EC4MACS
Modelling Methodology

The TREMOVE / COPERT Transport Models

European Consortium for Modelling of Air Pollution and Climate Strategies - EC4MACS

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Summary

This is a report of the LIFE EC4MACS project, which describes the methodologies to be used to estimate emissions from the transport modes. The TREMOVE model is considered as a tool to be integrated in the EC4MACS suite of models. However, TREMOVE consists of four different main sub-modules, a demand module, a stock module, an emissions and consumption module and a welfare module. As the EC4MACS will develop separate demand and welfare modules, the main elements of TREMOVE to be considered are the stock and the emissions module. These methodologies in TREMOVE originate from the TRENDS and the COPERT models, respectively. Hence, this report discusses the methodologies of these two models, with some recent updates on the fleets description in EU27, based on a project recently funded by the European Commission. The purpose of this report is to be used for consultation with the national experts in order to accept or improve the methodologies and the data considered in each country for transport.

Keywords

COPERT, TRENDS, vehicle fleet, vehicle stock, mileage, lifetime functions

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1 Introduction

1.1 Aim of the project

Aim of the EC4MACS project is to bring together most of the widely used policy assessment models in Europe in the areas of pollutant emissions. The long-term objective is to develop the links between the models in order to perform consistent policy impact assessments and scenario evaluations.

A very dynamic field is present in the area of transport emissions with a large area of policies in place and foreseen in the future, and an equally large number of technologies to address the policy requirements. Therefore, detailed models are required to describe the transport emissions and to make reliable projections.

This report describes the methodologies that are planned to be used in the framework of EC4MACS to calculate emissions from transport. The aim is that these methods are reviewed by national experts, in order to make projections which are consistent with those designated by the member states.

1.2 Background on the available tools

The initial proposal in the framework of the EC4MACS project has been to implement the TREMOVE model as the transport calculation methodology in the suite of models considered in EC4MACS. TREMOVE (www.tremove.org) is a tool which has been developed by the University of Leuven in Belgium and is currently further developed and extended by Transport Mobility Leuven (TML). LAT/AUTh has been also using and further developing the model in the framework of various projects funded by the European Commission. TREMOVE is mostly used to perform policy assessments in Europe, for various measures related either to the cost or to the technology of transportation. In order to perform this, TREMOVE consists of four main modules, a demand module, a vehicle stock module an emissions module and a welfare module (Figure 1-1). It covers all EU27 (+ Croatia, Norway, Switzerland and Turkey) from 1995 to 2030.

TREMOVE basically operates as follows: A baseline stock size and transport activity is described for each country up to 1995, based on statistical information collected from international and national sources. These are then projected to 2030, using information from different transport models (basically SCENES). The baseline stock projection is translated into different vehicle categories and technologies by the vehicle stock module. The main source of the stock module methodology is the TRENDS project. After preparing the detail vehicle stock per year and per country, this is then fed to the emissions module which performs the emission and consumption calculations. The emission module is a simplified version of COPERT, as it incorporates the emission factor functions and calculations routines of earlier COPERT versions. Finally, the welfare module calculates the direct costs of implementing a new measure, as well as external costs related to the impact of this measure on the level of air emissions. The source of information for external costs is CAFÉ.

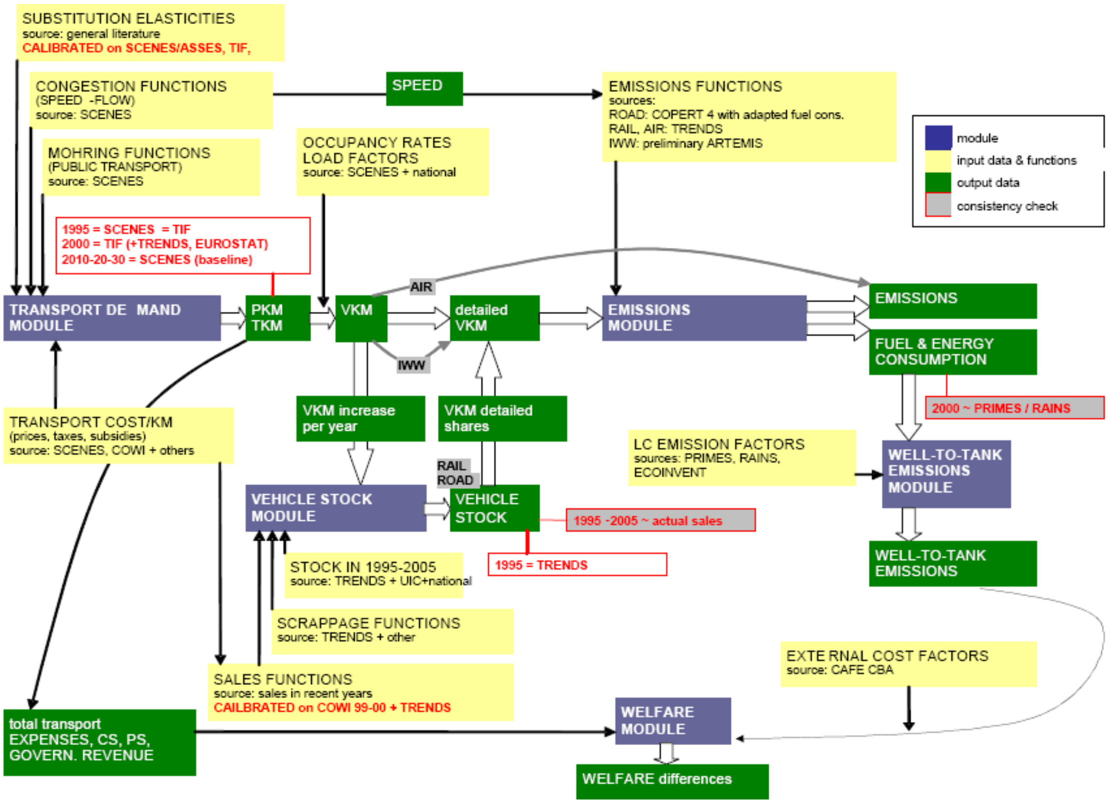


Figure 1-1: The TREMOVE model structure

TREMOVE could in principle be used directly in EC4MACS. However, this would produce some compatibility problems. First, the total demand for transport that will be developed in EC4MACS would not be equal to the baseline demand already included in TREMOVE. As a result, the TREMOVE total demand would have to be recalibrated to meet the demand produced by the PRIMES and GAINS modules. But even in this case, the synchronization of the two models in future scenario runs would have been impossible as a different demand would be projected from PRIMES and a different demand by TREMOVE. Clearly, in the framework of the EC4MACS environment, a separate demand module for transport would complicate the structure and the interface of the models. Similarly, the welfare model for transport, which is part of TREMOVE, is in principle only a part of the cost calculation models already included in GAINS. In the framework of EC4MACS it is not necessary to perform cost calculations by two different components, but the GAINS cost calculations suffice. Hence, the TREMOVE welfare model is of no use in the framework of EC4MACS.

As a result, the only components of TREMOVE which are necessary in the framework of EC4MACS are the vehicle stock and the emissions and consumption modules. As has been also mentioned before, the stock module basically incorporates the TRENDS methodology and the emissions module incorporates the COPERT methodology. Hence, it has been decided to present the methodologies of these two models in this report. Two more issues need to be clarified at this point: First, new statistical data for road transport have become available through the European Commission 'Fleets' project (http://lat.eng.auth.gr/copert). This information will become available to EC4MACS and this will be used to perform the projections. Second, a link with the PRIMES/GAINS energy demand output will have to be developed. Some ideas on this are presented in the current report (Chapter 6) and the details of this link will be the development plan for this second year of the EC4MACS project.

COPERT 4 (current version 5.1 as of November 2007) is a software programme aiming at the calculation of air pollutant emissions from road transport. The development of COPERT (http://lat.eng.auth.gr/copert) has been financed by the European Environment Agency (EEA), in the framework of the activities of the European Topic Centre on Air and Climate Change. In principle, COPERT has been developed for use by the National Experts to estimate emissions from road transport to be included in official annual national inventories. COPERT estimates emissions of all regulated air pollutants (CO, NOx, VOC, PM) produced by different vehicle categories (passenger cars, light duty vehicles, heavy duty vehicles, mopeds and motorcycles) as well as CO_2 emissions on the basis of fuel consumption. Furthermore, emissions are calculated for an extended list of non regulated pollutants, including CH_4, N_2O, NH_3, SO_2, heavy metals, PAHs and POPs. Finally, the software provides NMVOC emissions allocated to several individual species, distinction of NO_x to NO and NO_2, and PM distinction to elemental carbon and organic material. In order to calculate emissions, the software includes emission factors for a number (more than 200) different vehicle categories/technologies which need to be combined with appropriate activity data (number of vehicles, mileage, circulation data) to calculate total emissions.

TRENDS (http://circa.europa.eu/Public/irc/dsis/pip/library?l=/environment_trends) is a project funded by DG Transport and Eurostat to develop a projections method on the basis of available statistical information. The TRENDS method uses fleet renewal functions to calculate the composition of the fleet in different countries and years. The statistical information of the original model refers to EU15 only and it is quite outdated, as the project is already several years old. However, new statistical information up to year 2005 has become available from the European Commission's DG Environment 'Fleets' project. Hence, the methodology of TRENDS will be used on this new statistical information to perform projections. TRENDS also includes methodologies for the non-road transport modes (navigation, aviation, and railways). These methodologies have been also introduced in TREMOVE and will be also used in the framework of this project. New historical data for non-road modes will be made available by the EXTREMIS (www.ex-tremis.eu) project.

2 COPERT methodology: Emissions and Fuel Consumption for Road Transport

2.1 General

2.1.1 Description

In order to help identifying the vehicle categories, Table 2-1 gives the classification of vehicles according to the UN-ECE. The main vehicle categories can be allocated to the UN-ECE classification as follows:

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

2.1.2 Techniques

Traditionally, road vehicles have been powered by internal combustion engines which operate on fossil fuels combustion (gasoline, diesel, LPG, CNG, etc.). The combustion process produces CO_2 and harmless H_2O as the main products. Unfortunately, combustion also produces several by-products which either originate from incomplete fuel oxidation (CO, hydrocarbons, particulate matter) or from the oxidation of non-combustible species present in the combustion chamber (NO_x from N_2 in the air, SO_x from S in the fuel and lubricant, etc.). In order to comply with emission legislation, vehicle manufacturers have been installing aftertreatment devices, such as catalytic converters and diesel particle filters, to suppress by-product emission. However, such devices may also produce small quantities of pollutants such as NH_3 and N_2O.

they provide the highest power/size ratio of all concepts. Diesel engines (also compression-ignition) on the other hand dominate in large vehicle applications because of their improved fuel efficiency and torque characteristics over gasoline engines. Lately though, an increasing shift to diesel engines is observed also for passenger cars, which now correspond to the highest share of new passenger car registrations in several European countries. The ACEA (2006) statistics show that 48.3% of passenger cars sold in Europe in 2005 were diesel ones, with shares reaching as high as 70% for countries like Austria, Belgium and France. This is an outcome of the higher fuel efficiency of diesel engines and technology improvements which increase the power output density for given engine size.

Table 2-1: Vehicle classification categories according to UN-ECE

Category L:	Motor vehicles with less than four wheels
Category L1:	Two-wheeled vehicles with an engine cylinder capacity not exceeding 50 cm^3 and a maximum design speed not exceeding 40 km/h.
Category L2:	Three-wheeled vehicles with an engine cylinder capacity not exceeding 50 cm^3 and a maximum design speed not exceeding 40 km/h.
Category L3:	Two-wheeled vehicles with an engine cylinder capacity exceeding 50 cm^3 or a design speed exceeding 40 km/h.
Category L4:	Vehicles with three wheels asymmetrically arranged in relation to the longitudinal median axis, with an engine cylinder capacity exceeding 50 cm^3 or a design speed exceeding 40 km/h (motor cycles with sidecar).
Category L5:	Vehicles with three wheels symmetrically arranged in relation to the longitudinal median axis, with a maximum weight not exceeding 1,000 kg and either an engine cylinder capacity exceeding 50 cm^3 or a design speed exceeding 40 km/h (motor cycles with sidecar).
Category M:	Power driven vehicles having at least four wheels or having three wheels when the maximum weight exceeds 1 metric ton, and used for the carriage of passengers
Category M1:	Vehicles used for the carriage of passengers and comprising not more than eight seats in addition to the driver's seat.
Category M2:	Vehicles used for the carriage of passengers and comprising more than eight seats in addition to the driver's seat, and having a maximum weight not exceeding 5 metric tonnes.
Category M3:	Vehicles used for the carriage of passengers and comprising more than eight seats in addition to the driver's seat, and having a maximum weight exceeding 5 metric tonnes.
Category N:	Power-driven vehicles having at least four wheels or having three wheels when the maximum weight exceeds 1 metric ton, and used for the carriage of goods
Category N1:	Vehicles used for the carriage of goods and having a maximum weight not exceeding 3.5 metric tonnes.
Category N2:	Vehicles used for the carriage of goods and having a maximum weight exceeding 3.5 but not exceeding 12 metric tonnes.
Category N3:	Vehicles used for the carriage of goods and having a maximum weight exceeding 12 metric tonnes.

There are currently new technologies available, which aim at decreasing both energy consumption and pollutant emissions. Those technologies include new combustion processes for internal combustion engines (Gasoline Direct Injection (GDI), Controlled Auto-Ignition, Homogeneous Charge Compression Ignition), new fuels (CNG, Reformulated grades, eventually H_2) and alternative powertrains (hybrids – meaning a combination of internal combustion engine and electric motor, fuel cell vehicles, etc.). Some of these technologies (e.g. GDI, hybrids) become quite popular nowadays while others are still in the development phase.

Given the diversity in propulsion concepts, the calculation of emissions from road vehicles is a complicated and demanding procedure, which requires availability of good quality activity data and emission rates. This report aims at covering emissions from all widespread technologies today in a systematic manner that will allow the production of high quality emission inventories.

Gasoline powered (also spark-ignition) engines are used in small vehicles (up to 3.5 t GVW) because of their superior power/weight ratio and their wider operation range compared to diesel engines. Some less important reasons have also been responsible for this, such as lower noise and more refined operation. For very small vehicles (mopeds and motorcycles), two stroke engines have been favourable, especially in the past, because of their high power output vs weight ratio.

2.2 Emissions

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

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

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

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

Group 3: Pollutants for which a simplified methodology is applied mainly due to the absence of detailed data. This Group contains the pollutants given in Table 2-4.

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

Table 2-5.

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

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

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

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

Table 2-4: Pollutants included in Group 3 and methodology equivalencies

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

Dibenzo Furans (PCDFs)	

Table 2-5: Pollutants included in Group 4 and methodology equivalencies

Pollutant	Equivalent
Alkanes (C_nH_{2n+2}):	Given in Alkanes speciation
Alkenes (C_nH_{2n}):	Given in Alkenes speciation
Alkines (C_nH_{2n-2}):	Given in Alkines speciation
Aldehydes ($C_nH_{2n}O$)	Given in Aldehydes speciation
Ketones ($C_nH_{2n}O$)	Given in Ketones speciation
Cycloalkanes (C_nH_{2n})	Given as Cycloalkanes
Aromatics	Given in Aromatics speciation

2.3 Controls

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

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

2.3.1 Legislation classes of gasoline passenger cars

The production year of vehicles in this category has been taken into account by introducing different classes, which either reflect legislative steps (ECE, Euro) or technology steps ("Improved Conventional", "Open Loop").

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

- pre ECE vehicles up to 1971
- ECE 15 00 & 01 1972 to 1977

- ECE 15 02 1978 to 1980
- ECE 15 03 1981 to 1985
- ECE 15 04 1985 to 1992

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

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

For gasoline Passenger Cars <1.4 l

a. Improved Conventional, which took into account a German (Anl.XXIVC - Effective date: 1.7.1985) and a Dutch (NLG 850 -Effective date: 1.1.1986) incentive programmes. The emission standards called for improved engine technology but without the use of aftertreatment. This type of emission control technology also started to appear in Denmark from 1.1.1988.
b. Open Loop, which took into account German, Danish, Greek and Dutch incentive programmes where the required emission standards were met by applying open loop three way catalysts. Effective dates: Denmark 1.1.1989, Germany 1.7.1985, Greece 1.1.1990, the Netherlands 1.1.1987.

For gasoline Passenger Cars 1.4-2.0 l

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

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

a. Euro 1: These passenger cars were officially introduced by directive 91/441/EEC in July 1992 and were the first vehicles to be equipped with closed-loop three way catalyst. They also necessitated the use of unleaded fuel. Euro 1 vehicles were introduced earlier in some countries by means of incentives. These included the voluntary programmes in Germany, introduced after 1.7.1985, which called for compliance with the US 83 limits for cars <2.0 l. For cars larger that 2.0 l in engine capacity, some additional voluntary measures were introduced. These were directive 88/76/EEC (relevant for all countries), with implementation date for new vehicles: 1.1.1990 and US 83 (only relevant for Denmark, Germany, Greece, the Netherlands) with implementation dates for Denmark 1.1.1987, Germany 1.7.1985, Greece 1.1.1989, the Netherlands 1.1.1987.

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

2.3.2 Legislation classes of diesel passenger cars

Diesel vehicles of pre-1992 production are all lumped together under the "Conventional" vehicle class. This includes non regulated vehicles launched prior to 1985 and vehicles complying with directive ECE 15/04 (up to 1992). Diesel vehicles of this class are equipped with indirect injection engines. In 1992 the introduction of the "Consolidated Emissions Directive" 91/441/EEC introduced the Euro standards for diesel cars.

The Euro emission standards of diesel cars follow their gasoline counterparts. These include vehicles complying with directives 91/441/EEC (Euro 1, 1992-1996), 94/12/EC (Euro 2, valid from 1996 for indirect injection and 1997 for direct injection up to 2000), regulation 98/69/EC Stage 2000 (Euro 3), and the current regulation 98/69/EC Stage 2005 (Euro 4). Euro 1 were the first vehicles to be regulated for all four main pollutants CO, HC+NOx and PM. Few of those vehicles were equipped with oxidation catalysts. Directive 94/12/EC brought reductions over the former Directive of 68% for CO, 38% for HC+NOx and 55% for PM and oxidation catalysts were used in almost all vehicles. Euro 3 vehicles targeted an additional 40%, 60%, 14% and 37.5% less CO, NOx, HCs and PM than Euro 2 vehicles. The significant reductions were achieved with exhaust gas recirculation (NOx reduction) and optimisation of fuel injection with use of common rail systems (PM reduction). Also fuel refinements (mainly sulphur content reduction) played an important role in PM emission improvement. In addition, due to national incentives and manufacturers' competition, some Euro 3 vehicles were equipped with original diesel particle filters to reduce the PM emissions to levels much below the emission standard. Therefore, a special PM emission factor needs to be provided for these vehicles. The current Euro 4 vehicles further improve emission levels by 22% on CO and 50% to all other pollutants. Further to the voluntary introduction of the particle filter to some vehicles, such significant reductions have been made possible with advanced engine technology and aftertreatment measures, such as cooled EGRs, and NOx reduction - PM oxidation techniques.

As in the case of gasoline vehicles, a Euro 5 and 6 proposal has been recently adopted. For diesel vehicles NOx emissions decrease by 28% and 68% at the Euro 5 and 6 levels, respectively over Euro 4. However, the most important reduction is brought for PM, which equals 88% over Euro 4. In parallel a number emission limit has been decided, at 5×1011 km-1, which necessitates the use of diesel particle filters for compliance.

2.3.3 Legislation classes of LPG passenger cars

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

2.3.4 Legislation classes of 2-stroke passenger cars

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

2.3.5 Legislation classes of hybrid vehicles

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

2.3.6 Legislation classes of gasoline light duty vehicles <3.5 t

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

2.3.7 Legislation classes of diesel light duty vehicles <3.5 t

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

2.3.8 Legislation classes of gasoline heavy duty vehicles >3.5 t

Heavy duty gasoline vehicles >3.5 t play a negligible role in European emissions from road traffic. Any such vehicles are included in the "Conventional" class without further distinction to legislation steps because no specific emission standards have been set for such vehicles.

2.3.9 Legislation classes of diesel heavy duty vehicles >3.5 t

Emissions from diesel engines used in vehicles of gross weight over 3.5 t were first regulated in 1988 with the introduction of the original ECE 49 Regulation. Vehicles (or, better, engines) complying with ECE 49 and earlier are all classified as "Conventional". Directive 91/542/EEC, implemented in two stages, brought two standards of reduced emission limits valid from 1992 to 1995 (Stage 1 – Euro I) and 1996 up to 2000 (Stage 2 – Euro II). Directive 1999/96/EC Step 1 (Euro III) was valid since 2000 and introduced a 30% reduction of all pollutants over the Euro II case. The same directive included an intermediate step in 2005 (Euro IV) and a final step in 2008 (Euro V). Standards for 2009 are very strict, targeting an over 70% reduction of NOx and over 85% decrease of PM compared to 1996 standards. This will be achieved with engine tuning and oxidation catalyst for PM control and Selective Catalyst Reduction (SCR) for NO_x control.

A discussion is currently underway concerning the Euro VI emission standards to be introduced in 2014. The European Commission proposal is not known yet. However, it is expected that Euro VI emission standards will necessitate both SCR and diesel particle filter for NO_x control.

2.3.10 Legislation classes for 2 stroke mopeds <50 cm³

No EU-wide emission standards were agreed until lately for emissions of two wheelers but only national legislation was valid in a few countries. In June 1999, multi-directive 97/24/EC (Step 1 – Euro 1) introduced emission standards, which for the case of two-stroke mopeds <50cm³, were applied to CO (6 g/km) and $HC+NO_x$ (3 g/km). An additional stage of the legislation came into force in June 2002 (Euro 2) with emission levels of 1 g/km CO and 1.2 g/km $HC+NO_x$. New Euro 3 emission standards for such small vehicles are currently under preparation in the European Commission to be proposed to the European Council, which will not introduce arithmetic differences to the Euro 2 emission step, but will introduce a certification test initiated from ambient temperature conditions (as opposed to hot engine start currently in the regulations). Due to the very strict emission limits, it is expected that very few 2-stroke mopeds will be available after the new step becomes mandatory (possibly 2008) and those that will conform with the regulations will need to be equipped with precise air-fuel metering devices, possible direct injection and secondary air injection in the exhaust line.

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

Emissions from two and four stroke motorcycles >50 cm³ were first introduced in June 1999 (Euro 1) when directive 97/24/EC came into force. The directive imposes different emission standards for two and four stroke vehicles respectively, and separate limits are set for HC and NO_x to allow for a better distinction in the different technologies (2-stroke : CO 8 g/km, HC 4 g/km, NO_x 0.1 g/km; 4-stroke : CO 13 g/km, HC 3 g/km, NO_x 0.3 g/km). In 2002, regulation 2002/51/EC introduced the Euro 2 (2003) and the Euro 3 (2006) steps for motorcycles with differentiated emission standards depending on the engine size. No other emission standards have been planned for the future. However, it is soon expected that the World Motorcycle Test Cycle (WMTC) will be used worldwide as a certification test and this may bring some changes in the emission standards.

2.3.12 Summary of vehicle technologies / control measures utilised

Table 2-6 provides a summary of all vehicle categories and technologies (emission standards) covered by the present methodology. Due to the technological developments that occurred for heavy duty engines, but also their use in a wide range of vehicle types, in order to cover as many uses as possible, a detailed classification of Heavy Duty Vehicles and Busses is required. Table 2-6 includes this new categorization.

Table 2-6: Summary of all vehicle classes covered by the methodology

Vehicle Type	Class	Legislation
Passenger Cars	Gasoline <1.4l 1.4 - 2.0l >2.0l	PRE ECE ECE 15/00-01 ECE 15/02 ECE 15/03 ECE 15/04

Vehicle Type	Class	Legislation
		Improved Conventional Open Loop Euro 1 - 91/441/EEC Euro 2 - 94/12/EC Euro 3 - 98/69/EC Stage 2000 Euro 4 - 98/69/EC Stage 2005 Euro 5 – EC 715/2007 Euro 6 – EC 715/2007
	Diesel <2.0l >2.0l	Conventional Euro 1 - 91/441/EEC Euro 2 - 94/12/EC Euro 3 - 98/69/EC Stage 2000 Euro 4 - 98/69/EC Stage 2005 Euro 5 – EC 715/2007 Euro 6 – EC 715/2007
	LPG	Conventional Euro 1 - 91/441/EEC Euro 2 - 94/12/EC Euro 3 - 98/69/EC Stage 2000 Euro 4 - 98/69/EC Stage 2005
	2 Stroke	Conventional
	Hybrids <1.6l	Euro 4 - 98/69/EC Stage 2005
Light Duty Vehicles	Gasoline <3.5t	Conventional Euro 1 - 93/59/EEC Euro 2 - 96/69/EC Euro 3 - 98/69/EC Stage 2000 Euro 4 - 98/69/EC Stage 2005 Euro 5 – EC 715/2007 Euro 6 – EC 715/2007
	Diesel <3.5t	Conventional Euro 1 - 93/59/EEC Euro 2 - 96/69/EC Euro 3 - 98/69/EC Stage 2000 Euro 4 - 98/69/EC Stage 2005 Euro 5 – EC 715/2007 Euro 6 – EC 715/2007
Heavy Duty Vehicles	Gasoline >3.5t	Conventional
	Rigid <=7.5t	
	Rigid 7.5-12t	
	Rigid 12-14t	
	Rigid 14-20t	
	Rigid 20-26t	Conventional
	Rigid 26-28t	Euro I - 91/542/EEC Stage I
	Rigid 28-32t	Euro II - 91/542/EEC Stage II
	Rigid >32t	Euro III - 1999/96/EC Stage I
	Articulated 14-20t	Euro IV – 1999/96/EC Stage II
	Articulated 20-28t	Euro V – 1999/96/EC Stage III

Vehicle Type	Class	Legislation
	Articulated 28-34t	Euro VI – No proposal yet
	Articulated 34-40t	
	Articulated 40-50t	
	Articulated 50-60t	

Vehicle Type	Class	Legislation
Buses	Urban <=15t	Conventional Euro I - 91/542/EEC Stage I Euro II - 91/542/EEC Stage II Euro III - 1999/96/EC Stage I Euro IV – 1999/96/EC Stage II Euro V – 1999/96/EC Stage III Euro VI – No proposal yet
	Urban 15-18t	
	Urban >18t	
	Coaches standard <=18t	
	Coaches articulated >18t	
	CNG	Euro I – 91/542/EEC Stage I
		Euro II – 91/542/EEC Stage II
		Euro III – 1999/96/EC Stage I
		EEV – 1999/96/EC
Mopeds	<50cm³	Conventional 97/24/EC Stage I – Euro 1 97/24/EC Stage II – Euro 2 Euro 3 proposal
Motorcycles	2 Stroke >50cm³	Conventional
	4 stroke 50 - 250cm³	97/24/EC – Euro 1
	4 stroke 250 - 750cm³	2002/51/EC Stage I – Euro 2
	4 stroke >750cm³	2002/51/EC Stage II – Euro 3

2.4 Methodology

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

2.4.1 Types of emission

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

$$E_{TOTAL} = E_{HOT} + E_{COLD} \tag{1}$$

where,

- E_{TOTAL}: total emissions (g) of any pollutant for the spatial and temporal resolution of the application,
- E_{HOT}: emissions (g) during stabilised (hot) engine operation,
- E_{COLD}: emissions (g) during transient thermal engine operation (cold start).

2.4.2 Emissions under different driving conditions

Vehicle emissions are heavily dependent on the engine operation conditions. Different driving situations impose different engine operation conditions and therefore a distinct emission performance. In that respect, a distinction is made in urban, rural and highway driving to account for variations in driving performance.

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

$$E_{TOTAL} = E_{URBAN} + E_{RURAL} + E_{HIGHWAY} \tag{2}$$

where,

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

2.4.3 Calculation outline

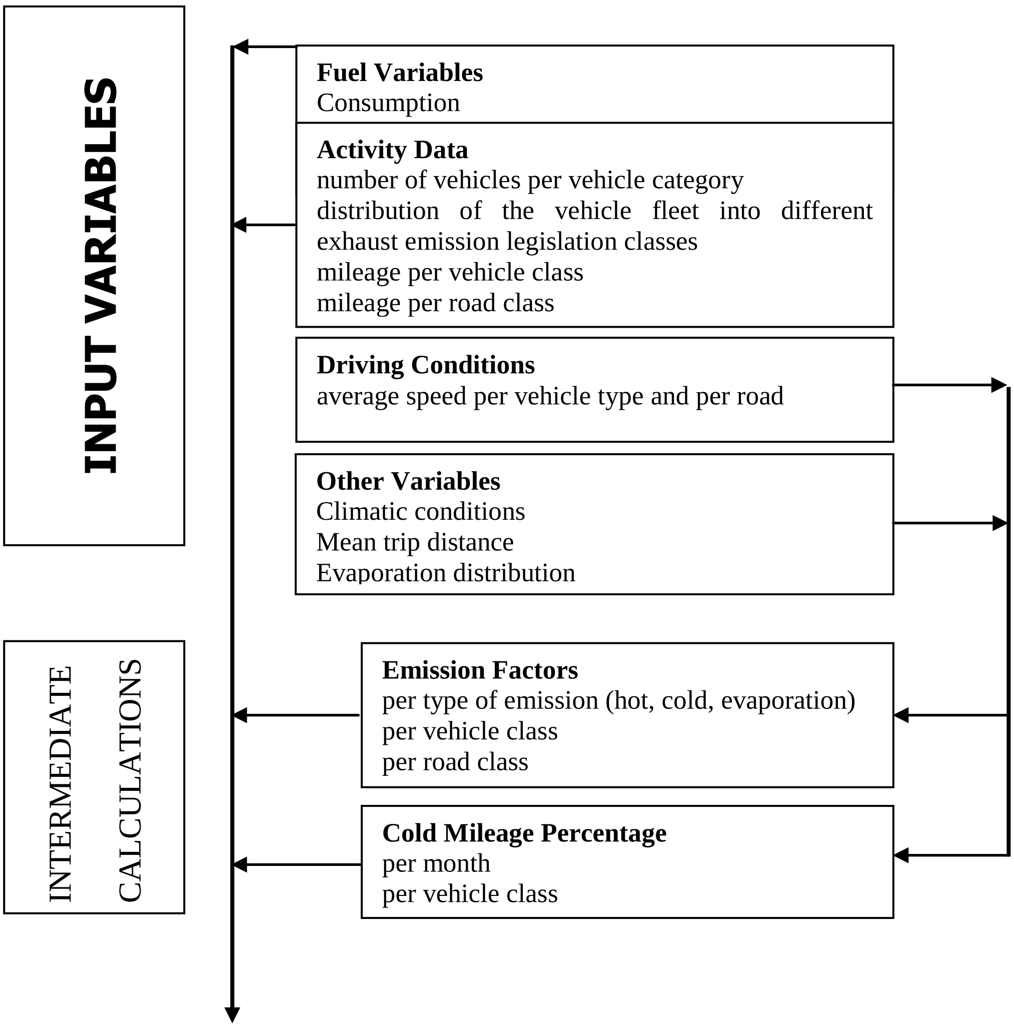
Calculation of total emissions is made by combining activity data for each vehicle category with appropriate emission factors. Those emission factors vary according to input data (driving situations, climatic conditions). Also, information on fuel consumption and specifications is required to maintain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

2.4.4 Hot emissions

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

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

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



Calculation of annual emissions of all pollutants for all CORINAIR road traffic source categories at all defined territorial units and road classes

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

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

Therefore, the formula to be applied for the calculation of hot emissions of pollutants in Groups 1 and 3 and in the case of an annual emission estimation, yields (Note: the same formula is also applied for the calculation of the total fuel consumed by vehicles of the specific class. But, in the case of fuel consumption, an additional distinction needs to be made for different fuel types):

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

where,

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

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

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

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

and,

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

j (vehicle class): 1-230 for the vehicle classes defined in the vehicle split (Table 2-6)

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

2.4.5 Accounting for vehicle speed

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

- to select one single average speed, representative of each of the road types "urban", "rural" and "highway" (e.g. 20 km/h, 60 km/h and 100 km/h, respectively) and to apply the emission factors taken from the graphs or calculated with the help of the equations, or to define mean speed distribution curves $f_{j,\,k}$ (V) and to integrate over the emission curves, i.e.

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

where,

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

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

$f_{j,\,k}$ (V): equation (e.g. formula of "best fit" curve) of the frequency distribution of the mean speeds which corresponds to the driving patterns of vehicles on road classes "rural", "urban" and "highway". $f_{j,k}$(V) depends on vehicle class j and road type k.

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

2.4.6 Cold start emissions

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

These emissions are calculated as an extra emission over the emissions that would be expected if all vehicles were only operated with hot engines and warmed-up catalysts. A relevant factor, corresponding to the ratio of cold over hot emissions, is used and applied to the fraction of kilometres driven with cold engines. This factor varies from country to country. Driving behaviour (varying trip lengths), as well as climate conditions affect the time required to warm up the engine and/or the catalyst and hence the fraction of a trip driven with cold engine. These factors can be taken into account, but again information may not be available to do this thoroughly in all countries, so that estimates have to close identified gaps.

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

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

where,

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

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

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

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

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

The β-parameter depends on ambient temperature t_a (for practical reasons the average monthly temperature is proposed to be used) and pattern of vehicle use, in particular the average trip length l_{trip}. However, since information on l_{trip} is not available in many countries for all vehicle classes, simplifications have been introduced for some vehicle categories. According to available statistical data (André et al., 1998) a European value of 12.4 km has been established for the l_{trip} value. Moreover, according to a relevant analysis, the value of l_{trip} for annual vehicle circulation should be found in the range of 8 to 15 km. Therefore it is proposed to use the value of 12.4 km unless firm national estimates are available.

The introduction of more stringent emission standards for catalyst gasoline vehicles has imposed shorter periods for the catalyst to reach the light-off temperature. This is reflected to less mileage driven under warming-up conditions. Therefore, the β-parameter is also a function of the level of legislation conformity for gasoline catalyst vehicles. Table 2-20 presents the fraction of the original β-parameter to be used for current and future catalyst vehicles and for the main pollutants.

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

As has already been discussed, cold start over-emission is attributed to urban driving only because the valid assumption is made that the majority of trips start in urban areas. However, a portion of cold start over-emissions may also be attributed to rural conditions, in cases where the mileage fraction driven with non-thermally stabilised engine conditions (β-parameter) exceeds the mileage share attributed to urban conditions (S_{URBAN}). This case requires a transformation of equation (5), which then yields:

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

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

In this case, it is considered that the total mileage driven under urban conditions corresponds to warming-up conditions, while the remaining over-emissions are attributed to urban conditions. The case demonstrated by equation (6) is rather extreme for a national inventory and can only happen in cases where a very small value has been provided for l_{trip}. Note also that the urban hot emission factor is used in both forms of equation (6). This is because total cold start related emissions should not be differentiated according to place of emission.

The calculation of N_2O, NH_3 and CH_4 emissions is based on cold urban, and hot urban, rural and highway emissions. The following paragraphs present the calculation algorithm that is used in order to calculate these emissions. In particular for methane, the estimation is of importance because NMVOC emissions are calculated as the difference between VOC and CH_4.

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

If $\beta_{i,j} > S_{URBAN;\,j}$	(7)
$E_{COLD\ URBAN;\,i,\,j} = \beta_{i,j} \times N_j \times M_j \times e_{COLD\ URBAN;\,i,\,j}$	(a)
$E_{COLD\ RURAL;\,i,\,j} = 0$	(b)
$E_{HOT\ URBAN;\,i,\,j} = 0$	(c)
$E_{HOT\ RURAL;\,i,\,j} = [S_{RURAL;\,j} - (\beta_{i,j} - S_{URBAN;\,j})] \times N_j \times M_j \times e_{HOT\ RURAL;\,i,\,j}$	(d)
$E_{HOT\ HIGHWAY;\,i,\,j} = S_{HIGHWAY;\,j} \times N_j \times M_j \times e_{HOT\ HIGHWAY;\,i,\,j}$	(e)
Else if $\beta_{i,j} <= S_{URBAN;\,j}$	(8)
$E_{COLD\ URBAN;\,i,\,j} = \beta_{i,j} \times N_j \times M_j \times e_{COLD\ URBAN;\,i,\,j}$	(a)
$E_{COLD\ RURAL;\,i,\,j} = 0$	(b)
$E_{HOT\ URBAN;\,i,\,j} = (S_{URBAN;\,j} - \beta_{i,j}) \times N_j \times M_j \times e_{HOT\ URBAN;\,i,\,j}$	(c)
$E_{HOT\ RURAL;\,i,\,j} = S_{RURAL;\,j} \times N_j \times M_j \times e_{HOT\ RURAL;\,i,\,j}$	(d)
$E_{HOT\ HIGHWAY;\,i,\,j} = S_{HIGHWAY;\,j} \times N_j \times M_j \times e_{HOT\ HIGHWAY;\,i,\,j}$	(e)

where,

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

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

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

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

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

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

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

2.4.7 Fuel consumption dependent emissions (excluding CO2)

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

$$E_{i,j,m}^{CORR} = E_{i,j,m}^{CALC} \times \frac{FC_{m}^{STAT}}{\sum_{j} FC_{j,m}^{CALC}} \qquad (9)$$

where,

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

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

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

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

In this respect, total emission estimates for any emission dependent pollutant equals that derived by the statistical fuel consumption (except of CO_2 due to the use of biofuels, see section 2.4.8) while there is still information provided for the allocation of emissions to different vehicle classes. The calculation of value $E^{CALC}_{i,j,m}$ is demonstrated in the following paragraphs.

2.4.8 Carbon dioxide (CO2) emissions

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

In the case of an oxygenated fuel described by the generic chemical formula $C_xH_yO_z$ the ratio of hydrogen to carbon atoms and the ratio of oxygen to carbon atoms are, respectively:

$$r_{H:C} = \frac{y}{x}$$

$$r_{O:C} = \frac{z}{x} \tag{10}$$

If the fuel composition is known from ultimate chemical analysis, then the mass fractions of carbon, hydrogen and oxygen atoms in the fuel are *c*, *h*, and *o* correspondingly, where $c + h + o = 1$. In this case, the ratios of hydrogen to carbon and oxygen to carbon in the fuel are respectively calculated as:

$$r_{H:C} = 11.916\frac{h}{c}$$

$$r_{O:C} = 0.7507\frac{o}{c} \tag{11}$$

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

$$\mathrm{E}^{\mathrm{CALC}}_{\mathrm{CO_2,j,m}} = 44.011 \times \frac{\mathrm{FC}^{\mathrm{CALC}}_{\mathrm{j,m}}}{12.011 + 1.008\mathrm{r}_{\mathrm{H:C,m}} + 16.000\mathrm{r}_{\mathrm{O:C,m}}} \tag{12}$$

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

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

$$\mathrm{E}^{\mathrm{CALC}}_{\mathrm{CO2,j,m}} = 44.011 \times \left(\frac{\mathrm{FC}^{\mathrm{CALC}}_{\mathrm{j,m}}}{12.011 + 1.008\mathrm{r}_{\mathrm{H:C,m}} + 16.000\mathrm{r}_{\mathrm{O:C,m}}} - \frac{\mathrm{E}^{\mathrm{CO}}_{\mathrm{j,m}}}{28.011} - \frac{\mathrm{E}^{\mathrm{VOC}}_{\mathrm{j,m}}}{13.85} - \frac{\mathrm{E}^{\mathrm{EC}}_{\mathrm{j,m}}}{12.011} - \frac{\mathrm{E}^{\mathrm{OM}}_{\mathrm{j,m}}}{13.85} \right) \tag{13}$$

Table 2-7 presents relevant hydrogen to carbon and oxygen to carbon ratios for different fuel types.

Oxygen in the fuel may be contained due to blending with bio-fuels (e.g. biodiesel in diesel or bioethanol in gasoline) or in additives not derived by biomass (e.g. MTBE or ETBE). Since biofuel derived CO_2 should not be reported as road-transport CO_2, in case of biodiesel blend, only the mass of fossil fuel should be used in the calculation of CO_2 emissions. In all calculations (fuel balance, SO_2 and HM emissions, etc.) the statistical fuel consumption should include both the biofuel and the fossil fuel mass according to eq. (9). In the calculation of CO_2 emissions though, only the fossil fuel statistical consumption should be taken into account in the calculation. This is consistent to the IPCC 1996 and IPCC 2006 guidelines, according to which emissions associated with use of biofuels are attributed to the land use, land-use change and forestry sector. Hence, for reporting, the CO_2 calculated per vehicle category should be corrected according to equation :

$$E^{CORR}_{CO_2,j,m} = E^{CALC}_{CO_2,j,m} \times \frac{FC^{STAT}_m - FC^{BIO}_m}{\sum_j FC^{CALC}_{j,m}} \quad (14)$$

In equation (14), the calculated CO_2 emission should be derived from eq. (12), without considering the oxygen content of the biofuel part. In the same equation FC^{BIO} is the mass of biofuel blended in the total fuel of type *m* sold.

Table 2-7: Ratios of hydrogen to carbon and oxygen to carbon atoms for different fuel types

Fuel (*m*)	**Chemical formula**	**Ratio of hydrogen to carbon**	**Ratio of oxygen to carbon**
Gasoline	$[CH_{1.8}]_x$	$r_{H:C}$=1.80	$r_{O:C}$=0.0
Diesel	$[CH_2]_x$	$r_{H:C}$=2.00	$r_{O:C}$=0.0
Ethanol	C_2H_5OH	$r_{H:C}$=3.00	$r_{O:C}$=0.5
Natural Gas	CH_4 (95%)- C_2H_6 (5%) CH_4 (85%)- C_2H_6 (15%)	$r_{H:C}$=3.90 $r_{H:C}$=3.74	$r_{O:C}$=0.0 $r_{O:C}$=0.0
LPG Fuel A	C_3H_8 (50%)-C_4H_{10} (50%)	$r_{H:C}$=2.57	$r_{O:C}$=0.0
LPG Fuel B	C_3H_8 (85%)-C_4H_{10} (15%)	$r_{H:C}$=2.63	$r_{O:C}$=0.0

2.4.9 Sulphur dioxide (SO2) emissions

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

$$E^{CALC}_{SO_2,j} = 2 \times k_{S,m} \times FC^{CALC}_{jm} \quad (15)$$

where,

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

2.4.10 Lead (Pb) and other heavy metals emissions

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

$$E_{Pb,j}^{CALC} = 0.75 \times k_{Pb,m} \times FC_{jm}^{CALC} \quad (16)$$

where,

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

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

$$E_{i,j}^{CALC} = k_{i,m} \times FC_{jm}^{CALC} \quad (17)$$

where,

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

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

2.4.11 Emission corrections

Corrections can be applied to the emission methodology, as it has been described by the baseline equations (3) - (4), to accommodate variation of emissions according to various environmental and technology effects. Specifically, the effect on emissions of the following parameters can be tackled:

a. Vehicle age (mileage). Baseline emission factors to be used in equation (3) correspond to a fleet of average mileage (30-60 Mm) and an inherent degradation factor is implemented. Further emission degradation due to increased mileage should be modelled by additional degradation factors. However, for the sake of consistency between the Member States, it is proposed not to introduce such corrections when compiling a baseline inventory up to the year 2000 because of the relatively young fleet age. However, when inventories and forecasts for future years need to be made, it is advised to correct emission factors according to mileage to introduce the effect of vehicle age in the calculations.

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

c. Road gradient and vehicle load on heavy duty vehicles emissions. Corrections need to be made to heavy duty vehicles emissions in cases of driving on non-flat roads. The corrections should only be applied in national inventories by those Member States where statistical data allow for a distinction of heavy duty vehicle mileage on roads of positive or negative gradient. Also, by default, a factor of 50% is considered for the load of heavy duty vehicles. In cases where significant deviations exist for the mean load factor of the heavy duty vehicle fleet, respective corrections should be brought by means of respective emission factors functions.

2.4.11.1 Emission degradation due to vehicle age

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

$$MC_{C,i} = A_M \times M_{MEAN} + B_M \tag{18}$$

where,

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

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

A_M: the degradation of the emission performance per kilometre

B_M: the emission level of a fleet of brand new vehicles

B_M is lower than 1 because the correction factors are determined using vehicle fleets with mileages ranging from 16,000 to 50,000 km. Therefore, brand new vehicles are expected to emit less than the sample vehicles. It is assumed that emissions do not further degrade above 120,000 km for Euro I and II vehicles and 160,000 km for Euro III and IV vehicles.

The effect of average speed on emission degradation is taken into account by combining the observed degradation lines over the two driving modes (urban, road). It is assumed that for speeds outside the region defined by the average speed of urban driving (19 km/h) and road driving (63 km/h), the degradation is independent of speed. Linear interpolation between the two values provides the emission degradation in the intermediate speed region. Table 2-77 presents the methodology parameters and the application of the scheme that are being discussed later on this document.

2.4.11.2 Fuel effects

Fuels of improved specifications become mandatory in Europe in two steps, January 2000 (Fuel 2000) and January 2005 (Fuel 2005) respectively. The specifications of those fuels are displayed in Table 2-8 (Gasoline) and Table 2-9 (Diesel). Because of their improved properties, the fuels result in lower emissions from vehicles. Therefore, the stringent emission standards of Euro 3 technology (introduced ~2000) are achieved with fuel quality "Fuel 2000" and the more stringent emission standards of Euro 4 and 5 with fuel quality "Fuel 2005". Table 2-10 shows the base emission fuel considered for each vehicle class.

However use of such fuels results in reduced emissions also from pre-Euro 3 vehicle technologies, for which the 1996 market average fuel is considered as a basis (Table 2-10). Those reductions are equally applied to hot and cold start emissions. To correct the hot emission factors proposed, equations derived in the framework of the EPEFE programme (ACEA and EUROPIA, 1996) are applied. Table 2-78, Table 2-79 and Table 2-80 display the equations for different vehicle categories and classes.

Table 2-8: Gasoline fuel specifications

Property	1996 Base Fuel (market average)	Fuel 2000	Fuel 2005
Sulphur [ppm]	165	130	40
RVP [kPa]	68 (summer) 81 (winter)	60 (summer) 70 (winter)	60 (summer) 70 (winter)
Aromatics [vol. %]	39	37	33
Benzene [vol. %]	2.1	0.8	0.8
Oxygen [wt %]	0.4	1.0	1.5
Olefins [vol. %]	10	10	10
E100 [%]	52	52	52
E150 [%]	86	86	86
Trace Lead [g/l]	0.005	0.003	0.003

Table 2-9: Diesel fuel specifications

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

Table 2-10: Base fuels for each vehicle class

Vehicle Class	Base Fuel	Available Improved Fuel Qualities
Pre- Euro 3	1996 Base Fuel	Fuel 2000 , Fuel 2005
Euro 3	Fuel 2000	Fuel 2005
Euro 4	Fuel 2005	-

The hot emission factors are corrected according to the equation:

$$FCe_{HOT; I, j, k} = FCorr_{i, j, Fuel} / FCorr_{i, j, Base} \times e_{HOT; i, j, k} \quad (19)$$

where,

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

$FCorr_{i, j, Fuel}$: the fuel correction for pollutant *i*, vehicle category *j*, calculated with equations given in Table 2-78, Table 2-79 and Table 2-80 for the available improved fuel qualities (Table 2-10)

$FCorr_{i, j, Base}$: the fuel correction for pollutant *i*, vehicle category *j*, calculated with equations given in Table 2-78, Table 2-79 and Table 2-80 for the base fuel

quality of vehicle class *j* (Table 2-10)

It is mentioned that equation (19) should not be used to provide the deterioration of emissions in case that an older fuel is used in a newer technology (e.g. use of Fuel 2000 in Euro 4 vehicles by inversion of FC coefficients). The emission factor calculated via equation (19) should be introduced in equations (3) and (5) or (6) respectively to estimate hot and cold start emissions.

2.4.12 Gasoline passenger cars

2.4.12.1 Pre Euro – "Conventional"

Hot Emissions

Hot emission factors for conventional vehicles are given in Table 2-11, Table 2-12 and Table 2-13 for different pollutants and Table 2-14 provides fuel consumption factors for the same vehicles. Those emission factors have been developed in the framework of older COPERT exercises (Eggleston et al., 1989). Separate equations are valid for different speed ranges and engine capacity classes.

Table 2-11: Speed dependency of CO emission factors for gasoline passenger cars

Vehicle Class	Engine Capacity	Speed Range (km/h)	CO Emission Factor (g/km)	R^2
PRE ECE	All capacities	10-100	$281V^{-0.630}$	0.924
	All capacities	100-130	$0.112V + 4.32$	-
ECE 15-00/01	All capacities	10-50	$313V^{-0.760}$	0.898
	All capacities	50-130	$27.22 - 0.406V + 0.0032V^2$	0.158
ECE 15-02	All capacities	10-60	$300V^{-0.797}$	0.747
	All capacities	60-130	$26.260 - 0.440V + 0.0026V^2$	0.102
ECE 15-03	All capacities	10-20	$161.36 - 45.62\ln(V)$	0.790
	All capacities	20-130	$37.92 - 0.680V + 0.00377V^2$	0.247
ECE 15-04	All capacities	10-60	$260.788 \cdot V^{-0.910}$	0.825
	All capacities	60-130	$14.653 - 0.220V + 0.001163V^2$	0.613

Improved Conventional	CC < 1.4 l	10-130	$14.577 - 0.294V + 0.002478V^2$	0.781
	1.4 l < CC < 2.0 l	10-130	$8.273 - 0.151V + 0.000957V^2$	0.767
Open Loop	CC < 1.4 l	10-130	$17.882 - 0.377V + 0.002825V^2$	0.656
	1.4 l < CC < 2.0 l	10-130	$9.446 - 0.230V + 0.002029V^2$	0.719

Table 2-12: Speed dependency of VOC emission factors for gasoline passenger cars

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

Cold start emissions

Table 2-15 provides e^{COLD}/e^{HOT} over-emission ratios for pollutants of Group 1. The β-parameter is calculated by means of equation provided in Table 2-16. Introduction of those values in equation (5), together with the hot emission factors quoted previously provides estimates of cold start emissions. Again, those ratios have been produced during older COPERT versions.

Table 2-13: Speed dependency of NO_x emission factors for gasoline passenger cars

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

Open Loop	CC < 1.4 l	10-130	-0.921 + 0.616ln(V)	0.791
	1.4 l < CC < 2.0 l	10-130	-0.761 + 0.515ln(V)	0.495

Table 2-14: Speed dependency of fuel consumption factors for gasoline passenger cars

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

Table 2-15: Over-emission ratios e^{COLD} / e^{HOT} for conventional gasoline vehicles (temperature range of –10°C to 30°C)

Conventional Gasoline Powered Vehicles	e^{COLD} / e^{HOT}
CO	$3.7 - 0.09\ t_a$
NO_x	$1.14 - 0.006\ t_a$

VOC	$2.8 - 0.06\ t_a$
Fuel Consumption	$1.47 - 0.009\ t_a$

Table 2-16: Cold mileage percentage β

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

2.4.12.2 Euro 1 and later

Hot emissions

Hot emissions estimates for Euro 2 and post-Euro 1 gasoline passenger cars are calculated as a function of speed. They have been developed in the framework of the *Artemis* project. Table 2-17 provides the factors of the function used to calculate the emission factors. The generic function used in this case is:

$$EF = (a + c \times V + e \times V^2)/(1 + b \times V + d \times V^2) \qquad (20)$$

Table 2-17: Values for eq.(20) to calculate emissions from Euro 1 and later gasoline passenger cars

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

		>2.0	10-130	0.99	2.53E+02	9.02E-02	5.02E-01	-4.69E-04	
	Euro 4	<1.4	10-130	0.95	1.36E+02	2.60E-02	-1.65E+00	2.28E-04	3.12E-02
		1.4-2.0	10-130	0.96	1.74E+02	6.85E-02	3.64E-01	-2.47E-04	8.74E-03
		>2.0	10-130	0.98	2.85E+02	7.28E-02	-1.37E-01	-4.16E-04	

Table 2-18 also presents simplified emission factors to be used for PM emission calculation from gasoline passenger cars of Euro 1 and later technologies. A separate emission factor is proposed for direct injection gasoline vehicles (GDI) due to the different combustion process of these engines.

Table 2-18: PM emission factors for Euro 1 and later gasoline passenger cars

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

Cold start emissions

Emissions of catalyst equipped vehicles during the warming up phase are significantly higher than during stabilised thermal conditions due to the reduced efficiency of the catalytic converter at temperatures below the light-off. Therefore, the effect of cold start has to be modelled in detail in the case of Euro I and later vehicles. Table 2-19 provides e^{COLD}/e^{HOT} over-emission ratios for three main pollutants (and fuel consumption). The values proposed are a result of fitting the existing COPERT methodology to the results published by MEET and are a function of ambient temperature and average travelling speed. Two speed regions have been introduced (5-25 km/h and 25-45 km/h). As in the case of hot emission factors, the value introduced for speed should correspond to the mean speed during travelling and not to the instantaneous speed. The speed range proposed is sufficient to cover most applications because cold start over-emissions are in principle allocated to urban driving only.

In the cases of CO and VOC over-emission occurs not only because of the low catalyst conversion efficiency but also because of the fuel enrichment during cold start conditions which allows for better drivability of a cold engine. The enrichment depends on the engine temperature during cold start. Therefore, over-emission of those pollutants during cold starts is not only higher than NO_x (which is generally not sensitive to fuel enrichment) but it also has a stronger dependence on temperature. This is why two different temperature ranges have to be distinguished for those pollutants.

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

The mileage fraction driven during the warming up phase is calculated by means of the formula provided in Table 2-16. After calculating the β-parameter and the e^{COLD}/e^{HOT} over-emission ratios, the application of equations (5) or (6) is straightforward.

Table 2-19: Over-emission ratios e^{COLD} / e^{HOT} for Euro 1 and later gasoline vehicles (V: speed in km/h, t_a: temperature in °C)

Case	Category	Speed [km/h]	Temp [°C]	$e^{COLD}/e^{HOT} = A \times V + B \times t_a + C$ A	B	C
CO	CC<1.4 l	5 - 25	-20 : 15	0.156	-0.155	3.519
		26 - 45	-20 : 15	0.538	-0.373	-6.24
		5 - 45	>15	8.032E-02	-0.444	9.826
	1.4 l < CC < 2.0 l	5 - 25	-20 : 15	0.121	-0.146	3.766
		26 - 45	-20 : 15	0.299	-0.286	-0.58
		5 - 45	>15	5.03E-02	-0.363	8.604
	CC>2.0 l	5 - 25	-20 : 15	7.82E-02	-0.105	3.116
		26 - 45	-20 : 15	0.193	-0.194	0.305
		5 - 45	>15	3.21E-02	-0.252	6.332
NOx	CC<1.4 l	5 - 25	> -20	4.61E-02	7.38E-03	0.755
		26 - 45	> -20	5.13E-02	2.34E-02	0.616
	1.4 l < CC < 2.0 l	5 - 25	> -20	4.58E-02	7.47E-03	0.764
		26 - 45	> -20	4.84E-02	2.28E-02	0.685
	CC>2.0 l	5 - 25	> -20	3.43E-02	5.66E-03	0.827
		26 - 45	> -20	3.75E-02	1.72E-02	0.728
VOC	CC<1.4 l	5 - 25	-20 : 15	0.154	-0.134	4.937
		26 - 45	-20 : 15	0.323	-0.240	0.301
		5 - 45	>15	9.92E-02	-0.355	8.967
	1.4 l < CC < 2.0 l	5 - 25	-20 : 15	0.157	-0.207	7.009
		26 - 45	-20 : 15	0.282	-0.338	4.098
		5 - 45	>15	4.76E-02	-0.477	13.44
	CC>2.0 l	5 - 25	-20 : 15	8.14E-02	-0.165	6.464
		26 - 45	-20 : 15	0.116	-0.229	5.739
		5 - 45	>15	1.75E-02	-0.346	10.462
FC	All Classes	-	-10 : 30	0	-0.009	1.47

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

Emission reduction compared to Euro 1 during the warming up phase of post-Euro 1 vehicle technologies mainly comes from the reduced time which is required from new catalytic systems to reach the light-off temperature. This time reduction is further reflected to a decrease in the distance travelled with a partial warmed engine and/or exhaust aftertreatment devices. Therefore, reduced cold start emissions are simulated with a respective decrease of the β-parameter, which stands for the mileage fraction driven with a cold or partially warmed engine. Table 2-20 provides reduction factors ($bc_{i,j}$) to be applied on the β-parameter according to pollutant and vehicle class.

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

Table 2-20: β-parameter reduction factors (bc) in case of post-Euro 1 gasoline vehicles for three main pollutants

Emission legislation	CO	NO_x	VOC
Euro 2 - 94/12/EC	0.72	0.72	0.56
Euro 3 - 98/69/EC Stage 2000	0.62	0.32	0.32
Euro 4 - 98/69/EC Stage 2005	0.18	0.18	0.18

Therefore, equation (5) in the case of post-Euro 1 vehicle classes yields:

$$E_{COLD;i,j} = bc_{i,j} \times \beta_{i,Euro\ 1} \times N_j \times M_j \times e_{hot,\ i,\ Euro\ 1} \times (e^{COLD} / e^{HOT} - 1)|_{I,\ Euro\ 1} \qquad (21)$$

Respective modifications should also be brought in equation (6) in cases where $bc_{i,j} \times \beta_{i,EURO\ I} > S_U$. It is obvious that the corrected value should be used for the mileage fraction during the warming up phase.

2.4.13 Diesel passenger cars

2.4.13.1 Pre Euro 1

Hot emissions

Based on a relatively large number of measured data on emissions of diesel passenger cars <2.5 tonnes (Hassel et al., 1987; Pattas et al., 1985; Rijkeboer et al., 1989; 1990) enabled to differentiate between cylinder capacities and to come up with speed dependent emission factors for conventional (pre Euro 1) vehicles. Emission factors to be introduced in equation (3) for the calculation of hot emissions from conventional diesel passenger cars are given in Table 2-21.

[1] However this statement probably fails to predict the additional emission reduction which might be brought by the cold start testing (-7°C) for Euro III and later vehicles. Most probably, the mixture enrichment strategy has to change in order that such vehicles comply with this test. This by turn will lead to a reduction of the e^{COLD}/e^{HOT} ratio. However the magnitude of the effect of such modification at higher temperatures is arguable. Because of this reason and in the absence of a more detailed analysis for the time being, it was decided to abandon any correction of e^{COLD}/e^{HOT} ratio.

Table 2-21: Speed dependency of emission and consumption factors for conventional diesel vehicles <2.5 t

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

Cold start emissions

Cold start over-emissions from diesel vehicles are not very significant compared to gasoline vehicles. Therefore, no distinction is made between conventional and Euro 1 vehicles. e^{COLD}/e^{HOT} ratios for calculating cold start over-emissions for those vehicles are quoted in Table 2-22.

Table 2-22: Over-emission ratios e^{COLD} / e^{HOT} for diesel passenger cars (temperature range -10°C to 30°C)

Pollutant	e^{COLD} / e^{HOT}
CO	$1.9 – 0.03\ t_a$
NO_x	$1.3 – 0.013\ t_a$
VOC	$3.1 – 0.09\ t_a$ (1)
PM	$3.1 – 0.1\ t_a$ (2)
Fuel Consumption	$1.34 – 0.008\ t_a$

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

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

2.4.13.2 Euro 1 and post-Euro 1

Hot emissions

Hot emissions estimates for Euro 1 and post-Euro 1 vehicles are calculated as a function of speed. They have been developed in the framework of the *Artemis* project. Table 2-23 provides the factors of the function used to calculate the emission factors. The generic function used in this case is:

$$EF = (a + c \times V + e \times V^2)/(1 + b \times V + d \times V^2) + f/V \quad (22)$$

Some manufacturers launched, already at Euro 3 emission standard, diesel passenger cars equipped with diesel particle filters. Those vehicle types that became popular did not significantly differ with 'conventional' Euro 3 vehicles in NOx (and secondarily) CO or HC emissions but only in PM. Table 2-24 presents PM specific emission factors for these vehicles. These emission factors assume the use of fuel fulfilling the EN590:2005 standards.

Table 2-23: Values for eq.(22) to calculate emissions from Euro 1 and later diesel passenger cars

Pollutant	Emission Standard	Engine capacity	Speed Range (km/h)	R^2	a	b	c	d	e	f
CO	Euro 1	All capacities	10-130	0.94	9.96E-01		-1.88E-02		1.09E-04	
	Euro 2	All capacities	10-130	0.91	9.00E-01		-1.74E-02		8.77E-05	
	Euro 3	All capacities	10-130	0.95	1.69E-01		-2.92E-03		1.25E-05	1.10E+00
	Euro 4	All capacities	10-130	See table footnote						
HC	Euro 1	<2.0	10-130	0.93	1.42E-01	1.38E-02	-2.01E-03	-1.90E-05	1.15E-05	
		>2.0	10-130	0.98	1.59E-01		-2.46E-03		1.21E-05	
	Euro 2	<2.0	10-130	0.99	1.61E-01	7.46E-02	-1.21E-03	-3.35E-04	3.63E-06	
		>2.0	10-130	0.98	5.01E+04	3.80E+04	8.03E+03	1.15E+03	-2.66E+01	
	Euro 3	<2.0	10-130	0.99	9.65E-02	1.03E-01	-2.38E-04	-7.24E-05	1.93E-06	
		>2.0	10-130	0.54	9.12E-02		-1.68E-03		8.94E-06	
	Euro 4	All capacities	10-130		3.47E-02	2.69E-02	-6.41E-04	1.59E-03	1.12E-05	0
NO_x	Euro 1	All capacities	10-130	0.96	3.10E+00	1.41E-01	-6.18E-03	-5.03E-04	4.22E-04	
	Euro 2	All capacities	10-130	0.94	2.40E+00	7.67E-02	-1.16E-02	-5.00E-04	1.20E-04	
	Euro 3	All capacities	10-130	0.92	2.82E+00	1.98E-01	6.69E-02	-1.43E-03	-4.63E-04	
	Euro 4	All capacities	10-130		1.11E+00		-2.02E-02		1.48E-04	0
PM	Euro 1	All capacities	10-130	0.70	1.14E-01		-2.33E-03		2.26E-05	
	Euro 2	All capacities	10-130	0.71	8.66E-02		-1.42E-03		1.06E-05	
	Euro 3	All capacities	10-130	0.81	5.15E-02		-8.80E-04		8.12E-06	
	Euro 4	All capacities	10-130		4.50E-02		-5.39E-04		3.48E-06	
FC	Euro 1	<2.0	10-130	0.98	1.45E+02	6.73E-02	-1.88E-01	-3.17E-04	9.47E-03	
		>2.0	10-130	0.96	1.95E+02	7.19E-02	1.87E-01	-3.32E-04	9.99E-03	
	Euro 2	<2.0	10-130	0.97	1.42E+02	4.98E-02	-6.51E-01	-1.69E-04	1.32E-02	
		>2.0	10-130	0.96	1.95E+02	7.19E-02	1.87E-01	-3.32E-04	9.99E-03	
	Euro 3	<2.0	10-130	0.95	1.62E+02	1.23E-01	2.18E+00	-7.76E-04	-1.28E-02	
		>2.0	10-130	0.96	1.95E+02	7.19E-02	1.87E-01	-3.32E-04	9.99E-03	

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

Cold start emissions

In order to calculate cold-start emissions of Euro 1 and later diesel passenger cars, the β-parameter is calculated by the formula given in Table 2-16 for all classes, while e^{COLD}/e^{HOT} ratios are quoted in Table 2-22 and are the same as in the case of conventional vehicles. However, some additional reductions need to be applied for vehicle technologies post-Euro 4 (RF_{ij}), which are given in Table 2-25. Based on these, the application of equation (5) is exact up to Euro 4 diesel passenger cars. For post Euro 4, this should be expressed as:

$$E_{COLD;i,j} = \beta_{i,j} \times N_j \times M_j \times (100\text{-}RF_{i,j}) / 100 \times e_{HOT;\, i,\, Euro\, 4} \times (e^{COLD} / e^{HOT}|_{i,\, Euro\, 1} - 1) \quad (23)$$

A similar transformation needs to be made in the case of equation (6).

Table 2-24: Emission factors of PM from Euro 3 diesel passenger cars equipped with diesel particle filters (EN590:2005 fuel considered)

Diesel Passenger Cars	Urban Driving (g/km)	Rural Driving (g/km)	Highway Driving (g/km)
Euro 3 + DPF	0.002	0.002	0.002

Table 2-25: Emission reduction percentage for Euro 5 and 6 diesel passenger cars applied to vehicles complying with Euro 4 standards.

Diesel Passenger Cars	CO [%]	NOx [%]	VOC [%]	PM [%]
Euro 5 – EC 715/2007 Stage I	0	28	0	95
Euro 6 – EC 715/2007 Stage II	0	68	0	95

2.4.14 LPG passenger cars

The methodology introduced in the case of gasoline passenger cars is valid also in the case of LPG vehicles. However, it has to be stressed that the amount of data in the case of LPG vehicles was very limited and therefore a large number of assumptions and extrapolations had to be made on the basis of existing information to provide a consistent set of emission factors to calculate hot and cold start emissions.

2.4.15 Hot emissions

Equation (3) is applied to calculate hot emissions for conventional and Euro 1 LPG vehicles. Table 2-26 provides hot emission factors for conventional passenger cars and Table 2-27 for those complying with 91/441/EEC (Euro 1). The former emission factors have been developed in the framework of earlier COPERT exercises and the latter ones in the framework of MEET (Samaras and Ntziachristos, 1997). With respect to post-Euro 1 LPG vehicles and in the absence of more updated data, reduction factors over Euro 1 emission factors are proposed. These can be introduced by means of equation (24), while the reduction factors are given in Table 2-28:

$$e_{HOT;\, i,\, j,\, k} = (100\text{-}RF_{i,j}) / 100 \times e_{HOT;\, i,\, Euro\, 1,\, k} \quad (24)$$

Cold start emissions

Very few data on cold start over-emission from LPG vehicles are available (AQA, 1990; Hauger et al.; 1991). For consistency however and since LPG emission limitation technology is similar to that of gasoline vehicles, the methodology applied to calculate emissions from gasoline vehicles is also applied here. Table 2-29 provides over-emission ratios which are valid for all emission classes of LPG vehicles. Equations (5) and (6) are applied up to Euro 1 vehicles while equation (23) is applied to post-Euro 1 ones. Reduction factors for the β-parameter equal those of gasoline vehicles (Table 2-20).

Table 2-26: Speed Dependency of Emission Factors for LPG Vehicles <2.5 t

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

2.4.16 Two-stroke passenger cars

Few measured data are available (Appel et al., 1989; Jileh, 1991; Pattas et al., 1983) which have been used to derive emission factors for urban, rural and highway driving for two-stroke gasoline powered cars in the framework of older COPERT exercises. Total emission factors (hot + cold) are given in Table 2-30. They are relevant mainly for some Eastern European countries (and to some extent for Germany). However, it should be noted that due to the limited knowledge of the authors about the actual driving behaviour in Eastern Europe (e.g. average speed on urban and rural roads and on highways) and the limited number of test data, the emission factors are less reliable than, for example, those given for other gasoline passenger cars.

Table 2-27: Speed dependency of emission and consumption factors for LPG vehicles <2.5t, complying with directive 91/441/EEC

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

Table 2-28: Emission reduction percentage for post Euro 1 LPG passenger cars, applied to vehicles complying with directive 91/441/EEC (Euro 1)

Engine Capacity	LPG Passenger Cars	CO [%]	NOx [%]	VOC[%]
CC < 1.4 l	Euro 2 - 94/12/EC	32	64	79
	Euro 3 - 98/69/EC Stage 2000	44	76	85
	Euro 4 - 98/69/EC Stage 2005	66	87	97
1.4 l < CC < 2.0 l	Euro 2 - 94/12/EC	32	64	79
	Euro 3 - 98/69/EC Stage 2000	44	76	86
	Euro 4 - 98/69/EC Stage 2005	66	87	97
CC > 2.0 l	Euro 2 - 94/12/EC	32	64	76
	Euro 3 - 98/69/EC Stage 2000	44	76	84
	Euro 4 - 98/69/EC Stage 2005	65	87	95

Table 2-29: Over-emission ratios e^{COLD} / e^{HOT} for LPG passenger cars (temperature range of –10°C to 30°C)

Pollutant	e^{COLD} / e^{HOT}
CO	$3.66 - 0.09\ t_a$
NO_x	$0.98 - 0.006\ t_a$
VOC	$2.24 - 0.06\ t_a$ (1)
Fuel Consumption	$1.47 - 0.009\ t_a$

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

Table 2-30: Emission Factors for Gasoline Two-Stroke Vehicles <2.5 t

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

2.4.17 Hybrid passenger cars <1.6l

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

$$EF = a + c \times V + e \times V^2 \qquad (25)$$

The factors used in the equation can be found in Table 2-31.

Table 2-31: Values for eq.(25) to calculate emissions from hybrid gasoline passenger cars

Pollutant	Emission Standard	Engine capacity	Speed Range (km/h)	R^2	a	c	e
CO	Euro 4	All capacities	10-130	1	1.95E-04	3.80E-05	-2.64E-07
HC		All capacities	10-130	1	5.50E-04	-8.54E-06	4.94E-08
NO_x		All capacities	10-130	1	1.48E-02	-4.20E-04	4.29E-06
FC		All capacities	10-130	1	1.94E+01	6.06E-02	7.54E-04

2.4.18 Gasoline light duty vehicles

Hot emissions

The emissions of these vehicles within EU countries were covered by the different ECE steps. All those vehicle classes have been introduced in a common "Conventional" class and emission factors for pollutants of Group 1 are given in Table 2-32. Emission factors of Euro 1 vehicles can also be found in the same Table. Hot emission factors of post-Euro 1 vehicles are calculated by application of equation (24) by introducing the reduction factors given in Table 2-33.

Table 2-32: Speed dependency of emission and consumption factors for gasoline light duty vehicles <3.5 t

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

Table 2-33: Emission reduction percentage post-Euro 1 light duty vehicles applied to vehicles complying with directive 93/59/EEC (Euro 1)

Gasoline Light Duty Vehicles	**CO [%]**	**NOx [%]**	**VOC [%]**
Euro 2 - 96/69/EC	39	66	76
Euro 3 - 98/69/EC Stage	48	79	86
Euro 4 - 98/69/EC Stage	72	90	94
Euro 5 – EC 715/2007	72	92.5	94
Euro 6 – EC 715/2007	72	92.5	94

PM emissions from gasoline light duty vehicles can be considered similar to passenger cars (Table 2-18).

Cold start emissions

The same over-emission ratios applied in the case of gasoline passenger cars of engine capacity >2.0 l are also applied in the case of light duty vehicles in the absence of more detailed data. Although this assumption used to be a very rough estimate for past vehicle classes, due to the very different emission standards of light duty vehicles and passenger cars, it tends to be a reality today since the technology introduced nowadays in light duty vehicles does not significantly differ from respective passenger cars. Therefore the over-emission ratios proposed in Table 2-15 (pre-Euro 1) and Table 2-19 (Euro 1 and on) are applied in the case of light duty vehicles. Furthermore, equations (5), (6) are valid for pre-Euro 1 vehicles and equation (23) for Euro 1 and later ones in conjunction with the β-parameter reduction factors given in Table 2-20.

2.4.19 Diesel light duty vehicles

Diesel light duty vehicles are treated as passenger cars. Hot emission factor speed dependencies have been developed in the framework of older COPERT exercises (Conventional vehicles) and in the MEET project (Euro I and later vehicles) and are quoted in Table 2-34 for pollutants of Group 1. Cold start over-emissions up to Euro 1 are calculated by equation (5), where e^{COLD}/e^{HOT} ratios are selected from Table 2-22. Emission factors of post-Euro 1 vehicle classes are calculated by the functions corresponding to Euro I vehicles by introducing the reduction factors given in Table 2-35 both for hot and cold start emissions (equations (24) and (23), respectively).

2.4.20 Gasoline heavy duty vehicles

Only hot emissions are calculated for gasoline heavy duty vehicles. Emission factors derived from an extrapolation of results from smaller vehicles are presented in Table 2-36 and are distinguished only to the three driving modes (urban, rural, highway). Total emission estimates are therefore calculated by application only of equation (3).

Table 2-34: Speed dependency of emission and consumption factors for diesel light duty vehicles <3.5 t

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

Table 2-35: Emission reduction percentage for future diesel light duty vehicles applied to vehicles complying with directive 93/59/EEC

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

Table 2-36: Emission factors for heavy Duty gasoline vehicles >3.5 t

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

2.4.21 Diesel heavy duty vehicles and busses

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

Equations (26) to (35) represent the main equations used to calculate the emission factors, while the Annex contains the necessary parameters in a specific structure. The name of the files in the Annex is "EFs_GXX%_LYYY%.xls", where XX is the road gradient and YYY is the load factor of the vehicle. The sheet names correspond to the emission factors described in the file, namely CO, THC (VOC), NOx, and PM.

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

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

where *EF* is the emission factor, *V* is the vehicle speed and the different parameters are found in the columns I to M in the *Annex* file, namely: a= 0.00094 – b= 0.00017 – c= -0.000001.

Equations (26) to (35), describe all the different equations that are potentially used in the *Annex* to calculate heavy duty vehicle and bus emission factors.

$EF = (a + (b \times V))+(((c - b) \times (1-\exp(((-1) \times d) \times V))) / d)$	(26)
$EF = (e + (a \times \exp(((-1) \times b) \times V))) + (c \times \exp(((-1) \times d) \times V))$	(27)
$EF = 1 / (((c \times (V^2)) + (b \times V)) + a)$	(28)
$EF = 1 / (a + (b \times (V^c)))$	(29)
$EF = 1 / (a + (b \times V))$	(30)
$EF = a - (b \times \exp(((-1) \times c) \times (V^d)))$	(31)
$EF = a + (b / (1+\exp((((-1) \times c) + (d \times \ln(x))) + (e \times V))))$	(32)
$EF = c + (a \times \exp(((-1) \times b) \times V))$	(33)
$EF = c + (a \times \exp(b \times V))$	(34)
$EF = \exp(a + (b / V)) + (c \times \ln(V))$	(35)

2.4.22 Natural gas busses

Natural gas vehicles (NGVs) are nowadays present in several urban captive fleets around Europe. France has already some 700 NG busses in operation, out of a total of 12000 while 416 NG busses are in operation in Athens, in a fleet of 1800 vehicles. NG as a fuel can neither be used on a diesel engine nor on a gasoline one without modifications because it has a high octane number (120-130) and a lower than 50 cetane number which makes it unsuitable for diesel combustion. Most commercial systems therefore utilize a spark plug to initiate natural gas combustion and a higher compression ratio than conventional gasoline engines to take advantage of the high octane rate and to increase efficiency. NGVs may also operate either on stoichiometric mode for low emissions or on lean-mode for higher efficiency. In addition, high pressure storage bottles are required to store Compressed NG (CNG) while liquid NG (LNG) stored at low temperature is not that common, mainly due to the higher complexity of storage on the bus. CNG powertrains are hence associated with more cost elements and higher maintenance costs than diesel engines.

CNG busses may have completely different combustion and aftertreatment technology, despite using the same fuel. Hence, their emission performance may significantly vary. Therefore, CNG busses also need to fulfil a specific emission standard (Euro II, Euro III, etc.). Due to the low NO_x and PM performance compared to diesel, an additional emission standard has been set for CNG vehicles, known as the standard for Enhanced Environmental Vehicles – EEV. The emission limits imposed for EEV are even below Euro V and usually EEVs are benefited from taxation waivers and free entrance to low emission zones. New stoichiometric buses are able to fulfil the EEV requirements, while older busses were usually registered as Euro II or Euro III. Table 2-37 provides typical emission and consumption factors that can be used to estimate the emission contribution of CNG busses, depending on their emission level. More information on the derivation of these emission values is given in Ntziachristos et al. (2007).

Table 2-37: Proposed emission and consumption factors for urban CNG busses in typical urban driving conditions

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

2.4.23 Two-stroke mopeds <50 cm³

Mopeds are mostly driven under "urban" driving conditions and therefore only an urban emission factor value is proposed in Table 2-38 and Table 2-39. Emissions factors should be considered as bulk values which include the cold start fraction, therefore no distinction is made to hot and cold start emissions.

2.4.24 Motorcycles >50 cm³

The equation used to calculate the emission factor of Euro Conventional and Euro 1 motorcycles over 50 cm³ engine displacement is eq. (25). The coefficients to calculate these emission factors up to the Euro I emission standard are given in Table 2-40 for 2-stroke vehicles and Table 2-42 for 4-stroke ones. For more recent vehicle technologies, reduction factors over the Euro 1 emission factor are proposed for 2-stroke ones, which should be applied according to Table 2-41. Urban, rural and highway emission factors are proposed for 4-stroke motorcycles of improved technology in Table 2-43.

Table 2-38: Emission and consumption factors for mopeds (corresponding to urban driving conditions)

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

Table 2-39: PM emission factors for conventional and post Euro mopeds (corresponding to urban driving conditions)

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

Table 2-40: Speed dependency of emission and consumption factors for conventional and Euro 1 2 stroke motorcycles of engine displacement over 50 cm³

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

Table 2-41: Emission correction factors for Euro 2 and later 2 stroke motorcycles of engine displacement over 50 cm³ over Euro 1

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

Table 2-42: Speed dependency of emission and consumption factors for 4 stroke conventional and Euro 1 motorcycles of engine displacement over 50cm³

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

Table continues in next page

Table 2-42(cont.): Speed dependency of emission and consumption factors for 4 stroke conventional and Euro 1 motorcycles of engine displacement over 50cm³

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

Table 2-43: Emission and consumption factors for 4 stroke Euro 2 and Euro 3 motorcycles of engine displacement over 50cm³

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

Table 2-44 also includes PM emission factors from power two wheelers, which are particularly important for 2-stroke vehicles. These emission factors correspond to a mix of mineral and synthetic lubricant used for 2-stroke engines.

Table 2-44: PM Emission factors for 2 and 4 stroke conventional and post Euro motorcycles of engine displacement over $50cm^3$

Pollutant	Cylinder Capacity	Emission Standard	Speed Range [km/h]	Emission Factor [gr/km]
PM	2-stroke	Conventional	10 - 110	2.0E-01
		Euro 1	10 - 110	8.0E-02
		Euro 2	10 - 110	4.0E-02
		Euro 3	10 - 110	1.2E-02
	<250cm3	Conventional	10 - 110	2.0E-02
		Euro 1	10 - 110	2.0E-02
		Euro 2	10 - 110	5.0E-03
		Euro 3	10 - 110	5.0E-03
	250<cc<750cm3	Conventional	10 - 110	2.0E-02
		Euro 1	10 - 110	2.0E-02
		Euro 2	10 - 110	5.0E-03
		Euro 3	10 - 110	5.0E-03
	>750cm3	Conventional	10 - 110	2.0E-02
		Euro 1	10 - 110	2.0E-02
		Euro 2	10 - 110	5.0E-03
		Euro 3	10 - 110	5.0E-03

2.4.25 Emissions of non-regulated pollutants

2.4.25.1 Distinction to methane / non methane VOC emissions

Legislation regulates total VOC emissions with no distinction to methane / non-methane split. Hence, previous tables have provided emission factors for VOC emissions. However, since CH_4 is a greenhouse gas, we need different emission factors to calculate its contribution. In order to calculate hot CH_4 emissions, equation (3) can be applied with the values given in Table 2-45. Reduction factors for more recent technologies are given in Table 2-46. In reference to those tables it should be noted that cold emission factors are applied only for passenger cars and light duty vehicles. In Table 2-46 the reductions are over Euro 1 for passenger cars and over Euro I for heavy duty vehicles and buses. For power two wheelers the reductions are over conventional technology.

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

NMVOC emission are deduced as the remainder of the subtraction of CH_4 total emissions from VOC total emissions, as calculated by equation (36). Hence, after VOC and CH_4 have been calculated by equation (1), NMVOC emissions can also be calculated by:

$$E_{NMVOC} = E_{VOC} - E_{CH4} \quad (36)$$

Table 2-45: Methane (CH_4) emission factors (mg/km)

Vehicle Type	Fuel	Vehicle Technology/Class	CH_4 Emission Factors (mg/km)			
			Urban		Rural	Highway
			Cold	Hot		
Passenger Car	Gasoline	pre-Euro	201	131	86	41
		Euro 1	45	26	16	14
		Euro 2	94	17	13	11
		Euro 3	83	3	2	4
		Euro 4	57	2	2	0
	Diesel	pre-Euro	22	28	12	8
		Euro 1	18	11	9	3
		Euro 2	6	7	3	2
		Euro 3	3	3	0	0
		Euro 4	0	0	0	0
	LPG	pre-ECE	80	80	35	25
		Euro 1				
		Euro 2				
		Euro 3 and later				
Light Duty Vehicles	Gasoline	pre-Euro	201	131	86	41
		Euro 1	45	26	16	14
		Euro 2	94	17	13	11
		Euro 3	83	3	2	4
		Euro 4	57	2	2	0
	Diesel	pre-Euro	22	28	12	8
		Euro 1	18	11	9	3
		Euro 2	6	7	3	2
		Euro 3	3	3	0	0
		Euro 4	0	0	0	0
Heavy Duty Vehicles & Busses	Gasoline	All Technologies	-	140	110	70
	Diesel	GVW<16t	-	85	23	20
		GVW>16t	-	175	80	70
		Urban Busses & Coaches	-	175	80	70
	CNG	Euro I	-	6800		
		Euro II	-	4500		
		Euro III	-	1280		
		EEV	-	980		
Power Two Wheelers	Gasoline	<50 cm^3	-	219	219	219
		>50 cm^3 2-stroke	-	150	150	150
		>50 cm^3 4-stroke	-	200	200	200

Table 2-46: Methane (CH_4) emission reduction factors (%). Reductions are over Euro 1 for passenger cars, Euro I for heavy duty vehicles and busses and the Conventional technology for power two wheelers.

Vehicle Type	Fuel	Vehicle Technology/Class	CH_4 Emission Reduction Factors (%)		
			Urban	Rural	Highway
Passenger Cars	LPG	Euro 2	76	76	76
		Euro 3	84	84	84
		Euro 4	95	95	95
Heavy Duty Vehicles	Diesel	Euro II	36	13	7
		Euro III	44	7	9
		Euro IV	97	93	94
		Euro V and later	97	93	94
Buses	Diesel	Euro II	35	35	35
		Euro III	41	41	41
		Euro IV	97	97	97
		Euro V and later	97	97	97
Power Two Wheelers	Gasoline	<50 cm^3 - Euro 1	80	-	-
		<50 cm^3 - Euro 2	89		
		<50 cm^3 - Euro 3	91		
		2-stroke >50 cm^3 - Euro 1	34	29	35
		2-stroke >50 cm^3 - Euro 2	80	79	80
		2-stroke >50 cm^3 - Euro 3	92	91	92
		4-stroke <250 cm^3 - Euro 1	29	28	34
		4-stroke <250 cm^3 - Euro 2	32	54	54
		4-stroke <250 cm^3 - Euro 3	59	84	86
		4-stroke 250-750 cm^3 - Euro 1	26	13	22
		4-stroke 250-750 cm^3 – Euro 2	22	40	39
		4-stroke 250-750 cm^3 - Euro 3	53	79	82
		4-stroke >750 cm^3 - Euro 1	54	54	23
		4-stroke >750 cm^3 - Euro 2	58	69	49
		4-stroke >750 cm^3 - Euro 3	75	89	85

2.4.25.2 PM characteristics

New emission factors for PM characteristics have been developed on the basis of the *Particulates* project and are presented in the following tables. These include the "Active Surface Area" in cm²/km, the "Total Particle Number" in #/km, and the "Solid Particle Number" in #/km , differentiated in three different classes (< 50 nm, 50-100 nm, 100-1000 nm). The total particle number emitted by vehicles is only indicative of the total emission flux, since vehicles emit both solid and volatile particles and the number concentration of the latter depends on the ambient conditions (temperature, humidity, traffic conditions, etc.). The values given in the following tables have been obtained in the laboratory under conditions expected to maximize the concentration of these particles, hence they should be considered to represent a close to maximum emission rate. More details on the sampling conditions and the relevance of these values is given by Samaras et al. (2005).

Table 2-47: PM characteristics of Diesel Passenger Cars

Pollutant	Category	Fuel sulphur content	Emission Factor		
			Urban	Rural	Highway
Active surface area [m²/km]	PC diesel Euro 1	later than 2000	2.10E+01	1.91E+01	2.94E+01
	PC diesel Euro 2	2005-2009	1.68E+01	1.71E+01	2.78E+01
		2000			3.62E+01
	PC diesel Euro 3	2005-2009	1.53E+01	1.34E+01	1.85E+01
		2000			3.93E+01
	PC diesel Euro 3 DPF	2005-2009	1.21E-02	1.32E-02	2.20E-01
		2000		4.03E+00	4.46E+01
	PC petrol Euro 1	later than 2000	6.82E-01	4.33E-01	4.98E-01
	PC petrol Euro 3	later than 2000	2.38E-02	3.32E-02	7.43E-02
	PC petrol Euro 3 DISI	later than 2000	2.04E+00	1.77E+00	2.48E+00
Total particle number [#/km]	PC diesel Euro 1	later than 2000	4.04E+14	3.00E+14	3.21E+14
	PC diesel Euro 2	2005-2009	2.12E+14	2.05E+14	4.35E+14
		2000			7.10E+14
	PC diesel Euro 3	2005-2009	1.64E+14	1.73E+14	2.82E+14
		2000			1.23E+15
	PC diesel Euro 3 DPF	2005-2009	6.71E+10	9.00E+12	1.79E+14
		2000		1.67E+14	1.34E+15
	PC petrol Euro 1	later than 2000	8.76E+12	7.35E+12	1.81E+13
	PC petrol Euro-	later than 2000	6.99E+11	5.26E+12	5.59E+12
	PC petrol Euro 3 DISI	later than 2000	1.47E+13	1.13E+13	9.02E+13

Table 2-48: Solid particle number emission from Diesel Passenger Cars (not affected by fuel sulphur content)

Pollutant	Category	Emission Factor (#/km)		
		Urban	Rural	Highway
Number of solid particles <50 nm	PC diesel Euro 1	8.5E+13	8.6E+13	7.2E+13
	PC diesel Euro 2	7.6E+13	7.6E+13	6.1E+13
	PC diesel Euro 3	7.9E+13	7.1E+13	5.8E+13
	PC diesel Euro 3 DPF	5.5E+10	4.0E+10	2.3E+11
	PC gasoline Euro 1	3.2E+12	2.4E+12	8.6E+11
	PC gasoline Euro 3	9.6E+10	1.1E+11	5.5E+10
	PC gasoline Euro 3 DISI	8.1E+12	6.1E+12	2.8E+12
Number of solid particles 50-100 nm	PC diesel Euro 1	9.3E+13	7.8E+13	7.3E+13
	PC diesel Euro 2	8.8E+13	7.7E+13	7.2E+13
	PC diesel Euro 3	8.7E+13	6.8E+13	6.9E+13
	PC diesel Euro 3 DPF	2.3E+10	1.6E+10	9.4E+10
	PC gasoline Euro 1	1.4E+12	1.0E+12	3.4E+11
	PC gasoline Euro 3	4.4E+10	5.4E+10	2.8E+10
	PC gasoline Euro 3 DISI	6.5E+12	3.6E+12	1.9E+12
Number of solid particles 100-1000 nm	PC diesel Euro 1	5.4E+13	3.8E+13	4.0E+13
	PC diesel Euro 2	5.1E+13	3.6E+13	4.0E+13
	PC diesel Euro 3	4.5E+13	3.2E+13	3.5E+13
	PC diesel Euro 3 DPF	1.6E+10	1.2E+10	2.8E+10
	PC gasoline Euro 1	5.2E+11	3.7E+11	1.2E+11
	PC gasoline Euro 3	2.6E+10	3.4E+10	5.1E+10
	PC gasoline Euro 3 GDI	4.1E+12	2.1E+12	1.5E+12

Table 2-49 to Table 2-53 include particle properties information for busses and heavy duty vehicles. Further to the technology classification given in Table 2-6, some additional technologies are included in these tables, just because of their large influence on PM emissions. These tables include Euro II and Euro III vehicles retrofitted with continuously regenerated particle filters (CRDPF) and selective catalytic reduction aftertreatment (SCR). They also include new emission technologies (Euro IV and Euro V) equipped with original equipment aftertreatment devices.

Table 2-49: PM characteristics of Buses

Pollutant	Emission Standard	Speed Range [km/h]	Emission Factor		
			Urban	Rural	Highway
Active Surface Area [cm²/km]	Euro II & III	10 - 110	5.65E+05	1.99E+05	2.57E+05
	Euro II & III + CRDPF	10 - 110	8.07E+04	1.77E+04	2.18E+04
	Euro II & III+SCR	10 - 110	9.13E+05	3.37E+05	3.93E+05
	Euro IV +CRDPF	10 - 110			
	Euro V + SCR	10 - 110			
Total Particle Number [#/km]	Euro II & III	10 - 110	6.88E+14	4.55E+14	1.12E+15
	Euro II & III + CRDPF	10 - 110	2.72E+14	4.77E+13	8.78E+13
	Euro II & III+SCR	10 - 110	7.66E+14	5.68E+14	1.28E+15
	Euro IV +CRDPF	10 - 110	5.93E+12	3.57E+12	2.93E+12
	Euro V + SCR	10 - 110	1.73E+13	1.09E+13	1.22E+13
Solid Particle Number < 50 nm [#/km]	Euro II & III	10 - 110	1.25E+14	5.08E+13	7.43E+13
	Euro II & III + CRDPF	10 - 110	3.87E+12	1.89E+12	4.18E+12
	Euro II & III+SCR	10 - 110	1.19E+14	5.26E+13	7.67E+13
	Euro IV +CRDPF	10 - 110	1.25E+10	6.43E+09	8.20E+09
	Euro V + SCR	10 - 110	7.98E+12	2.87E+12	2.04E+12
olid Particle Number 50-100 nm [#/km]	Euro II & III	10 - 110	1.44E+14	5.44E+13	6.82E+13
	Euro II & III + CRDPF	10 - 110	3.31E+12	1.43E+12	2.54E+12
	Euro II & III+SCR	10 - 110	1.57E+14	6.14E+13	7.25E+13
	Euro IV +CRDPF	10 - 110	1.04E+10	4.14E+09	3.88E+09
	Euro V + SCR	10 - 110	9.13E+12	3.06E+12	2.10E+12
Solid Particle Number 100-1000 nm [#/km]	Euro II & III	10 - 110	2.09E+14	7.25E+13	7.16E+13
	Euro II & III + CRDPF	10 - 110	2.29E+12	8.53E+11	1.12E+12
	Euro II & III+SCR	10 - 110	3.30E+14	1.21E+14	1.10E+14
	Euro IV +CRDPF	10 - 110	3.27E+10	9.48E+09	5.89E+09
	Euro V + SCR	10 - 110	1.57E+13	5.16E+12	3.36E+12

Table 2-50: PM characteristics of Coaches

Pollutant	Emission Standard	Speed Range [km/h]	Emission Factor		
			Urban	Rural	Highway
Active Surface Area [cm²/km]	Euro II & III	10 - 110	6.75E+05	2.23E+05	2.13E+05
	Euro II & III + CRDPF	10 - 110	9.65E+04	1.98E+04	1.81E+04
	Euro II & III+SCR	10 - 110	1.09E+06	3.77E+05	3.26E+05
	Euro IV +CRDPF	10 - 110			
	Euro V + SCR	10 - 110			
Total Particle Number [#/km]	Euro II & III	10 - 110	8.23E+14	5.09E+14	9.28E+14
	Euro II & III + CRDPF	10 - 110	3.25E+14	5.34E+13	7.28E+13
	Euro II & III+SCR	10 - 110	9.16E+14	6.35E+14	1.06E+15
	Euro IV +CRDPF	10 - 110	7.29E+12	4.03E+12	2.42E+12
	Euro V + SCR	10 - 110	2.15E+13	1.24E+13	1.01E+13
Solid Particle Number < 50 nm [#/km]	Euro II & III	10 - 110	1.49E+14	5.68E+13	6.16E+13
	Euro II & III + CRDPF	10 - 110	4.63E+12	2.11E+12	3.47E+12
	Euro II & III+SCR	10 - 110	1.43E+14	5.89E+13	6.36E+13
	Euro IV +CRDPF	10 - 110	1.53E+10	7.27E+09	6.76E+09
	Euro V + SCR	10 - 110	9.92E+12	3.27E+12	1.69E+12
Solid Particle Number 50-100 nm [#/km]	Euro II & III	10 - 110	1.72E+14	6.08E+13	5.65E+13
	Euro II & III + CRDPF	10 - 110	3.96E+12	1.60E+12	2.10E+12
	Euro II & III+SCR	10 - 110	1.88E+14	6.86E+13	6.01E+13
	Euro IV +CRDPF	10 - 110	1.28E+10	4.68E+09	3.19E+09
	Euro V + SCR	10 - 110	1.14E+13	3.49E+12	1.73E+12
Solid Particle Number 100-1000 nm [#/km]	Euro II & III	10 - 110	2.49E+14	8.11E+13	5.94E+13
	Euro II & III + CRDPF	10 - 110	2.74E+12	9.54E+11	9.30E+11
	Euro II & III+SCR	10 - 110	3.95E+14	1.36E+14	9.13E+13
	Euro IV +CRDPF	10 - 110	4.02E+10	1.07E+10	4.85E+09
	Euro V + SCR	10 - 110	1.95E+13	5.89E+12	2.77E+12

Table 2-51: PM characteristics of HDVs 3.5-7.5 tn

HDVs 3.5-7.5 tn					
Pollutant	**Emission Standard**	**Speed Range [km/h]**	**Emission Factor**		
			Urban	**Rural**	**Highway**
Active Surface Area [cm²/km]	Euro II & III	10 - 110	2.62E+05	1.19E+05	1.61E+05
	Euro II & III + CRDPF	10 - 110	3.74E+04	1.06E+04	1.36E+04
	Euro II & III+SCR	10 - 110	4.23E+05	2.02E+05	2.45E+05
	Euro IV +CRDPF	10 - 110			
	Euro V + SCR	10 - 110			
Total Particle Number [#/km]	Euro II & III	10 - 110	3.19E+14	2.72E+14	6.99E+14
	Euro II & III + CRDPF	10 - 110	1.26E+14	2.85E+13	5.48E+13
	Euro II & III+SCR	10 - 110	3.55E+14	3.40E+14	8.01E+14
	Euro IV +CRDPF	10 - 110	2.73E+12	2.12E+12	1.80E+12
	Euro V + SCR	10 - 110	7.96E+12	6.41E+12	7.44E+12
Solid Particle Number < 50 nm [#/km]	Euro II & III	10 - 110	5.79E+13	3.04E+13	4.64E+13
	Euro II & III + CRDPF	10 - 110	1.80E+12	1.13E+12	2.61E+12
	Euro II & III+SCR	10 - 110	5.52E+13	3.15E+13	4.79E+13
	Euro IV +CRDPF	10 - 110	5.75E+09	3.81E+09	5.04E+09
	Euro V + SCR	10 - 110	3.66E+12	1.69E+12	1.24E+12
Solid Particle Number 50-100 nm [#/km]	Euro II & III	10 - 110	6.68E+13	3.25E+13	4.26E+13
	Euro II & III + CRDPF	10 - 110	1.53E+12	8.56E+11	1.59E+12
	Euro II & III+SCR	10 - 110	7.27E+13	3.67E+13	4.53E+13
	Euro IV +CRDPF	10 - 110	4.78E+09	2.46E+09	2.38E+09
	Euro V + SCR	10 - 110	4.19E+12	1.81E+12	1.28E+12
Solid Particle Number 100-1000 nm [#/km]	Euro II & III	10 - 110	9.66E+13	4.34E+13	4.47E+13
	Euro II & III + CRDPF	10 - 110	1.06E+12	5.10E+11	7.01E+11
	Euro II & III+SCR	10 - 110	1.53E+14	7.26E+13	6.88E+13
	Euro IV +CRDPF	10 - 110	1.51E+10	5.62E+09	3.62E+09
	Euro V + SCR	10 - 110	7.21E+12	3.05E+12	2.04E+12

Table 2-52: PM characteristics of rigid HDVs 7.5-14 tn

HDVs 7.5-16 tn					
Pollutant	**Emission Standard**	**Speed Range [km/h]**	**Emission Factor**		
			Urban	**Rural**	**Highway**
Active Surface Area [cm2/km]	Euro II & III	10 - 110	5.56E+05	2.19E+05	2.37E+05
	Euro II & III + CRDPF	10 - 110	7.95E+04	1.95E+04	2.00E+04
	Euro II & III+SCR	10 - 110	8.99E+05	3.70E+05	3.61E+05
	Euro IV +CRDPF	10 - 110			
	Euro V + SCR	10 - 110			
Total Particle Number [#/km]	Euro II & III	10 - 110	6.78E+14	5.00E+14	1.03E+15
	Euro II & III + CRDPF	10 - 110	2.68E+14	5.24E+13	8.07E+13
	Euro II & III+SCR	10 - 110	7.54E+14	6.23E+14	1.18E+15
	Euro IV +CRDPF	10 - 110	5.81E+12	3.90E+12	2.66E+12
	Euro V + SCR	10 - 110	1.69E+13	1.18E+13	1.10E+13
Solid Particle Number < 50 nm [#/km]	Euro II & III	10 - 110	1.23E+14	5.58E+13	6.83E+13
	Euro II & III + CRDPF	10 - 110	3.82E+12	2.07E+12	3.84E+12
	Euro II & III+SCR	10 - 110	1.17E+14	5.78E+13	7.05E+13
	Euro IV +CRDPF	10 - 110	1.22E+10	7.02E+09	7.44E+09
	Euro V + SCR	10 - 110	7.77E+12	3.12E+12	1.84E+12
Solid Particle Number 50-100 nm [#/km]	Euro II & III	10 - 110	1.42E+14	5.97E+13	6.27E+13
	Euro II & III + CRDPF	10 - 110	3.26E+12	1.57E+12	2.33E+12
	Euro II & III+SCR	10 - 110	1.55E+14	6.73E+13	6.66E+13
	Euro IV +CRDPF	10 - 110	1.02E+10	4.52E+09	3.52E+09
	Euro V + SCR	10 - 110	8.90E+12	3.33E+12	1.89E+12
Solid Particle Number 100-1000 nm [#/km]	Euro II & III	10 - 110	2.05E+14	7.95E+13	6.58E+13
	Euro II & III + CRDPF	10 - 110	2.26E+12	9.36E+11	1.03E+12
	Euro II & III+SCR	10 - 110	3.25E+14	1.33E+14	1.01E+14
	Euro IV +CRDPF	10 - 110	3.20E+10	1.04E+10	5.35E+09
	Euro V + SCR	10 - 110	1.53E+13	5.62E+12	3.02E+12

Table 2-53: PM characteristics of rigid HDVs 14-32 t and truck trailer/articulated 14-34t

HDVs 16-32 tn					
Pollutant	**Emission Standard**	**Speed Range [km/h]**	**Emission Factor**		
			Urban	**Rural**	**Highway**
Active Surface Area [cm2/km]	Euro II & III	10 - 110	8.68E+05	3.38E+05	3.14E+05
	Euro II & III + CRDPF	10 - 110	1.24E+05	3.01E+04	2.65E+04
	Euro II & III+SCR	10 - 110	1.40E+06	5.71E+05	4.79E+05
	Euro IV +CRDPF	10 - 110			
	Euro V + SCR	10 - 110			
Total Particle Number [#/km]	Euro II & III	10 - 110	1.06E+15	7.71E+14	1.36E+15
	Euro II & III + CRDPF	10 - 110	4.19E+14	8.08E+13	1.07E+14
	Euro II & III+SCR	10 - 110	1.18E+15	9.62E+14	1.56E+15
	Euro IV +CRDPF	10 - 110	9.07E+12	6.02E+12	3.54E+12
	Euro V + SCR	10 - 110	2.64E+13	1.83E+13	1.46E+13
Solid Particle Number < 50 nm [#/km]	Euro II & III	10 - 110	1.92E+14	8.61E+13	9.05E+13
	Euro II & III + CRDPF	10 - 110	5.96E+12	3.20E+12	5.09E+12
	Euro II & III+SCR	10 - 110	1.83E+14	8.92E+13	9.35E+13
	Euro IV +CRDPF	10 - 110	1.91E+10	1.09E+10	9.89E+09
	Euro V + SCR	10 - 110	1.22E+13	4.83E+12	2.45E+12
Solid Particle Number 50-100 nm [#/km]	Euro II & III	10 - 110	2.22E+14	9.22E+13	8.31E+13
	Euro II & III + CRDPF	10 - 110	5.09E+12	2.42E+12	3.09E+12
	Euro II & III+SCR	10 - 110	2.41E+14	1.04E+14	8.84E+13
	Euro IV +CRDPF	10 - 110	1.59E+10	6.99E+09	4.67E+09
	Euro V + SCR	10 - 110	1.39E+13	5.15E+12	2.52E+12
Solid Particle Number 100-1000 nm [#/km]	Euro II & III	10 - 110	3.21E+14	1.23E+14	8.73E+13
	Euro II & III + CRDPF	10 - 110	3.52E+12	1.44E+12	1.37E+12
	Euro II & III+SCR	10 - 110	5.08E+14	2.06E+14	1.34E+14
	Euro IV +CRDPF	10 - 110	5.00E+10	1.60E+10	7.10E+09
	Euro V + SCR	10 - 110	2.39E+13	8.69E+12	4.02E+12

2.4.25.3 Nitrous oxide (N2O) emissions

Nitrous oxide emission factors have been developed on the basis of an LAT/AUTh study (Papathanasiou and Tzirgas, 2005), based on literature data collected in studies around the world. N_2O emission factors are particularly important for catalyst vehicles, and especially under conditions that the catalyst is under partial oxidizing behaviour. This may occur wither when the catalyst has not yet reached its light-off temperature or when the catalyst is aged. Just because the emission of N_2O received increased importance lately, due to its contribution to the greenhouse effect, a detailed calculation of N_2O needs to take vehicle age (mileage) into account. In parallel, the aftertreatment ageing depends on the fuel sulphur level. Hence different emission factors need to be derived depending on the fuel sulphur content. In order to take both these effects into account, N_2O emission factors are calculated according to eq. (37), with its parameters receiving values from Table 2-54 to Table 2-61 for different passenger cars and light duty vehicles. These values differ according to the fuel sulphur level and the driving conditions (urban, rural, highway). In particular, the urban emission factor is distinguished between a cold-start and a hot-start one.

$$EF_{N2O} = [a \times \text{Mileage} + b] \times EF_{BASE} \quad (37)$$

Table 2-54: Parameters for eq.(37) to calculate N2O emission factors for gasoline passenger cars under cold urban conditions

Emission Standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	10	0.00E+00	1
Euro 1	0-30	17.5	5.60E-07	0.936
Euro 1	30-350	40.5	1.76E-06	0.839
Euro 1	>350	57.6	7.24E-06	0.748
Euro 2	0-30	11.5	5.85E-07	0.978
Euro 2	30-350	24.4	4.61E-07	0.972
Euro 2	>350	37.4	2.41E-06	0.918
Euro 3	0-30	7.9	5.68E-07	0.95
Euro 3	30-90	11.4	-2.54E-07	1.02
Euro 3	>90	11.7	-5.61E-07	1.04
Euro 4	0-30	5.4	3.79E-07	0.96
Euro 4	30-90	6.4	4.46E-07	0.951
Euro 4	>90	10.5	4.51E-07	0.95

Table 2-55: Parameters for eq. (37) to calculate N2O emission factors for gasoline passenger cars under hot urban conditions

Emission Standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	10	0.00E+00	1
Euro 1	0-350	23.2	8.81E-07	0.92
Euro 1	>350	60.4	1.54E-05	0.255
Euro 2	0-350	11.1	9.21E-07	0.962
Euro 2	>350	17.9	3.14E-06	0.93
Euro 3	0-30	1.3	1.85E-06	0.829
Euro 3	30-90	1.8	2.34E-06	0.801
Euro 3	>90	3	-3.34E-07	1.03
Euro 4	0-30	1.9	6.61E-07	0.931
Euro 4	30-90	2.4	2.39E-06	0.738
Euro 4	>90	4.2	8.65E-07	0.903

Table 2-56: Parameters for eq. (37) to calculate N2O emission factors for gasoline passenger cars under hot rural conditions

Emission Standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	6.5	0.00E+00	1
Euro 1	0-30	9.2	1.31E-06	0.851
Euro 1	30-350	18.5	2.90E-06	0.747
Euro 1	>350	48.9	1.37E-05	0.227
Euro 2	0-30	4	1.45E-06	0.945
Euro 2	>30	4.2	4.93E-06	0.799
Euro 3	0-30	0.3	1.35E-06	0.875
Euro 3	30-90	1.1	4.10E-06	0.539
Euro 3	>90	2.2	4.20E-06	0.68
Euro 4	0-30	0.3	2.61E-06	0.726
Euro 4	30-90	1.1	4.09E-06	0.549
Euro 4	>90	2.5	4.82E-07	0.946

Table 2-57: Parameters for eq. (37) to calculate N2O emission factors for gasoline passenger cars under hot highway conditions

Emission Standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	6.5	0.00E+00	1
Euro 1	0-30	4.7	1.30E-06	0.846
Euro 1	30-350	9.4	2.87E-06	0.739
Euro 1	>350	24.7	1.33E-05	0.219
Euro 2	0-30	2.2	1.45E-06	0.944
Euro 2	>30	2.3	4.92E-06	0.797
Euro 3	0-30	0.19	1.49E-06	0.967
Euro 3	30-90	0.61	6.32E-06	0.832
Euro 3	>90	1.3	5.56E-06	0.9
Euro 4	0-30	0.17	3.30E-06	0.918
Euro 4	30-90	0.63	6.23E-06	0.838
Euro 4	>90	1.4	5.03E-07	0.987

Table 2-58: Parameters for eq. (37) to calculate N2O emission factors for gasoline LDVs under cold urban conditions

Emission Standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	10	0.00E+00	1
Euro 1	0-350	46.5	3.30E-07	0.933
Euro 1	>350	83.6	1.55E-05	0.686
Euro 2	All	67.7	2.13E-06	0.812
Euro 3	0-30	16.8	3.38E-07	0.957
Euro 3	30-90	20.5	-1.81E-07	1.02
Euro 3	>90	32.9	-2.84E-07	1.02
Euro 4	0-30	13.7	1.14E-06	0.87
Euro 4	30-90	16.5	4.75E-07	0.946
Euro 4	>90	23.2	1.27E-07	0.986

Table 2-59: Parameters for eq. (37) to calculate N2O emission factors for gasoline LDVs under hot urban conditions

Emission Standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	10	0.00E+00	1
Euro 1	0-350	41.5	2.33E-06	0.53
Euro 1	>350	60.4	1.54E-05	0.255
Euro 2	0-350	23.9	2.40E-06	0.68
Euro 2	>350	42.1	1.17E-05	0.56
Euro 3	0-30	7.4	2.81E-06	0.64
Euro 3	30-90	12.7	1.41E-06	0.83
Euro 3	>90	36.7	1.44E-06	0.86
Euro 4	0-30	1.2	6.57E-07	0.925
Euro 4	30-90	0.85	5.72E-07	0.935
Euro 4	>90	7.9	3.07E-07	0.965

Table 2-60: Parameters for eq. (37) to calculate N2O emission factors for gasoline LDVs under hot rural conditions

Emission Standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	6.5	0.00E+00	1
Euro 1	0-350	18.5	2.90E-06	0.747
Euro 1	>350	26.3	2.96E-05	0.49
Euro 2	0-350	12.2	2.67E-06	0.76
Euro 2	>350	21.1	1.92E-05	0.66
Euro 3	0-30	1.4	1.27E-06	0.837
Euro 3	30-90	6	1.88E-06	0.77
Euro 3	>90	18.1	1.78E-06	0.83
Euro 4	0-30	0.3	6.33E-06	0.278
Euro 4	30-90	2.2	3.62E-06	0.587
Euro 4	>90	8.7	2.03E-06	0.768

Table 2-61 Parameters for eq. (37) to calculate N2O emission factors for gasoline LDVs under hot highway conditions

Emission Standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	>0	6.5	0.00E+00	1
Euro 1	0-350	9.4	2.87E-06	0.739
Euro 1	>350	26.3	2.96E-05	0.49
Euro 2	0-350	7.7	2.50E-06	0.75
Euro 2	>350	21.1	1.92E-05	0.66
Euro 3	0-30	1.4	1.27E-06	0.837
Euro 3	30-90	6	1.88E-06	0.77
Euro 3	>90	18.1	1.78E-06	0.83
Euro 4	0-30	0.3	6.33E-06	0.278
Euro 4	30-90	2.2	3.62E-06	0.587
Euro 4	>90	8.7	2.03E-06	0.768

Nitrous oxide emission factors for diesel vehicles and motorcycles are not that important compared to catalyst equipped passenger cars and are more roughly estimated on the basis of earlier literature review (Pringent et al., 1989; Perby, 1990; de Reydellet, 1990; Potter, 1990; OECD, 1991; Zajontz et al., 1991 and others) and the work of TNO (2002). These data are shown in Table 2-62. For heavy duty vehicles and motorcycles, there is no separate methodology for estimating cold start over-emissions but they are assumed to be already incorporated in the bulk emission factors, as shown in Table 2-62.

Table 2-62: Bulk (hot + cold) nitrous oxide (N_2O) emission factors (mg/km)

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

2.4.25.4 Ammonia (NH3) emissions

Ammonia emissions from passenger cars and light duty vehicles are estimated on a similar manner to N_2O emissions, presented in the previous section. NH_3 emission factors are calculated according to eq. (37), with its parameters receiving values from Table 2-63 to Table 2-70. As already mentioned, these values differ according to the fuel sulphur level and the driving conditions (urban, rural, highway).

Table 2-63: Parameters for eq. (37) to calculate NH_3 emission factors for gasoline passenger cars under cold urban conditions

Emission Standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	2	0.00E+00	1
Euro 1	0-150	50	1.52E-06	0.765
Euro 1	>150	11.7	2.92E-06	0.351
Euro 2	0-150	51	1.70E-06	0.853
Euro 2	>150	14.6	3.89E-06	0.468
Euro 3	0-30	5.4	1.77E-06	0.819
Euro 3	>30	4.8	4.33E-06	0.521
Euro 4	0-30	5.4	1.77E-06	0.819
Euro 4	>30	4.8	4.33E-06	0.521

Table 2-64: Parameters for eq. (37) to calculate NH_3 emission factors for gasoline passenger cars under hot urban conditions

Emission Standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	2	0.00E+00	1
Euro 1	All	70	0.00E+00	1
Euro 2	All	143	1.47E-06	0.964
Euro 3	0-30	1.9	1.31E-06	0.862
Euro 3	>30	1.6	4.18E-06	0.526
Euro 4	0-30	1.9	1.31E-06	0.862
Euro 4	>30	1.6	4.18E-06	0.526

Table 2-65: Parameters for eq. (37) to calculate NH_3 emission factors for gasoline passenger cars under hot rural conditions

Emission Standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	2	0.00E+00	1
Euro 1	0-150	131	5.94E-08	0.999
Euro 1	>150	100	8.95E-07	0.978
Euro 2	0-150	148	5.95E-08	0.999
Euro 2	>150	90.7	9.08E-07	0.992
Euro 3	0-30	29.5	5.90E-08	0.994
Euro 3	>30	28.9	8.31E-07	0.908
Euro 4	0-30	29.5	5.90E-08	0.994
Euro 4	>30	28.9	8.31E-07	0.908

Table 2-66: Parameters for eq. (37) to calculate NH_3 emission factors for gasoline passenger cars under hot highway conditions

Emission Standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	2	0.00E+00	1
Euro 1	0-150	73.3	5.94E-08	0.998
Euro 1	>150	56.2	8.86E-07	0.968
Euro 2	0-150	83.3	5.94E-08	0.999
Euro 2	>150	51	9.05E-07	0.988
Euro 3	0-30	64.6	5.95E-08	0.999
Euro 3	>30	63.4	9.02E-07	0.985
Euro 4	0-30	64.6	5.95E-08	0.999
Euro 4	>30	63.4	9.02E-07	0.985

Table 2-67: Parameters for eq. (37) to calculate NH_3 emission factors for gasoline LDVs under cold urban conditions

Emission Standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	>0	2	0.00E+00	1
Euro 1	0-150	50	1.52E-06	0.765
Euro 1	>150	11.7	2.92E-06	0.351
Euro 2	0-150	51	1.70E-06	0.853
Euro 2	>150	14.6	3.89E-06	0.468
Euro 3	0-30	5.4	1.77E-06	0.819
Euro 3	>30	4.8	4.33E-06	0.521
Euro 4	0-30	5.4	1.77E-06	0.819
Euro 4	>30	4.8	4.33E-06	0.521

Table 2-68: Parameters for eq. (37) to calculate NH_3 emission factors for gasoline LDVs under hot urban conditions

Emission Standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	>0	2	0.00E+00	1
Euro 1	>0	70	0.00E+00	1
Euro 2	>0	143	1.47E-06	0.964
Euro 3	0-30	1.9	1.31E-06	0.862
Euro 3	>30	1.6	4.18E-06	0.526
Euro 4	0-30	1.9	1.31E-06	0.862
Euro 4	>30	1.6	4.18E-06	0.526

Table 2-69: Parameters for eq. (37) to calculate NH_3 emission factors for gasoline LDVs under hot rural conditions

Emission Standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	>0	2	0.00E+00	1
Euro 1	0-150	131	5.94E-08	0.999
Euro 1	>150	100	8.95E-07	0.978
Euro 2	0-150	148	5.95E-08	0.999
Euro 2	>150	90.7	9.08E-07	0.992
Euro 3	0-30	29.5	5.90E-08	0.994
Euro 3	>30	28.9	8.31E-07	0.908
Euro 4	0-30	29.5	5.90E-08	0.994
Euro 4	>30	28.9	8.31E-07	0.908

Table 2-70: Parameters for eq. (37) to calculate NH_3 emission factors for gasoline LDVs under hot highway conditions

Emission Standard	Sulphur content (ppm)	Base EF (mg/km)	a	b
pre-Euro	All	2	0.00E+00	1
Euro 1	0-150	73.3	5.94E-08	0.998
Euro 1	>150	56.2	8.86E-07	0.968
Euro 2	0-150	83.3	5.94E-08	0.999
Euro 2	>150	51	9.05E-07	0.988
Euro 3	0-30	64.6	5.95E-08	0.999
Euro 3	>30	63.4	9.02E-07	0.985
Euro 4	0-30	64.6	5.95E-08	0.999
Euro 4	>30	63.4	9.02E-07	0.985

For all other vehicle classes, bulk ammonia emission factors are given in Table 2-71. No separate calculation is made for cold start over-emissions. These emission factors are based on literature review only and should be considered as broad estimates (de Reydellet, 1990; Volkswagen, 1989).

2.4.25.5 PAHs and POPs

Emission factors (in [µg/km]) for polycyclic aromatic hydrocarbons (PAHs) and persistent organic pollutants (POPs) are given in Table 2-72 for different species and vehicle categories. A rough distinction is made to conventional (pre Euro I) and closed loop catalyst equipped vehicles (Euro I and on). For diesel passenger cars and light duty vehicles, different emission factors are quoted for direct injection and indirect injection vehicles. Since statistical information on the distribution of fleet vehicles according to their combustion concept is difficult to collect, it is proposed to use the average (DI, IDI) emission factor to estimate emissions from diesel non heavy duty vehicles.

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

Table 2-71: Bulk (hot + cold) ammonia (NH_3) emission factors (mg/km)

Vehicle category	**Urban**	**Rural**	**Highway**
Passenger Cars			
Diesel CC < 2.0 l	1	1	1
Diesel CC > 2.0 l	1	1	1
LPG	nd	nd	nd
2 - stroke	2	2	2
Light Duty Vehicles			
Diesel	1	1	1
Heavy Duty Vehicles			
Gasoline Veh. > 3.5 t	2	2	2
Diesel < 7.5 t	3	3	3
Diesel 7.5 t < W < 16 t	3	3	3
Diesel 16 t < W < 32 t	3	3	3
Diesel W > 32 t	3	3	3
Urban Buses	3	-	-
Coaches	3	3	3
Motorcycles			
< 50 cm³	1	1	1
> 50 cm³ 2 stroke	2	2	2
> 50 cm³ 4 stroke	2	2	2

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

2.4.25.6 Dioxins and furans

Emission factors of Dioxins and Furans are given in Table 2-73 separately to other POPs because an aggregate toxicity equivalent emission factor is provided in this case. This emission factor takes into account the toxicity of different Dioxin and Furan species according to the NATO - Committee on the Challenges of the Modern Society (NATO-CCMS). Actual emission rates of different Dioxin and Furan species have been collected from the available literature sources (Umweltbundesamt, 1996). The final value is a bulk emission factor expressed in [pg/km]. Due to the limited available information, emission factors provided need to be reconsidered when updated data become available. In order to keep a consistent approach for all vehicle sources, Dioxin and Furan emissions from 4 stroke motorcycles are calculated with the same toxicity equivalent emission factors as of conventional gasoline vehicles.

Table 2-72: PAHs and POPs bulk (hot + cold) emission factors

Species	Bulk emission factors (μg/km)					
	Gasoline PC & LDV		Diesel PC &LDV		HDV	LPG
	Convent.	Euro I & on	DI	IDI	DI	
indeno(1,2,3-cd)pyrene	1.03	0.39	0.70	2.54	1.40	0.01
benzo(k)fluoranthene	0.30	0.26	0.19	2.87	6.09	0.01
benzo(b)fluoranthene	0.88	0.36	0.60	3.30	5.45	
benzo(ghi)perylene	2.90	0.56	0.95	6.00	0.77	0.02
fluoranthene	18.22	2.80	18.00	38.32	21.39	1.36
benzo(a)pyrene	0.48	0.32	0.63	2.85	0.90	0.01
pyrene	5.78	1.80	12.30	38.96	31.59	1.06
perylene	0.11	0.11	0.47	0.41	0.20	
anthanthrene	0.07	0.01	0.07	0.17		
benzo(b)fluorene	4.08	0.42	24.00	5.21	10.58	0.71
benzo(e)pyrene	0.12	0.27	4.75	8.65	2.04	
triphenylene	7.18	0.36	11.80	5.25	0.96	0.48
benzo(j)fluoranthene	2.85	0.06	0.32	0.16	13.07	
dibenzo(a,j)anthacene	0.28	0.05	0.11	0.12		
dibenzo(a,l)pyrene	0.23	0.01		0.12		
3,6-dimethyl-phenanthrene	4.37	0.09	4.85	1.25		0.18
benzo(a)anthracene	0.84	0.43	3.30	2.71	2.39	0.05
acenaphthylene			25.92	25.92		
acenapthene			34.65	34.65		
fluorene					39.99	
chrysene	0.43	0.53	2.40	7.53	16.24	
phenanthrene	61.72	4.68	85.50	27.63	23.00	4.91
napthalene	11.20	610.19	2100	650.5	56.66	40.28
anthracene	7.66	0.80	3.40	1.37	8.65	0.38
coronene	0.90	0.05	0.06	0.05	0.15	
dibenzo(ah)anthracene	0.01	0.03	0.24	0.56	0.34	

Table 2-73: Dioxins and Furans toxicity equivalence emission factors

	Toxicity Equivalent Emission Factors [pg/km]		
Polychlorinated Dibenzo Dioxins	**PC Gasoline Conventional**	**PC Diesel IDI**	**Heavy Duty Diesel**
TeCDD.TOTAL	3.8	0.2	1.4
PeCDD.TOTAL	5.2	0.2	0.9
HxCDD. TOTAL	1.0	0.1	0.3
HpCDD.TOTAL	0.2	0.0	0.2
OCDD	0.1	0.0	0.2
Total Dioxins	10.3	0.5	3.0
Polychlorinated Dibenzo Furans			
TeCDF.TOTAL	3.6	0.1	0.6
PeCDF.TOTAL	8.2	0.5	2.8
HxCDF.TOTAL	8.1	0.4	3.9
HpCDF.TOTAL	1.3	0.0	0.5
OCDF	0.0	0.0	0.1
Total Furans	21.2	1.0	7.9

2.4.25.7 Fuel consumption dependant emission factors

Emissions of heavy metals are calculated by means of equation (16). Table 2-74 provides emission factors of heavy metals for different vehicle categories.

Table 2-74: Heavy metal emission factors for all vehicle categories in mg/kg fuel

Category	Cadmium	Copper	Chromium	Nickel	Selenium	Zinc
Passenger cars, gasoline	0.01	1.7	0.05	0.07	0.01	1
Passenger cars, gasoline catalyst	0.01	1.7	0.05	0.07	0.01	1
Passenger cars, diesel	0.01	1.7	0.05	0.07	0.01	1
Passenger cars, LPG	0.0	0.0	0.0	0.0	0.0	0.0
Light duty vehicles, gasoline	0.01	1.7	0.05	0.07	0.01	1
Light duty vehicles, gasoline catalyst	0.01	1.7	0.05	0.07	0.01	1
Light duty vehicles, diesel	0.01	1.7	0.05	0.07	0.01	1
Heavy duty vehicles, gasoline	0.01	1.7	0.05	0.07	0.01	1
Heavy duty vehicles, diesel	0.01	1.7	0.05	0.07	0.01	1
Motorcycles < $50cm^3$	0.01	1.7	0.05	0.07	0.01	1
Motorcycles > $50cm^3$	0.01	1.7	0.05	0.07	0.01	1

2.4.26 Emission degradation functions

Tables 8.38 and 8.39 provide the degradation functions to be used for simulating the deterioration of emission performance of gasoline passenger cars and light duty vehicles equipped with three way catalysts. Relevant methodology given in section 5.7.1.

Table 2-75: Emission degradation due to vehicle age for Euro I and Euro II gasoline passenger cars and light duty vehicles

$MC = A^M \times M^{MEAN} + B^M$	Capacity Class [l]	Average Mileage [km]	A^M	B^M (Value at 0 km)	Value at ≥ 120000 km
Correction for V<19 km/h (MC_{URBAN})					
CO - MC_{URBAN}	≤1.4	29,057	1.523E-05	0.557	2.39
	1.4-2.0	39,837	1.148E-05	0.543	1.92
	>2.0	47,028	9.243E-06	0.565	1.67
NO_x - MC_{URBAN}	ALL	44,931	1.598E-05	0.282	2.20
HC - MC_{URBAN}	≤1.4	29,057	1.215E-05	0.647	2.10
	1.4-2.0	39,837	1.232E-05	0.509	1.99
	>2.0	47,028	1.208E-05	0.432	1.88
Correction for V>63 km/h (MC_{ROAD})					
CO - MC_{ROAD}	≤1.4	29,057	1.689E-05	0.509	2.54
	1.4-2.0	39,837	9.607E-06	0.617	1.77
	>2.0	47,028	2.704E-06	0.873	1.20
NO_x - MC_{ROAD}	ALL	47,186	1.220E-05	0.424	1.89
HC - MC_{ROAD}	≤1.4	29,057	6.570E-06	0.809	1.60
	1.4-2.0	39,837	9.815E-06	0.609	1.79
	>2.0	47,028	6.224E-06	0.707	1.45

Table 2-76: Emission degradation due to vehicle age for Euro III and Euro IV gasoline passenger cars and light duty vehicles (and Euro I & II vehicles in case of an enhanced I&M scheme)

$MC = A^M \times M^{MEAN} + B^M$	Capacity Class [l]	Average Mileage [km]	A^M	B^M (Value at 0 km)	Value at ≥ 160000 km
Correction for V<19 km/h (MC_{URBAN})					
CO - MC_{URBAN}	≤1.4	32,407	7.129E-06	0.769	1.91
	>1.4	16,993	2.670E-06	0.955	1.38
NO_x - MC_{URBAN}	≤1.4	31,313	0	1	1
	>1.4	16,993	3.986E-06	0.932	1.57
HC - MC_{URBAN}	≤1.4	31,972	3.419E-06	0.891	1.44
	>1.4	17,913	0	1	1
Correction for V>63 km/h (MC_{ROAD})					
CO - MC_{ROAD}	≤1.4	30,123	1.502E-06	0.955	1.20
	>1.4	26,150	0	1	1
NO_x - MC_{ROAD}	ALL	26,150	0	1	1
HC - MC_{ROAD}	ALL	28,042	0	1	1

Table 2-77: Emission degradation correction factor as a function of speed

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

2.4.27 Fuel effects functions

Table 2-78, Table 2-79 and Table 2-80 provide the correction functions required to estimate the effect of fuel properties on emissions according to section 5.7.2.

Use of biodiesel as a blend with diesel may also lead to some change in emissions. The values proposed in Table 2-81 are differences in emissions caused by different fuel blends on fossil diesel and correspond to a Euro 3 vehicle/engine technology. The effect of biodiesel on other technologies may vary but the extent of the variation is difficult to estimate in the absence of detailed literature data. With regard to NO_x, CO_2 and CO, any effect of technology should be negligible, given the marginal effect of biodiesel on these pollutants in general. The effect of biodiesel on PM for different technologies is more difficult to assess. For older diesel technologies with no advanced combustion concepts and aftertreatment systems, biodiesel may lead to a higher reduction than the one shown in Table 2-81 because the presence of a carbon-atom chemical bond reduces the PM formation by intervening on its chemical mechanism. For more recent technologies, with ultra high pressure combustion and aftertreatment, the biodiesel effect is difficult to predict. On one hand the chemical mechanism demotes the PM formation. On the other hand, the different physical properties of the fuel (viscosity, surface tension, gum content, etc.) may change the flow characteristics and affect the in-cylinder spray development. This may lead to poor combustion and increase in the soot formation potent. Hence, the proposed values of Table 2-81 should be used with care for post Euro 3 diesel technologies

Table 2-78: Relations between emissions and fuel properties for passenger cars and light duty vehicles

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

Legend: O_2 = Oxygenates in %
S = Sulphur content in ppm
ARO = Aromatics content in %
OLEFIN = Olefins content in %
E100 = Mid range volatility in %
E150 = Tail end volatility in %

Table 2-79: Relations between emissions and fuel properties for Diesel passenger cars and light duty vehicles

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

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

Table 2-80: Relations between emissions and fuel properties for Diesel heavy duty vehicles

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

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

2.4.28 SPECIES PROFILES

2.4.28.1 VOC Speciation

The content of non methane VOCs in different species is given in Table 2-82a and Table 2-82b. Proposed fractions have been obtained by results published in the literature (BUWAL, 1994; TNO, 1993; Volkswagen, 1989; Umweltbundesamt, 1996). Fractions quoted in those Tables are applied to the total NMVOC emissions from vehicle classes classified as conventional (pre Euro I) or closed loop catalyst equipped (Euro I and on) gasoline passenger cars and light duty vehicles, diesel passenger cars and light duty vehicles, diesel heavy duty vehicles and LPG passenger cars. A common speciation is proposed for diesel passenger cars and light duty vehicles, regardless of the combustion concept (DI or IDI).

Table 2-81: Effect of biodiesel blends on diesel vehicle emissions

Pollutant	Vehicle type	B10	B20	B100
CO_2	Passenger Cars	-1.5%	-2.0%	
	Light Duty Vehicles	-0.7%	-1.5%	
	Heavy duty vehicles	0.2%	0.0%	0.1%
NO_x	Passenger Cars	0.4%	1.0%	
	Light Duty Vehicles	1.7%	2.0%	
	Heavy duty vehicles	3.0%	3.5%	9.0%
PM	Passenger Cars	-13.0%	-20.0%	
	Light Duty Vehicles	-15.0%	-20.0%	
	Heavy duty vehicles	-10.0%	-15.0%	-47.0%
CO	Passenger Cars	0.0%	-5.0%	
	Light Duty Vehicles	0.0%	-6.0%	
	Heavy duty vehicles	-5.0%	-9.0%	-20.0%
HC	Passenger Cars	0.0%	-10.0%	
	Light Duty Vehicles	-10.0%	-15.0%	
	Heavy duty vehicles	-10.0%	-15.0%	-17.0%

NMVOC speciation from four stroke motorcycles is estimated with fractions derived from conventional gasoline vehicles as in the case of PAHs and POPs. This approach needs to be reconsidered when more complete data become available.

The last row of Table 2-82b shows the total that these fractions sum to. It is assumed that the remaining fraction consists of PAHs and POPs.

Table 2-82a: Composition of NMVOC in exhaust emissions (alkanes, cycloalkanes, alkenes, alkines)

Group	Species	NMVOC Fraction (% wt.)				
		Gasoline 4 stroke		Diesel PC & LDV	HDV	LPG
		Convent.	Euro I & on	IDI & DI		
ALKANES	ethane	1.65	3.19	0.33	0.03	2.34
	propane	0.47	0.65	0.11	0.10	49.85
	butane	2.90	5.24	0.11	0.15	15.50
	isobutane	1.29	1.59	0.07	0.14	6.95
	pentane	1.78	2.15	0.04	0.06	0.35
	isopentane	4.86	6.81	0.52		1.26
	hexane	1.29	1.61			
	heptane	0.36	0.74	0.20	0.30	0.18
	octane	0.56	0.53	0.25		0.04
	2-methylhexane	0.80	1.48	0.45	0.63	0.25
	nonane	0.06	0.16	0.67		0.01
	2-methylheptane		0.57	0.12	0.21	0.09
	3-methylhexane	0.56	1.14	0.22	0.35	0.19
	decane	0.22	0.19	1.18	1.79	
	3-methylheptane	0.40	0.54	0.20	0.27	0.08
	Alkanes C10-C12	0.03	1.76	2.15		0.01
	Alkanes C>13	0.06	1.45	17.91	27.50	
CYCLOALKANES	All	0.88	1.14	0.65	1.16	0.10
ALKENES	ethylene	8.71	7.30	10.97	7.01	5.20
	propylene	4.87	3.82	3.60	1.32	5.19
	propadiene		0.05			
	1-butene	0.50	0.73			
	isobutene	4.21	2.22	1.11	1.70	0.63
	2-butene	1.27	1.42	0.52		0.53
	1,3-butadiene	1.42	0.91	0.97	3.30	0.15
	1-pentene	0.09	0.11			
	2-pentene	0.23	0.34			
	1-hexene		0.17			
	dimethylhexene		0.15			
ALKINES	1-butine	0.05	0.21			
	propine	0.76	0.08			
	acetylene	5.50	2.81	2.34	1.05	1.28

Table 2-82b: Composition of NMVOC in exhaust emissions (aldehydes, ketones, aromatics)

Group	Species	NMVOC Fraction (% wt.)				
		Gasoline 4 stroke		Diesel PC & LDV	HDV	LPG
		Convent.	Euro I & on	IDI & DI		
ALDEHYDES	formaldehyde	2.08	1.70	12.00	8.40	1.56
	acetaldahyde	0.59	0.75	6.47	4.57	1.81
	acrolein	0.16	0.19	3.58	1.77	0.59
	benzaldehyde	0.60	0.22	0.86	1.37	0.03
	crotonaldehyde	0.02	0.04	1.10	1.48	0.36
	methacrolein		0.05	0.77	0.86	0.10
	butyraldehyde		0.05	0.85	0.88	0.11
	isobutanaldehyde			2.09	0.59	
	propionaldehyde	0.11	0.05	1.77	1.25	0.70
	hexanal			0.16	1.42	
	i-valeraldehyde			0.11	0.09	0.01
	valeraldehyde		0.01	0.41	0.40	
	o-tolualdehyde	0.19	0.07	0.24	0.80	
	m-tolualdehyde	0.38	0.13	0.34	0.59	
	p-tolualdehyde	0.19	0.06	0.35		
KETONES	acetone	0.21	0.61	2.94		0.78
	methylethlketone	0.11	0.05	1.20		
AROMATICS	toluene	12.84	10.98	0.69	0.01	1.22
	ethylbenzene	4.78	1.89	0.29		0.24
	m,p-xylene	6.66	5.43	0.61	0.98	0.75
	o-xylene	4.52	2.26	0.27	0.40	0.26
	1,2,3 trimethylbenzen	0.59	0.86	0.25	0.30	0.05
	1,2,4 trimethylbenzen	2.53	4.21	0.57	0.86	0.25
	1,3,5 trimethylbenzen	1.11	1.42	0.31	0.45	0.08
	styrene	0.57	1.01	0.37	0.56	0.02
	benzene	6.83	5.61	1.98	0.07	0.63
	C9	3.12	4.21	0.78	1.17	0.25
	C10		3.07			
	C>13	6.01	3.46	13.37	20.37	
TOTALS (all NMVOC species)		**99.98**	**99.65**	**99.42**	**96.71**	**99.98**

2.4.28.2 NOx Speciation

Table 2-83 provides the range of NO_2/NO_x values developed in the framework of two relevant studies in Europe. The AEAT (2007) study has been performed on behalf of DG Environment within a project aiming at assessing air quality targets for the future. The TNO study refers to national data used for the NO_2 emission assessment in the Netherlands (Smit, 2007). The same table includes the values suggested for use. These values correspond to the AEAT study for Euro 4 and previous vehicle technologies. In general, the TNO and AEAT studies do not significantly differ for older vehicle technologies. It could be considered that the difference is lower than the expected uncertainty in any of the values proposed, given the limited sample of measurements available and the measurement uncertainty relevant to NO_2 emission determination. The AEAT study was considered more up-to-date given the detailed discussion within UK concerning primary NO_2 emission rates (AQEG, 2006) and NO_2/NOx data provided to AEAT by LAT. The ranges proposed in the AEAT study for passenger cars have been transferred to light duty vehicles as well.

Table 2-83: Mass fraction of NO_2 in NO_x emissions

Category	**Emission Standard**	**NO2/NOx primary mass ratio (%)**		
		AEAT Study	TNO Study	Suggested Value
Gasoline PCs	pre-Euro	4	5	4
	Euro 1 - Euro 2	4	5	4
	Euro 3 - Euro 4	3	5	3
	Euro 5	3	5	3
	Euro 6	-	-	2
Diesel PCs	pre-Euro	11	20	11
	Euro 1 - Euro 2	11	20	11
	Euro 3	25	40	25
	Euro 4	55	40-70	55
	Euro 5	55	70	5-70
	Euro 6			5-70
LPG PCs	pre-Euro	5	5	5
	Euro 1 - Euro 3		5	5
	Euro 4		5	5
	Euro 5		-	5
	Euro 6		-	5
Gasoline LDTs	pre-Euro	-	5	4
	Euro 1 - Euro 2	-	5	4
	Euro 3 - Euro 4	-	5	3
	Euro 5	-	5	3
	Euro 6	-		2
Diesel LDTs	pre-Euro	-	20	11
	Euro 1 - Euro 2	-	20	11
	Euro 3	-	40	25
	Euro 4	-	40-70	55
	Euro 5	-	70	5-70
	Euro 6	-	-	5-70
HDVs (ETC)	pre-Euro	11	10	11
	Euro I - Euro II	11	10	11
	Euro III	14	10	14
	Euro IV	10	10	14
	Euro V	-	10	10
	Euro VI	-	-	10
	Euro III+CRT	35	-	35

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

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

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

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

2.4.28.3 PM Speciation in elemental and organic carbon

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

Table 2-84 suggests ratios of organic material (OM) over elemental carbon (OM/EC) and EC/$PM_{2.5}$ that can be used on the exhaust PM emissions calculated from Copert and similar models for different vehicle technologies. Organic material is the mass of organic carbon corrected for the hydrogen content of the organic species collected. The sources of these data and the methodology followed to estimate these values is given in Ntziachristos et al. (2007). An uncertainty range is also proposed according to literature values. The uncertainty is in percentage units and is given as a ±range for both ratios proposed. For example, if the OM/EC ratio for a particular technology is 50% and the uncertainty is 20%, this would mean that the OM/EC ratio is expected to range from 40% to 60%. This is the uncertainty expected on fleet-average emissions and not on an individual vehicle basis (e.g. emissions from individual vehicles falling in a specific category may exceed this uncertainty range). The ratios suggested correspond to average driving conditions with no distinction between driving modes or cold-start operation.

Table 2-84: Split of PM in elemental (EC) and organic mass (OM)

Category	Euro Standard	EC/PM2.5 (%)	OM/EC (%)	Uncertainty (%)
Gasoline PC and LDT	PRE-ECE	2	4900	50
	ECE 15 00/01	5	1900	50
	ECE 15 02/03	5	1900	50
	ECE 15 04	20	400	50
	Open Loop	30	233	30
	Euro 1	25	250	30
	Euro 2	25	250	30
	Euro 3	15	300	30
	Euro 4	15	300	30
Diesel PC and LDT	Conventional	55	70	10
	Euro 1	70	40	10
	Euro 2	80	23	10
	Euro 3	85	15	5
	Euro 4	87	13	5
	Euro 3, Euro 4, Euro 5	10	500	50
	Euro 3, Euro 4, Euro 5	20	200	50
Diesel HDV	Conventional	50	80	20
	Euro I	65	40	20
	Euro II	65	40	20
	Euro III	70	30	20
	Euro IV	75	25	20
	Euro IV	75	25	20
	Euro VI	15	300	30
Power Two Wheelers	Conventional	10	900	50
	Euro 1	20	400	50
	Euro 2	20	400	50
	Conventional	15	560	50
	Euro 1	25	300	50
	Euro 2	25	300	50
	Euro 3	25	250	50

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

3 TREMOVE methodology: Non-Road Mode Emissions

3.1 General

TREMOVE has adopted the TRENDS methodology to estimate emissions from non-road modes (navigation, aviation, railways). Based on this and on available historical data, TREMOVE estimates – for the period 1995–2030 – the passenger and freight transport demands, modal shifts, vehicle stock renewal, emissions of air pollutants and the welfare for EU 27 plus six additional countries, based on the selected scenario assumptions. The actual modes covered, based on the TREMOVE terminology are:

- Railways
- Metro/Tram
- Inland waterway
- Air transport

In addition, TREMOVE covers maritime transport in a separate module. However, maritime transport demand is considered to be exogenous in TREMOVE, and it is assumed that maritime movements are not affected by policy measures on land-based transport and vice versa. Due to its stand-alone character, modal shift effects cannot be modelled in the current design of the module. However, the maritime sub-model is not described in the TREMOVE report so that no details can be given.

In the framework of the FLEETS project, a review of the TRENDS/TREMOVE methodologies was conducted to identify areas for improvements. It is useful to describe this review also in the framework of EC4MACS, in order:

1. To identify improvements to be implemented within the given structure of TREMOVE, e.g. implementing the proposal would just require a re-calibration

2. To identify the need for more radical changes in the methodology which would most likely require re-designing the baseline

This also means that it is not subject of this analysis to identify options how other transport or energy models could be integrated in the methodology.

3.2 General features used for the non-road sector

While the methodologies used in TRENDS/TREMOVE for the non-road sector differ in many details, they have nevertheless a few features in common:

Most of the non-road methodology follows in principle the on-road approach, e.g. the (simplified) general equations

Emissions = Sources * Activities * Emission Factors   ("static" part)

New Sources = Delta Replacement + New Activities ("dynamic" part)

When applying such an approach, as a rule, it is necessary to compare the results with energy data, available from statistics or forecasted in other standard models. TREMOVE, however, does not include such a step as a general feature. Instead, the TREMOVE baseline is calibrated, taking into account PRIMES energy data (actually, no further details with regard to the reference are given). But the scenario runs are not balanced against energy data. In principle, this approach makes sense for some non-road modes because the statistical energy data are often not reliable, e.g. the electric energy consumption of rails ways (due to losses) or the national energy consumption data of inland waterways (due to fuel bunkered outside the countries). In other modes, e.g. air transport and diesel consumption of railways, the energy data are very reliable and it would make sense to take them into account as input for calibrating the scenario runs. In fact, the quality of these data is so good that it is planned to make use of them for future emission trading systems.

The transport volumes of the baseline are, as mentioned above, mainly based on the ASSESS project (ASSESS, 2005) which used the SCENCES (2002) model. The transport demand baseline in TREMOVE is based on several sources. The 1995 and 2000 historical figures are derived from the DG TREN statistics (Transport in Figures). For some countries, they have been updated with national statistics. The main source for the growth factors (passenger-km and tonne-km) is the Scenes run for the ASSESS project. The partial scenario, described in the ASSESS reports is considered the most likely future scenario. (Remark: ASSESS has two partial scenarios (A and B). It is not clear from the report which one has been taken for what purpose). For road freight transport, the growth factors have been derived from the most recent Energy Outlook (PRIMES model). The vehicle-km for road are also derived from the ASSESS project. The vehicle-km for rail and inland waterways come from sources as the TRENDS and International Union of Railways (UIC), and have been made consistent with the pkm and tkm. In principle, for a model like TREMOVE (see comments given to the review report) this makes sense since the national transport statistics contain key data on transport volume, which can be used for the future calibration work, as shown in the Annex which summarises the data available in the EUROSTAT databank (relevant are here the code numbers 121/124/125/126/128 and 129). Thus, this part of the methodology should not be modified when addressing improvements within the given system. However, this means that TREMOVE will continue depending in future on high quality transport volume input, including consistent projections. In fact, this could be considered as a weakness of the model. An interview with a key model builder of SCENES, Prof. Dr. Rothengatter (IWW, Karlsruhe), gave clear signals that he considers the SCENES version used for calibrating TREMOVE version 2.5 as out-of-date. In the TREMOVE report it is mentioned that the TRANS-TOOLS model is expected to replace SCENES in the REFIT project, currently ongoing.

Somewhat simplified, and as already mentioned, one could say, that the TREMOVE methodologies are composed of a "static" and a "dynamic" part. The static part covers the basic equations used to calculate emissions. The dynamic part deals with the turnover of the fleets. That is, starting from the transport demand forecasts and 1995-2005 vehicle stock data, the sales model and the scrappage model in the vehicle stock turnover module are used in TREMOVE to allocate transport volumes to specific vehicle types for all modes. Both parts of equal importance and for both the general "wisdom" of modelling should apply: use and leave untouched as much as possible good quality data, and - since in no case only such data are available - estimate or model with priority such data that are of less good quality. The review carefully analyses whether this golden rule is applied for the non-road sectors. Another rule is that the efforts should increase with the importance of the source. For non-road sectors this means that aviation should receive major attention, followed by - equally - rail and inland waterways (metro/tram, is about 15 % of Rail). The PRIMES baseline projection can be used as a guide to this rule (Table 3-1).

Table 3-1: PRIMES Baseline projection

Mtoe	2005	2010	2015	2020	2025	2030
Rail transport	8,7	8,0	7,1	6,6	6,3	6,2
Aviation	48,5	53,0	57,4	63,3	65,7	71,2
Inland Waterways	5,8	6,3	6,7	7,1	7,4	7,8

TREMOVE is a country specific model, e.g. it consists of about EU 27 + 6 non-EU country models. This means that the values of parameters considered in the following, as a rule, differ among countries. In theory, one could develop for some countries more and for other countries less sophisticated methodologies because the availability and the quality of the data bases differ among countries. However, this makes little sense for a centralized applied EU model since it is difficult to execute scenarios applying a number of different non-road methodologies and, for obtaining results acceptable in the political discussions, there must be something like a common yardstick applied to all countries. This yardstick is the common methodological treatment of all countries linked to the joint boundary conditions used for the baseline run. The fact that the data quality among countries differ is sufficiently reflected by the input data used. This, however, means that one should in fact use the best quality input data available for the individual countries, e.g. carefully identify and apply these data country-by-country, and that one has to make methodological compromises between "best" and "worst" national data availability.

In the following sections of this review, parameters and equations are used in order to explain the methodologies. With regard to TREMOVE it is worth indicating the character of the parameters in order to distinguish between

- Parameters which are given in TREMOVE and which are, as a rule, not modified in the scenario runs; they have a blue colour;

- Parameters which can be modified in the scenario runs; they have a red colour;
- Parameters which are calculated in the dynamic part of the model; they have a green colour. These parameters are an endogenous output of the model calculations used internally;
- Parameters which are output of TREMOVE; they have an orange colour.

Some parameters are set (blue) but could be modified in scenario runs, if desired. In these cases they are put into red brackets (black brackets have no specific meaning; they are just used to as a mathematical notation or to display the mathematical formula in an easy-to-read form).

It should be noted that the fact that all data are country-specific is not further highlighted in the equations or attributed to the parameters by indices; it is just assumed to be known.

TREMOVE delivers comprehensive output in great detail. In the Annex the output relevant for non-road sectors is shown. This allows also identifying the key variables taken into account by the methodology.

3.3 Railways

3.3.1 Basic methodology

The key equations used for estimating the emissions of the rail sector ("static part") are:

$$\mathbf{E_{ijklmnt} = (TVP/OR) * ENP * (EF) + (TVF/LF) * ENF * (EF)} \qquad (38)$$

With

$E_{ijklmnt}$ = Emissions of pollutant i in region j at trip distance k and time period l of train type m and fuel type n in the year t (unit: tons)

TVP_{jklmnt} = Total transport volume of passenger trains in region j at trip distance k and time period l of train type m and fuel type n in the year t (unit: pkm)

OR_{jm} = Occupancy rate of passenger train type m in the region j (unit: pkm/vkm)

ENP_{jlmn} = Specific energy consumption of passenger train type m and fuel type n in region j at the time period l (unit: kJ/vkm)

EF_{imn} = emission factor of pollutant i of train type m powered by fuel type n (tons/kJ)

TVF_{jklmt} = Total transport volume of freight trains in region j at trip distance k and time period l of train type m in the year t (unit: tkm)

LF_{jm} = Load factor of freight train type m in the region j (unit: tkm/vkm)

ENF_{jlmn} = Specific energy consumption of train freight type m and fuel type n in region j at the time period l (unit: kJ/vkm)

And with the indices

i = pollutants (CO_2, CO, VOC, NOx, PM, SO_2)

j = Region (urban, metropolitan, non-urban)

k = trip distance (short, long)

l = time period (peak, off-peak)

m = train type (9 types in total: passenger locomotive diesel, passenger railcar diesel, passenger locomotive electric, passenger railcar electric, passenger train electric, passenger high speed train electric; freight locomotive diesel; freight railcar diesel, freight locomotive electric, freight railcar electric)

n = fuel type (electric, diesel)

t = year

The parameters TVP and TVF are results of the dynamic calculations, which are initiated by the scenario settings.

The methodology does not distinguish between technologies within the defined train types, e.g. the emission factors do not change with time.

The key "dynamic" equation which determines the turnover of the fleet is:

$$\mathbf{(N)_{jklmt} = TVF_{jklmt} / (AM * LF) + TVP_{jklmt} / (AM * OR)} \qquad (39)$$

With

N_{jklmt} = Number of vehicles of train type m in region j at trip distance k and time period l in the year t (unit: -)

AM_m = Annual mileage of train type m (unit: vkm/year)

In numerical terms the parameters LF and OR are the same as in equation (38).

In policy simulations the sale shares, thus the evolution of the train stock, can be changed exogenously (therefore N is put into red brackets). This allows simulating the effects of policies related to e.g. accelerated introduction of electric trains or high-speed trains.

The parameter AM is derived from historic UIC fleet and vehicle-km statistics and is assumed to remain constant in the forecast years.

Since the methodology does not distinguish between technologies there is no technology turn-over. The information with regard to data and parameter names included in the TREMOVE report is summarized in Table 3-2.

3.3.2 Assessment of the basic TREMOVE methodology

Based on equations (38) and (39) it is obvious that improvements of the methodology (within the given boundaries of TREMOVE) should concentrate on improving the parameters OR and LF, ENP and ENF as well as EF used for the countries.

The issues to be looked at are:

1. Trends: How do these parameters change with time: Are these changes reflected in the database and the methodology?
2. National particularities: Have national data been taken into account, or are averaged data being used?
3. Break-downs: Are the covered break-down, expressed by the indices, sufficiently detailed, e.g. the source category split, or could one increase the parameterisation? Alternatively, are they too detailed?

Table 3-2: Information summary for railways emission methodology

Demand and Stock Emissions	**Description**	**Parameter**	**Quality**
Rail transport volumes	Activity by train type: pkm, tkm vkm, load factor from UIC, 1995, Tab 21; UIC, 1995, Tab 41; UIC 2000, supple-mentary statistics, Tab A24; TRENDS	TACTTRENDSalleng, TVKMTRENDS, TLOADfDif <u>In equations given above:</u> **TVP, TVF LF**	OK
Rail vehicle stock	Base year stock of train vehicles per train vehicle type and age from UIC 2000, supplementary statistics, Tab A24	TSTBY, TSTNBY <u>In equations given above:</u> **N**	OK, data quality for new countries rather poor.
Rail electricity consumption	Train electricity consumption factor from UIC, 1995, Tab 21; UIC, 1995, Tab 41; UIC 2000, supplementary statistics, Tab A24; TRENDS	TCONSFelec <u>In equations given above:</u> **ENP, ENF** (indirectly; needs to be derived from TCONSFelec)	Data for all countries available.
Rail Emissions and fuel consumption	Train direct emission factor from UIC, 1995, Tab 21; UIC, 1995, Tab 41; UIC 2000, supplementary statistics, Tab A24; TRENDS	TEMIF <u>In equations given above:</u> **EF**	Data for EU15 used for all countries.

Parameters	
Name	**Description**
TSTNBY	Base year stock of train vehicles per train vehicle type and age - in thousands vehicles
TACTTRENDSalleng	TRENDS activity by train type - million pkm or tkm per year – historic years and projections
TVKMTRENDS	TRENDS vehicle-kilometres by train type - million vkm - historic years and projections
TLOADfDif	UIC % difference between load factor for diesel and electric - 0 for electric
TEMIF	Train direct emission factor - g per vkm
TCONSFelec	Train electricity consumption factor - kWh per vkm

In theory, the issues should be evaluated for all countries by TREMOVE. However, the budget does not allow such an extensive analysis. Therefore, the analysis is carried out taking mainly German data as point of comparison (IFEU, 2005).

From the TREMOVE report and the identified methodology it can be concluded that the key parameters OR and LF as well as the parameters ENP and ENF are set. They are mainly derived from TRENDS data (Georgakaki et al., 2002). The parameters OR and LF differ for different train types (e.g. high speed trains have higher occupancies) but are kept constant in the model. In TRENDS the parameters ENP and ENF differ from country to country (see Table 7.2 of the TRENDS report). In TREMOVE, TCONSFelec, the train electricity consumption factor (in kWh per vkm), is the same for each country and TEMIF, the train direct emission factor (in g per vkm), differs from country to country. With regard to OR and EF there are clear indications from the German data that both parameters change over time (see Table 3-3). The parameters ENP and ENF change as well over time since they are calculated from the quotient energy consumption/driven vehicle mileage. With regard to EF it should be noted that the parameter is partly outside the scope of this analysis because for electric trains it relates to the emissions of power plants. For diesel-powered trains the 1995 average emission factors that are derived from TRENDS are applied to the whole 1995-2020 period within TREMOVE, i.e. they are kept constant. This is a questionable assumption since the emission standard change over time (see Table 3-4).

Thus, in the German TREMOD model the emission factors are inserted as a function of time (Table 3-5). Another issue is the share between diesel and electric traction. In TREMOVE this is defined by the "dynamic" equation (13). However, from the TREMOVE report it remains unclear whether the replacement of vehicles change take into account the shift from diesel to electric traction. In the German TREMOD model this issue is covered (Table 3-6).

Table 3-3: Occupancy rates for German trains (PNV = short distance passenger train, PFN = long distance passenger train, GV = freight train – Source: IFEU, 2005)

	PNV	PFV	GV
1994	26,0%	42,1%	30,0%
1995	26,0%	43,4%	29,6%
1996	26,0%	42,5%	35,9%
1997	26,0%	39,9%	29,2%
1998	24,9%	39,0%	32,2%
1999	21,9%	38,3%	33,4%
2000	21,8%	40,2%	36,3%
2001	20,9%	42,3%	34,1%
2002	19,5%	39,7%	34,9%
2003	20,6%	41,0%	38,0%
2004	20,6%	42,6%	41,8%
Quelle: Bahn-Umwelt-Zentrum; PNV vor 1997 geschätzt			IFEU Heidelberg 2005

Table 3-4: Emission limit values (g/KWh)for trains depending on their registration (Source: IFEU, 2005)

	Gültig ab*	Leistungs-klasse	CO	HC	NO_x	Part
Triebwagen						
Stufe IIIa	1/2006	Alle	3,5	4,0		0,2
Stufe III b	1/2012	Alle	3,5	0,19	2,0	0,025
Lokomotiven						
Stufe IIIa	1/2007	P ≤ 560 kW	3,5	4,0		0,2
Stufe IIIa	1/2009	P > 560 kW	3,5	0,5	6,0	0,2
Stufe IIIa	1/2009	P > 2000 kW	3,5	0,4	7,4	0,2
Stufe IIIb	1/2012	All	3,5	4,0		0,025
Bemerkungen: *Gültig für neue Fahrzeuge; neue Typen 6-12 Monate später; P: Motorleistung						
Quelle: EU 2002a						

Table 3-5: Emission factors (g/kg fuel) for diesel trains in Germany (Train categories as in caption of Table 3-3 - Source: IFEU, 2005)

Komp.	Zugart	1995	2004	2010	2020	2030
CO	Rangieren	18,0	11,5	6,8	4,4	4,4
	GV	11,5	9,5	8,1	7,1	7,1
	PFV	14,1	8,0	6,1	5,4	5,4
	PNV	10,8	5,9	4,8	4,7	4,7
HC	Rangieren	2,9	2,9	2,1	1,8	1,8
	GV	5,3	5,8	3,4	1,9	1,9
	PFV	6,8	3,4	2,5	2,4	2,4
	PNV	4,1	2,2	2,2	2,0	2,0
NOx	Rangieren	49,4	42,7	34,7	29,5	29,5
	GV	50,6	55,0	48,3	41,1	41,1
	PFV	60,0	49,3	47,4	43,2	43,2
	PNV	51,2	49,6	40,4	29,6	29,6
Part	Rangieren	1,87	1,64	0,78	0,43	0,43
	GV	1,90	1,74	0,92	0,40	0,40
	PFV	1,77	0,95	0,91	0,90	0,90
	PNV	1,89	0,67	0,72	0,56	0,56
SO2	alle	3,00	0,02	0,02	0,02	0,02
Quelle: IFEU 2003c						

Table 3-6: Share of diesel/electric train activity in Germany (Train categories as in caption of Table 3-3 - Source: IFEU, 2005)

Zuggattung	Betriebsart	2004	2010	2020	2030
GV	Diesel	7,2%	6,0%	5,0%	4,0%
GV	Elektrisch	92,8%	94,0%	95,0%	96,0%
PFV	Diesel	2,4%	2,0%	2,0%	2,0%
PFV	Elektrisch	97,6%	98,0%	98,0%	98,0%
PNV	Diesel	22,9%	20,0%	18,0%	16,0%
PNV	Elektrisch	77,1%	80,0%	82,0%	84,0%
Quelle: DB AG, IFEU-Annahmen					

With regard to the parameterisation, the TREMOVE split, including the source category split, seems reasonable.

3.3.3 Proposals for improvements assessment

With regard to improvements of the current methodology, the following are recommended: From the assessment of the previous section it seems to be worth considering to insert the parameters LF and OR, ENP and ENF as well as EF, country-by-country, as variables which change over time. Moreover, the split into diesel and electric traction should be inserted, country-by-country, as a variable.

With regard to improvements based on a re-design of the given methodology, the following recommendations can be made:

The methodology applied in TREMOVE as such seems to be reasonable. It would be difficult to find data for a more refined methodology, but it is as well unnecessary to take a less detailed approach.

From the German TREMOD experiences it is obvious that special attention has to be given to the correct allocation of the energy consumption to rail transport. Therefore, it is worth checking whether TTREMOVE data and (corrected) national statistics fit to each other.

3.4 Metro/tram

3.4.1 Basic TREMOVE equations

In theory, this is a sub-sector of railways. However, since the data sources are different it makes sense to treat this sector separately. The equations used in TREMOVE are much simpler than for the railways sector. The key equations for estimating the emissions of the metro/tram sector ("static part") are:

$$E_{ijlmnt} = (TVP/OR) * ENP * (EF) \qquad (40)$$

With

E_{ijlmnt} = Emissions of pollutant i of metro/trams in region j at the time period l and fuel type n in the year t (unit: tons)

TVP_{jlt} = Total transport volume of metro/trams trains in region j at the time period l in the year t (unit: Pkm)

OR_j = Occupancy rate of metro/trams in the region j (unit: Pkm/vkm)

ENP_j = Specific energy consumption of metro/trams in region j (unit: kJ/vkm)

EF_{il} = emission factor of pollutant i of metro/trams powered by electricity at time period l (unit: tons/kJ)

And with the indices

i = pollutants (CO_2, CO, VOC, NOx, PM, SO_2)

j = Region (urban, metropolitan)

l = time period (peak, off-peak)

m = train type (just one type: metro/tram)

n = fuel type (just one: electric)

t = year

There is no explicit "dynamic" equation that determines the turnover of the fleet. In theory, the following equation applies:

$$\mathbf{N_{jlmt} = TVF_{jlmt} / (AM * LF)} \qquad (41)$$

With

N_{jlmt} = Number of metro/tram vehicles in region j at the time period l in the year t

AM = Annual mileage of metro/tram

However, in practical terms it is assumed that there will be always enough metro/trams available so that only the vehicle mileage counts. This means that the equation (40) for the emission calculation is simplified to

$$\mathbf{E_{ijlmnt} = TVP / OR * ENP * (EF)} \qquad (42)$$

Thus, the vkm are a direct result of the demand calculations since the parameters OR and ENP are kept stable. Since there is no turn-over of technologies, EF is kept stable (but could be modified internally, if desired). The TREMOVE report provides information with regard to data and parameter names, which is summarized in Table 3-7. The parameter TVP is the result of the dynamic calculations, which are initiated by the scenario settings. The parameter EF is outside the scope of this analysis because it relates to the emissions of power plants.

Table 3-7: Information summary for metro/tram emission methodology

Data			
Demand and stock and emissions	**Description**	**Parameter**	**Quality**
Rail electricity consumption	Metro, tram electricity consumption factor from UIC, 1995, Tab 21; UIC, 1995, Tab 41; UIC 2000, Supplementary statistics, Tab A24; TRENDS	METRAMCONSFelec, In equations given above: **ENP**	Data for all countries available.
Parameter names			
METRAMCONSFele	Metro and tram electricity consumption factor - kWh per vkm.		

3.4.2 Assessment of the basic TREMOVE methodology

Based on equations (41) and (42) it is obvious that improvements of the methodology (within the given boundaries of TREMOVE) should concentrate on improving the complex ((TVP/OR) * ENP), e.g. by improving the parameters OR and ENP used for the individual countries. In the current version of TREMOVE the parameters OR and ENP are set and kept constant. According to the TREMOVE report ENP is set at 3 kWh/vkm. The TRENDS report does not include data for metro. In the German TREMOD model metro and tram is included in short-distance electric rail transport of passengers, e.g. what has been said above under rail applies here as well. Thus, improvements of the complex ((TVP/OR)*ENP) require the availability of more detailed data.

3.4.3 Proposals for improvements assessment

As mentioned two aspects are of importance for this review: Improvements of the given structure and more radical changes in the methodology.

With regard to the given methodology and from the assessment of the previous section it seems to be worth considering to insert the parameters OR and ENP or the complex ((TVP/OR)*ENP) as well as EF, country-by-country, as variables which change over time.

With regard to a redesign of the current methodology, it can be generally stated that the methodology applied in TREMOVE as such seems to be reasonable. Although it seems possible to obtain more detailed data (e.g. from cities) it seems not to be worth to define a more detailed methodology since the source category as such is too small (see criterion most efforts to biggest polluter).

3.5 Inland waterways

3.5.1 Basic TREMOVE equations

Inland waterways do not exist as a transport option for all countries. Therefore, only countries where inland waterways have a significant transport share are included in TREMOVE, e.g. Austria, Belgium, Switzerland, Czech Republic, Germany, Slovakia, France, Hungary, Italy, Netherlands, Poland and Romania.

Passenger transport is not covered by the methodology due to its negligible volume. The key equations used in TREMOVE for estimating the emissions of the sector inland waterways ("static part") are:

$$\mathbf{E_{ijkmnt} = (TVF/LF) * (EF)} \qquad (43)$$

With

E_{ijkmnt} = Emissions of pollutant i in region j at trip distance k of vessel type m and commodity type n in the year t (unit: tons)

EF_{im} = Emission factor of pollutant i of vessel type m (unit: tons/vkm)

TVF_{kmnt} = Total transport volume of inland waterways at trip distance k of vessel type m of commodity type n in the year t (unit: tkm)

LF_m = Load factor of vessel type m (unit: tkm/vkm)

And with the indices

i = pollutants (CO_2, CO, VOC, NOx, PM, SO_2, N_2O, CH_4, NMVOC)

j = Region (just one: non-urban)

k = trip distance (short = national; long = international)

m = vessel type (21 types in total)

n = commodity type (bulk, general cargo, unitized)

t = year

The parameter LF is set and kept constant.

The parameter TVF results from the dynamic calculations, which are initiated by the scenario settings.

Endogenous 'allocation keys' are used to allocate tkm to specific ship types. The vehicle-km is further split to configurations by using a 'configuration matrix' in conjunction with the allocation keys. This allows allocating vehicle-km by vessel type and configuration (i.e. the kind of propulsion technology) in each country. In practical terms the endogenous "allocation matrix" and "configuration key" distribute the transport volume on the vessels.

For inland waterways there is no "dynamic" equation which determines the turnover of the fleet. However, a turnover of the engines used in the vessels can be applied which is based on configuration matrix. For each vessel type, this matrix specifies the share of different fuel–engine–equipment configurations. In the base case as well as in the simulation, the share figures in the configuration matrix for each year and each vessel type is determined by solving a 'technology-cost minimising problem'. However, in the baseline, only one configuration (1 type of fuel, 1 type of engine) is available for each ship type. Thus, the engine turn-over is an option which is currently not used in TREMOVE. To make use of it would require to fill-in the configuration matrix, e.g. with emission factors and costs for new engines. The TREMOVE reports provides the information in Table 3-8 with regard to data and parameter names.

Table 3-8: Information summary for inland shipping emission methodology

Demand and stock and emissions	**Description**	**Parameter**	**Quality**
Inland waterways vkm	Inland waterways stock, engines	IWCONFIG In equations given above: **TVP**	OK, predominantly Dutch data.
Inland waterways emission factors	Inland waterway fuel consumption and emission factors from preliminary Artemis	IWCONSFfuel, IWEMIF In equations given above: **EF**	OK, predominantly Dutch data.

Parameter names	
I IWTKMSHexo	Share of total tonne-kilometres transported by a specifiic ship type - allocation key – country specific % of total tonne-kilometers for a type of good and trip distance In equations given above: **None**
IWLFexo	Inland ship load factor – tonnes per ship In equations given above: **LF**
IWCONFIG	Indicates for each configuration if and when it becomes available for each vessel type separately – only one configuration is modelled in the base case In equations given above: **None**
IWCONSFfuel	Inland waterway fuel consumption factor - g per vkm In equations given above: **EF**
IWFREDUC	Reduction in fuel consumption of the configuration compared to the basecase configuration - % In equations given above: **None**
IWEMIF	Inland waterway emission factor per vessel type and pollutant - g per vkm In equations given above: **EF**

3.5.2 Assessment of the basic TREMOVE methodology

The TREMOVE methodology is mainly based on an inland water way model used for the Netherlands. This explains the extremely differentiated source category split (21 categories).

Since the model has no real dynamic part the detailed split does not influence the turn-over of the fleet but is just of importance for the allocation of emission factors. The fuel consumption and emission factors as such are used throughout the 1995 to 2030 period, e.g. there is no improvement over time.

3.5.3 Proposals for improvements

With regard to the current methodology, and taking equation (43) and the explanations given it is obvious that improvements of the methodology (within the given boundaries of TREMOVE) should concentrate on improving the parameters EF and LF.

The emission factors, EF, are taken from the ARTEMIS project (Gergakaki et al., 2002). As mentioned, the fuel consumption and emission factors are used throughout the 1995 to 2030 period. In reality the emission factors and fuel consumption factors are a function of the waterway depth and width and the vessel speed. In TREMOVE just one factor per vessel type is taken for all countries (and all waterways). In summary, the methodology simplifies the emissions factors with regard to the boundary conditions of vessel usage and technology improvement over time but complicates the methodology with regard to vessel types. One could wonder whether this is justified. An alternative approach would be to reduce the number of vessel types but to vary the emission factors at national level, e.g. based on data on river dimensions and average vessel speed.

The emission factors are expressed in g/vkm. In principle, this makes sense, since emission factors expressed in g/kg fuel consumed would require high quality energy consumption statistics. However, the available energy consumption data are not very reliable since vessel bunker fuel wherever it is cheapest. This makes it very difficult to allocate emissions correctly.

As a rule vkm data can be obtained for all countries since the tkm are given in the statistics. These have to be corrected by the load factor. It is therefore the load factor LF to which attention should be given.

The load factors used are based on historic load factor figures and allocation keys valid for the Netherlands. This information was derived from Dutch government statistics (i.e. CBS database). Different load factors and allocation keys are specified by type of good, domestic vs. international trips and vessel type, as differences between types of good and domestic vs. international are important. In summary, the issues to be looked at are national emission factor and load factors and their trends.

With regard to a redesign of the current methodology, one may say that the TREMOVE methodology is very detailed, mainly due to the source category split. One could wonder whether this it is necessary since the transport demand and the emissions can be modelled using a much simpler approach. In fact, for most of the Member States such a detailed category spilt cannot be provided. The TREMOVE methodology simply assumes that the detailed Dutch source applies to other countries as well without being able to verify the data.

A simpler methodology could be based on the tkm which are given in national statistics and apply emission factor expressed in g/tkm. For example, the German methodology is based on transported tkm (from statistics) and uses for all vessels a fuel consumption factor of 10 g/tkm. This allows calculating the fuel consumption (statistics are of no help in this case because the vessels bunker a significant share of diesel fuel in the neighbouring countries) which is then multiplied by a set of emission factors expressed in g pollutant/g fuel (Table 3-9). Instead of using a dynamic turn-over approach (for engines as foreseen, but practically not used in TREMOVE) the emissions factors are simply reduced based on reasonable assumptions.

Table 3-9: Emission factors for inland shipping in TREMOD (Source: IFEU, 2005).

Komponente	EFA(g/kg):	Kommentar:
HC	5	Nach /IFEU 1994a/
CO	12	Nach /IFEU 1994a/
NOx	60	Nach /IFEU 1994a/
Part	2	Nach /IFEU 1994a/
CO_2	3175	
CH_4	0,12	Nach /IFEU 1995b/
NMHC	4,88	Nach /IFEU 1995b/
SO_2	3	
Benzol	0,095	Nach /IFEU 1995b/
		IFEU Heidelberg 2002

In the light of the fact that inland waterways are used as a means of transport just in a few Member States, one could wonder whether this approach would not fit the purpose.

3.6 Air transport

3.6.1 Basic TREMOVE equations

The key equations used in TREMOVE for estimating the emissions of the air transport sector ("static part") are:

$$\mathbf{E_{ijkmnt} = (TVF/LF) * (EF)} \qquad (44)$$

With

E_{ijklnt} = Emissions of pollutant i in region j at trip distance k and time period l of fuel type n of air transport in the year t (unit: tons)

TVP_{klt} = Total transport volume of air transport at trip distance k and time period l in the year t (unit: pkm)

OR = Occupancy rate of passenger aircrafts (unit: pkm/vkm)

EF_{ik} = emission factor of pollutant i of at trip distance k (tons/vkm)

And with the indices

i = pollutants (CO_2, CO, VOC, NOx)

j = Region (just one: non-urban)

k = trip distance (> 500 km; 500-1000 km; 1000-1500 km; 1500-2000 km; > 2000 km)

l = time period (peak, off-peak)

n = fuel type (just one: kerosene)

t = year

There are no "dynamic" equations, e.g. there is no turnover of the fleet.

The TREMOVE reports provides the information summarized in Table 3-8, with regard to data and parameter names for aviation emissions.

3.6.2 Assessment of the basic TREMOVE methodology

The parameters OR and EF are set and are assumed to remain constant in the forecast years. They are mainly derived from TRENDS/AVIOPOLL (psiA Consult, 2002) data.

With regard to OR, an overall occupancy rate of 70 % is taken and kept constant.

With regard to EF the fuel consumption and emissions figures from the AVIOPOLL database given in seatkm are used and recalculated to pkm assuming OR (70 %). The factors in gram per pkm, for each distance class, obtained in this way are kept constant. The factors are then multiplied for each distance class (0-500 km, 500-1000 km, 1000-1500 km, 1500-2000 km , +2000 km) with the pkm from the demand module in order to obtain emission figures.

The transport demand module assumes flight distances when calculating the number of pkm. For planes, the real distance may vary, as planes usually take detours. Therefore, a detour factor is included in the model as an input variable. In theory, this simple approach is supposed to enable TREMOVE modelling "Single European Sky" policies, which aim at reducing detours in air transport.

Freight transport is not covered by TREMOVE although figures suggest that it currently accounts to about 3 % of total air transport with increasing tendency.

As fuel only kerosene is taken into account. This is reasonable since the consumption flight petrol is negligible (below about 0,3 %).

Based on equation (44) and the explanations given above it is obvious that improvements of the methodology (within the given boundaries of TREMOVE) should concentrate on improving the parameters OR and EF used for the countries as well as, if possible, the detour factors (figures not given in the TREMOVE report – to be extracted from the model from the parameter AIRDETOUR).

Table 3-10: Information summary for aviation emission methodology

Demand and stock and emissions	Description	Parameter	Quality
Air Transport classes	Air distance classes	AIRFRACT	Values for EU25, CH and NO are from ASSESS-Scenes and TIF, sometimes updated with national data. Values from other countries are based on national statistics and growth factors. An update of both EU25 and other countries is needed, and will be done in the iTREN2030 project (by 2008).
Air transport emissions	TRENDS & "Atmosfair Emissions Calculator": detour, fuel consumption, LTO and cruise split, emission factors	AIR_DETOUR, AIR-CONSFfuelD, AIRCONSFfuelDsplit_alt, AIREMIFD, AIREMIFDsplit_alt In equations given above: EF (via fuel consumption)	OK, data quality for new countries rather poor.
Parameter names			
AIR_DETOUR	% detour-deviation from straight OD distance. AIR_DETOUR indicates the difference between crow's flight and real distance. In the base case the detour factor values are: 25% for <500 km flights and 11.1% for >500 km flights		
AIRCONSFfuelDsplit_alt	LTO and cruise in total aircraft fuel consumption		
AIREMIFDsplit_alt	LTO and cruise in total aircraft emissions		
AIRCONSFfuelD	Fuel consumption factor for aircrafts by distance class - g fuel per pkm		
AIREMIFD	Emission factor for aircrafts by distance class - g pollutant per pkm		

3.6.3 Proposals for improvements Assessment

Improvements of the given methodology should concentrate on EF and OR. The emission factors used in Germany, for example, are a function of time (Table 3-11) and it is more than likely that this holds as well for other countries. ICAO also has new emission factors that can be provided through EUROCONTROL.

The occupancy rate OR should vary as well. However, since - as a rule of thumb - air transport needs OR values of about 65 % to operate profitable it is not unreasonable to keep OR constant at a level of 70 %. However, more detailed data and tends, if possible as a function of distance, could improve the quality of the emission estimates.

Table 3-11: Emission factors (g/kg fuel) for aviation used in TREMOD (Source: IFEU, 2005)

Emissionsfaktoren für Flugzeuge (in g/kg Kraftstoff)								
Jahr	CO_2	H_2O	SO_2	NO_X	NMHC	CH_4	CO	Partikel
Flugturbinenkraftstoff								
Flugverkehr der ehemaligen DDR (nur grenzüberschreitend)								
1980	3120	1350	1,0	10	5	0,25	16	0,2
1990	3120	1350	1,0	12	3	0,15	10	0,1
Inlandsverkehr der BRD (1995 und 2020: Deutschland)								
1980	3120	1350	1,0	12	3,3	0,18	12	0,1
1990	3120	1350	0,6	15	1,4	0,08	6	0,06
1995	3120	1350	0,6	11,1	1,6	0,08	7,4	0,06
2005	3150	1280	0,4	14	1,61	0,04	9,2	0,04
2020	3150	1280	0,2	12	1,4	0,03	7,0	0,02
Grenzüberschreitender Verkehr der BRD (1995 und 2020: Deutschland)								
1980	3120	1350	1,0	12	2,4	0,13	8	0,1
1990	3120	1350	0,8	15	1,4	0,08	3	0,06
1995	3120	1350	0,8	12,9	0,83	0,04	4,0	0,02
2005	3150	1280	0,4	14	1,61	0,04	9,2	0,04
2020	3150	1280	0,2	12	1,4	0,03	7,0	0,02
Flugbenzin								
Flugverkehr der BRD, der DDR und Deutschlands								
1980-2020	3100	1400	0,4	3	18	1,0	250	0,1

Anmerkungen: Werte für die Darstellung z.T. gerundet; NMHC = Nicht-Methan-Kohlenwasserstoffe; 2010 = Vorschläge für eine Trendabschätzung der Emissionsfaktoren im Jahre 2010; NMHC und CH_4 ohne Treibstoffschnellablässe, Betankungs- und Leckagenverluste sowie ohne Verdampfungsemissionen; NMHC = Kohlenwasserstoffe ohne Methan; Werte für 1995 aus /TÜV Rheinland 1999a/, Werte für 2005 und 2020 aus /UBA 2004a/

IFEU Heidelberg 2005

One could wonder whether a split into distance classes is the most appropriate one. However, as mentioned above, the whole methodology is mainly based on TRENDS/AVIOPOLL. This includes in particular as well the sub-source category split. It is therefore not possible to change the source category split without modifying at the same time the methodology as such.

With regard to improvements of the current methodology, the psiA-Consult report provides a comprehensive overview about the state-of-the-art of air transport modelling. The TREMOVE methodology which is based on this work can therefore be considered as still up-to-date. However, there are two possibilities to modify the methodology: a simplification, e.g. as done in Germany or a further sophistication, e.g. on the basis of more detailed data.

A simplification might be interest because it allows using statistics generally available, e.g. the energy consumption of the sector, and to up-date emission factors in an easier way, losing, however, at the same time some transparency. The key for this approach is a "corrected fuel consumption" calculation (if, for example, the emission factors mentioned above would be considered as appropriate).

The German TREMOD model energy estimates the fuel consumption of passenger flights on the basis of the following equations:

$$BL = (PVL*WPP+GVL)/ALG \quad (45)$$

with

ALG = weight-related load factor [%]

WPP = Weight per passenger (= 92 kg for inland and 97,5 kg for international flights (Lufthansa data))

PVL = Passenger transport volume [Pkm]

GVL = Freight (goods and mail) transport volume [tkm]

BL = offered transport capacity [otkm]

And

$$KV_i = KV_t \cdot BL_i *1,5/(BL_i*1,5+BL_a) \quad (46)$$

$$KV_a = KV_t \cdot BL_a/(BL_i * 1,5 + BL_a) \quad (47)$$

both, in accordance with the availability of statistics, differentiated for regular and charter flights, with

KV = Fuel consumption [t]

BL = offered transport capacity [otkm]

and the indices

i = National traffic

a = Departing international traffic

t = total

The factor 1,5 results from the (statistically proven) assumption that inland flights consume in average and related to the offered transport capacity 50% more fuel than international flights.

For each of these four groups (regular/charter and national/international) the distribution of the fuel consumption is calculated with the equations:

KVP = KV*PVL*WPP*1,7/(PVL*WPP*1,7+GVL) (48)

KVG = KV – KVP (49)

with

KVP = fuel consumption for passenger transport

KVG = Fuel consumption for freight transport

The factor 1,7 results from Lufthansa estimates between the ratio of passenger to freight transport and corrects for the fact that passenger transport is more transport volume intensive (In practical terms it means that the fuel consumption related to pkm is about 1,7 times higher than the fuel consumption related to tkm). The data necessary for these calculations are available in German statistics. This, of course is just an example which illustrates the need to carry out national calculations in order to obtain fuel consumption data which can be applied to the available emissions factors. The very limited data available from national statistics (mainly number of LTOs and passenger-km) makes it difficult for this methodological approach to be applied for other countries as well.

A sophistication of the methodology would go into a detailed aircraft-type/fuel consumption-based emission inventory. The basis for such an inventory could be the reporting under the Commission proposal for a Directive of the European Parliament and of the Council amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=SEC:2006:1684:FIN:EN:HTML). The monitoring is planned to be based on the actual fuel use by airlines on a flight by flight basis. Moreover, it is planned to use a standardised tiered method to estimate emissions (CO_2 in first place, NO_x at a later stage).

Concerning emission factors, there is wide agreement among experts who studied the monitoring issue that CO_2 emissions factors are not a complex issue in the aviation sector as the fuel used is relatively homogenous. It seems also to be possible to agree on emission factors for other pollutants on this basis.

Since the Commission will in cooperation with Member States and Eurocontrol follow developments in the implementation of the proposed Directive and the main sources of data will be the annual reporting of emissions data from operators combined with data on any non-compliant operators and air traffic data provided by Eurocontrol it can be assumed that a very rich data bank will be available in a couple of years (The co-decision procedure should allow the directive to enter into force around 2008, with monitoring and reporting obligations starting in 2010 and compliance obligations starting in 2011.). In accordance with the transparency rules of the Commission these data (The data to be reported are defined in the Commission’s proposal under amendments to Annex IV.), may be slightly aggregated, would be public and could therefore be used for a sophisticated methodology.

4 TRENDS methodology: Vehicle Stock Module

4.1 Simulation of vehicle fleet turnover

The TRENDS methodology has been introduced to calculate the vehicle technology mix in each year. In other words, this methodology has been used to estimate the internal turnover of the fleet, that is, the rate at which old vehicles are replaced by new ones. The prediction of the internal turnover of installations for each year is based on the following equation:

$$C_i(t) = C_i(t-1) - C_{si}(t) + C_{ri}(t) + C_{ei}(t) \quad (50)$$

where

$C_i(t), C_i(t-1)$ number of vehicles of type i during years t and t-1 respectively;

$C_{si}(t)$ number of vehicles of type i that were scrapped during year t;

$C_{ri}(t)$ number of new vehicles of type i that replaced old ones during year t;

$C_{ei}(t)$ number of new vehicles of type i entering the market during year t without replacing old ones (causing market extension).

The simulation of survival and scrappage rates was conducted with the aid of a modified, two-parameter Weibull function with the following reliability function:

$$\varphi_i(k) = \exp -\left[\left(\frac{k+b_i}{T_i}\right)^{b_i}\right] \text{ and } \varphi_i(0) \equiv 1 \quad (51)$$

where

k age of vehicles, expressed in years;

$\varphi_i(k)$ presence probability of vehicles of type i having age k (i.e. the probability that their lifetime is greater or equal to k);

b_i failure steepness for vehicles of type i ($b_i > 1$, i.e. failure rate increases with age);

T_i characteristic service life for vehicles of type i.

By examining the values of *T* and *b*, it was observed that *T* is close to the 99th percentile of the lifetime, while the value of *b* can be roughly approximated by the 50th percentile (i.e. approximately the maximum and the median lifetime respectively) of the fleet. This analogy, which works well for almost all EU countries, should be viewed as rather indicative and by no means precise.

In order to calculate the number of vehicles scrapped over the years, the age distribution for a starting year can be used as an initial condition. In accordance with Eq. (51), for each consecutive year the number of scrapped vehicles of age k is

$$CC_{si}(t,k) = CC_i(t-1,k-1) \cdot \left(1 - \frac{\varphi_i(k)}{\varphi_i(k-1)}\right) \tag{52}$$

and consequently the total number of scrapped vehicles in year t

$$C_{si}(t) = \sum_{k=1}^{n} CC_{si}(t,k) = \sum_{k=1}^{n} \left[CC_i(t-1,k-1) \cdot \left(1 - \frac{\varphi_i(k)}{\varphi_i(k-1)}\right) \right] \tag{53}$$

where

$CC_{si}(t,k)$ the number of scrapped vehicles of age k in year t;

$CC_i(t-1,k-1)$ the number of vehicles of type i and age k-1 that existed in the previous year.

The forecast of the total number of vehicles of type i per year, allows the calculation of the number of new vehicles entering the market either in replacement of old ones or because of an increase in the total vehicle park.

4.2 Technology Classes and Implementation Matrices

The approach described so far is age-driven, as scrapping and replacement of vehicles was assumed to follow a pattern similar to that of other commercial products. According to this process, the lifetime of vehicles depends primarily on the ordinary ageing process rather than on external factors. However, since emission behaviour is mainly technology-driven, the age distribution of vehicles has to be transformed into a technology distribution showing the technology mix for each consecutive year. To this aim, a technology implementation matrix was formed containing the technologies applicable from the starting year onwards and over the whole forecast horizon (see for example Table 3-4). The information contained in the implementation matrix is partly derived from knowledge on emission legislation already in force or scheduled for the near future and partly by assumptions with regard to future legislation.

There are cases where different technologies apply to new vehicles because of national incentive programs aiming at specific categories. In such cases a 'distribution matrix' is used assigning to each relevant technology a fraction for every year. An example of such a matrix is given in Table 3-5.

Taking all the above into consideration, the share of each technology (to which a special emission factor for each pollutant is assigned) for a given year was obtained and the total amount of emissions from road traffic in this year was calculated.

Table 4-1: Example of a technology implementation matrix concerning gasoline passenger cars with a cylinder capacity of less than 1.4 litres

Technology	Period of implementation
Non-catalyst cars complying with Regulation ECE 15/04	1985-1990
Improved non-catalyst cars	1986-1991
Cars equipped with oxidation catalyst	1986-1991
Cars complying with Euro 1	1986-1996
Cars complying with Euro 2	1997-1999
Cars complying with Euro 3	2000-2004
Cars complying with Euro 4	2005-2009
Cars complying with Euro 5	2010-2014
Cars complying with Euro 6	2015 onwards

4.3 Lifetime functions

In the EU, a number of legislative interventions have over the last two decades obliged the car manufacturing industry to produce "cleaner", environmentally friendly, cars to replace the older, more polluting, ones. This implies that the vehicle fleet turnover, the rate at which old vehicles are scrapped and replaced with new ones, is an important parameter for the emission impact of vehicles. Within the FLEETS project vehicle lifetime functions have played an important role in the estimation of the highly disaggregated data on vehicle fleets. In the following, the derivation of lifetime functions is based on German detailed data. Of ocurse, lifetime function may differ from country to country. However, this will affect the value of the lifetime function parameters and not the shape. Hence, the following analysis has a generic value for all countries. The actual values of the parameters will depend in the statistical data of each country. This analysis can be performed in the framework of EC4MACS,

The functional form most widely used in the literature is an S-shape curve, which is obtained by using a "modified" Weibull distribution with three parameters:

$$\varphi(k) = \exp\left[-\left(\frac{k+b}{T}\right)^{b}\right]; \varphi(0) = 1 \quad (54)$$

where:

$\varphi(k)$ is the probability that a vehicle will survive k years after its registration

b is the failure steepness for the vehicle ($b > 1$ which implies that the failure rate increases over time). It can be roughly approximated by the 5oth percentile of the lifetime.

T is the characteristic service life for the vehicle and it can be approximated by the 99th percentile of the lifetime.

The estimation of the lifetime functions requires long time series of vehicle stock, vehicle scrapping and vehicle new registrations, which must be available by each vehicle type and age. In the context of the FLEETS project the estimation was based on data provided for Germany, due to the lack of suitable information for the rest of the countries considered in the project. The analysis was carried out for passenger cars, light duty vehicles, buses, heavy duty trucks and motorcycles. The functions obtained for Germany were used in the reconciliation process for the rest of the countries, in order to provide an initial indication of individual country survival rates for each vehicle type in a way that ensured overall consistency specifically for the country.

In order to estimate equations following the general specification of equation 24 for each vehicle type non linear methods were used. We have experimented with the many alternative specifications of the parameter b, including the examination of different b by vintage for the same vehicle type as well as specification involving b as a function of k. This led to a simultaneous estimation procedure. The general algebraic specification of the estimation model used is given below:

$$\varphi_i = \exp\left(-\left(\frac{k_i + b_i(k_i)}{T}\right)^{b_i(k_i)} + \varepsilon_i\right) \quad (55)$$

$$b_i(k_i) = h_{1,i} + h_{2,i} \cdot k_i + h_{3,i} \cdot e^{h_{4,i} \cdot k_i} \quad (56)$$

where *i* is the vintage of the vehicle type under consideration and ε_i is the error term of the estimated equation. In the above specification the estimated parameters are the T and $h_{j,i}$, $j = 1...4$ for each vehicle type of vintage *i*. The estimation method used is the

Seemingly Unrelated Regression (SUR) method, which is appropriate when all right hand side regressors are assumed to be exogenous and the errors are heteroscedastic and contemporaneously correlated. It should be noted that filters have been used whenever discontinuities in the dataset used for the estimation process were identified.

The following set of experiments were studied in detail in the context of the FLEET project regarding the alternative specifications of the parameter b :

- Different b according to vintages (but b's are not functions of age)
- Formation of groups of vintages (1980-1991, 1992 onwards) and estimation of one b per each group. This discontinuity is mainly due to the German unification
- One single b for all vintages (but b is not a function of age)
- One single b for all vintages as a linear function of vintage
- One single b for all vintages as an exponential function of vintage

In Figure 4-2 an example of the experiments assuming different b according to vintage i is given. The figure shows the mean and the ± 2 standard errors range. The concrete algebraic specification of the estimation model is:

$$\varphi_i = \exp\left(-\left(\frac{k_i + b_i}{T} \right)^{b_i} + \varepsilon_i \right) \qquad (57)$$

The above specification implies a b, which is not a function of age. The estimation process gave robust results, as can be judged by the small error ranges in comparison to mean values of the betas displayed in the graph. Two main groups of vintages can be easily identified in the graph: cars registered from 1980-1991 and cars registered from 1992 onwards. The means of b of the first group are higher than the means of the second group implying higher failure rates for the older cars.

Looking at the range of betas of the first group, it can be assumed that the sample of betas could have been derived from one distribution. This is also noticeable for the second group, although there are some cases when this assumption does not appear to be statistically valid. This has led to the next experiment, which was to estimate one single beta for each one of the two groups above. By forming two groups of vintages (1980-91, 1992-onwards), the following estimation model was applied:

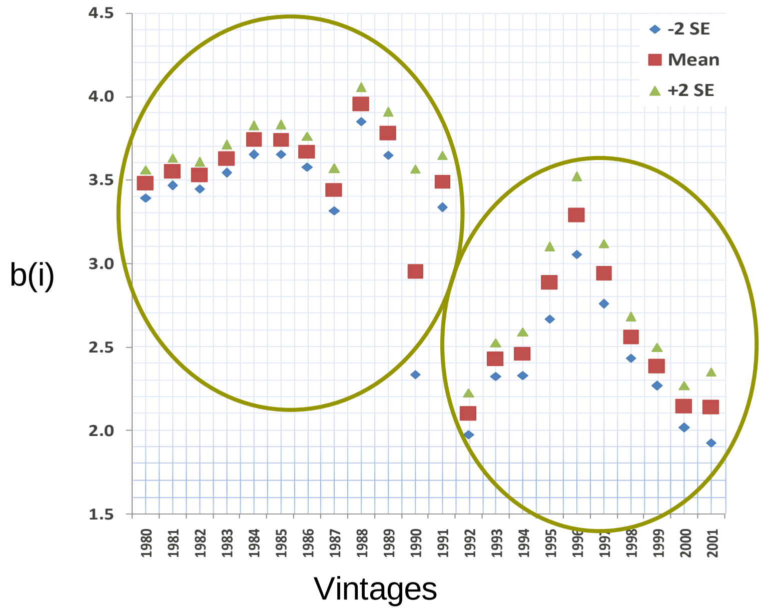


Figure 4-1: Example of the experiments assuming different *b* according to vintage *i* - Passenger cars in Germany

$$\varphi_i(k_i) = \exp\left(-\left(\frac{k_i + b_i}{T}\right)^{b_i} + \varepsilon_i\right), \text{ i=80-91, 92-01} \qquad (58)$$

Figure 4-2 presents the results of the estimation process. The t-Statistic of the estimated coefficients is very high, which implies robust estimation results. The two estimates of the betas are negatively correlated, with a correlation coefficient of approximately -0.42. This implies that a probability of a high b in the post 1992 period increases if the b in the earlier period turns out lower.

	Coefficient	Std. Error	t-Statistic	Prob.
B_1980-1991	3.509233	0.019142	183.3235	0.0000
T	18.48026	0.025678	719.6898	0.0000
B_1992	2.572252	0.036112	71.22988	0.0000

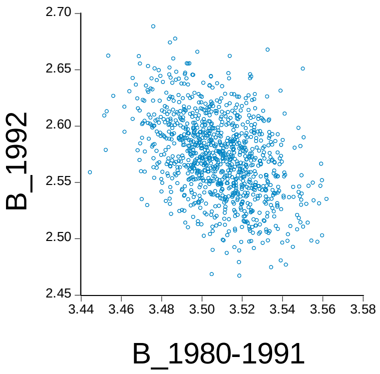


Figure 4-2: Example of the experiments assuming different *b* for each group of vintages

By plotting the survival curves and the scrapping rates of these two groups of vintages it can be seen that scrapping rates are more concentrated in the period between 7 to 23 years after the first registration for both groups.

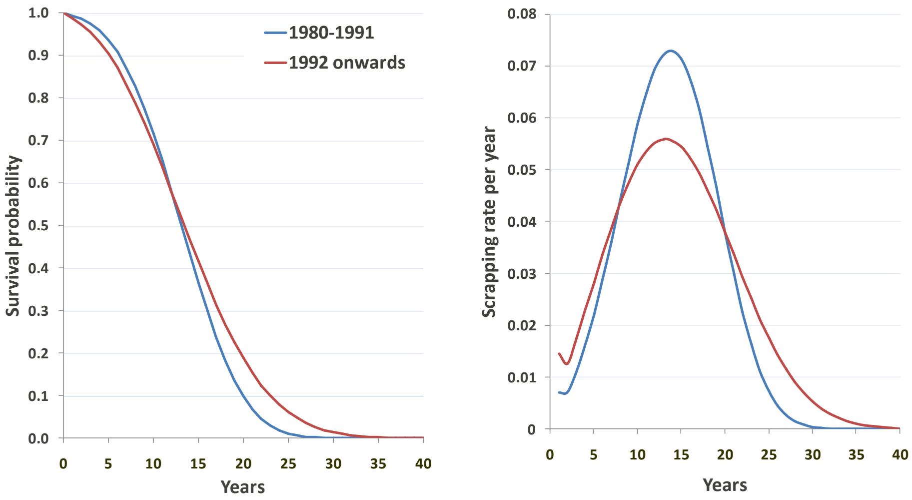


Figure 4-3: Survival curve and scrapping rates in the case of two groups of vintages (passenger cars in Germany)

The third experiment performed is to use the classical survival curve model described by equation 24. The results of estimating one beta for passenger cars in Germany are given in Table 4-2. In comparison with the approach of two betas it can be seen that the T parameter is more or less the same, implying the stability of this estimator, while the mean of the beta is closer to the mean of the beta of the first group which can be explained by the fact that the share of these cars in deregistration is significantly higher than the cars of the second group.

Table 4-2: Example of the experiments performed using a single beta - Passenger cars for Germany

	Coefficient	Std. Error	t-Statistic	Prob.	
B	3.490394	0.016736	208.5564	0.0000	Single beta
T	18.43489	0.024116	764.4182	0.0000	

	Coefficient	Std. Error	t-Statistic	Prob.	
B_1980-1991	3.509233	0.019142	183.3235	0.0000	Two groups of beta (repeated for comparison)
T	18.48026	0.025678	719.6898	0.0000	
B_1992	2.572252	0.036112	71.22988	0.0000	

By plotting the survival curve function of the single beta experiment and the scrapping rate curve and comparing them with the ones of the two betas approach (Figure 4-5), it can be seen that the single beta function has lower scrapping rates at the early years and higher scrapping rates at later years while at the same time imply very small probabilities of survival in the very long term (above 25 years). All the above are intuitively sound.

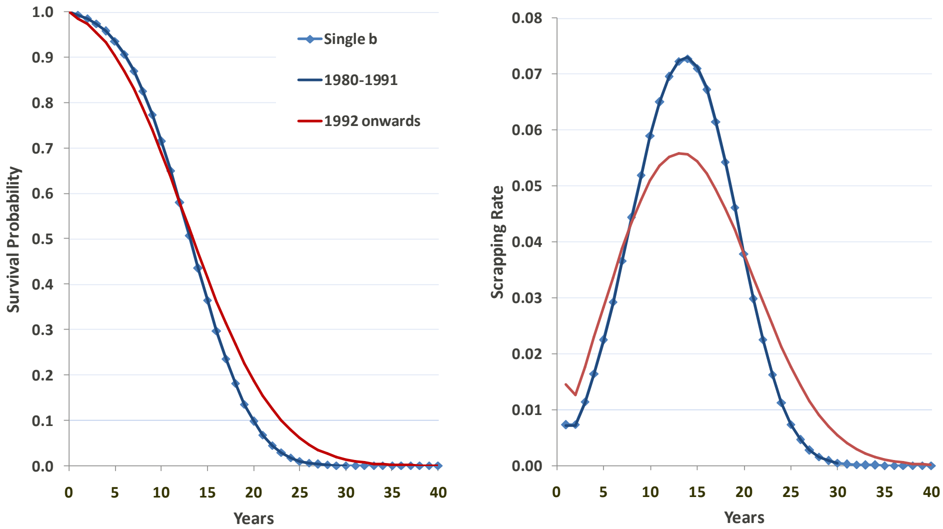


Figure 4-4: Comparison of the survival curve and scrapping rates in the cases of a single beta and two groups of vintages

The next experiment was to make beta a linear function of vintage. The estimation model used is the following:

$$\varphi(k) = \exp\left(-\left(\frac{k + b(k)}{T}\right)^{b(k)} + \varepsilon\right) \tag{59}$$

$$b(k) = h_1 + h_2 \cdot k \tag{60}$$

An example of the output of the estimation for buses is given in Table 4-3..

Table 4-3: Example of making b a linear function of age - Buses in Germany

	Coefficient	Std. Error	t-Statistic	Prob.
H(1)	1.698018	0.080206	21.17070	0.0000
H(2)	0.030591	0.014619	2.092611	0.0378
T(1)	28.99423	0.985381	29.42439	0.0000

By plotting the survival curve and scrapping rates and comparing them with the single beta approach it can be observed that the linear function produces higher scrapping rates in the later years than the single beta function. As an example, the traditional approach of a single beta gives 20% probability that a vehicle of 40 years of age will be still operational, while if the linear function is used this probability falls to around 5%. The latter result is by far more acceptable.

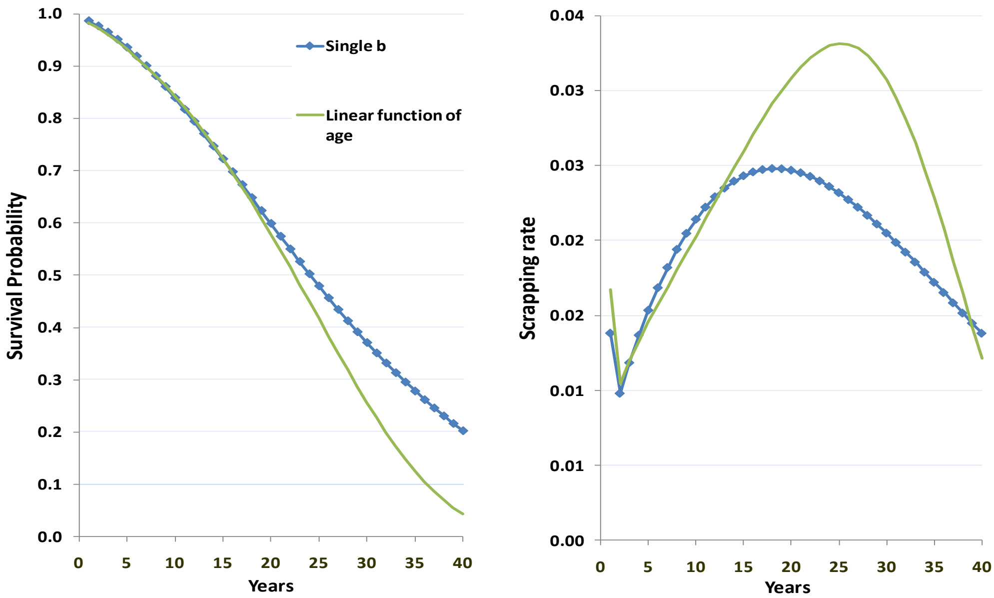


Figure 4-5: Comparison of the single beta with the linear approach

The last type of experiment examined in the context of the FLEETS project was to make beta an exponential function of age. The estimation model used in this experiment is:

$$\varphi(k) = \exp\left(-\left(\frac{k + b(k)}{T} \right)^{b(k)} + \varepsilon \right) \tag{61}$$

$$b(k) = h_1 \cdot e^{h_2 \cdot k} \tag{62}$$

Table 4-4 presents the estimation output in the case of the Heavy Duty Vehicles.

Table 4-4: Example of making b an exponential function of age - Heavy duty trucks in Germany

	Coefficient	Std. Error	t-Statistic	Prob.
H(1)	3.498560	0.260080	13.45188	0.0000
H(2)	-0.024968	0.005169	-4.830016	0.0000
T	15.33555	0.086397	177.5004	0.0000

By comparing the survival curves and the scrapping rates of the single beta approach, the beta as a linear function of age and the beta as an exponential function of age for the case of the heavy duty trucks it can be observed that the exponential function constitutes a better specification than the other two. It does not display the undesirable property of the linear function to become negative in the later years and it also has lower scrapping rates than the single beta approach.

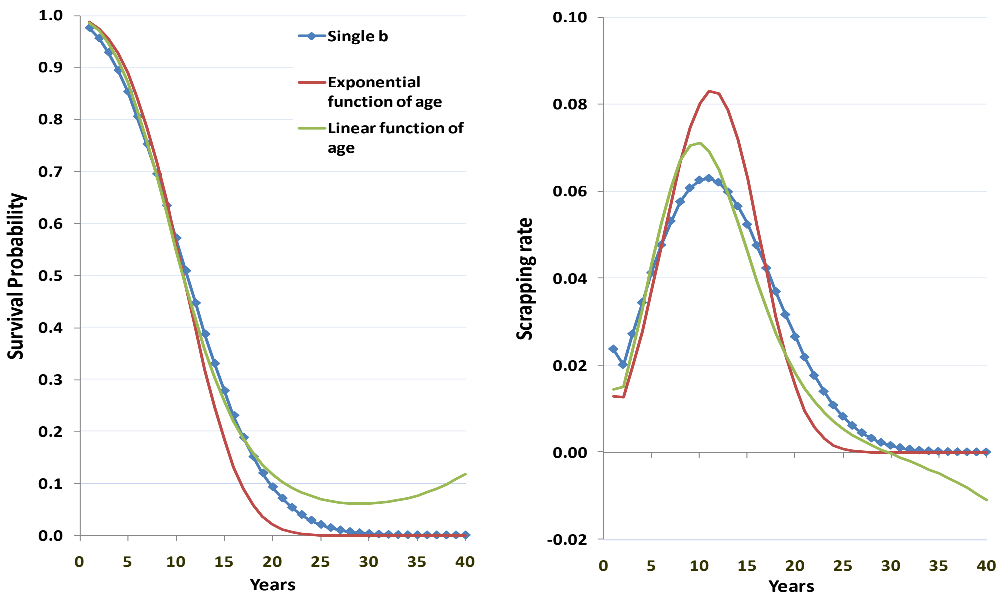
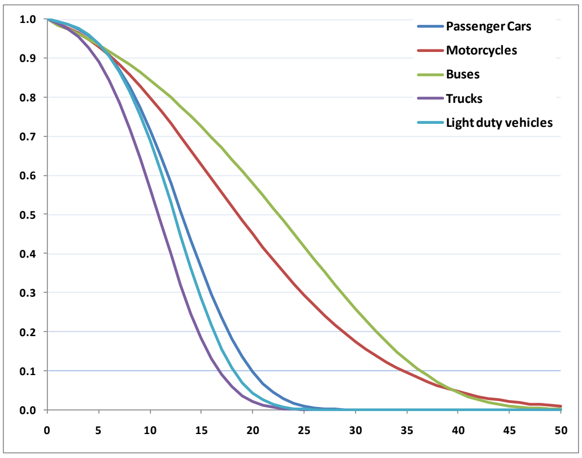


Figure 4-6: Comparison of survival curves and scrapping rates - Heavy duty vehicles in Germany

Figure 4-7 presents a comparison between the estimated survival curves and scrapping rates for the different vehicle types for Germany. It can be seen that trucks and light duty vehicles display the highest scrapping rates in the early years, since these are commercial vehicles and their renewal can be viewed as capital turnover subject to strict productivity considerations. Passenger cars also display a narrow scrapping rate distribution over time reflecting during the last decade a shift in consumer preference for newer cars. Buses display significantly lower rates than the other vehicle types to the point of producing paradoxical situations (survival and presumably circulation of buses older than 40 years in substantial numbers). This, however, is confirmed by other studies on survival curves (e.g. TREMOVE). It must be noted that most buses belong to public authorities and maybe subject to different de-registration requirements. An even more acute problem is identified in motorcycles where the very long survival of part of the fleet is difficult to justify. A very likely reason for this seeming paradox is that de-registration of two wheelers is not always recorded with the vehicles may either abandoned or kept without using them. The seeming long life of two wheelers has also been identified in earlier studies.

Although a comparison of the above lifetime functions with the lifetime functions used in TREMOVE, TRENDS and ARTEMIS project is tempting, such a comparison cannot be made because:

- The estimation in FLEETS was based only on data for Germany because there were no other available sources in the project
- Even if the same data sources were used, the specification of the lifetime functions is different between the FLEETS and the other projects.
- In FLEETS project direct statistical methods were used instead of ad-hoc approximations



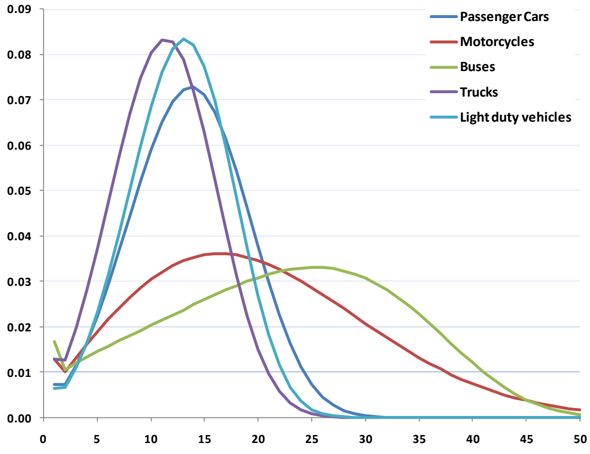


Figure 4-7: Results of the estimated survival curves and scrapping rates for the different vehicle types in Germany

An attempt of a comparison is given in the figure below for passenger cars in France. Although the FLEETS curve has been estimated using data from Germany, it follows the actual data better than the lifetime function of the TREMOVE.

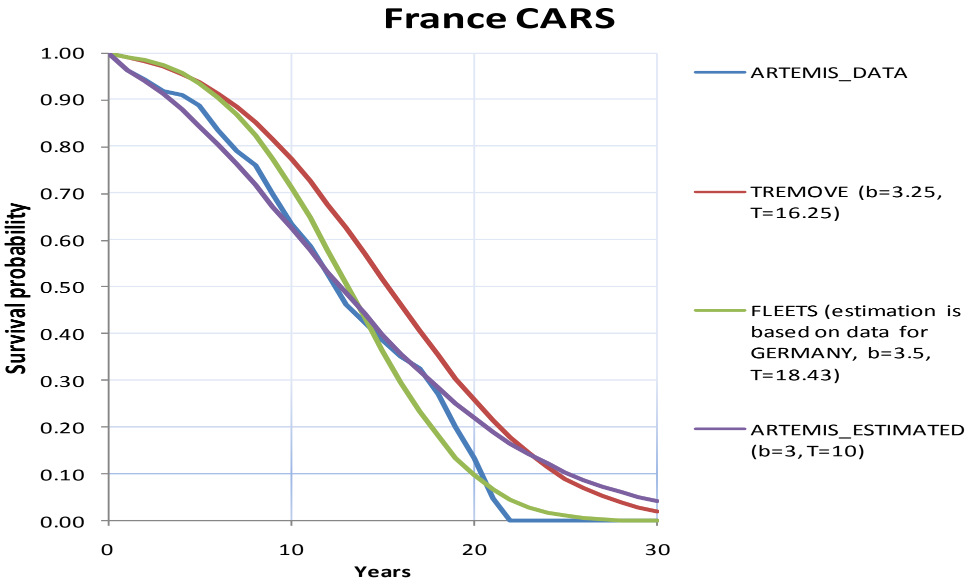


Figure 4-8: Comparison of lifetime functions of FLEETS and the ones used in ARTEMIS and TREMOVE

In comparison with the ad-hoc estimation it can be seen that the FLEETS project by using direct statistical methods displays lower absolute error, especially in the later years. Finally Table 4-5 displays in an aggregate form the estimated lifetime functions and their parameters obtained in the FLEETS project using data for Germany.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
B	3.752580	0.127444	29.44493	0.0000
T	11.90511	0.344965	34.51109	0.0000

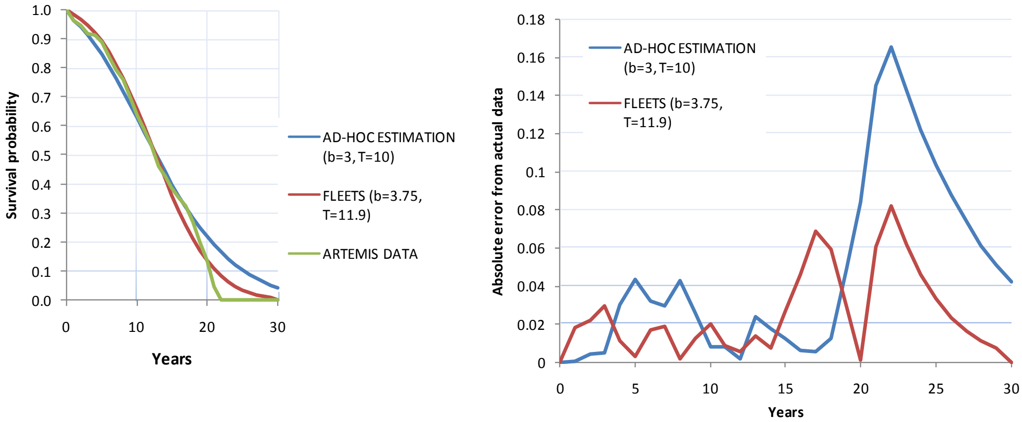


Figure 4-9: Comparison of the passenger cars lifetime function between FLEETS and ad-hoc estimation for FRANCE (using data from the ARTEMIS project)

Table 4-5: Overview of the obtained life time functions and their parameters (Germany)

PASSENGER CARS

$$\varphi(k)=\exp\left[-\left(\frac{k+b}{T}\right)^{b}\right];\varphi(0)=1$$

	Coefficient	Std. Error	t-Statistic	Prob.
B	3.490394	0.016736	208.5564	0.0000
T	18.43489	0.024116	764.4182	0.0000

TWO WHEELERS

$$\varphi(k)=\exp\left[-\left(\frac{k+b}{T}\right)^{b}\right];\varphi(0)=1$$

	Coefficient	Std. Error	t-Statistic	Prob.
B	2.101381	0.012820	163.9165	0.0000
T	24.56400	0.071218	344.9140	0.0000
FILTER_1989-1994	-0.086336	0.008104	-10.65291	0.0000

BUSES

$$\varphi(k)=\exp\left[-\left(\frac{k+\left(h_1+h_2\cdot k\right)}{T}\right)^{\left(h_1+h_2\cdot k\right)}\right];\varphi(0)=1$$

	Coefficient	Std. Error	t-Statistic	Prob.
H(1)	1.698018	0.080206	21.17070	0.0000
H(2)	0.030591	0.014619	2.092611	0.0378
T	28.99423	0.985381	29.42439	0.0000

LIGHT DUTY VEHICLES

$$\varphi(k)=\exp\left[-\left(\frac{k+\left(h_1e^{h_2\cdot k}\right)}{T}\right)^{\left(h_1e^{h_2\cdot k}\right)}\right];\varphi(0)=1$$

	Coefficient	Std. Error	t-Statistic	Prob.
H(1)	3.498560	0.260080	13.45188	0.0000
H(2)	-0.024968	0.005169	-4.830016	0.0000
T	15.33555	0.086397	177.5004	0.0000

HEAVY DUTY TRUCKS

$$\varphi(k)=\exp\left[-\left(\frac{k+\left(h_1e^{h_2\cdot k}\right)}{T}\right)^{\left(h_1e^{h_2\cdot k}\right)}\right];\varphi(0)=1$$

	Coefficient	Std. Error	t-Statistic	Prob.
H(1)	2.931193	0.272243	10.76684	0.0000
H(2)	-0.016694	0.006329	-2.637554	0.0092
T	17.38097	0.163947	106.0158	0.0000

5 Historical data availability

5.1 Model Requirements

5.1.1 Road transport

Both COPERT and TREMOVE include a detailed list of vehicle categories /technologies which have been defined by the legislation in Europe. The tables with the detailed category and technology classification, together with the implementation years of each technology are given in Annex I. In total, COPERT 4 includes 223 individual vehicle descriptions that need to be annually calculated for the 35 years of time series included in this work.

In addition to size of the vehicle stock, which by itself is a very important figure, activity data need to be collected in order to allow the calculation of total emissions. The main activity data to be collected include the total mileage driven per year and per vehicle category, the share of mileage driven in urban, rural and highway road networks and the mean travelling speeds in these conditions.

This section describes the sources of data that were collected in the framework of the FLEETS project to develop a consistent dataset of activity data. The actual method used is not presented, as this can be found in the final FLEETS report (Ntziachristos et al., 2008).

5.1.2 Non-road transport modes

A less detailed category classification is required by TREMOVE for the non-road transport modes.

For aviation the required classification is into air distance travelled rather than aircraft type. Five air distance classes are specified: (i) up to 500 km, (ii) 500-1000 km, (iii) 1000-1500 km, (iv) 1500-2000 km and (v) more than 2000 km. The activity data required include total passenger-km over the entire flight, as well as during LTO (Landing and Take-Off) and cruise.

For inland shipping, three main vessel categories are identified, further distinguished into tonnage classes. The vessel population is not necessary; however activity data on vessel-km and ton-km are needed for the emissions calculations.

Twenty-four vessel types are included in maritime shipping. The activity data needed include vessel-km, which are distinguished into three types of activity: (i) sea cruising, (ii) port and (iii) manoeuvring. The vessel population is also required.

A larger number of activity data has be collected for railways transport. These include train-km, ton-km, passenger-km, average age and sulphur content of fuel. There are four main train categories, which are further distinguished into diesel and electric trains.

5.2 Data detailing/quality requirements

Not all data require the same amount of detail in their description, because their end effect on total emission estimates varies. Obviously, the total number of vehicles is of particular importance as emissions are directly proportional to the number of vehicles in circulation. The total vehicle number is a figure which is rather well known to public authorities, since they keep a register for each vehicle circulating in the country. These figures are also reported to EUROSTAT per vehicle category. One issue related to the size of the fleet is the extent to which some vehicles are registered but are not used during the year. These, despite they are included in the total fleet, are negligibly contributing to total emissions. The exact number of these vehicles is not an easy figure to estimate because it depends on the driving habits of particular drivers, the existence or not of scrappage incentives, taxation as a function of vehicle age, etc. Most of the times, targeted surveys are required. Such statistics are available for some countries (e.g. Cyprus, Germany, UK) while this is more difficult to estimate for others (e.g. France).

The second important element in the analysis is the classification of vehicles to different technology levels. Emission levels of vehicles regulated by different emission standards may differ by several percentage units and this has direct implications to the total emission calculations. For a given year considered, the exact technology classification is basically inherited from the previous year. New vehicle registrations will comply with the emission standard applicable to the particular year and this will modify the percentage contribution of each technology class. There are two issues that need to be considered in this analysis. The first is the new registrations of (imported) used vehicles which may be of various emission standards. This is mostly an issue for less developed countries, due to the lower cost of imported vehicles. The second is the extent and the technology level of vehicles scrapped each year, which again will have an effect on the technology structure. The exact technology classification requires the development of lifetime functions, which are discussed in chapter 5.5 of this report.

The vehicle distinction to fuel use is also a very important element in estimating total emissions. This is a rather well-known figure as vehicle registration includes the type of fuel used. Therefore, the same criteria as with total vehicle number also apply in this case. On the other hand, the distinction of passenger cars to capacity classes and the distinction of heavy duty vehicles to weight classes are important mainly for the correct estimation of CO_2 emissions, which directly increase with size. With regard to conventional pollutants, the engine capacity distinction for passenger cars is not of particular importance as there is no straightforward function of emission rate with engine size. For heavy-duty vehicles the distinction to weight classes is more important since, in this vehicle category, engines rather than vehicles are type-approved. Since larger vehicles require more energy and since engines are type-approved on a per unit energy basis, the emission level is a direct function of vehicle size. Therefore, a detailed distinction of heavy duty vehicles to different classes is required to obtain a better estimate of their emissions.

Of equal importance to total fleet and vehicle allocation to different technologies is the annual mileage driven by each vehicle. Again, total emissions are directly proportional to the total distance travelled in one year. There are not always detailed statistics available to estimate the annual mileage driven. However, large errors in the estimation can be avoided because mileage is usually the tuning parameter to match the statistical with the calculated fuel consumption. One important element of the equation is the mileage vs. age function. It is generally known that the mileage driven each year drops as the vehicle age increases. This has an impact on the relevant contribution of old vs. more recent vehicle technologies. Such figures can be obtained from inspection and maintenance records available to each country.

The mean driving speed and the mileage allocation to different road networks are rather of secondary importance in the calculation of total emissions. This is not to say that emissions do not significantly depend on speed. Rather, the speed range variation expected, in particular, for rural and highway driving is not expected to lead to significant variation of the emission levels at such driving conditions. For urban driving, speed may have a more significant influence due to the higher dynamics involved in urban driving which affect the emission performance. Therefore, the urban driving speed needs to be estimated more accurately than urban or highway speeds.

Table 5-1 provides a summary of this discussion. The quality indicator in the availability of statistics refers to the 'average' country. It is obvious that the actual availability will differ from country to country.

Table 5-1: Importance and availability of statistics of different parameters

Parameter	Importance	Availability of statistics	Notes /Particular Issues
Total number of vehicles per class	↑	👍	Question is the scooter and mopeds registration availability
Distinction of vehicle to fuel used	↑	👍	Question is the availability of records for vehicles retrofitted for alternative fuel use
Distribution of cars/motorcycles to engine classes	→	☞	Not important for conventional pollutants, more important for CO2 emission estimates
Distribution of heavy duty vehicles to weight classes	↑	☞	Vehicle size important both for conventional pollutant and CO2 emissions
Distinction of vehicles to technology level	↑	☞	Imported, second-hand cars and scrappage rates are an issue
Annual mileage driven	↑	👍	Can be estimated from total fuel consumption. The effect of mileage with age requires attention.
Urban driving speed	→	☞	Affects the emission factors
Rural, highway driving speeds	↓	☞	Little affect the emission factors, within their expected range of variation
Mileage share in different driving modes	↓	☞	Little affect emissions, within their expected range of variation

5.3 International Organizations

5.3.1 Eurostat data

Eurostat is a source of complete data series but on an aggregated level. In principle, Eurostat (http://epp.eurostat.ec.europa.eu/portal/page?_pageid=0,1136228,0_45572945&_dad=portal&_schema=PORTAL) only includes total vehicle numbers and new registrations, distinguished per vehicle category (passenger cars, heavy duty vehicles, etc.) but contains no technological distinction. It also contains fuel consumption in road transport, distinguished per fuel type. This general picture may vary, depending on the country considered. Table 5-2 provides a summary of this information.

5.3.2 ACEA Statistics

The European Automobile Manufacturers' Association (ACEA) is also a source of information as it contains updated information of total number, registration and deregistration per vehicle category, and fuel type.

Table 5-2: Summary of statistical information provided by EUROSTAT

	AUT	**BEL**	**DK**	**FIN**	**FR**	**GER**	**GRE**	**IRL**
Population*	x (1989-2004)	x (1970-2004)	x (1970-2002)	x (1989-2004)	x (1970-2003)	x (1970-2003)	x (1970-2003)	x (1970-2004)
New registrations**	x (1989-2004)	x (1970-2004)	x (1970-2002)	x (1989-2004)	x (1970-2003)	x (1970-2003)	x (1970-2003)	x (1970-2004)
Fuel consumption (total)	x (1985-2004)	x (1985-2004)	x (1985-2004)	x (1985-2004)	x (1985-2004)	x (1985-2004)	x (1985-2004)	x (1985-2004)
	IT	**L**	**NL**	**POR**	**ESP**	**SWE**	**UK**	**BUL**
Population*	x (1970-2002)	x (1970-2001)	x (1970-2004)	x (1970-2002)	x (1970-2004)	x (1989-2004)	x (1970-2004)	
New registrations**	x (1970-2002)	x (1970-2001)	x (1970-2004)	x (1970-2002)	x (1970-2002)	x (1989-2004)	x (1970-2004)	
Fuel consumption (total)	x (1985-2004)	x (1985-2004)	x (1985-2004)	x (1985-2004)	x (1985-2004)	x (1985-2004)	x (1985-2004)	x (1990-2004)
	TCH	**EST**	**HUN**	**LET**	**LIT**	**POL**	**ROM**	**SLV**
Population*	x (1990-2003)	x (1990-2004)	x (1970-2004)	x (1970-2004)	x (1970-2004)	x (1970-2004)		x (1990-2004)
New registrations**	x (2003)	x (1992-2004)	x (1990-2004)	x (1995-2004)	x (1995-2004)	x (1990-2004)		x (1993-2004)
Fuel consumption (total)	x (1990-2004)	x (1990-2004)	x (1990-2004)	x (1990-2004)	x (1990-2004)	x (1990-2004)	x (1990-2004)	x (1990-2004)
	SLO	**CYP**	**MAL**	**NOR**	**CRO**	**TUR**		
Population*	x (1970-2004)	x (1990-2004)	x (1990-2002)	x (1988-2000)				
New registrations**	x (1992-2004)	x (1990-2004)	x (1990-2002)	x (1988-2000)				
Fuel consumption (total)	x (1990-2004)	x (1990-2004)	x (1990-2004)	x (1990-2004)	x (1990-2004)	x (1990-2004)		

* Per vehicle type. Few data by fuel.

** Passenger cars and motorcycles. Few data on lorries and buses.

Table 5-3a: Summary of statistical information provided by ACEA (Part A)

	AUT	BEL	DK	FIN	FR	GER	GRE	IRL	IT
					Available data				
Population	x (2000-2006)	x (2000-2006)	x (2000-2006)	x (2000-2006)	x (2000-2006)	x (2000-2006)	x (2000-2006)	x (2000-2006)	x (2000-2006)
New registrations (by vehicle type)	x (2001-2006)	x (2001-2006)	x (2001-2006)	x (2001-2006)	x (2001-2006)	x (2001-2006)	x (2001-2006)	x (2001-2006)	x (2001-2006)
Deregistrations (only total vehicles)	x (1995-2005)	x (1991-2005)	x (2001-2005)	x (1992-2005)		x (1991-2005)	x (1991-2003)	x (1991-2002)	x (1991-2005)
Vehicles by age	x (2005)	x (2005)	x (2005)	x (2005)	x (2005)	x (2005)	x (2005)		x (2005)
					Level of aggregation				
Total	x	x	x	x	x	x	x	x	x
Vehicle type	x	x	x	x	x	x	x	x	x
Fuel (only passenger cars)	x (1993-2005)	x (1991-2005)	x (2001-2005)	x (1993-2005)	x (1991-2005)	x (1993-2005)	x (1994-2005)	x (1992-2005)	x (1991-2005)

Table 5-3b: Summary of statistical information provided by ACEA (Part B)

	L	NL	POR	ESP	SWE	UK	BUL	TCH	EST
					Available data				
Population		x (2000-2006)	x (2000-2006)	x (2000-2006)	x (2000-2006)	x (2000-2006)		x (2000-2006)	
New registrations (by vehicle type)	x (2001-2006)	x (2001-2006)	x (2001-2006)	x (2001-2006)	x (2001-2006)	x (2001-2006)	x (2006)	x (2003-2006)	x (2003-2006)
Deregistrations (only total vehicles)		x (1996-2005)		x (1991-2005)	x (1991-2005)				
Vehicles by age	x (2005)	x (2005)	x (2005)	x (2005)	x (2005)	x (2005)			
					Level of aggregation				
Total	x	x	x	x	x	x	x	x	x
Vehicle type	x	x	x	x	x	x	x	x	x
Fuel (only passenger cars)		x (1991-2005)	x (2003)	x (1991-2005)	x (1991-2005)	x (1991-2005)		x (2005)	

Table 5-3c: Summary of statistical information provided by ACEA (Part C)

	HUN	LET	LIT	POL	ROM	SLV	SLO	CH	NOR
					Available data				
Population		x (2000-2006)		x (2000-2006)					
New registrations (by vehicle type)	x (2003-2006)	x (2003-2006)	x (2003-2006)	x (2003-2006)	x (2006)	x (2003-2006)	x (2003-2006)	x (2001-2006)	x (2001-2006)
Deregistrations (only total vehicles)		x (2002-2005)							
Vehicles by age									
					Level of aggregation				
Total	x	x	x	x	x	x	x	x	x
Vehicle type	x	x	x	x	x	x	x	x	x
Fuel (only passenger cars)									

5.3.3 AAA/CBD Databases

In addition to the above, the AAA database provides data on new registrations of passenger cars for 2000 and 2005. Data for 2000 are aggregated per vehicle manufacturer and not by country. 2005 data are available for each EU15 and include information on fuel type and engine size.

Further information on newly registered passenger cars per fuel type and engine size for the years 2000-2004 were extracted from the central CO_2 monitoring Database of the European Commission for each EU15 member state.

5.3.4 International Union of Public Transport

The public transport statistics report including figures on the urban bus fleet in the EU has been made available to the consortium. Data include information on urban buses circulating in cities of over 100,000 inhabitants around Europe, using a sample of vehicles from 25 member states (EU27 except Cyprus that has no urban bus fleet and Slovakia). Year 2005 is considered as the reference. The report does not contain total fleet values but only technology and configuration characteristics of the different busses. The information available includes distinction to fuel and drive-train technologies, Euro standards, accessibility features, age of fleet and some miscellaneous information. These data can be used to cross-check information generated within the project, rather as input information.

5.3.5 Eurocontrol

Eurocontrol was approached by the coordinator of the project with the request to deliver the detailed data they have on flight activities in all European countries. A specific meeting was set at Eurocontrol offices in Brussels. Indeed, Eurocontrol possesses detailed data of each flight from and to Europe, including actual distance travelled and type of aircraft. They also collect detailed information on fuel used for international and domestic flights. Based on this information and using updated ICAO emission factors, Eurocontrol have set a web-application where detailed calculation of emissions and consumption per country can be performed, using the Tier 3 methodology of the EMEP/Corinair Emission Inventory Guidebook. Figure 5-1 shows an example of the interface of the Eurocontrol Pagoda application for the case of Greece and years 2005-2007.

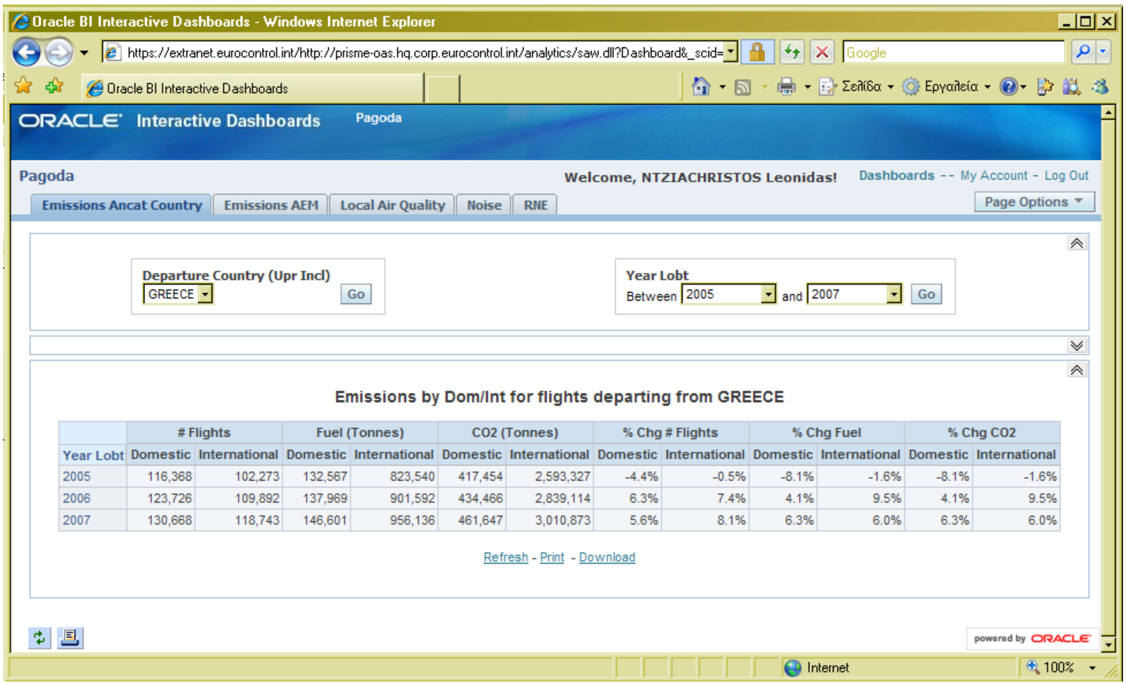


Figure 5-1: Example of the Eurocontrol Pagoda interface

Although Eurocontrol have not provided actual data to our project, they have confirmed their willingness to allow access to the Pagoda application website, which can then be used to extract all relevant information on any level of detail. In principle, the only information which is considered confidential is the aircraft type used for particular individual flights, as this is considered as an element of competition. Eurocontrol has requested a specific meeting with the European Commission and other stakeholders (e.g. EEA, TFEI, etc.) in order to clarify access rights and detail of the data delivery.

5.4 Independent Sources

5.4.1 Conference organized by KTI

In 2002, KTI (a partner to our consortium) organized a conference aiming at collecting information of road-transport fleets from new (at that time in the process of accession) member states. The information collected at that conference is summarized in Table 5-4.

5.4.2 IIASA/Met.No/ENTEC Report on maritime emissions

In 2006, a consortium of IIASA. Met.No and ENTEC compiled a report on ship emissions, in the framework of the revision of the National Emissions Ceilings Directive. In the report, vessel movement data for the year 2000 are available for EU27, Croatia and Turkey. The data are further distinguished into passenger and cargo ships, national and international ships (by flag). The primary information is not available n the report but the consortium expects that this will be made available through IIASA.

Table 5-4: Summary of statistical information collected at the KTI conference

	TCH	EST	HUN	LIT	LET	MAL	POL	SLV
Years	**1993-2005**	**1990-2006**	**2000-2005**	**1995-2005**	**1997-2006**	**1998-2006**	**1999-2004**	**1990-2005**
				Available data				
Population	x	x	x	x	x	x	x	x
New registrations			x (1990-2005)	x (2000-2005)				
Mileage (only few data)	x (1996-1998)		x (2002)	x (2004)	x (2004)	x (2000)	x (2002)	
Other activity data			shares					
				Level of aggregation				
Total	x	x	x	x	x	x	x	x
Vehicle type	x	x	x	x	x	x	x	x
Fuel			x		x	x		
Technology			x					

5.4.3 ARTEMIS information

The EU 5FP Artemis includes information related to activity statistics from different countries. These include travelling speeds, driving share in different road networks, average trip distance, etc. This will be summarized together with information from the national sources.

5.4.4 National data

A wealth of data became available to the consortium by contacting the national experts in all countries. All countries reported their available data except of Bulgaria, Croatia and Malta. The range of information submitted ranged from complete data series over a number of years, including the full technological split of vehicles (e.g. Denmark, France, Spain, Switzerland, Norway and others) to some aggregated data for only a number of years (e.g. Greece, Romania and others). Also, the quality of data ranged from fully consistent information related to stock development, registrations and deregistrations to inconsistent data related to the fleet size and the fleet replacement.

One issue that needs to be clarified is that national information was not always in the structure requested by the consortium. One typical example is the Netherlands, where no information on the classification of HDVs to different GVWs was available. This was confirmed by both the responsible inventorying agency in the Netherlands (Anco Hoen – MNP) and the statistics authority in the Netherlands (Hermine Molnar-in 't Veld – CBS). Instead, only the number of lorries (rigid trucks), tractors (articulated truck power movers), and the loading capacity and the weight of semi-trailers was available. In this case, the weight allocation of trucks had to be devised based on the available data. The classification of articulated vehicles components according to their weight is shown in Figure 5-2, with data corresponding to 2001. The figure shows that 86% of the tractors have an empty weight between 6-8 t. Similarly, the weight of 75% of the empty semi-trailers is between 6-9 t. Hence, it was considered that the combined weight of the empty semi-trailer and the tractor was 16 t. This weight was then added to the loading capacity to deduce the articulated vehicles classification based on their GVW in the Netherlands. Similar examples of reallocations and processing of the available information has also been made in different countries.

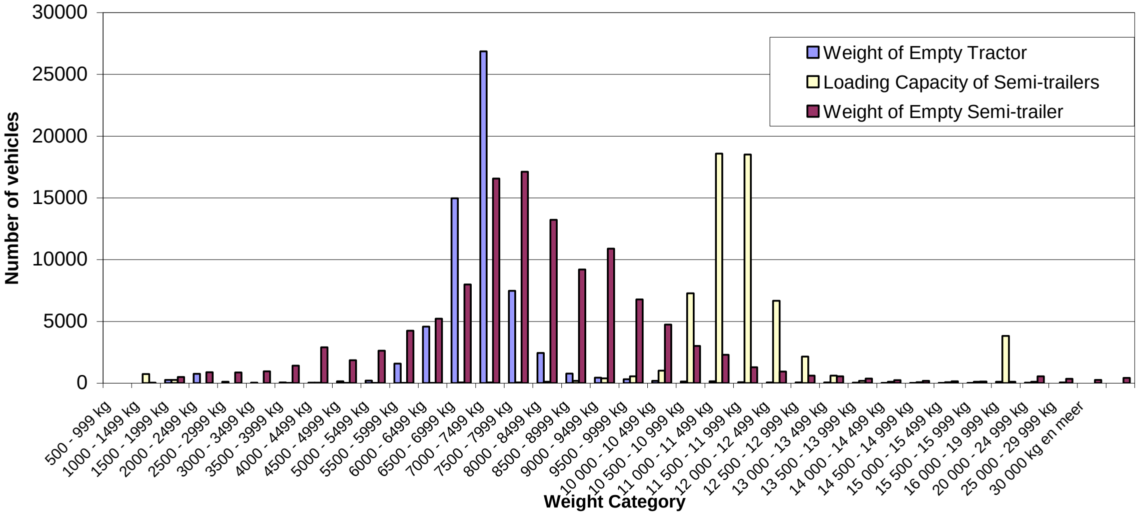


Figure 5-2: Articulated vehicle components weight in the Netherlands (data from CBS corresponding to 2001).

5.4.5 Data Summary

A summary of the national data submitted in this way are presented in Table 5-5 (split to part-A and part-B due to space limitations). These tables are a composite of all the information that we managed to collect from all available sources (national, international and specific), after consultation within the study team and with the national experts. This is both primary information and information that the study team had to streamline before including it in the database. The table, although tries to present an overall summary fails to present all details for all countries considered. For example, data for some particular vehicle categories may be missing or being beyond the range of years shown in the tables. In addition, some data were received at the last minute and may not be fully reflected. Therefore, exact details of the datasets can be found in the electronic databases.

As a summary, the data that were made available to the consortium range from a few years and sparse information to complete data series including full technological distinction from a number of years. In general, total fleets distinguished per vehicle category were available in most countries and new registrations for passenger cars were also available. Technology splits and the distinction of heavy duty vehicles in the different categories. The information collected for non-road modes is more scarce and less countries have delivered information. Off-road data are not further commented but are summarized in the DVD containing all data collected in the project.

5.5 Methodology and Data Processing

5.5.1 Data screening and reconciliation

The main problem in developing a homogenized dataset involves the use of data and other information collected by the different sources and synthesises it in order to produce a full and consistent data set for all the items that are critical for model work and other analytical purposes.

The data collected from the different sources consist of time series covering the broad areas of fuel consumption (gasoline, diesel and LPG), vehicle population by sector and technology, new registrations by sector, de-registrations (scrappage) by sector, total vehicle kilometres by sector, and technology and annual mileage by sector and technology. Although all the countries of Europe are covered to some extent, considerable gaps exist in many of them for a number of years and concepts. Furthermore it is clear that a lot of the information included constitutes essentially what is usually termed as "soft data" i.e. results of estimates of varying degrees of accuracy produced through different procedures and methodologies involving varying degrees of rigour. It can therefore be reasonably assumed that such data is characterised by a considerable amount of uncertainty. In addition, very often the data appears to be "inconsistent" with regard to key identities as well as generally accepted technological, legal and socio-economic hypotheses. In some cases the evolution of some quantities over time also displays erratic patterns casting doubts on its credibility.

A detailed methodology was developed to streamline the data and to develop a consistent dataset. The details of the methodology may be found in the final report of the FLEETS project (Ntziachristos et al., 2008). In this report only the results of this reconciliation methodology are given for review of the different stakeholders.

Table 5-5a: Summary of national data submitted for road-transport (part A)

	AT	BE	BG	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HR	HU	IE
Population	x (1990-2005)	x (1991-2005)	x (1989-2005)	x (1990-2006)	x (1995-2006)	x (1990, 1993-2006)	x (1995-2005)	x (1985-2005)	x (1999-2005)	x (1990-2005)	x (1989-2005)	x (1990-2006)	x (1990-2005)	x (1998-2005)	x (2000-2005)	x (1990-2005)
Vehicle category	x	x (1991-2005)	x (2005)	x	x	x	x	x	x	x	x	x	x	x	x	x
Fuel	x	x (1996-2005)	x (2005)	x	x (2000-2006)	x	x	x	x	x	x (1990, 1999-2005)	x	x	x (2000, 2005)	x	x
Size	x	x (1996-2005)	x (2005)	x	x (2000)	x	x	x	x	x	x (1990, 1999-2005)	x	x	x (2005)	x	x
Technology	x	x (1996-2005)	x (2005)	x	x (2000)	x (2002-2005)	x	x	x	x	x (1990, 2001, 2005)	x	x (1995, 2000)	x (2005)	x	x
New registrations	x (1999-2004)	x (2001-2006)		x (1990-2006)	x (1987-2006)	x (2003-2006)	x (1991-2006)	x (1979-2006) PC & PTW	x (various years)	x (1985-2006)	x (1996-2004)	x (1975, 1979-2006)	x (1985-2006)	x (1998, 2005)	x (2000-2005)	x (1990-2006)
Vehicle category	x (only PCs)			x	x	x		x (2001-2006)	x	x (2001-2006)	x	x	x	x	x	x
Fuel	x (only PCs)	x (2001-2006)		x	x (1990-2006)		x (2002-2006)	x (2001-2006)	x	x (1993-2002)	x	x	x (1993-2006)	x (1999, 2000)	x	x (1990-2004, only PCs)
Size	x (only PCs)								x				x (1995-2006)		x	
Technology															x	
Mileage	x (1990-2005)	x (2000-2005)		x (1990-2006)	x (2005, only HDV)	x (2002-2005)	x (1995-2005)	x (1985-2005)	x (1999-2005)	x (1990-2005)	x (1990, 2000, 2005)	x (1995, 2000, 2005)	x (2005)			x (1990-2005)
Fuel data	x (1985-2006)	x (1985-2004)		x (1970-2006)	x (1980-2006)	x (1993-2006)	x (1985-2005)	x (1985-2005)	x (1990-2005)	x (1985-2005)	x (1985-2004)	x (1985-2005)	x (1985-2004)	x (1991-2004)	x (1990-2004)	x (1985-2005)
Other activity data	shares, speeds			speeds, shares, load	occupancy rates (1985-2005)	speeds, shares, load		speeds, shares	shares, speeds, loads	shares, speeds, loads	shares, speeds, load	shares, speeds, loads	shares, speeds			shares, speeds, loads

Table 5-5b: Summary of national data submitted for road-transport (part B)

	IT	LT	LU	LV	MT	NL	NO	PL	PT	RO	SE	SI	SK	TR	UK
Population	x (1995-2005)	x (1990-2006)	x (1990-2005)	x (1990-2006)	x (1990-2006)	x (1991-2006)	x (1980, 1986-2005)	x (1990-2004)	x (1990-2005)	x (1990-2006)	x (1980-2006)	x (1989-2005)	x (1990-2005)	x (1995-2006)	x (1995-2005)
Vehicle category	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Fuel	x		x	x	x (1999, 2000, 2002)	x	x	x (1995-2004)	x	x (2005-2006)	x	x	x (1990, 2002-2005)	x (2000, 2005, only LDVs)	x
Size	x (1995, 2000-2005)	x	x	x	x (1999, 2000, 2002)	x	x	x (2000-2001)	x	x (2005-2006)	x	x (1997-2000, 2005)	x (1990, 2002-2005)	x (2004, only gasoline PCs)	x
Technology	x (1995, 2000-2005)	x (age distributions)	x	x	Adopted from Cyprus	x (2001-2006)	x	x (2000-2001)	x	x (2005-2006)	x	x (2000, 2005)	x (1990, 2002-2005)	x (2004, only gasoline PCs)	x (2000, 2005)
New registrations	x (2001-2006)		x (1998-2006)	x (1995-2004)		x (1975-2006)	x (1988-2006)	x (1990-2004)	x (2001-2006)	x (1997-2006)	x (1989-2004)	x (1993-2006)	x (1996-2004)	x (1994-2006)	x (1990-2006)
Vehicle category	x		x	x		x	x (2001-2006)	x	x	x (only PCs)	x	x	x	x	x (2001-2006)
Fuel			x (2002-2006)	x		x (2002-2006)		x (1995-2004)			x	x (1993-2002, only PCs)	x		x (1992-2004, only PCs)
Size												x (1997-2002, only PCs)			x (1996-2004, only PCs)
Technology															
Mileage	x (1995, 2000-2005)	x (2005-2006)		x (1990-2006)		x (2005)	x (1980, 1986-2005)	x (2000-2001)			x (1980-2006)		x (1990, 2002-2005)		x (2000, 2005)
Fuel data	x (1985-2004)	x (1990-2006)	x (1985-2004)	x (1990-2006)	x (1990-2005)	x (1985-2004)	x (1986-2005)	x (1990-2005)	x (1985-2005)	x (1990-2006)	x (1980-2006)	x (1990-2004)	x (1990-2006)	x (1990-2004)	x (1985-2005)
Other activity data	shares, speeds, loads	shares, speeds, loads		shares, speeds			shares, speeds, loads	speeds, shares			speeds	speeds	shares, speeds		shares, speeds, loads

Table 5-6a: Summary of national data submitted for non-road transport modes (part A)

	AT	BE	BG	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HR	HU	IE
Air	**x** (1990-2005)		**x** (1990-2006)	**x** (2000-2005)	**x** (1980-2005)	**x** (1993-2006)	**x** (1980-2005)		**x** (2001-2005)							**x** (1990-2005)
Type of data	Pass-km		Pass-km	Fuel cons, number of passengers	Number of passengers, LTOs	Number of passengers, LTOs, Pass-km	Number of passengers		Number of passengers, Pass-km							Energy cons, number of LTOs
Level of aggregation	Total		Total	Total	Total	Total	Total (only international)		Total							Domestic / International
Rail	**x** (1990-2005)		**x** (1996-2004)			**x** (1993-2006)	**x** (1985-2005)		**x** (1992-2006)		**x** (1995, 2000, 2005)					**x** (1996-2005)
Type of data	Train-km, Ton-km, load factors		Train-km			Population, Train-km, Ton-km, Pass-km	Ton-km, Pass-km		Population, Train-km, Ton-km, Pass-km		Population, Train-km, Ton-km, Pass-km					Energy consumption
Level of aggregation	Total		Passenger/ Freight, train type, fuel			Passenger/ Freight, train type, fuel	Passenger/ Freight, train type, fuel		Passenger/ Freight, train type, fuel		Passenger/ Freight					Total
Inland shipping	**x** (1990-2005)		**x** (1990-2006)			**x** (1997-2006)	**x** (1960-2006)									**x** (1990-2005)
Type of data	Ton-km, load factors, fuel consumption		Vessel-km, Ton-km, population			Ton-km, Pass-km	Population									Energy cons, sulphur content
Level of aggregation	Total		Vessel type			Vessel type (for Ton-km only)	Passenger/ Freight, vessel type									Total
Maritime			**x** (1990-2006)		**x** (1980-2005)		**x** (1980-2006)		**x** (2002-2006)							
Type of data			Vessel-km, Ton-km, population		Vessels called		Population		Population							
Level of aggregation			Vessel type		Passenger/ Freight,vessel type (2005)		Passenger/ Freight, vessel type		Passenger/ Freight, vessel type							

Table 5-6b: Summary of national data submitted for non-road transport modes (part B)

	IT	LT	LU	LV	MT	NL	NO	PL	PT	RO	SE	SI	SK	TR	UK
Air		x (1990-2006)	x (1990, 2000-2006)	x (2003-2005)	x (1998-2006)	x (1990-2004)		x (2004-2006)		x (1990-2005)			x (2003-2005)	x (2000-2005)	
Type of data		Passengers, LTOs, Pass-km, Ton-km	Passengers, LTOs, freight carried	Pass-km	Number of passengers, LTOs	Fuel cons, number of LTOs		Number of passengers, LTOs		Pass-km			Pass-km	Pass-km	
Level of aggregation		Total	Total	Total	Total	Activity		Total		Total			Total	Total	
Rail		x (1991-2006)	x (1990, 2000-2006)	x (1980-2005)		x (2000-2005)		x (1990-2004)		x (1991-2005)			x (1999-2005)	x (2005-2006)	x (1990, 2000, 2005)
Type of data		Population, Train-km, Ton-km, Pass-km	Pass-km, Ton-km	Ton-km		Fuel consumption		Population, Train-km, Ton-km		Population, sulphur content			Population, Ton-km, Pass-km	Train-km, Ton-km, Pass-km	Train-km, Ton-km, average age
Level of aggregation		Passenger/ Freight, fuel	Total	Total		Passenger/ Freight, fuel		Passenger/ Freight, train type, fuel		Fuel			Total	Passenger/ Freight, train type, fuel	Passenger/ Freight
Inland shipping		x (1991-2006)				x (1990-2004)		x (2005-2006)		x (1991-2005)			x (2002-2006)		x (2000, 2005)
Type of data		Ton-km, Population				Fuel consumption		Ton-km		Population			Ton-km		Ton-km
Level of aggregation		Vessel type (for population only)				Total		Total		Passenger/ Freight, vessel type			Total		Vessel type
Maritime		x (2000-2006)	x (2000-2006)		x (1996-2004)	x (1990-2004)				x (1991-2005)				x (2005-2006)	x (2000, 2005)
Type of data		Population	Population		Population	Fuel consumption				Population				Population	Population
Level of aggregation		Vessel type	Vessel type		Fuel, activity	Fuel, activity				Vessel type				Passenger/ Freight,vessel type	Passenger/ Freight,vessel type

5.6 Results

5.6.1 Stock of vehicles

The vehicle stock per country that was developed based on the available statistical data is available on http://lat.eng.auth.gr/copert, under the "Data" menu item. This is open for review and commenting.

5.6.2 Annual mileage driven

Before presenting results on mileage there need to be given some definitions related to what annual mileage stands for, in terms of its use as input to emission inventories. According to the draft revised UNECE guidelines for reporting emissions (ECE/EB.AIR/WG.5/2008/6), Article 15 states: "For emissions from transport, Parties should calculate and report emissions consistent with national energy balances reported to Eurostat (the Statistical Office of the European Communities) or the International Energy Agency. For example, emissions from road vehicle transport should be attributed to the country where the fuel is sold to the end-user. Alternatively, a Party may report emissions from road vehicle transport calculated on the basis of national vehicle kilometres. If cross-border movement of fuel in or out of the geographic area of a Party accounts for a significant proportion of its emissions in a particular source category, as calculated on this basis, the Party should provide separate estimates to quantify the effect of such fuel transfer on the emissions from the source category concerned and on its total national emissions. The basis for the separate estimates should be clearly specified in the IIR. Any approach chosen should be used consistently across all years and pollutants."

The definition of "national vehicle kilometres" in the guidelines is equivocal. One could consider the vehicle kilometres driven by the national fleet despite which territory (country) these distances are driven. The other way of considering the term national vehicle kilometres would be only the vehicle-kilometres occurring within each country's territory both from the national fleet and due to international traffic. The first definition is consistent with the emission models in all countries (e.g. COPERT, TREMOD, EMV, etc.) because it is this (total) mileage that can be revealed by the vehicle statistic sources in each country. The second definition is more appropriate when emission models are combined with transport activity statistics models, e.g. models which estimate total veh-km within each territory. The mileage considered in this report is consistent with the first definition, i.e. total mileage driven per national fleet vehicle, regardless of where this mileage has been driven. This has been decided as national and international stock databases refer to the number of vehicles registered by each country and not the number of vehicle operating in each country. Using this definition, care has to be given when comparing data from activity models to the total veh.km calculated by the data presented in this report. It may occur that activity models refer only to the activity taking place in the territory of each country.

Ideally, the total mileage driven in each country should be proportional to the total fuel sold in the country. However, this is not always the case as, in several countries, there is significant 'tank tourism', i.e. vehicles are refuelled in a neighbouring country where fuel is cheaper and consume this fuel in the country where they are registered (or vice versa). Therefore, tank tourism between countries takes place whenever the price differences of fuels at the pump are high. As a consequence the fuel consumed in a country is not represented by the statistics which correspond to the fuel sold in the country. As a rule, only neighbouring countries are affected and the effect is stronger for diesel than for petrol due to the mainly diesel freight transport. The effect is known to a number of countries, causing several problems in energy balances and the allocation of emissions [234]. It is important to consider the extent of tank tourism when using the statistical fuel consumption to calibrate the activity level in each country, using the fuel consumption figures of each vehicle category. In countries where significant (positive or negative) tank tourism takes place, e.g. the fuel sold in the country is much less than what is actually consumed because the price is neighbouring countries is much cheaper, then one should allow for a margin between the statistical and the calculated fuel consumption.

Tank tourism is not a stable phenomenon but changes over time due to changes in the fuel prices and the transport volume. As a rule countries with more transit transport are more affected than those with little transit. For the year 2006 the countries potentially affected by tank tourism can be identified on the basis of the valid excise duties on fuels, see http://www.acea.be/files/2007ACEATaxGuidedef~Introduction.pdf and a summary of those is provided in Table 5-7.

Table 5-7: Major tank tourism between countries in Europe

Country	Diesel imports likely from	Gasoline imports likely from
AT		
BE	LU	LU
DE	AT,BE,NL,PL,HR,LU,DK,SL,SE	AT, PL, HR, LU, DK, SI
DK		SE
FI		SE, EE, LT, LV, PL
FR	ES, LU, BE	ES, LU
GR	BU	
HR	PL	
HU	BU, RO	BU, RO
IE		
IT	AT, GR, FR	AT
NL	BE, LU	
PT	ES	ESP
RO	BU	
SE	FI	
SK	PL	
UK	IE, FR	IE, FR

[2] http://ec.europa.eu/environment/climat/pdf/lux_nap_final.pdf
[3] http://www.umweltbundesamt.at/fileadmin/site/publikationen/REP0058.pdf
[4] http://www.statistics.gov.uk/downloads/theme_environment/transport_report.pdf

5.6.2.1 Mileage tuning

In many of the cases identified in the table the error associated with tank tourism is most likely too small to be worth considering it further. Small in this sense means that it is smaller than the usual uncertainties of the methods used to produce total mileage estimates. If to be considered further, the following values need to be compared:

- The statistical fuel consumption per fuel
- The calculated fuel consumption, derived on the basis of consumption factors multiplied by the total vehicle-kilometres

The most straightforward way to alter the calculated fuel consumption in order either to match the statistical one or to account for the tank tourism is to adjust the total mileage driven per vehicle category. This is a usual practice, since the stock size is usually known with good confidence, while total mileage is a more 'soft' parameter, i.e. it is bound to larger uncertainties. Therefore, mileage is usually tuned during the compilation of an emission inventory to provide the desired total fuel consumption.

No tuning of the mileage has been attempted in the data presented in this dataset. This is due to two reasons: First, data collected from national experts have, to a large extent, already been adjusted to account for differences in the statistical and calculated fuel consumption. The extent of matching the two has been left to the national experts who are aware of the effect of the problem in each country, and no additional correction has been attempted. The second reason is because we believe that results are more transparent in this way. Any calibration of the annual mileage to reach the statistical fuel consumption can also be attempted at wish, before using the data. This is an issue to discuss within the EC4MACS project.

5.6.2.2 Annual Mileage per Country

Table 5-8 shows the annual mileage collected for the different countries, based on the national data submitted. The table is split in two parts, Part A corresponding to passenger cars and Part B corresponding to all other vehicle categories. Only a few types have been included per category due to space limitations. The database collect detailed data for all types involved.

As regards the general trends, most of the countries report a falling annual mileage with vehicle age, as also discussed in the previous section. They also report a higher mileage driven by larger than smaller passenger cars. Finally, diesel cars are consistently shown to be driven by 50% to more than 100% more than gasoline ones. Most probably, the cheaper price and fuel consumption of diesel, as well as the most frequent use of diesel cars as company cars is the driving force of this distinction. A typical example is Greece where diesel passenger cars are banned from the two major cities (Athens and Thessaloniki) for pollution control. The only diesel cars allowed are Taxis, hence the average mileage is over 80 Mm per year.

With respect to the absolute values of annual mileage driven per year, there are some important differences between the countries. For example, a Euro 2 gasoline passenger car (1.4-2.0 l) is shown to be driven by some 11 Mm in Italy, Germany, Netherlands and Spain by up to 17,5 Mm in Denmark and 22 Mm in Ireland. In part, this is due to different urban and commuting conditions in each country. However, one cannot exclude part of the differences to be also attributable to the different annual mileage estimates in each country.

These differences are even more important in the case of light duty and heavy duty vehicles. For example, the mean annual mileage of a Euro 2 diesel light duty truck seems to range from ~12 Mm in Spain to 59 Mm in Ireland. This again may reflect differences in freight transport between the two countries. Small trucks may be used more often to deliver goods in the countryside of Ireland while vans maybe mostly used for urban freight transport in Spain. In another example, an articulated Euro II truck of 14-20 t seems to operate for ~20 Mm per year in Switzerland to 111 Mm in UK. Again, this may reveal a true difference in the operation vehicles in the countries concerned. However, such differences are rather large to expect on average for the total fleet and the estimation methods need to be clarified to understand them.

Table 5-8 only includes 16 countries (some additional countries submitted data at a very late stage to be included in this report – they can be found in the electronic database files). In order to facilitate emission calculation for the countries that submitted no information we assumed that the average mileage of these countries that submitted data is a good estimator for the unknown mileage driven in the rest of the countries. This is shown in Table 5-9 and includes the effects of vehicle size and fuel on the annual mileage driven.

Table 5-8a: Annual mileage per country, provided by the national sources. Part A: Passenger cars

Category	Type	Technology	Austria	Denmark	Cyprus	Finland	France	Belgium (Wal	Germany	Greece	Ireland	Italy	Netherlands	Norway	Spain	Sweden	Switzerland	UK
Passenger Cars	Gasoline <1,4 l	PRE ECE	4404	11037		2000			8692	1699		2500	8200			3504	1 069	
		ECE 15/00-01	4404	11037		3000				1747		2500	8200	13635			1627	
		ECE 15/02	4404	11037		5000	2010		5163	2022		2500	8200	13635		4446		
		ECE 15/03	4404	11037		8000	4443		6127	3761		2500	8200	13635	10797	7014	2 693	
		ECE 15/04	4404	11037		10000	6634	15394	7287	6309	18000	5500	8200	13635	10847	8189	4 252	9035
		Improved Conventional							6993				8200					
		Open Loop							7252	8638			8200			8873		
		PC Euro I - 91/441/EEC	11800	12828		13000	8824	15394	9082	8638	19000	7500	8200	13635	10779	9992	6 926	11400
		PC Euro II - 94/12/EEC	11800	17465		15000	10527	16716	10783	9585	20000	9000	11000	13635	10779	11373	11 581	14257
		PC Euro III - 98/69/EC Stage2000	11800	21983		22000	12474	16847	11603	10858	20000	10000	13500	13635	10779	16476	13 270	18043
		PC Euro IV - 98/69/EC Stage2005				22000	13934		12695	13103	20000	11000	21100		10779	15775	12 380	20683
		PC Euro V (post 2005)																
	Gasoline 1,4 - 2,0 l	PRE ECE	4404	11037		3000			8692	2310		3500	8200			3744	1 309	
		ECE 15/00-01	4404	11037		4000				2376		3500	8200	13635			2 011	
		ECE 15/02	4404	11037		6000	4360		5163	2750		3500	8200	13635		5424		
		ECE 15/03	4404	11037		9000	6793		6127	5115		3500	8200	13635	10774	6810	3 282	
		ECE 15/04	4404	11037		12000	8983	15394	7287	8580	19000	6500	8200	13635	10816	9005	5 198	9035
		Improved Conventional							6993				8200					
		Open Loop							7252	11748			8200			10217		
		PC Euro I - 91/441/EEC	11800	13691		15000	11173	17235	9082	11748	22000	8500	8200	13635	10711	11839	8 464	11400
		PC Euro II - 94/12/EEC	11800	17475		16000	12877	15394	10783	13035	22000	11000	11000	13635	10711	13895	14 172	14257
		PC Euro III - 98/69/EC Stage2000	11800	21861		24000	14824	17115	11603	14767	22000	12500	13500	13635	10711	17519	16 174	18043
		PC Euro IV - 98/69/EC Stage2005				25000	16284		12695	17820	22000	13000	21100		10711	16301	15 095	20683
		PC Euro V (post 2005)																
	Gasoline >2,0 l	PRE ECE	4404	11037		4000			8692	2472		4500	8200			3777	1 501	
		ECE 15/00-01	4404	11037		5000				2542		4500	8200	13635			2 343	
		ECE 15/02	4404	11037		6000	5358		5163	2943		4500	8200	13635		4462		
		ECE 15/03	4404	11037		10000	7792		6127	5473		4500	8200	13635	10762	7814	3 770	
		ECE 15/04	4404	11037		12000	9982	15394	7287	9181	19000	8000	8200	13635	10785	11148	5 994	9035
		PC Euro I - 91/441/EEC	11800	13587		17000	11442	15394	9082	12570	21000	10000	8200	13635	10660	13455	9 775	11400
		PC Euro II - 94/12/EEC	11800	17764		22000	13876	15394	10783	13947	22000	12000	11000	13635	10660	16473	16 451	14257
		PC Euro III - 98/69/EC Stage2000	11800	22039		25000	15822	15394	11603	15801	22000	13000	13500	13635	10660	20119	18 786	18043
		PC Euro IV - 98/69/EC Stage2005				29000	17282		12695	19067	22000	14000	21100		10659	19789	17 517	20683
		PC Euro V (post 2005)																
	Diesel <2,0 l	Conventional		21880		16000	12010	29967	10203	84152	30000	14000	15000	18166	17264	16179	9 100	8457
		PC Euro I - 91/441/EEC		26472		19000	14875	27708	12528	84152	30000	16000	15000	18166	17295	20051	18 359	10391
		PC Euro II - 94/12/EEC		34638		28000	16308	27708	17912	84152	31000	17500	20700	18166	17295	23573	23 848	12921
		PC Euro III - 98/69/EC Stage2000		43419		30000	17945	27708	22860	84152	31000	18500	24700	18166	17295	33772	24 914	18293
		PC Euro IV - 98/69/EC Stage2005				30000	19173		25773	84152	30000	19500	45900		17295	24642	17 196	
		PC Euro V (post 2005)																
	Diesel >2,0 l	Conventional		21880		20000	13051	42308	10203	84152	30000	15000	15000	18166		18532	9856	8457
		PC Euro I - 91/441/EEC		26935		22000	15916	40622	12528	84152	30000	17000	15000	18166		22929	20541	10391
		PC Euro II - 94/12/EEC		35215		30000	17349	27708	17912	84152	30000	18000	20700	18166		28703	26 656	12921
		PC Euro III - 98/69/EC Stage2000		43691		38000	18986	27708	22860	84152	31000	19000	24700	18166		40683	28 129	18293
		PC Euro IV - 98/69/EC Stage2005				40000	20214		25773	84152	31000	20000	45900			26239	19 342	
		PC Euro V (post 2005)																
	LPG	Conventional		11037			9291	27951		84152		17300	13300					
		PC Euro I - 91/441/EEC					14127	24630		84152		18000	13300					
		PC Euro II - 94/12/EEC					16545	24630		84152		18500	19900					
		PC Euro III - 98/69/EC Stage2000					19308	25464		84152		19500	23200					
		PC Euro IV - 98/69/EC Stage2005					21380	28440				20000	64400					
		PC Euro V (post 2005)																
	2-Stroke	Conventional				4000												
	Hybrid Gasoline <1,4 l	PC Euro IV - 98/69/EC Stage2005						17590					21100					
		PC Euro IV - 98/69/EC Stage2005						18290					21100					
		PC Euro IV - 98/69/EC Stage2005						24810					21100					

Table 5-8b: Annual mileage per country, provided by the national sources. Part B: Light and heavy duty vehicles and power two wheelers

Category	Type	Technology	Austria	Denmark	Cyprus	Finland	France	Belgium (Wal	Germany	Greece	Ireland	Italy	Netherlands	Norway	Spain	Sweden	Switzerland	UK
Light Duty Vehicles	Gasoline <3,5t	Conventional	22983	14797		8000	3433	7743	12640	19916	44000	9500	11300	13635	4965	7857	4 598	11738
		LD Euro I - 93/59/EEC	22983	14797		8000	10767	10037	15135	19916	44000	12500	11300	13635	4965	11055	11 147	16621
		LD Euro II - 96/69/EEC	22983	14797		10000	13469	10167	18414	19916	44000	13500	16300	13635	4965	14418	16 523	20681
		LD Euro III - 98/69/EC Stage2000	22983	14797		13000	15786	10189	27696	19916	44000	14500	22500	13635	4965	17368	18 104	28445
		LD Euro IV - 98/69/EC Stage2005				13000		10580	28698	19916	44000	15000	32500			15639	15 979	
		LD Euro V - 2008 Standards																
	Diesel <3,5 t	Conventional	18713	31047		13000	9780	11755	7672	19916	59000	15125	15000	16742	11910	11741	5 442	12474
		LD Euro I - 93/59/EEC	25033	31047		15000	18243	12434	15151	19916	59000	17500	15000	16742	11906	16949	11 609	15305
		LD Euro II - 96/69/EEC	25033	31047		16000	21361	12476	21415	19916	59000	18500	20000	16742	11906	19692	18 804	19044
		LD Euro III - 98/69/EC Stage2000	25033	31047		20000	24034	11874	26192	19916	59000	19500	30000	16742	11906	19883	19 753	26193
		LD Euro IV - 98/69/EC Stage2005				20000			28780	19916	59000	20000	35000			11591		
		LD Euro V - 2008 Standards																
	LPG	Conventional						16190					17500					
		LD Euro I - 93/59/EEC						16190					17500					
		LD Euro II - 96/69/EEC						16190					25000					
		LD Euro III - 98/69/EC Stage2000						16190					40000					
		LD Euro IV - 98/69/EC Stage2005						16190					50000					
		LD Euro V - 2008 Standards																
Heavy Duty Trucks	Gasoline >3,5 t	Conventional	21005	34709	13597	20000	36054	75897			38000	5000			43684	9000		
	Rigid <=7,5 t	Conventional	26102	56191	13597	15000	6368		23414		59000	25000	25600	14631	49455	8268	2 111	25645
		HD Euro I - 91/542/EEC Stage I	26102	56191	13597	20000	26359		31938		59000	27000	29900	14631	49462	17750	4 526	34365
		HD Euro II - 91/542/EEC Stage II	26102	56191	13597	25000	47991		42580		59000	28000	34200	14631	49455	27048	8 763	51458
		HD Euro III - 2000 Standards	26102	56191	13597	30000	72327		63899		59000	30000	51300	14631	49457	31176	8 598	60107
		HD Euro IV - 2005 Standards			13597	35000			74681		59000		68400		49453		6 100	
		HD Euro V - 2008 Standards			13597													
	Rigid >32 t	Conventional	26102	87030	13597	15000	7026		23414			37000	25600		52914	22667	81 685	25645
		HD Euro I - 91/542/EEC Stage I	26102	87030	13597	25000	35634		31938			54000	29900		53233	17000	53 074	34365
		HD Euro II - 91/542/EEC Stage II	26102	87030	13597	30000	57266		42580			55000	34200		53457	29000	85 830	51458
		HD Euro III - 2000 Standards	26102	87030	13597	35000	81603		63899			60000	51300		53455	28200	91 059	60107
		HD Euro IV - 2005 Standards			13597	35000			74681				68400		53455		53 205	
		HD Euro V - 2008 Standards			13597													
	Articulated 14 - 20 t	Conventional	48980	46761	37293	40000	8485		31445			37000	33100	32566	49461		7 774	68800
		HD Euro I - 91/542/EEC Stage I	48980	46761	37293	50000	37758		43820			54000	38700	32566	49439		16 246	78152
		HD Euro II - 91/542/EEC Stage II	48980	46761	37293	60000	59391		73313			55000	44200	32566	49460		20 242	111361
		HD Euro III - 2000 Standards	48980	46761	37293	90000	83727		123014			60000	60700	32566	49460		28 499	135176
		HD Euro IV - 2005 Standards			37293	90000			138544				88400		49457		18 874	
		HD Euro V - 2008 Standards			37293	90000												
	Articulated 50 - 60 t	Conventional	48980	87030	37293	40000	7026		31445			37000	33100		52914			68800
		HD Euro I - 91/542/EEC Stage I	48980	87030	37293	50000	35634		43820			54000	38700		53233			78152
		HD Euro II - 91/542/EEC Stage II	48980	87030	37293	70000	57266		73313			55000	44200		53457			111361
		HD Euro III - 2000 Standards	48980	87030	37293	90000	81603		123014			60000	60700		53455			135176
		HD Euro IV - 2005 Standards			37293	90000			138544				88400		53455			
		HD Euro V - 2008 Standards			37293	90000												
Buses	Urban Buses Standard 15 - 18 t	Conventional	52005	115061		30000	9835	70241	26333		71500	45000	26900	45751	75901	42333	28 900	23536
		HD Euro I - 91/542/EEC Stage I	52005	115061		35000	38338	129614	36078		71500	45000	27900	45751	75902	52250	45 814	35932
		HD Euro II - 91/542/EEC Stage II	52005	115061		70000	50339	126770	42934		71500	45000	27900	45751	75901	66889	54 463	54042
		HD Euro III - 2000 Standards	52005	115061		90000	63840	129137	50390		71500	45000	27900	45751	75901	71500	57 456	62769
		HD Euro IV - 2005 Standards				90000			54326		71500		77800		75903		30 256	64090
		HD Euro V - 2008 Standards				90000												
	Coaches Standard <=18 t	Conventional	52005	80181		45000	11124		45994	65000	74000	51000	26900		63175	33600	21 983	23536
		HD Euro I - 91/542/EEC Stage I	52005	80181		55000	39627	70241	50676	65000	74000	51000	27900		63169	37000	45 589	35932
		HD Euro II - 91/542/EEC Stage II	52005	80181		70000	51628	72770	59693	65000	74000	51000	27900		63146	47385	55 142	54042
		HD Euro III - 2000 Standards	52005	80181		90000	65129	70241	73742	65000	74000	51000	27900		63178	62000	54 685	62769
		HD Euro IV - 2005 Standards				90000			68599		74000		77800		63160		28 822	64090
		HD Euro V - 2008 Standards				90000												
Power Two Wheelers	<50 cm³	Conventional	1000	1291		1600	2045	1500	2331	4000	12500	3400	1800	3200		851	710	2775
		Mop - Euro I	1000	1291		1600	2045	1500	2528	4000	12500	3900	1800			1059	2 179	2775
		Mop - Euro II	1000	1291		1600	2045	1500	3219	4000		3900	1800		691	1779	2 726	2775
		Mop - Euro III				1600	2045											
	2-stroke >50 cm³	Conventional	2800	6267		4000	5034	3638	2492	9000			3400	6800	1804	1842	1 647	5138
		Mot - Euro I				5000	5034	3638	2941	9000			4500		1804	2688	3 468	5138
		Mot - Euro II				5000	5034	3638	4097	9000			6100			2529	3 518	5138
		Mot - Euro III				5000	5034											
	4-stroke 250 - 750 cm³	Conventional	2800	6267		5000	6293	3638	3122	9000	20500	5300	3400		1804	2105	2 448	5639
		Mot - Euro I		6267		5000	6293	3638	3665	9000	20500	6000	4500		1804	3833	4 629	5639
		Mot - Euro II		6267		5000	6293	3638	5024	9000			6100			3667	5 046	5639
		Mot - Euro III				5000	6293											

Table 5-9: Average mileage considered for countries that provided no data

Category	Type	Technology	Mileage (km/a)
Passenger Cars	Gasoline <1,4 l	PRE ECE	4789
		ECE 15/00-01	5769
		ECE 15/02	5842
		ECE 15/03	6884
		ECE 15/04	9248
		Impr. Conv.	7597
		Open Loop	8241
		Euro 1	11467
		Euro 2	12900
		Euro 3	14885
		Euro 4	15768
		Euro 5	
	Gasoline 1,4 2,0 l	PRE ECE	5133
		ECE 15/00-01	6145
		ECE 15/02	6447
		ECE 15/03	7390
		ECE 15/04	9938
		Impr. Conv.	7597
		Open Loop	9354
		Euro 1	12632
		Euro 2	13869
		Euro 3	16003
		Euro 4	
		Euro 5	
	Gasoline >2,0 l	PRE ECE	5398
		ECE 15/00-01	6458
		ECE 15/02	6570
		ECE 15/03	7793
		ECE 15/04	10339
		Euro 1	12934
		Euro 2	14803
		Euro 3	16480
		Euro 4	18527
		Euro 5	
	Diesel <2,0 l	Conventional	16787
		Euro 1	18911
		Euro 2	22275
		Euro 3	25275
		Euro 4	25498
		Euro 5	
	Diesel >2,0 l	Conventional	18538
		Euro 1	21002
		Euro 2	23611
		Euro 3	27601
		Euro 4	28559
		Euro 5	
	LPG	Conventional	27172
		Euro 1	30842
		Euro 2	32745
		Euro 3	34325
		Euro 4	33555
		Euro 5	
	2-Stroke	Conventional	4000
	Hybrid<1,4 l	Euro 4	19345
Light Duty Vehicles	Gasoline <3,5t	Conventional	13140
		Euro 1	15124
		Euro 2	16918
		Euro 3	19192
		Euro 4	21701
		Euro 5	
	Diesel <3,5 t	Conventional	17288
		Euro 1	20056
		Euro 2	22062
		Euro 3	24071
		Euro 4	27755
		Euro 5	
	LPG	Conventional	16845
		Euro 1	16845
		Euro 2	20595
		Euro 3	28095
		Euro 4	33095
		Euro 5	
Power Two Wheelers	<50 cm³	Conventional	2786
		Euro 1	2937
		Euro 2	2179
		Euro 3	1823
	2-stroke >50 cm³	Conventional	4143
		Euro 1	4321
		Euro 2	4895
		Euro 3	5017
	4-stroke <250 cm³	Conventional	5367
		Euro 1	5969
		Euro 2	5287
		Euro 3	5646
	4-stroke 250 - 750 cm³	Conventional	5523
		Euro 1	6213
		Euro 2	5567
		Euro 3	5646
	4-stroke >750 cm³	Conventional	5606
		Euro 1	6389
		Euro 2	5713
		Euro 3	5646

Category	Type	Technology	Mileage (km/a)
Heavy Duty Trucks	Gasoline >3,5 t	Conventional	29694
	Rigid <=7,5 t	Conventional	25027
		Euro I	29344
		Euro II	34573
		Euro III	40456
		Euro IV	43747
		Euro V	13597
	Rigid 7,5 - 12 t	Conventional	25746
		Euro I	32331
		Euro II	37972
		Euro III	44907
		Euro IV	49023
		Euro V	13597
	Rigid 12 - 14 t	Conventional	22452
		Euro I	29326
		Euro II	35058
		Euro III	43739
		Euro IV	45108
		Euro V	13597
	Rigid 14 - 20 t	Conventional	28257
		Euro I	35433
		Euro II	40833
		Euro III	47342
		Euro IV	48380
		Euro V	13597
	Rigid 20 - 26 t	Conventional	28299
		Euro I	35905
		Euro II	41173
		Euro III	48899
		Euro IV	44550
		Euro V	13597
	Rigid 26 - 28 t	Conventional	28186
		Euro I	34693
		Euro II	39883
		Euro III	46865
		Euro IV	48135
		Euro V	13597
	Rigid 28 - 32 t	Conventional	28251
		Euro I	35147
		Euro II	40440
		Euro III	48019
		Euro IV	45263
		Euro V	13597
	Rigid >32 t	Conventional	34807
		Euro I	38406
		Euro II	47127
		Euro III	54279
		Euro IV	49723
		Euro V	13597
	Articulated 14 - 20 t	Conventional	36805
		Euro I	44476
		Euro II	53214
		Euro III	66348
		Euro IV	70428
		Euro V	63646
	Articulated 20 - 28 t	Conventional	40810
		Euro I	48481
		Euro II	58052
		Euro III	70352
		Euro IV	70428
		Euro V	63646
	Articulated 28 - 34 t	Conventional	43813
		Euro I	51411
		Euro II	61489
		Euro III	74157
		Euro IV	80739
		Euro V	63646
	Articulated 34 - 40 t	Conventional	41781
		Euro I	53713
		Euro II	63708
		Euro III	76918
		Euro IV	81538
		Euro V	63646
	Articulated 40 - 50 t	Conventional	48235
		Euro I	59168
		Euro II	72803
		Euro III	86942
		Euro IV	81538
		Euro V	63646
	Articulated 50 - 60 t	Conventional	44359
		Euro I	52684
		Euro II	63790
		Euro III	77725
		Euro IV	81538
		Euro V	63646
Buses	Urban Buses Midi <=15 t	Conventional	44744
		Euro I	55090
		Euro II	58800
		Euro III	62723
		Euro IV	59254
		Euro V	60000
	Urban Buses Standard 15 - 18 t	Conventional	47378
		Euro I	57582
		Euro II	64182
		Euro III	68444
		Euro IV	66268
		Euro V	90000
	Urban Buses Articulated >18 t	Conventional	45388
		Euro I	57904
		Euro II	65222
		Euro III	69222
		Euro IV	65721
		Euro V	90000
	Coaches Standard <=18 t	Conventional	45654
		Euro I	53380
		Euro II	58849
		Euro III	63702
		Euro IV	66639
		Euro V	90000
	Coaches Articulated >18 t	Conventional	45183
		Euro I	54471
		Euro II	62220
		Euro III	65950
		Euro IV	65884
		Euro V	90000

6 Link with higher level models

The link of the transport projections with higher level models has not yet been established. However, this is the major objective of the EC4MACS project, in order to develop a baseline which is consistent with the energy projections developed by PRIMES. Some ideas are only proposed in this chapter which will be discussed in the months to come.

The first schematic which can be considered is shown in Figure 6-1. In principle, a total energy projection and an average efficiency per year are determined in PRIMES. These are then translated into vehicle choice, given the efficiency of different vehicle types. According to the vehicle choice, total vkm are fed to the stock module which then calculates the technology distribution in each year. Based on this, the consumption module estimates the fuel consumption which is the compared to the PRIMES projections. These are not necessarily the same because the efficiency is decided at a more aggregated level at the "vehicle choice" module and it is in more detail calculated, after the exact technologies have been decided. Therefore, a certain round of loops is required to equilibrate the initial assumptions with the actual calculations.

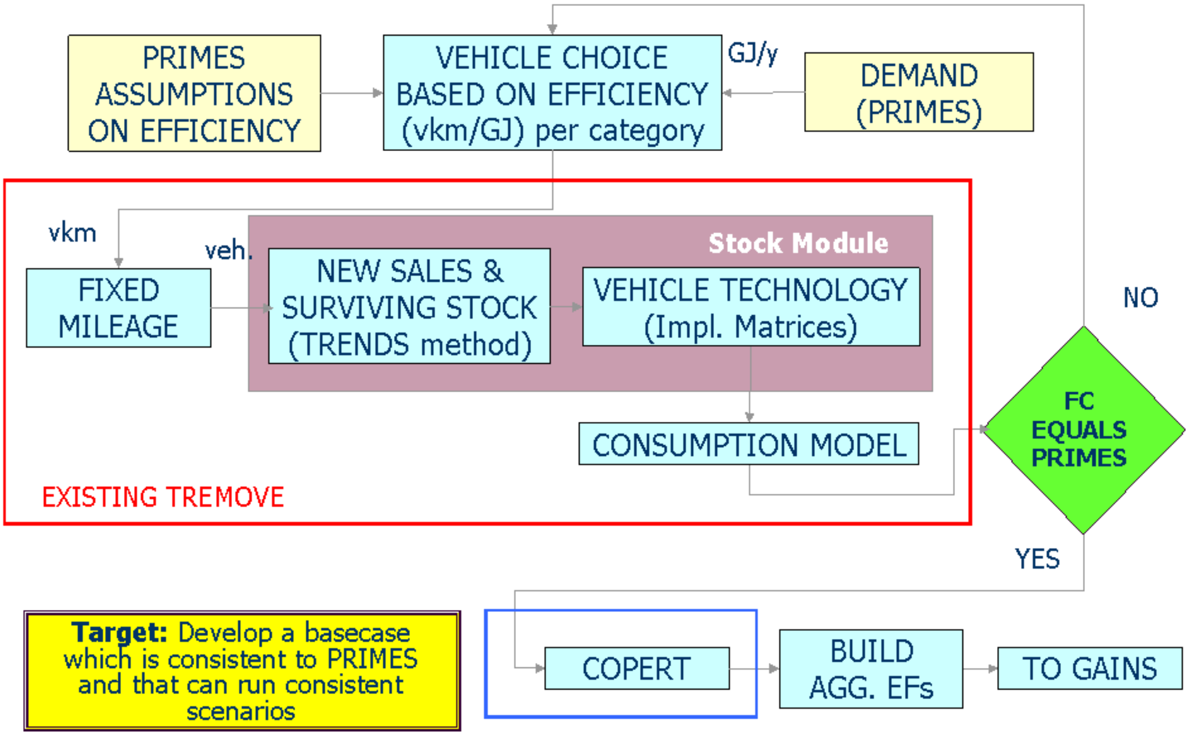


Figure 6-1: Possible realization of the road transport with higher level models (Alternative 1)

There is also a second possible alternative to realize the link between the road transport models and PRIMES/GAINS. This is shown in Figure 6-2. In this second alternative the vehicle choice is based both on energy efficiency limitations as well as in cost efficiency limitations. Therefore, the values on technology cost from GAINS are also used as input, together with the energy efficiency values from PRIMES to make a choice selection. The difference in the two approaches is obvious. In this last alternative, high-cost options will be less preferable than lower cost ones, even if the former have higher efficiency. After the vehicle selection has been decided, then the estimate of the vehicle technology mix, the fuel consumption and the emissions calculations are performed as in the previous case.

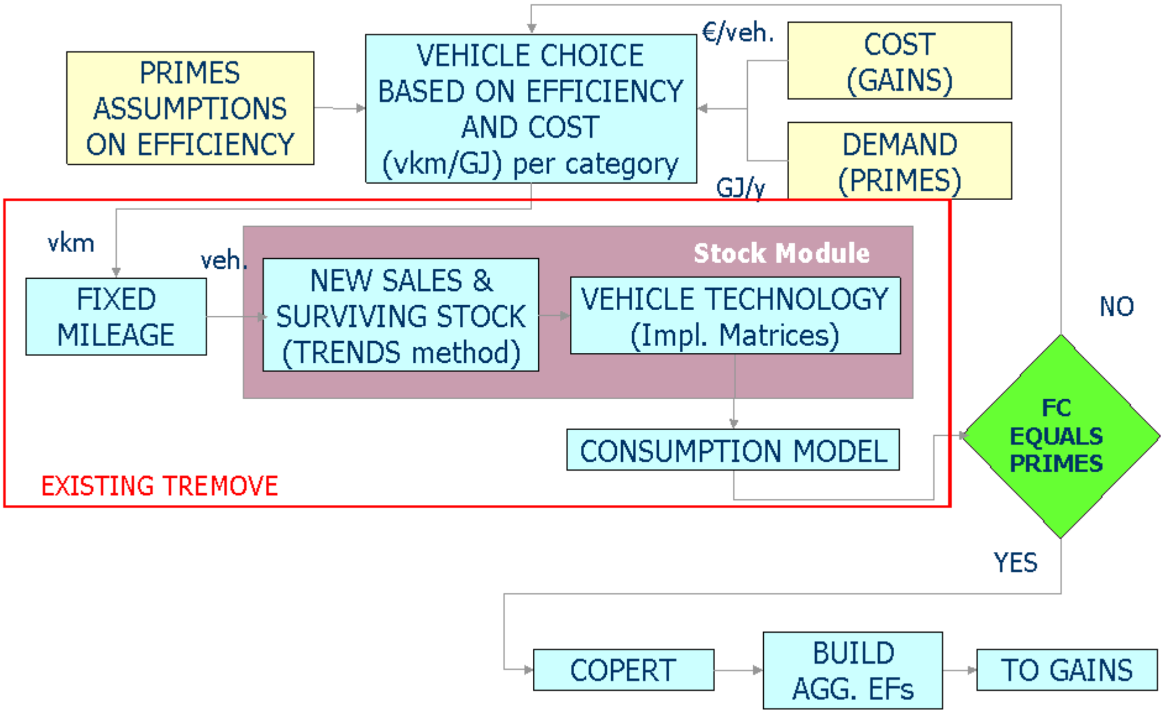


Figure 6-2: Possible realization of the road transport with higher level models (Alternative 2)

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Nomenclature, symbols

Acronyms

CC	Cylinder Capacity of the Engine
CH_4	Methane
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
EC	Elemental Carbon
FC	Fuel Consumption
GVW	Gross Vehicle Weight
HDV	Heavy Duty Vehicle
I&M	Inspection and Maintenance
LDV	Light Duty Vehicle
LPG	Liquid Petroleum Gas
NH_3	Ammonia
NMVOC	Non-Methane Volatile Organic Compounds
N_2O	Nitrous Oxide
NO_x	Nitrogen Oxides (sum of NO and NO_2)
NUTS	Nomenclature of Territorial Units for Statistics (0 to III). According to the EU definition, NUTS 0 is the territory of individual Member States
OBD	On-Board Diagnostics
OC	Organic Carbon
OM	Organic Matter
Pb	Lead
PC	Passenger Car
SNAP	Selective Nomenclature for Air Pollution
SOx	Sulphur Oxides
VOC	Volatile Organic Compounds

List of symbols

$\mathbf{A_0 \ldots A_6}$	constants for the emission correction due to road gradient
$\mathbf{A^M}$	emission performance degradation per kilometre
$\mathbf{B^M}$	relative emission level of brand new vehicles
bc	correction coefficient for the β-parameter to be applied for improved catalyst vehicles
$\mathbf{E_{HOT}}$	total emissions during thermally stabilised (hot) engine and exhaust aftertreatment conditions

$\mathbf{E^{CALC}}$	emission of a fuel dependent pollutant (CO_2, SO_2, Pb, HM) estimated on the basis of the calculated fuel consumption
$\mathbf{E^{CORR}}$	corrected emission of a fuel dependent pollutant (CO_2, SO_2, Pb, HM) on the basis of the statistical fuel consumption
$\mathbf{e^{COLD}/e^{HOT}}$	ratio of emissions of cold to hot engines
$\mathbf{e_{HOT}}$	average fleet representative baseline emission factor in [g/km] for thermally stabilised (hot) engine and exhaust aftertreatment conditions
EF	fuel consumption specific emission factor
ES	emission standard according to the legislation
e(V)	mathematical expression of the speed dependency of e_{HOT}
f(V)	equation (e.g. formula of "best fit" curve) of the frequency distribution of the mean speeds which corresponds to the driving patterns of vehicles on road classes "rural", "urban" and "highway"
$\mathbf{FC^{CALC}}$	calculated fuel consumption)
$\mathbf{FCe_{HOT}}$	hot emission factor corrected for the use of improved fuel
FCorr	emission correction for the use of conventional or improved fuel
$\mathbf{FC^{STAT}}$	statistical (true) total consumption
$\mathbf{FC^{BIO}}$	statistical fuel consumption of biofuel
GCorr	emission correction factor for the effect of road gradient
$\mathbf{GCe_{HOT}}$	corrected hot emission factor for road gradient
k	weight related content of any component in the fuel [kg/kg fuel]
$\mathbf{LCe_{HOT}}$	corrected hot emission factor for vehicle load
LCorr	vehicle load correction factor
LP	the actual vehicle load factor (expressed as a percentage of the maximum load. That is, **LP** = 0 denotes an unloaded vehicle and **LP** = 100 represents a totally laden one)
$\mathbf{l_{trip}}$	average trip length [km]
M	average mileage in [km]
$\mathbf{MCe_{HOT}}$	hot emission factor corrected for degraded vehicle performance due to mileage
MCorr	correction coefficient for emission performance degradation due to mileage
$\mathbf{M^{MEAN}}$	mean fleet mileage [km]
N	number of vehicles [veh.]
$\mathbf{r_{H:C}}$	ratio of hydrogen to carbon atoms in fuel
RF	reduction factor for emissions of pollutant of a class over a reference class
S	share of mileage driven in different road types
t	ambient temperature [°C]
V	vehicle mean travelling speed in [km/h]
β	fraction of mileage driven with cold engines

List of indices

a	monthly mean
Base	referred to the base fuel quality
c	cycle (c= UDC, EUDC)
COLD	referring to cold start over-emissions
Fuel	referred to improved fuel quality
HIGHWAY	referring to highway driving conditions
HOT	referring to thermally stabilised engine conditions
i	pollutant index (i = 1-36)
j	vehicle class (j = 1-230)
jm	vehicle class operating on fuel type m
k	road classes (k= urban, rural, highway)
m	fuel type (m= gasoline, diesel , LPG)
Pb	Lead content in fuel
RURAL	referring to rural driving conditions
S	Sulphur content in fuel
TOT	referring to total calculations
URBAN	referring to urban driving conditions