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TREM-

Transport Emission Model for Line Sources - Methodology

Technical report

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Executive Summary

The prime objective of the TREM model is the estimation of road traffic emissions with high temporal and spatial resolution, to be used as a tool in urban air quality management. The model provides emission data, an important input to dispersion and photochemical models, health effect analysis, impact studies and Air Quality Management. Besides the estimation of road transport emissions, the model calculates the fuel and energy consumption usable in different types of applications.

The TREM model describes the vehicle emissions based on the average speed approach proposed by MEET/COST319 projects. This approach considers aggregated information for various driving patterns, where the driving pattern is represented by average speed. The emission factors suggested by the methodology were derived from the data collected during several European experiments and based on best-fit curves that correlate emission measurements with speed. This methodology is recommended for average speeds above 10 $km.h^{-1}$ and for the applications when vehicle kinematics is not relevant. The following pollutants are covered: CO, NO_x, SO_2, VOC, CO_2 and particulate matter.

Keywords: emission modelling, road traffic emissions, air pollution

Contents

1 Introduction

At present, road traffic constitutes one of the principal sources of air pollution in urban areas and it is responsible for a significant portion of anthropogenic emissions. To develop a consistent approach for analysing traffic-induced environmental pressure, a precise quantification of pollutant amount emitted by vehicles to the atmosphere is essential. One of the approaches commonly used for this purpose is emission modelling.

1.1. Background

The main purpose of emission models consists on estimating emission data on different spatial and temporal scale to be used in extend type of applications. The current state-of-the-art in vehicle emission models comprises a set of methodologies. They range from calculations at a microscopic scale (i.e. for a single vehicle, or for a street) to a macroscopic calculation (i.e. regional, national and global levels) through the inventory of an urban transport network [Joumard, 1999]. Furthermore, the models differ by the way they take into account the following parameters: pollutants covered; type of emissions (hot, cold, evaporative); fleet composition (vehicle categories, age); driving pattern (average speed only or instantaneous speed and acceleration).

A significant effort to harmonize different methodologies and emission factors concurrently and independently developed in the last years has been carried out by several projects including the action COST 319 (on The Estimation of Emissions from Transport), the European Commission sponsored project MEET (Methodologies to Estimate Emissions from Transport), and CORINAIR framework. In the scope of these activities it is currently available a harmonized methodology to road traffic emission estimation [MEET, 1999; EEA, 1999].

Based on the mentioned above methodologies, several emission models have been developed. One of the widely used is COPERT model, which development was financed by the European Environmental Agency and is contemplate yearly emission estimation on national level. [COPERT III, 2000].

1.2. Objectives

This report describes the methodology implemented in TREM -Transport Emission Model for Line Sources. The current model has been developed to support quantification of emissions induced by road traffic and based on the emission functions derived from MEET/COST methodology. This model is recommended for emission estimations on the urban level with hourly resolution and particularly designed for line sources. For this purpose the model is implemented in GIS environment (ArcView). Additionally, a link to transportation modelling has been developed in order to obtain traffic volume data to assign for each road segment.

2. Methodology

In general terms, the estimation of transport-related emissions can be based on the equation

$$\boldsymbol{E} = \boldsymbol{e} * \boldsymbol{a},$$

were ***E*** is the amount of emission, ***e*** is the emission factor per unit of activity, and ***a*** is the amount of transport activity. This equation has to be applied for each vehicle category, since the emission factors and the activity are different.

The emission factor, ***e***, is usually expressed in $g.km^{-1}$ and primarily related to driving conditions and vehicle type. The activity, ***a***, is a product of the number of vehicles for each of the categories and the travelled distance by vehicle over the time unit, in km.

2.1. Emission factors

As mentioned above, the methodology used to calculate emission factors is based on MEET/COST approach. Furthermore, to compile a consistent model the following conditions were taken into consideration:

- Input data availability, and
- Intended use of modelling results.

Thus, emission factors based on average speed were considered as the best approach due to the absence of more detail information relating to vehicle dynamic. Different technology (engine type, model year) and engine capacity are distinguished in TREM model to derive emission factors.

2.1.1. Pollutants covered

In this model version the calculation algorithm for the following pollutants emitted by road traffic is implemented:

- Carbon monoxide (CO);

- Nitrogen Oxides (NO_x), given as NO_2 equivalent;
- Volatile Organic Compounds (VOC), including methane,
- Carbon Dioxide (CO_2);
- Sulphur Dioxide (SO_2);
- Particulate matter (PM).

2.1.2. Emission type

Road traffic emission calculation is accessed as the sum of hot emission (i.e. under stabilised engine operation), cold start (water temperature is below 70ºC) and evaporative (from fuel evaporation) emissions.

2.1.3. Vehicle categories

To an accurate estimation of air pollutant emissions from road transport splitting of vehicles by categories is required. In the current model, the following vehicle categories are distinguished:

- Gasoline Passenger Cars;
- Diesel Passenger Cars;
- LPG Passenger Cars;
- Gasoline Light Duty Vehicles;
- Diesel Light Duty Vehicles;
- Diesel Heavy Duty Vehicles;
- Urban Busses and Coaches;
- Motorcycles;
- New Technologies.

2.1.4. Vehicle classes

In addition to the different categories, a detailed classification of the vehicle is implemented in the emission model. This classification is based on model year, engine type, emission standards and engine capacity. A detailed list of vehicle classes can be found in Annex 1. In order to identify the level of emission control, the years of introduction of the various amendments to EU legislation is linked with the model years of vehicles within the fleet. The emission standards implementation dates are presented in Table 1.

Table 1. Classification of vehicles in accordance with EC emission standards implementation dates

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Gasoline Pass. Cars	Pre ECE		ECE 1500 & 01						ECE 15 02			ECE 1503				ECE 1504					
Diesel pass. Cars & LPG	Conventional																	EURO 1			
Light Duty Vehicles	Conventional																				
Heavy Duty Vehicles & Bus	Conventional																				
Motorcycles	Conventional																				

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Gasoline Pass. Cars	ECE 1504		EURO 1				EURO 2					EURO 3					EURO 4				
Diesel Pass. Cars & LPG	EURO 1							EURO 2				EURO 3					EURO 4				
Light Duty Vehicles	Conventional						EURO 1			EURO 2			EURO 3					EURO 4			
Heavy Duty Vehicles & Bus	Conventional				EURO 1				EURO 2			EURO 3					EURO 4			EURO 5	
Motorcycles	Conventional							Stage 1				Stage 2									

2.2. Transport activity

As previously mentioned, transport activity is one of the principal input data to estimate road traffic emissions. Transport activity is defined as:

$$a = n * l,$$

where: ***n*** is the number of vehicles for each of the categories and ***l*** is the average distance travelled by the average vehicle of the category over the time unit, in km.

There are two possible ways to obtain transport activity data: direct traffic flow measurements or transport modelling. Each of these approaches has advantages and disadvantages. Direct measurements represent real data at determined point for a specific time period those minimizing data error in comparison with modelling. However, usually it is not possible to obtain enough measurements for all study area with the required resolution. From the other side, transportation models provide detailed information concerning traffic flux for each road segment. Also, it is possible to distinguish between different vehicle categories, such as passenger cars, light duty vehicles, bus, etc. while automatic measurement systems usually provide only total number of vehicles. Nevertheless, as any modelling tool transportation model has an associated error and the results should be carefully validated. These uncertainties could be not significant for the objectives for which the models have been initially developed (analysis of congestion, economic inefficiencies, alternative development patterns, etc..) but for linking with emission models the degree of certitude for input data, such as average speed, trip distance, has to be assessed [Gilson *et al*., 1997].

2.3. Link to other modelling tools

The TREM model is directly connected to other modelling tools, such as transportation model to obtain the traffic volume data for each road segment, and air quality model that calculate pollutant concentration based on emission data provided by TREM (Figure 1).

Transport models are designed to simulate traffic demand taking into account a defined transport network structure and by means of the estimated “Origin-Destination” (O-D) matrix. The ultimate goal is to simulate traffic on a geographic network per time period. The following features are of main concern:

- Transport flow. i.e. number of vehicles by mode (private passenger cars, public transport, etc.) per time interval for each road segment;
- Average speed for each link;
- Number of starts and trip length for each vehicle category.

Outputs from these models are adapted in order to obtain input information to the emission model with the required resolution and in the specified format.

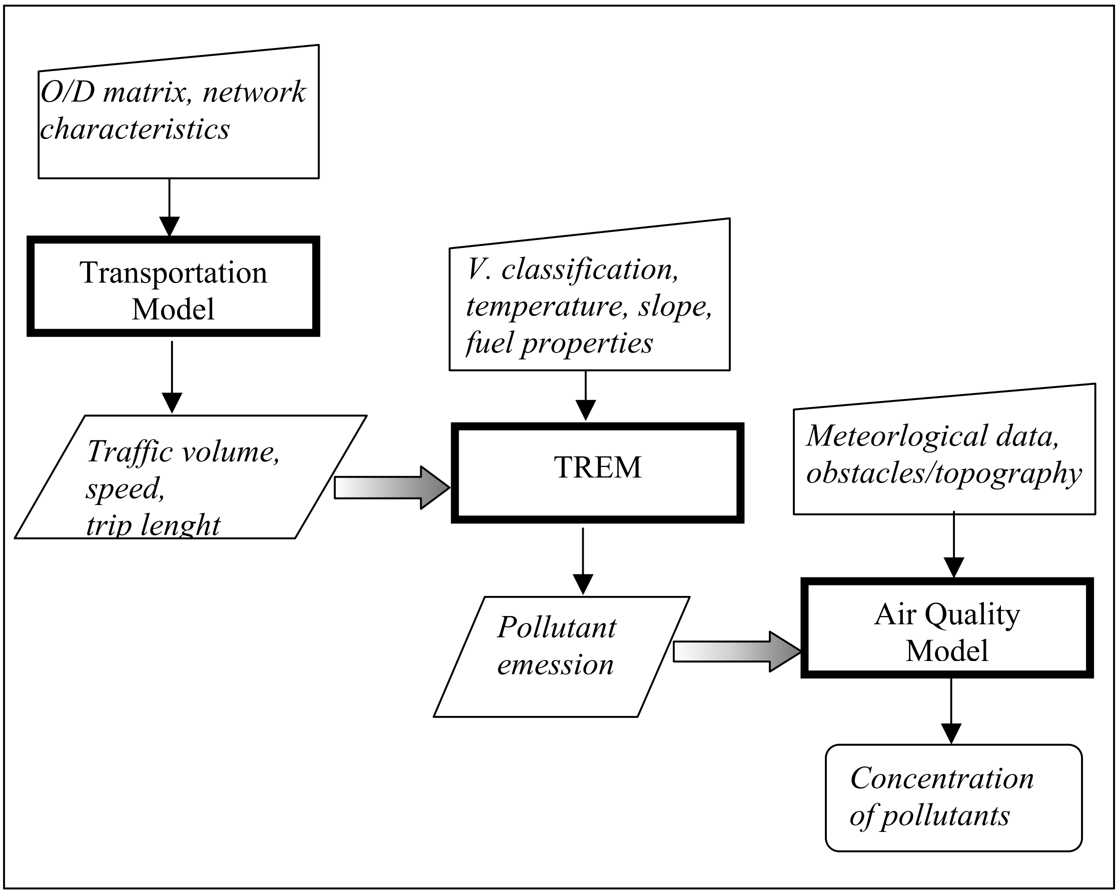


Figure 1. Information flow between modelling tools

TREM model use traffic volume estimated by transportation model and other required information to calculate emission rate of several pollutants induced by vehicles. This data is essential input for air quality models able to simulate physical and chemical processes in the atmosphere and to predict concentration of the pollutants. Depending on air quality model requirements, emission data estimated for each road segment can be aggregated for regular cells using Geographical Information System.

3 Model structure and Data requirements

The TREM model is implemented as a FORTRAN program. The link to the transportation model and to the ArcView spatial information is possible through the input and output data files structure where each road segment have unique ID number and is used to join the tables created in different applications. An example of input files used by the TREM is presented in Annex 3.

3.1. Data requirements

The emission model needs a set of data to be used in calculations. This data are mainly related to traffic characteristics and driven conditions, but some additional parameters such as air temperature and fuel properties are also required. The following information is required for each road segment:

- Traffic volume,
- Vehicle speed,
- Distribution of vehicles by categories (passenger cars, LDV,HDV, etc.),
- Distribution of vehicles by classes (based on age and technology),
- Road segment length.

In information absence, the same distribution of vehicles by categories and by classes may be considered for all roads.

3.2. Calculation algorithm

All the calculations are performed within the main module, implemented as a FORTRAN program. A diagram of the module items and their interrelations is shown in Figure 2. Several steps during the model execution can be distinguished:

Step 1: Read all input information from the text files created in the graphic interface.

Step 2: The total number of vehicles for each link is disaggregated into vehicle categories and classes.

Step 3: The hot emission factors [g.km-1] for each pollutant and for each vehicle class are estimated as a function of average speed in the link.

Step 4: The weighted hot emission factor [g.km-1] for each link is calculated by multiplying the emission factor of each vehicle class by the number of vehicles of the respective vehicle class.

Step 5: The total amount [g] emitted from the hot engine for each road link is estimated by multiplying the weighted emission factor by road length.

Step 6: A cold distance [km] for catalyst and non-catalyst cars is estimated as a function of ambient temperature and average speed.

Step 7:The total amount of cold emissions [g] during cold trips is calculated taking into account ambient temperature and average speed.

Step 8: The cold emissions rate [g.km-1] is calculated for each pollutant assuming a uniform distribution along the cold distance.

Step 9: The total cold emission is calculated using the cold emissions rates and the number of vehicles with and without catalysts.

Step 10: The total hot plus cold emission for each pollutant for each road link is calculated.

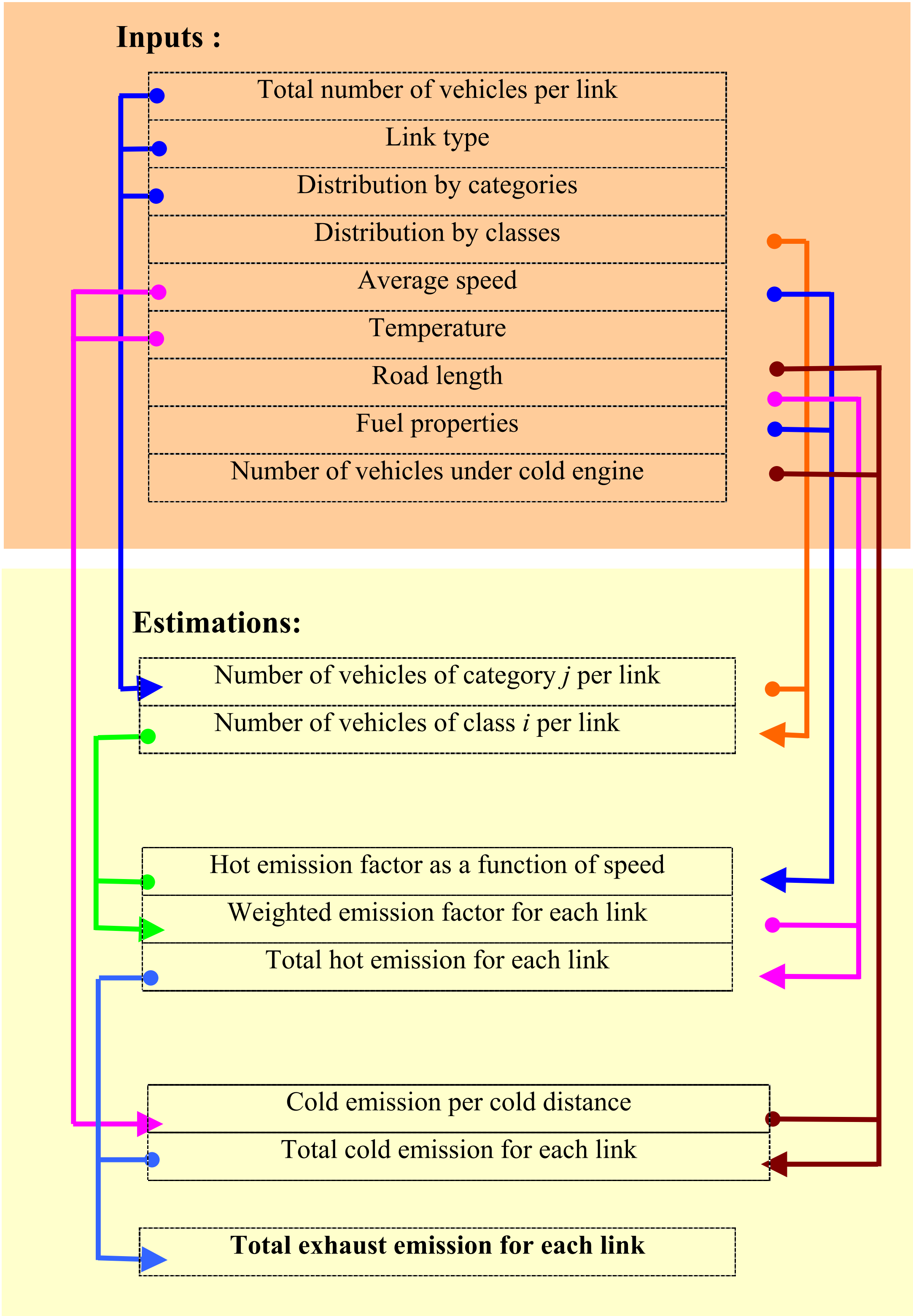
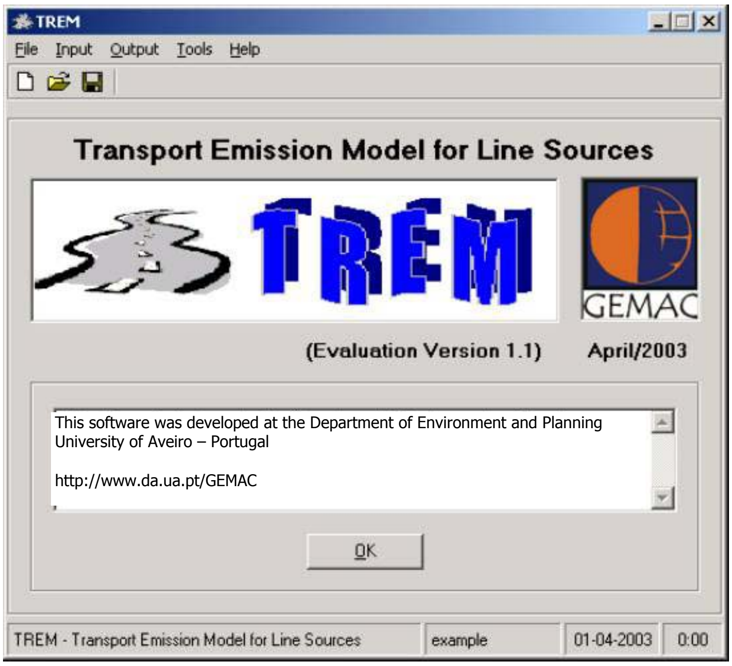


Figure 2. TREM main calculation module for exhaust emission quantification.

3.3. Graphic interface

- A user-friendly graphic interface has been developed in order to simplify the input of information required by the emission model. One of the additional functions of the interface is the preliminary verification of the values introduced by the user, allowing elimination of a number of errors in the input data. A detailed description of each menu is given in the model manual (see Annex A.9).



All input information and configuration required by the model are arranged as individual projects saved in separate directories. Creating a new project from the interface will automatically create a new directory and set initial values for main project variables. The values used for initialisation are based on average European values on fleet composition projection and fuel properties for the year 2000 derived from the MEET study [Hickman, 1999]. These values are stored as a default project and can be changed by the user.

The input data are grouped in the following sets:

- **Network definition:** All information used for the network characterisation is compiled outside of interface, preferably in ACCESS. The data should be saved in *.dbf format

- **Vehicle categories:** The distribution of the vehicles by categories is introduced directly in the interface. The Type Number used in this menu makes a link to the Link Type from the network description and defines a fraction of each vehicle category on each road type. The distribution used to define each type can be based on statistical information or derived from the counting points. At least one link type has to be defined for the network. However, if the required information is available, all road links may have a particular distribution of vehicle categories.

- **Vehicle classes:** More detailed information on fleet composition related to the emission reduction technology and engine capacity is introduced in the Vehicle Classes menu. It is assumed that only one distribution is defined for the entire network and no variation for the links is accessible. This fact is associated to the limited information frequently available on the topic. The total contribution of vehicle classes to a category has to be 100%.

- **Cold distance:** Similar to the network definition, all information used for the cold distance dialog is compiled outside the interface, preferably in ACCESS. The data should be saved in *.dbf format. The information introduced in this dialog is not required for hot emission estimation. However, if the total emission is the objective of the analysis, the inputs for cold emissions are required.

- **Other parameters:** contain information on fuel properties and ambient temperature.

The hot, cold and total emissions are calculated independently from the respective dialog boxes by running the executable file in the main calculation module. The user can select a set of pollutants to be calculated and their respective units. The outputs can be provided by the emission model in [g.km-1] or in [g] for each road link. In the second case, the emission rate is multiplied by the road length and is useful for analysis of the total emissions. However, emissions presented in [g.km-1] are more suitable when a not entire road link is considered for the analysis. This situation may occur when the air quality model domain does not agree with road cross-sections and in this case only a fraction of the road link within the domain has to be taken into account.

The export of the data is also available from the graphic interface. The function facilitates the output data processing by allowing the sort of the data by road name, ID-number or any other attribute. Additionally, a set of relevant columns can be selected from the list. This function is specifically suitable for large networks. The export of the data is recommended when emissions are to be used as input to an air quality model.

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4. References

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Annex 1: Vehicle categories and classes

Vehicle category	Classification based on age and capacity		**TREM code**
Gasoline Passenger Cars	PRE ECE	CC < 1,4 l 1,4 l < CC < 2,0 l CC > 2,0 l	**k1** **k2** **k3**
	ECE 15-00/01	CC < 1,4 l 1,4 l < CC < 2,0 l CC > 2,0 l	**k4** **k5** **k6**
	ECE 15-02	CC < 1,4 l 1,4 l < CC < 2,0 l CC > 2,0 l	**k7** **k8** **k9**
	ECE 15-03	CC < 1,4 l 1,4 l < CC < 2,0 l CC > 2,0 l	**k10** **k11** **k12**
	ECE 15-04	CC < 1,4 l 1,4 l < CC < 2,0 l CC > 2,0 l	**k13** **k14** **k15**
	Improved Conv.	CC < 1,4 l 1,4 l < CC < 2,0 l	**k16** **k17**
	Open. Loop	CC < 1,4 l 1,4 l < CC < 2,0 l	**k18** **k19**
	EURO1	CC < 1,4 l 1,4 l < CC < 2,0 l CC > 2,0 l	**k20** **k21** **k22**
	EURO2	CC < 1,4 l 1,4 l < CC < 2,0 l CC > 2,0 l	**k23** **k24** **k25**

	EURO3	CC < 1,4 l 1,4 l < CC < 2,0 l CC > 2,0 l	**k26** **k27** **k28**
	EURO4	CC < 1,4 l 1,4 l < CC < 2,0 l CC > 2,0 l	**k29** **k30** **k31**
Diesel Passenger Cars	Coventional Euro1 Euro2 Euro3 Euro4		**k32** **k33** **k34** **k35** **k36**
LPG Passenger Cars	Coventional Euro1 Euro2 Euro3 Euro4		**k37** **k38** **k39** **k40** **k41**
Gasoline Light Duty vehicles	Coventional Euro1 Euro2 Euro3 Euro4		**k42** **k43** **k44** **k45** **k46**
Diesel Light Duty vehicles	Coventional Euro1 Euro2 Euro3 Euro4		**k47** **k48** **k49** **k50** **k51**
Diesel Heavy Duty vehicles	Coventional	Weight <7.5 t 7.5< Weight <16 t 16 < Weight <32 t Weight >32 t	**k52** **k53** **k54** **k55**
	Euro1	Weight <7.5 t 7.5< Weight <16	**k56** **k57**

		t 16 < Weight <32 t Weight >32 t	**k58** **k59**
	Euro2	Weight <7.5 t 7.5< Weight <16 t 16 < Weight <32 t Weight >32 t	**k60** **k61** **k62** **k63**
	Euro3	Weight <7.5 t 7.5< Weight <16 t 16 < Weight <32 t Weight >32 t	**k64** **k65** **k66** **k67**
	Euro4	Weight <7.5 t 7.5< Weight <16 t 16 < Weight <32 t Weight >32 t	**k68** **k69** **k70** **k71**
	Euro5	Weight <7.5 t 7.5< Weight <16 t 16 < Weight <32 t Weight >32 t	**k72** **k73** **k74** **k75**
Diesel Urban Busses	Conventional Euro1 Euro2 Euro3 Euro4 Euro5		**k76** **k77** **k78** **k79** **k80** **k81**
Coaches (inter urban busses)	Conventional Euro1 Euro2 Euro3 Euro4 Euro5		**k82** **k83** **k84** **k85** **k86** **k87**
Motorcycles	Mopeds		

	Conventional Stage1 Stage2		**k88** **k89** **k90**
	Motorcycles 2-stroke Conventional Stage1		 **k91** **k92**
	Motorcycles 4-stroke Conventinal	 <250 cm3 250<cc>750 >750	 **k93** **k94** **k95**
	Stage1		**k96**
New Technologies			
	Electiric Vehicles		
		Passenger	**k97**
		LDV	**k98**
	Hybrid Electric Vehicles		
		Passenger	**k99**
		LDV	**k100**
	Fuel Cell Vehicles		
		Passenger	**k101**
		LDV	**k102**
		Urban Bus	**k103**

Annex 2: Example of emission factors estimation for CO from passenger cars

Vehicle class	Cylinder capacity	Speed range	CO emission factor (g/km)
PRE ECE	All categories	10-100	$281V^{-0.630}$
	All categories	100-130	$0.112V + 4.32$
ECE 15-00/01	All categories	10-50	$313V^{-0.760}$
	All categories	50-130	$27.22 - 0.406V + 0.0032V^2$
ECE 15-02	All categories	10-60	$300V^{-0.797}$
	All categories	60-130	$26.260 - 0.440V + 0.0026V^2$
ECE 15-03	All categories	10-20	$161.36 - 45.62 \ln(V)$
	All categories	20-130	$37.92 - 0.680V + 0.00377V^2$
ECE 15-04	All categories	10-60	$260.788V^{-0.910}$
	All categories	60-130	$14.653 - 0.220V + 0.001163V^2$
Improved conventional	CC < 1.4 l	10-130	$14.577 - 0.294V + 0.002478V^2$
	1.4 l < CC < 2.0 l	10-130	$8.273 - 0.151V + 0.000957V^2$
Open loop	CC < 1.4 l	10-130	$17.882 - 0.377V + 0.002825V^2$
	1.4 l < CC < 2.0 l	10-130	$9.446 - 0.230V + 0.002029V^2$
EURO I	CC < 1.4 l	10-130	$9.846 - 0.2867V + 0.0022V^2$
	1.4 l < CC < 2.0 l	10-130	$9.617 - 0.245V + 0.001729V^2$
	CC > 2.0 l	10-130	$12.826 - 0.2955V + 0.00177V^2$