Vehicle Category	Pollutants										
	NOx	**CO**	**NMVOC**	**CH_4**	**PM**	**N_2O**	**NH_3**	**SO_2**	**CO_2**	**Pb**	**FC**
Gasoline Passenger Cars											
Pre-ECE	A	A	A	C	-	C	D	D	D	D	A
ECE 15/00-01	A	A	A	C	-	C	D	D	D	D	A
ECE 15/02	A	A	A	C	-	C	D	D	D	D	A
ECE 15/03	A	A	A	C	-	C	D	D	D	D	A
ECE 15/04	A	A	A	C	-	C	D	D	D	D	A
Improved conventional	A	A	A	C	-	C	D	D	D	D	A
Open Loop	A	A	A	C	-	C	D	D	D	D	A
Closed Loop	A	A	A	C	-	C	D	D	D	D	A
Diesel Passenger Cars											
CC <2.0l	B	B	B	C	B	C	D	D	D	D	B
CC >2.0l	B	B	B	C	B	C	D	D	D	D	B
LPG Passenger Cars	B	B	B	-	-	--	-	-	D	-	B
2 Stroke Passenger Cars	C	C	C	C	-	C	D	D	D	D	C
Gasoline Light Duty	C	C	C	C	-	C	D	D	D	D	C
Diesel Light Duty	C	C	C	C	C	C	D	D	D	-	C
Gasoline Heavy Duty	C	C	C	C	-	D	D	D	D	D	C
Diesel Heavy Duty 3.5-16t	C	C	C	C	C	D	D	D	D	-	C
Diesel Heavy Duty >16t	C	C	C	C	C	D	D	D	D	-	C
Two Wheelers<50 cc	D	D	D	D	-	-	-	D	D	D	D
> 50 cc 2 stroke	D	D	D	D	-	-	-	D	D	D	D
> 50 cc 4 stroke	D	D	D	D	-	-	-	D	D	D	D
Cold Start Emissions											
Pass. Cars Conventional	A	A	A	-	-	-	-	-	A	A	A
Pass. Cars Closed Loop	A	A	A	-	-	-	-	-	A	A	A
Pass. Cars Diesel	A	A	A	-	A	-	-	-	A	-	A
Pass. Cars LPG	B	B	B	-	-	-	-	-	B	-	B
Gas Light Duty Vehicles	C	C	C	-	-	-	-	-	C	C	C
Diesel Light Duty Vehicles	C	C	C	-	C	-	-	-	C	-	C

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 (and only for some countries, e.g. Kraftfahrtbundesamt 1993) 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 and evaporative losses) are available only in a few countries. As an example for the EC member states, Tables 7.16 to 7.18 give relevant statistics as submitted by the national experts to the CORINAIR 1985 exercise. For a more detailed analysis of the availability of relevant statistical data in the EC member states see Eggleston et al. 1989

Table 7.16: 1985 Vehicle fleet in the EC

Country	GAS PC	DSL PC	LPG PC	LDV	HDV	TW
B	2670945	590960	81072	189000	122620	492264
DK	1414392	63656	22903	219000	55402	185995
D	23503765	2341000	-	635000	1305000	2881000
F	19628999	1464800	5000	-	496700	4031000
GR	1727408	15000	4058	505000	113700	347882
IRL	644450	66280	4590	-	28180	26025
I	19306126	2303110	885394	1862000	445972	5342353
L	135432	14214	1402	20000	8137	4585
NL	3881600	347000	543000	283000	131400	637000
P	1313589	388861	-	563000	105632	750000
E	8454371	719110	100000	1434000	269140	2236230
UK	15973197	1764446	-	1470000	663243	1128000
EC 12	98654274	10078437	1647419	7180000	3745126	18062334

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.

Table 7.17: 1990 total vehicle-kilometers (in 10^6) in the EC as reported to CORINAIR90

Country	GAS PC	DSL PC	LPG PC	LDV	HDV	TW
B	37687.4	22339.1	980.4	6881.6	7848.7	413.9
DK	26300.9	3104.5	170.1	4205.5	3244.6	691.5
D	380340.0	83243.0	-	16984.0	31427.0	9186.0
F	212157.0	80628.3	-	83117.4	30497.3	16468.0
GR	22125.8	2853.7	500.0	7972.7	6649.8	4412.6
IRL	13761.0	2271.4	84.9	3241.7	1286.0	341.2
I	163783.6	52101.0	22718.1	31672.2	40766.1	35861.7
L	2268.8	504.9	7.8	493.3	231.0	41.6
NL	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
P	17378.1	1929.5	-	1520.9	8304.2	958.6
E	111488.6	28158.4	892.5	32370.6	22357.3	10278.4
UK	318220.0	12510.0	-	36030.0	33320.0	6400.0
EC 12	1305511.3	289643.7	25353.8	224489.8	185932.0	85053.4

n.a.: not available

Table 7.18: Examples of Values for Average Estimated Trip Length l_{trip} as taken by EC Member States in COPERT 85

COUNTRY	TRIP LENGTH [km]
B	12
DK	9
D	14
F	12
GR	12
IRL	14
I	12
L	15
NL	13.1
P	12
E	6.31
UK	10

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

The emission factors proposed in the following 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, F.R.Germany, Greece, Italy, the Netherlands and the United Kingdom. In addition, some data measured in Austria, Sweden and Switzerland were incorporated.

For the application of the proposed methodology, one theoretically needs emission factors $e_{hot,year,i,j,k}$ for:

- 10 pollutants (CO, NOx, N_2O, SO_2, VOC, CH_4, CO_2, NH_3, diesel particulates, lead)
- 10 vehicle categories
- 3 road types

In practice, the picture looks somewhat different because:

- for some pollutants (e.g. CO_2, SO_2, lead, NH_3, partly N_2O) emissions are calculated based on fuel consumption only so that no distinction with regard to road types is necessary,
- for some other pollutants, due to the lack of measured data, emissions can be reported only as fractions of other emissions (e.g. CH_4) or by applying lumped emission factors (partly N_2O) so that no separate full calculation is necessary,
- for some vehicle types (e.g. motorcycles), no distinction with regard to emission factors can be made currently for different road types,
- for all on-road vehicle categories with the exception of gasoline passenger cars, no differentiation can be made with regard to the production year of vehicles,
- for some pollutants no emission factor could be derived for certain vehicle categories,

so that the total number of emission factors is substantially smaller than theoretically necessary.

The emission factors proposed can be distinguished into two classes: those for which detailed evaluations are necessary and possible and those for which only very simple "bulk" emission factors or equations can be provided. The pollutants CO, VOC and NOx 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 NOx 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.

It should be noted that the reliability of emission factors differs substantially and this should be taken into account when interpreting the results of the emission estimates.

8.1 SNAP codes 070101 and 070102: Gasoline Passenger Cars

8.1.1 Hot Start Emission Factors

Gasoline passenger cars <2.5 tonnes certainly contribute to the largest part of emissions of road traffic. Therefore, special attention was given to this vehicle category with regard to emission factors and the methodology. It is one of the few categories where, instead of simple emission factors for only one, two or three road types (driving modes), the emission factors are presented in a fully speed-dependent form.

The curves have been derived by regression analysis of all data available to the working group (Avella 1989, Biegstraten et al. 1984, Bundesamt für Umweltschutz 1984, CCMC 1989, Gorißen 1990, 1991, Hassel et al. 1987, 1991, Hollemans et al. 1987, Joumard 1990, Pattas et al. 1983, 1985, 1991, Rijkeboer 1982, 1985, Rijkeboer et al. 1989, 1990).

The equations of the best-fit curves for the emission factors $e_{hot,i,j,g}$, as well as fuel consumption factors, are given in Tables 7.19 - 7.22. They may be used, if necessary, for extrapolation purposes. However, it should be noted that the emission factors have been derived from general test cycles which are not specific for driving at speeds above 130 km/h or below 10 km/h. Therefore they should not be applied for driving at very high and very low speeds. Moreover, 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 emission factor $e_{hot,year,i,j,k}$, introduced in equation (1) is by definition the average fleet representative factor of pollutant i, relevant for the vehicle category j (here this means vehicles with cylinder capacities of <1.4 l/1.4-2 l/>2 l), operated on roads of type k with hot engines. The emission factors presented in this chapter describe the emissions of pollutant i for each vehicle category j and six periods of legal conformity, that means: pre-ECE state and periods of application of ECE 15-00/01, 15-02, 15-03, 15-04 and three post 15-04 technologies: improved conventional, open loop, closed loop.

This presentation allows countries to introduce into the calculation the composition of their fleet and "representative driving patterns". 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[(1)].

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(1) It is possible that driving patterns depend on additional parameters, such as age of the vehicle or cylinder capacity. However, such dependencies should only be taken into account if sound statistical data are available.

Table 7.19: Speed Dependency of CO Emission Factors for Gasoline Passenger Cars

Vehicle Class	Cylinder Capacity	Speed Range	CO Emission Factor [g/km]	R^2
PRE ECE	All categories	10-100	$281 \cdot V^{-0.630}$	0.924
	All categories	100-130	$0.112 \cdot V+4.32$	-
ECE 15-00/01	All categories	10-50	$313 \cdot V^{-0.760}$	0.898
	All categories	50-130	$27.22-0.406 \cdot V+0.0032 \cdot V^2$	0.158
ECE 15-02	All categories	10-60	$300 \cdot V^{-0.797}$	0.747
	All categories	60-130	$26.260-0.440 \cdot V+0.0026 \cdot V^2$	0.102
ECE 15-03	All categories	10-20	$161.36-45.62 \cdot \ln(V)$	0.790
	All categories	20-130	$37.92-0.680 \cdot V+0.00377 \cdot V^2$	0.247
ECE 15-04	All categories	10-60	$260.788 \cdot V^{-0.910}$	0.825
	All categories	60-130	$14.653-0.220 \cdot V+0.001163 \cdot V^2$	0.613
Improved Conventional	CC < 1.4 l	10-130	$14.577-0.294 \cdot V+0.002478 \cdot V^2$	0.781
	1.4 l < CC < 2.0 l	10-130	$8.273-0.151 \cdot V+0.000957 \cdot V^2$	0.767
Open Loop	CC < 1.4 l	10-130	$17.882-0.377 \cdot V+0.002825 \cdot V^2$	0.656
	1.4 l < CC < 2.0 l	10-130	$9.446-0.230 \cdot V+0.002029 \cdot V^2$	0.719
Closed Loop	All categories	10-130	$2.913-0.085 \cdot V+0.000873 \cdot V^2$	0.7

V: Average speed expressed in km/h
R^2: Correlation coefficient

Table 7.20: Speed Dependency of VOC Emission Factors for Gasoline Passenger Cars

Vehicle Class	Cylinder Capacity	Speed Range	VOC Emission Factor [g/km]	R^2
PRE ECE	All categories	10-100	$30.34 \cdot V^{-0.693}$	0.980
	All categories	100-130	1.247	-
ECE 15-00/01	All categories	10-50	$24.99 \cdot V^{-0.704}$	0.901
	All categories	50-130	$4.85 \cdot V^{-0.318}$	0.095
ECE 15-02/03	All categories	10-60	$25.75 \cdot V^{-0.714}$	0.895
	All categories	60-130	$1.95-0.019 \cdot V+0.00009 \cdot V^2$	0.198
ECE 15-04	All categories	10-60	$19.079 \cdot V^{-0.693}$	0.838
	All categories	60-130	$2.608-0.037 \cdot V+0.000179 \cdot V^2$	0.341
Improved Conventional	CC < 1.4 l	10-130	$2.189-0.034 \cdot V+0.000201 \cdot V^2$	0.766
	1.4 l < CC < 2.0 l	10-130	$1.999-0.034 \cdot V+0.000214 \cdot V^2$	0.447
Open Loop	CC < 1.4 l	10-130	$2.185-0.0423 \cdot V+0.000256 \cdot V^2$	0.636
	1.4 l < CC < 2.0 l	10-130	$0.808-0.016 \cdot V+0.000099 \cdot V^2$	0.49
Closed Loop	All categories	10-130	$0.165-0.002 \cdot V+0.000019 \cdot V^2$	0.092

V: Average speed expressed in km/h
R^2: Correlation coefficient

Table 7.21: Speed Dependency of NOx Emission Factors for Gasoline Passenger Cars

Vehicle Class	Cylinder Capacity	Speed Range	NOx Emission Factor [g/km]	R^2
PRE ECE	CC < 1.4 l	10-130	$1.173+0.0225 \cdot V-0.00014 \cdot V^2$	0.916
ECE 15-00/01	1.4 l < CC < 2.0 l	10-130	$1.360+0.0217 \cdot V-0.00004 \cdot V^2$	0.960
	CC > 2.0 l	10-130	$1.5+0.03 \cdot V+0.0001 \cdot V^2$	0.972
ECE 15-02	CC < 1.4 l	10-130	$1.479-0.0037 \cdot V+0.00018 \cdot V^2$	0.711
	1.4 l < CC < 2.0 l	10-130	$1.663-0.0038 \cdot V+0.00020 \cdot V^2$	0.839
	CC > 2.0 l	10-130	$1.87-0.0039 \cdot V+0.00022 \cdot V^2$	-
ECE 15-03	CC < 1.4 l	10-130	$1.616-0.0084 \cdot V+0.00025 \cdot V^2$	0.844
	1.4 l < CC < 2.0 l	10-130	$1.29 \cdot e^{0.0099 \cdot V}$	0.798
	CC > 2.0 l	10-130	$2.784-0.0112 \cdot V+0.000294 \cdot V^2$	0.577
ECE 15-04	CC < 1.4 l	10-130	$1.432+0.003 \cdot V+0.000097 \cdot V^2$	0.669
	1.4 l < CC < 2.0 l	10-130	$1.484+0.013 \cdot V+0.000074 \cdot V^2$	0.722
	CC > 2.0 l	10-130	$2.427-0.014 \cdot V+0.000266 \cdot V^2$	0.803
Improved Conventional	CC < 1.4 l	10-130	$-0.926 + 0.719 \cdot \ln(V)$	0.883
	1.4 l < CC < 2.0 l	10-130	$1.387+0.0014 \cdot V+0.000247 \cdot V^2$	0.876
Open Loop	CC < 1.4 l	10-130	$-0.921 + 0.616 \cdot \ln(V)$	0.791
	1.4 l < CC < 2.0 l	10-130	$-0.761 + 0.515 \cdot \ln(V)$	0.495
Closed Loop	All categories	10-130	$0.260 - 0.0036 \cdot V+0.000061 \cdot V^2$	0.752

V: Average speed expressed in km/h
R^2: Correlation coefficient

Table 7.22: Speed Dependency of Fuel Consumption Factors for Gasoline Passenger Cars

Vehicle Class	Cylinder Capacity	Speed Range	Fuel Consumption Factor [g/km]	R^2
PRE ECE	CC < 1.4 l	10-60	$521 \cdot V^{-0.554}$	0.941
		60-80	55	-
		80-130	$0.386 \cdot V+24.143$	-
	1.4 l < CC < 2.0 l	10-60	$681 \cdot V^{-0.583}$	0.936
		60-80	67	-
		80-130	$0.471 \cdot V+29.286$	-
	CC > 2.0 l	10-60	$979 \cdot V^{-0.628}$	0.918
		60-80	80	-
		80-130	$0.414 \cdot V+46.867$	-
ECE 15-00/01	CC < 1.4 l	10-60	$595 \cdot V^{-0.63}$	0.951
		60-130	$95-1.324 \cdot V+0.0086 \cdot V^2$	0.289
	1.4 l < CC < 2.0 l	10-60	$864 \cdot V^{-0.69}$	0.974
		60-130	$59-0.407 \cdot V+0.0042 \cdot V^2$	0.647
	CC > 2.0 l	10-60	$1236 \cdot V^{-0.764}$	0.976
		60-130	$65-0.407 \cdot V+0.0042 \cdot V^2$	-
ECE 15-02/03	CC < 1.4 l	10-50	$544 \cdot V^{-0.63}$	0.929
		50-130	$85-1.108 \cdot V+0.0077 \cdot V^2$	0.641
	1.4 l < CC < 2.0 l	10-50	$879 \cdot V^{-0.72}$	0.950
		50-130	$71-0.7032 \cdot V + 0.0059 \cdot V^2$	0.830
	CC > 2.0 l	10-50	$1224 \cdot V^{-0.756}$	0.961
		50-130	$111-1.333 \cdot V+0.0093 \cdot V^2$	0.847
ECE 15-04	CC < 1.4 l	10-25	$296.7-80.21 \cdot \ln(V)$	0.518
		25-130	$81.1-1.014 \cdot V+0.0068 \cdot V^2$	0.760
	1.4 l < CC < 2.0 l	10-60	$606.1 \cdot V^{-0.667}$	0.907
		60-130	$102.5-1.364 \cdot V+0.0086 \cdot V^2$	0.927
	CC > 2.0 l	10-60	$819.9 \cdot V^{-0.663}$	0.966
		60-130	$41.7+0.122 \cdot V+0.0016 \cdot V^2$	0.650
Improved Conventional	CC < 1.4 l	10-130	$80.52-1.41 \cdot V+0.013 \cdot V^2$	0.954
	1.4 l < CC < 2.0 l	10-130	$111.0-2.031 \cdot V+0.017 \cdot V^2$	0.994
Open Loop	CC < 1.4 l	10-130	$85.55-1.383 \cdot V+0.0117 \cdot V^2$	0.997
	1.4 l < CC < 2.0 l	10-130	$109.6-1.98 \cdot V+0.0168 \cdot V^2$	0.997
Closed Loop	CC < 1.4 l	10-130	$82.4-1.278 \cdot V+0.0107 \cdot V^2$	0.994
	1.4 l < CC < 2.0 l	10-130	$106.43-1.862 \cdot V+0.0156 \cdot V^2$	0.994
	CC > 2.0 l	10-130	$140.5-2.655 \cdot V+0.0223 \cdot V^2$	0.994

V: Average speed expressed in km/h
R^2: Correlation coefficient.

8.1.2 Emission Factors for Cold Starts

Since cold start emissions are quite sensitive to ambient temperatures, the estimates are made on a monthly basis (Joumard 1991).

Conventional Gasoline Passenger Cars

All non-closed loop 3-way catalyst equipped vehicles belong to this category. The application of the methodology which was outlined requires values for the parameter β (cold mileage percentage) and the ratio e^{cold}/e^{hot}. Table 7.23 provides estimates for β. It should be mentioned that this table applies to all vehicle categories considered. Table 7.24 provides estimates for e^{cold}/e^{hot}. Both tables have been derived from French, German, Dutch and English measurements and are identical to those of the 1985 report (Delsey 1980, Vallet et al. 1982, André et al. 1987, Potter et al. 1983, Hassel et al. 1987, Joumard et al. 1990, Rijkeboer et al. 1989). For application of Table 7.23, a value for the average trip length has to be determined (compare Table 7.18 showing values taken by EC Member States in the 1985 project).

Table 7.23: Cold Mileage Percentage β (Share of Mileage Driven with Cold Gasoline Powered Engines)

	Factor Beta β
Estimated l_{trip}	$0.647 - 0.025 \cdot l_{trip} - (0.00974 - 0.000385 \cdot l_{trip}) \cdot t_a$
Measured l_{trip}	$0.698 - 0.051 \cdot l_{trip} - (0.01051 - 0.000770 \cdot l_{trip}) \cdot t_a$

Table 7.24: Relative Emission Factors e^{cold} / e^{hot} (Only Valid for Conventional Gasoline Powered Engines and temperature range of -10 °C to 30 °C)

Conventional Gasoline Powered Vehicles	e^{cold}/e^{hot}
CO	$3.7 - 0.09 \cdot t_a$
NOx	$1.14 - 0.006 \cdot t_a$
VOC	$2.8 - 0.06 \cdot t_a$
Fuel Consumption	$1.47 - 0.009 \cdot t_a$

Catalyst Gasoline Passenger Cars

For closed loop 3-way catalyst gasoline passenger cars the extra cold start emissions differ significantly from those of conventional gasoline cars (Rijkeboer et al. 1989, AQA 1990, Laurriko et al. 1987). The methodology as such, however, does not require modifications (at least as long as no further measurements are available). Table 7.25 provides an overview of the cold start emission factors.

Table 7.25: Relative Emission Factors e^{cold} / e^{hot} (Only valid for Closed Loop Gasoline Powered Engines and temperature range of -10°C to 30°C)

Closed Loop Gasoline Powered Vehicles	e^{cold}/e^{hot}
CO	$9.04 - 0.09 \cdot t_a$
NOx	$3.66 - 0.006 \cdot t_a$
VOC	$12.59 - 0.06 \cdot t_a$
Fuel Consumption	$1.47 - 0.009 \cdot t_a$

8.2 SNAP code 070103 Diesel Passenger Cars

8.2.1 Hot Emission Factors

Based on a relatively large number of measured data on emissions of diesel passenger cars <2.5 tonnes (CCMC 1989, Joumard 1990, Gorißen 1990, 1991, 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 (see Table 7.26). It should be mentioned that apart from other parameters, the emission factors, in particular those for VOC and particulates can vary substantially, depending on fuel quality and state of maintenance.

Table 7.26: Speed Dependency of Emission Factors for Diesel Vehicles <2.5 t

Pollutant	Cylinder Capacity	Speed Range	Emission Factor [g/km]	R^2
CO	All categories	10-130	$5.413 \cdot V^{-0.574}$	0.745
NOx	CC < 2.0l	10-130	$0.918-0.014 \cdot V+0.000101 \cdot V^2$	0.949
	CC > 2.0l	10-130	$1.331-0.018 \cdot V+0.000133 \cdot V^2$	0.927
VOC	All categories	10-130	$4.61 \cdot V^{-0.937}$	0.794
PM	All categories	10-130	$0.45-0.0086 \cdot V+0.000058 \cdot V^2$	0.439
Fuel Consumption	All categories	10-130	$118.489-2.084 \cdot V+0.014 \cdot V^2$	0.583

V: Average speed expressed in km/h
R^2: Correlation coefficient

8.2.2 Cold Start Emission Factors

The relative extra emissions of diesel passenger cars are shown in Table 7.27 (Joumard 1990, Gorißen 1990).

Table 7.27: Relative Emission Factors e^{cold} / e^{hot} (Only Valid for Diesel Passenger Cars and temperature range of -10 °C to 30 °C)

Diesel Passenger Cars	e^{cold}/e^{hot}
CO	$1.9 - 0.03 \cdot t_a$
NOx	$1.3 - 0.013 \cdot t_a$
VOC	$3.1 - 0.09 \cdot t_a$ (1)
PM	$3.1 - 0.1 \cdot t_a$ (2)
Fuel Consumption	$1.34 - 0.008 \cdot t_a$

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

8.3 SNAP code 070104 LPG Passenger Cars

8.3.1 Hot Emission Factors

As in the case of gasoline and diesel passenger cars <2.5 tonnes, emission factors are provided for LPG fuelled cars (Joumard 1990, TNO 1980), see Table 7.28. It should be mentioned that the given emission factors are valid for well-adjusted engines, otherwise they are of the same order of magnitude as those valid for gasoline vehicles <2.5 tonnes.

Table 7.28: Speed Dependency of Emission Factors for LPG Vehicles <2.5 t

Pollutant	Cylinder 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	59	-
		Rural	45	-
		Highway	54	-

V: Average speed expressed in km/h
R^2: Correlation coefficient

8.3.2 Cold Start Emission Factors

For LPG passenger cars the available data base is very small (AQA 1990, Hauger et al. 1991). Therefore a temperature dependent emission factor, is provided assuming that the cold start behaviour of these cars is similar to that of conventional gasoline vehicles (Table 7.29).

Table 7.29: Relative Emission Factors e^{cold} / e^{hot}
(Only Valid for LPG Passenger Cars and temperature range of -10 °C to 30 °C)

LPG Passenger Cars	e^{cold}/e^{hot}
CO	$3.66 - 0.09 \cdot t_a$
NOx	$0.98 - 0.006 \cdot t_a$
VOC	$2.24 - 0.06 \cdot t_a$ (1)
Fuel Consumption	$1.47 - 0.009 \cdot t_a$

(1) VOC: if ta > 29°C then $e^{cold}/e^{hot} > 0.5$

8.4 SNAP code 070105 Two Stroke Gasoline 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.

The emission factors are given in Table 7.30. They are relevant mainly for some Eastern European countries (and to some extent for the F.R.Germany). However, it should be noted that due to the limited knowledge of the authors about the actual driving behaviour in Eastern European countries (e.g. average speed on urban and rural roads and on highways) and the limited number of test data, the emission factors are less reliable than, for example, those given for other gasoline passenger cars.

Table 7.30: Emission Factors for Gasoline Two-Stroke Vehicles <2.5 t

	CO [g/km]	NOx [g/km]	VOC [g/km]	Fuel Consumption [g/km]
Urban	20.7	0.30	15.4	111.5
Rural	7.50	1.0	7.20	66.0
Highway	8.70	0.75	5.90	56.9

8.5 SNAP code 070200 Light Duty Vehicles

8.5.1 Hot Emission Factors

Gasoline Powered Light Duty Vehicles

The emission factors for gasoline light duty vehicles are given in Table 7.31. They are based on data of TNO, Greece and CCMC (Heaton et al. 1991, Kyriakis et al. 1991, CCMC 1989 respectively).

Table 7.31: Emission Factors for Gasoline Light Duty Vehicles <3.5 t

	CO [g/km]	NOx [g/km]	VOC [g/km]	Fuel Consumption [g/km]
Urban	30	3.0	3.6	120
Rural	15	2.7	1.7	67.5
Highway	12	3.2	1.0	63.8

Diesel Powered Light Duty Vehicles

Table 7.32 displays the emission factors proposed which have been derived from the same data sources as those for gasoline powered light duty vehicles.

Table 7.32: Emission Factors for Diesel Light Duty Vehicles <3.5 t

	CO [g/km]	NOx [g/km]	VOC [g/km]	PM [g/km]	Fuel Consumption [g/km]
Urban	2.00	1.60	0.40	0.25	106.3
Rural	0.80	1.20	0.25	0.25	68.0
Highway	0.60	1.25	0.13	0.16	63.8

8.5.2 Cold Start Emission Factors

Due to the lack of better data, gasoline and diesel light duty vehicles are treated in the same way as the corresponding passenger cars. This implies that the vehicle usage data for passenger cars are also applied for light duty vehicles. However, it should be underlined that this is a very rough approach, which was chosen only because the working group considered as more appropriate to allocate some cold start emissions to this category rather than to neglect them.

8.6 SNAP code 070300 Heavy Duty Vehicles

8.6.1 Gasoline Powered Heavy Duty Vehicles

Heavy duty gasoline vehicles > 3.5 tonnes play a negligible role in European emissions from road traffic. Emission factors derived from an extrapolation of results from smaller vehicles are presented in Table 7.33.

Table 7.33: Emission Factors for Heavy Duty Gasoline Vehicles >3.5 t

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

8.6.2 Diesel Powered Heavy Duty Vehicles 3.5 - 16 t

The data available on emissions from heavy duty vehicles (Hassel 1983, Umweltbundesamt 1988, Eggleston 1991) are still not detailed enough to take into account all relevant parameters, e.g. different types of engines. Table 7.34 displays the proposed factors. It should be mentioned that the cut-off point of 16 tonnes GVW is somewhat arbitrary. The values given may apply for a range of 12-18 tonnes GVW.

Table 7.34: Emission Factors for Heavy Duty Diesel Vehicles 3.5 - 16 t(1)

	Particulates g/kg fuel (g/km)	CO g/kg fuel (g/km)	VOC g/kg fuel (g/km)	NOx g/kg fuel (g/km)	FC l/100 km(2) (g/km)
Urban	4.3	82.8	12	38.5	27.5
	(0.95)	(18.8)	(2.75)	(8.7)	(227)
Rural	4.3	38.6	4	39.1	22.9
	(0.82)	(7.3)	(0.76)	(7.4)	(189)
Highway	4.3	27.1	4	38.9	18.7
	(0.66)	(4.2)	(0.6)	(6.0)	(154)

(1) The 16 tonne split is somewhat arbitrary. Figures may apply in the range of 12 to 18 tonnes.
(2) Assumed density 0.825 kg/l

However, there is relatively high uncertainty with the data, because recently measured values show somewhat lower emission factors for vehicles put on the market after about 1986 (Umweltbundesamt 1991):

Particulates:	2.9 g/kg fuel
CO:	18.6 g/kg fuel
VOC:	8.1 g/kg fuel
NOx:	36.1 g/kg fuel

irrespective of road type.

8.6.3 Diesel Powered Heavy Duty Vehicles >16 t

The situation with regard to diesel vehicles >16 tonnes GVW is the same as the one for vehicles <16 tonnes (see above). Table 7.35 shows the emission factors proposed.

Table 7.35: Emission Factors for Heavy Duty Diesel Vehicles >16 t(1)

	Particulates g/kg fuel (g/km)	CO g/kg fuel (g/km)	VOC g/kg fuel (g/km)	NOx g/kg fuel (g/km)	FC l/100 km(2) (g/km)
Urban	4.3	51.4	16	44.2	44.4
	(1.6)	(18.8)	(5.8)	(16.2)	(366)
	(1.4)	(17.0)	(5.3)	(16.5)	(Buses: 330)
Rural	4.3	22.2	8	45.2	39.7
	(1.4)	(7.3)	(2.6)	(14.8)	(328)
	(1.2)	(6.2)	(2.2)	(18.2)	(Buses: 280)
Highway	4.3	14.2	8	45.8	35.6
	(1.25)	(4.2)	(2.3)	(13.5)	(294)
	(0.9)	(3.0)	(1.7)	(13.9)	(Buses: 215)

(1) The 16 tonne split is somewhat arbitrary. Figures may apply for vehicles in the range of 12 to 18 tonnes.
(2) Assumed density 0.825 kg/l.

However, there is some uncertainty with the data, because recently measured values show somewhat lower emission factors for vehicles put on the market after about 1986 (Umweltbundesamt 1991):

Particulates:	2.1 g/kg fuel
CO:	19.3 g/kg fuel
VOC:	5.3 g/kg fuel
NOx:	49.1 g/kg fuel

irrespective of road type.

8.7 SNAP codes 070400 Mopeds & Motorcycles < 50cc and 070500 Motorcycles > 50cc

Two wheelers are differentiated further into two classes: motor cycles <50cc cylinder capacity (two stroke only) and motor cycles >50cc cylinder capacity. Moreover, it has been shown worthwhile to distinguish for the second group between two stroke and four stroke engines. While mopeds are mostly driven under "urban" driving conditions, motor cycles are also used for "rural" and "highway" driving. However, the emission data base for these two modes is quite small, so that no detailed breakdown into the three road types can be provided. Therefore, based on relatively rough assumptions, the values available for urban driving (Hartung et al. 1991, Gaudioso 1991, Pattas 1985, TNO 1988, EMPA) were corrected in order to take rural and highway driving into account. Table 7.36 displays the emission factors proposed. These values are considered as relatively unreliable because they are to a large extent based on measurements taken under unrealistic driving conditions. However, it is believed that they nevertheless provide a starting point for the estimation work.

Table 7.36: Emission Factors for Motorcycles

	CO [g/km]	NOx [g/km]	VOC [g/km]	Fuel Consumption [g/km]
< 50 cc	10	0.05	6.0	18
> 50 cc 2 Stroke	22	0.08	15	30
> 50 cc 4 Stroke	20	0.30	3.0	38

8.8 Carbon Dioxide 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 to CO_2. The following formula is applied

$$\text{mass of } CO_2 = 44.011 \text{ (mass of fuel}/(12.011 + 1.008 \cdot r_{H/C})) \qquad (12)$$

with

$r_{H/C}$ = 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:

$$\begin{aligned}\text{mass of } CO_2 = 44.011 &\text{ (mass of fuel}/(12.011 + 1.008 \cdot r_{H/C})) \\ &- \text{mass of CO}/28.011 - \text{mass of VOC}/13.85 \\ &- \text{mass of particulates}/12.011) \qquad (12a)\end{aligned}$$

8.9 Sulphur Dioxide 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:

$$E_{SO2} = 2\sum_j \sum_l k_{S,l} \; b_{j,l} \qquad (13)$$

with

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

$b_{j,l}$ = total annual consumption of fuel of type l in [kg] by vehicles of category j. For the actual $b_{j,l}$ the calculated fuel consumption is taken.

8.10 Lead and other Heavy Metal 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:

$$E_{Pb} = 0.75\sum_{j} k_{Pb}\ b_j \qquad (14)$$

with

k_{Pb} = weight related lead content of gasoline in [kg/kg]

b_j = total annual consumption of gasoline in [kg] by vehicles of category j operated in the reference year

For the actual figure of b_j the statistical fuel consumption should be taken.

Table 7.37 presents emission factors expressed in mg/kg fuel for Cadmium, Copper, Chromium, Nickel, Selenium and Zinc, as provided by the Panel on Heavy Metals and POPs. However, these emission factors have to be considered as preliminary estimates only. More measurements are needed in order to confirm these values.

Table 7.37: Heavy Metal Emission Factors for all Vehicle Categories in mg/kg fuel

Vehicle Category Split (SNAP Code)	Cadmium	Copper	Chromium	Nickel	Selenium	Zinc
Passenger cars, gasoline (070101)	0.01	1.7	0.05	0.07	0.01	1
Passenger cars, catalyst - gasoline (070102)	0.01	1.7	0.05	0.07	0.01	1
Passenger cars, diesel (070103)	0.01	1.7	0.05	0.07	0.01	1
Passenger cars, LPG (070104)	0.0	0.0	0.0	0.0	0.0	0.0
Light duty vehicles, gasoline (070201)	0.01	1.7	0.05	0.07	0.01	1
Light duty vehicles, diesel (070202)	0.01	1.7	0.05	0.07	0.01	1
Heavy duty vehicles, gasoline (070301)	0.01	1.7	0.05	0.07	0.01	1
Heavy duty vehicles, diesel (070302)	0.01	1.7	0.05	0.07	0.01	1
Motorcycles < 50cc (070401)	0.01	1.7	0.05	0.07	0.01	1
Motorcycles > 50cc (070402)	0.01	1.7	0.05	0.07	0.01	1

In addition to the above heavy metals, noble metals used in the catalysts of vehicles (e.g. platinum, rhodium) should also be taken into account.

8.11 Methane Emissions

Methane emission factors could be derived from the literature for all types of vehicles (Bailey et al. 1989, Volkswagen 1989, OECD 1991, Zajontz et al. 1991). It should be reminded that non methane VOC emissions are produced by deducting the CH_4 emissions from total VOC. Table 7.38 provides an overview of CH_4 emission factors. Additional cold start emissions are not taken into account separately but are assumed to be included in the bulk emission factors.

Table 7.38: Methane (CH_4) Emission Factors for all Vehicle Categories

CH_4 Emission Factors [g/km]	Urban	Rural	Highway
Passenger Cars			
Conventional	$0.268 - 0.00573 \cdot V + 0.0000331 \cdot V^2$		
Closed Loop	0.020	0.020	0.020
Diesel CC < 2.0 l	0.005	0.005	0.005
Diesel CC > 2.0 l	0.005	0.005	0.005
L P G	0.080	0.035	0.025
2-stroke	0.150	0.040	0.025
Light Duty Vehicles			
Gasoline	0.150	0.040	0.025
Diesel	0.005	0.005	0.005
Heavy Duty Vehicles			
Gasoline Veh. > 3.5 t	0.140	0.110	0.070
Diesel Veh. 3.5 - 16 t	0.085	0.023	0.020
Diesel Veh. > 16 t	0.175	0.080	0.070
Motorcycles			
< 50 cc	0.100	0.100	0.100
> 50 cc 2 stroke	0.150	0.150	0.150
> 50 cc 4 stroke	0.200	0.200	0.200

V: average speed expressed in km/h

8.12 Nitrous Oxide 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). Again these data are still quite unreliable and need further confirmation by measurements. Cold start emissions are not taken into account separately but are assumed to be already incorporated in the bulk emission factors. The emission factors are shown in Table 7.39.

Table 7.39: Nitrous Oxide (N_2O) Emission Factors for all Vehicle Categories

N_2O Emission Factors [g/km]	Urban	Rural	Highway
Passenger Cars			
Conventional	0.005	0.005	0.005
Closed Loop	0.050	0.050	0.050
Diesel CC < 2.0 l	0.010	0.010	0.010
Diesel CC > 2.0 l	0.010	0.010	0.010
L P G	n.a.	n.a.	n.a.
2-stroke	0.005	0.005	0.005
Light Duty Vehicles			
Gasoline	0.006	0.006	0.006
Diesel	0.017	0.017	0.017
Heavy Duty Vehicles			
Gasoline Veh. > 3.5 t	0.006	0.006	0.006
Diesel Veh. 3.5 - 16 t	0.030	0.030	0.030
Diesel Veh. > 16 t	0.030	0.030	0.030
Motorcycles			
< 50 cc	0.001	0.001	0.001
> 50 cc 2 stroke	0.002	0.002	0.002
> 50 cc 4 stroke	0.002	0.002	0.002

n.a.: not available

8.13 Ammonia Emissions

For estimating ammonia emissions average emission factors are given for conventional and closed loop gasoline passenger cars and light duty vehicles and diesel passenger cars and light duty vehicles, related to the total annual kilometers driven.

These emission factors are based on literature review only and should be considered as broad estimates (de Reydellet 1990, Volkswagen 1989). Table 7.40 shows the emission factors proposed.

Table 7.40: Ammonia (NH_3) Emission Factors for all Vehicle Categories

NH_3 Emission Factors [g/km]	Urban	Rural	Highway
Passenger Cars			
Conventional	0.002	0.002	0.002
Closed Loop	0.070	0.100	0.100
Diesel CC < 2.0 l	0.001	0.001	0.001
Diesel CC > 2.0 l	0.001	0.001	0.001
L P G	n.a.	n.a.	n.a.
2-stroke	0.002	0.002	0.002
Light Duty Vehicles			
Gasoline	0.002	0.002	0.002
Diesel	0.001	0.001	0.001
Heavy Duty Vehicles			
Gasoline Veh. > 3.5 t	0.002	0.002	0.002
Diesel Veh. 3.5 - 16 t	0.003	0.003	0.003
Diesel Veh. > 16 t	0.003	0.003	0.003
Motorcycles			
< 50 cc	0.001	0.001	0.001
> 50 cc 2 stroke	0.002	0.002	0.002
> 50 cc 4 stroke	0.002	0.002	0.002

n.a.: not available

9. SPECIES PROFILES

There is no systematic approach concerning the evaluation and the reporting of species profiles, e.g. it is not clear whether individual compounds, chemical groups or reactivity classes should be reported.

With regard to VOC profiles, Tables 7.41, 7.42 and 7.43 provide information as used by Veldt, Derwent and Loibl et al. in their work on emission estimates for the sector road traffic. In principle the composition given there can also be used for the sectors covered by this Guidebook.

Table 7.41: Composition of VOC Emissions of Motor Vehicles (Data as provided by C.Veldt)
A) Non-methane VOC (composition in weight % of exhaust)

Species or group of species	Gasoline			Diesel	LPG
	Exhaust gas		Evaporation		
	4-stroke engine				
	conventional	3-way catalysts			
Ethane	1.4	1.8		1	3
Propane	0.1	1	1	1	44
n-Butane	3.1	5.5	20	2	
i-Butane	1.2	1.5	10		
n-Pentane	2.1	3.2	15	2	
i-Pentane	4.3	7	25		
Hexane	7.1	6	15		
Heptane	4.6	5	2		
Octane	7.9	7			
Nonane	2.3	2			
Alkanes C>10	0.9	3		30 (1)	
Ethylene	7.2	7		12	15
Acetylene	4.5	4.5		4	22
Propylene	3.8	2.5		3	10
Propadiene	0.2				
Methylacetylene	0.3	0.2			
1-Butene	1.7	1.5	1	)	
1,3 Butadiene	0.8	0.5		) 2	
2-Butene	0.6	0.5	2	)	
1-Pentene	0.7	0.5	2		
2-Pentene	1.1	1	3	1	
1-Hexene	0.6	0.4	)		
1,3 Hexene	0.6	0.4	) 1.5		
Alkanes C>7	0.3	0.2	)	2 (1)	
Benzene	4.5	3.5	1	2	
Toluene	12.0	7	1	1.5	
o-Xylene	2.5	2		0.5	
m,p-Xylene	5.6	4	0.5	1.5	
Ethylbenzene	2.1	1.5		0.5	
Styrene	0.7	0.5			0.1
1,2,3-Trimethylbenzene	0.5	1			
1,2,4-Trimethylbenzene	2.6	4			
1,3,5-Trimethylbenzene	0.8	2			
Other aromatic compounds C9	3.8	3			
Aromatic compounds C>10	4.5	6		20 (1)	
Formaldehyde	1.7	1.1		6	4
Acetaldehyde	0.3	0.5		2	2
Other Aldehydes C4	0.3	0.2		1.5	
Acrolein	0.2	0.2		1.5	
2-Butenal				1.0	
Benzaldehyde	0.4	0.3		0.5	
Acetone	0.1	1		1.5	
	100	100	100	100	100

(1) C13

Table 7.41 (cont.): Composition of VOC Emissions of Motor Vehicles (Data as provided by C.Veldt)

B) Methane (composition in weight % of exhaust)

Gasoline	
- conventional	5
- 3-way catalyst equipped	12
Diesel	4
LPG	3

Table 7.42: Composition of VOC Emissions of Motor Vehicles (Data as used by R. Derwent)

No.	Species	Percentage by mass speciation by source category, w/w %		
		petrol engines exhaust	diesel exhaust	petrol evaporation vehicles
0	methane	8.00	3.7	
1	ethane	1.30	0.5	
2	propane	1.20		
3	n-butane	1.95	2.5	19.990
4	i-butane	0.93	2.5	10.480
5	n-pentane	2.78	2.5	7.220
6	i-pentane	4.45	2.5	10.150
7	n-hexane	1.76	2.5	2.020
8	2-methylpentane	2.14	2.5	3.020
9	3-methylpentane	1.49	2.5	2.010
10	2,2-dimethylbutane	0.28	2.5	0.600
11	2,3-dimethylbutane	0.54	2.5	0.740
12	n-heptane	0.74	2.5	0.703
13	2-methylhexane	1.39	2.5	0.924
14	3-methylhexane	1.11	2.5	0.932
15	n-octane	0.37	2.5	0.270
16	methylheptanes	3.90	2.5	0.674
17	n-nonane	0.18	2.5	
18	methyloctanes	1.58	2.5	
19	n-decane	0.37	2.5	
20	methylnonanes	0.84	2.5	
21	n-undecane	2.75	2.5	
22	n-duodecane	2.75	2.5	
23	ethylene	7.90	11.0	
24	propylene	3.60	3.4	
25	1-butene	1.40	0.5	1.490
26	2-butene	0.50		2.550
27	2-pentene	0.90		2.350
28	1-pentene	0.70	0.7	0.490
29	2-methyl-1-butene	0.70		0.670
30	3-methyl-1-butene	0.70	0.5	0.670
31	2-methyl-2-butene	1.40	0.5	1.310
32	butylene	0.50		
33	acetylene	6.30	3.2	
34	benzene	3.20	2.6	2.340
35	toluene	7.20	0.8	5.660
36	o-xylene	1.58	0.8	1.590
37	a-xylene	2.06	0.8	1.880
38	p-xylene	2.06	0.8	1.880
39	ethylbenzene	1.20	0.8	1.320
40	n-propylbenzene	0.16	0.5	0.410
41	i-propylbenzene	0.13	0.5	0.120
42	1,2,3-trimethylbenzene	0.40	0.5	0.310
43	1,2,4-trimethylbenzene	1.60	0.5	1.600
44	1,3,5-trimethylbenzene	0.50	0.5	0.390
45	o-ethyltoluene	0.38	0.5	0.370
46	a-ethyltoluene	0.63	0.5	0.640
47	p-ethyltoluene	0.63	0.5	0.640
48	formaldehyde	1.60	5.9	
49	acetaldehyde	0.35	1.0	
50	proprionaldehyde	0.57	1.0	
51	butyraldehyde	0.07	1.0	
52	i-butyraldehyde		1.0	
53	valeraldehyde	0.03		
54	benzaldehyde	0.39		
55	acetone	0.14	2.0	

Table 7.43: Composition of VOC Emissions of Motor Vehicles (Loibl et al. 1993)

	Exhaust - Conventional Cars	Exhaust - Catalyst Cars	Exhaust - Cold Start (all cars)	2 stroke Engines	Diesel Engines	Evaporation losses
Non reactive						
Ethane	2	3	1	1	-	-
Acetylene	8	3	4	2	-	-
Paraffins						
Propane	-	-	-	1	-	2
Higher Paraffins	32	48	45	72	52	85
Olefins						
Ethene	11	7	6	3	6	-
Propene	5	4	2	1	3	-
Higher Olefins (C4+)	6	9	7	9	3	10
Aromatics						
Benzene	5	1	4	2	-	1
Toluene	10	11	140	3	-	1
Higher Aromatics (C8+)	21	6	21	6	12	1
Carbonyls						
Formaldehyde	-	8	-	-	13	-
Acetaldehyde	-	-	-	-	3	-
Higher Aldehydes (C3+)					4	
Cetones					1	
Other NMVOC						
Alcohols, esters, ethers						
Acids						
Halogenated Compounds						
Other/undefined					3	

10. UNCERTAINTY ESTIMATES

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 in emission factor measurements. While, in principle and apart from the problems mentioned above, the data base for hot emission factors is quite rich and reliable, there is still much uncertainty associated with cold start and evaporative emission measurements, and possible systematic errors in these areas cannot be excluded.

- 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. However, analysis presented elsewhere (Andrias et al. 1993b) shows that in most cases such errors are less important that errors in emission factors. 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. Nevertheless, it should be mentioned that assumptions which affect evaporative emissions are not always reflected in the calculated fuel consumption, which might lead to largely dispersed VOC estimates that do not violate the fuel balance. Although such a problem is rather unlikely to appear, this is a case where a systematic error in the assumption of one parameter can have a significant impact on the overall calculation.
  - ⇒ 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 7.44 provides qualitative indications of the "precision" which can be allocated to the calculation of the individual emissions. The table is based on subjective estimates of the working group members. It should be mentioned that only where the indicator 'A' is given the emission estimate is considered to be of satisfactory quantity (i.e. based on statistically significant number of measurements).

In order to illustrate this above evaluation, Table 7.45 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, using the data base which was constituted by the CORINAIR Working group. It is interesting to note that the mean CV for measured VOC emission factors is 33%, while the mean CV for fuel consumption factors is 11%. Moreover, measured data from older ECE classes (conventional cars) show lower variation than measurements of catalyst-equipped vehicles. This is partly due to the fact that there are fewer data from cars of recent model years compared to the data available for older classes; another reason for these variations is that, since the emission factors have been determined for on-road vehicles, the emission behaviour of recent vehicle classes differs according to the maintenance level of each vehicle, because the emission control systems of catalyst-equipped cars are sensitive to bad maintenance. Moreover, the category "Closed Loop Catalyst Cars" covers a number of different emissions standards and consecutively emission control techniques of different efficiency.

Table 7.44: Precision Indicators of the Emission Estimate for the Different Vehicle Categories and Pollutants

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

Vehicle Category	Pollutants										
	NOx	**CO**	**NMVOC**	**CH_4**	**PM**	**N_2O**	**NH_3**	**SO_2**	**CO_2**	**Pb**	**FC**
Gasoline Passenger Cars											
Pre-ECE	A	A	A	A	-	C	C	A	A	B	A
ECE 15/00-01	A	A	A	A	-	C	C	A	A	B	A
ECE 15/02	A	A	A	A	-	C	C	A	A	B	A
ECE 15/03	A	A	A	A	-	C	C	A	A	B	A
ECE 15/04	A	A	A	A	-	C	C	A	A	B	A
Improved conventional	A	A	A	A	-	C	C	A	A	B	A
Open Loop	A	A	A	A	-	C	C	A	A	B	A
Closed Loop	A	A	A	B	-	C	C	A	A	B	A
Diesel Passenger Cars											
CC <2.0l	A	A	A	B	A	C	C	A	A	-	A
CC >2.0l	A	A	A	B	A	C	C	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
Gasoline Light Duty	A	A	A	C	-	D	D	A	A	B	A
Diesel Light Duty	A	A	A	C	B	D	D	A	A	-	A
Gasoline Heavy Duty	D	D	D	D	-	D	D	D	D	D	D
Diesel Heavy Duty 3.5-16t	B	B	B	D	B	D	D	B	B	-	B
Diesel Heavy Duty >16t	B	B	B	D	B	D	D	B	B	-	B
Two Wheelers <50 cc	B	B	B	D	-	-	-	B	B	B	B
> 50 cc 2 stroke	B	B	B	D	-	-	-	B	B	B	B
> 50 cc 4 stroke	B	B	B	D	-	-	-	B	B	B	B
Cold Start Emissions											
Pass. Cars Conventional	B	B	B	-	-	-	-	-	B	B	B
Pass. Cars Closed Loop	C	C	C	-	-	-	-	-	C	B	C
Pass. Cars Diesel	C	C	C	-	C	-	-	-	C	-	C
Pass. Cars LPG	C	C	C	-	-	-	-	-	C	-	C
Gas Light Duty Vehicles	D	D	D	-	-	-	-	-	D	D	D
Diesel Light Duty Vehicles	D	D	D	-	D	-	-	-	D	-	D

Table 7.45: 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
	Improved Conventional	1.4 l < CC < 2.0 l	39.9
	Open Loop	CC < 1.4 l	47.5
	Open Loop	1.4 l < CC < 2.0 l	49.2
	Closed Loop	All categories	44.2
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
	Closed Loop		17.2
	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
	Closed Loop		21.2
	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
	Closed Loop		23.8
	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 revealed once more that knowledge of these emissions is far from complete. The points listed below are those for which the gaps in knowledge seem to be most striking and additional studies are required.

In particular the following points require further attention:

i) emission factors for heavy duty vehicles and motor cycles;

ii) definition of realistic transient driving modes for all vehicle categories, but in particular for heavy duty vehicles and motor cycles;

iii) description of driving behaviour (statistical data), e.g. average mileage per vehicle, number of trips per day, average trip length and so on;

iv) correction factors for local particularities, e.g. mountain regions (altitude and slopes), climatic particularities, local speed profiles;

v) cold start emissions for all vehicle categories;

vi) independent estimations, e.g. nationwide 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;

viii) other unregulated pollutants (e.g. PAH, benzene)

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.

Above all, there are additional requirements of scientists, e.g. modellers, concerning the description of emissions in time, space and composition. The group got the impression that these tasks can only be accomplished if the work on emission estimates for road traffic is enlarged and becomes a permanent topic.

Finally, for many reasons, but in particular for the development of an efficient air pollution management policy, the work on estimation techniques for the prediction of future emissions is to a large extent based on the development of emission inventorying methodology (e.g. Samaras et al. 1991, Metz et al. 1993, Joumard et al. 1994).

12. SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

This is a difficult task which should not be underestimated. In general one can distinguish two approaches for the spatial disaggregation of road transport emissions :

The top-down approach: Such an approach can be used in the absence of vehicle use data in smaller areas. 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 coordinates can be provided by the statistical office of the EC (EUROSTAT) in Luxembourg.

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 F.R.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.

The bottom-up approach: A few countries may already have available the input data needed for the calculation scheme for a smaller NUTS than the whole of their country. These countries, of course, should directly apply the calculation scheme to the smaller units and subsequently build 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.

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 (and evaporative losses) 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.

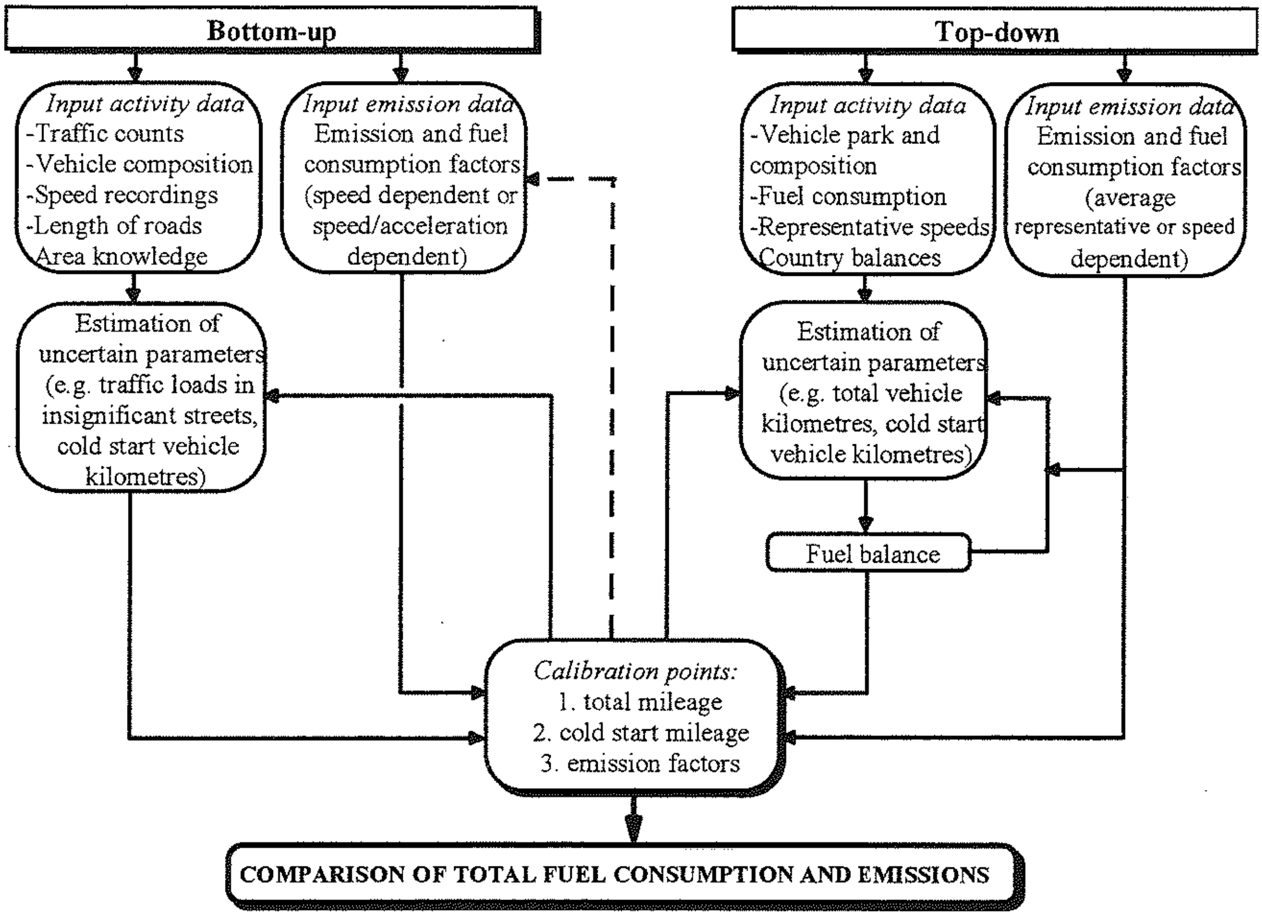
At this point it has to be recalled that spatial and temporal disaggregation of the emissions is coupled with a deterioration of the accuracy of the emission estimates. This is particularly true in the case of road transport emissions, because

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.



Flowchart of the proposed reconciliation method.

The above Figure 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 (e.g. Wegerer 1990, Jost et al. 1992) 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.

The scheme shown in Fig. 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 cooperation of local experts.

14. ADDITIONAL COMMENTS

As mentioned above the results of this work have been translated into a menu-driven spreadsheet computer programme, called COPERT90 (**Co**mputer **P**rogramme to Calculate **E**missions from **R**oad **T**raffic), which substantially facilitates the practical application of the methodology (see Andrias et al. 1993).

At this point it has to be mentioned that since 1994 a COST action was signed by a large number of countries, aimed at the harmonisation of the estimates from road and non-road transport. *COST319 "Estimation of Pollutant Emissions from Transport"*. This activity can be categorised under two major headings:

- studies to estimate the current situation and to forecast the future situation
- studies to develop and evaluate solutions.

The COST 319 objectives as they are formulated today include the *Estimation of pollutant emissions from transport in Europe* and the *Evaluation of alternative solutions for the future*. The wide field covered by the action, as well as the large number of experts involved, imposed the formation of four main working groups, specialised in ***emission factors, traffic characteristics, inventory tools and non-road traffic***. It is evident that the technical work carried out in the framework of this action can be of great help to the development and improvement of the work carried out both in the framework of UN-ECE EMEP Task Force on emission inventories and for the activities of the European Environment Agency's - Topic Center on Air Emissions.

In addition, national programmes under development (e.g. German/Swiss/Austrian collaboration) have already started producing results, which will greatly help to close the gaps in knowledge also identified in this report. In particular, in the framework of this project a large data base containing instantaneous measurements of pollutant emissions over a variety of cycles for passenger cars, but - more important - for goods vehicles is about to be finalised (see for example Hassel et al. 1993), together with a computerised Handbook of emission factors.

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

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16. VERIFICATION PROCEDURES

In the following only some concepts for emissions inventory verification are outlined, that are applicable in the case of road transport emission inventories. For a more detailed discussion on these issues, refer to Mobley et al. 1994 (chapter AVER 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 E.P.A. 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.

iii) The second category comprises:

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

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

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

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

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

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List of Abbreviations

CC:	Cylinder Capacity of the Engine
CH_4:	Methane
CO:	Carbon Monoxide
CO_2:	Carbon Dioxide
FC:	Fuel Consumption
GVW:	Gross Vehicle Weight
NH_3:	Ammonia
NMVOC:	Non-Methane Volatile Organic Compounds
N_2O:	Nitrous Oxide
NOx:	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
Pb:	Lead
SOx:	Sulphur Oxides
VOC:	Volatile Organic Compounds

List of Symbols

a_j = number of gasoline vehicles of category j, operated in 1990

$a_{j,g}$ = number of vehicles of category j produced within the period of ECE legal conformity g or belonging to a distinct technology step (only vehicles passenger cars)

$b_{j,l}$ = total annual consumption of fuel of type l in [kg] by vehicles of category j operated in 1990

$c_{j,k}$ = average fuel consumption in [g/km] of vehicle category j on road class k

$d_{j,k}$ = share of annual mileage driven on road class k by vehicle category j

$e_{hot,year,i,j,k}$ = average fleet representative baseline emission factor in [g/km] for the pollutant i, for the vehicle category j, operated on roads of type k with hot engines.

$e_{*,hot,year,i,j,k}$ = average fleet representative baseline emission factor in [g/kg fuel] for the pollutant i, relevant for the vehicle category j, operated on roads of type k with hot engines.

e^{cold}/e^{hot} = ratio of emissions of cold to hot engines

$e_{hot,i,j,k,g}$ = emission factor in [g/km] for pollutant i, for the vehicle category j, operated on roads of type k with hot engines, valid for regulatory step g

$e(z)$ = mathematical equation (e.g. formula of best fit curve) of the speed dependency of $e_{hot,z;i,j,g}$

$f_k(z)$ = equation (e.g. formula of "best fit" curve) of the speed distribution which corresponds to the driving patterns of gasoline vehicles < 2.5 t on road classes "rural", "urban" and "highway"

$g_{j,k,l}$ = share of annual consumption of fuel of type l used by vehicles of category j, driven on road type k

h_j = number of vehicles of category j

$k_{s,e}$ = weight related sulphur content of fuel of type l in [kg/kg]

k_{Pb} = weight related lead content of gasoline in [kg/kg]

l_{trip} = average trip length

m_j = total annual mileage in [km] of vehicle category j

$m_{j,k}$ = total annual mileage in [km] of vehicle category j on road class k

$r_{H/C}$ = ratio of hydrogen to carbon atoms in the fuel

$s_{j,g}$ = share of vehicles of category j of total national fleet, belonging to a period of legal conformity g (only applicable for gasoline vehicles < 2.5 t)

t_a = monthly mean ambient temperature in [°C]

v_j = average annual mileage driven by each vehicle of category j

z = the speed of gasoline vehicles <2.5 t on road classes "rural", "urban" and "highway"

β_j = fraction of mileage driven with cold engines

$E_{hot,i,j,k}$ = emissions of the pollutant i in [g] caused in the reference year 1990 by vehicles of category j driven on roads of type k with hot engines

$E_{cold,i,j}$ = emissions of the pollutant i due to cold starts in urban areas, caused by vehicles of category j

O_l = total annual consumption of fuel [kg] of type l

V = vehicle speed in [km/h]

List of Indices

g	=	indicator of regulatory situation applicable to vehicle ECE regulation steps 0 - 4 or earlier (1 - 6, only relevant for gasoline powered vehicles <2.5 t) or technology steps
i (pollutants)	=	1 - 10 for the pollutants covered
j(vehicles category)	=	1 - 39 (or 34 if only on-road vehicles are considered) for the vehicle categories defined in the COPERT 90 nomenclature
k (road classes)	=	1 - 3 for "urban", "rural" and "highway" driving pattern
l	=	fuel type (1 - 3 for gasoline, diesel, LPG)

19. RELEASE VERSION, DATA AND SOURCES

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SNAP CODE : **070600**

SOURCE SECTOR TITLE : **Gasoline Evaporation from Vehicles**

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. CONTRIBUTION 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 1 shows.

Table 1: 1990 Total Evaporative Emissions as Percentage of the National and EU Total VOC of Road Transport

B	DK	D	F	GR	IRL	I	L	NL	P	E	UK	EU (12)	Europe (28)
34.2	34.9	22.1	30.1	28.2	44.8	23.9	41.9	n.a.	33.0	27.1	14.5	23.7	22.7

n.a. = not available

3.1 Definitions

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

(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.

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. Carburetor 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.

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

and

$$S^c = (1-q)\,(p \cdot x \cdot e^{s,hot} + w \cdot x \cdot e^{s,warm}) \quad (2)$$

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

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

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

$$x = v_j / (365 \cdot l_{trip}) \quad (5)$$

$e^{s,hot}$ = 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

(1) Engines are defined as "cold" or "warm" if the water temperature is below 70°C

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 7.14, Table 2 summarizes the methods proposed for application for the calculation of evaporation losses.

Table 2: Summary of Calculation Methods applied for Calculation of Evaporation Losses (cf. chapter B710, table 7.14)

Evaporation	NMVOC
Pass. Cars Conventional	A
Pass. Cars Closed Loop	A
Light Duty Vehicles	C
Two Wheelers <50 cc	D
Two Wheelers >50 cc .	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 3 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 3: 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 [%]
	< 1.4 l	0.0
B	1.4 - 2.0 l	3.1
	> 2.0 l	1.8
	< 1.4 l	8.4
D	1.4 - 2.0 l	8.4
	> 2.0 l	8.4
	< 1.4 l	0.0
DK	1.4 - 2.0 l	0.0
	> 2.0 l	0.0
	< 1.4 l	4.9
E	1.4 - 2.0 l	4.9
	> 2.0 l	4.9
	< 1.4 l	0.0
F	1.4 - 2.0 l	4.2
	> 2.0 l	15.5
	< 1.4 l	1.0
GR	1.4 - 2.0 l	1.0
	> 2.0 l	1.0
	< 1.4 l	5.0
I	1.4 - 2.0 l	5.0
	> 2.0 l	5.0
	< 1.4 l	0.0
IRL	1.4 - 2.0 l	0.0
	> 2.0 l	0.0
	< 1.4 l	5.0
L	1.4 - 2.0 l	10.0
	> 2.0 l	15.0
	< 1.4 l	0.0
NL	1.4 - 2.0 l	0.0
	> 2.0 l	10.0
	< 1.4 l	0.0
P	1.4 - 2.0 l	10.0
	> 2.0 l	30.0
	< 1.4 l	0.0
UK	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 4 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 4: Summary of Emission Factors for Estimating Evaporative Emissions of Gasoline Powered Vehicles (all RVP in kPa, all temperatures in ^oC)

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 behavior 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 7.44, Table 5 provides qualitative estimates of the precision which can be allocated to the calculation of evaporative losses.

Table 5: Summary of Precision Indicators of the Evaporative Emission Estimates (cf. Chapter B710 Table 7.44)

Evaporation	NMVOC
Pass. Cars Conventional	C
Pass. Cars Closed Loop	C
Light Duty Vehicles	D
Two Wheelers <50 cc	D
Two Wheelers >50 cc 2 str.	D
Two Wheelers >50 cc 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 COPERT90 (**Com**puter **P**rogramme to Calculate **E**missions from **R**oad **T**raffic), which substantially facilitates the practical application of the methodology (see Andrias et al. 1993).

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

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 (standardized vapour pressure measurement, conducted at 38 °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 [°C]

$t_{a,min}$ = monthly mean minimum ambient temperature in [°C]

$t_{a,rise}$ = monthly mean of the daily ambient temperature rise in [°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 carburetor

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

19. RELEASE VERSION, DATA AND SOURCES

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Source :

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