Emission factor modelling and database for light vehicles - Artemis deliverable 3

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EMISSION FACTOR MODELLING AND DATABASE FOR LIGHT VEHICLES

Artemis deliverable 3

Report n°LTE 0523
June 2007

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Emission factor modelling and database for light vehicles

(Artemis deliverable 3)

Report n° LTE 0523
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13 Summary

In the frame of the Artemis project, the emission models for atmospheric pollutants have been updated and strongly improved for the road light vehicles. This development is based on a wide and specific measurement campaign, with more than 150 vehicles and about 3500 tests for a large number of pollutants, regulated and non regulated ones. The results of these measurements carried out by several European laboratories are included in a database especially designed, the Artemis LVEM database, available and open to future European measurements data.

The Artemis model for light vehicles contains a set of complementary sub-models. The base model calculates the hot emissions for each vehicle category according to the driving behaviour. It contains 5 alternative models: The main model considers traffic situations (discrete model), with emission factors for each of them; A simplified model, built on the same data, takes into account the driving behaviour through the average speed (continuous model); A continuous model, so-called kinematic, considers a limited number of aggregated kinematic parameters; 2 instantaneous models consider some instantaneous parameters as instantaneous speed.

These models need input kinematic data of variable complexity and are therefore adapted to different usages, for assessing national emissions, as far as for calculating the impact of a local traffic control. They are associated to models taking into account the influence of several parameters, as cold start, using of auxiliaries like air conditioning, vehicle mileage, ambient air temperature and humidity, road slope and vehicle load, as far as evaporation. The building methods of all these models and the data or models they are based on are presented, as far as the models themselves.

14 Key Words emission factor, passenger car, light vehicle, model, inventory, Europe, regulated and unregulated pollutant, cold start, auxiliary, mileage, temperature, humidity, slope, load, traffic situation, kinematic, instantaneous		15 Distribution statement limited free X	
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12 Remarques

13 Résumé

Dans le cadre du projet européen Artemis, les modèles d'émissions de polluants atmosphériques ont été actualisés et très fortement améliorés pour les véhicules routiers légers. Ce développement est basé sur une très importante campagne de mesures spécifique, sur plus de 150 véhicules et environ 3500 tests, pour un grand nombre de polluants réglementés ou non. Les résultats de cette campagne de mesures menées par plusieurs laboratoires européens sont intégrés dans une base de données créée spécialement, la base de données Artemis LVEM, disponible et ayant vocation à accueillir de futures mesures européennes.

Le modèle Artemis pour les véhicules légers comporte un ensemble de sous-modèles complémentaires. Le modèle de base calcule les émissions à chaud pour chaque catégorie de véhicule en fonction du comportement de conduite. Il comporte 5 modèles alternatifs. Le modèle principal considère des situations de trafic (modèle discret), avec des facteurs d'émission pour chacune d'entre elles ; un modèle simplifié, construit sur les mêmes données, tient compte du comportement de conduite à travers la vitesse moyenne (modèle continu) ; un modèle continu, dit cinématique, tient compte d'un nombre limité de paramètres cinématiques agrégés ; 2 modèles instantanés tiennent compte de divers paramètres instantanés comme la vitesse.

Ces modèles demandent des données d'entrée cinématiques de complexité variable et sont donc adaptés à des utilisations différentes, aussi bien pour calculer des émissions nationales que pour calculer l'impact d'une gestion locale du trafic. Ils sont associés à des modèles tenant compte de l'influence de divers paramètres comme le départ à froid, l'usage d'auxiliaires tels l'air conditionné, le kilométrage des véhicules, les température et humidité ambiantes, la pente et la charge des véhicules, ainsi que les évaporations. Les méthodes de construction de ces différents modèles et les données ou modélisations dont ils sont issus sont présentées, ainsi que les modèles eux-mêmes.

14 Mots clés émission unitaire, voiture particulière, véhicule léger, modèle, inventaire, Europe, polluant réglementé et non réglementé, départ à froid, auxiliaire, kilométrage, température, humidité, pente, charge, situation de trafic, cinématique, instantané	15 Diffusion restreinte libre X

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1. Introduction

Emissions from transport are an important and often dominant source of air pollution with direct and indirect negative impacts in particular on human health. At the same time, transport also contributes significantly to greenhouse gases, which should be reduced as has been agreed, for example, in the Kyoto protocol. It is therefore a widely accepted and undisputed objective to reduce pollutant and greenhouse gas emissions by appropriate ways and means. In order to assess the present and future state of the emissions from transport and to evaluate different policies for reducing the emissions, it is necessary to have reliable knowledge about the sources and causes of the pollution, the technological and behavioural parameters of influence and the potentials of different strategies to reduce the pollution. For evaluating different measures it is necessary to quantify the past, present and future status of pollution, but also the potentials and effects of different approaches. The quantitative effects in general are calculated by emission models, which are also the basis for inventory systems at different levels of spatial resolution (local, regional, national, international). It is therefore a basic requirement that these emission models produce accurate, reliable and consistent results. Calculation of emissions has therefore gained institutional importance in the European Community, particularly with the development of the CAFÉ (EC, 2005a) and ECCP (EC, 2005b) programmes.

The *Artemis* project "*Assessment and reliability of transport emission models and inventory systems*" proposes to combine the experience from different emission calculation models and ongoing research in order to arrive at a harmonised methodology for emission estimates at the national and international level. It addresses the Competitive and sustainable growth programme of the 5th framework programme of the European Commission, Key Action KA 2: Sustainable mobility and intermodality, Task 2.2: Infrastructures and their interfaces with transport means and systems, Sector 2.2.2: Environment, Sub-Task 2.2.2/2: Monitoring emissions from transport including particulates. The project develops a harmonised emission model for all transport modes, which aims to provide consistent emission estimates at the national, international and regional level. This requires first of all additional basic research and a better understanding of the causes of the differences mainly with respect to emission factors.

The *Artemis* project is the following step after two inventorying model developments in Europe:

- The European MEET (Methodologies for Estimating air pollutant Emissions from Transport) project (Hickman et al., 1999) and the COST 319 action (Joumard, 1999), focused in particular on the production of emission factors and functions using most of the available measured data in Europe. These research projects are the basis of the Copert 3 software, well known in many countries.
- The German and Swiss emission model HBEFA (Keller, 2004), mainly used in some countries.

The main difference between the Copert and HBEFA approaches is, beside the data base differences, the taking into account of the kinematics: through the trip average speed in a continuous model for Copert, but through discrete traffic situations in HBEFA based on instantaneous modelling. A new method for synthesising the emission measurements from different laboratories is necessary, and should integrate existing methods that are based either on instantaneous vehicle operation or average speed.

In order to account for new concerns about air pollution, we must have a much better understanding of types of emission that have not yet been studied extensively. This mainly concerns the non-regulated pollutants: speciation of the volatile organic compounds necessary to model photochemical pollution, greenhouse gases, polyaromatic hydrocarbons, and particulate sizing which is becoming increasingly important in the assessment of health effects.

Therefore it is necessary to produce emission factors for exhaust emissions of regulated and non-regulated pollutants, and especially for the latest vehicle concepts (Euro 2 to Euro 4 petrol and diesel-engined vehicles) for which very few data exist. Extensive emission measurements have to be conducted in order to provide a wide and representative base for the estimation of the emission factors.

A rigorous statistical evaluation should be made of the whole sequence of operation of the inventory model, including the basic data (emission measurements, traffic statistics etc.), the parameters and assumptions of the models.

This report concerns only the light vehicles, i.e. the passenger cars and light duty vehicles. For that purpose a wide European emission data base has been designed and most of the emission measurements available in Europe have been collected, including of course the measurements carried out within the project itself.

Then a deep and comprehensive analysis of the ways to take into account the driving behaviour has been made, allowing us to design several emission models adapted to different purposes, more applied or research oriented. Several sub-models are then built for taking into account the hot emission, cold start, auxiliaries, ambient air temperature and humidity, road gradient and vehicle load, but also evaporations not treated in detail in this report.

2. Emission data base

The database used to derive the Artemis light vehicle emission models includes the existing European emission data, either already collected within the MEET or Copert exercises or later than them, and the results of the vehicle tests carried out specifically within the project by the different partners. Finally all these data were included in the so-called Artemis LVEM database, aiming at gathering all European emission measurements.

2.1. Specific measurements

About 3000 tests (1 vehicle, 1 driving cycle) were carried out within the Artemis project to improve the quality of the emission database and then the quality of the emission models designed within Artemis. The pollutants considered differ from one test to another. They are presented together with the vehicles tested and the test conditions, including the driving cycles.

2.1.1. Pollutants considered

The regulated pollutants (CO, CO_2, HC, NOx, and PM for diesel cars) are systematically measured for all the tests.

In addition a large number of unregulated pollutants, especially hydrocarbon species, are measured by five laboratories (Aakko et al., 2005; 2006). The compounds quantified and characterised are given per laboratory and per pollutant group in Table 1 and in detail in Annex 1. All together 169 unregulated pollutants are measured.

Unregulated pollutant group	Empa	IM	Inrets +			KTI	VTT	total
			ULCO	US	USTL			
non VOC			1			1		2
alkanes (saturated)	35	15	41			1	3	50
alkenes and alkynes (unsaturated)	24	3	19				5	28
monoaromatic hydrocarbons	25	2	32			4	5	39
polyaromatic hydrocarbons (light)	1	6	3	6		1		8
polyaromatic hydrocarbons (heavy)		20		10		1		22
carbonyl compounds (aldehydes and ketones)	13	12			16	1		20
total	98	58	96	16	16	9	13	169

Table 1: Numbers of unregulated pollutants measured per laboratory.

The sampling procedures and the analysis methods for unregulated pollutants depend on the laboratory and of the pollutant group: they are detailed in Annex 2.

On-line measurements are performed by EMPA by chemical ionization mass spectrometry (CI-MS) for methane, benzene, toluene, xylenes and ethyl benzene, and by VTT by Fourier transform infrared (FTIR) for N_2O, NO/NO_2, NH_3 and formaldehyde.

The other measurements are off-line. Different methods are used:

- gas chromatography with flame ionization detection (GC-FID) for about 110 VOC species by EMPA (Heeb et al., 2002; 2004; Saxer et al., 2002; 2003; Weilenmann et al., 2003b; 2005), for 18 species by IM (Prati et al., 2003a; b; 2005), for C_2-C_6 compounds by Inrets-ULCO (Caplain et al., 2004; 2006; Joumard et al., 2004a; 2004b),
- gas chromatograph with a mass spectrometer (GC-MS) for PAHs by IM (Prati et al., 2003a; b; 2005) and KTI, for C_6-C_{15} compounds by Inrets-ULCO (Caplain et al., 2004; 2006; Joumard et al., 2004a; 2004b),
- gas chromatography for 13 compounds up to C_8 by VTT.
- high performance liquid chromatography (HPLC) for aldehydes and ketones by EMPA (Saxer et al., 2002; 2003; Weilenmann et al., 2003b; 2005), IM (Prati et al., 2003a; b; 2005), Inrets-USTL (Caplain et al., 2004; 2006; Joumard et al., 2004a; 2004b), KTI and VTT, for PAHs by Inrets-US (Paturel et al., 2003; 2005; Devos et al., 2006; Joumard et al., 2004a; 2004b).

2.1.2. Vehicle sample

154 vehicles were tested specifically for designing the new emission models, i.e. 152 passenger cars and 2 light duty vehicles. The samples per fuel, emission standard and laboratory are described in Table 2. Two thirds of the vehicles are petrol fuelled. 39 and 42 % of the vehicles are resp. Euro 2 and 3 vehicles, and 6 % Euro 0, Euro 1 and Euro 4 vehicles.

		petrol						CNG			diesel					total
		Euro 0	Euro 1	Euro 2	Euro 3	Euro 4	*total*	Euro 3	Euro 4	*total*	Euro 0	Euro 1	Euro 2	Euro 3	*total*	
Passenger cars	Empa	6		1	15		*22*						6		*6*	28
	IM	1	1	3	4	1	*10*						1	2	*3*	13
	Inrets		6	7	4		*17*				2	3	11	2	*18*	35
	KTI			1	1		*2*						1		*1*	3
	LAT			3	10		*13*						1	1	*2*	15
	TNO			3	1		*4*						1	3	*4*	8
	TUG				7	5	*12*	1	1	*2*				7	*7*	21
	VTT			15	5	2	*22*						5	2	*7*	29
	Total	7	7	33	47	8	*102*	1	1	*2*	2	3	26	17	*48*	152
LDV	KTI											1	1		*2*	2

Table 2: Vehicle sample as regards laboratory, fuel and emission standard.

All these vehicles were tested for hot emissions, and some of them in addition for other tasks. The average characteristics of the vehicle samples per task are given in Annex 3, and the characteristics of each vehicle tested per task in Annex 4. The vehicle samples of each laboratory were chosen to be representative of the national fleets.

Parameter		lab.	N. veh.	NEDC		Artemis			Other cycles or families of cycles
cold	hot			UDC	EUDC	urban	rural	motorway[A]	
Instantaneous emissions		EMPA	20			1[B]	1[B]	1[B]	EMPA BAB 1000 Handbook[C] R1, R2, R3 & R4
		TUG	21[D]	2	2	2	2	2	Handbook[C] R1, R2, R3 & R4, TUG Ries Road Gradient
Hot regulated pollutants (PC)		EMPA	18	1	1	1[E]	1[E]	1[E]	EMPA BAB 1000 Handbook[C] R1, R2, R3 & R4 FTP 75
			10			1	1	1	
		IM	13			1	1	1	2 x 5 x Inrets urbain fluide court 2 x 5 x Inrets route court for 1 vehicle: see[F]
		INRETS	29		1	1	1	1	3 x 5 x Inrets urbain fluide court VP fa/fo mot.[G] urbain fuide, urbain, urbain dense, route, motorway US FTP 75 2nd & 3rd
			6						idem + Handbook R1, R2, R3 & R4 Napoli 15-18-21, 6-17, 10-23 modem 5-7-13 modem-Hyzem pure road PVU commerciale grand routier
		KTI	3			1	1	1	3 x 5 x Inrets urbain fluide court 3 x 5 x Inrets route court for 1 vehicle: see[F]
		LAT	15	1	1	1	1	1	
		TNO	8			1	1	1	for 1 vehicle: see[F]
		TUG	21		2	2	2	2	Handbook[C] R1, R2, R3 & R4, TUG Ries Road Gradient
		VTT	29			1[E]	1[E]		2 x 5 x Inrets urbain fluide court (only 13 vehicles)
Unregulated pollutants (PC)		EMPA (7 URP[H])	18	1	1	1[E]	1[E]	1[E]	3 x 5 x Inrets urbain fluide court[E] 3 x 5 x Inrets route court
									EMPA BAB 1000 Handbook[C] R1, R2, R3 & R4 FTP 75
		EMPA (190 HCs)							3 x 5 x Inrets urbain fluide court[E]
		IM	11	1	1	1	1		5 x Inrets urbain fluide court 5 x Inrets route court
									2 x 5 x Inrets urbain fluide court 2 x 5 x Inrets route court
		INRETS-US-ULCO-USTL	30						15 x Inrets urbain fluide court
									15 x Inrets urbain fluide court VP fa/fo mot. urbain & aut.[G]
		KTI	2	1	1				3 x 5 x Inrets urbain fluide court

								3 x 5 x Inrets route court
	VTT	13	1	1	1[E]	1[E]		5 x Inrets urbain fluide court
								2 x 5 x Inrets urbain fluide court
Light Duty Vehicles	KTI	2	1					5 PVU fourgon 3.5 t
Influence of vehicle mileage	LAT	2	2	1	1	1	1	
Influence of ambient temperature	EMPA	18			1	1	1	
	VTT	13			1	1		
Influence of ambient humidity	VTT	11			1	1		
Influence of gradient	TUG	1			1[I]	1[I]		
		4						TUG Ries Road Gradient[I]
Influence of load	TUG	2			1[J]	1[J]	1[J]	
		3				1[J]		TUG Ries Road Gradient[J]
Influence of auxiliaries (PC)	TUG	3	2	2	2[I]	2[I]	2[I]	TUG Ries Road Gradient[I]
Cold start emissions (PC)	IM	10	1					15 x Inrets urbain fluide court 15 x Inrets route court
	INRETS	30	1					15 x Inrets urbain fluide court 15 x Inrets route court US FTP 75 1st, 2nd, 3rd
	VTT	13	1					3 x 5 x Inrets urbain fluide court[E]

A Artemis mway means Artemis motorway or Artemis motorway 130 alternatively

B with 6 conditions of road gradient & vehicle load for the Artemis driving cycles: -6% & 0%, -3% & 50%, 0% & 0%, 0% & 100%, 3% & 0%, 3% & 50%

C 3 bags per Handbook driving cycle

D 11 other cars have been also tested recently, especially Euro 4 ones, but not within the Artemis project

E at 3 ambient temperatures: -20, -7 and +23°C

F Handbook R1, R2, R3, R4, Napoli 15-18-21, 6-17, 10-23, modem 5-7-13, modem-Hyzem pure road, PVU commerciale grand routier, VP faible/forte motorisation autoroute [b]

G the cycles 'VP faible motorisation' and 'VP forte motorisation' are alternative

H Methane, Benzene, Toluene, Xylenes, NH_3

I for 7 slopes: -10, -5, -2.5, 0, +2.5, +5, +10 %

J with unloaded, half loaded and loaded situations. The “loaded” situation designates the measurement with the full payload for this car type, in average it is 450 kg, and the “half loaded” designates the situation in the middle of “unloaded” and “loaded”.

Table 3: Number of driving cycles tested per vehicle and per parameter studied, and number of vehicles tested by parameter and laboratory. The driving cycles and families of them are defined in Annex 5.

2.1.3. Driving cycles used

36 driving cycles were used, but some of them only with few cars. The 3 Artemis cycles were used by almost all the vehicles tested; Then the most used driving cycles are the Artemis low or high motorisation, the EMPA BAB 1000, the Handbook, and the Inrets urbain fluide court ones. The main parameters of the driving cycles used are in Annex 5, with their description in Annex 6.

The driving cycles tested per vehicle and the number of vehicles tested are given per parameter studied and per laboratory in Table 3.

Parameter		lab.	N. veh.	N. driving cycles	Tested cases	N. bags	
Instantaneous emissions		EMPA	20	16[B, C, K]	all together 37 bags per vehicle	740	1223
		TUG	21[D]	23	Different vehicle loadings and road gradients[I, J]	483	
Hot regulated pollutants (PC)		EMPA	18	25	3 ambient temperatures (-20, -7 and +23°C) for the Artemis cycles	450	2444
			10	19		190	
		IM	13	7 or 18		102	
		INRETS	29	14		406	
			6	24		142	
		KTI	3	9 or 20		32	
		LAT	15	5		75	
		TNO	8	3 or 14		35	
		TUG	21	21		441	
		VTT	29	5	3 ambient temperatures (-20, -7 and +23°C) for 2 cycles	571	
Unregulated pollutants	7 URP[H]	EMPA	18	39		702	1639
	190 HCs			18		342	
	VOC & PAH	IM	11	11	15 repetitions	136	
	VOC & PAH	INRETS-US-ULCO-USTL	30	4		120	
	VOC & PAH	KTI	2	8		16	
	VOC	VTT	6	7[L]	by gas chromatography	102	
			13	7[L]	by FTIR	221	
Light Duty Vehicles		KTI	2	6	10 and 50 % load for 3 among 6 cycles	18	18
Influence of vehicle mileage		LAT	2	6	Test every 20 000 km, before and after maintenance; 1, 2 or 3 repetitions	174	174
Influence of ambient temperature		Empa	18	3	3 ambient temperatures: -20, -7 and +23°C	240	240
		VTT	13	2			
Influence of ambient humidity		VTT	11	2	3 ambient humidity levels, tests repeated	131	131
Influence of gradient		TUG	1	2	7 slopes: -10, -5, -2.5, 0, 2.5, 5, 10 %	14	42
			4	1		28	
Influence of load		TUG	2	3	Unloaded, half loaded, loaded	18	36
			3	2		18	
Influence of auxiliaries		TUG	3	53	with and without air conditioning, lighting, rear-window heater, radio	159	159
Cold start emissions		IM	10	7		70	470
		Inrets	30	9		270	
		VTT	13	10[M]		130	

B, C, D, F, H, I, J: see Table 3

K with 2 gearshift strategies for 2 Handbook driving cycles.

L 2 cycles at 1 temperature, 5 cycles at 3 ambient temperatures: -20, -7 and +23°C

M 1 cycle at 1 temperature, 3 cycles at 3 ambient temperatures: -20, -7 and +23°C

Table 4: Description of the tests carried out, per parameter and laboratory.

2.1.4. Test sequence

The tests carried out are briefly described Table 4 per parameter studied and per laboratory. The test sequence depends on each laboratory: see specific reports describing the results per parameter, as given in section 3, or laboratory reports (as Joumard et al., 2004a and Stettler et al., 2004 resp. for INRETS and EMPA tests).

The vehicles were tested as received on a chassis dynamometer. The emissions are sampled usually with a bag or a trap, giving an physical average of emission along the sampling time, or sampled and analysed continuously. In the first case the unit of measurement is the so-called bag or vehicle-test, corresponding to a driving cycle and the analysis of different pollutants. In the second case, either the instantaneous emissions are considered (to design instantaneous models, see section 3.2), or the continuous signal is averaged for the whole cycle or a sub-cycle, defining again a unit of measurement called also bag or vehicle-test. The numbers of bags are given in Table 4. All together about 3500 bags or vehicle-tests were produced specifically within Artemis for the light vehicles, to improve the design of the Artemis emission models developed in section 3. About 2400 tests were carried out to design the basic hot emission model for regulated pollutants, 1600 tests for the emission factors of unregulated pollutants, 1200 tests to design the instantaneous models, 500 tests for the cold start model, and 800 tests for the other sub-models (LDV, influence of mileage, ambient temperature and humidity, gradient, load), but some tests are common to different tasks.

2.2. Other Artemis measurements

In parallel to emission tests performed to design new emission models for light vehicles, more than 2000 tests were carried out to study the influence of 20 parameters of the tests on vehicle bench, in order to improve the accuracy, reliability and representativeness of emission factors: driving patterns, vehicle related parameters, vehicle sampling, and laboratory related parameters. These tests concern the regulated atmospheric pollutants and pre-Euro to Euro 4 vehicles. Some tests were common to the model design and the accuracy research. They are presented and discussed in Joumard et al. (2006a).

In addition specific measurements of evaporative emissions were performed in order to design the evaporative emission model (Hausberger et al., 2005), and measurements of particle properties carried within the clustered project Particulates (Samaras et al., 2005b).

2.3. External data

Beside specific tests, external emission data were used to derive emission models, coming either from the literature, or from measurement campaigns carried out by the different partners, or from the former MEET project, or from the Handbook data base. Such data were used especially in the design of the traffic situation model, the average speed model, the Light Duty Vehicle model, and the cold start model.

2.4. Artemis light vehicle emission measurement database (Artemis LVEM DB)

Beside the emission measurement campaign carried out within the project, a database was developed to collect these data and other European data.

2.4.1. Objectives

The Artemis project is aiming, among other, at improving the exhaust emission factors for the passenger cars and light duty vehicles, by enlarging the emission factor database especially for non-regulated pollutants, recent passenger cars and light duty vehicles.

In this frame, the Artemis database is aimed at collecting all emission measurements made in Europe for passenger cars (PC) and light duty vehicles (LDV) for a driving cycle. Such data can be derived from measurements on a vehicle bench or on the road, but always after integration on a time period, so-called driving cycle or sub-cycle. It allows the Artemis partners to use the same internal and external data for designing the different PC and LDV emission factors, according to different parameters, as presented in section 3.

In order to be usable by Artemis partners but also by any other research team in the field of the emissions from transport modes, the data must contain not only the measured emissions but also all the explanatory parameters of the emission, as far as they are available.

A last aim of the database is to be easily supplemented in the future by new emission measurements.

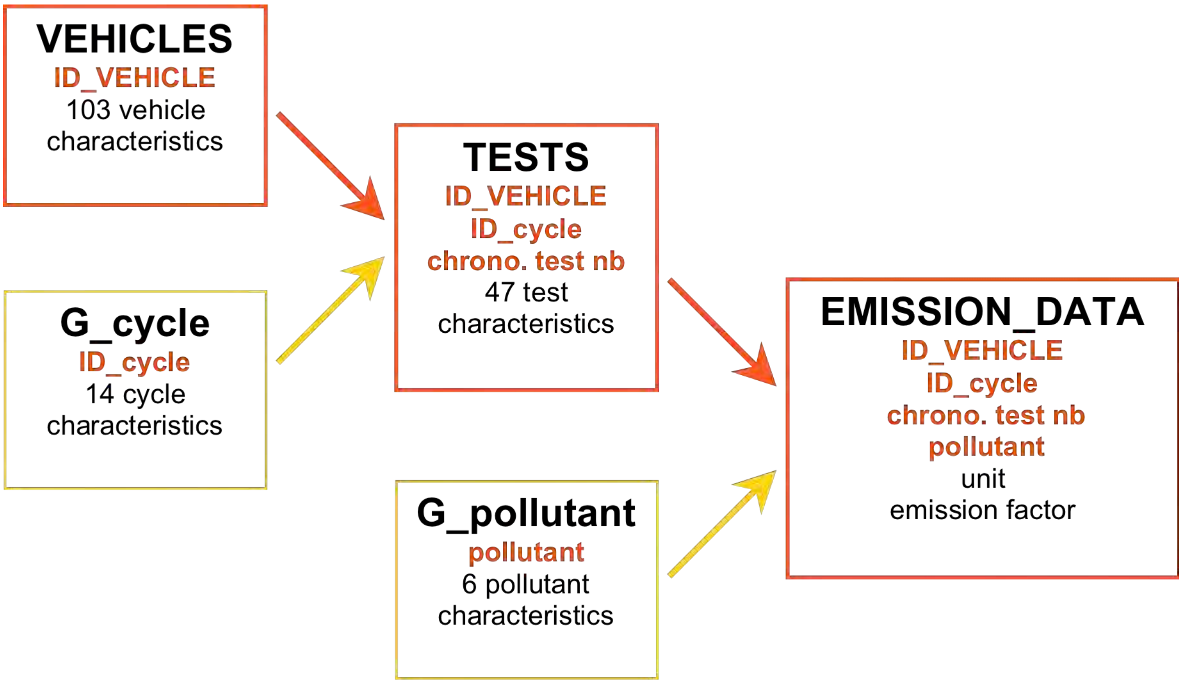


Figure 1: Simplified design of the database, including the 3 main tables and the 2 most important secondary tables.

2.4.2. Building

The design of the database (Kljun et al., 2005) is linked to the way how an emission factor is measured: an emission factor comes from the exhaust emission of a vehicle which followed a driving cycle on a dynamometer bench or on the road. Therefore to explain an emission factor we have to know the vehicle characteristics and the test characteristics, i.e. the driving cycle characteristics and the roller bench characteristics. The design of the database is basically made by 3 main tables and 2 secondary tables, shown Figure 1. The 3 main tables are:

- a vehicle identification through 103 parameters, providing information on the tested vehicles, such as testing laboratory, make, model, year of registration, size of engine, fuel type, etc.,
- a test identification through the vehicle and driving cycle identifications and 47 other test parameters, providing information on the measured tests, such as test date, technical details on the test procedure, dynamometer settings, etc.
- finally an emission identification through the test and pollutant identifications, the emission factor itself and its unit.

In complement to the main tables, 41 tables denoted as "G_xxx" provide additional information: see a more detailed design in Annex 7. In the following, a small selection of the “G_xxx” tables is listed:

G_cycle:	description of the cycles through 14 parameters, e.g., cycle names, lists of subcycles,
G_cycle_family:	name of the cycle family, e.g., Artemis cycles or Legislative cycles,
G_cycle_stat:	provides the statistics and kinematic parameters of each cycle,
G_EU_emis_standard:	lists the European emission standards each vehicle should be assigned to,
G_fuel_veh:	lists the fuel types of the included vehicles (e.g., diesel, petrol, LPG). A more detailed description of the fuel used for the particular tests can be found in *G_fuel_test*,
G_laboratory: l	aboratory names,
G_pollutant:	lists the pollutants (regulated and unregulated), described through 6 parameters,
G_veh_sample:	categorises the measurement campaigns (e.g., national program, Artemis, Particulates).

In each table, some parameters are compulsory. Each table contains a numerical identifier for simpler and faster handling of the data. For instance each vehicle has its own unique identifier. The identifier code provides information on the laboratory conducting the test and is derived as follows: two first digits (10 to 99) denote the laboratory identifier, the following four digits (0001 to 9999) denote the chronological number of the vehicle as provided by each laboratory.

The tables VEHICLES and TESTS are connected on the basis of a 1:n-relationship. This allows one vehicle to be measured for several tests. A counter named CHRONOLOGICAL_TEST-NB allows distinguishing the data of one vehicle measured several times for the same driving cycle. The EMISSION_DATA finally are assigned to the corresponding vehicle and test conditions using the vehicle identifier, the test identifier and the CHRONOLOGICAL_TEST-NB.

The present version of Artemis LVEM database is formatted as an Access XP-Database. It contains raw data (tables) plus some few queries giving an overview of the available data. There are no forms or macros included.

The actual emission factors are formatted using scientific notation to allow for a useful accuracy independent of their magnitude. They should be given in g km^{-1}. Detailed information on other fields' format and contents are given in the description of the respective tables.

2.4.3. Data submission

A datasheet provides the format that should be used when submitting data for the Artemis LVEM database. For every car involved, a separate copy of this Excel file should be used. This datasheet, detailed in Annex 8, contains five sheets:

- *README*: provides additional information and helps on how to use the datasheet.
- *car*: summarises the characteristics of the tested vehicle.
- *test xx*: describes the test characteristics of the tested car. One copy of this sheet is needed for each cycle tested.
- *instantaneous data test xx*: contains instantaneous data as a function of time. The use of this sheet for instantaneous data is recommended but not compulsory.
- *pollutant names*: lists the name convention for unregulated pollutants.

2.4.4. Data harmonisation

The database includes functions allowing to harmonise the emission data, to obtain comparable data. Four parameters are taken into account: the gearshift strategy, the vehicle mileage, the ambient air temperature, and the ambient air humidity. They are standardised at the following values, respectively: Artemis strategy, 50 000 km, 23°C, 10.71 g H_2O/kg dry air. These four test parameters were found to have a quantifiable influence on the emission level (Joumard et al., 2006a). The harmonisation is an option and in any case the raw data, non harmonised, remain in the database. These corrections are quite important, as shown Table 5, and can be much higher for vehicle sub-classes or individual tests.

	diesel						petrol					
	pre-E.	Euro 1	Euro 2	Euro 3	Euro 4	*mean*	pre-E.	Euro 1	Euro 2	Euro 3	Euro 4	*mean*
CO	0.92	0.97	0.83	1.07	1.00	*0.96*	1.02	1.01	1.30	1.06	1.20	*1.12*
THC	0.93	1.01	0.84	1.01	1.00	*0.96*	0.99	0.97	1.23	0.99	1.01	*1.04*
NOx	0.98	0.96	0.92	0.99	1.00	*0.97*	0.89	0.89	1.48	0.90	0.94	*1.02*
PM	1.00	1.00	1.01	1.00	1.00	*1.00*	1.00	1.00	1.00	1.00	1.00	*1.00*
CO_2	1.00	1.01	1.00	1.00	1.00	*1.00*	0.99	1.00	1.01	0.99	0.99	*0.99*

Table 5: Influence of the data harmonisation (ratio after / before) on the whole Artemis LVEM database, per pollutant and vehicle class.

In addition the total HC emission factor units can be harmonised in g eq. C_3H_8 or in g eq. CH_4 (see section 3.1.2). The difference is about 9 %.

2.4.5. Content

The Artemis LVEM DB merges emission data measured within the Artemis project itself plus data derived from other European measurement campaigns such as the Particulates database, the MEET data (data from INRETS, TNO, TRL, and LAT), the Handbook data (mainly EMPA, TUEV), OSCAR data (TRL, TNO), and additional INRETS and TNO data.

The present version of the Artemis LVEM database contains data of 2847 passenger cars and light duty vehicles, measured from 1980 to 2004. Their laboratories of origin are given in Table 6 together with the umber of vehicle-tests. Table 7 shows how the tested vehicles are distributed between different European emission standards and fuel types. With these vehicles, 12 685 tests were conducted when splitting up into the sub-cycle level, and 18 824 tests respectively when analysing the cycle-level. Regarding pollutants per vehicle and sub-cycle, 177 861 emission factors (g km^{-1}) have been derived, for 404 pollutants, which are detailed in Table 8. 25 430 among these emission factors concern unregulated pollutants.

André (2005) gives a more detailed description of the content of the database in terms of vehicle characteristics, driving cycles and pollutants (but for the database dated December 1st, 2004).

Laboratory	Country	Number of Vehicles	Number of Tests
ADAC	Germany	39	117
CNR-IM	Italy	13	457
EMPA	Switzerland	203	3838
Ford	Germany	1	14
IFP	France	4	98
INRETS	France	180	2294
KTI	Hungary	5	237
LAT	Greece	73	1026
MTC	Sweden	9	439
RW TUEV	Germany	293	1867
Shell	United Kingdom	4	643
TNO-Automotive	The Netherlands	1629	4508
TRL	United Kingdom	127	998
TUEV Rheinland	Germany	217	1417
TUG	Austria	21	290
VTT	Finland	29	581
Total (all laboratories)		2847	18824

Table 6: Number of vehicles and tests measured by each laboratory in the Artemis LVEM database. The tests are summed at the level of cycles.

emis. standard	petrol	LPG	CNG	diesel	biodiesel	Total
pre-Euro 1	901			231		1132
Euro 1	1227	7		68		1302
Euro 2	169	3		64		236
Euro 3	100	2	1	54	2	159
Euro 4	15		1	2		18
total	2412	12	2	419	2	2847

Table 7: Number of vehicles per emission standard and per fuel type in the Artemis LVEM database.

2.4.6. Public availability

In a first step, the Artemis LVEM database was developed and used only by the Artemis partners. After the completion of the project and with the authorisation of all providing laboratories, the main part of the database is now available for anybody. It is managed by INRETS, but could be managed in the near future by another partner laboratory.

The database is at the same time open for data submission, through the same laboratory.

group		Family	Number of pollutants
regulated pollutants			6
unregulated pollutants		metals	10
		nitro-PAH	68
		PAH	93
	VOC	aldehydes	18
		alkanes	77
		alkenes	51
		alkynes	9
		aromatics	61
		ketones	5
		ketones + aldehydes	2
		other	4
Total			404

Table 8: Number of pollutants per group and per family in the Artemis LVEM database.

3. Emission modelling

After a quick presentation of the shape of the emission model for the light vehicles, and of the pollutants considered, each sub-model is presented in detail, synthesizing a lot of reports.

3.1. General shape

The *Artemis* project is the following step after two inventorying model developments in Europe:

- The European MEET (Methodologies for Estimating air pollutant Emissions from Transport) project (Hickman et al., 1999) and the COST 319 action (Joumard, 1999). These research projects are the basis of the Copert 3 software, used in many countries.
- The German and Swiss emission model Handbook of emission factors HBEFA (Keller, 2004), mainly used in some countries.

The main shape difference between the MEET/Copert and HBEFA approaches is the taking into account of the kinematics: through the trip average speed in a continuous model for MEET/Copert detailed in Samaras and Ntziachristos (1998), but through discrete traffic situations in HBEFA based on instantaneous modelling.

A new method is presented here for synthesising the emission measurements from different laboratories, integrating former methods. In addition the pollutants taken into account and the emission units are presented.

3.1.1. Shape of the emission model

Some preliminary studies on the best way to take into account the explaining parameters of the emission data of passenger cars (Kadenko, 2001) compared three statistical methods such as “Linear parametrical identification”, “Linear regression” and “Non-linear regression: the Box-Cox model”. The last one was more suitable. This statistical work was completed by different authors, as presented in sections below.

Finally the Artemis model for light vehicles was improved a lot in comparison with MEET/Copert or HBEFA approaches, especially with different ways to take into account the driving behaviour for hot and cold start sub-models, beside the considerable amount of new emission data presented in section 2. The driving behaviour and more generally the traffic characteristics are presented in a parallel report (André et al., 2006a).

The emission model, whose scheme is presented in Figure 2, is the sum of 3 sub-models:

emission = hot emission + cold start emission + evaporation

All the models and sub-models consider as an input parameter the technical characteristics of the vehicles, and especially the fuel used and the emission standard: See Samaras et al. (2005a) for a detailed analysis of the influencing characteristics.

Hot emission

$$hot\ emission = f_K(kinematics,\ vehicle\ load,\ road\ gradient)\ .\ f_M(mileage)\ .\ f_T(ambient\ temperature)\ .\ f_H(\ ambient\ humidity)\ .\ f_A(auxiliaries)$$

For the passenger cars (PC), 4 parallel models are proposed to take into account the kinematics (and secondly the vehicle load and road gradient):

$$f_K(kinematics,\ load,\ gradient) = f_{K\ I\ PC}(instantaneous\ kinematics,\ vehicle\ load,\ road\ gradient)$$

or

$$f_K(kinematics,\ load,\ gradient) = f_{K\ A\ PC}(average\ kinematics)\ .\ f_L(vehicle\ load,\ road\ gradient)$$

or

$$f_K(kinematics,\ load,\ gradient) = f_{K\ TS\ PC}(traffic\ situation)\ .\ f_L(vehicle\ load,\ road\ gradient)$$

or

$$f_K(kinematics,\ load,\ gradient) = f_{K\ V\ PC}(average\ speed)\ .\ f_L(vehicle\ load,\ road\ gradient)$$

For light duty vehicles (LDV) a unique model is proposed:

$$f_K(kinematics,\ load,\ gradient) = f_{K\ LDV}(average\ speed,\ vehicle\ load)$$

$f_{K\ I\ PC}$(instantaneous kinematics, vehicle load, road gradient) is an instantaneous model, presented in section 3.2, with 2 parallel models: The EMPA model (section 3.2.1) and the PHEM model (section 3.2.2).

$f_{K\ A\ PC}$(average kinematics) is the so-called kinematic regression model presented in section 3.3.

The instantaneous and kinematic models are the best way to take into account the kinematics, but need quite complex kinematic data, either through the speed curve, or some average parameters.

$f_{K\ TS\ PC}$(traffic situation) is the so-called traffic situation model presented in the section 3.4. It is the main way to take into account the kinematics in an accurate but simple way.

$f_{K\ V\ PC}$(average speed) is the so-called average speed model presented in section 3.5. It is comparable to Copert, but less accurate than the traffic situation model.

f_L(vehicle load, road gradient) models the influence of the vehicle load and road gradient, and is presented in section 3.10.

$f_{K\ LDV}$(average speed, vehicle load) is the LDV model taking into account the kinematics and vehicle load, presented in section 3.7.

Cold start emission

A first model models the extra-emission per start (section 3.12.3). For a traffic, 2 models are proposed:

$$cold\ start\ emission = f_{COLD\ 2}(driving\ statistics,\ ambient\ temperature)$$

or

$$cold\ start\ emission = f_{COLD\ 3}(average\ speed,\ ambient\ temperature,\ season,\ hour)$$

The cold start models are presented in section 3.12, and more specifically in section 3.12.4.

$f_{COLD\ 2}$(driving statistics, ambient temperature) is the second cold start model taking into account the driving statistics in a very complex but accurate way.

$f_{COLD\ 3}$(average speed, ambient temperature, season, hour) is the third cold start model, based on an aggregation of the second one and therefore much easier to use.

Evaporation

evaporation = running losses + hot soak emissions + real time diurnal emissions

The model is briefly presented in section 3.13.

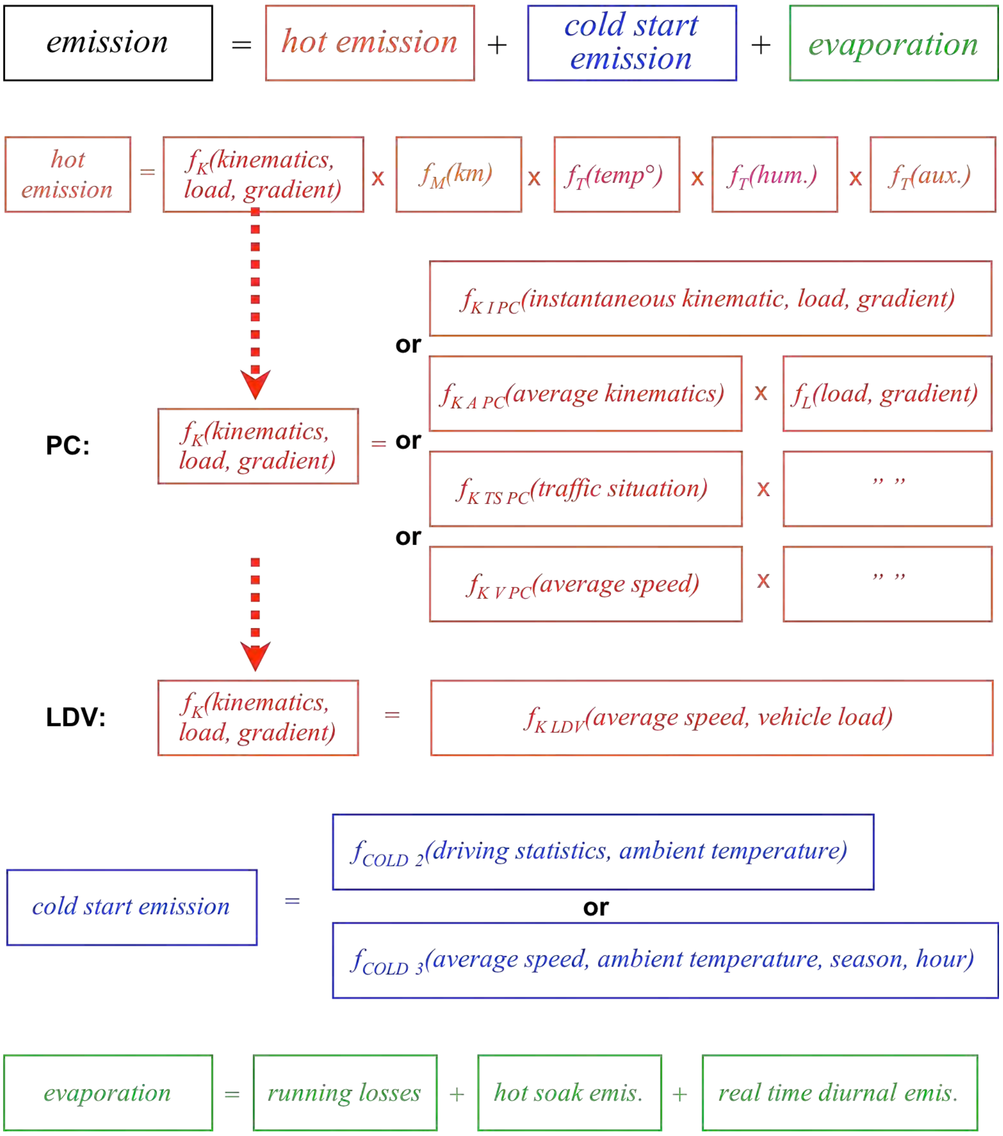


Figure 2: Shape of the emission model.

3.1.2. Pollutants and units

The name and the unit of each pollutant considered must be clear, not ambiguous and scientifically based. It is especially the case for some pollutants as CO_2, NOx, THC, groups of pollutants like alkanes... We consider the emissions of pollutants themselves and not of the pollutants after their physico-chemical transformations, which is out of the scope of this report.

For most of the pollutants, they correspond to a clearly defined molecule. Therefore the pollutant and the unit considered are not ambiguous. The unit is usually the mass emitted per distance unit, except when specified differently (particle properties for instance). For some pollutants, it must be specified.

For instance CO_2 is the carbon dioxide emitted at the end of the tailpipe and not the ultimate CO_2, whose calculation needs assumptions on the evolution of the pollutants, to be done by the users of the emission model. CO_2 emission factors are expressed in mass of CO_2 per distance or time unit. CO_2 emission could be also expressed in mass equivalent of carbon C, by a simple proportionality by the factor 12.0110 / 44.011.

An emission of carbon C can be calculated by carbon balance of all the pollutants emitted, expressed in mass of C per distance unit: it is proportional to the fuel consumption (see below), but with a specific equivalence unit.

NOx is the sum of NO and NO_2, expressed in mass equivalent NO_2 per distance unit.

HC or THC is the sum of all hydrocarbons, to be expressed in mass equivalent of a specified hydrocarbon per distance unit. We use in this report the mass equivalent propane C_3H_8, but is could be another hydrocarbon like methane CH_4. In this case, the following correction must be applied when to correct a mass expressed in eq. $(HC)_1$ into a mass expressed in eq. $(HC)_2$:

$$\frac{\text{mass in eq. }(HC)_2}{\text{mass in eq. }(HC)_1} = \frac{\text{molar mass }(HC)_2}{\text{C number of }(HC)_2} \times \frac{\text{C number of }(HC)_1}{\text{molar mass }(HC)_1}$$

$$= \frac{12.011 + 1.008.r_{H/C_2}}{12.011 + 1.008.r_{H/C_1}}$$

$r_{H/C}$ is the hydrogen / carbon ratio in the hydrocarbon considered. In the case of passing from eq. C_3H_8 to eq. CH_4, the correction coefficient is 1.091. The accuracy of HC measurements by flame ionisation is quite low: Although the method is based on the detection of the carbon atoms, the detection rate depends in fact on the hydrocarbon molecule.

The VOC and PAH species are expressed in real mass, for instance in g C_6H_{14}/km for hexane. emission factors. Concerning the groups of VOCs and groups of PAHs (see sections 3.1.3 and 3.1.4 resp.), the mass of the group is the sum of the masses of each pollutant concerned, without any equivalent unit like for NOx or THC.

The calculation of the fuel consumption should be done by the software by carbon balance, adding the different sources of carbon emission: CO_2 but also CO, HC, PM, considering hot and cold phases, and evaporation:

$$\frac{\text{fuel mass}}{12.011 + 1.008.R_{H/C \text{ in fuel}}} = \frac{\text{mass } CO_2}{44.011} + \frac{\text{mass CO}}{28.011} + \frac{\text{mass HC}}{12.011 + 1.008.R_{H/C \text{ in HC}}} + \frac{\text{mass particles}}{12.011}$$

$R_{H/C \text{ in fuel}}$ is the hydrogen / carbon ratio in the fuel considered. It is often 1.8 for petrol fuel and 2.0 for diesel fuel. The fuel consumption calculated can be expressed in any mass equivalent: mass equivalent $CH_{1.85}$ for petrol and diesel vehicles, or with different mass equivalences (but real ones) for petrol and diesel vehicles for instance. $R_{H/C \text{ in HC}}$ is the hydrogen / carbon ratio in unit HC is expressed. When mass HC is expressed in eq. C_3H_8, $R_{H/C \text{ in HC}}$ is 8/3. In any case the units have to be clearly mentioned.

The fuel mass can be transformed into a fuel volume, taking into account the average density for petrol (740 g/l) and diesel (830 g/l) fuels.

3.1.3. Volatile organic compounds VOCs considered

The emissions of the volatile organic compounds (VOC) are necessary to assess two environmental impacts of the traffic: the impact on the human health and the formation of photochemical oxidants.

Classification of VOCs according to their direct toxicity

The 1990 amendment of the US Clean Air Act mentioned some pollutants as Toxic air pollutants, whose PAHs and 4 VOCs are emitted by the traffic: benzene, 1,3-butadiene, formaldehyde and acetaldehyde. These 4 VOCs have very different impacts levels on the health: after an emission measurement campaign on 25 passenger cars, and using the lung cancer risk factors from USEPA, Flandrin et al. (2002) showed that, for the French traffic of the year 2000, the most toxic compound in highly dense areas for the lung cancer is the 1,3-butadiene, then benzene, then formaldehyde and finally acetaldehyde. More generally the US EPA (2000) gives 9 VOCs known as Mobile air toxics and Flandrin et al. give a list of 12 VOCs emitted by transport to be considered as toxic for the health: See Table 9. Naphtalene belongs to the second list, but was already included in the group of the 4 most volatile PAHs.

Compound	US EPA	Flandrin	Cassadou	Toxicity (IARC classification)
acetaldehyde	X	X	XX	possibly carcinogenic (2B)
acetone		X	x	
acrolein	X		XX	
benzene	X	X	XX	carcinogenic (1)
benzo[a]pyrene (PAH)	X		XX	
bromomethane			x	
1,3-butadiene	X	X	XX	probably carcinogenic (2A)
cumene		X		
1,2 dibromoethane			x	
ethylbenzene	X	X	x	possibly carcinogenic (2B)
formaldehyde	X	X	XX	probably carcinogenic (2A)
1,2,3,7,8,9 hexachlorodibenzodioxine			x	carcinogenic
n-hexane	X	X	x	peripheric nervous system
naphtalene (PAH)		X	x	
styrene		X	x	bone medulla, liver, possibly carcinogenic (2B)
2,3,7,8 tetracholodibenzo-para-dioxine			x	teratogene
toluene	X	X	x	teratogene (3)
xylenes	X	X	x	not classifiable as to its carcinogenicity (3)

Table 9: List of VOC considered as toxic for the human health (US EPA, 2000; Flandrin et al., 2002; Cassadou et al., 2004).

Recently a working group of the French ministry of health selected the hazardeous compounds to take into account for the health risk assessment from road infrastructures, after considering a long list of atmospheric pollutants (see Annex 9) (Cassadou et al., 2004). Emission factors were known for some compounds (Ntziachristos and Samaras, 2000a; Fontaine, 2000; Flandrin et al., 2002), and some compounds have reference toxicological values, but both lists do not correspond. By combining both lists, the working group calculated the score of each compound (emission factor x reference toxicological value). The 16 compounds with the highest score are selected, whom 6 are VOCs (Table 10).

In addition the group recommended research on the emissions of 3 compounds, because of the proximity of the reference toxicological values and the ambient concentrations and/or the high health hazard: monobromomethane, 1,2 dibromoethane, and manganese. The acetone was not selected because of too low emission factors, but as Denox systems should emit it, it would be usefull to select this coumpound. The ethylbenzene, n-hexane, naphtalene (PAH), styrene, toluene, xylenes were not selected because of too low emission factors. As these compounds have high reference toxicological values, it would be useful to provide emission factors more accurate than the existing ones. The 1,2,3,7,8,9 hexachlorodibenzodioxine (carcinogenic, one of the hexachlorodibenzodioxines) and 2,3,7,8 tetracholodibenzo-para-dioxine (teratogene, one of the tetracholodibenzodioxines) have also high reference toxicological values and should be taken into account. Therefore the compounds listed as additional ones in Table 10 should be considered in addition.

	1st level compounds	2nd level or additional compounds
Non VOC	arsenic	manganese
	baryum	
	cadmium	
	chrome	
	lead	
	mercury	
	nickel	
	nitrogene dioxide	
	particles (diesel)	
	sulfur dioxide	
VOC	**acetaldehyde**	acetone
	acrolein	monobromomethane
	benzene	1,2 dibromoethane
	benzo[a]pyrene (PAH)	**ethylbenzene**
	1,3-butadiene	1,2,3,7,8,9 hexachlorodibenzodioxine
	formaldehyde	**n-hexane**
		naphtalene (PAH)
		styrene
		2,3,7,8 tetrachlorodibenzo-para-dioxine
		toluene
		xylenes (= m-xylene + p-xylene + o-xylene)

Table 10: Compounds with the highest score (1st level – Cassadou et al., 2004), and additional compounds to consider. Pollutants in green bold correspond to emission factors proposed in section 3.6: particles, five 1st level VOCs (BaP excluded), 8 VOCs (BaP excluded).

The particles should be expressed according to different parameters (Samaras et al., 2005b), as the integrated active surface of the total particle population, the total particle number, the particle size distribution, the number of solid particles in different size ranges (aerodynamic diameter of 7-50 nm, 50-100 nm and 100 nm - 1 µm for instance).

Classification of VOCs according to their ozone forming potential

The second interest of the VOC species is for smog modellers to assess the formation of photochemical oxidants, which have themselves, as secondary pollutants, health impacts among other impacts. The different VOC species contribute very differently to the ozone and other oxidants formation. Carter and Atkinson developed in 1987 a scale of Maximum Incremental Reactivity (MIR) in order to assess the ozone forming potential of any emitted molecule, so-called

OFP, which is defined by OFP = Σ (MIR x EF), according to the emission factors EF. Such method was used often to assess the ozone formation potential of the VOC emission from a traffic. Carter (2000) updated the MIR factors: See Annex 10. This scale is developed for low VOC/NOx ratios, when the ozone formation is more sensible to VOC concentrations. As each VOC specy has a specific MIR, it is justified to present as possible VOC emission factors per VOC compound.

It should be noted that, at the moment, the Carter proposal is the best one, but has been obtained following a theoretical modelling exercise using US input data from South California field, and an analysis using a specific photochemical mechanism: It is not stiff and should not be considered universal. Consequently this choice is clearly submitted to evolution and progress in this field.

Moreover the choice of the VOC species in the Artemis model depends on the actual VOC molecules which have been sampled and titrated by the various Artemis teams, which differ from a laboratory to another (see below).

When we calculate the OFP per VOC for different vehicle types for the motorway driving (Annex 11), it can be concluded that alkenes (olefins) and monoaromatics are fully necessary to be measured, for diesel as for petrol cars. In addition, aldehydes+ketones (= carbonyl compounds) should not be omitted for the diesel cars (with or without oxydation catalyst) because they are at the head of the two tables (formaldehyde and acetaldehyde).

The family of volatile organic compounds groups a vast array of molecules, which are classically classified as shown in Table 11.

VOC group	number in Annex 9
- alkanes (saturated)	64
- alkenes and alkynes (unsaturated)	46
- monoaromatic hydrocarbons	37
- polyaromatic hydrocarbons (light and heavy)	13 and 42
- carbonyl compounds (aldehydes and ketones)	23
- ethers	4
- POP (persistant organic pollutants)	8
- dioxines and furanes	5 and 5

Table 11: Groups of VOC, as listed in Annex 9. The groups with the highest ozone forming potential OFP are in orange.

We can also divide these compounds into hydrocarbons of low molecular weight called "light" (C_2 to C_6), and hydrocarbons of high molecular weight called "heavy" (C_6 to $C_{15\text{ and }+}$).

The models of ozone used in the past only groups of VOC; The new ones use the species themselves, differentiating the species inside each group, with different MIR as shown in Annex 10. Therefore we should express the emission factors per compound, and if possible per group. The advantage to express the emission factors per group is the possibility to extrapolate the emissions more easily.

VOCs reported as emission factors

Artemis produced data on a huge number of different unregulated compounds and especially VOCs (Aakko et al., 2005; 2006; see section 3.6.1). The list of individual compounds analyzed, however, varied from laboratory to another. But VOCs analyzed at different laboratories build up an inharmonic set of data. Clear differences were seen in the emission levels obtained at different laboratories for some pollutants. In addition, some suspected outliers were found. Thus ozone forming potential could not be calculated collectively from the Artemis database, but is however reported by the laboratories as specific reporting to ensure correct and reliable conclusions.

On the other hand, many individual VOC compounds, like benzene and formaldehyde, were analyzed extensively at all five laboratories that participated in the program.

It was necessary to select the species, which can be regarded as most important, most informative and most representative when limitations of Artemis data are taken into account. These VOCs are listed Table 10: they are all the 6 first level VOCs and 4 among the second level additional VOCs.

But the Artemis database includes a number of pollutants that does not belong to this short list. These results, e.g. ozone forming potential, cold temperatures, and FTIR results, will be reported later on or in specific reporting by laboratories as shown in Table 12.

Thus further analysis on the unregulated emission database would be beneficial.

Specific reporting	references
individual VOCs other than reported in this report	Caplain et al., 2004; 2006; Heeb et al., 2002; Joumard et al., 2004a; 2004b; Prati et al., 2003a; b; 2005; Stettler et al., 2004
ozone forming potential	Caplain et al., 2004; 2006; Joumard et al., 2004a; 2004b
the group of the 4 most volatile PAHs	Devos et al., 2006; Joumard et al., 2004a; 2004b; Paturel et al., 2003; 2005
group of 12 least volatile PAHs	Devos et al., 2006; Joumard et al., 2004a; 2004b; Paturel et al., 2003; 2005
individual PAHs other than benzo[a]pyrene	Devos et al., 2006; Joumard et al., 2004a; 2004b; Paturel et al., 2003; 2005; Prati et al., 2003a; b; 2005
PAH results divided into gaseous and particulate phases	Devos et al., 2006; Joumard et al., 2004a; 2004b; Paturel et al., 2003; 2005
nitrogen containing compounds (N_2O, NH_3)	

Table 12: Specific reporting on unregulated pollutants by participating laboratories.

3.1.4. Polyaromatics PAH considered according to their toxicity

16 PAHs are recommended to be analysed by the US Environment Protection Agency according to their carcinogenic and mutagenic power: See Table 13 their list and their classification by the International Association for Research on Cancer (IARC, 1983; 1987) according to their toxicity. The group, defined here, of the 6 most carcinogenic PAHs among the 16 PAHs contains all the PAHs classified in 1987 by IARC as probably (group 2A) or possibly (group 2B) carcinogenic. We should note that the IARC classification has changed recently (IARC, 2002; 2006): We have now 1 PAH (BaP) classified 1, 1 PAH classified 2A and 7 PAHs classified 2B: 3 PAHs (BjF, Chr, N) should now belong in addition to the group of the most carcinogenic PAHs. In parallel the group of the 4 most volatile PAHs, with the lightest molecular weight (N, Ace, Flu, Acy), are analysed with difficulty because the losses are important. Therefore the accuracy of their emission factors is low. Most of the authors do not give any result for them. The 12 other PAHs should therefore be considered as the group of the 12 least volatile PAHs, including the group of the 6 most carcinogenic PAHs. The benzo[a]pyrene (BaP) belongs to both groups of the 12 least volatile and 6 most carcinogenic PAH. It is the PAH measured the most often because it is very easy, and therefore the most known PAH. It is also the only PAH classified now as carcinogenic (class 1). Therefore specific emission factors should be provided for BaP.

A recent European directive (2004/107/EC of 15 December 2004) asks the Member States to monitor at least 7 relevant PAHs at a limited number of measurement sites (see Table 13), i.e. the 6 most carcinogenic PAHs and the BjF. BghiP is also an indicator of the petrol emissions, with IP.

In addition we could differentiate PAHs as gaseous and particulate phases. Both phases are present in the 3 groups with ratios from 20 to 80 % for Euro 2 vehicles (Joumard et al., 2004a; 2004b).

The different groups of PAHs are given in Table 13.

full name	short name	IARC classification		USEPA	2004/107/EC	4 most volatile	12 least volatile	**6 most carcinogenic**
		1983; 1987	2002; 2006					
acenaphthene	Ace	-	-	X		Ace		
acenaphthylene	Acy	-	-	X		Acy		
anthracene	An	3	3	X			An	
benzo[a]anthracene	BaA	2A	2B	X	X		BaA	BaA
benzo[a]pyrene	**BaP**	**2A**	**1**	**X**	**X**		**BaP**	**BaP**
benzo[b]fluoranthene	BbF	2B	2B	X	X		BbF	BbF
benzo[g,h,i]perylene	BghiP	3	3	X			BghiP	
benzo[j]fluoranthene	BjF	-	2B		X			
benzo[k]fluoranthene	BkF	2B	2B	X	X		BkF	BkF
chrysene	Chr	3	2B	X			Chr	
dibenzo[a,h]anthracene	DBahA	2A	2A	X	X		DBahA	DBahA
fluoranthene	F	3	3	X			F	
fluorene	Flu	3	3	X		Flu		
indeno[1,2,3-c,d]pyrene	IP	2B	2B	X	X		IP	IP
naphthalene	N	-	2B	X		N		
phenanthrene	Phe	3	3	X			Phe	
pyrene	P	3	3	X			P	

Table 13: List of PAHs proposed by USEPA and the European directive 2004/107, the 12 least volatile PAHs and the 6 most carcinogenic, according to the IARC classifications for humans (group 1: carcinogenic, group 2A: probably carcinogenic, group 2B: possibly carcinogenic, group 3: not classifiable as to its carcinogenicity, group 4: probable non- carcinogenic). Pollutants in green bold correspond to emission factors proposed in section 3.6.

PAHs reported as emission factors

As for VOCs, the PAH Artemis database is an inharmonic set of data, with large differences between laboratories. Therefore only the benzo[a]pyrene and the sum of the 6 most carcinogenic PAHs are considered (see Table 13) when providing emission factors in section 3.6.

In addition the participating laboratories did specific reporting as shown in Table 12, using only the data whose they are the source.

3.1.5. Nitrogen oxydes

Most of the NOx in vehicle exhaust is usually present as NO, whereas most of the NO_2 in the atmosphere is formed by the reaction of NO with ozone (O_3). In ambient roadside air, NO_2 levels are generally limited by the local concentration of O_3 rather than the emission of NO from vehicles. The NO_2 which is emitted directly from vehicle exhaust is commonly referred to as 'primary NO_2'. Even though NO_2 is an important pollutant there is surprisingly little information on direct emissions. It is generally assumed for air quality modelling purposes that the proportion of NOx in vehicle exhaust which is emitted as NO_2 is 5 % (volume fraction). The figure of 5 % was based on relatively old measurements, from vehicles without after-treatment system. However, laboratory work, remote sensing studies, tunnel studies and ambient air pollution measurements have indicated that the actual proportion varies according to factors such as vehicle type, operating condition, and the measurement method, and can be much higher than 5 %, especially for diesel vehicles (Latham et al., 2001; Jimenez et al., 2000; Kurtenbach et al., 2001; Jenkin, 2004; Carslaw and Beevers, 2004; Carslaw, 2005). It has also been suggested that recent increases in the NO_2 proportion in NOx from diesel vehicles are linked to exhaust after-treatment devices, such as oxidation catalysts and continuously regenerating traps (CRTs) (e.g. Carslaw and Beevers, 2004). A recent working group raised the same conclusion in the UK (AQEG, 2006).

These issues highlight the need for investigating the direct NO_2 emissions from the current vehicle fleet in order to be able to assess the process leading to stagnation in the downward trend in annual mean NO_2 concentrations (see section 3.6.3).

3.1.6. Particulates

Current vehicle type-approval legislation requires the filter-based measurement of total mass of particulate matter (i.e. g/kWh for heavy-duty engines and g/km for light-duty vehicles) and applies only to vehicles powered by diesel engines. However, there are a number of reasons why alternatives to a standard based on total mass alone are desired, and why the emphasis may change from particle mass to other metrics relating to particle size, number and surface area. For example, the mass concentration of particles in the exhaust of diesel engines has reduced steadily over the last 20 years following the development and application of new technologies. Current and future legislation is reducing particulate mass emissions, and diesel targets, towards the threshold of reliable measurement. Standards based solely on total particulate mass are not ideal in terms of minimising the risks to health, as the size of particles determines how deeply they penetrate into the human respiratory system and where they are deposited. Conventional filter methods for assessing total exhaust particulate matter do not provide meaningful information on the ultrafine particles (smaller than 0.1 µm), which contribute little to the total mass.

3.2. Instantaneous models

There are basically two types of emissions and fuel consumption models: one based on bag measurements and the other based on instantaneous measurements. Bag measurement procedure consists in drawing the entire content of the tailpipe exhaust into a constant volume sampling (CVS) system, where it is diluted with fresh air and, afterwards, a representative sample is put into bags. The analysis of the bags gives a single overall figure for each emission, representing the total mass of emission produced over the driving cycle.

In an instantaneous (modal) emission model, the emissions and other vehicle-related data (vehicle speed, engine speed, etc.) are collected on a high time resolution (one to ten samples per second). When integrated over the driving cycle, the instantaneous emissions data should be equivalent to the bag results.

Emission models based on bag values give results for the driving pattern similar to the one used to fill the bag. If the driving behaviour changes, new measurements with comparable driving patterns have to be performed. To account for the additional effects as load, slope or gearshift strategies, bag based models include correction functions. However, these correction functions are based on a small number of measurements with few vehicles, which may not be representative for the emissions behaviour. Moreover, the combination of these correction factors (i.e. when a vehicle drives uphill with a full load) can be extremely misleading.

Instantaneous emission modelling maps the emissions at a given time to their generating "engine state", like vehicle speed, engine speed, torque, etc. This makes it possible to integrate new, unmeasured driving patterns over the model and calculate their emission factors without further measurements. Thus, emission factors for a large number of driving situations can be determined from a small number of measurements.

Examples of instantaneous emission models for light-duty vehicles can be found in Joumard et al. (1995a) and Barth et al. (1996), but their accuracy was questionable (Sturm et al., 1998). Two new models were built within Artemis: a first EMPA model and a second PHEM model (Zallinger et al., 2005a).

3.2.1. EMPA model

A first approach for characterizing light-duty vehicle modal events is to set-up an emission matrix based on engine speed *n* [rpm], brake mean effective pressure *bmep* [bar] and the derivative of manifold pressure $\dot{p}$ as dynamic variable able to express the transient generation of emissions (Ajtay and Weilenmann, 2004a; Ajtay, 2005). This matrix provides the instantaneous emissions and fuel consumption for different combinations of instantaneous *n*, *bmep* and $\dot{p}$. The brake mean effective pressure can be considered as "scaled" engine torque size since:

$$bmep = \frac{T_e 4\pi}{V_d}$$

where V_d = displacement volume of the engine
T_e = engine torque
4 = number of strokes per engine cycle

Thus the brake mean effective pressure is equal for different engines when running in similar operating points (unlike torque) and is useful for comparison of different cars.

For the model development, data of 3 classical petrol vehicles of pre Euro-1 level, 10 petrol cars with three way catalyst of Euro-3 level, and 7 Euro-2 diesel vehicles were available (see section 2.1.2, Annex 3 and Annex 4). Each car has been measured according to a program that includes sixteen different real-world driving cycles (see section 2.1.3.). Each of the considered cycles accounts for a different driving pattern, like urban, rural, highway driving, etc. During the measurements, emission signals (CO, CO_2, HC, NOx) and all other engine related signals (vehicle speed, engine speed, vehicle torque, etc.) were logged at a frequency of 10 Hz.

For each cell of the *bmep* x *n* x $\dot{p}$ matrix (11 x 14 x 9 cells), the emission or fuel consumption rates *e* are averaged to give a mean value. Instantaneous emissions and fuel consumption are afterwards estimated by interpolating values from the corresponding combination of *bmep*, *n*, and $\dot{p}$:

$$e\ [g/s] = f(bmep, n, \dot{p})$$

Such *bmep* x *n* x $\dot{p}$ maps are built for the fuel consumption and the emissions using the same time basis as for the input signals. The basic model outputs of this model are the instantaneous fuel consumption and emissions at their location of formation (catalyst-out or engine-out). For this purpose the emission signal after the catalyst is built from the emission signal measured after the CVS (Weilenmann et al., 2002b; 2003a; Ajtay et al., 2003; 2004; 2005; Ajtay and Weilenmann, 2004b; Le Anh et al., 2005a and b; Joumard et al., 2006a), so that emissions at their location of formation could be properly related to the engine variables. The objective is not to have a good prediction quality at each time step, but only the integrated emission results of a cycle of several minutes duration to be reasonably accurate.

Validation

The developed model has been validated in a two level procedure: Firstly by a cross validation method, secondly by comparing measured and calculated emissions for new tested cars.

For the first model verification, a cross validation method was used. Fifteen of the measured cycles were used to develop the vehicle emission maps and the sixteenth left cycle was used for the verification of the model. Thus, its emission factors were calculated from the model and compared afterwards to the measured values. This was done for two cars and choosing different cycles as verification cycles.

The numerical qualification of the model is performed by calculating R^2 and the normalised mean square error NMSE

$$NMSE = \overline{\left(E_m - E_p\right)^2} \Big/ \left(\overline{E}_m\,\overline{E}_p\right)$$

Here E_m and E_p represents the measured and predicted emission factors for all the sixteen cycles.

These results indicate a very good agreement in both integrated results and the instantaneous comparison.

In order to assess the application of the model at fleet level, the prediction quality of the emission factors for each vehicle category is studied by averaging the results obtained for individual vehicles, in the case of the static model (according to *bmep* and *n* only).

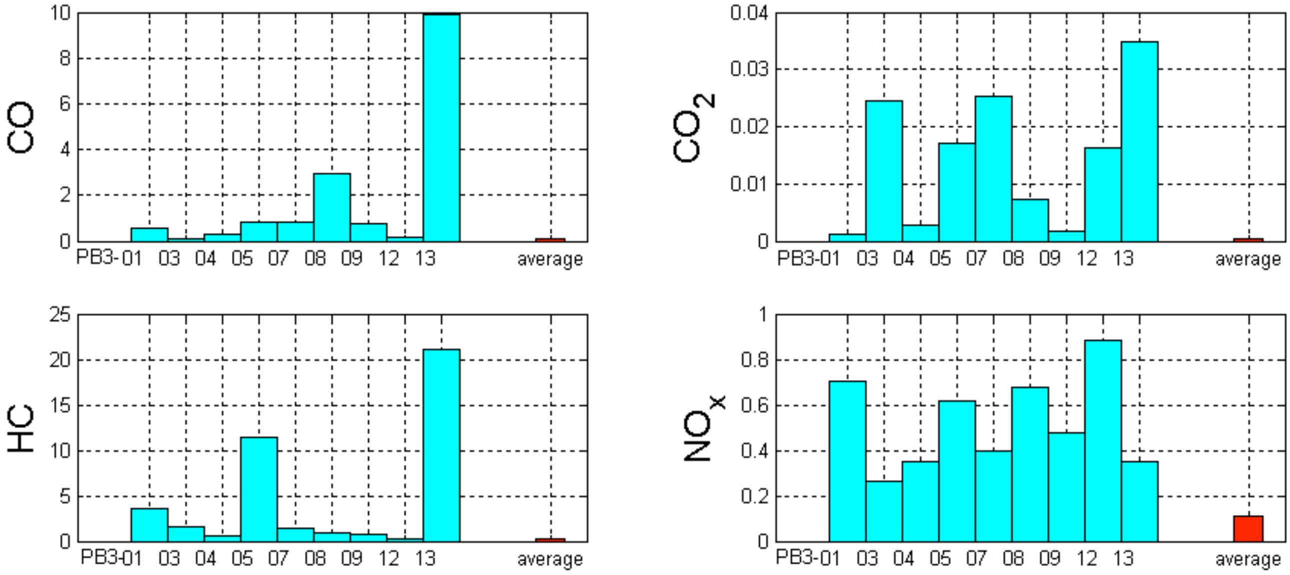


Figure 3: Normalised mean square error for Euro 3 petrol vehicles (blue) and for average Euro 3 petrol car (red).

For the further use of the instantaneous emission models not just at micro-scale level, but also at meso-scale level, the prediction quality of the emission factors for each vehicle category is studied by averaging again the results obtained for individual vehicles. Figure 3 shows this statistical measure for each individual vehicle and for the average vehicle at each vehicle class, in the case of Euro 3 petrol vehicles. For all vehicle classes, the error becomes smaller, in the sense of lower average error (smaller *NMSE* value) and higher correlation (bigger R^2), when compared to individual vehicles. Therefore, these errors in prediction can be considered as random and not systematic (Ajtay and Weilenmann, 2005b). Thus the instantaneous emission models could be used at meso-scale level, such as for city or regional level.

For the second level validation, extensive vehicle measurements of three Euro 3 petrol vehicles and of one Euro 3 diesel car are available. For each vehicle, the measurement program included 16 basic cycles which were used to develop the vehicle instantaneous emission model. Beside that, eighteen traffic situations with different vehicle loadings (medium or full load), different slopes of the road (uphill or downhill), different gear-shift strategies and combinations of them were also measured. Each of these traffic situations accounts for a different driving pattern like urban, rural, highway driving, etc. To verify the model quality, the emission factors for each cycle were simulated using the developed emission matrices and the so predicted emission factors were compared to the measured values (Ajtay and Weilenmann, 2005a).

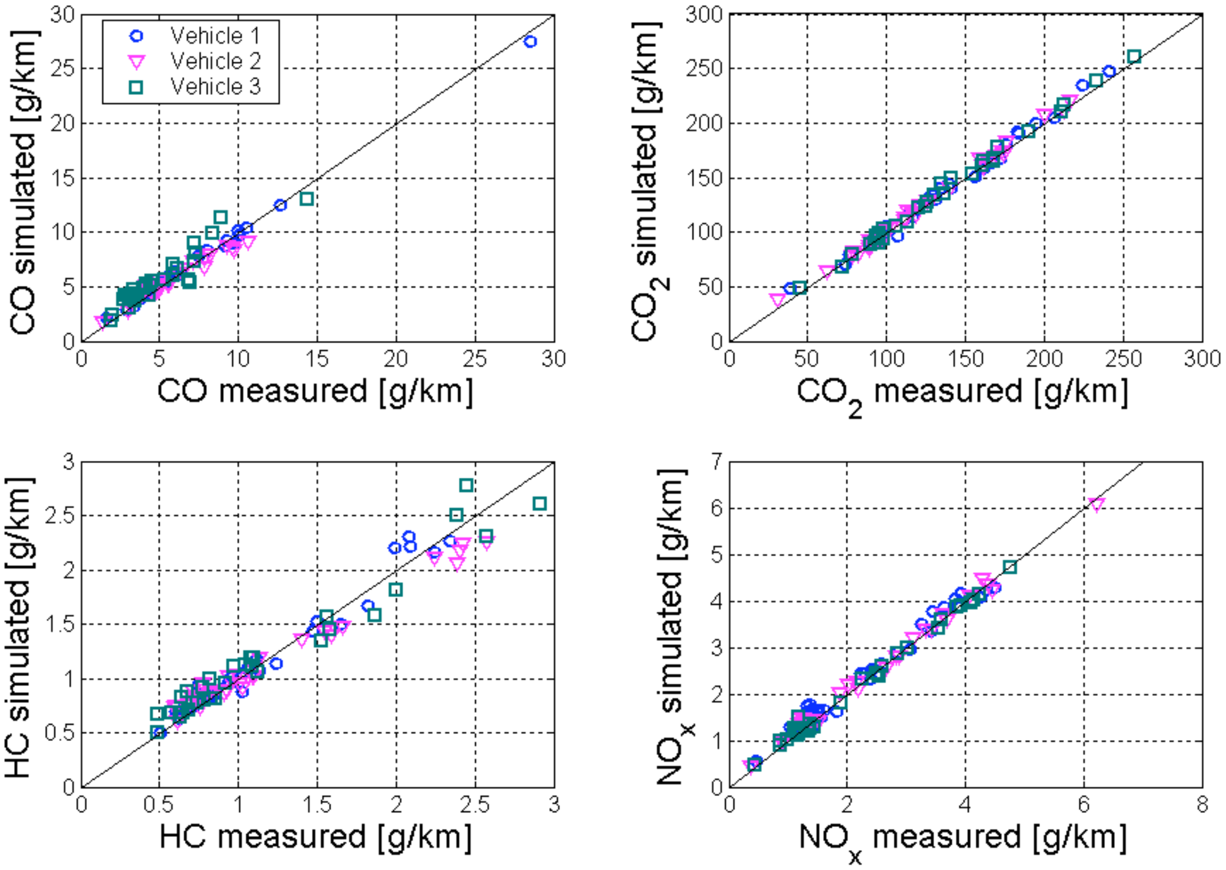


Figure 4: Simulation quality for the engine-out emission factors of the three Euro 3 petrol vehicles with the EMPA instantaneous emission model. A point represents a driving pattern.

The results show excellent prediction quality for the engine-out emissions of the petrol vehicles (Figure 4). For the diesel vehicle, the quality of the simulation is very good for CO_2 and for NO_x and satisfactory for HC and CO (Figure 61 in Annex 12). However, this result is predictable since the CO analyzer is calibrated at a range of 5% and the CO emissions of this vehicle are significantly lower.

No extrapolation of data points is possible in the map, which is the basis for the model due to the highly nonlinear character of the problem. Thus, measurements should be designed to add extreme points in the map, in order to be able to predict situations with different slopes of the road and loading of the vehicle.

3.2.2. PHEM model

The TUG approach involved the definition of an emission matrix based on engine speed n [rpm] and effective engine power P [kW] (Zallinger et al., 2005a and b).

To generate the emission matrixes the instantaneous emission measurements on the roller test beds in the Artemis cycles are used. In the first step, as in the previous section, the measured instantaneous emissions are corrected from the time delay of the analyzer and the variable transport time in the measurement system according to Le Anh et al. (2005) or Joumard et al. (2006). In the second step, the instantaneous emissions are allocated to the corresponding engine load and engine power value for each second in the test cycle. As a result 2638 values for the emission map are obtained from the Artemis cycles (i.e. one point per second). From the measured points in the engine map the emission values for a defined matrix are then interpolated using a modifies Shepard method. This method is preferred to simply rasterize the measured values into a grid of the engine map since the interpolation method does not leave cells blank and is in line with the calculation applied for simulating the vehicle emissions from a given driving cycle.

To simulate fuel consumption and emissions in any other cycle than in Artemis ones, the actual engine power and the engine speed are simulated in 1 Hz resolution and the corresponding emission value is interpolated from the emission matrix.

The engine power P is simulated second per second, based on the driving resistances and the transmission losses:

$$P = P_{rolling\ resis\tan ce} + P_{air\ resis\tan ce} + P_{acceleration} + P_{road\ gradient} + P_{transmission\ losses} + P_{auxiliaries}$$

The formulas used are described in the final report of the Heavy Duty Vehicle part of Artemis (Rexeis et al., 2005), since the simulation routine is similar for cars and HDV.

The actual engine speed is calculated from the transmission ratios, the wheel diameter and the gear shift rules from the actual test cycle. For the simulation of real world driving a driver gear shift model is included.

To improve the accuracy of the model, the interpolated emission values are corrected in a final step for the "dynamics" of the actual cycle. This transient correction function explains different emission levels at similar engine loads as a function of differences in the engine load course between one to 40 seconds before the emission happens (Zallinger et al., 2005a and b).

Cold start extra emissions are simulated by the model based on a simplified heat balance of the engine and the exhaust gas after treatment system. The temperature of the coolant and of the catalyst are calculated as function of the heat losses Q_l. Q_l is the difference of the energy flow delivered by the fuel and the actual engine power output. The cold start extra emissions are then interpolated from emission matrices as function of the actual temperatures and the engine power. The emission matrices are set up also from the measurements of cold starts on the roller test beds where the relevant temperatures have to be measured too.

At the end of 2006 the model PHEM includes input data for 32 single passenger cars (21 vehicles tested within the Artemis project, then 11 vehicles tested outside Artemis). From this data "average passenger cars" are generated for Euro 0 to Euro 4 for petrol and diesel. The user can either simulate single vehicles or average vehicle fleets. The model PHEM also offers an interface to micro traffic models where the total vehicle fleet (passenger cars and heavy duty vehicles) can be simulated in all relevant driving conditions.

Validation

The validation of the model for the simulation of different road gradients was done in Zallinger and Hausberger (2004). In the following, some validation results for different driving cycles are described.

For the validation, the average emissions measured in 12 Handbook driving cycles for 5 Euro 2 diesel and 6 Euro 3 petrol cars were compared with the simulation results for resp. the average Euro 2 diesel car (see Figure 62 in Annex 12) and the average Euro 3 petrol car (see Figure 5). The engine maps for the average cars were created using the instantaneous measurements resp. of eight diesel cars in the Artemis driving cycles and six Euro 3 petrol cars in the Handbook driving cycles. From the engine maps of the single cars, simply the average for each map point was calculated to establish the average engine map for a vehicle category. In the simulation the average vehicle characteristics (mass, drag coefficient etc) were used together with the average engine map.

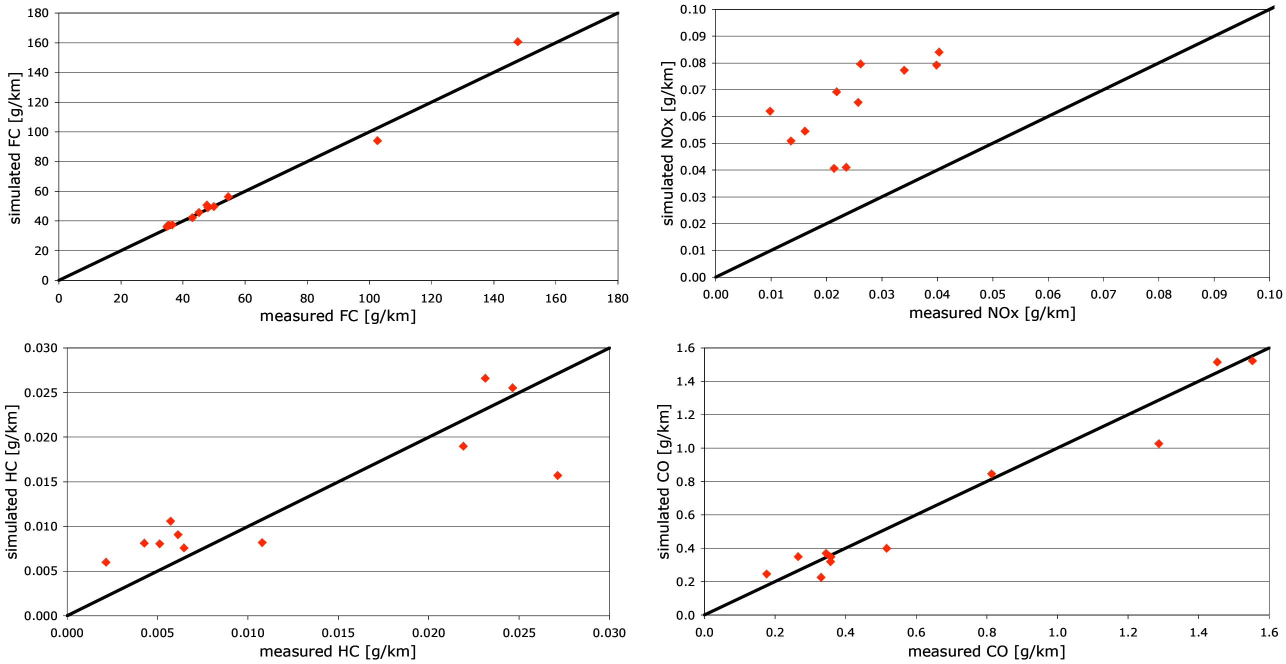


Figure 5: Simulation quality for the emission factors of the average Euro 3 petrol car in the instantaneous model PHEM.

The results of the average diesel car already show a high accuracy for fuel consumption and NO_x and adequate results for HC, CO and particulate mass even without transient correction functions. Similar results were gained for all single diesel cars. Since the engine maps were created from a completely different set of measurements (Artemis) than the simulated cycles (Handbook) in terms of gear shift rules and acceleration values, the model for diesel cars seems to be very reliable.

The results of the average petrol car show that for fuel consumption, CO and HC the accuracy of the simulation is already good. The reasons for NO_x overestimation are still not clear. But the very low absolute values have to be taken into consideration, when looking at the deviation between measurement and simulation.

3.2.3. Conclusion of instantaneous models

Emission models based on mapping the emissions onto engine speed and brake mean effective pressure (or engine torque) were developed at EMPA and TU-Graz. Both models give accurate results for the pre Euro 1 petrol and for diesel vehicles. However, the prediction quality using this static map is not satisfactory for three-ways catalysts vehicles. Since emissions of modern catalyst cars are very low in regular hot conditions and some short peaks, which mainly occur during transient loads, dominate the overall emission factor.

To predict such emission peaks, the models were extended by adding transient corrections. The EMPA model uses as dynamic variable the derivative of the manifold pressure. Using this dynamic map the engine-out emissions are very well predicted. A catalyst model is being furthermore considered which has as basic approach the modelling of the oxygen storage and release phenomena. The PHEM model uses empirical transient correction functions based on several transient parameters, such as derivates of the engine power and engine speed over different time spans.

Considering fleets (groups) of vehicles, the quality of the models improves compared to the individual vehicle, even with a small number of vehicles. This proves that the errors in the individual vehicle models are random and not systematic. Thus, the two instantaneous emission models elaborated, although rather complex to develop, are able to predict contributory aspects like load, slope or different gear-shift scenarios, without introducing any ambiguous correction functions as it is usual for the bag based models.

For the model PHEM, already average engine maps and transient correction functions for Euro 0 to Euro 4 were elaborated, allowing the simulation of fleet emission factors for passenger cars. The model was used to assess the correction factors for road gradients and vehicle load (see section 3.10).

3.3. Kinematic regression model

The general objectives of this activity presented in detail in (Della Ragione et al., 2003; Rapone et al., 2003; Rapone et al.; 2005a to e; 2006a; b) were:
- To analyse emissions data of different combination of vehicle type and driving behaviour in a large data base,
- To develop a prediction model capable to evaluate emissions relative to a micro-trip as a function of kinematic parameters detectable by urban, rural or highway micro-trip speed profile, as obtained for example either by on-road records or by micro-simulation programs.

3.3.1. Data

We have considered the full data set of emission data available in the Artemis data base (see section 2.4). That means to consider besides data obtained within Artemis tasks (detected under operating conditions assumed as reference ones, without considering emission data obtained with specific treatment relative to the assessment of different factors, as humidity, temperature etc.), also data relative to different projects and delivered by all laboratories.

Emission data considered are relative to emission measurements performed utilizing complete driving cycles and sub-cycles. Driving cycles considered in the analyses are Artemis Motorway (1-4), Artemis Rural (1-5), Artemis Urban (1-5); Handbook (R1-R4); Oscar (C, D1, D2, E, F, G1, G2, H1, H2, H3); TRL Motorway, Sub-urban and Rural, Urban; TUG; Modem (urban5713, road_total);

Napoli (10_23; 15_18_21; 6_17); LDV_PVU. They are reported in the Figure 6, ordered by mean speed.

Vehicles of data base have been grouped into classes making reference to homologation (Euro 1 to 4) and engine displacement. Three displacement classes have been considered (1200-1400, 1400-2000, > 2000 cm^3) when data were consistent, otherwise data were grouped in larger classes.

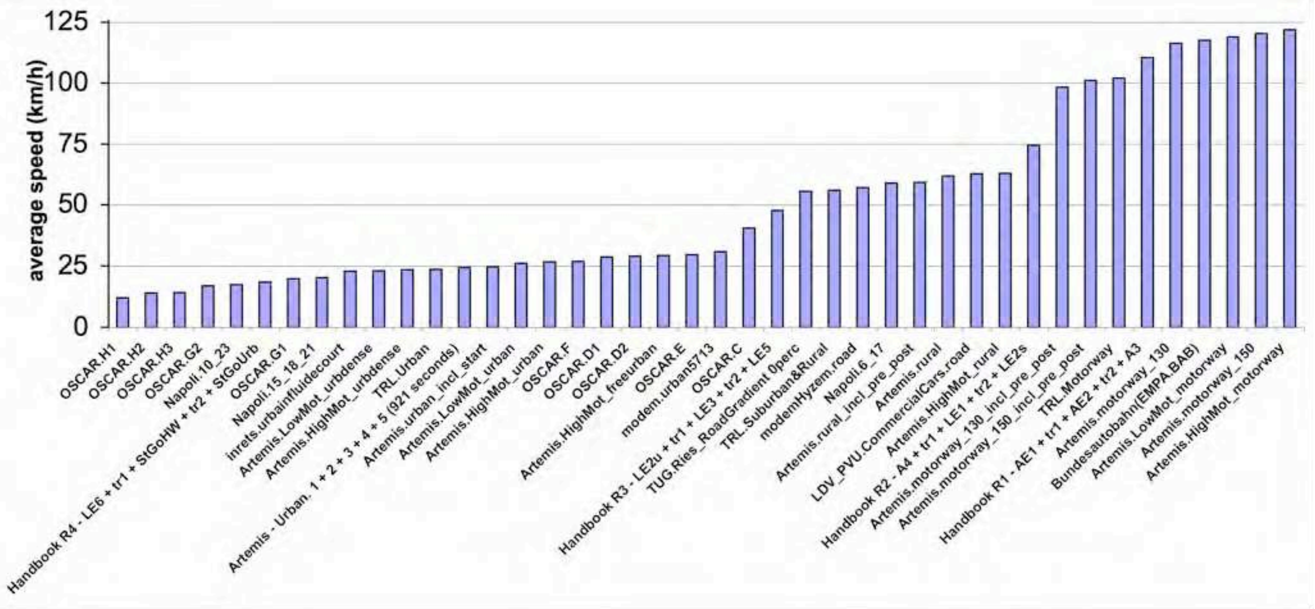


Figure 6: Diagram of driving cycles used for developing the kinematic model, ordered by mean speed.

3.3.2. Method

Firstly, an analysis of variance was carried out on the whole set of data to examine the effects of driving cycle, emission standard and engine size (assumed as qualitative factors) on emissions, and to estimate the amount of emission variability contributed by each factor.

Then, for each case study, the effect of driving cycles on emission factors is estimated as a function of kinematic parameters, calculating regression models. To this end an analytical model has been developed using a consistent set of kinematic parameters and a multivariate regression method based on principal components (Rapone, 2005).

The considered emission is the unit emission mass of CO, HC, NOx, CO_2 and PM (only for diesel) measured in a driving cycle, expressed in g/km. A log-transform of these emissions was applied in the regression because driving cycle emission quantities are close to zero with large coefficient of variation and because analysed emission data result generally distributed according to a lognormal distribution, moreover this transform better explains non linear relations of response with explicative variables.

The explicative variables characterize the kinematics of driving cycles: They were determined considering two complementary ways of explaining emission variation: the exhaust mass, function of total energy spent by vehicle in a driving cycle, and the frequency of acceleration events at different speeds. Hence, variables were divided into two conceptually meaningful blocks.

The regression models used were based on the following two blocks of variables:

- Block 1 of 7 variables, referring to variables defined from the dynamic vehicle equation, plus idling time to consider emission production during vehicle stand still and the reciprocal of driven distance to take into account that response variables are unit emissions:

mv: average running speed ($v>0$) [km/h]
mv2: average of the square speed($v>0$) [$(km/h)^2$]
mv3: average of the cube speed ($v>0$) [$(km/h)^3$]
t_{idle}: idling duration ($v=0$) [s]
$t_{running}$: duration at running speed (driving speed without stops) [s]
mva: average product of instantaneous speed and acceleration (with $v(t)>0$ and $a(t)>0$) [m^2/s^3]
1/d: reciprocal of the trip length d [m^{-1}]

- Block 2 of 42 variables, summarizing kinematic acceleration events, which especially affect CO, HC and NOx emissions, proposed and used to analyse and determine Artemis driving cycles on the basis of a wide collection of real driving cycles sampled in on road tests (André, 2004):

$f_{va}(v, a)$: Two-dimensional distribution of the instantaneous speed v and acceleration a with 6 speed classes limited by 0, 20, 40, 60, 80 and 100 km/h, and 7 acceleration classes limited by -1.4, -0.6, -0.2, 0.2, 0.6 and 1.0 ms^{-2}. These quantities are the log of a relative frequency divided by the geometric mean, thus they are dimensionless.

A logarithm transform was applied to the response Y_i (i.e. the emission), thus quantities predicted by model fit to data as lnY are to be retransformed in original scale to get emission factors expressed in g/km. The following naïve estimate was used to calculate model expectations (Duan, 1983):

$$e(p, \text{veh.class})\,[g/km] = \hat{Y} = \exp\left[\ln\hat{Y} + \left(RMSE\hat{E}\right)/2\right]$$

where $\ln\hat{Y}$ is the quantity calculated by putting coefficients and $RMSE\hat{E}$ (i.e. the root mean square error, i.e. the standard deviation of model residuals) is calculated by the model fit for each case data set.

Because of the high number of variables and co-linearity problems (variables correlation) the Partial Least Squares (PLS) regression method has been utilized to calculate models (Tenenhaus, 1998; Westerhuis et ali, 1998). According to the multi-block PLS approach, a regression model is fitted to any block of variables (1 or 2) separately; As a consequence a base model 1 was defined for the block 1, a model 2 was calculated on the block of variables 2. Finally an upper level model (model 3) was calculated on the pooled two blocks of variables 1 and 2.

Then emission factors can be calculated from of each of these three models (1 to 3), according to the best fit for each specific case study.

Preliminarily, for each case study, a model considering individual vehicle effect on emissions has been fitted to data, to outline individual emission trends and determine eventual outliers. The effect of individual vehicle has been estimated by building a further model so called model 1D, which is an extension of the model 1, by including beside the 7 quantitative variables of the block 1 a set of dummy variables having values (0 or 1), indicating respectively the absence or presence of a specific vehicle. By this model the percentage effects of individuals (vehicles) on the expected emission were calculated and vehicles have been divided into three sets: normal emitters, i.e. vehicles having a percentage effect less than 150 %, high emitters i.e. vehicles having a percentage greater than 150 % but less than 300 %, vehicles having a percentage effect greater than 300%. The last set of vehicles was considered as abnormal and excluded by the analysis.

Then emission factors are obtained for each set of vehicles defined in a case study considering vehicle effect as a random effect not explained by the model.

On the basis of relative vehicle effect on emissions detectable within each class of vehicle analysed in a case study, emission factors (mean and confidence intervals) were calculated for all vehicles in the class, for normal and for high emitters.

3.3.3. Results

The final kinematic model is made, for each vehicle class (fuel, capacity, emission standard) of:
- a model for low emitters
- a model for high emitters
- a model for all vehicles
- a model for all vehicles with dummy quantifying the relative effect of each vehicle on the overall mean.

For each of the 3 first cases, for a pollutant p and per vehicle class, we have 3 models of emission factor e:
- a model 1 according to 7 kinematic parameters
- a model 2 for 42 parameters
- a model 3 for 7+42 parameters

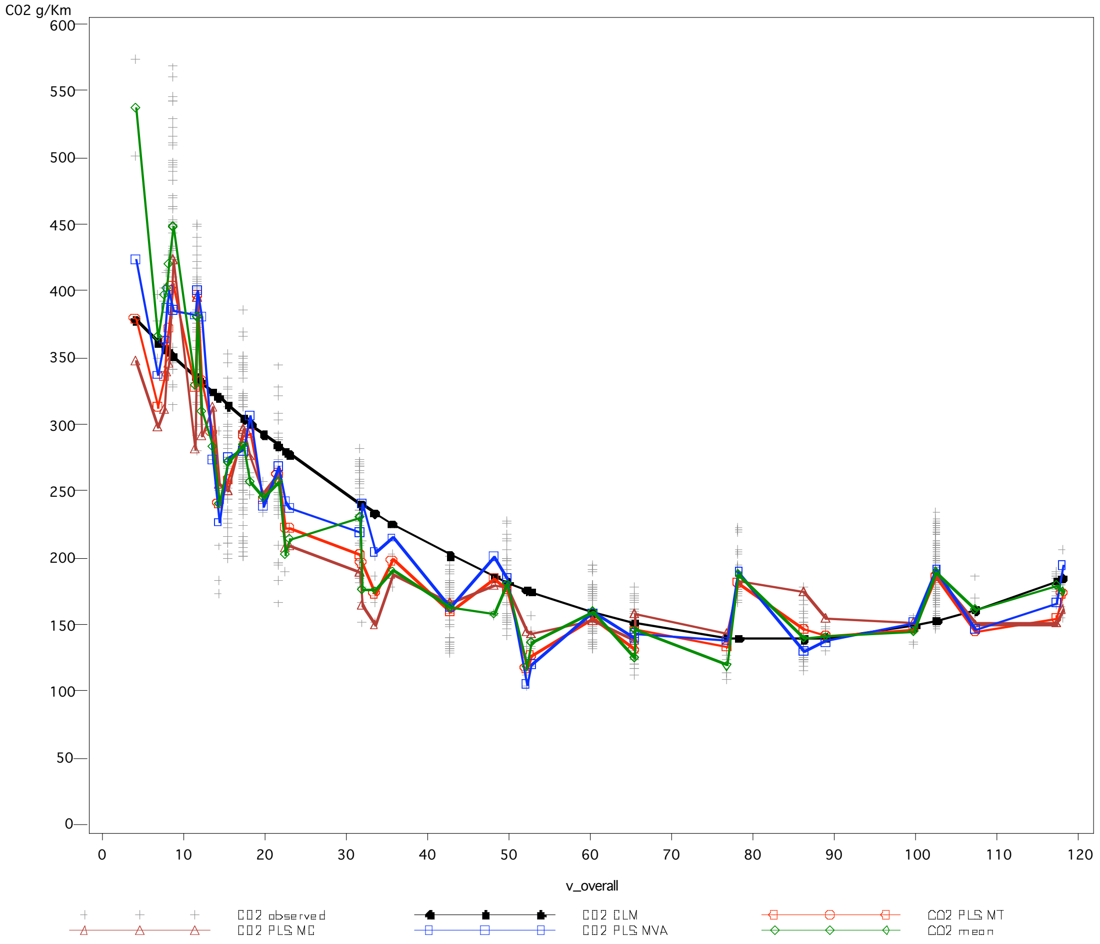


Figure 7: Comparison of measured and calculated emissions of CO_2 [g/km] for the kinematic regression model 1 (PLS MG, dark red), model 2 (PLS MVA, blue) and model 3 (PLS MT, red), and for a average speed regression model (GLM, black) with the mean measured emission (mean, green) versus the driving cycle mean speed.

(model 1) $e(p, \text{veh. class})\ [g/km] = \exp\,[\,a_1 \,.\, mv + a_2 \,.\, mv2 + a_3 \,.\, mv3 + a_4 \,.\, t_{idle} + a_5 \,.\, t_{running} + a_6 \,.\, mva + a_7\ 1/d + (RMSEE)^2/2]$

(model 2) $e(p, \text{veh. class})\ [g/km] = \exp[\Sigma\ b_{ij} \,.\, (f_{va}(i,j) + (RMSEE)^2/2]$

(model 3) $e(p, \text{veh. class})\ [g/km] = \exp[c_1\ mv + c_2 \,.\, mv2 + c_3 \,.\, mv3 + c_4 \,.\, t_{idle} + c_5 \,.\, t_{running} + c_6 \,.\, mva + c_7 \,.\, 1/d + \Sigma\ d_{ij} \,.\, f_{va}(i,j) + (RMSEE)^2/2]$

a_1 to a_7, b_{ij}, c_1 to c_7, d_{ij} are coefficients, functions of the pollutant, of driving cycle and of the vehicle class (see Annex 13) calculated by model fit to each case such as $RMSE\hat{E}$ (standard deviation of model residuals).

The values of a_1 to a_7, b_{ij}, c_1 to c_7, d_{ij} relative to different pollutants for the case study of Euro 3 petrol 1.4-2.0 l passenger car class are reported in Annex 13. Coefficients c_1 to c_7 and d_{ij} are not explicitly reported, but quantities from which they can be calculated are shown.

The Figure 7 illustrates for CO_2 and the same case data set above mentioned, the measured emissions and the emissions calculated with the three models, to illustrate models ability to follow the data trend and the comparison with a simple average speed regression model.

Goodness of model fit to emission data of same data set of above are reported in Table 14, where the R^2 determination coefficients are shown. Cases relative to normal + high emitters, normal and high emitters separately are considered in the three tables. R^2 are generally low for all pollutants except for CO_2. This is mostly due to large variability of emission data relative to each driving cycle. In fact, the component of data variance contributed by driving cycles is comparable or less than the component contributed by vehicle model, as it is shown in Table 15, where variance components for the normal emitters data set relative to vehicle model, cycle and experimental error (considered as random effect factors) computed by analysis of variance are reported.

	ln emission	model 1	model 2	model 3
normal + high emitters	ln CO (g/km)	0,461	0,463	0,478
	ln HC (g/km)	0.268	0.285	0.298
	ln NOx (g/km)	0.228	0.275	0.280
	ln CO_2 (g/km)	0.804	0.847	0.851
normal emitters	ln CO (g/km)	0.394	0.409	0.416
	ln HC (g/km)	0.299	0.315	0.332
	ln NOx (g/km)	0.228	0.262	0.270
	ln CO_2 (g/km)	0.826	0.855	0.864
high emitters	ln CO (g/km)	0.792	0.748	0.793
	ln HC (g/km)	0.411	0.427	0.419
	ln NOx (g/km)	0.364	0.521	0.502
	ln CO_2 (g/km)	0.884	0.932	0.922

Table 14: Model fit coefficients of correlation R^2 for the 3 data sets (normal + high emitters considered together, normal and high emitters considered separately), and for the 3 kinematic regression models.

	CO	HC	NOx	CO_2
cycle	44.4	29.2	41.5	88.6
model	33.4	47.9	37.7	9.0
error	22.3	22.8	20.8	2.4

Table 15: Contribution of the variance components in percentage, for the normal emitter data set.

The model 1 is the most understandable because the input parameters are average parameters, but it has the worst efficiency in terms of goodness of fit (R-square determination coefficient) as on overall for all emissions. The model 2 performs better and is in the most cases very close to the model 3, which is the most representative.

3.4. Traffic situations model

The estimation of the pollutant emissions from the road transport is needed at a low spatial scale (i.e. in one street, as a function of the traffic conditions), to enable detailed inventories or impact studies. As shown in sections 3.2 and 3.3, pollutant emissions are very sensitive to the driving conditions, but the existing emission estimation tools were however not always ready, nor designed for such a low scale usage. In the previous European approaches for estimating the pollutant emissions (Joumard, 1999), we had the trivial structure in urban, rural and motorway traffic situations. A more detailed structure was designed in the Handbook approach used in Switzerland, Germany and Austria (Keller, 2004) that considered traffic situations as a combination of road and traffic parameters.

In the frame of Artemis and of the COST 346 action (Sturm et al., 2006), it was considered that a low scale approach was necessary and requested by the users. Such an approach was called a “traffic situation approach”. This approach is a non continuous or discrete model, in opposition to instantaneous, kinematic or average speed models (described resp. in sections 3.2, 3.3 and 3.5). Compared to instantaneous or kinematic models, this approach could be less accurate, but:
- the kinematic input data are much simpler, as no speed profile neither complex kinematic parameters are necessary
- the kinematic input data are replaced by user oriented parameters, usually known by the traffic engineers.

Works have then been conducted in these aims (André et al., 2006a; b; c) to:
- Develop a pertinent structure of traffic situations
- Describe these traffic situations in terms of driving behaviour
- Estimate the pollutant emissions for each of these newly defined traffic situations

3.4.1. Traffic situation definition

The estimation of the pollutant emissions at a street level implies the definition of "traffic situations" which should be understandable across the different countries and users, and preferably close to the classifications usually implemented by traffic engineers (Fantozzi et al., 2005; André et al., 2006c). The definition concerns also the road characteristics (sinuosity, gradient, speed limit, etc.) and the traffic conditions.

The definition of traffic situations was elaborated after a large review of the European practices and of long discussion within the Artemis and COST 346 projects and also with traffic engineers (André, 2002a).

In the following of numerous international works and recommendations, a road classification should distinguish urban and rural according to a morphological point of view (i.e. continuity of the buildings around a centre and coherence) or to a functional point of view (Functional Urban Area), as mobility and traffic are to a large extent linked to these contexts, and as the traffic is mainly generated and managed at such a scale. It was proposed to adopt a road classification according to the function (access / distribution / through) and to the road network hierarchical organization. The distinction between motorway and normal road and the road characteristics were then considered according to the most usual practices in Europe to propose an agreed urban and rural road typology. The resulting traffic situation scheme is relatively complex but it relies on rigorous bases. The urban and rural typologies are presented in Table 16, and in a more detailed way in Table 30 and Table 31 in Annex 14. They are illustrated by pictures in Annex 15, to help model users in the understanding of the current definitions.

	Main function	Characteristics	Speed limit (km/h)
urban	National and regional network - Through-traffic	5a - Motorway	80 - 130
		5b – Non-motorway	70 - 100
	Agglomeration primary network - Primary distributor	4a - Motorway (ring, etc.)	60 - 110
		4b - Non-motorway	50 – 90
	Districts distributor	3 - Road	50 - 80
	Local distributor- Inner exchange, local traffic	2 - Road	50 – 60
	Access road - Local traffic.	1 - Road, side road, etc.	30 – 50

rural	National and regional network - Through and distribution	5 - Motorway	80 - 150
		4 - Trunk road	60 - 110
	Distributor	3 - Road	50 - 100
	Local distributor - Inner exchange, local traffic	2 - Road	50 - 80
	Access road - Local traffic	1 - Road, side road, etc.	30 - 50

Table 16: Typologies of urban roads and of rural roads.

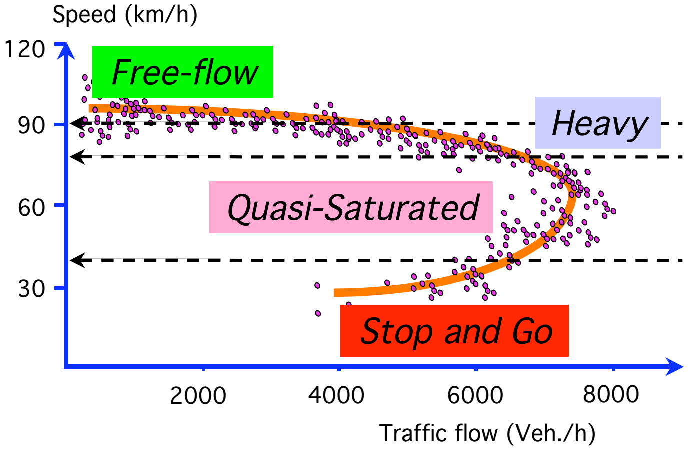


Figure 8: Traffic conditions as regards speed and traffic flow (Lhuillier, 2004) .

The road gradient and sinuosity should also be considered, especially because they influence the heavy duty vehicle emissions and fuel consumption. For large scale estimation, a qualitative approach was proposed (Flat – sinuous / non-sinuous, Hilly – ramps / sinuous, Mountainous). Indeed, a gradient value (i.e. 4 %) has a sense for a short road section but not for one entire trip or a road network. Because of the poor information about the sinuosity and gradient as regards driving, these parameters are only considered for rural roads.

For a good coverage of the actual traffic conditions, a structure in 4 levels was proposed (Figure 8), with free-flow traffic (average speed at 85-100 % of the free (or maximum) speed), heavy traffic (constraint speed at 65-85 % of the free speed), unsteady quite saturated traffic (variable speed with possible stops in the range of 30 to 60 % of the free speed) and the stop-and-go (speed in the range of 10 km/h).

The traffic situation scheme constitutes the basic structure for the elaboration of an emission estimation model at a local scale. The next steps should consist in acquiring the necessary data for that structure (i.e. speed data for each traffic situation) and in building-up a method for calculating the emissions at that level.

3.4.2. Speed data representative of the traffic situations

Apart from the traffic situation definition, the estimation approach requires speed data characterizing each of the traffic situations. A large collection of the existing European data recorded on-board vehicles was managed in that aim (André et al., 2006c).

In all, more than 1500 speed versus time curves were considered, but most often, the information on the traffic condition was not available. Few data was available for rural, hilly and mountainous situations. The available speed data were affected to the different traffic situations according to the background information. This affectation was validated considering the driving statistics (average speed, stop number, etc.) and by comparison between similar situations (coherency).

This process enabled a direct affectation of representative speed data for 69 traffic situations amongst more than 400. In addition 19 traffic situations correspond to each of the Artemis driving cycles or sub-cycles (see the list of these 88 situations in Annex 19). For the other traffic situations, an affectation by similarity was done (i.e. congestion for two roads with close speed limits should be comparable, etc.), giving a simple correspondence between each remaining traffic situation and one of the 69 traffic situations well defined. However, this lack of data remains the main weakness of the approach and complementary data collection should be envisaged to improve it.

3 among the 19 traffic situations are macro situations, corresponding to urban, rural and motorway situations, equivalent resp. to the Artemis urban cycle, the rural one, and a combination of the Artemis motorway and motorway_130 driving cycles.

In addition to all these traffic situations, we designed the most macroscopic traffic situation corresponding to the European situation, aggregating all other situations.

3.4.3. Emission data harmonization through Reference test patterns

The Artemis project has enabled the collection of a large number of car emission data (2 800 passenger cars, 27 700 vehicle x test cycle - including sub-cycles and transition cycles, hot emissions – see section 2.4), using more than 800 different driving cycles. In spite of its richness this heterogeneous dataset required a correction as regards the driving cycle. An approach was developed in that aim, which consists in the building-up of a typology of test patterns to aggregate similar test cycles and the calculation of reference emissions (André et al., 2006b; André and Rapone, 2006).

824 cycles/sub-cycles were analysable and 375 pertinent, i.e. after eliminating transition and pre-conditioning phases, artificial cycles such as constant speed, constant accelerations, cycles with a gradient, cycles without representativity, cycles for vans, etc. The most significant driving cycles, i.e. 98 cycles or sub-cycles representing the actual driving conditions and for which there are a significant number of emission data, were used to develop a typology of the test cycles. The other pertinent cycles do not contribute to the construction of the typology but are also classified according to this typology.

In this aim, we consider the 2-dimensional distribution of the instant speed and acceleration to describe the cycles. We apply then a Binary Correspondence Analysis (factorial or multidimensional analysis) and an automatic clustering. The typology into classes maximizes then the cycles homogeneity within the classes and the contrast between classes. These 15 classes or Reference Test Patterns (RTP) include then a sub-set of homogeneous driving cycles (as regards kinematic conditions), which can be combined together at a later stage to compute emissions (Figure 9).

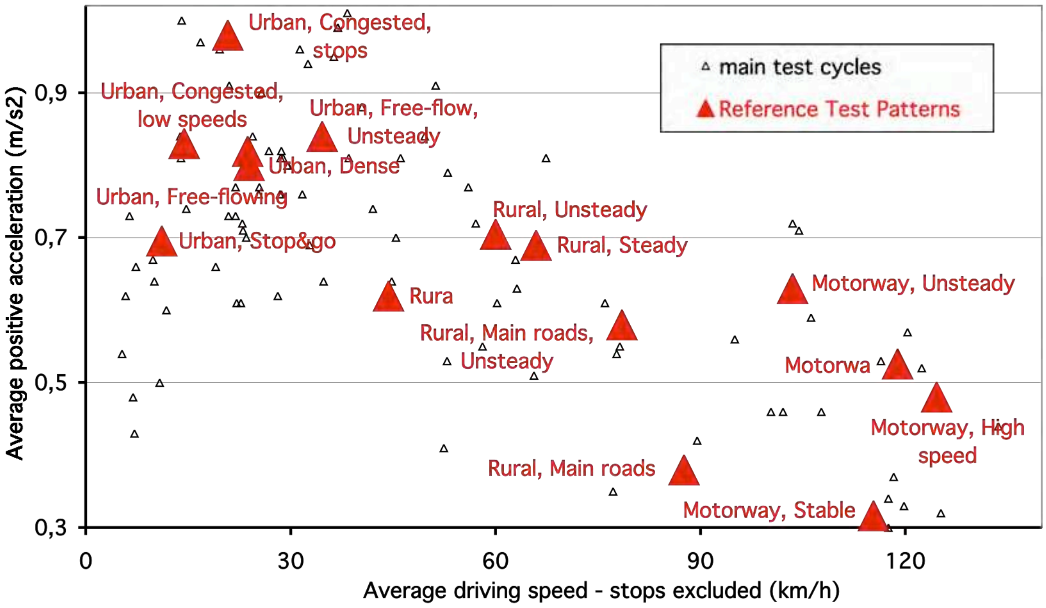


Figure 9: Variability of the test driving cycles and 15 Reference Test Patterns as regards driving speed and acceleration.

For each Reference Test Pattern, one or several Reference Test Cycles are selected amongst the most significant (in term of representativeness and of number of associated emission data). They are given in Table 32 and the characteristics of the Reference Test Patterns in Table 33, both in Annex 16.

3.4.4. Emission factors of Reference test patterns

After designing the 15 Reference test patterns, it is necessary to process the emission data to assess the emission factors of each reference test pattern.

As a first step, the measured emission data were corrected according to the vehicle mileage (section 3.8), gearshift behaviour, ambient temperature and humidity (section 3.9), in order to process standardised data. A detailed description of the correction factors can be found in Joumard et al. (2006a to c). In average per fuel and pollutant, the correction factors tend to be between 0.99 and 1.12 for petrol vehicles, and between 0.96 and 1.00 for diesel vehicles (see Table 5 on page 19). However, for certain vehicle sub-classes or individual tests, the correction factors can be even higher. Applying these correction factors, the so-called “harmonised” data base was derived. The emission data, and later the emission models, were harmonised as follows:

- vehicle mileage = 50 000 km
- ambient air temperature = 23°C
- ambient air humidity = 10.71 g H_2O/kg dry air

As a second step two models for deriving the emission factors for the Reference test patterns were developed.

Model 1

Model 1 took into account a subset of the emission database (Kljun and Keller, 2006). For each of 14 Reference test patterns out of 15, the emission data of 15 respective Reference test cycles (out of 21 – see Table 32 in Annex 16) were selected (14 Artemis sub-cycles plus one additional cycle); For the last Reference test pattern (urban stop and go), the emission data of another cycle were selected (Handbook StGoAB: see Figure 49 in Annex 6). The Reference test patterns considered here are therefore not rigorously those designed in section 3.4.3. The emission factor per Reference test pattern is then derived from the average of measured emissions of the vehicle sample.

Model 1 thus emphasises the importance of the sample of vehicles. The emission factors are computed based on a consistent sample of vehicles, i.e. the same vehicle sample for all Reference test patterns as far as possible. Nevertheless for 3 out of the 15 Reference test patterns, the sample of vehicles was only a subset of the sample for the 12 other ones. The objective was to avoid that the emissions behaviour was dominated by the vehicle choice rather than by engine specifications. With this restriction, the number of available measurements was significantly reduced to mostly Artemis subcycle measurements of Euro 2 and Euro 3 vehicles. However, the subset still consists of 1 500 vehicle.tests corresponding to 94 hours of measurements and 9 200 emission measurements.

For vehicle categories other than Euro 2 and Euro 3 where no coherent data (i.e. same vehicle sample for the selected driving cycles) were available, the emission factors were derived from those of Euro 2 and Euro 3 by applying conversion ratios. The conversion ratios for vehicles earlier than Euro 2 were computed from emission data of Copert 3 (Ntziachristos and Samaras, 2000a and b) and the Handbook (Keller, 2004), included in the Artemis database, but using a different methodology. For vehicle categories later than Euro 3, the conversion ratios were computed from the assumptions for new (not yet measured) vehicle technologies provided in Section 3.5.4.

Model 2

The model 1 has however some drawbacks:

- Loss of representativity due to the low number of cars considered in comparison with the whole Artemis database, although a larger quantity of data doesn't mean necessarily a better quality of the model.
- Weakness of the emission data measured with short sub-cycles (2-3 minutes) only, compared to entire cycles.
- Loss of representativity of the driving cycles used compared to the whole set of Reference test cycles, statistically representative of the emission data set with respect to their kinematic content and of the large variability of the driving conditions.
- The use of conversion ratios, for vehicle categories other than Euro 2 and Euro 3, implicitly supposes that the ratios do not depend on the traffic dynamic, but an attempt of characterizing the dynamic response for different car categories does not indicate such a similarity (see the example of NOx in Annex 18). The validity of the conversion ratios based on emissions functions established in different context, using different data set and approaches, is therefore questionable.

Model 2 considered the whole Artemis light vehicle emission measurement database (version 3 October 2005) described in section 2.4 (André et al., 2006a). In a first step the passenger car and 4x4 emission data were extracted. It was intended to set-up a definitive list of coherent cycles for each test / driving pattern, to compute then their reference emissions. This implied the analysis of the variability and coherency of the emission data within each class and for each vehicle category (the emission standard is considered) and fuel. The coherency throughout the vehicle categories was also examined. Out of the 25 000 data, about 19 000 were analysed. The average emission values observed for the Reference test pattern (i.e. the whole class) were considered and for the Reference test cycles on one side, and the individual figures for each of the cycles belonging to the class on the other side. Some deviating cycles, generally far away from the Reference test cycles in term of kinematic, showed however quasi-systematic under- or over-estimation: When they did not represent a high quantity of tests, the corresponding data were cancelled. When the difference was not at all systematic or understandable, the cancellation of the related data was unavoidable. From the 19 000 initial data, 10 000 coherent data (2672 diesel and 7381 petrol cars), corresponding to 1280 hours of emission measurements (of which 7350 vehicle.tests and 940 hours for Euro 2 and 3 vehicles), were retained (after exclusion of the non pertinent cycles). The number of emission measurements is given per pollutant and vehicle category in Annex 17.

It enabled the computation of the emission for diesel and petrol cars, from pre-Euro to Euro 4 passenger cars (see an example on Figure 10). For Euro 2 - Euro 3 vehicles, the amount of data processed was thus 5 and 10 times larger than in for model 1 resp. when considering the number of data and the hours of measurements.

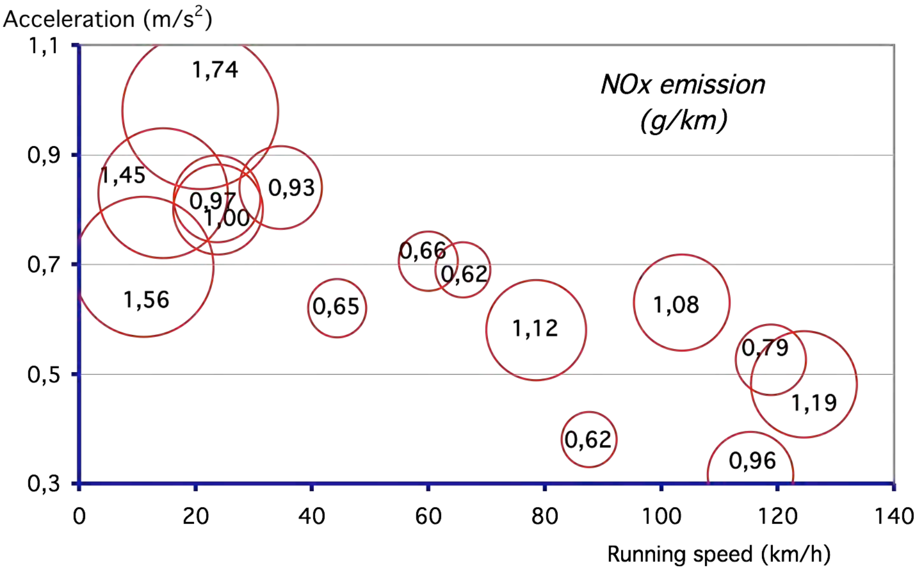


Figure 10: Variation of the pollutant emissions (NOx of Euro 3 Diesel) according to the 15 Reference test patterns.

Several cases were however insufficiently covered. Mechanisms of interpolation were thus implemented to cover these cases as follows:

- Extrapolation of the rate Euro4/Euro3 (resp. Euro 3/Euro 2, etc.) observed on a similar test pattern (urban, rural or motorway)
- Equivalence between close vehicle categories (i.e. Euro 4 and Euro 3, etc.) when they were too few data (case of the particulates and CO_2 per engine size)

We should note that, weighing factors – as initially envisaged and according to the quality of the cycles and to the number of data - were implicitly (but not rigorously) implemented through the above cycle selection process.

The emission factors for diesel Euro 4 vehicles must be taken with precaution, as they are based on few measurements.

The whole set of emission data is provided in Annex 17, including the extrapolations. This process (computation of the emission per driving pattern) is a robust approach as it relies on contrasted driving conditions and considers the cycles according to their quality. It seems then pertinent to build-up emissions functions while starting from this basis. However, at the same time, the larger vehicle sample introduces some heterogeneity since the different Reference test patterns are represented by different vehicle samples. Furthermore, the cartography of the test cycles constitutes a good mapping of the driving conditions as regards the average speed and acceleration, i.e. the dynamic of the traffic conditions. Indeed, we clearly identify for certain pollutants (NOx and CO_2) and vehicle categories, two classes of driving along the speed scale, i.e. the stable or normal driving with low acceleration and stop frequencies on one side, and the unsteady driving on the opposite, as shown in an example in Figure 11.

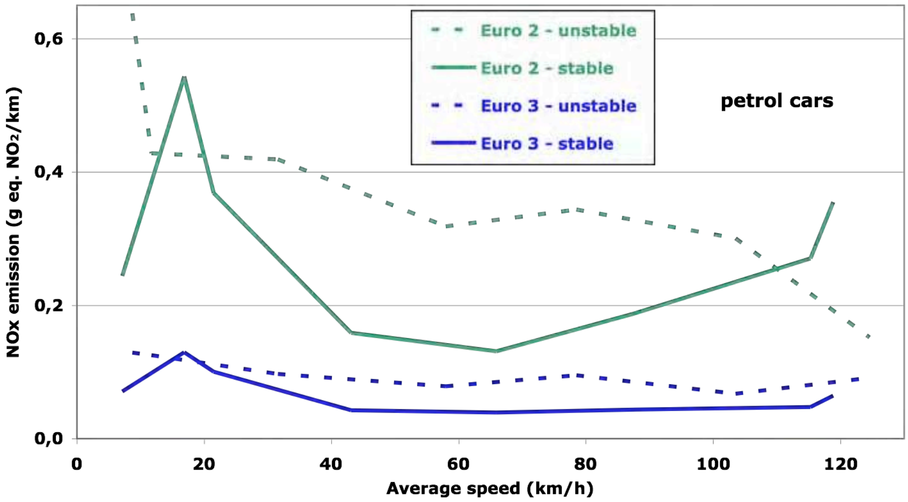


Figure 11: Dynamic influence on the NOx emissions for petrol cars. Stable and unstable Reference test patterns are defined in Annex 16.

3.4.5. Emission factors of Traffic situations

The emission cartography developed through the Reference test patterns is particularly appropriated to compute emission for the different traffic situations defined in sections 3.4.1 and 3.4.2, as the structure enables already the analysis at a relatively microscopic scale. The idea was then to “link” a given traffic situation as a function of the different sub-cycles for which emissions are known (André et al., 2006c).

In that aim, the representative speed curves of the traffic situations designed in section 3.4.2 were analysed together with the test cycles described in section 3.4.3 as regards their speed and acceleration distribution. Binary Correspondences Analysis enabled to transform the time distribution into factorial coordinates (orthonormal axes system) and to compute thus and easily distances between a speed curve (i.e a traffic situation) and the test cycles. It should be noted that it was exactly the same method that was implemented to characterize the driving patterns, to build-up the Artemis driving cycles, and also to constitute the emission factors of the Reference test patterns in the second model, above.

The distances between a traffic situation (represented by its speed curve) and the test cycles, enabled thus identifying the closest test patterns and to consider each traffic situation as a linear combination of the Reference test patterns, proportional to the proximity – in term of kinematic – to these test patterns. We realised then a projection on the plan (when 3 reference points are selected), on the line (with 2 points), or on a hyper-plan (4 or 5 points) determined by the reference points (always an interpolation process, and never an extrapolation). A set of weighting coefficients for each traffic situation were determined according to the 15 Reference test patterns, given in Annex

19.

Therefore the emissions of hundreds traffic situations are computed by linear combination (Annex 19) of the reference emissions of the closest Reference test patterns, as defined in the model 2 (Annex 17). These emission factors are illustrated in Figure 12 according to some vehicle classes and for the four traffic conditions described in Figure 8. The use of the model 1 to calculate these emission factors is possible but needs a new computation of the combination factors (compared to those given in Annex 19).

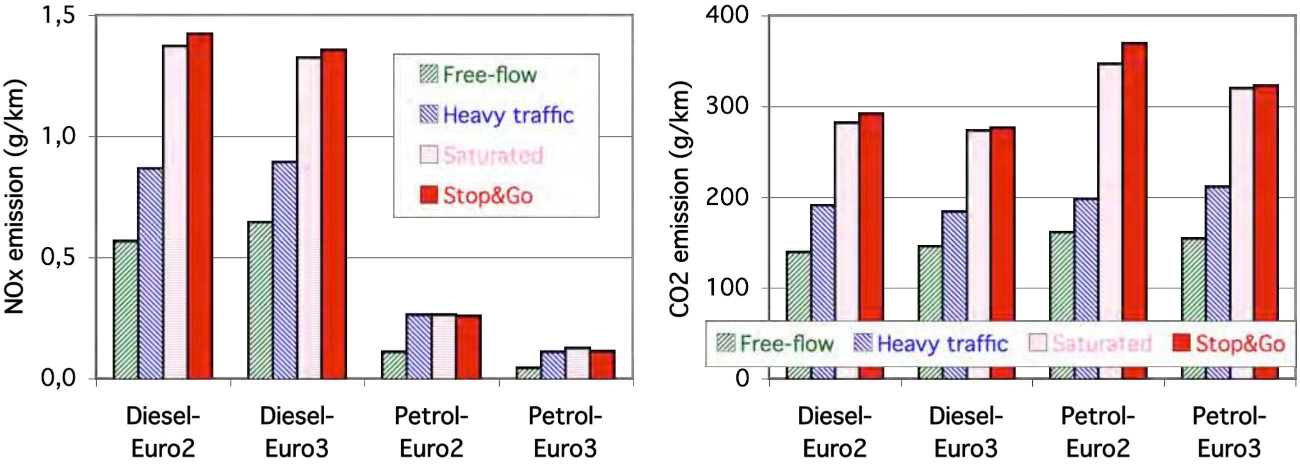


Figure 12: Traffic situation approach illustration: NOx and CO_2 emissions of cars have been estimated for an urban trunk road (speed limit: 50 km/h), at different traffic conditions, according to dedicated speed curves.

3.4.6. Emission factors of macro traffic situations

The four macro traffic situations (urban, rural, motorway, European) are based on the weight of the Artemis cycles in the traffic, part of the design of these driving cycles (André, 2004a). They can be expressed according to the three Artemis cycles or according to all Artemis sub-cycles. As each of the Artemis cycles and sub-cycles are also specific traffic situations, the macro traffic situations can be expressed according to these traffic situations (see their weights according to the situations 1002 to 1024 in Annex 19). The macro traffic situations are called "composite" when they are expressed according to the Artemis sub-cycles.

As all the traffic situations are expressed according the Reference test patterns, the macro traffic situations, including the composite ones, can be expressed according to the reference test patterns (Annex 19).

The composite macro traffic situations are not useful to calculate the hot emission factors, where the normal macro traffic situations are simpler as they are expressed according to the main Artemis cycles. They are useful when emission factors are expressed according to the average speed and are not linear functions of the speed, as for instance for the cold start emissions (third model – see section 3.12.4), or for the LDVs (see section 3.7). The taking into account of the composite macro traffic situations rather than the non-composite macro situations should improve hardly the accuracy of the corresponding emission factors.

3.5. Average speed model

A fourth type of hot emission model was designed, similar to the Meet or Copert ones (Eggleston et al., 1993; Joumard, 1999; Ntziachristos and Samaras, 2000a and b), i.e. taking into account kinematics through the average speed. Only hot emissions were used, but data were processed following two different statistical approaches, with different data clustering, leading to two alternative sets of speed dependent emission equations:

- A first model based on emission data clustering through speed range averaging
- And a second model designed from the 15 Reference test pattern emission factors.

3.5.1. Design through speed range averages

Model 1 was made from the emission data of the Artemis LVEM database – see section 2.4 (Samaras and Geivanidis, 2005), after averaging emission data per speed range.

All artificial driving cycles or cycles used in parametric studies were excluded in order to get data as close as possible to the real world performance. Cycles produced as sum of bags already contained in the database were excluded in order to avoid overweighting of certain data points. Only the average emission sub-factor of each vehicle and cycle combination was taken into account as a measure to avoid overweighting of vehicles. In addition to passenger cars, all 4 wheel drive vehicles were also included as none of them resided in the N1 category due to their low vehicle weight.

All data were corrected and homogenized against the ambient temperature and humidity (see section 3.9), and gear choice strategy effects (Joumard et al., 2006), but not according to vehicle mileage. The correction had minimal or no effect on the level of emissions. The mileage correction should be applied as a post processing procedure after the estimation of the emission factor of a specific vehicle class, according to its average mileage.

Due to the low number of data available at certain speed levels and in order to avoid overweighting of specific speed points with high number of data, emission data were averaged per speed range of 10 km/h, i.e. for 0-10 km/h, 10-20 km/h, etc. 130 km/h and above. Each average emission is associated to an average speed from 5 up to 135 km/h. These average values were then evaluated taking into account the number of data which each average value consisted of. Average values that were a product of a low number of data were considered in some cases not reliable due to the high scatter of data in conjunction with the low number of data, and eliminated. Outliers were also eliminated in this aspect according to the relative average value quality. In the uniform case of all data points consisting of low number of data, no data were excluded and an emission factor was produced with reduced reliability though.

In all cases an equation of the following general form was used:

$$y = \frac{a + c \cdot x + e \cdot x^2}{1 + b \cdot x + d \cdot x^2} + \frac{f}{x}$$

where:
y: speed dependent emission factor of fuel consumption [g/km]
x: average speed [km/h]
a to f: coefficients

The characteristic of this equation is the ability to reproduce the high emissions that was observed in some cases at low and high speed, due to enrichment and low catalyst efficiency at high speed.

The choice of the split of emission factors into more detailed segmentation according to engine capacity was applied in the cases where there was an obvious effect of engine capacity on the emission factor. Restrictive parameter was the availability of data.

Finally, an example of hybrid petrol vehicle emission and fuel consumption factors is being presented. The data were derived from measurements on a specific vehicle (Toyota Prius) with can be considered as highly representative of this vehicle segment especially for the European market (Fontaras et al., 2006).

The calculation was made for Euro 1 to Euro 3 petrol and diesel vehicles, and Euro 4 petrol ones. The whole set of emission functions is given in Annex 20 and examples are shown in Figure 13 for NOx. The equations lead sometimes to abrupt changes of behaviour out of the range of computation, and, therefore, it is not allowed to apply these equations out of their boundary limits, i.e. from 5 up to 135 km/h. Out of these limits, the model should use the figures at the limits.

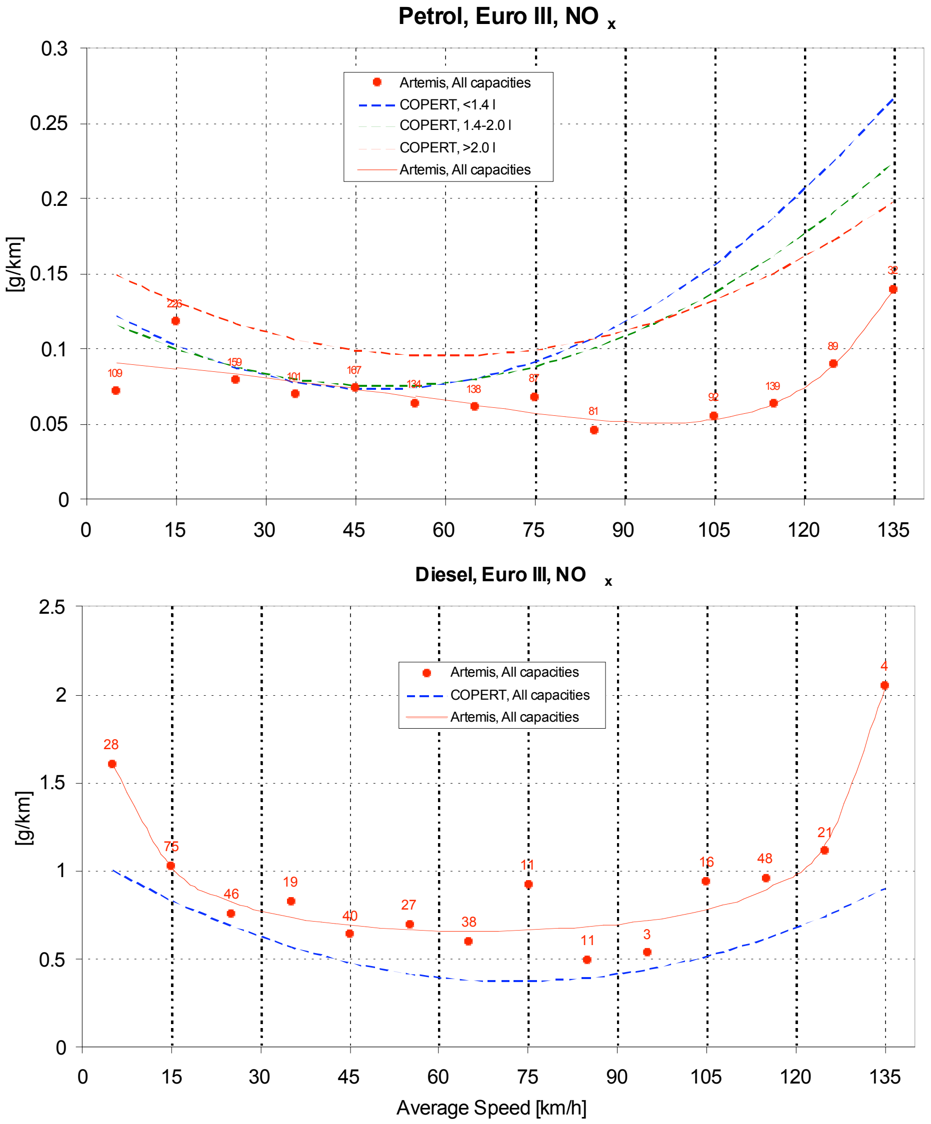


Figure 13: Petrol and diesel Euro 3 NOx emission functions according to average speed, as designed through speed range averages, with the number of data per average emission (clustered), and comparison with Copert 3 functions.

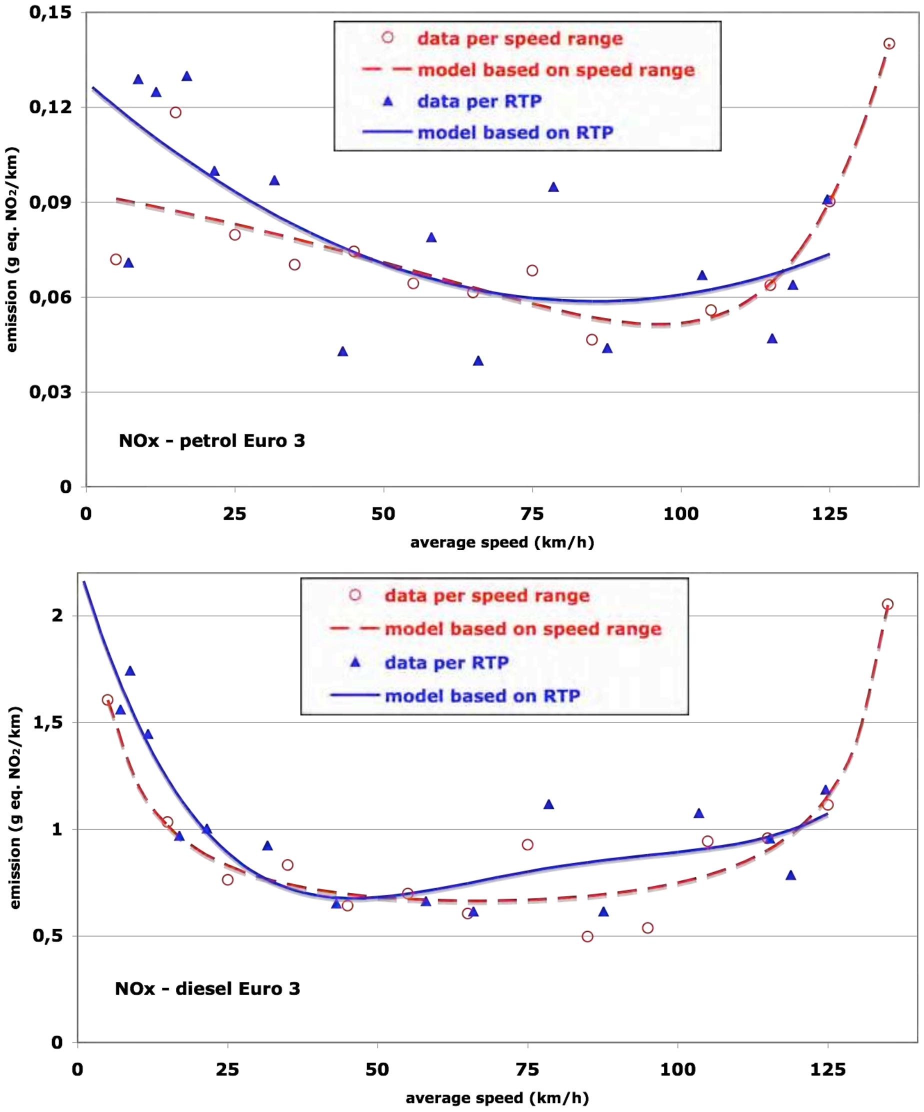


Figure 14: Petrol and diesel Euro 3 NOx emission functions and data according to average speed, as designed through Reference Test Patterns or through speed range averages.

3.5.2. Design through Reference test patterns

Another approach was developed, in line with the Reference test patterns. Here the emission data of the Artemis LVEM database (3 October 2005 version) are firstly averaged per Reference test pattern, producing the Reference test pattern emission factors derived in section 3.4.4 (model 2) and given in Annex 17. Then an emission function is calculated by regression between these 15 Reference test pattern emission factors, expressed according to the average speed. The emission factors cover CO, HC, NOx, PM and CO_2 for pre-Euro to Euro 4 petrol and diesel vehicles, and according to engine size for CO_2. The whole set of emission functions is given in Annex 21, and the example of NOx in Figure 14.

The choice of the regression (power or 2nd to 5th order polynomial) is made for each data set with the following objectives:

- not to go outside the envelope of the measured points as far as possible, in order to avoid systematic over- or underestimation of emission for some speed ranges
- correspond to the apparent shape of the points according to the average speed

- avoid important oscillations
- never give negative figures
- be as simple as possible

This approach has the advantage to be fully coherent with the traffic situation model, based also on the Reference test pattern emission factors.

Although it is tried to avoid oscillations, the shape of some curves according to the average speed can show sometimes smooth oscillations, especially in the speed range 80-125 km/h, as a compromise between the different objectives. These smooth oscillations could not be representative of real behaviour. But in any case, the average speed model should not be used to compare close speeds.

The shape of the curves at the highest speeds could nevertheless give unexpected figures for out-of-range speeds. It is not the case for speeds lower than the slowest traffic situation (7 km/h), but it is sometimes the case for speeds higher than the quickest traffic situation at 125 km/h. Therefore in this case the model uses the figures at 125 km/h.

3.5.3. Comparison of the two average speed models

The comparison of the second approach based on Reference test patterns with the first one based on speed range averages shows some differences in terms of curve shape and emission level, sometimes up to a factor 2. These differences may be attributed to:

- The homogenization of the data as regard the vehicle mileage, done only in the second method, and giving fully standardised emission factors.
- The way the emission data are clustered, by 10 km/h speed range in the first method, by a statistical multi-dimensional clustering in the second case. The clustered emission factors can be very different between the two methods, as shown in Figure 14.
- The choice of the equation type, made in the first method for its adaptability to the high slope at low and high speed, making often the extreme points (lowest, highest speeds) better adjusted than the other points. In the second method the equation is chosen mainly to avoid to go outside the envelope of the points.

The differences between the two models show that such model depends a lot on the methodological assumptions. It is the reason why the second approach was developed in order to be fully coherent with the main Artemis emission model, the so-called traffic situation model. Indeed in both approaches (traffic situations, average speed model based on RTP), the emission measurements are firstly aggregated into Reference test patterns emission factors and then into traffic situations factors or into an emission function according to speed.

The range of vehicle categories and pollutants covered by each of the two methods differs slightly: The second model does not cover CO_2 for diesel Euro 4 vehicles > 2 l, and the first one does not cover the pre-Euro vehicles, the diesel Euro 4 vehicles and the PM of petrol cars. In addition the first model considers fuel consumption and not CO_2, the second one considering CO_2 only.

A speed dependent emission model should nevertheless not be used to compare different driving patterns, as the taking into account of the driving behaviour only through the average speed is not accurate enough and too simplified: either the traffic situation model (section 3.4), or the kinematic regression model (section 3.3) or an instantaneous model (section 3.2) is necessary for such assessment. A speed dependent emission model could be used for a quick emission estimation or if information on the driving patterns is especially poor, without allowing the use of another model: but even in this case we advice to use the macro traffic situations defined in sections 3.4.2 and the corresponding emission factors defined in section 3.4.6.

3.5.4. Reduction factors for future technologies

Due to the lack of both measurement and literature data, it was decided to cover future vehicle technologies using reduction factors (Samaras and Geivanidis, 2005).

Petrol vehicles

Considering the fact that Euro 5 emission standards will remain the same as Euro 4 it is proposed to use the Euro 4 equations for Euro 5 petrol vehicles as well.

As regards direct ignition petrol vehicles (DISI), both literature and the limited available data lead to an estimation of about 10 % reduction of fuel consumption which is proposed to be used as a reduction factor against the respective technology emission factors. All other factors are considered not to be altered by Direct Injection technology.

Diesel vehicles

Table 17 presents the reduction of emissions expected in Euro 4 and 5 diesel vehicles using as basis the emissions of Euro 3 vehicles. These factors where derived from the ratios of the established Euro 4 or expected Euro 5 emission standards (Table 18) over the emission standards of Euro 3.

Table 19 presents the PMm reduction potential of the installation of a Diesel Particulate Filter (DPF) on a vehicle. The factors were derived under the assumption that the application of DPF leads to PMm levels comparable to the expected Euro 5 limit.

	CO	HC	NOx	PMm	
Euro 4	0.781	0.833	0.5	0.5	x Euro 3
Euro 5	0.781	0.833	0.35	0.1	x Euro 3

Table 17: Reduction factors for future diesel vehicle technologies.

	CO	HC	HC+NOx	NOx	PM
Euro 3	0.64	0.06	0.56	0.5	0.05
Euro 4	0.5	0.05	0.3	0.25	0.025
Euro 5 (expected)				0.175	0.005

Table 18: Emission standards of diesel passenger cars.

	PM	
Euro 3 + DPF	0.1	x Euro 3
Euro 4 + DPF	0.1	x Euro 4

Table 19: Reduction of PMm emissions due to the addition of a Diesel Particulate Filter.

3.6. Unregulated pollutants of passenger cars

Unregulated pollutants concern VOCs, PAHs, NO_2 and particle properties.

3.6.1. Homogeneity of the VOC and PAH emission data

As shown by (Aakko et al., 2005; 2006), clear differences were seen in the emission levels measured at different laboratories for some pollutants, sometimes with differences of several orders of magnitude, and some suspected outliers were found for instance. In some cases, a single VOC compound emission was even higher than total hydrocarbons THC (e.g. one test showed 1,4-diethylbenzene emission, 5.3 g/km, which was 14 times higher value than the total HC result from this specific test). Individual cars varied from laboratory to another, and also, the test matrices at different laboratories varied as regards test cycles, emission class of cars etc (see section 2.1). Due to the different measurement methods and protocols, the set of compounds analyzed varied from laboratory to another, and thus the sums of groups, like VOCs or alkanes, are not comparable between laboratories.

More detailed discussion of uncertainty is needed as it is one of the key issues when emission factors are determined. In principle, the emission levels of cars tend to differentiate more than the uncertainties of the typical measurement methods. Thus emission factors of individual cars may be reliable, if a representative set of cars are measured. However, this does not necessarily apply to low-emission cars, especially Euro 3 or newer, due to their low emission level, near to the detection limits. Thus, representative set of cars in more than one laboratory is needed to define reliable emission factors for different pollutants. The most problematic emission categories, when number of samples is considered, were Euro 4 petrol cars (2 cars tested), pre-Euro 1 diesel cars (2 cars tested) and Euro 1 diesel cars (3 cars tested). The sample size in these emission categories was so low that the final conclusions on VOC and PAH emission factors should be taken very carefully.

A first way to analyse the data is the comparison of the results from different laboratories, even without a common basis for comparison, due to the absence of round-robin of unregulated components in the project. The major obstacle for comparability study is that typically major differences are found between individual cars, and secondly due to differences in the analytical methods. The emissions between individual cars can vary a lot even in the same emission class. This is pronounced for old cars (pre-Euro 1), as for newer cars. For example the publicly available type approval data from UK of present-day petrol cars show that, amongst some 1000 Euro 3 and 1500 Euro 4 cars, the spread in HC emissions varies by a factor 17 and 29 resp. Therefore, the spread for Euro 4 was even twice as large as with Euro 3.

The comparability between laboratories was studied by screening the results with cars representing the same emission class. A few test cycles were same at different laboratories. Especially at EMPA, IM, KTI and VTT several common test cycles were used.

For benzene, EMPA, IM, KTI and VTT figures seem coherent (in the same range), but INRETS results seem an order of magnitude higher, especially but not only for petrol cars. For formaldehyde, INRETS data seem also an order of magnitude higher than EMPA figures, IM results being intermediate.

In the case of polyaromatic hydrocarbons PAHs analyzed by INRETS, IM and KTI, INRETS figures for BaP are 2 or 3 orders of magnitude lower than IM results, KTI results being intermediate. These results seem to be in accordance with the results from literature. However, the differences in the level of PAH results obtained at IM and INRETS are significant, and has to be taken into account when the conclusions are drawn. The simple averages of emission factors may give misleading results when test matrices are not harmonized and emission levels vary from laboratory to another. However, evolution of the emission categories of cars can be monitored within laboratory. Only final emission factors of PAHs need careful consideration.

One interesting parameter to study is the share of VOC from THC, even though it should be noted that VOC and THC cannot be reliably compared with each other due to different measurement principles, e.g. FID used for measuring THC is sensitive for oxygen containing compounds (aldehydes). In addition, THC measurement does not take into account carbonyl compounds, which are included in the sum of VOCs in this report. Figure 15 shows that there are significant inconsistencies when total VOCs are compared to THCs, whereas comparison of sum of considered VOCs shows more reasonable trends. This phenomenon should be studied more closely before further analysis of other VOC compounds than the considered ones.

Comparability of the laboratories was fairly good as concerns benzene and formaldehyde emission, even though benzene level was somewhat higher at INRETS, and formaldehyde level lower at EMPA, than respective emissions at other laboratories. The most significant difference between laboratories was seen in PAH results. This is specifically important due to the fact that the test matrix on PAH emissions was not as extensive as e.g. matrix on benzene and formaldehyde. Thus PAH results have to be carefully considered when conclusions are drawn.

Thus the emission factors given below should be taken with caution as large inconsistencies between laboratories occur. Further analysis is needed.

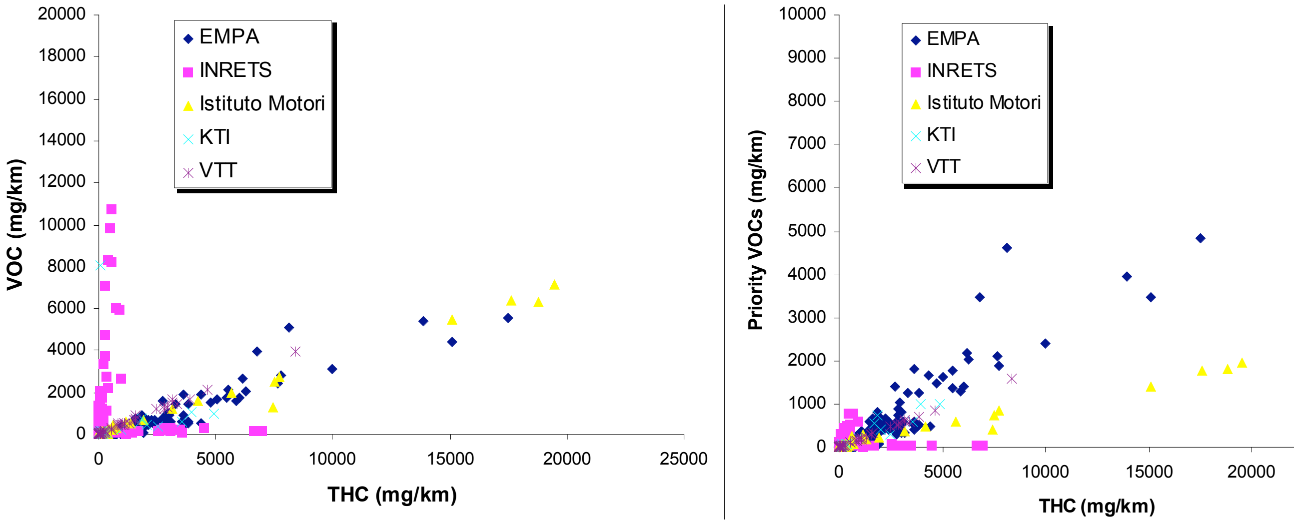


Figure 15: Total VOCs and considered VOCs only, compared to total hydrocarbons.

3.6.2. VOC and PAH emission factors

Taking into account the limitation on the results pointed above, average emission factors were calculated for the so-called considered unregulated compounds listed in Table 10 on page 28 and Table 13 on page 31 (Aakko et al., 2005; 2006). The average emission factors, deviation and number of measurements are summarized in Annex 22 per vehicle category.

Individual emission factors of benzene are shown in Figure 16, as an example.

The influence of the emission standard is illustrated for sums of VOCs and the sum of the 6 most carcinogenic PAHs in Figure 17. The VOC emission factors are drastically decreasing from pre-Euro 1 to Euro 1 petrol cars (in average by an order of magnitude). Thereafter the decrease is lower, by a factor 5 to 10 from Euro 1 to Euro 3. This evolution depends in fact on the species. For diesel cars, the decrease occurs also, but to a much lower extent: by 50 % only from Euro 0 to Euro 1 and from Euro 1 to Euro 2.

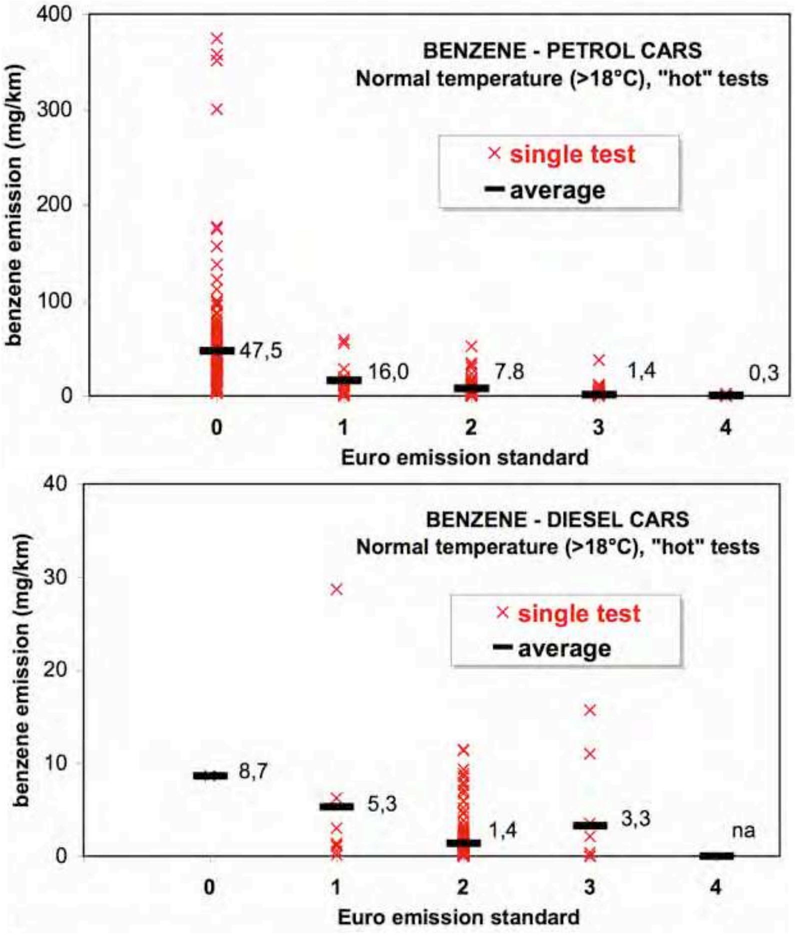


Figure 16: *Benzene emission factors in the hot-start tests at temperature >18°C. Each marker represents a single test. "average" is the arithmetic mean for each emission class of cars; na=not available.*

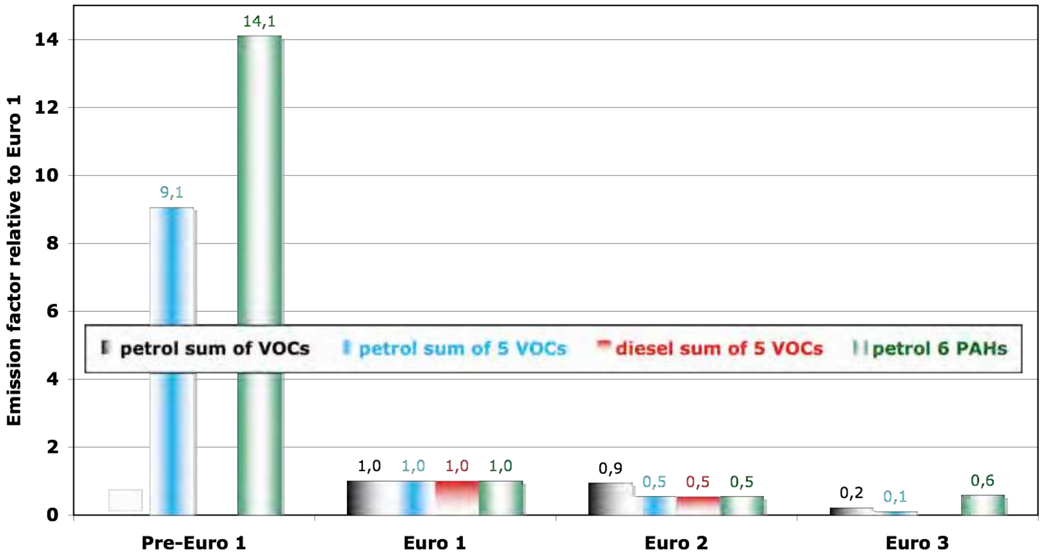


Figure 17: *Influence of the emission standard on the emission factors of the sum of the eight VOCs considered, the sum of the five 1st level VOCs, all BaP exluded, and the sum of the 6 most carcinogenic PAHs (see Table 10 and Table 13 the definition of these compounds).*

The PAHs of petrol cars are decreasing also by a order of magnitude from Euro 0 to Euro 1 and then only by 40 % from Euro 1 to Euro 3. Emission of benzo(a)pyrene is even increasing by a factor 3 between Euro 1 and Euro 2 (or 3).

When comparing with literature results, it is seen that generally the results from Artemis and other studies are in line.

Other results have been drawn by each partner laboratory for their data, as listed in Table 12, but they are not figures from the whole Artemis data. For instance, the separate measurement of particulate and semi-volatile phases showed that for petrol cars 35 % and for diesel cars 23 % of the 6 most carcinogenic PAHs were found from semi-volatile (gaseous) phase and the rest from particulate matter in the hot-start tests (Joumard et al., 2004a; 2004b).

3.6.3. NO_2 emission factors

Gense et al. (2006) and AQEG (2006) present state-of-the-art reviews of the origins, measurement and impacts of primary NO_2 emissions in relation to modern road vehicles and specific emission-control technologies. Data on direct NO_2 emissions, and the proportion of NO_2 in NOx, were gathered from measurement programmes carried out by Ricardo (2003), Millbrook (2005), LAT and mainly TNO Automotive and EMPA. These data were reviewed with respect to their accuracy and reliability.

The available data showed that the measurement method had a substantial influence on the measured direct NO_2 emission. The balance between NO and NO_2 was also found to be very sensitive to the measurement conditions. The authors defined a measurement procedure which is suitable for the assessment of NO_2 emissions from current vehicles. This procedure mainly focuses on diesel vehicles, for which primary NO_2 emissions represent a particular problem. The procedure involves the determination of the NO_2 mass emission by means of simultaneous analysis of the NO and NO_x concentrations in the raw (undiluted) exhaust gas, sampled on-line at the exhaust pipe. For the gas analysis an instrument using the chemoluminescence principle was proposed. However, problems relating to interference from ammonia will need to be considered when testing near-future SCR-DeNO$_x$ systems (and also petrol-engined vehicles which known to emit substantial amounts of ammonia). The test procedure was used as the basis for a large-scale measurement programme at TNO Automotive and EMPA, in which a total of 63 passenger cars were tested, from pre Euro to Euro 4 petrol and diesel ones (see the number of vehicles tested Table 20). Some other vehicles were tested by Ricardo, Millbrook and LAT.

vehicle type	petrol			diesel	
	pre Euro	Euro 1-2	Euro 3-4	pre Euro to Euro 2	Euro 3-4
veh. tested by Gense et al.	7		17	21	18
NO_2 fraction (%)	3	6	9	17	50

Table 20: NO_2 as a percentage of NOx for different car categories, based on the results presented by Gense et al. (2006) and AQEG (2006).

The results from the emission measurement programme showed some clear trends (see emission factors and NO_2 fractions resp. in Figure 18 and Figure 19). The measured levels of NO_2 and the fraction of NO_2 in NOx were higher for diesel cars then for petrol cars. For diesel cars the fraction ranged from about 5% to almost 80 %. A large step change was evident for diesel cars from Euro 2 to Euro 3. From pre Euro to Euro 2 the average NO_2 fraction did not vary much, and was about 15 % to 20% (an average of 17 % was assumed). For Euro 3 diesel cars the measured NO_2 fraction was considerably higher, at around 50%. The absolute NO_2 emission increased sharply from Euro 2 to Euro 3, and remained at the same level for Euro 4. Measurements on four cars (three with a catalysed diesel particle filter and one with a D-kat) yielded NO_2 proportions which were higher than 50 %.

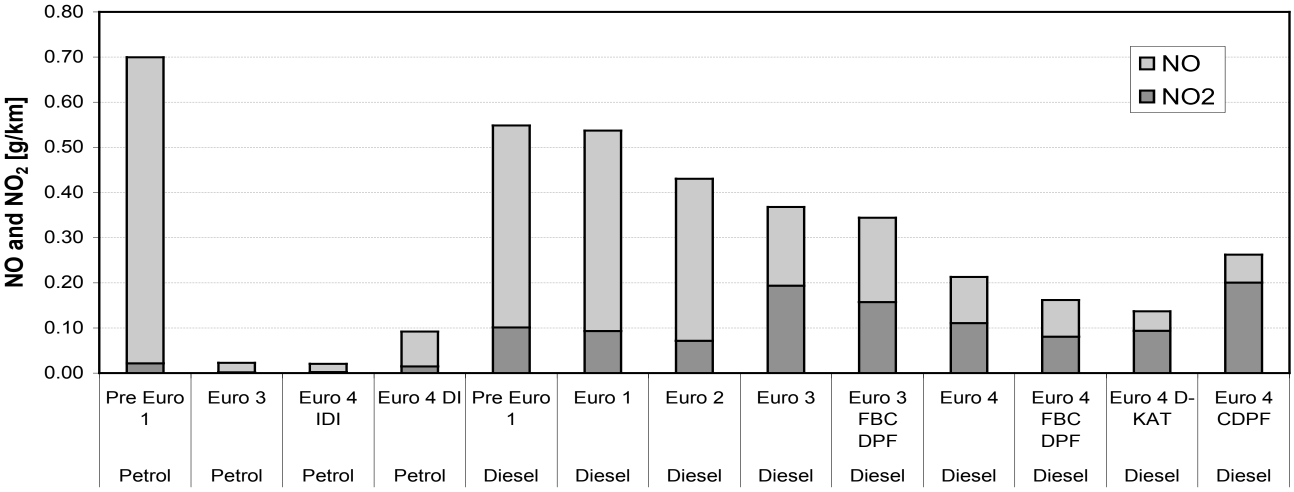


Figure 18: NO and NO_2 emissions of various technologies and emission standards. The values are derived from a mixture of driving situations (urban with a cold start, rural and highway), as measured by TNO Automotive (Gense et al., 2006).

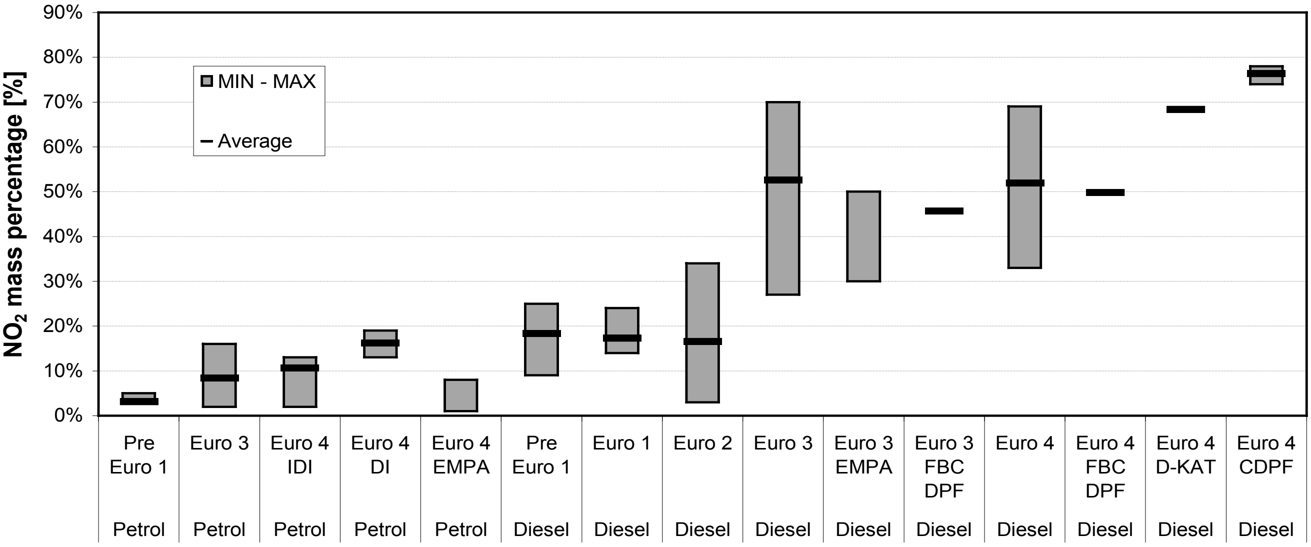


Figure 19: NO_2 percentage of NOx for various technologies and emission standards, including the ranges (minimum and maximum values) as measured by TNO Automotive and EMPA (Gense et al., 2006).

For petrol cars the measured absolute NO_2 emissions were low compared with those of modern diesel cars, as both the fraction of NO_2 and the absolute level of NOx were much lower. As the values were too low to determine reliable estimates, Gense et al. (2006) considered that no accurate NO_2 fractions could be determined for petrol cars. However, it has been assumed here that typical average NO_2 fractions would be 3 % and 9 % for pre-Euro and Euro 3-4 petrol cars respectively. For petrol Euro 1-2 cars, an intermediate fraction of 6 % has been assumed.

The average speed seems to have a negative influence on the NO_2 fraction for pre Euro to Euro 2 vehicles (AQEG, 2006), but no influence for more recent Euro 3 and Euro 4 vehicles (Ricardo, 2003; Millbrook, 2005). We propose in a first step not to take into account the average speed.

The NO_2 fractions for the different passenger car categories are given in Table 20.

3.6.4. Emission factors for particle properties

In the framework of the Particulates project (Samaras et al., 2005b), a dedicated sampling and measurement system was employed in several laboratories in order to characterize the particle emissions of light duty vehicles of various technologies and using several fuels, under a number of test cycles (Samaras et al., 2005b). The results obtained from these measurements have been used for the development of emission factors for several particle properties of light duty vehicle exhaust (Samaras and Geivanidis, 2005).

In particular, emission factors were developed for the particle number (size range >7 nm) and the integrated active surface area (7 nm – 1 µm) of the total particle population as well as the number of solid particles of three different size ranges: 7-50 nm, 50-100 nm and 100 nm-1 µm (aerodynamic diameter). Hot-start cycles of real-world (transient) pattern were considered in this analysis. Specifically, separate emission factors were developed for urban, rural and motorway conditions, using the results obtained under the corresponding Artemis cycles.

The only significant fuel effect observed was that of sulphur on the total particle number and surface of diesel vehicles. Therefore, separate emission factors were derived for diesel fuels fulfilling different specifications of directive 2003/17/EC. The fuels have been distinguished into EN590:2000 speciations (<350 ppm wt. S) and EN590:2005-2009 speciations (<50 ppm wt. S). On the other hand, a single emission factor, irrespective of the fuel used, was produced for petrol vehicles.

Table 21 gives the vehicle categories tested in the Particulates project (and therefore considered here) and the sample size. Due to the relatively small vehicle sample no further categorization was applied with respect to engine capacity.

Vehicle category		Number of vehicles tested
diesel	Euro 1	1 simulated*
	Euro 2	2
	Euro 3	4
	Euro 3 DPF	4 OEM + 1 retrofitted with 2 particle traps
petrol	Euro 1	1
	Euro 3	4
	Euro 3 DISI	3 in lean mode + 2 in stoichiometric mode

* The particular vehicle was a Euro 2 diesel which was tested with its oxidation catalyst removed in an attempt to simulate Euro 1 levels.

Table 21: Passenger car categories considered in the Particulates project, and number of sample vehicles in each category.

The pooled average of the vehicle emissions in each category were used for the derivation of the emission factors. A significant fuel effect was only observed over the motorway tests for the conventional diesels and over the rural and motorway tests for the Diesel Particulate Filter vehicles. In that respect separate emission factors (for each fuel type) were only derived for these driving conditions.

The emission factors for the total and solid particle population are summarized in Table 34 and Table 35 respectively, both in Annex 23. A more detailed representation is given as an example in Figure 20.

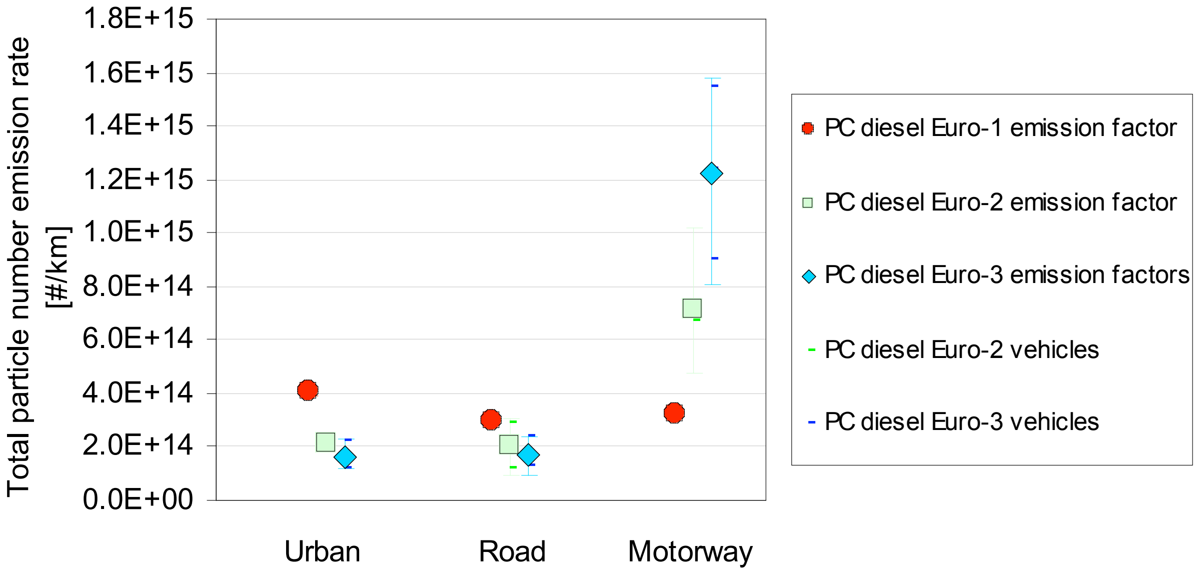


Figure 20: Emission factors of the total particle population for conventional diesel Euro 1 to 3 vehicles and EN590:2000 diesel fuel. The average emissions of each individual vehicle are also plotted as dots. The error-bars correspond to the minimum and maximum result obtained for each vehicle category.

3.7. Light Duty Vehicles

In the most recent version of the European inventorying tool Copert (Ntziachristos and Samaras, 2000a and b), the Light Duty Vehicle emission factors have been built by extrapolating data obtained from passenger cars to light duty vehicles. Only pre-Euro 1 and Euro 1 vehicles were studied and emission factors expressed according to the average speed. To improve the accuracy of this model, we incorporated the results of a former Inrets project (Joumard *et al.*, 2001, 2003) and the tests carried out previously by other European laboratories (Tuev in Germany, TRL in UK, TNO in the Netherlands, Empa in Switzerland and KTI in Hungary). Specific cycles for light duty vehicles were developed for some of these programmes, taking into account the road type and loading rates (André et al., 2000).

This study is described in detail in Markewitz and Joumard (2005; 2006).

3.7.1. Data extraction and classification

The first step of the analysis consisted in exhaustively extracting all the light duty vehicles from the Artemis LVEM database (Kljun *et al.*, 2005 ; Andre, 2005). The LDV database concerns light vans, vans and minivans, i.e. 150 vehicles and 2035 tests (1 test = 1 vehicle and 1 driving cycle). The vehicles were then grouped according to the European categorisation (N1-I to N1-III) based on the vehicle tare weight (cut points: 0, 1305, 1760 and 3859 kg), associated with the European emission standards (pre-Euro 1 to Euro 3) and the type of fuel used (diesel, petrol). 24 different groups were distinguished, but the different groups were not equal because 19 groups contained less than 4 vehicles while 5 groups contained more than 10 vehicles. In addition, whereas 6 laboratories tested LDVs, no group contained data of more than 4 laboratories and, in a third of cases, only one laboratory was represented per group. This may have had an artificial homogenising effect on the data since the production source of each group was not very diversified. However, as shown in Figure 21, the source of the vehicles was balanced for 5 laboratories out of 6, meaning that the representativeness of 5 out of 6 laboratories was satisfactory.

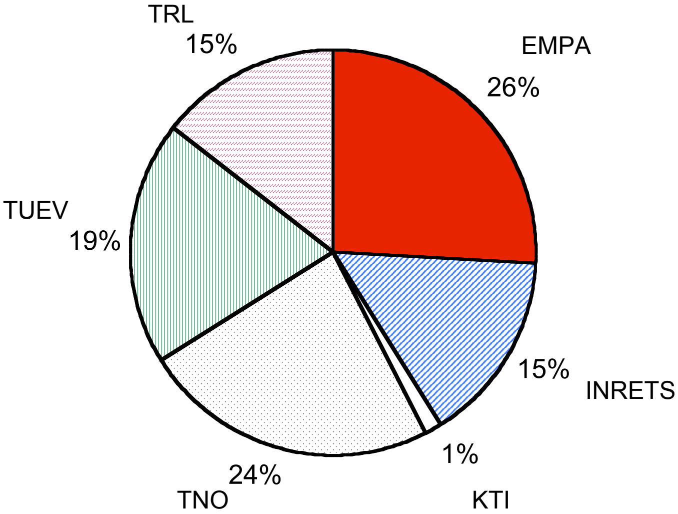


Figure 21: Source laboratory of Light Duty Vehicle data.

3.7.2. Emission as a function of average speed

In contrast to passenger cars, the emission measurements available did not allow to derive emission factors for traffic situations. Hence, the emission factors were developed based on the average speed approach only.

To build a model of emission factors, 4 hypotheses were applied:

- The group of vehicles extracted is representative of the global fleet of light duty vehicles and its conditions of use.
- All the vehicles of a group are equivalent. The emission measured is independent of vehicle make and analysis laboratory.
- All the cycles have the same weight as a function of representativeness.
- The number of tests carried out on a vehicle does not influence the weight of the emission.

The consequence of these hypotheses is that each data is considered with the same weight of representativeness.

For each vehicle, the emission data were analysed according to the average speed of the cycle. The best fit is chosen to minimise the standard deviation between the model and the measurement points. The emissions describe a polynomial curve of order 2 in the great majority of cases and a power curve in a few cases. The coefficients of determination were generally significant (> 0.7). However, for certain vehicles and pollutants, the values obtained were low (< 0.3) showing that other parameters than the average speed (e.g. acceleration) have a significant influence on the emissions.

For each of the 24 groups, the average equation was also calculated by polynomial equation of order 2 or power equation with an average coefficient of determination of 0.41 for diesel and 0.5 for petrol vehicles (see an example Figure 22). The validity of using an average equation was verified by Pearson's test with an error of 0.5 %. The aim of this statistical test was to verify the hypothesis that the two groups were identical, i.e. the data calculated by the average equation and either the raw data or the data obtained from the equations of each vehicle.

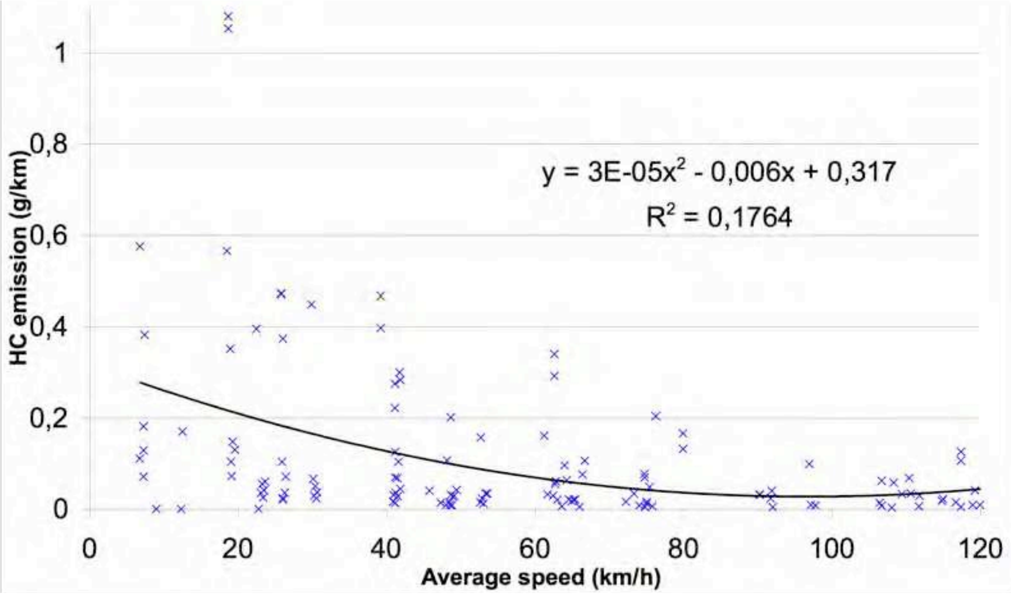


Figure 22: Average emission for the vehicle group N1-III diesel Euro 1, as a function of average speed only.

The results were then analysed in several steps. The first step consisted in distinguishing the vehicles that satisfied Pearson's test or not. The vehicles that verified Pearson's test were separated into 3 groups as a function of the coefficient of determination obtained. If it was higher than 0.7, the emission was considered as depending only on the average speed. If the coefficient of determination was from 0.5 to 0.7, the equation for this group of vehicles was satisfactory, but other parameters could play a role. If the coefficient of determination was lower than 0.5 and the test validated, the equation was only accepted if the addition of the parameter did not permit any increase of the coefficient of determination. In this case, it was necessary to carry out additional searches.

The results are as follows: the petrol vehicles had 18 validated emission factors (confirmation of Pearson's test and a coefficient of correlation higher than 0.7) – i.e. 34 % of the equations – and the diesel vehicles had only 12 – i.e. 12 %. Furthermore, 8 diesel vehicle emission factors and 6 petrol vehicle factors were not validated by Pearson's test. The emission factors were therefore not only dependent on average speed despite the fact that a large number of emissions can be determined by using this single parameter.

3.7.3. Emission as a function of vehicle loading rate

The loading rate τ is expressed in % and is calculated according to the weight of the vehicle during the test M_{test} and the vehicle tare weight M_{empty}, using the following equation:

$$\tau = \frac{M_{test} - M_{empty}}{M_{empty}} \times 100$$

The loading rate, calculated for all the vehicles and all the cycles carried out, varied from 0 to 91 %. However, for 12 % of the tests, it was not possible to calculate the loading rate due to the lack of the vehicle weight during the test: the corresponding emission data won't be used for the calculation of emission factor as a function of loading rate.

The vehicle load is not the only parameter influencing emission variations since the emission as a function of the average speed of the groups with a low range of loads has not necessarily a high coefficient of determination nor even validate Pearson's test.

It appears that the entire emission curve is changed by the increase of the vehicle weight: For a given pollutant whose emission curve y has as equation according to the average speed v $y=av^2+bv+c$ (the most frequent case), the coefficients a, b and c are related to the load. To define the link between these coefficients and the loading rates, we defined speed zones so that the variety of the group in terms of load and vehicles was represented. The equation describing the pollutant emission as a function of load was calculated for each zone. It is a polynomial curve of order 2 at most (order 1 for groups in which fewer than 4 vehicles were studied). The equation in each speed zone was therefore $y=a'\tau^2+b'\tau+c'$. The coefficients of determination between this curve and the emission data were 0.65 and 0.52 on average for diesel and petrol vehicles respectively. The equations for which the coefficient of determination was less than 0.2 were not used.

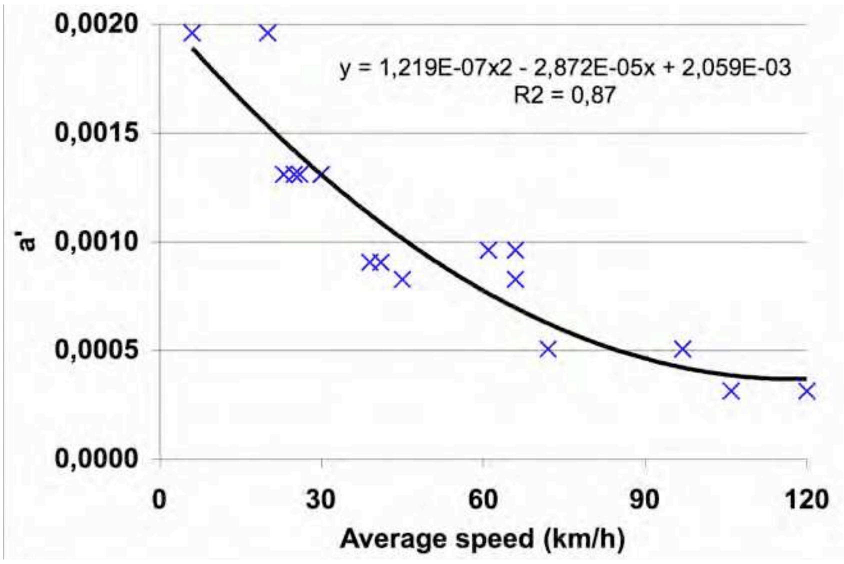


Figure 23: *Coefficient a' of the HC emission of group N1-III diesel Euro 1 as a function of average speed.*

Then the coefficients a', b' and c' were expressed according to the average speed of the speed zone (see an example Figure 23). If the coefficient of determination was lower than 0.5, the speed zones were revised until a better coefficient was obtained, otherwise this group of vehicles was withdrawn from the load study. The coefficients obtained were thus 0.75 and 0.76 on average for diesel and petrol vehicles respectively. The equation of each coefficient was then incorporated into the pollutant emission equation, which depends on the average speed and load: $y=a'(v)\tau^2+b'(v)\tau+c'(v)$.

Two series of verifications were applied to the equation obtained. The first verification consisted in verifying that the group of measured emission data and that of calculated emissions could be considered identical. To do this, Pearson's test was performed and compared with Student's law with (n-2) degrees of freedom for an error of less than 0.5 %. The second verification consisted in comparing the values calculated by the equation to the values of the emission curves. As before, the two groups were compared using Pearson's test for an error less than 0.5 %. The equations were also classified into 4 groups as a function of the validation of Pearson's test and of the coefficient of determination obtained. Figure 24 shows an example of correspondence between the emissions calculated as a function of speed and loading rate for the group of vehicles and the raw data or the emissions calculated as a function of speed for each vehicle.

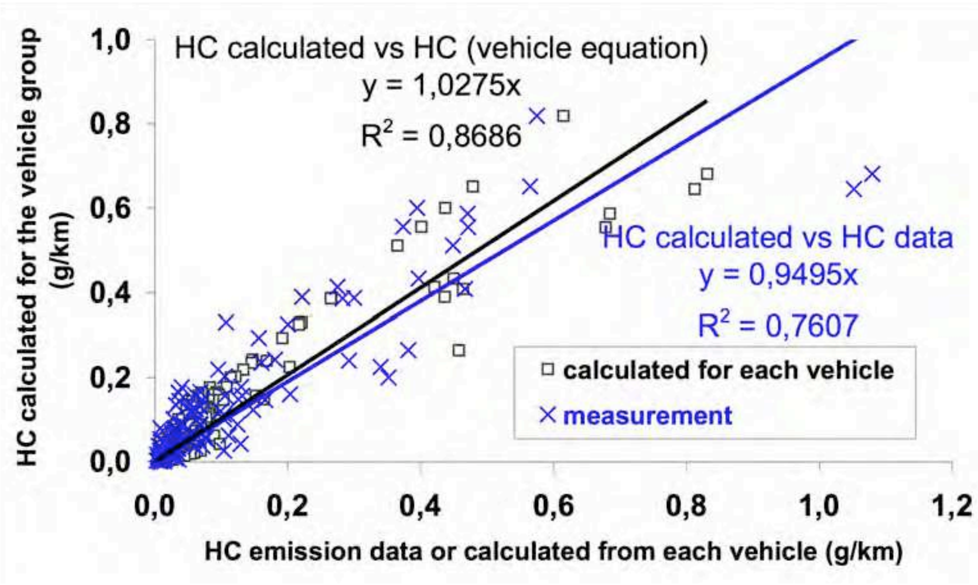


Figure 24: *Statistical validation of the emission as a function of loading rate and average speed for the HC emission of group N1-III diesel Euro-1.*

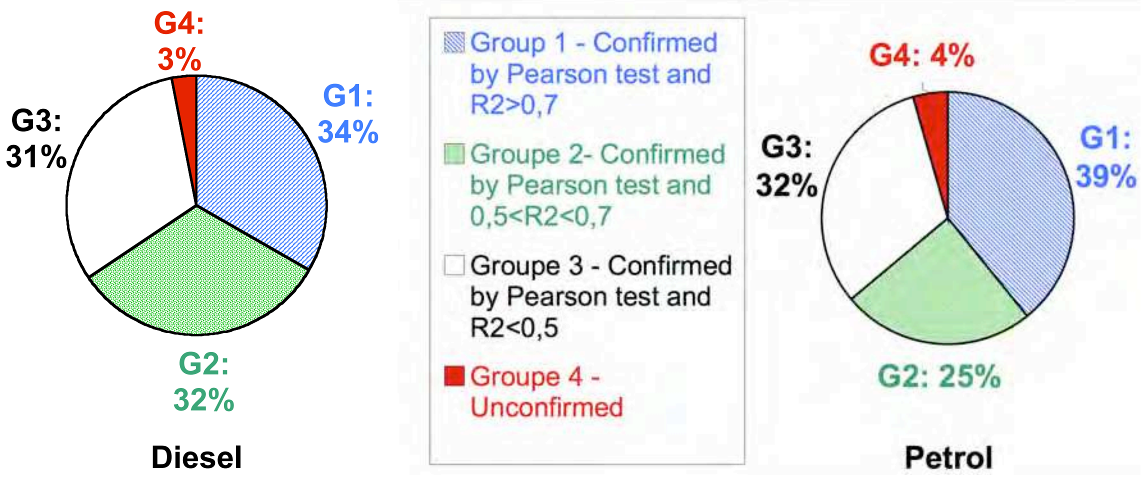


Figure 25: *Distribution and validation of the equations obtained.*

The emissions of N1-I diesel pre-Euro 1 and Euro 2, N1-II diesel Euro 2, N1-I petrol Euro-1 and N1-III petrol Euro 2 and the hydrocarbon emissions of N1-I petrol Euro 1, N1-II petrol pre-Euro 1 and Euro 1 are not linked with the vehicle load. For the other groups, an equation defining the emission as a function of average speed and load was established with an average coefficient of determination of 0.56 for diesel vehicles and 0.61 for petrol vehicles. This shows that the load parameter has a significant impact on the precision of the emission factor equation. In addition, load and speed permit defining a satisfactory emission factor (Pearson test validated and coefficient of determination higher than 0.7) for 26 % and 27 % of the groups of diesel and petrol vehicles respectively. A synthesis of the results is presented in Figure 25.

A result is considered as satisfactory when the Pearson test is validated and the coefficient of determinations is higher than 0.7. This is the case for 34 % and 39 % of the emission factors calculated for diesel and petrol vehicles respectively. For these groups it was possible to determine an equation highly representative of the group by using average speed and/or the loading rate as sole parameters. A result is considered as valid but needing further analysis for another impact parameter on the emission, when the result is validated by Pearson's test and the two coefficients of correlation are higher than 0.5 (and do not belong to the previous case). This is the case of 32 % and 25 % of the emission factors calculated for diesel and petrol vehicles respectively. Thus, in 66 % of groups containing diesel vehicles and 64 % of the groups containing petrol vehicles, an equation representing the group is determined and validated with a coefficient of determination higher than 0.5 and therefore higher than the average value of the equations used in Copert. Regarding the remaining vehicles, it was necessary to study another factor even though only 3 % and 4 % of the equations were not validated by the Pearson test. These are HC and particle emissions for the vehicles of group N1-II diesel Euro 2 and CO, HC and NOx of N1-III petrol Euro 2 where few data were obtained with only two vehicles.

For each of the equations obtained and in particular for those including the load factor, it was necessary to model the behaviour of the emission outside the load zone studied. For that, the lower and higher values of the emission at the limit test load were compared to the values calculated at 0 % and 100 % respectively. When the difference is greater than 30 %, the equation is not used outside the study zone and the value used outside is equal to that of the nearest bound. In other cases, the calculation is carried out on the basis of the equation for any load or speed.

3.7.4. Conclusion

After extracting the emission data of light duty vehicles from the European Artemis LVEM database, it was possible to formulate equations of emission factors for these vehicles as a function of average speed [km/h] and loading rate [%] as calculated in section 3.7.3: See Annex 24. This method was used to statistically validate 97 % and 96 % of the emission factors of diesel and petrol LDV respectively.

Furthermore, a considerable increase in precision of the quality of the equations was observed. In the Copert model, the average coefficient of determination was 0.39 for diesel LDV and 0.49 for petrol LDV. By updating the data in Artemis and calculating the emission factors by using only the average speed as parameter, a slight improvement of the coefficients of determination could be observed since it was resp. 0.41 and 0.5. However, by adding load as a parameter, the average coefficient of determination changed to 0.59 for diesel and 0.56 for petrol vehicles. In addition, whereas Copert only deals with pre-Euro 1 and Euro 1 vehicles, we propose emission factors for Euro 2 vehicles.

Testing of the emission factors obtained must, however, be continued and their equations improved, if necessary, by using additional vehicles added during updates of the Artemis LVEM database.

3.8. Influence of mileage

The influence of the vehicle mileage on hot emissions is presented in details in (Geivanidis and Samaras, 2004 and 2005) and in the Artemis deliverable 2 (Joumard et al., 2006a). It is only synthesized hereafter.

As regards Euro 1 and Euro 2 vehicles, MEET data are proposed to be used as the majority of data covering these vehicle categories contained in the Artemis database (see section 2) originated from the same dataset used for the MEET estimations. In order to estimate the degradation of modern Euro 3 and Euro 4 vehicles, an analysis was performed on the data derived from the Artemis LVEM database (version 1/12/2004). The mileage effect on CO, HC and NO_x emissions was examined as CO_2 emissions have been proven to be unaffected by mileage.

The analysis was performed in two driving mode regions: urban and rural. The effect of average speed on emission degradation is taken into account by combining the observed degradation lines over the two driving modes (urban, rural). It is assumed that for speeds outside the region defined by the average speed of urban driving (19 km/h) and rural 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.

The correction factor by which the basic emission factor should be multiplied in order to take into account the degradation of emissions due to mileage which is given by the equation:

$$y(M, p, V) = a(p, V) \times M + b(p, V)$$

where:

y: the mileage correction for a given mileage (M), a pollutant p and an average speed V
M: the fleet mileage of vehicles for which correction is applied
p: pollutant
V: average speed, in km/h
a(p, V): the degradation of the emission performance per kilometre
b(p, V): the emission level of a fleet of brand new vehicles

Then, for mileages M_1 and M_2:

$$\frac{emission(M_1)}{emission(M_2)} = \frac{y(M_1)}{y(M_2)}$$

y is available in Annex 25, for Euro 1 and 2 petrol cars in Table 36, and for Euro 3 and 4 petrol cars in Table 37, in both cases for urban and rural situations, i.e. resp. for an average speed lower than 19 km/h and higher than 63 km/h.

For an intermediate speed V, the following formulae has to be used:

$$y(V) = y(urban) + \frac{(V - 19) \cdot (y(rural) - y(urban))}{44}$$

By lack of data, it is assumed that emissions do not further degrade above 120 000 km for Euro 1 and 2 vehicles and 160 000 km for Euro 3 and 4 vehicles.

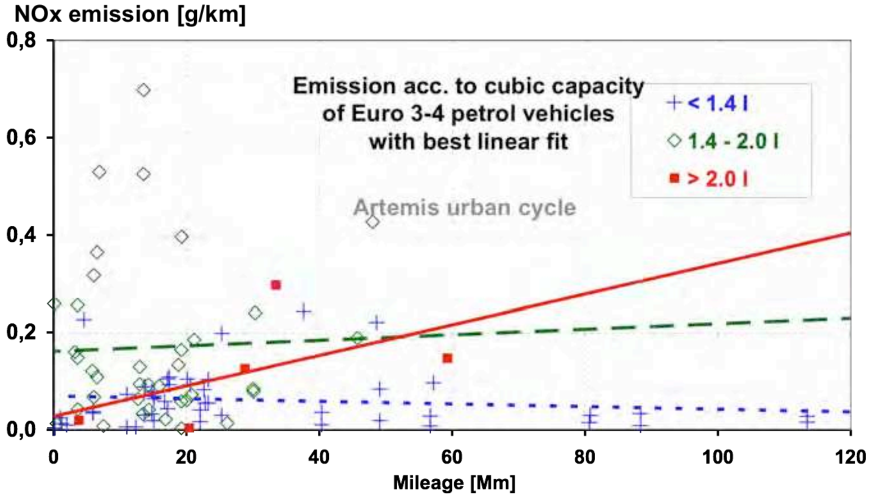


Figure 26: NO_x degradation according to petrol vehicle mileage in urban driving behaviour.

Globally, the mileage has no influence on the CO_2 emission neither on the emissions of diesel vehicles, but increases a lot CO, HC and NOx emissions of petrol cars: between 0 and 100 000 km, these emissions increase by a factor 3.6 in average for Euro 1 and 2 vehicles, but only by 15 % for Euro 3 and 4 vehicles (see an example Figure 26).

3.9. Influence of ambient air temperature and humidity

The influences of the ambient air temperature and humidity are presented in details in the Artemis deliverable 2 (Joumard et al., 2006a). They are only synthesized hereafter.

3.9.1. Influence of ambient air temperature

The methodology followed (31 passenger cars tested with hot Artemis driving cycles but for 3 ambient air temperatures: See section 2.1) shows that the lowering of the ambient temperature increases generally the emissions of CO, HC, NOx and CO_2 (Laurikko, 2005a). However, in some cases a decrease in CO was detected, most notably in case of CO for petrol-fuelled cars in rural and motorway driving.

On average over all tested driving cycles, the ratio between emissions at -10°C and at +20°C was for all tested petrol-fuelled cars (Euro 2, Euro 3 and Euro 4) 0.96, 1.54, 1.11 and 1.05 respectively for CO, HC, NOx and CO_2, and for diesel Euro 2 cars the ratios were respectively 2.14, 1.73, 1.04, 1.04 and 1 for PM. Therefore in most of the cases, emission is a decreasing function of the ambient temperature.

On average, these ratios do not depend much on the emission standard of the vehicle, as almost equal responses were observed for each type approval level tested. However, in urban type of driving (i.e. low speed and low thermal load in the engine) the hydrocarbon emissions showed increasing sensitivity to low ambient temperature with the advance in Euro standards, i.e. Euro 4 cars were the most sensitive ones, and the Euro 0 cars were least affected. In terms of CO, the responses were most scattered regarding the influence of the driving type (urban, rural, motorway), whereas regarding CO_2, the response was most uniform, i.e. less dependence on the road type.

The influence of the ambient temperature on the emissions was in most cases linear (see an example Figure 27), but in a few cases (urban HC for petrol Euro 4, and motorway HC for diesel Euro 2), exponential type of function gave better match. In a few cases we could not set any trend, as ambient temperature did not seem to have any effect.

The influence of the temperature T_1 or T_2 [°C] is expressed by the formulae

$$\frac{emission(T_1)}{emission(T_2)} = \frac{y(T_1)}{y(T_2)}$$

y is available for urban, rural and motorway driving behaviour in Table 38 in Annex 26.

Globally the hot emissions decrease with increasing temperature for petrol cars but mainly for diesel ones. Between 10 and 20°C, the CO and HC emissions varies by 15-20 %, the NOx and CO_2 emissions by 2 %, and PM is constant.

3.9.2. Influence of ambient air humidity

The results of the measurements carried out (see section 2.1) show that overall an increase in ambient humidity lowers the NOx emissions (Laurikko, 2005b), which is also the expected general trend according to the humidity correction established in legislative testing (EEC, 1991). Figure 28 shows that in urban test cycle the standard correction is nearly valid for diesel cars with less than 5 % deviation from the now-established model. However, both groups of petrol cars would need much stronger correction, as the relative change over the allowed humidity range is about 35 % for the Euro 2 to and over 55 % for the Euro 3 test fleet, and the normative factor corrects only by some 20 % within the same range of humidity. Therefore, the normalisation provided by the standard correction factor is not enough. However, the case is very different when rural driving cycle is employed. All linear correction models developed here lie almost on top of each other, and the necessary correction is less than 20 %, even somewhat less than provided by the standard method. So, using the standard correction factor here actually leads to a slight “overcorrection”.

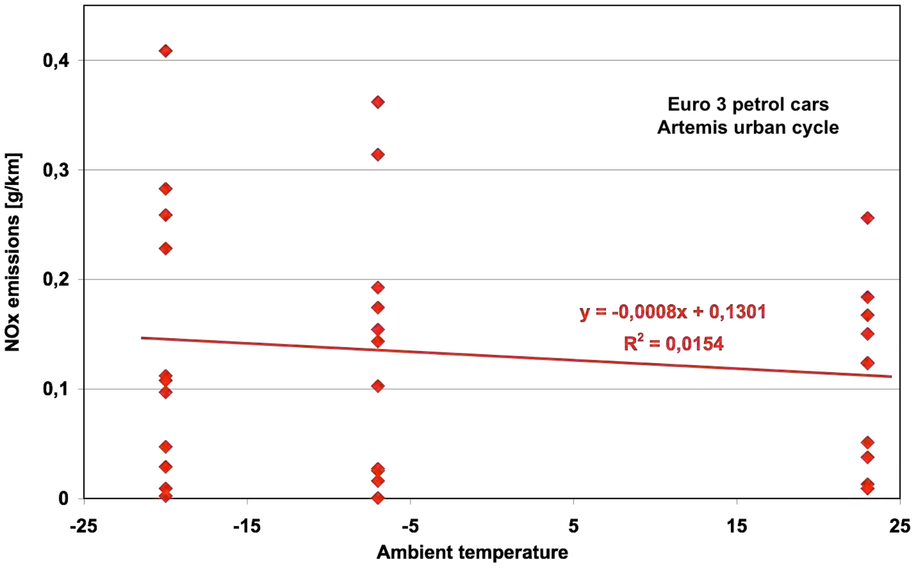


Figure 27: Influence of the ambient temperature on the NOx emissions of Euro 3 petrol cars over the Artemis urban driving cycle.

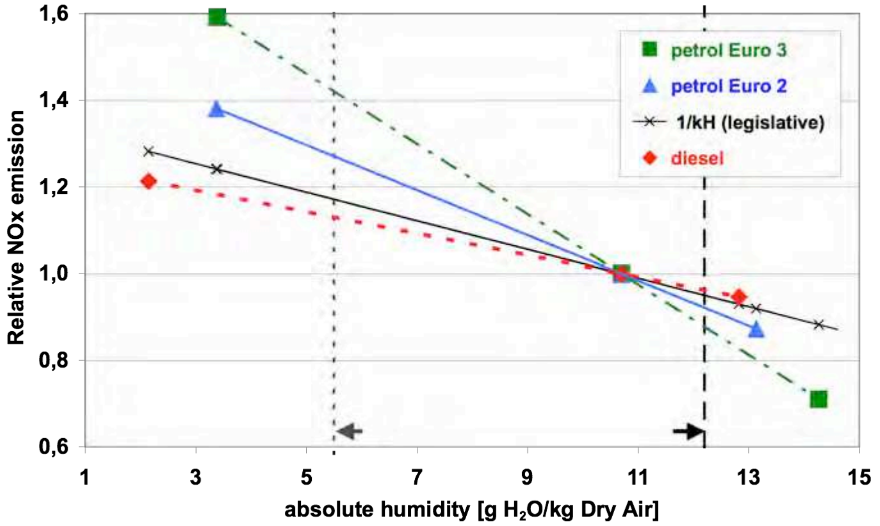


Figure 28: Linear models of (uncorrected) NOx emissions measured in Artemis urban driving cycle, fitted in average values for high, medium and low humidity, and correction factor according to legislative test protocol (as 1/kH).

For CO and HC, in case of diesel vehicles, CO correlates to the absolute humidity by 0.60 (rural) to 0.73 (urban), and HC to humidity by 0.28 (urban) and 0.41 (rural). The plotting of the relative influence of the humidity shows a clear influence of the humidity in the following cases:

- CO for diesel cars
- CO for petrol Euro 2 vehicles in urban situation
- HC for diesel cars and for petrol Euro 2 cars
- HC for petrol Euro 3 cars in urban situation

However, no correction factors have been proposed in these cases.

In the case of NOx emissions, the influence of the humidity is expressed by the formulae

$$\frac{emission(H_1)}{emission(H_2)} = \frac{y(H_1)}{y(H_2)}$$

y is available for some vehicle classes and for urban and rural driving behaviour in Table 39 in Annex 27:

$$y = a \times \text{Humidity} + b$$

with Humidity in g H_2O/kg dry air
y normalised at 10.71 g H_2O/kg dry air

a and b depend on the driving behaviour and also on the initial correction applied to NOx emission: either NOx is not corrected, or NOx is already corrected by using the standard (or legislative) correction factor.

It is recommended to use the rural figures for motorway driving behaviour, and to use the petrol Euro 2 figures for petrol Euro 0 and 1, petrol Euro 3 figures for petrol Euro 4, and diesel Euro 2 figures for the other diesel cases. For other pollutants, no correction factors are proposed.

3.10. Influence of road gradient and vehicle load

Positive road gradient increases and negative road gradient decreases the driving resistance of a vehicle. Engine power demand is a decisive parameter for the vehicle emissions and fuel consumption. Nevertheless it is a fact, that additional emissions at positive road gradient will not be compensated by lower emissions at negative road gradient (Hassel et al., 1994).

Engine power demand is also increasing by increasing the vehicle loading. The increase of the power demand due to vehicle loading is less than the increase due to road gradient. It is therefore not obvious that emissions will also increase with increasing vehicle loading, because it may happen that the conversion efficiency of the exhaust after treatment system is better (it was the case for some light duty vehicle classes: see section 3.7). Thus the net emission may even decrease, even if the raw engine-out emissions increase.

Measurements of cycles with different road gradients exist, however they do not cover new vehicle technologies. For emission factors of current and near future vehicles these data had to be established. Therefore new measurements were carried out within ranges of statistical significance in Europe for road gradients and payloads (see section 2.1). The numbers of measurements are too small to obtain emission factors for all driving and gear shift situations, thus the results are only valid for the driving situations of the measurements carried out. Therefore after a comparison between measurement and simulation, all factors were simulated with the model PHEM. A more detailed report is available: See Zallinger and Hausberger (2004).

3.10.1. Measurement results

Road gradient

Because of the small sample and the different vehicles (engine power and capacity) in this sample it is not reasonable to calculate the average emission for diesel and petrol for the different road gradients. It is better to calculate the ratio between measured and 0 % road gradient for every measurement and afterwards to calculate the average ratio for the varying road gradients for diesel and petrol vehicles.

$$Road\ gradient\ factor = \frac{Emissions\ at\ x\%\ road\ gradient}{Emissions\ at\ 0\%\ road\ gradient}$$

Examples of these road gradient factors are represented for NOx in Figure 29 for Euro 3 diesel vehicles. For NOx, PM and fuel consumption from diesel vehicles, a trend can be seen where as for CO and HC no describable shape was indicated. The level of these emissions (CO and HC) is quite low for diesel engines and therefore a small difference in the measured values for road gradients has a great influence on the factor.

Fuel consumption, CO and HC factors of petrol vehicles show a progressive shape of the curve, where as for NOx no describable shape was indicated.

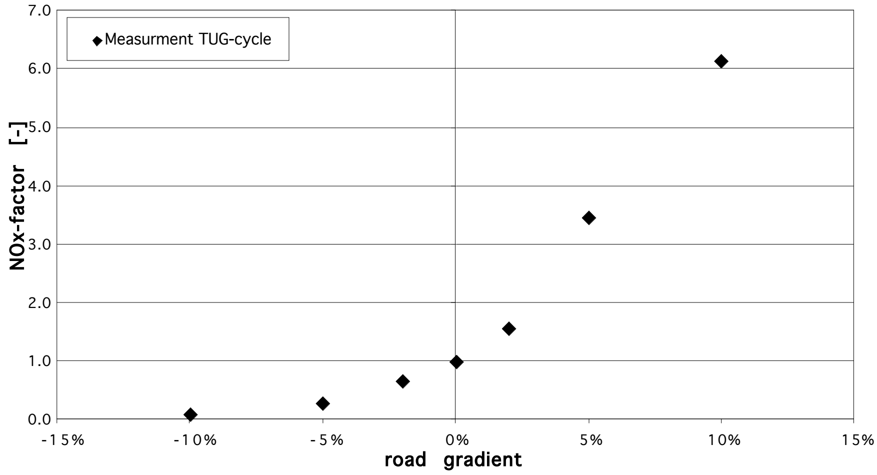


Figure 29: Measured road gradient NOx factors for Euro 3 diesel vehicles on different road gradients.

Vehicle load

The base for all driving cycles was the common measurement situation (vehicle plus driver; “unloaded”). The “loaded” situation designates the measurement with the full payload for this car type – in average it is 450 kg and the “half loaded” designates the situation in the middle of “unloaded” and “loaded”.

$$Loading\ factor = \frac{Emissions\ with\ load}{Emissions\ with\ 90[kg]\ load}$$

Examples of results for Euro 3 vehicles and NOx are shown in Figure 30.

For the diesel vehicle relevant emissions (NOx, PM and FC) the influence of the loading situation can be seen and thus it is possible to generate loading factors for these emissions. For HC and CO the influence of vehicle loading is in the same range as the standard deviation of the repeatability tests (see section 3.2.2. of Joumard et al., 2006). In this case (small vehicle sample) it is not correct to produce loading factors for CO and HC.

Concerning petrol vehicles it is only possible to generate a loading factor for fuel consumption. Because of the small sample, the results for the emissions are again in the range of repeatability.

From these measurements the final factors (see section 3.10.4) for diesel (FC, NOx and PM) and petrol vehicles (FC) were calculated for an average loading situation by linear interpolation. This loading situation should describe the average payload of a car with approximately 1.5 persons.

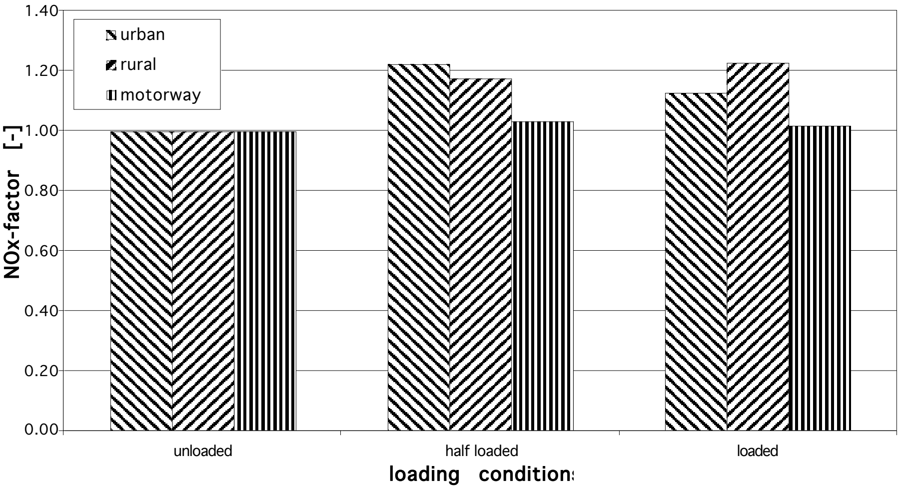


Figure 30: Measured NOx loading factors for Euro 3 diesel vehicles for different loading situations.

3.10.2. Comparison with other sources

To increase the data base on road gradient and vehicle load a comparison with other researches is provided in this chapter.

Road gradient

For road gradient a comparison with two other sources was done. One of the sources is the Handbook of emission factors or HBEFA (Keller, 2004), whose road gradient factors are based on measurements of Euro 0 and Euro 1 vehicles (Hassel et al., 1994). The other source was the simulation with our instantaneous emission model PHEM which was developed within Artemis (see section 3.2 and Rexeis et al., 2005).

Using the *HBEFA*, emission factors for road gradients from -6 % up to 6 % can be gained. For this comparison a rural cycle (AO_HVS3) was chosen, whose average cycle velocity is in the same range as the average velocity of the measured cycle. Figure 31 shows the comparison of the measured and the Handbook factors, in the case of NOx for diesel vehicles.

In the case of diesel vehicles, for fuel consumption and particulate mass the agreement between Handbook factors and measurement is very good, whereas for NOx, especially for positive gradient, it is worse. This disagreement can perhaps be explained in the different gearshift strategy of Handbook cycles and TUG-cycle measurement on one hand and in the difference between the cycle velocities on the other hand. A reasonable technical explanation may be the fact that Euro 3 cars have EGR (Exhaust Gas Recirculation, to lower the NOx emissions), which is not active at high engine loads and engine speeds, which occur frequently at high road gradients. The inactive EGR explains the strong NOx increase at 6 % and at 10 % road gradient, because the cars measured for the HBEFA did not have EGR. For CO and HC the measurement produces a higher factor than the Handbook. But for these emissions the measurement is quite sensible because of the high deviations.

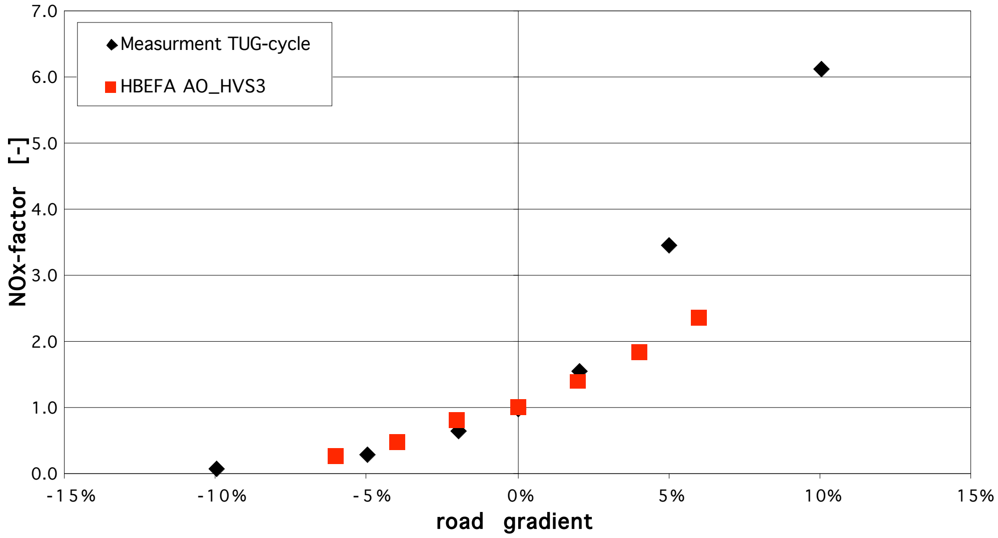


Figure 31: Comparison of measured and HBEFA road gradient factors for diesel vehicles and NOx.

In the case of petrol vehicles, the agreement of the measurement and the Handbook factors is quite good for fuel consumption and CO. For HC and NOx emissions the congruence is not that good, however for HC the calculation of an average road gradient factor (±) is in the same range as the Handbook factor.

To validate whether our *simulation tool PHEM* is useful for the road gradient emission simulation, a comparison with the measurement was done, using the Artemis rural cycle for 0, ±2 and ±4 % road gradient. For ±6, ±8 and ±10 % road gradient the average velocity of this cycle was adapted to the average velocity of the Handbook cycles (decreased). By using a multiplicative adjustment (<1) the acceleration was also decreased, which seems to be logical for higher road gradients. The following calculation results are valid for average Euro 3 diesel and petrol vehicles (average engine emission maps of 8 petrol and 7 diesel Euro 3 vehicles were used as model input). Example of comparisons is shown on Figure 32 for Euro 3 diesel vehicles, in the case of NOx.

For the diesel relevant emissions (NOx and PM) and fuel consumption, the simulation results are in good congruence with the measurements. Simulation of road gradients higher than 8 % is quite sensible. This is due to the fact, that the engine map used for the simulation is not filled up with data at this engine map range and therefore the calculation in this area had to be extrapolated. The comparison for HC shows also good results, but for CO the result is worse. Nevertheless for CO (and for HC) the measured emission values for 0 % road gradient (basis) are almost near to zero and therefore the results, calculated with factor of ten or more for road gradients still produces low emissions.

For relevant petrol emissions (CO and HC) and fuel consumption the simulation results have a good agreement with the measurements. For road gradients which are higher than 8 % the result for CO and HC shows the same effect which was reflected for diesel vehicles for NOx.

The simulation reproduces the measurement in a wide range of road gradient with an excellent congruence for diesel as well as for petrol vehicles. Thus the simulation is a useful tool to generate emission factors for other traffic situations, which can be found in section 3.10.4.

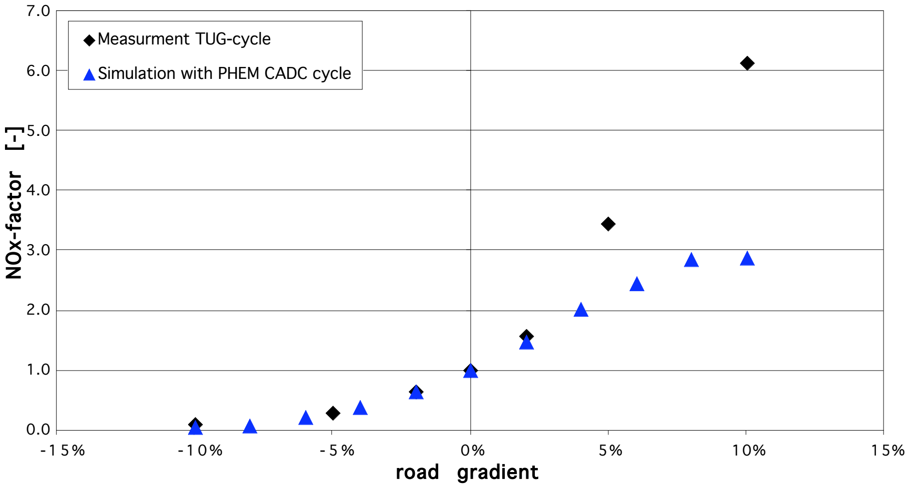


Figure 32: Comparison of simulation and measured road gradient factors for Euro 3 diesel vehicles.

Vehicle loading

Because of the small vehicle sample a comparison with other sources is necessary to evaluate the influence of loading rates on the emissions and fuel consumption. For this purpose we used INRETS investigation on LDV and a simulation with PHEM.

In the *INRETS investigation*, 27 diesel light duty vehicles were tested on a chassis dynamometer with different driving cycles and loading rates (Joumard et al., 2003). The vehicles comply with the European emission standards 88/436 (1 vehicle), Euro 1 (7 vehicles) and Euro 2 (19 vehicles). The mileage and age of the vehicles vary significantly from one category to another. For light vans the load generally leads to a decrease in emissions, slight for gaseous emissions (-2 to -7% depending on the pollutant), and more marked for particles (-20 %).

For vans the load has a contradictory influence depending on the pollutant. For 2.5 t vans the load has a very clear influence on CO and HC emissions (a decrease by one third on average, and even more in urban traffic) and only a slight influence on particles (-8 %). For NOx, CO_2 and fuel consumption, the increase in load systematically increases the emissions by 10 to 20 %, whatever the speed. For the 3.5 t vans, the load decreases the HC and the particle emissions by -10 to -15 %, has practically no influence on the CO emissions and considerably increases the CO_2 emissions (+14 % regardless of the average speed) and especially the NOx emissions (+44 % and in an even more marked fashion in extra urban areas).

The comparison between that study for light duty vehicles should be considered with caution if comparing with passenger cars, because the mass ratio between unloaded/loaded for passenger cars differs to the mass ratio for light duty vehicles (less payload for cars compared to the empty weight).

The results of the *simulation with PHEM* reproduce the emission ratio of a Euro 3 vehicle loaded/unloaded. For the calculation of the three different driving situations (urban, rural and motorway) the Artemis driving cycle was chosen.

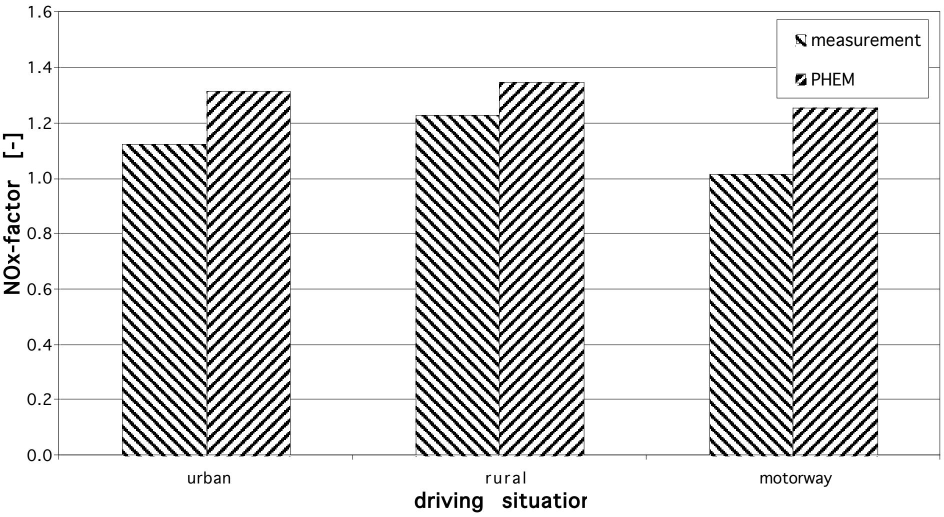


Figure 33: Loading factors for different driving situations for diesel Euro 3 vehicle and NOx.

In the case of diesel vehicles, for NOx, PM and fuel consumption, the agreement of the simulation with the measurement is good (see Figure 33). The results for CO look worse at first view. Nevertheless the basis emission (unloaded) is quite low and therefore the factor will be extremely high. And a further fact is the worse repeatability for CO (see section 3.2.2. of Joumard et al., 2006), which made this comparison not so good, as the measurement results are based only on two vehicles without cycle repetition.

For petrol Euro 3 vehicles, only the simulation of FC has a good congruence with the measurement, but for the emissions the agreement is not so good. The repeatability for petrol vehicle emissions shows a worse repeatability, so it is not possible to gain an accurate loading factor from that small sample of measurements without repetitions.

3.10.3. Combination of road gradient and vehicle loading

For reasons of economy no tests were performed with different loading situations and road gradients, but nevertheless it is important to know whether the influence of the vehicle weight will be stronger at higher road gradients. That is one of the fields of application for the emission simulation. To find out the influence of loading at different road gradients the same driving cycles as above (urban, rural and motorway) were simulated with varying vehicle payload (unloaded, half loaded and loaded) for both average diesel and petrol Euro 3 vehicles.

For the relevant diesel emissions (NOx and PM) and fuel consumption the simulation indicates a minor influence of loading as it was expected at higher road gradients (see Figure 34). CO and HC factors are too sensible to make a statement about the influence of the loading rate.

The influence of the loading rate on the emissions and fuel consumption of petrol vehicles is more or less the same at different road gradients. Only for NOx emissions the influence of loading at higher road gradients is increased, but that emission component is not relevant as emission level is quite low. Higher road gradients (>8 %) can not be simulated with the common engine map generated from the Artemis cycles.

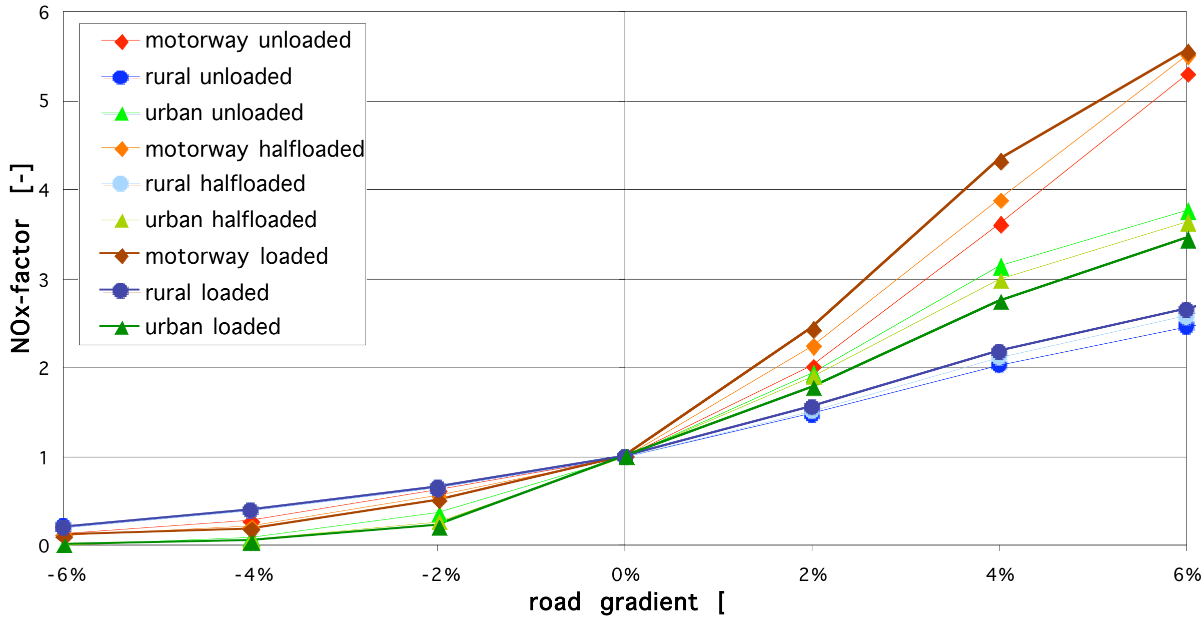


Figure 34: Progression of the road gradient and loading factors for Euro 3 diesel vehicle and NOx.

3.10.4. Final correction factors

To extend the data pool of road gradient emission factors for other traffic situations and for all European emission standards the factors for the final Artemis data base were simulated with the model PHEM. The vehicle loading correction is proposed for fuel consumption, NOx and particulate mass for diesel vehicles and for petrol vehicles only for fuel consumption.

Road gradient

As it is described above some adjustments on the used driving cycles were made. The cycle for the motorway driving situation was recorded on a hilly highway in Austria on all road gradients (-6 up to 6 %). For the rural driving situation the Artemis rural cycle was used. The urban driving situation was simulated with one of the Handbook driving cycles for urban traffic situations, at different road gradients. The main focus for the simulation cycles was to adjust the average velocity to be in the same range as the average velocity of the Handbook traffic situations for urban, rural and motorway.

For all European emission regulations (Euro 0 to Euro 4), diesel and petrol car engine maps were obtained for the simulation from available measurements. Unfortunately, vehicles were not measured with the Artemis cycle for Euro 1 and Euro 2 petrol vehicles, which is necessary for the map building. Consequently the factors for petrol vehicles have the same values for Euro 1 and for Euro 0 and furthermore the Euro 2 factors are the same as the Euro 3. Likewise for diesel vehicles the Euro 4 factors are the same as the Euro 3 factors. With this adjustment the final road gradient factors for the Artemis database were calculated with the model PHEM (see the factors in Annex 28).

Vehicle load

From the measurement with different loading rates the final factors for diesel cars (FC, NOx and PM) and petrol cars (FC) were calculated by linear interpolation. These final factors are representative for an average loading situation in Europe with approximately 1.5 persons in the vehicle: see Table 22.

		FC	NOx	PM
Diesel vehicle	urban	1.014	1.112	0.951
	rural	1.006	1.086	0.886
	motorway	0.993	1.016	1.011
Petrol vehicle	urban	1.026		
	rural	1.010		
	motorway	1.039		

Table 22: Loading factors for diesel and petrol vehicles for different traffic situations.

3.10.5. Conclusion and discussion

Road gradient

Because of the different vehicles (engine capacity, power, etc.) from every single measurement a factor was calculated which represents the ratio between measured emissions at x % road gradient to measured emissions at 0 % road gradient. Afterwards with this single measurement factor, average factors for all road gradients were generated separately for petrol and diesel vehicles. Due to the fact that there were measured Euro 3 vehicles only and in one cycle only, which represents a rural traffic situation, it was not possible to create factors for other traffic situations and different Euro categories from these measurements. Thus the absent factors were calculated with PHEM, an instantaneous emission model which was generated for passenger cars as well as for heavy duty vehicles (Rexeis et al., 2005).

Before the application of the emission model a comparison between simulation and measurement was done. For this comparison as well as for the subsequent simulation, cycles had to be defined. For the urban driving situation the Handbook cycle LE6, for the rural traffic situation the Artemis rural cycle (adjusted for higher road gradients) and for the motorway situation a recorded cycle of a hilly highway in Austria were chosen. With these three cycles and the average engine maps the road gradient factors for all Euro categories for diesel and petrol vehicles were calculated.

Vehicle loading

Three different loading rates were measured with four different cycles which should stand for the three traffic situations: urban, rural and motorway. The loading rates at no payload and at the maximum vehicle payload were measured, as well as one setting between these two rates.

The simulation of the loading influence is quite sensible for vehicle payload of 100 kg, therefore the loading factors were generated from the measurements. These final factors represent an average loading situation in Europe (1.5 persons), but only for NO_x and PM for diesel and fuel consumption for both diesel and petrol vehicles factors are calculated. For the other exhaust gas components, the load factors measured are within the range of the repeatability in emission tests.

3.11. Influence of auxiliaries of passenger cars

A European Climate Change Programme working group estimated that the usage of air conditioning (AC) systems under average European conditions causes an increase of fuel consumption between 4 and 8 % in 2020 (ECCP, 2003). A recent study valuated an increase of fuel consumption in 2025 below 1 % (Hugrel & Joumard, 2004). That is why it is proposed to undertake a state-of-the-art review of this area, to include fleet characteristics and a collection of data on auxiliaries, in order to improve the exhaust emission factors for the passenger cars and light duty vehicles, by enlarging the emission factor database, especially for effects of auxiliaries (Roujol, 2005; Roujol and Joumard, 2006).

Studies about air conditioning have been done in Europe focussed on the evaluation of individual passenger car emission due to AC (Barbusse et al., 1998; Gense, 2000; Pelkmans et al., 2003; Weilenmann et al., 2004), or on the improvement of AC (Benouali et al., 2003). A major study about AC impact has been carried out in the framework of Mobile 6 by the USEPA, focussed on the real use of AC in real conditions (Koupal, 2001) and on the effect of air conditioning running at full load on regulated pollutants (Koupal & Kremer, 2001).

3.11.1. Emission database and analysis of effects on fuel consumption and CO_2

Air conditioning database is made up of experimental data from 3 European laboratories (Utac and Cenerg in France, Vito in Belgium), i.e. 27 vehicles and 146 tests. Driving cycle, number of vehicle tests, type of vehicle, experimental objectives vary with experimentation. The choice of vehicles covers the main types of vehicle (small and large vehicles), different propulsion systems (petrol and diesel) and the emission standards (mainly Euro 1, but also Euro 3 and 4). The climatic conditions are specific to each laboratory, but have been chosen in order to represent severe climatic conditions. The small size of the database allows us to perform a simple statistical analysis. According to Mobile 6, emitter classes, vehicle type, driving cycle, emission AC off and mean speed have to be distinguished to estimate effect of AC. At this short list, we can add, as proposed by Benouali et al. (2003), the regulation type and the compressor technology type.

The excess emission of pollutants due to air conditioning is the difference of emission with and without air conditioning running in the same condition. We have first to decide the type of unit to express the excess fuel consumption due to AC: in volume per distance unit or in volume per time unit. For physical reason (no strong relation between cooling demand and vehicle speed), it seems that volume per time (l/h for instance) is better.

Effects of mean vehicle speed and driving cycle

The mean speed has little impact on excess fuel consumption, but variance test indicates that the relation is statistically significant. The relationship is mainly influenced by the data at 90 and 120 km/h constant speed. It seems due to the engine efficiency, which varies with load and engine speed. The effect of AC on fuel consumption is partially hidden by the improvement of engine efficiency, but not at high speed or load. A similar conclusion is given in a recent experimental study on two vehicles in real driving conditions (Roumégoux et al., 2004). The effect of speed is explained by the fact that the engine load for EUDC cycle is particularly low. For real driving cycle, engine load is slightly higher, and fuel consumption due to AC should be quite independent of the speed or type of driving cycle.

Effects of technological parameters

Technological parameters analysed are parameters connected to the vehicle engine, to the AC system and to the body shape of the vehicle. The data are displayed according to the engine size, the fuel type, the vehicle size, the type of compressor and the type of regulation. Most of the test vehicles were equipped with a variable-displacement compressor. Only two small vehicles and one large vehicle were equipped with fixed-displacement compressors. All cars with an engine size > 2.0 litres and SUVs were equipped with automatic temperature regulation systems. Apart from one vehicle, all small cars and medium-size cars with an engine size < 2.0 litres were equipped with manual temperature regulation systems. In order to get enough data per class, only 4 types of vehicles are distinguished (see Table 23). The results show that the fuel consumptions are quite close with large standard deviations. Therefore we assume that the fuel consumption of AC does not depend on technical parameters.

vehicle type				fuel consumption (l/h)	
	fuel	AC regulation	nber veh.-tests	average	st. dev.
Small, Medium 1	Petrol	manual	38	0.7	0.2
	Diesel		55	0.68	0.22
Medium 2, Large, SUV	Petrol	automatic	25	0.75	0.34
	Diesel		28	0.85	0.35

Table 23: Average fuel consumption due to air conditioning (l/h) for the 4 vehicle types.

Effects of climatic conditions

The climatic conditions and set temperature have certainly a huge influence on AC running, and then on pollutants emissions. No experimentation is performed according to the solar radiation, although, according to Barbusse et al. (1998), solar load represents 45 % of the total load of the air conditioning. According to Figure 35, the variation of excess fuel consumption with the outside temperature is lower than expected: although the uncertainty of the measurements, the outside temperature at which there is no cooling or heating, obtained by linear extrapolation, seems to be below 0°C. Theoretically, the relation between fuel consumption and outside temperature is quite linear because of convective heat gains linearly linked with the difference between outside and inside temperatures. That seems to demonstrate that AC is running quite close to full load for outside temperature higher than 28°C. An extrapolation of these data is therefore non applicable. As the experiments do not allow us to take into account temperature below 28°C and solar heat radiation, a physical model is therefore developed.

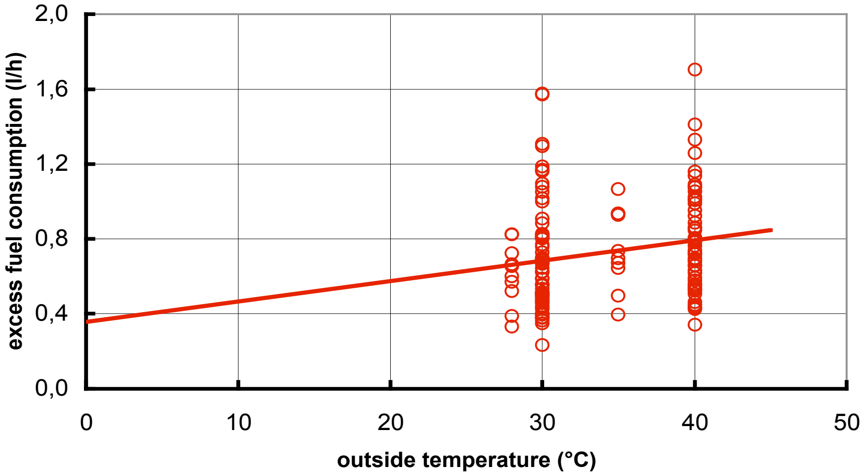


Figure 35: Excess fuel consumption (l/h) due to AC versus outside temperature (°C), with linear regression.

3.11.2. A physical model for air conditioning effects

The physical modelling approach needed to take into account each component involved in the system, including the cabin, the A/C system and the engine. The phenomena taken into account were heat exchanges between the cabin air and the outdoor air, heat exchanges between the evaporator and the A/C system - which allows a reduction in air flow temperature and leads to its dehumidification - and between the A/C system and the engine.

Passenger compartment

The passenger compartment modelling is based on a description of heat exchange as it is usually done in mono-zone thermal building modelling (Bolher et al., 2000). Air temperature and humidity in the cabin is assumed to be uniform. Heat exchanges governing temperature of cabin are due to the global heat exchange coefficient, UA ($W.m^{-2}.K^{-1}$), the untreated air flow rate due to permeability, m_p ($kg.s^{-1}$), the internal heat gains due to occupants and electrical equipments, A_{int} (W), the solar gains, A_{sol} (W), and the treated air flow, m_t ($kg.s^{-1}$).

The modelling of solar gains (Fraisse & Virgone, 2001) depends on the direct and diffuse solar radiation, the position of the sun in sky and the geometric and physical properties of the vehicle window. Temperature and flow rate of treated air flow are regulated in order to maintain cabin air temperature to set temperature.

The thermal mass of the vehicle's interior has an effect in dynamic behaviour, increasing cooling demands during cool down for instance, but has no effect during steady state cooling and is therefore neglected. Weilenmann et al. (2004) have studied initial cool down, by combining the effect of initial cool down of the overheated passenger compartment and the effect of cold start. Two counteracting effects occur: Because of thermal mass, AC running involves more power than at steady state, and AC running involves that engine compartment is heated much faster than without AC running. These two effects compensate each other, and excess emission due to initial cool down in comparison to steady state emission is in the same order of magnitude than the cold start excess emission in the same temperature conditions.

With the internal temperature T_{int}, the temperature of treated air T_t, and the outside temperature T_{ext}, the conservative equation of energy is:

$$(m_t + m_p) \cdot T_{int} - (m_t \cdot T_t + m_p \cdot T_{ext}) = A_{int} + UA \cdot (T_{ext} - T_{int}) + A_{sol}$$

The internal temperature is chosen according to the thermal comfort theory (Fanger, 1972). The conditions of thermal comfort are a combination of skin temperature and body's core temperature providing a sensation of thermal neutrality and the fulfilment of body's energy balance. From ASHRAE standard 55 (1992) and Charles (2003), 23°C is chosen as default value. The sensible heat exchange P_{sens} at evaporator to maintain internal temperature at the comfort temperature can be deduced, and, if air treated rate m_t is known, air treated temperature T_t can be calculated:

$$P_{sens} = m_t \cdot (T_{ext} - T_t) = (m_t + m_p + UA) \cdot (T_{ext} - T_{int}) + A_{sol} + A_{int}$$

Evaporator and A/C regulator modelling

Heat exchange at the evaporator can cause dehumidification of air treated. . The total heat exchange at the evaporator is the sum of sensible heat exchange and dehumidification. The average surface temperature humidity of air treated across AC evaporator depends on the heat transfer coefficients of evaporator and the temperature of coolant. If the average surface temperature is known, the air-side heat exchange efficiency can be used to calculate the average surface temperature and humidity of the outlet air. The value of this efficiency is usually between 60% and 80% (Morisot et al., 2002).

In the model, the value of the air side efficiency was assumed to be 0.8. With the air side heat exchange efficiency, it allows us to calculate the average surface temperature and humidity of outlet air.

It was assumed that the user or A/C regulation tries to maintain a minimum air flow rate (in order to reduce thermal load). On the other hand, the temperature of the treated air must not to be too low because of comfort consideration and the risk of freezing condensed water in the evaporator. A minimum air flow rate of 300 m^3/h and a minimum average surface temperature of 0°C were therefore assumed.

Efficiency energy ratio of A/C and energy efficiency of engine

It was assumed that the efficiencies of the A/C and the engine were constant. For energy efficiency of the engine, experimental data show that running conditions of the engine have a small effect on CO_2 emissions due to air conditioning. According to Park et al. (1999), the main parameters on AC efficiency are the temperature conditions, but the effects of temperature on energy efficiency are lower than on cooling demands.

Validity of the model

The model is applied to all experimental conditions either presented in section 3.11.1, or by Weilenmann et al. (2004), with temperature range resp. of 28-40°C and 13-37°C. The results of the model are compared to the experimental results (see Figure 36). They are quite close for temperature higher than 30°C. From 20°C to 30°C, the model underestimates the fuel consumption; And below 20°C, hourly fuel consumption from model are null, but experimental excess fuel consumption can be linked to the electrical consumption of ventilation to avoid windscreen fogging.

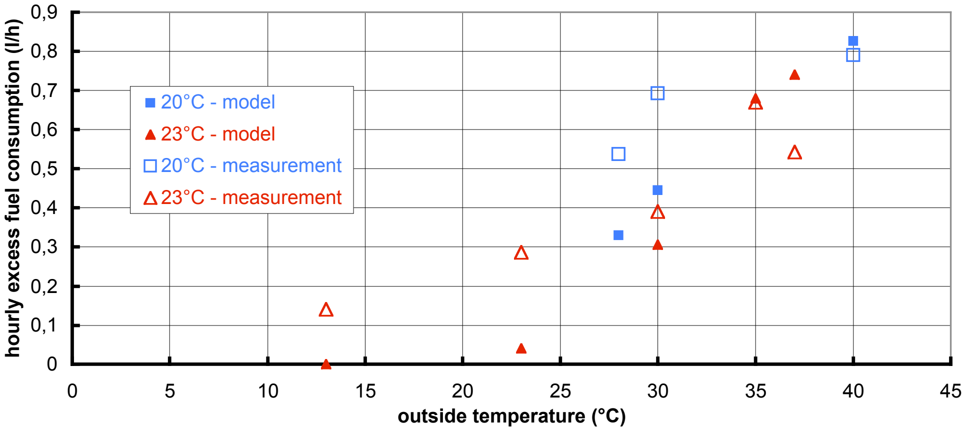


Figure 36: Comparison of the results from model and from experiments as a function of outside temperature for two internal temperatures (20 and 23°C).

A second comparison is done with the Mobile 6 model of demand factor based on experimental measurements. Demand factor is defined by Mobile 6 as the fraction of running time of AC, but can be also defined as the ratio of part load power consumption to the full load power consumption, estimated at 0.85 l/h. The Mobile 6 model and the proposed model are applied with hourly weather data of Seville in Spain, which has the closest climate in Europe to the climate of Denver where vehicle were followed in order to determine demand factor in Mobile 6. In order to take into account the solar loads, Mobile 6 distinguishes daytime and night, and our model calculates the solar loads for each climatic condition described in the weather data. As shown Figure 37, demand factors obtained by Mobile 6 and our model are quite close for temperature higher than 20°C.

Below 20°C, demand factor from Mobile 6 model is null but slightly above 0 for our model because of solar loads heating.

We consider that the model satisfied our objective, which is to determine hourly fuel consumption in non-tested weather conditions. The differences between results from model and data from EMPA (Figure 36) at temperature below 20°C are not well understood and required additional experiments at these particular conditions.

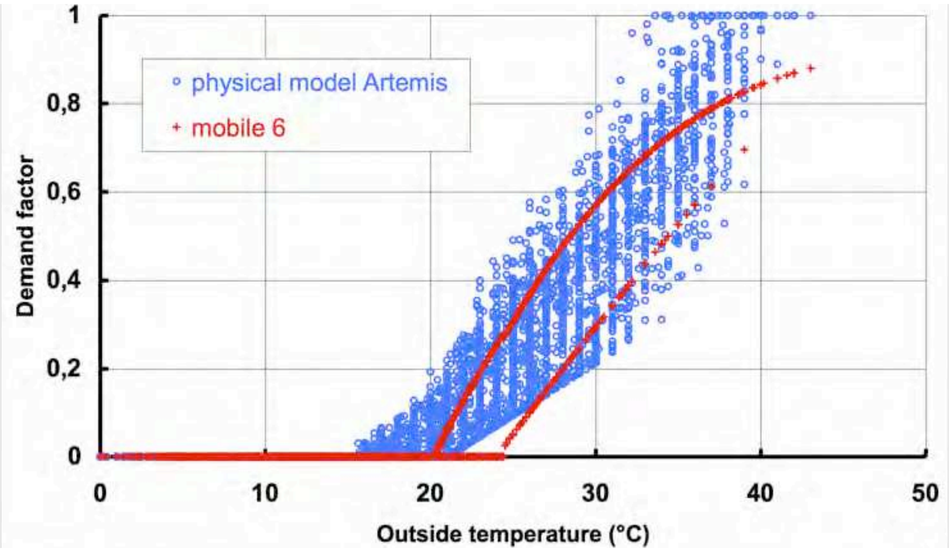


Figure 37: Comparison of the Mobile 6 model (upper curve for daytime and lower curve for night) with the proposed model (set temperature at 23°C).

3.11.3. Simplified model of excess fuel consumption and weather data

A physical model of excess fuel consumption due to AC seems to be too complex to be implemented in an inventory software as Artemis. Therefore we computed the physical model with weather data of 91 regions all over Europe defined in Annex 29, and looked for a relationship by statistical regressions between hourly fuel consumption and the following explicative variables: ambient temperature, humidity, position of sun in the sky, and solar radiation, replaced by the hour in the day. The general form of the simplified model is:

$$hfc = a_{1,wf} + a_{2,wf} \cdot T_{ext,wf} + a_{3,wf} \cdot (T_{\text{int}} - 23) + a_{4,wf} \cdot h + a_{5,wf} \cdot h^2 \qquad \text{with } hfc \geq 0$$

with:

hfc: hourly excess fuel consumption (l/h)

$T_{ext,wf}$: external temperature provided by hourly, daily or monthly weather data (°C), which contain resp. 8760, 365 and 12 values

T_{int}: set temperature in the cabin; default value is 23°C

h: the hour (between 1 and 24)

$a_{1,...5}$: coefficients depending on the location

The coefficients a_1 to a_5 are available for each location in Annex 30. But in addition, two other sets of coefficient a are provided: The first set is given according to 6 modified Köppen climate classification (see Annex 29), based on the annual and monthly averages of temperature and precipitation (DOE, 2004), and the second set corresponds to an average.

The excess fuel consumption and CO_2 emission for a fleet is calculated by summing hfc according to the number of vehicles with AC running for a given road segment, expressed in number of vehicles per hour. The general equation to calculate the excess fuel consumption fc_f for a fleet f due to the use of air conditioning is (more details are given in Annex 31):

$$fc_f = \sum_{loc}\sum_{T}\sum_{TS}\sum_{i} n_{AC,i,TS,T,loc} \cdot hfc(h, T_{ext}, T_{int})$$

Excess CO_2 emission is:

$$eCO_{2f} = \sum_{loc}\sum_{T}\sum_{TS}\sum_{i} n_{AC,i,TS,T,loc} \cdot c_{CO_2,i} \cdot hfc(h, T_{ext}, T_{int})$$

where:

$n_{ac,i,TS,T,loc}$: number of vehicles with AC running for segment i, at the traffic situation TS (i.e. urban, rural, highway), at the time T, at the location loc, expressed in number of vehicle per hour.

hfc: hourly fuel consumption depending on the hour of the day, external temperature and internal temperature (l/h).

$c_{CO_2,i}$: transformation factor from fuel to CO_2 depending on vehicle segment i.

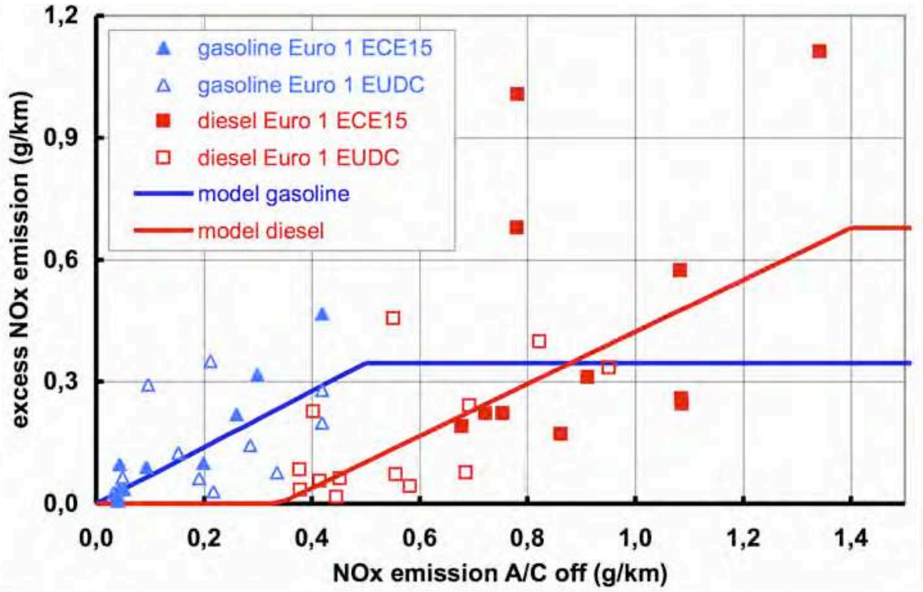


Figure 38: NOx excess emission versus NOx emission AC off according to the fuel and driving cycle for Euro 1 vehicles, for urban ECE15 and extra-urban EUDC driving cycles, with the corresponding modelling.

3.11.4. Excess pollutants emissions analysis

Data available for pollutant emissions (CO, HC, NOx, PM) due to AC are rare in comparison with data available for CO_2 emission, mainly because only 13 petrol and diesel vehicles are tested.

As it was shown in section 3.11.1, AC system is running quite close to the full load at the test conditions (outside temperature > 28°C), where pollutants emissions are assumed to be full load ones. An example of data is shown in Figure 38: NOx emission and effect of AC are larger during the urban driving cycle ECE15 than during the extra-urban cycle EUDC. For each pollutant a relationship is proposed between excess emission and hot emission without AC (Figure 38). Results of petrol vehicles are in accordance with the theoretical explanation proposed by Soltic and

Weilenmann (2002): As long as the increased torque does not cause a air fuel mixture enrichment, an increase in the exhaust temperature, a slight reductions of HC and CO emissions, and an increase of NOx emission are expected. If an increased torque level causes an increase of enrichment, CO and HC emissions will also increase.

For the pollutants emissions modelling, we assume that pollutants emissions $ef_{pollutant, AC}$ at part load are a fraction of emissions at full load f(hot emission without AC), with the fraction being equal to the demand factor. The demand factor is the ratio of hourly fuel consumption at given condition hfc to hourly fuel consumption at full load (0.85 l/h).

$$ef_{pollutant, AC} = f(\text{hot emission without AC}) \, . \, hfc / 0.85$$

Because of the lack of data, only a distinction between the petrol and diesel vehicles is proposed. The model does not explicitly distinguish the age of vehicle, because we consider it has no influence on excess CO_2 emission. The effect of emission standard on pollutant emission is taken into account through the hot emission, which depends on standard emission. The emission models (functions cf) are given in Annex 32.

For the future vehicles, some counteracting effects occur: Firstly, technological improvements of efficiency of AC system are expected:

- By reducing the thermal load of the vehicle (Türler et al., 2003; Farrington et al., 1998, 1999) through the use of advanced glazing which reduces the transmission of infrared solar radiation. The improvement of air cleaning allows reducing the amount of outside air, reducing by the way thermal load and power consumption of fan. Advanced regulation of ventilation allows ventilating parked vehicles reducing the peak cooling load.
- By increasing energy efficiency ratio of AC system (Benouali et al., 2002; Barbusse and Gagnepain, 2003). The first improvement will be due to the improvement of AC components as the external control of compressor, the electrical compressor, a high efficiency heat exchanger. At long term, alternative technologies are investigated as magnetic cooling, desiccant cooling, and absorption.

Secondly, the evolution in the vehicle design and in the leakage refrigerant standard will certainly increase the CO_2 emission due to the use of AC. The constraint against refrigerant leakage drives to use alternative refrigerant with a lower Global Warming Potential as HFC 152a and CO_2. These alternative refrigerants have the drawback to reduce the efficiency of AC system because their lower thermodynamic properties. The use of alternative refrigerant as the CO_2 allows using AC system as a heat pump in order to warm passenger compartment, made more and more difficult by the development of high efficiency engine which could reduce the possibility to use the engine heat to warm the passenger compartment and which justifies the development of reversible system.

At short time, we assume that these two effects compensate each other. No correction is proposed for future vehicles.

3.11.5. Other auxiliaries

The effects of other auxiliary systems on emissions were determined based on the work done by Soltic and Weilenmann (2002). Excess fuel consumption due to other auxiliary systems hfc_{aux} was expressed in litres per hour, as for A/C, and it was assumed that excess fuel consumption was proportional to electrical load. Table 24 lists auxiliary systems, and gives electrical power consumption. The group of auxiliary systems in the Table excludes some other important electrical power consumers, such as components linked to the engine or linked to security. According to these authors, we evaluated an average excess fuel consumption of 0.075 l/h for an electrical load of 160 W, corresponding to dipped headlights.

$$hfc_{aux}\ (l/h) = 0.075\ (l/h).\ \text{Power of the auxiliaries (W)} / 160\ (W)\ .\ \%\ \text{of use time}$$

In order to be in accordance with excess pollutant emission due to AC, we proposed to use a similar way for excess emission due to auxiliaries $ef_{pollutant,\ aux}$. Excess pollutant emission due to AC at a given conditions is a fraction to excess pollutant emission at full load. This fraction is calculated as a ratio of excess fuel consumption at given condition hfc_{aux} to excess fuel consumption at full load, estimated at 0.85 l/h (see section 3.11.2). We proposed to use the same model by replacing the excess fuel consumption of AC by the excess fuel consumption of auxiliaries.

$$ef_{pollutant,\ aux} = f(\text{hot emission without AC})\ .\ hfc_{aux} / 0.85;\ \text{with}\ hfc_{aux} / 0.85 \leq 1$$

For instance, in the case when dipped headlights are used, the value of fraction is 0.075/0.85.

Auxiliary	Electrical consumption (W)	Use of auxiliary (time proportion)
Dipped headlights	160	during night
Full headlight	170	
Turn indicator / stop light	40	1 %
Fresh air ventilator	60	50 %
Wipers	60	
Radio	15	85 %
Rear window defroster	150	50 % if outside temperature < 0°C
Seat heating	150	1 %

Table 24: Power consumption of auxiliaries and estimation of the use of auxiliaries [Soltic and Weilenmann, 2002].

3.11.6. Conclusion

The different analyses show that the excess fuel consumption expressed in l/h is quite independent to the speed or to the traffic situation. No significant technological parameters are found. That does not mean that no relation exists between excess fuel consumption and technological parameters, but that the number of data is not sufficient to extract this type of relation or that the technological solutions are too close each other.

The excess fuel consumption due to air conditioning is well know in warm conditions because of the large number of experiments. It is quite different in normal climatic conditions with lower solar radiation, because of the reduced number of experiments. To approach the behaviour of AC system at these conditions, a physical model is proposed and compared to experimental data. According to the objective of the model, the results show a good agreement in warm conditions. At normal conditions, the model underestimates the excess fuel consumption without understanding the reason. The effect of AC in normal conditions should be studied more, because of the high occurrence of these conditions in comparison to warm conditions. In the model, based on the usual comfort theory, we assume that the set temperature is 23°C for all the vehicles equipped with AC, but experiments on real world vehicles with air conditioning could improve the knowledge of user's behaviour.

3.12. Cold start emissions of passenger cars

As expressed by Duboudin and Crozat (2002), as long as a vehicle does not reach its running temperature, the emissions of atmospheric pollutants are increased. In the case of cars not equipped with a 3-way catalyst, this excess of emission comes from a non-optimal engine running. Therefore the engine temperature is the main parameter. In the case of vehicles equipped with a 3-way catalyst, the catalyst temperature and fuel-to-air ratio determine the functioning of the catalytic converter and thus also the net emissions. In both cases we define the time needed for a vehicle to reach its normal running temperature, and an over-emission occurring before that. The concept of over-emission is defined below.

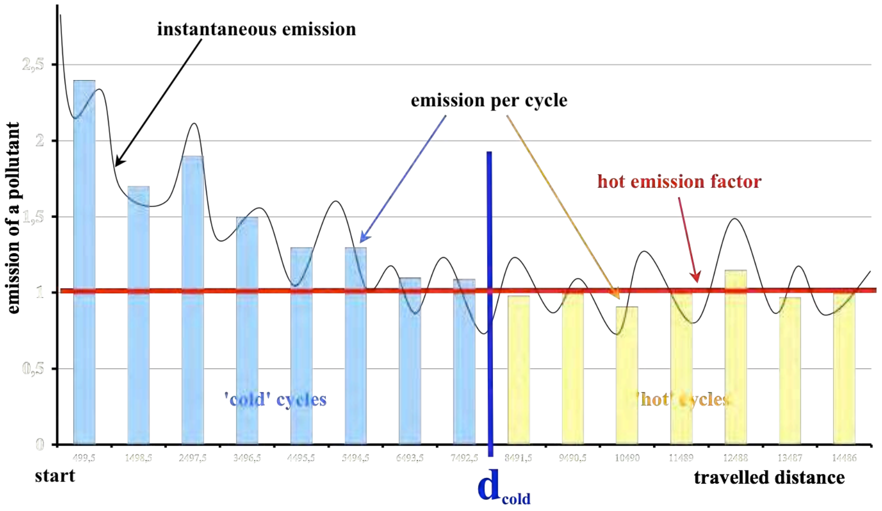


Figure 39: Evolution of the instantaneous emission of a vehicle according to travelled distance in given running conditions, together with the emission per cycle.

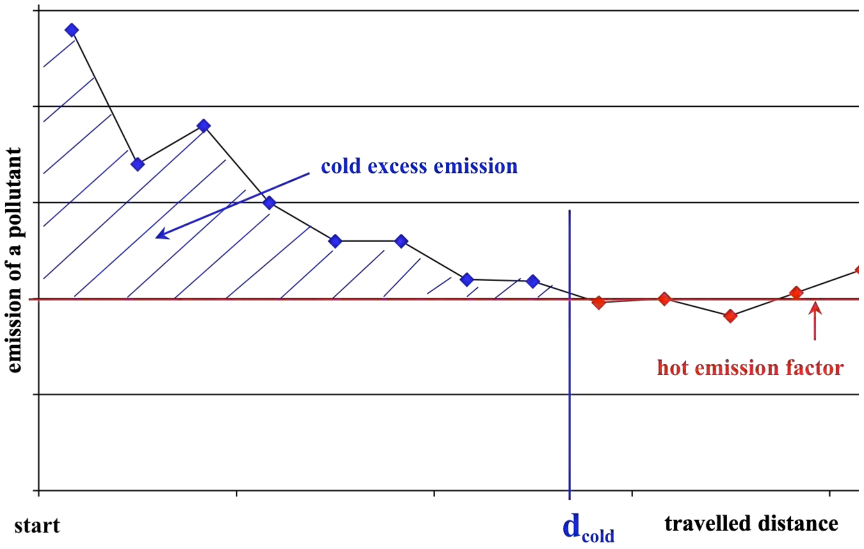


Figure 40: Calculation of hot emission factor and cold excess emission from the emission measured using repeated cycles, for given running conditions.

The evolution of the instantaneous emission of a vehicle along the time, for a given pollutant, an engine speed and an initial engine temperature, can be split up into a first phase with a decreasing emission due to the progressive increase in the engine or catalyst temperature, followed by a quite stable phase when the normal engine temperature is reached (Figure 39). The first phase corresponds to the time t_{cold}. This time t_{cold} is linked to the distance d_{cold} by the mean speed of the driving cycle during the cold period. The total emission E_{tot} during a driving cycle of a vehicle which does not start in hot conditions can be calculated by the sum of the hot emission E_{hot} and the cold start excess emission EE_{cold}:

$$E_{tot}=E_{hot}+EE_{cold}$$

EE_{cold} is the absolute cold start excess emission (in gram) defined as the additional emission value obtained under cold conditions compared to the emissions values that have been recorded for the same driving distance or time period (cycle) under hot conditions (Figure 40).

When we consider a driving cycle, composed of a succession of different vehicle speeds and therefore different engine speeds, the instantaneous emission is much more complex and unsteady. It depends on the different running phases and on the progressive temperature increase (the Figure 39 is not really an example, but rather an illustration of that, when the engine speed variations are much quicker than the temperature increase).

Three methods are till now available in Europe to model excess emission at start:

- The Handbook, applied mainly in Germany and Switzerland (Keller et al., 1995; Keller, 2004)
- The MEET approach, based on a synthesis of the available cold emission data in Europe (Joumard and Serié, 1999)
- The Copert III approach (Ntziachristos and Samaras, 2000a), which is a mixture of the former Copert and MEET approaches.

Samaras et al. (2001) evaluated the values of excess emissions for various situations in Europe, by using the three approaches. They found that, due to the differences between the methodologies of Copert III and MEET, there are differences between the modelled cold excess emissions. These effects however are mostly exhibited at very low values of the speed and ambient temperature and become negligible when intermediate values of these parameters are approached. In general, the difference between the results obtained by Copert and those by MEET are reduced for temperatures between 15°C and 25°C and also for high vehicle speeds. The agreement between the results of Copert III and those of the model suggested in the Handbook is very good, especially in the case of Euro 1 vehicles, even though the two models exhibit several differences with respect to the methodology. All these calculations show that the excess emissions depend of course on the methodology used and on the emission data used.

The model developed here (André & Joumard, 2005; 2006) should have a wide range of applications: Large-scale applications as national inventories, but also smaller scale applications as at street level for instance.

3.12.1. New method to calculate the absolute cold start excess emission

At the beginning of the work, two methods were available to calculate cold start excess emissions on the basis of repeated or successive driving cycles.

- The first method, so-called standard deviation method, (developed at INRETS by Joumard & Série, 1999 - see Figure 41) consists in calculating the standard deviation on the measurements working backwards from the end of the cycle, adding one measurement at a time. As long as the emissions are stable (*i.e.* hot), the variation occurs randomly around a mean (the hot emission), and the standard deviation is therefore a decreasing function of the number of points considered. However, the standard deviation increases rapidly as soon as cold-start part of the cycle is reached, and the cold-start distance d_{cold} therefore equates to the minimum value of the standard deviation. The hot emission is calculated from the values beyond (forward in time) the minimum. The absolute cold-start emission is calculated over the entire cold-start distance, and the cold-start excess emission is calculated by subtracting the hot emission from the absolute cold-start emission.

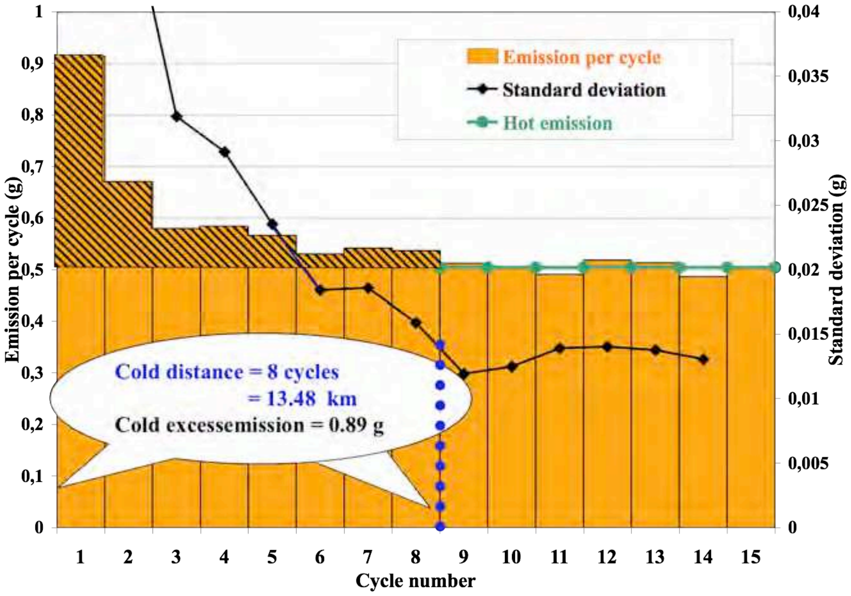


Figure 41: Standard deviation method for calculating the cold start excess emission: Example of cold start distance and emission calculation for Euro 1 diesel vehicle and CO at 18°C. The distance is in km and the emission in g per cycle.

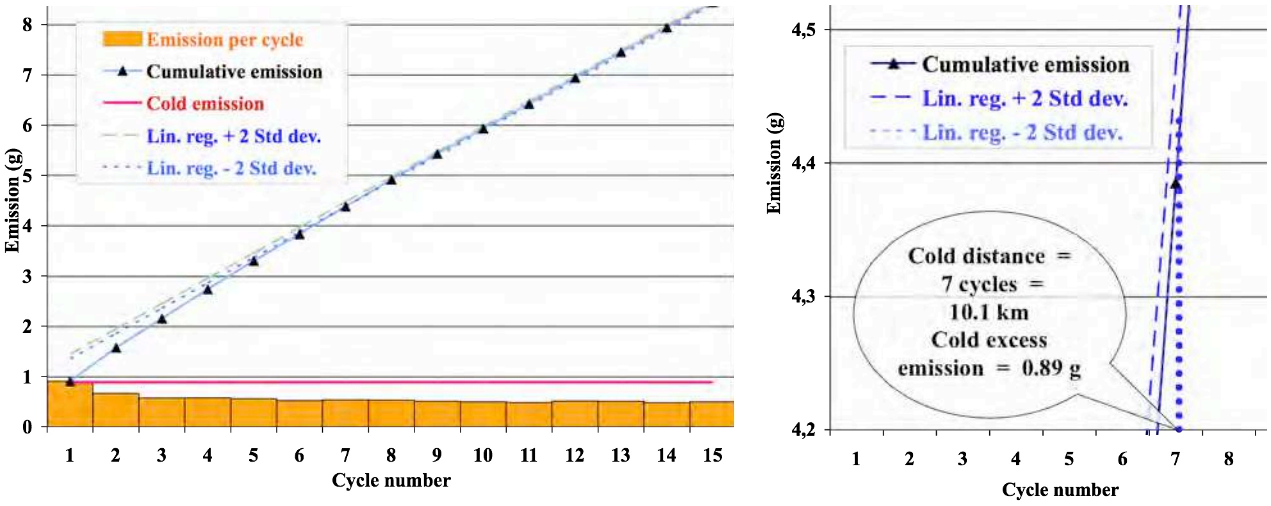


Figure 42: Linear regression method for calculating the cold start excess emission: Example of cold start distance and emission calculation.

- The second method, so-called linear regression method, developed at EMPA by (Weillenmann, 2001; Weillenmann et al., 2002a) - see Figure 42 - consists in calculating the continuous cumulative emissions from the start. A linear regression model is then fitted to the cumulative emission data from the hot part of the cycle alone, and the regression value at zero distance gives the cold-start emission value. The hot/cold limit is firstly arbitrary chosen, and then by plotting two straight lines parallel to the linear regression during the rough hot part. They have the same slope but the constant of the first line is equal to 95 % of the emission while the second is equal to 105 %. The precise cold driving distance is determined by the last time the total emission falls between these two lines.

These two first methods show that there are quite distinct differences in cold start excess emission calculation and, above all, in cold start distance. In the first method, the cold distance is overestimated because the method looks for the minimum of the standard deviation, which appears during hot conditions. In the second method, the determination of the cold distance is based on calculation along the hot conditions which are not determined rigorously. So we decided to develop a new method based on the advantages of these two first methods.

In the new method developed, so-called Artemis method (see Figure 43 and Figure 44), we first calculate a rough cold start distance by using the first method. Then we calculate the hot emission, the standard deviation and the linear regression of the cumulative hot emission. The value of the regression at zero distance gives the cold start excess emission. The exact cold start distance is determined by looking at the distance where the emission falls entirely between two straight lines which are the hot emission ±2 standard deviations.

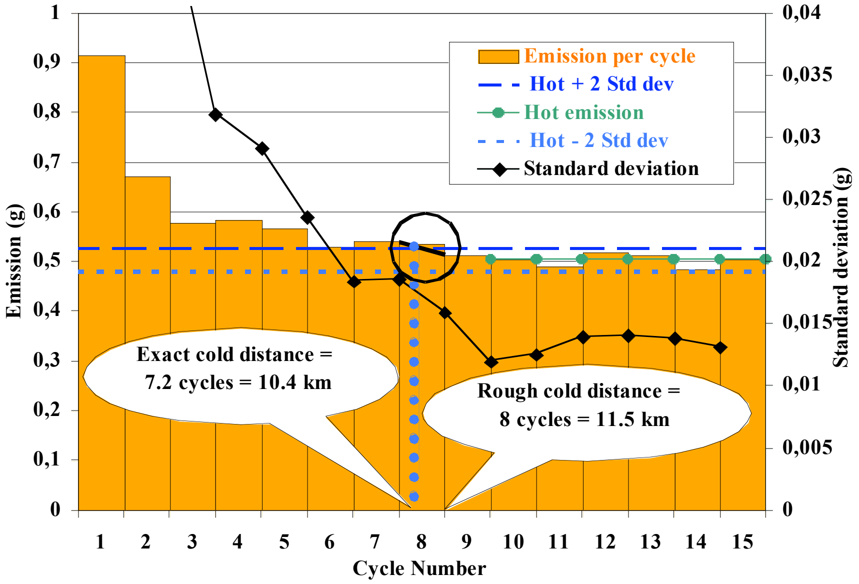


Figure 43: Artemis method for calculating the cold start excess emission: Example of calculation of the rough and exact cold start distances.

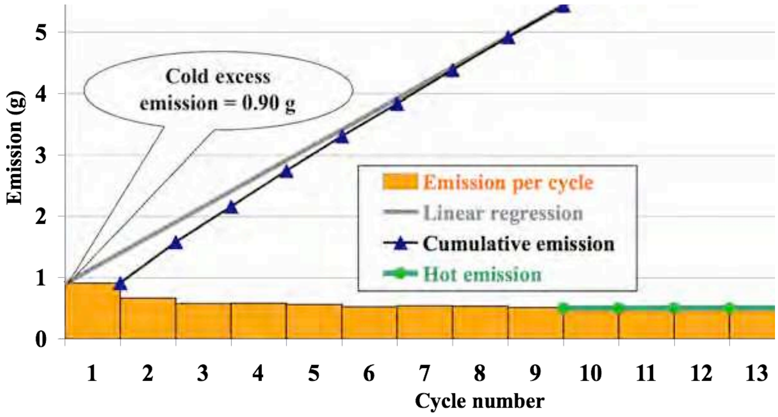


Figure 44: Artemis method: Example of cold start excess emission calculation.

Table 25 shows that, for the same emission data, the three methods give almost the same cold-start excess emission, but not the same cold-start distance.

The method is used for the regulated pollutants. For the unregulated pollutants, as the emissions were not measured on successive cycles, we apply the cold start distance calculated for total hydrocarbons (HC). The cold start excess emission is calculated by the difference of the value for a cycle beginning in cold conditions to the value of the same cycle beginning in hot conditions.

Method	Cold-start distance (km)	Cold-start excess emission (g)
Standard deviation	13.5	0.89
Linear regression	10.1	0.89
ARTEMIS	10.4	0.90

Table 25: Comparison of the cold-start distance and the cold-start CO emission (Euro 1 diesel at 18°C) calculated using the different methods.

3.12.2. Data considered

The work is aiming at modelling the cold start impact on road vehicle emissions as functions of the pollutant and the vehicle type, using all the existing data in Europe. This model is developed empirically, considering the available data in Europe for passenger cars: Excess emissions indeed, but also ambient temperature, and driving behaviour statistics.

The cold start excess emission data come from the MEET project, from national programs and from measurements made within the Artemis study (see section 2.1). The external data were obtained through two inquiries made among 14 European laboratories, in January 1994 and then December 2002. After elimination of data without both hot and cold emission factors and selection of usable data, the data used to design the cold start models come from five laboratories: EMPA, INRETS, IM, TNO and VTT.

Concerning excess emission data as a function of the cycle, the total number of obtained data is 35 941, all categories and all pollutants merged, i.e. 28 337 and 8 604 data resp. for regulated and unregulated pollutants. These data were measured with 1 766 vehicles, i.e. 1 604 and 102 vehicles resp. for regulated and unregulated pollutants, over five different driving cycles (FTP-72, ECE-15, Inrets urbain fluide court (IUFC), Inrets route court, and Artemis urban – see Annex 5). All vehicle samples were selected by various laboratories, in order the vehicle distribution to be representative, to some extent, of the fleet corresponding to each country. The number of vehicles tested and the corresponding driving cycles are given for the regulated and unregulated pollutants in (André and Joumard, 2005; 2006; André et al., 2004), together with the number of measurements according to the mean temperature, and the minimal and maximal temperatures per driving cycle and per laboratory. The vehicles taken into account comply with the emission standards Euro 0 to Euro 4 for diesel and petrol fuel type.

We used data recorded with Inrets court and Artemis driving cycles (André, 2002b; 2004a; b; André and Joumard, 2004), and with legislative cycles. We know that these last cycles do not reflect the reality, but they represent the main part of the data.

A previous study (Joumard et al., 1995b) showed that ECE-15 cycle could not cover entirely the cold period due to the cold start. So, we introduced a correction coefficient for this cycle to transform the measured excess emission during standard cycles into a full cold excess emission. This coefficient is deduced from measurement data recorded using IUFC cycle (because the mean speed is near the ECE-15 mean speed), which covers the whole cold period. Using this “cold” distance, calculated with the Artemis method on the short Inrets cycle data, we calculate the correction coefficient to be applied to adjust the standardised cycles to the representative cycles.

When applying the whole methodology, the cold-start distance for the four regulated pollutants, two driving cycles (at 19.0 and 41.1 km/h) and a number of cases (vehicle type, ambient temperature) ranged from 2 km to 9 km, with an average of 5.2 km at 20°C.

3.12.3. Cold excess emission for a start

The collected data allow us to express the cold start excess emission (EE) for a start and a vehicle type (i.e. a emission standard and a fuel type) and a regulated pollutant as a function of the ambient temperature (T), the mean speed during the cold period (V), the distance (d) and the parking time duration (t) before starting. So EE could be expressed as:

$$EE(T,V,\delta,t) = \omega_{20\ °C,20\ km/h}.f(T,V).h(\delta).g(t)$$

with:

$EE\ (T,\ V,\ \delta)$: excess emission in mass per start
T: temperature (°C)
V: average speed (km/h)
$\delta = d/d_c$: dimensionless travelled distance
d: travelled distance (km)
d_c: cold distance (km)
t: parking time
$\omega_{20°C,20km/h}$: excess emission at 20 °C and 20 km/h
$f(T,V)$: cycle speed and the temperature influence dimensionless function, with $f(T,V) = \omega(T,V)/\ \omega_{20°C,20km/h}$
$\omega(T,V)$: cycle speed and the temperature influence function
$h(\delta)$: distance influence function
$g(t)$: parking-time influence function

The cold distance d_c, $\omega(T,V)$ and $h(\delta)$ are computed from the data by using the method described in section 3.12.1., and then modelled. The cold distance $d_c(T,V)$ is a 3D linear regression depending on T and V, whose function is given in Annex 33.

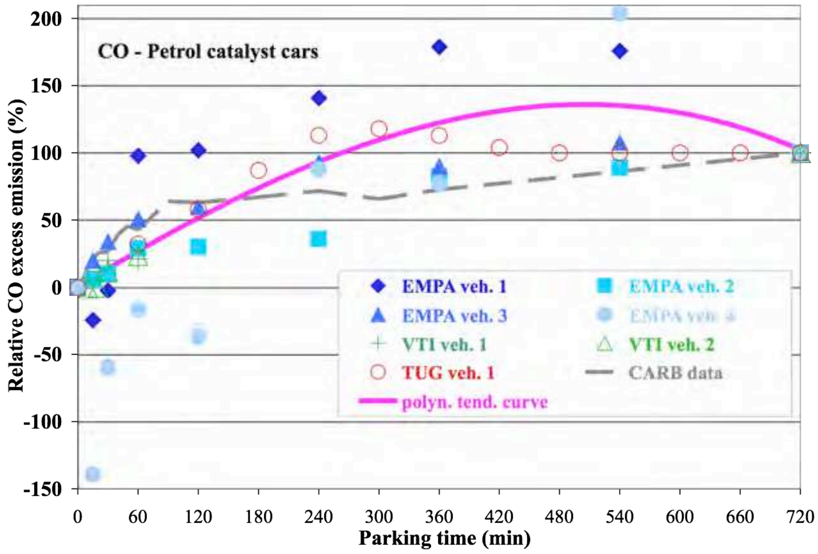


Figure 45: Parking duration influence on the total excess CO emission for petrol cars with catalyst.

f(T,V) is a 3D linear regression which depends of T and V with the condition that the function f must tend toward 0 when T increases. f(T,V) and then ω(T,V) are given in Annex 34.

h(δ) is an exponential function of δ which can be expressed as $h(\delta) = \frac{1-e^{a.\delta}}{1-e^{a}}$ where a is deduced from the data. The coefficient a is given in Annex 35.

To take into account the parking duration, which influences the initial engine temperature, we process the rare data available, from CARB (Sabate, 1996), EMPA (Schweizer et al., 1997), TUG (Hausberger, 1997) and VTI (Hammarström, 2002): See an example Figure 45. We calculate an average table of parking time influence for each pollutant and vehicle category and plot the best fit, after excluding the CARB data because they do not represent the European behaviour. It was thus possible to give a polynomial function for each case, equal to 1 for 12 h parking: See Annex 36.

When applying the functions given in annexes, we obtain for instance the following model for the CO cold excess emission for a start, EE(T,V,δ,t), in the case of Euro 2 petrol cars:

$$\underset{CO,Euro\,2,Gasoline}{EE(T,V,\delta,t)} = \left| \begin{array}{l} \underbrace{17.060}_{\omega_{20^\circ C,20km/h}} \cdot \underbrace{\left[1.927 - 0.043 \cdot T + 0.003 \cdot V\right]}_{f(T,V)} \cdot \underbrace{\left[\frac{1-e^{-9.007 \frac{.d}{4.409-0.002 \cdot T+0.024 \cdot V}}}{1-e^{-9.007}} \right]}_{h(\delta)} \\ \cdot \underbrace{\left(-2.916 \cdot 10^{-7} \cdot t^{3} - 1.941 \cdot 10^{-4} \cdot t^{2} + 4.315 \cdot 10^{-1} \cdot t\right)}_{g(t)} \end{array} \right.$$

We also introduce in the above model, the possibility to compute excess emission for near future vehicles by using the reduction rates proposed by Samaras and Geivanidis (2005) for Euro 4 and Euro 5 vehicles in comparison with present vehicles (see section 3.5.4). These rates are deduced from the future evolution of the European emission standards and from some rare measurements: See Table 26.

Emission standard	Petrol					Diesel			
		CO	CO_2	HC	NOx	CO	CO_2	HC	NOx
Euro 3						base = 1			
Euro 4	base = 1					0.781	1	0.833	0.5
Euro 5	no DISI	1	1	1	1	0.781	1	0.833	0.35
	DISI	1	0.9	1	1				

Table 26: Reduction rates to apply to the cold excess emissions for petrol and diesel vehicles. For petrol vehicles, the direct ignition vehicles (DISI) should have a specific behaviour.

The rate α can be applied either to the cold start distance d_c or to the cold start excess emission $\omega_{20°C,20km/h}$ of present vehicles, but not to both parameters (the total decrease would be in this case α^2). We propose to apply these rates to the cold start excess emission $\omega_{20°C,20km/h}$.

3.12.4. The different cold start Artemis models

The final Artemis model is provided for different users. Each one has not the same information to compute emissions. So it was decided to give three different models depending on the available input data.

First model

The first model gives an excess emission per start (i.e. per trip) in mass unit for a vehicle type i and a given pollutant p as a function of the ambient temperature T, the mean speed V during the cold period, the travelled distance d and the parking time t. It is the equation described in the section above 3.12.3.

$$EE(i,p,T,V,d,t) = \omega_{20\,°C,20\,km/h}(i,p)\ .\ f(i,p,T,V)\ .\ h(i,p,\delta(i,p,T,V,d))\ .\ g(i,p,t)$$

$\omega_{20°C,\ 20km/h}(i,p)$ and $f(i,p,T,V)$ are given in Annex 34 for each vehicle category i and for each pollutant p (regulated or unregulated one).

$h(i,p,\delta(i,p,T,V,d))$ and $g(i,p,t)$, given resp. in Annex 35 and Annex 36, are not available for the unregulated hydrocarbons (URHC). For theses components, the functions h and g used are the specific ones for the total hydrocarbons (THC):

$$h(i,URHC,\delta(i,URHC,T,V,\delta))= h(i,THC,\delta(i,THC,T,V,\delta)) \text{ and } g(i,URHC,t)= g(i,THC,t)$$

Second model

In a number of cases, assessing cold-start-related excess emissions for a single trip (for some micro inventories) is sufficient, but most emission inventories require calculating cold-start-related excess emissions not for a single vehicle and over a single trip, but for the whole traffic characterised by a number of parameters such as vehicle flow, average speed and environment conditions (hour, ambient temperature...). It is the aim of the second model.

The first model, initially applied to a single trip, must be extended to the whole traffic by using the available statistical data relative to traffic parameters. The excess emission of a traffic due to cold starts is therefore the product of the unit excess emission for a trip EE (first model), by the number of trips cold starting N_{tcs}:

$$E_c = N_{tcs}\ .\ EE$$

N_{tcs} is expressed globally as the ratio of the total distance started with cold start $L_{cold}Total$ by the mean distance of the trips started in cold conditions $L_{cold}Mean$:

$$N_{tcs} = L_{cold}Total\ /\ L_{cold}Mean$$

$L_{cold}Total$ is the product of the traffic flow t_{fi} expressed in veh.km by the percentage of mileage cm(s,i) started at cold start. This last parameter depends of the season s and the mean trip speed v_i.

$$L_{cold}Total = tf_i.cm(s,v_i)$$

If we consider only the cold started trips of length d_m, their number is expressed as:

$$N_{tcs}(d_m) = L_{cold}Total\ .\ p_m\ /\ d_m$$

Where p_m is the share of total distance started with a cold start corresponding to trips of length d_m. In the same way, if we consider the cold started trips with an average speed v_i, these trips correspond to a cold distance of average cold speed v_j:

$$N_{tcs}(d_m,v_i)= \sum_j L_{cold}Total\ .\ p_{m,j}\ .\ p_{i,j}\ /\ d_m$$

Where $p_{i,j}$ is the distribution (%) of the cold started distance with an average trip speed v_i among the different speeds v_j during the cold distance. At the same time p_m has to be related to the speed v_j and expressed as $p_{m,j}$. In the same way, if we consider a stop or a parking time t_n, it corresponds to a distance share p_n:

$$N_{tcs}(d_m,v_i,t_n) = \sum_j L_{cold}Total.p_{m,j}\ .\ p_{i,j}\ .\ p_n\ /\ d_m$$

As we must take into account all the cold started trips length d_m and all parking time duration t_n, the number of trips cold starting is therefore the summations over m and n of the above expression.

In addition we would like to take into account the influence of the hour of the day on the start number and on the parking time. Therefore the traffic flow t_{fi} and the parking time share p_n are functions of the hour and are transformed into $tf_{i,h}$ and $p_{n,h}$. At the same time, the cold starts must be distributed along the day by introducing the relative number of cold starts $ptf_{i,h}$ of the hour h (relative to the average hourly cold start number) p_h. Moreover, all the distributions depend hardly on the season s because the driving behaviour changes hardly between the seasons. So the equation of the model 2 could be expressed as:

$$E_c(p) = \sum_i \frac{cm(s,v_i)}{100}\cdot\omega_i(p)\cdot\left[\sum_h tf_{i,h}\cdot\frac{p_h(s)}{ptf_{i,h}}\cdot\right.$$
$$\left.\left\{\sum_j\sum_m\sum_n \frac{p_{i,j}(s)\cdot p_{m,j}(s)\cdot p_{n,h}(s)}{10^6 d_m}\cdot f(p,v_j,T)\cdot h(p,\delta(p,T,v_j,d_m))\cdot g(p,t_n)\right\}\right]$$

This equation gives an excess emission of a traffic in g as a function of the traffic flow, the season, the average speed, the ambient temperature and the hour of the day. Among all the parameters of this equation, we can distinguish three types:

- Some ones are purely internal and should not be modified by the user: $d_c(p,v_j,T)$, $\omega_i(p)$, $f(p,v_j,T)$, $h(p,\delta)$ and $g(p,t_n)$, coming from the first model (and given in Annex 33, Annex 34, Annex 35 and Annex 36)
- Some ones are input parameters: i, s, v_i, h, $tf_{i,h}$, $ptf_{i,h}$ and T
- Some ones are internal parametres but could be modified by an advanced user: $cm(s,v_i)$, p_h, $p_{i,j}$, $p_{m,j}$, $p_{n,h}$, d_m and v_j

According to Duboudin and Crozat (2002), the taking into account of the average speed in the above equation is problematic, because the difference between the average speed during the cold period and the average speed during the whole trip. A trip with an average trip speed v_i is subdivided into a cold and a hot phase. The cold one can have an average speed v_j different from the global speed v_i. To calculate the global emission, we add a hot emission calculated with v_i and a cold excess emission calculated with v_j:

$$E_{total}(trip) = EE_{cold}(v_j)+E_{hot}(v_i)$$

It is not really coherent: If the distance travelled during the cold phase d_c corresponds to an average speed v_j different from the speed of the whole traffic v_i, the travelled distance in hot conditions cannot have an average speed v_i, and the global emission should be calculated with the formulae:

$$E_{total}(d_c+d_{hot}) = EE_{cold}(v_j,d_c) + E_{hot}(v_j,d_c) + E_{hot}(v_{hot},d_{hot})$$

where v_{hot} is the average speed of the hot distance d_{hot}. Therefore, when we calculate the traffic emission, we should use the equation of the model 2, but add $(E_{hot}(v_j,d_c)-E_{hot}(v_i,d_c))$. As the difference should be quite small, we do not apply this correction.

Third model

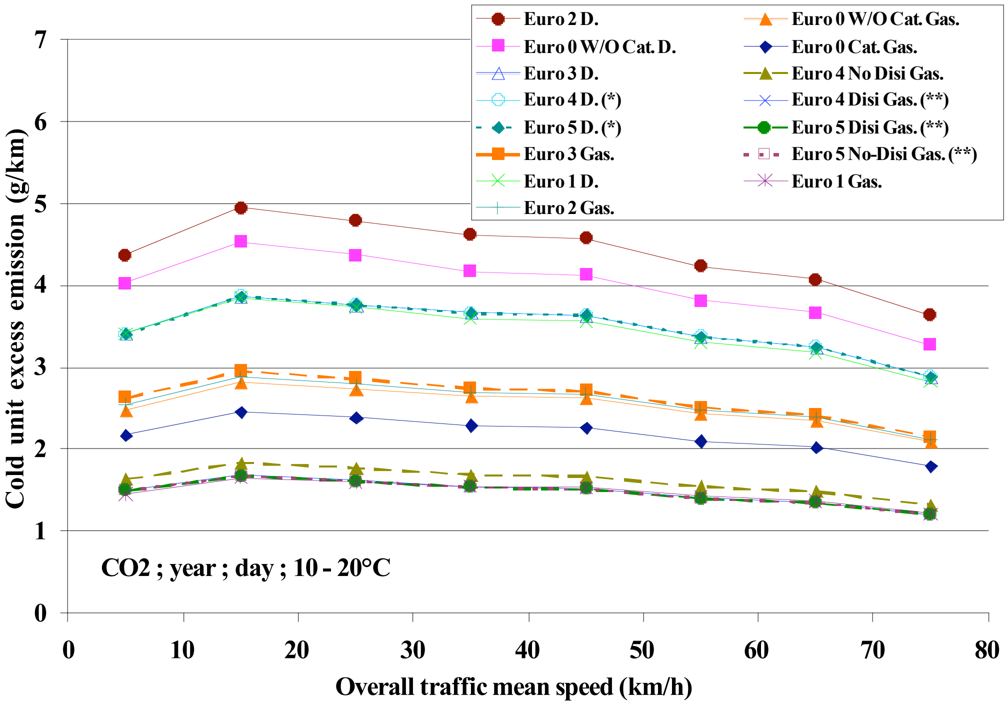
Both models 1 and 2 are not at all easy to be used by a common user: The first model needs to be completed by a model giving the number and the characteristics of the starts, which is far from simple. The second model is the most comprehensive and accurate model, the most open to any user data, but is especially complex to use: As a lot of necessary statistics are really not common, to use the model can lead to misleading results.

Therefore, a simplified approach was developed, whereby the second model, with all its default values, was executed and the outputs were transformed to give excess cold-start emission factors in mass per unit distance, needing only few open input data: It is the third model.

This third model gives for a given vehicle type and an atmospheric pollutant an excess unit emission of a traffic in g/km, according to the season s, the ambient temperature T, the average speed v_i and the hour h of the day. It is a combined table for 4 seasons (winter, summer, intermediate, whole year), 8 speed classes (5 to 75 km/h), 7 temperature classes (-25°C to 35°C) and 25 hours (24 hours and the whole day): See all these tables in the appendices 23 to 37 of André and Joumard (2005) and only as Excel sheet for each of the 24 hours.

The third model allows us to take into account the distribution of the cold starts along the day. But the development of the third model needs a specific assumption on the relative traffic distribution along the day ($ptf_{i,h}$): We used the so-called base distribution presented in Annex 37. But when applying this third model, if the actual traffic distribution is very different from this base distribution, the overall emission calculated during the day can be wrong. For instance for average traffic distributions representative of USA, Belgium and Switzerland (Figure 70 in Annex 37), the using of the third model introduces an error for the whole day between 3 and 7 %. In this case, we recommend not to use the third model hour per hour, but:

- Either to use the second model: the calculation will be very precise, with a detailed distribution of the cold excess emission along the day and an accurate summation over the day,
- Or to use the third model for the whole day (hour = whole day): the summation over the day of the hourly cold excess emissions will be accurate, but its distribution among the hours will not be accurate.



*: computed from Euro 3 diesel

**: computed from Euro 4 no DISI petrol

Figure 46: CO_2 cold start unit excess emission according to vehicle type and average speed.

In order to look at the relative influence of different parameters, the Figure 46 shows the influence of the average speed on the cold start emission. Other illustrations are given in Annex 38 for the ambient temperature, the vehicle category, the season and the hour. The influence of all these parameters depends on the pollutant considered. Nevertheless the ambient temperature, the mean speed and the hour in the day play the major role. The season, for a same temperature, plays a minor role.

3.12.5. Conclusion

This modelling of excess emission under cold start conditions for passenger cars was achieved using data provided by various European research organisations. The models take into account the average speed, ambient temperature, travelled distance and parking duration, among other parameters. The modelling counts in fact three models.

The models can be applied at different geographic scales: at a macroscopic scale (national inventories) using road traffic indicators and temperature statistics, or at a microscopic scale for a vehicle and a trip. Where a model user does not have access to the necessary statistics, it is recommended that the most aggregated model (*i.e.* the third model) is used, which is parallel to the hot emission modelling, with the same shape.

This study corresponds to the state-of-the-art at the present time. In the future, this model could be improved by different ways:

- By updating this model using new data when available, either for the most recent passenger cars, or the light duty vehicles, or the heavy duty vehicles.
- It would be much more precise to have crossed distributions for different speeds and ambient temperatures.
- The amount of supporting data has to be increased, especially for different speeds, lower and higher temperatures, and unregulated pollutants.

3.13. Evaporative emissions

Evaporative emissions mainly occur as a result of temperature changes of the vehicle fuel system, which occur due to the daily variation of the ambient temperature and during a normal driving procedure. Although this report focuses on exhaust emissions, we present shortly the work done within Artemis on the evaporative emissions of light vehicles, detailed in Hausberger et al. (2005).

The following reasons for evaporation are considered:

- Running losses
- Hot soak emissions
- Real time diurnal emissions (sum of diurnal emissions and resting losses)

From the literature review and the measurements carried out with three cars in SHED tests, it was possible to cover the following petrol driven vehicles:

- Cars pre Euro
- Cars Euro 1 and 2
- Cars Euro 3 and 4
- Cars Euro 1 to Euro 4 with failures in the fuel system (leakages)

Evaporative emissions from diesel-fueled vehicles are considered negligible due to the extremely low volatility of diesel fuel. Data for light goods vehicles (< 3.5 t maximum gross vehicle weight) is not available, and thus we suggest using the formulas for passenger cars for this category.

The new model, based to a large extent on extensive work of the US EPA, shows that evaporative emissions of Euro 3 and 4 are substantially lower than for Euro 1 and 2. Reasons for this can mainly be found in the more stringent emission legislation and the advanced test procedure. This leads to the introduction of more sophisticated and durable technologies, which are monitored by on board diagnostic systems. The main remaining sources of evaporative emissions in road traffic are thus old cars without a carbon canister and newer cars with failures in the fuel system.

The introduction of failure rates for the vehicles (only based on assumptions) as well as the different model approaches lead to evaporative emission levels which are higher than those provided by the European Corinair model (Eggleston et al., 1993). For typical driving of a vehicle on a summer day, the new Artemis model gives approx. 145 % higher evaporative emissions for the average pre Euro car, +360 % for the Euro 1 and 2 cars and +80 % for Euro 3 and 4 cars than compared to the Corinair approach. Since Corinair does not include emissions measured within the last decade and Artemis is only based on 3 new European cars measured, it is obvious that the database is much too small to establish a really reliable model on evaporative emissions.

4. Conclusion

The aim of Artemis was to improve and update the European emission inventorying tools, but also to develop an harmonised approach, common to all European countries, by avoiding the former situation where several models were concurrent and gave different outputs for the same situation. This objective was only partially achieved. However, the Artemis model provides a series of models for distinct situations.

For the hot emissions, an new discrete model approach based on traffic situations is provided. This approach is similar to the one used in the German-Swiss handbook, but the traffic situations used here are defined differently. In addition to a broad set of specific traffic situations, the model also provides emission factors for aggregate traffic situations for “urban”, “rural” and “motorways” as well as an “overall European average” for simple or macroscopic assessments.

In addition to the traffic situation approach a model similar to Copert was developed taking into account the driving behaviour only through the average speed. For deriving the corresponding emission functions, the same database was used as for the traffic situation approach, in order to keep a basic consistency between the two approaches. Both models are based on the whole Artemis light vehicle emission measurement database through the definition of Reference test patterns and their corresponding emissions.

Beside these models, three additional models (instantaneous or kinematic models) were developed within the project. They take into account the driving behaviour very accurately, either through the instantaneous driving data for two of them, or through quite complex kinematic parameters for the third. These models are, for the first time, able to calculate the emissions of a vehicle or a traffic for any driving behaviour, and should be used for assessing the influence of local policies influencing the driving behaviour (traffic lights, traffic management, speed control...). The availability of these instantaneous and kinematic models is restricted to scientists, as they need a more profound expertise on the driving behaviour.

The improvement of the models is also the result of new modelling of the influence of many additional parameters, as cold start, auxiliaries like air conditioning, mileage, ambient air temperature, and road gradient (and evaporation detailed elsewhere). All these models are based on a large amount of specific measurements made within the project. Some of them are given in different versions, some in different levels of complexity, for simplified aggregate to very specific and complex applications.

Specific emission factors were derived for light commercial vehicles, and for non regulated pollutants, on the basis of specific measurements. These emission factors, however, are only provided as average speed functions and only for a subset of vehicle classes due to limited availability of emission measurements.

The model has been tested to calculate the road emissions for the period 1990-2004 in Sweden (Sjödin et al., 2006) for international reporting obligations on air emissions. There was in general a fairly good agreement with on-road emission data.

The model for passenger cars and light commercial vehicles is implemented in the Artemis software (Boulter et al., 2007), together with the models for 2 wheelers and heavy duty vehicles. In addition, separate models are provided for the non-road transport modes.

All the light vehicle Artemis models (except the instantaneous and kinematic ones) and the software are publicly available and distributed free of charge.

The new vehicles, not tested in depth within the project, as Euro 4 and future Euro 5 ones, should be integrated on the basis of more extensive measurement campaign, including new or quite new concepts as for instance hybrid vehicles. For that the Artemis LVEM database could be used as far as this database includes all new emission measurements carried out in Europe on light vehicles.

The Artemis Light Vehicle Emission Measurement (LVEM) database includes almost all the measurements made in Europe until now on light vehicles, with all the necessary test conditions: about 2800 vehicles, 18 000 tests and 180 000 emission factors, including 25 000 for the unregulated pollutants. Its main part is publicly available and could be used by any user, for his or her own purposes. It should be updated and extended with the future European emission tests, if possible.

For information on the other tasks of Artemis, including the whole model for the different transport modes, the software and the Artemis LVEM database, or the future side developments, please look at the Artemis website www.trl.co.uk/artemis.

The Artemis models were developed mainly for European users, although the model will be used, as Copert, by many users outside Europe. In some cases and especially for developing countries, the driving behaviour, the vehicles and the emission factors could be quite far from the European ones. The user's demand could also be different. It would be therefore very useful in the future to adapt the models to all the users, European or not.

Annex 1 : Unregulated pollutants measured per laboratory

Count means number of data in the database. More information on the pollutants is given in Annex 9, except for pollutants written in blue, which are not considered as toxic in Annex 9.

NAME	**Formulae**	**CAS**	**Empa**	**IM**	**Inrets-ULCO-US-USTL**	**KTI**	**VTT**
Carbon oxides		(2 compounds)					
Carbon monoxide	CO	630-08-0	X	X	X	X	X
Carbon dioxide	CO_2	37210-16-5	X	X	X	X	X
Nitrogen oxides		(7 compounds)					
Nitrogen monoxide	NO	10102-43-9	X	X	X	X	X
Nitrogen dioxide [2]	NO_2	10102-44-0					
monoxyde de diazote	N_2O	10024-97-2			571		
peroxyde d'azote	N_2O_4	10544-72-6					
acide nitrique [2]	HNO_3	7697-37-2					
acide nitreux[2]	HNO_2	7782-77-6					
nitrate de peroxyacyle [2]	$C_{15}H_{11}N_3O$	85-85-8					
Ammonia		(1 compound)					
	NH_3	7664-41-7				64	
Sulfur oxides		(5 compounds)					
Sulfur dioxide	SO_2	7446-09-5					
Sulfur trioxide [2]	SO_3	7446-11-9					
acide sulfurique [2]	H_2SO_4	7664-93-9					
sulfate d'ammonium acide [2]	NH_4HSO_4	7803-63-6					
sulfate d'ammonium neutre [2]	$(NH_4)_2SO_4$	7783-20-2					
Particles		(4 compounds)					
PTS							
PM10							
PM2,5							
PM0,1							

VOC - Alkanes		(64 compounds)					
methane	CH_4	74-82-8	352	116	1514		126
ethane	C_2H_6	74-84-0	50	116	108		126
propane	C_3H_8	74-98-6	42	116	113		126
isobutane or 2-methylpropane	C_4H_{10}	75-28-5	47	116	104		
butane	C_4H_{10}	106-97-8	48	116	20		
dimethylpropane	C_5H_{12}	463-82-1		116	104		
isopentane	C_5H_{12}	78-78-4	49	116	9		
pentane	C_5H_{12}	109-66-0	50	115	111		
cyclopentane	C_5H_{10}	287-92-3	19				
methylcyclopentane	C_6H_{12}	96-37-7	26	116			
2,2-dimethylbutane	C_6H_{14}	75-83-2	30	116	84		
2,3-dimethylbutane	C_6H_{14}	79-29-8	30		4		
2-methylpentane	C_6H_{14}	107-83-5	40	116	17		
3-methylpentane	C_6H_{14}	96-14-0	36	116	16		
hexane or n-hexane	C_6H_{14}	110-54-3	42	116	10		
cyclohexane	C_6H_{12}	110-82-7	18		39		
2,4-dimethylpentane	C_7H_{16}	108-08-7	20				
2-methylhexane	C_7H_{16}	591-76-4			4		
2,3-dimethylpentane	C_7H_{16}	565-59-3					
2,3-dimethylpentane + 2-methylhexane	C_7H_{16}	565-59-3 + 591-76-4	33				
2,2-dimethylpentane	C_7H_{16}	590-35-2	7		1		
2,2,3-trimethylbutane	C_7H_{16}	464-06-2					
3,3-dimethylpentane	C_7H_{16}	562-49-2					
trimethylpentane	C_8H_{18}	29222-48-8					
2,3,4-trimethylpentane	C_8H_{18}	565-75-3	14				
3-methylhexane	C_7H_{16}	589-34-4	35		4		
3-ethylpentane	C_7H_{16}	617-78-7					
2,3-dimethylhexane	C_8H_{18}	584-94-1	19				
2,2-dimethylhexane	C_8H_{18}	590-73-8	12				
2,4-dimethylhexane	C_8H_{18}	589-43-5	23				
2,5-dimethylhexane	C_8H_{18}	592-13-2	23				
3,4-dimethylhexane	C_8H_{18}	583-48-2					
2,2,5-trimethylhexane	C_9H_{10}	3522-94-9	9				
methyloctane	C_9H_{20}	61193-19-9					
isooctane or 2,2,4-trimethylpentane	C_8H_{18}	540-84-1	30	116			
heptane	C_7H_{16}	142-82-5	34	116	7		
2-methylheptane	C_8H_{18}	592-27-8	23		4		
3-methylheptane	C_8H_{18}	589-81-1	24		4		
4-methylheptane	C_8H_{18}	589-53-7	16				
methylcyclohexane	C_7H_{14}	108-87-2	19				
ethylcyclopentane	C_7H_{14}	1640-89-7					
1,3-dimethylcyclohexane	C_8H_{16}	591-21-9					
1,4-dimethylcyclohexane	C_8H_{16}	589-90-2					

1,4-dimethylcyclohexane cis	C_8H_{16}	624-29-3			35		
1,4-dimethylcyclohexane trans	C_8H_{16}	02207-04-7			43		
1,2-dimethylcyclohexane	C_8H_{16}	583-57-3					
1,2-dimethylcyclohexane cis	C_8H_{16}	02207-01-4			59		
1,2-dimethylcyclohexane trans	C_8H_{16}	6876-23-9			68		
cycloheptane	C_7H_{14}	291-64-5					
butylcyclohexane	$C_{10}H_{20}$	1678-93-9					
methyl heptane	C_8H_{18}	50985-84-7					
methylnonane	$C_{10}H_{22}$	63335-87-5					
octane	C_8H_{18}	111-65-9	27		8		
nonane	C_9H_{20}	111-84-2	6		50		
decane	$C_{10}H_{22}$	124-18-5	1		73		
undecane	$C_{11}H_{24}$	1120-21-4	3		72		
dodecane	$C_{12}H_{26}$	112-40-3	1		84		
tridecane	$C_{13}H_{28}$	629-50-5			67		
tetradecane	$C_{14}H_{30}$	629-59-4			64		
pentadecane	$C_{15}H_{32}$	629-62-9			58		
hexadecane	$C_{16}H_{34}$	544-76-3			59		
heptadecane	$C_{17}H_{36}$	629-78-7			38		
octadecane	$C_{18}H_{38}$	593-45-3			28		
nonadecane	$C_{19}H_{40}$	629-92-5			13		
icosane	$C_{20}H_{42}$	112-95-8			5		
henicosane	$C_{21}H_{44}$	629-94-7			2		
docosane	$C_{22}H_{46}$	629-97-0					
tricosane	$C_{23}H_{48}$	638-67-5					
1,2-dibromoethane (circ)	$C_2H_4Br_2$	106-93-4					
monobromomethane	CH_3Br	74-83-9					
1,2-dichloroethane (circ)	$C_2H_4Cl_2$	1300-21-6					
aliphatic hydrocarbons						64	
VOC - Alkenes and alkynes		(46 compounds)					
ethylene (circ) or ethene	C_2H_4	74-85-1	47	116	103		126
propene	C_3H_6	115-07-1	48	116	113		126
propadiene	C_3H_4	463-49-0	8		4		
1-butene	C_4H_8	106-98-9	23		89		
1-heptene or n-heptene	C_7H_{14}	592-76-7	1				
isobutene or 2-methyl-propene or isobutylene	C_4H_8	115-11-7	45				126
i-butene	C_4H_8	107-01-7			4		
1,3-butadiene (circ)	C_4H_6	106-99-0	24	116	4		127
cis-2-butene	C_4H_8	590-18-1	20		110		
1-butyne	C_4H_6	107-00-6			4		
2-butyne	C_4H_6	503-17-3					
cis-2-butene + trans-2-butene	C_4H_8	590-18-1 + 624-64-6			4		

trans-2-butene	C_4H_8	624-64-6	19		80		
cyclopentadiene	C_5H_6	542-92-7					
cyclopentene	C5H8	142-29-0	1				
isopentene or 3-methyl-1-butene or 3-methylbutene or isoamylene	C_5H_{10}	563-45-1	5		4		
1-pentene	C_5H_{10}	109-67-1	5		113		
trans-2-pentene	C_5H_{10}	646-04-8	7		4		
cis-2-pentene	C_5H_{10}	627-20-3	3				
2-methyl-1-butene	C_5H_{10}	563-46-2	16		4		
1-hexene or hexene	C_6H_{12}	592-41-6	2		97		
cis-2-hexene (+1-hexyne)	C_6H_{12}	7688-21-3					
trans-2-hexene	C_6H_{12}	4050-45-7					
trans-3-hexene	C_6H_{12}	13269-52-8					
2-methyl-2-pentene	C_6H_{12}	625-27-4	3				
3-methyl-1-pentene	C_6H_{12}	760-20-3	3				
1-methylcyclopentene or 1-methyl-1-cyclopentene	C_6H_{10}	693-89-0	7				
4-methyl-t-2-pentene	C_6H_{12}	27236-46-0	2				
cis-4-methyl-2-pentene	C_6H_{12}	691-38-3					
cis-3-methyl,2-pentene	C_6H_{12}	922-62-3					
trans-3-methyl,2-pentene	C_6H_{12}	616-12-6					
2-methyl,1-pentene or 1-methyl-1-propyl ethylene	C_6H_{12}	763-29-1	2				
2-methyl,1,4-pentadiene	C_6H_{10}	763-30-4					
trans-2-methyl-1,3-pentadiene	C_6H_{10}	926-54-5					
2,3,3-trimethyl,1-butene	C_7H_{14}	594-56-9					
cyclohexene	C_6H_{10}	110-83-8					
2-methyl,1-hexene	C_7H_{14}	6094-02-6					
trans-2-heptene	C_7H_{14}	14686-13-6			4		
cycloheptene	C_7H_{12}	628-92-2					
1-octene (+1,1-dimethylcyclohexane)	C_8H_{16}	111-66-0					
trans-2-octene	C_8H_{16}	13389-42-9					
cis-2-octene	C_8H_{16}	7642-04-8					
1-nonene	C_9H_{18}	124-11-8					
cis-4-nonene	C_9H_{18}	10405-84-2					
trans-4-nonene + trans-3-nonene	C_9H_{18}	10405-85-3 + 20063-92-7					
1-undecene	$C_{11}H_{22}$	821-95-4					
1-dodecene	$C_{12}H_{24}$	112-41-4					
acetylene or ethyne	C_2H_2	74-86-2	33		5		126
propyne	C_3H_4	74-99-7	10		4		
isoprene	C_5H_8	78-79-5					
2-methyl-2-butene	C_5H_{10}	513-35-9	18		4		
dimethylhexene	C_8H_{16}	78820-82-3					
VOC - Monocyclic Aromatic Hydrocarbons		(37 compounds)					

benzene (circ)	C_6H_6	71-43-2	640	115	68	64	126
toluene	C_7H_8	108-88-3	640	114	105	64	126
ethylbenzene	C_8H_{10}	100-41-4	46		98	64	126
m-xylene	C_8H_{10}	108-38-3				64	126
p-xylene	C_8H_{10}	106-42-3					
o-xylene	C_8H_{10}	95-47-6	47		94		126
ethylbenzene + m-xylene + p-xylene + o-xylene	C_8H_{10}	100-41-4 + 108-38-3 + 106-42-3 + 95-47-6	209				
m-xylene + p-xylene	C_8H_{10}	108-38-3 + 106-42-3	49		101		
styrene	C_8H_8	100-42-5	24		4		
isopropylbenzene	C_9H_{12}	98-82-8	2		34		
propylbenzene	C_9H_{12}	103-65-1	26		65		
3-ethyltoluene	C_9H_{12}	620-14-4	44		59		
4-ethyltoluene	C_9H_{12}	622-96-8	41		63		
3-ethyltoluene + 4-ethyltoluene	C_9H_{12}	620-14-4 + 622-96-8			4		
1,3,5-trimethylbenzene	C_9H_{12}	108-67-8	40		63		
1,3,5-triphenylbenzene	$C_{24}H_{18}$	612-71-5		111			
2-ethyltoluene	C_9H_{12}	611-14-3	36		67		
1,2,4-trimethylbenzene	C_9H_{12}	95-63-6	45		50		
tert-butylbenzene	$C_{10}H_{14}$	98-06-6			22		
isobutylbenzene	$C_{10}H_{14}$	538-93-2			7		
sec-butylbenzene	$C_{10}H_{14}$	135-98-8					
butylbenzene	$C_{10}H_{14}$	104-51-8			2		
1,2,3-trimethylbenzene	C_9H_{12}	526-73-8	36		4		
1-methyl-4-isopropylbenzene or p-cymene or p-isopropyltoluene	$C_{10}H_{14}$	99-87-6			15		
indane	C_9H_{10}	496-11-7	20		4		
1,2-diethylbenzene	$C_{10}H_{14}$	135-01-3					
1-methyl-4-isopropylbenzene + 1,2-diethylbenzene	$C_{10}H_{14}$	99-87-6 + 135-01-3			3		
1,3-diethylbenzene	$C_{10}H_{14}$	141-93-5	10		14		
methylindane	$C_{10}H_{12}$	27133-93-3					
1,4-diethylbenzene	$C_{10}H_{14}$	105-05-5			46		
n-butylbenzene	$C_{10}H_{14}$	104-51-8					
1-methyl-2-propylbenzene	$C_{10}H_{14}$	527-84-4			2		
1-methyl-3-propylbenzene or 3-propyltoluene	$C_{10}H_{14}$	1074-43-7	13		4		
1-methyl-3-isopropylbenzene	$C_{10}H_{14}$	535-77-3			1		
1-methyl-4-propylbenzene or 4-propyltoluene	$C_{10}H_{14}$	1074-55-1	5				
1-methyl-4-isopropylbenzene	$C_{10}H_{14}$	99-87-6			13		
1,4-dimethyl-2-ethylbenzene	$C_{10}H_{14}$	1758-88-9			4		
1,3-dimethyl-4-ethylbenzene	$C_{10}H_{14}$	874-41-9	18		15		
1,3-dimethyl-5-ethylbenzene	$C_{10}H_{14}$	934-74-7	22				
1,2-dimethyl-4-ethylbenzene	$C_{10}H_{14}$	934-80-5	27		2		
1,3-dimethyl-2-ethylbenzene	$C_{10}H_{14}$	2870-04-4					
1,2-dimethyl-3-ethylbenzene	$C_{10}H_{14}$	933-98-2					

1,2,4,5-tetramethylbenzene	$C_{10}H_{14}$	95-93-2	18		5		
1,2,3,5-tetramethylbenzene	$C_{10}H_{14}$	527-53-7	20		10		
1,2,3,4-tetramethylbenzene	$C_{10}H_{14}$	488-23-3	1				
Polycyclic Aromatic Hydrocarbons "light"		(13 compounds)					
naphtalene	$C_{10}H_8$	91-20-3	42	103	15+ 116	64	
2-methylnaphtalene	$C_{11}H_{10}$	91-57-6			18		
1-methylnaphtalene	$C_{11}H_{10}$	90-12-0			18		
acenaphthylene	$C_{12}H_8$	208-96-8		111	115		
fluorene (circ)	$C_{13}H_{10}$	86-73-7		111	116		
aromatique $C_{13}H_{12}$	$C_{13}H_{12}$						
phenanthrene (circ)	$C_{14}H_{10}$	85-01-08		112	116		
anthracene (circ)	$C_{14}H_{10}$	120-12-7		112	116		
acenaphtene	$C_{12}H_{10}$	83-32-9		110	116		
1-nitronaphtalene (circ)	$C_{10}H_7NO_2$	86-57-7					
2-nitronaphtalene (circ)	$C_{10}H_7NO_2$	581-89-5					
2- nitrofluorene (circ)	$C_{13}H_9NO_2$	607-57-8					
9-nitroanthracene (circ)	$C_{14}H_9NO_2$	602-60-8					
	Underlined: gaseous and particulate (2 samples)						
Polycyclic Aromatic Hydrocarbons "heavy"		(42 compounds)					
	PAH from IM: semivolatile + particulate phase (1 sample)						
anthanthrene (circ)	$C_{22}H_{12}$	191-26-4		112			
fluoranthene (circ)	$C_{16}H_{10}$	206-44-0		113	116		
pyrene (circ)	$C_{16}H_{10}$	129-00-0		113	116		
chrysene (circ)	$C_{18}H_{12}$	218-01-9			116		
chrysene + triphenylene	$C_{18}H_{12}$	218-01-9 + 217-59-4		109			
benzo[a]fluorene (circ)							
benzo[b]fluorene (circ) or 2,3-benzofluorene	$C_{17}H_{12}$	243-17-4		112			
benzo[a]anthracene (circ)	$C_{18}H_{12}$	56-55-3		112	116		
benzo[b]fluoranthene (circ)	$C_{20}H_{12}$	205-99-2		109	116		
benzo[k]fluoranthene (circ)	$C_{20}H_{12}$	207-08-09			116		
benzo[j]fluoranthene (circ)	$C_{20}H_{12}$	205-82-3					
benzo[b]naphto[1,2-d]thiophene	$C_{16}H_{10}S$	205-43-6		113			
benzo[ghi]fluoranthene (circ)	$C_{18}H_{10}$	203-12-3		112			
benzo[b]chrysene	$C_{22}H_{14}$	214-17-5					
picene or 1,2:7,8-dibenzphenanthrene	$C_{22}H_{14}$	213-46-7					
benzo[b]chrysene + picene	$C_{22}H_{14}$	214-17-5 + 213-46-7		112			
benzo[e]pyrene (circ)	$C_{20}H_{12}$	192-97-2		110			
benzo[ghi]perylene (circ)	$C_{22}H_{12}$	191-24-2		108	116		
benzo[a]pyrene (circ)	$C_{20}H_{12}$	50-32-8		113	116	64	
benzo[c]phenanthrene (circ)	$C_{18}H_{12}$	195-19-7		112			
cyclopenta[cd]pyrene (circ)	$C_{18}H_{10}$	27208-37-3		113			

dibenzo[a,c]anthracene	$C_{24}H_{14}$	215-58-7		113			
dibenzo[a,h]anthracene (circ)	$C_{22}H_{14}$	53-70-3		113	116		
dibenzo[a,j]anthracene	$C_{22}H_{14}$	224-41-9					
dibenzo[a,e]pyrene (circ)							
dibenzo[a,h]pyrene (circ)							
dibenzo[a,l]pyrene	$C_{24}H_{14}$	191-30-0					
1,4-dimethylphenantrene (circ)							
3,6-dimethylphenantrene	$C_{16}H_{14}$	1576-67-6					
2-methylchrysene (circ)							
3-methylchrysene (circ)							
4-methylchrysene (circ)							
5-methylchrysene (circ)							
6-methylchrysene (circ)							
1-methylphenanthrene (circ)							
perylene (circ)	$C_{20}H_{12}$	198-55-0		107			
triphenylene (circ)	$C_{18}H_{12}$	217-59-4					
propylene (circ)	C_3H_6	115-07-1					
indeno[1,2,3-cd]pyrene (circ)	$C_{22}H_{12}$	193-39-5		111	116		
coronene (circ)	$C_{24}H_{12}$	191-07-1		109			
3,7-dinitrofluoranthene (circ)							
3,9-dinitrofluoranthene (circ)							
1-nitropyrene (circ)							
3-nitrofluoranthene (circ)							
1,3-dinitropyrene (circ)							
1,6-dinitropyrene (circ)							
1,8-dinitropyrene (circ)							
6-nitrobenzo[a]pyrene (circ)							
COV - Aldehydes and ketones (Carbonyl compounds)		(23 compounds)					
formaldehyde (circ)	CH_2O	50-00-0	51	121	177		
acetaldehyde (circ)	C_2H_4O	75-07-0	48	120	176		
acetone	C_3H_6O	67-64-1	34		148		
acroleine (circ)	C_3H_4O	107-02-8	31		78		
formaldehyde + acetaldehyde + acroleine		50-00-0 + 75-07-0 + 107-02-8				64	
acetone + acroleine		67-64-1 + 107-02-8		100	28		
propionaldehyde	C_3H_6O	123-38-6	22	121	162		
crotonaldehyde	C_4H_6O	4170-30-3	30	121	76		
2-butanone or methyl ethyl ketone	C_4H_8O	78-93-3	8	121	119		
methacroleine	C_4H_6O	78-85-3	12		72		
butyraldehyde	C_4H_8O	123-72-8	8	121	104		
2-butanone + methacroleine + butyraldehyde		78-93-3 + 78-85-3 + 123-72-8			24		
isobutanaldehyde	C_4H_8O	78-84-2					
benzaldehyde	C_7H_6O	100-52-7	47	121	127		

isovaleraldehyde	$C_5H_{10}O$	590-86-3		121			
valeraldehyde	$C_5H_{10}O$	110-62-3	6	121	167		
o-tolualdehyde	C_8H_8O	529-20-4	17	121			
m-tolualdehyde	C_8H_8O	620-23-5	39		57		
p-tolualdehyde	C_8H_8O	104-87-0			99		
hexaldehyde	$C_6H_{12}O$	66-25-1		120	172		
2,5-dimethylbenzaldehyde	$C_9H_{10}O$	5779-94-2		121			
1,2-ethanedione	$C_2H_2O_2$	107-22-2					
propanedione	$C_3H_4O_2$	78-98-8					
methylvinylcetone	C_4H_6O	78-94-4					
acide formique	CH_2O_2	64-18-6					
acide acetique	$C_2H_4O_2$	64-19-7					

Annex 2: Analysis methods for unregulated pollutants

The sampling procedures, the measurements and other analysis methods depend on the laboratory (Aakko et al., 2005; 2006). The list of compounds quantified and characterised is given in Annex 1 per laboratory.

A2.1. EMPA methods

The EMPA methods are presented in (Saxer et al., 2002; 2003; Weilenmann et al., 2003b; 2005; Heeb et al., 2002; 2004).

On-line measurement by chemical ionization mass spectrometry

At a time-resolution of about 1 second, concentrations of individual hydrocarbons were investigated on-line by chemical ionization mass spectrometry (CI-MS) either from diluted exhaust (CVS-system) or at the tail pipe from heated raw exhaust. Two different ionization modes were used. Methane and benzene are ionized with xenon ions (Xe^+, 12.2eV), benzene, toluene and the C_2-benzene class of compounds (xylenes and ethyl benzene) were monitored using mercury ions (Hg^+, 10.4 eV).

Prior to each test cycle both mass spectrometers were calibrated using gas standards. Validation of the analytical procedures was achieved with an independent method based on gas chromatography with flame ionization detection (GC-FID, see section below) revealing good comparability for the reported pollutants.

Off-line measurement by gas chromatography

The exhaust gas was diluted in the CVS-system of the chassis dynamometer. As for regulated measurements a bag was filled with a constant flow during the test. The hydrocarbons were analysed by gas chromatography with flame ionisation detection (GC-FID). Two different GC systems were used for the light end ($C_1 - C_5$) and the mid-range ($C_6 - C_{12}$) hydrocarbons. An aliquot of two milliliters of the diluted exhaust gas was injected directly into the gas chromatograph. The GC-systems were calibrated by means of reference gases consisting of thirteen compounds (ethene, ethine, propane, propene, isobutane, isobutene, n-hexane, benzene, toluene, ethylbenzene, o-xylene, m-xylene, p-xylene). About 110 VOC species were specified. The compounds were identified by gas chromatography coupled with mass spectrometry (GC-MS). The samples were analysed within 8 hours to minimize the degradation of instable compounds. A sample of the dilution air was analysed simultaneously to every test and the VOC concentration of the exhaust samples corrected with the VOC concentration of the dilution air.

Aldehydes and ketones

The exhaust gas was sampled from the CVS-system into impingers containing a solution of 2,4-dinitrophenylhydrazine in acetonitrile. The aldehydes and ketones were analysed as their 2,4-dinitro-phenylhydrazone derivatives using high performance liquid chromatography (HPLC) with UV detection. The target list of the method includes 13 carbonyl compounds.

A2.2. IM – methods

VOC, or better HCs, have been sampled from the CVS Tedlar-bags immediately after the test phase through a non heated Teflon line (Prati et al., 2003a; b; 2005). Analysis has been performed by GC-

FID (HP 5890). 18 hydrocarbons (from C1 to C8) have been calibrated individually with the corresponding compounds in pressurized calibration gas mixture. The calibration curves have shown a good linearity with a minimum correlation coefficient of 0.99. VOC's have been quantified without background correction.

PAHs sampling line is constituted by a particulate filter (Ø 47 mm Pallflex Fiberfilm T60A20) and a washed XAD-2 tube with a front amberlite load of 100 mg and a back amberlite load of 50 mg (Supelco ORBO 43). Both filters have been positioned upstream a pump and a volumetric counter. Diluted exhaust sample rate through this line was about 8 l/min. After sampling, sorbent tube was put in refrigerant (+2°C). The PAH compounds were Soxhlet extracted either from the filter and from the XAD tube with methylene chloride (CH_2Cl_2 - DCM). In order to estimate sample losses because of hot extraction, a standard mix of 5 deuterated compounds (PAH – mix 31 containing naphtaleneD8, acenaphteneD10, phenantreneD10, criseneD12, perileneD12) diluted to 1 m g/ml in DCM is added to solution before Soxleth extraction. Then the extracted were concentrated by evaporation of the solvent in a rotary evaporator under vacuum to 1 cm^3. The quantitative analysis of 16 and more PAHs have been done by GC-MS (gas chromatograph HP 5890 equipped with a mass spectrometer detector HP 5971) in SIM mode. Calibration method has been realised by using a standard mixture concentration (PAH mix 45) and diluting it with methylene chloride to obtain 5 points for calibration. The calibration curves have shown a good linearity with a minimum correlation coefficient of 0.98.

Carbonylic compounds sampling line is composed by a dynamic probe inserted in dilution tunnel, a filter holder to block particulate matter, a DNPH-cartridge, a pump and a volumetric counter. The flow rate in the cartridge was kept at about 1 liter/min. The carbonyl compounds, highly reactive, in the presence of 2,4-dinitrophenylhydrazine form the correspondent and much more stable hydrazones. The cartridges are Sep-Pak DNPH-silica cartridges short body (360 mg) by Waters. The cartridges after the test have been extracted by 5 cc of acetonitrile and stored in vials in a refrigerator at 2°C. The quantification of carbonylic compounds is performed by High Pressure Liquid Chromatography (HPLC) with UV detection. The chromatographic column was a Waters Nova-Pack C18 , 150 mm lenght and 3.9 mm as internal diameter. The evaluation of 15 carbonylic compounds (aldehydes/ketones) has been realized by using a standard mixture concentration containing 2,4-dinitrofenilidrazonici derivatives (Mix TO11/IP-6A DNPH Mix) and diluting it in acetonitrile to obtain five concentration points.

N_2O analysis and quantification is carrier out by FT-IR (NICOLET).

A2.3. INRETS-US-ULCO-USTL methods

VOC measurement

The methods for VOC and carbonyl compounds are presented in (Caplain et al., 2004; 2006; Joumard et al., 2004a; 2004b). VOC are sampled in the dilution tunnel using sorbent tubes: Carbotrap B and C, Carbosieve III for "light" hydrocarbons C_2-C_6 and Tenax for semi-volatile hydrocarbons C_6 -C_{12}. The tubes were transferred to CCM for analyses in a temperature controlled container at 0°C and were stored at -18°C before analysis. As soon as it's possible sorbent tubes are thermally desorbed before analysis by gas chromatography. The "light" compounds (C_1-C_6) are separated on RT alumina Restek column and detected by FID Detector (Perkin Elmer).The "heavy" compounds (C_6-C_{15}) are separated on a 5% diphenyl – 95% dimethylpolysiloxane (DB5) column and detected by mass spectrometry (EM 640 Brucker), the identification is made by comparison of retention times and comparison of mass spectrum. The sampling was optimized by the use of two cartridges in series because during the first tests about 30% of light hydrocarbons are sampled on the second cartridge, by decreasing the sampling flow and by recording the background contribution of the air dilution (corrected, sum of quantities trapped on the two cartridges). By combining the two sets of speciation data we provided a profile of the gas phase hydrocarbons emissions from unleaded petrol and diesel fuel.

GC-FID (C2 to C6): ULCO

Thermodesorber: Cartridge desorption: 7,5 min at 250 °C; Cold trap desorption: 1min at 300 °C; Transfer line: 200 °C; GC/FID: Air pressure: 2 bars, Hydrogen pressure: 3,3 bar, Column : RT alumina Restek (50 m*0.53*1µm,Al_2O_3/KCl), Carrier gas: Nitrogen, Pressure: 8 Psis, T° détector : 250°C, Temperature programm : 35 °C during 5 min, 5°C/min until 110°C, 10°C/min until 200°C, 200°C during 40 min

GC-MS (C6 to C15): ULCO

Detection mass : 40 à 300 u.m.a., Column: JW Scientific DB5 (25 m x 0,32 mm x 0,25 µm), (5% diphényl et 95% diméthylpolysiloxane), Carrier gas : Nitrogen, Pressure : 0,3 bar, T° cap : 200°C, T° detector : 200°C, T° connector : 200°C, T° Interface : 200°C, T° thermodesorber: 220°C, Desorption time: 5 min, Injection time: 8 s, Injector purge : 10 min, Temperature: 35 °C during 5 min, 5°C/min until 220°C, 220°C during 20 min

Carbonyl compounds measurement: USTL

Carbonyl Compounds are sampled by the method of derivatisation using 2,4 dinitrophenylhydrazine (2,4DNPH) traps. Emissions were passed on cartridges filled with C18 phase impregnated with acidified 2,4 –DNPH. After elution with 2ml of acetonitrile the sample is analysed by High Performance Liquid Chromatography (SPECTRA PHYSICS P4000) with an UV detection (365nm) (Spectra Focus 3000). Column: ALLTIMA C18 50 (250mm * 4.6mm), Flow : 1,2 ml/min, Volume : 20µl

Polycyclic Aromatic Hydrocarbons (PAH) measurement: US

The PAH were sampled at the end of the CVS dilution tunnel using two successive cartridges (Paturel et al., 2003; 2005; Devos et al., 2006; Joumard et al., 2004a; 2004b). The packing, Teflon wool and Amberlite XAD2 resin were purified in the laboratory by two successive Soxhlet cycles of 8 hours with cyclohexane. The two sampling media were subjected to special treatment before the analysis as such, i.e. extraction of PAH from the media by an organic solvent, concentration of the extract and purification of the matrix obtained. After evaporation under nitrogen flow until the eluate was almost dry, the purified sample was retreated with 0.5ml acetonitrile.

The study was carried out on a Merck-Hitachi chromatograph equipped with a LiChroCart column, fed by an injection loop with a volume fixed at 20µl and coupled with adsorption and fluorescence spectrometers. Elution was performed using ACN/H2O in mobile phase at a flow of 1ml/mn.

A2.4. KTI methods

Ammonia

Sampling: at the end of the dilution tunnel of the CVS using diluted sulfuric acid absorbing agent in two series connected recipients being cooled by melting water

Analysis:Giving Nessler – reagent to the sample, evaluation by change of its colour by photocolorimetry at 440 nm

VOC

Sampling: at the end of the dilution tunnel of the CVS using Anasarb CSC cartridge filled by active carbon

Analysis: Gas Chromatography (HP 5890)

Aldehydes

Sampling: at the end of the dilution tunnel of the CVS using a a two zones cartridge filled by silica gel impregnated by 2,4 DPNH

Analysis: Liquid Chromatography (HP 1090)

PAH

Sampling: at the end of the dilution tunnel of the CVS using filtering (teflon wool)

Analysis: Gas Chromatography (HP 5890)

A2.5. VTT methods

Hydrocarbon speciation (13 compounds up to C_8) from bag samples with GC (Hewlett-Packard)

Exhaust gas was diluted with CVS unit and a part of the diluted exhaust gas was collected to tedlar bags (the same as used for regulated emissions). The samples from tedlar bags were taken immediately after the test phase through direct lines to the gas chromatograph (GC: HP 5890 Series II, sample loop of 2 cm_3). The gas was dried using an inline $CaCl_2$ drying tube. Hydrocarbons from C1 to C8 were identified by retention times and quantitative analysis was done by external standard method. The standard gas mixtures were used including methane, ethene, propene, i-butene, i-pentane, 1,3-butadiene, benzene, toluene, ethylbenzene, m-, p- and o-xylenes. Programmed heating starting from +60°C, 50 m x 0.53 mm ID x 10 µm df Al_2O_3/KCl PLOT fused silica column added with a particle trap (Chrompack Particle Trap 2.5 m x 0.53 mm ID x 10 µm df).

Aldehydes

Aldehyde samples were collected from the diluted exhaust gas (CVS) by using dinitrophenylhydrazine (DNPH) cartridges. The DNPH derivatives were extracted with acetonitrile/water mixture. Altogether 11 aldehydes (formaldehyde, acetaldehyde, acrolein, propionaldehyde, crotonaldehyde, methacrolein, butyraldehyde, benzaldehyde, valeraldehyde, m-tolualdehyde, hexanal) were analyzed with the HPLC-technology (HP 1050, UV detector, Nova-Pak C18 column).

Analysis of unregulated components with SESAM/FTIR: N_2O, NO/NO_2, NH_3 and formaldehyde.

The on-line multicomponent analysis was made using Siemens Sesam II Fourier transform infrared (FTIR) which monitors simultaneously 20 gaseous emission components at one second time interval. Hot, filtered raw exhaust was monitored. Each component is multipoint calibrated The primary result is vol-ppm which is converted into mg/km using the momentary dilution ratio which is obtained from tracers measuring raw and diluted CO_2.

Annex 3: Average characteristics of the vehicle samples

Parameter	Lab.	Sample size			Cubic capacity (cm^3)			Power (kW)		
		Petrol	Diesel	total	Petrol	Diesel	total	Petrol	Diesel	total
instant. emis.	EMPA	7	13	20	2095	1642	1801	78	76	77
	PHEM / TUG	14	7	21	1785	1882	1817	85	81	83
hot reg. poll. PC	all	95	48	143	1609	1971	1730	76	72	75
unregul. poll. PC	all	44	30	74	1602	1954	1745	74	68	72
Light Duty Veh.	KTI	0	2	2	0	2340	2340	0	59	59
mileage	LAT	2	0	2	1073	-	1073	46	-	46
ambient temp.	all	22	9	31	1785	2001	1848	81	77	80
amb. humidity	VTT	9	2	11	1572	1947	1640	76	73	76
gradient, load	TUG	2	2	4	1610	1688	1649	65	63	64
auxiliaries	TUG	1	2	3	1895	2047	1996	77	81	80
cold start	all	43	30	73	1610	1954	1752	75	68	72

Parameter	Lab.	Weight (kg)			Mileage (Mm)		
		Petrol	Diesel	total	Petrol	Diesel	total
instant. emis.	EMPA	1432	1165	1258	66	50	56
	PHEM / TUG	1270	1315	1285	10	16	12
hot reg. poll. PC	all	1161	1281	1201	37	56	43
unregul. poll. PC	all	1125	1244	1173	46	72	57
Light Duty Veh.	KTI	0	1590	1590	0	3	3
mileage	LAT	933	-	933	47	-	47
ambient temp.	all	1215	1337	1251	53	71	58
amb. humidity	VTT	1241	1375	1265	24	26	24
gradient, load	TUG	1233	1165	1199	1	39	20
auxiliaries	TUG	1385	1373	1377	0	27	18
cold start	all	1129	1244	1176	47	72	57

Annex 4: Characteristics of the tested vehicles

All the vehicles, except LDVs, are PC tested for hot regulated pollutant emissions.

In the column 'Emis. standard', 'E0' means 'pre Euro 1', and '04' means 'ECE 1504'.

Lab.	Make	Model	Petrol / CNG / Diesel	Emis. standard	Year	Capacity (cm^3)	Max. power (kW)	Weight (kg)	Mileage (Mm)	instantaneous emis..	unreg. pollutants PC	LD: Light Duty Veh.	G: gradient, H: humidity	L: load, T: temperature	A: auxiliaries, M: mileage	cold start
EM.	Alfa Romeo	156 2.4 JTD	D	E2	1998	2387	100	1410	71	1	1			T		1
EM.	Ford	Focus 1.8 TD	D	E2	2000	1753	66	1273	36	1	1			T		1
EM.	Mitsubishi	Pajero	D	E2	1999	2835	92	2065	59	1						
EM.	Opel	Zafira A 20 TD	D	E2	1999	1995	60	1430	69	1	1			T		1
EM.	Peugeot	406 1.9 DT	D	E2	1997	1905	66	1365	94	1	1			T		1
EM.	Seat	Ibiza GT TDI	D	E2	1999	1896	81	1105	31	1	1			T		1
EM.	Volkswagen	Passat	D	E2	2001	1896	81	1375	103	1	1			T		1
EM.	BMW	635CSI	P	E0	1985	3430	160	1470	167		1			T		1
EM.	Fiat	Uno 45	P	E0	1986	999	33	795	110		1			T		1
EM.	Honda	Accord 2.0I Auto	P	E0	1985	1954	85	1155	117		1			T		1
EM.	Opel	Kadett D 1.3	P	E0	1984	1296	50	920	128	1	1			T		1
EM.	Peugeot	505 GTI Auto	P	E0	1984	2164	95,5	1235	58	1	1			T		1
EM.	Volkswagen	Golf 19E	P	E0	1984	1595	55	910	164	1	1			T		1
EM.	Alfa Romeo	156 2.0 TwinS.16V	P	E2	1998	1970	114	1250	74							
EM.	BMW	323CI	P	E3	2000	2494	125	1370	28		1			T		1
EM.	Citroën	Xsara	P	E3	2001	1360	55	1191	21	1						
EM.	Fiat	Punto HGT	P	E3	2000	1747	96	1095	22	1						
EM.	Ford	Focus 1.6 16V	P	E3	2000	1596	74	1151	16		1			T		1
EM.	Ford	Mondeo	P	E3	2001	1999	107	1460	32	1						
EM.	Honda	Accord	P	E3	2000	1997	108	1500	28	1						
EM.	Hyundai	Accent 1.3 GS	P	E3	2000	1341	62	990	22	1	1			T		1
EM.	Mazda	Demia	P	E3	2001	1498	55	1100	21	1						
EM.	Mitsubishi	Galant 2.5 V6 Auto	P	E3	2000	2498	120	1445	33		1			T		1
EM.	Nissan	Primera 2.0 CVT	P	E3	2000	1998	103	1325	30		1			T		1
EM.	Peugeot	306	P	E3	2001	1761	81	1245	19	1						
EM.	Renault	Mégane	P	E3	2001	1598	79	1195	20	1						
EM.	Renault	Mégane Scénic	P	E3	2001	1998	100	1400	80	1						
EM.	Toyota	Yaris 1.0	P	E3	2000	998	50	900	37	1	1			T		1
IM	Fiat	Marea Wee. TD100	D	E2	1997	1910	74	1255	187		1					1
IM	Fiat	Bravo 105 JTD SX	D	E3	2000	1910	77	1095	25		1					1
IM	Fiat	Punto JTD	D	E3	2001	1910	59	965	1		1					1
IM	Fiat	Regata Giardinetta	P	E0	1987	1585	74	1005	96		1					1
IM	Fiat	Uno 1.1 IE	P	E1	1995	1108	36	845	79		1					1
IM	Alfa Romeo	146 J 1.4 Twin Sp.	P	E2	1998	1370	76	1160	107		1					1
IM	Fiat	Marea bipower	P	E2	1997	1581	76	1185	10							
IM	Fiat	Punto	P	E2	1997	1242	54	950	7		1					1

Lab.	Make	Model	Petrol / CNG / Diesel	Emis. standard	Year	Capacity (cm^3)	Max. power (kW)	Weight (kg)	Mileage (Mm)	instantaneous emis.	Unreg. pollutants PC	LD: Light Duty Veh.	G: gradient, H: humidity	L: load, T: temperature	A: auxiliaries, M: mileage	cold start
IM	Alfa Romeo	156J TwinSp. 16v	P	E3	2001	1970	121	1335	0		1					1
IM	Alfa Romeo	156	P	E3	2000	1800	106	1265	21		1					1
IM	Lancia	Y Elefantino Rosso	P	E3	2000	1242	59	920	81		1					1
IM	Lancia	Y Elefantino Rosso	P	E3	1999	1242	59	930	15		1					
IM	Volkswagen	Golf	P	E4	2002	1598	77	1259	4							
Inr.	Mercedes-B	190D 2.5l	D	04	1988	2497	66	1175	220		1					1
Inr.	Peugeot	309 GLD	D	04	1990	1905	48	950	212		1					1
Inr.	Fiat	Brava 1.9LD	D	E1	1996	1929	48	1130	114		1					1
Inr.	Ford	Fiesta 1.8L	D	E1	1995	1753	44	925	135		1					1
Inr.	Renault	19 1.9D	D	E1	1995	1870	48	1030	135		1					1
Inr.	Citroen	ZX TD Break	D	E2	1997	1905	66	1150	65		1					1
Inr.	Fiat	Punto TD Cult	D	E2	1999	1698	46	1025	59		1					1
Inr.	Opel	Astra DTI 16V	D	E2	1999	1995	60	1239	70		1					1
Inr.	Peugeot	206D	D	E2	1999	1868	51	1009	0		1					1
Inr.	Peugeot	306 HDI	D	E2	2000	1997	66	1155	11		1					1
Inr.	Peugeot	406 HDI	D	E2	2000	1997	80	1410	26		1					1
Inr.	Renault	Espace 2.2DT	D	E2	2000	2188	83	1630	15		1					1
Inr.	Renault	Mégane 1.9D	D	E2	2000	1870	55	1115	30		1					1
Inr.	Renault	Clio 1.9d	D	E2	1999	1870	47	995	47							
Inr.	Volkswagen	Passat TDI	D	E2	2000	1896	85	1437	74		1					1
Inr.	Volkswagen	Sharan TDI	D	E2	1998	1896	81	1691	110		1					1
Inr.	Peugeot	307 HDI	D	E3	2001	1997	66	1260	24		1					1
Inr.	Renault	Mégane Scénic DCI	D	E3	2001	1870	75	1290	5		1					1
Inr.	Citroen	AX 1.0	P	E1	1995	954	37	706	33		1					1
Inr.	Citroen	ZX 1.4I	P	E1	1996	1361	55	895	103							
Inr.	Hyundai	Pony 5	P	E1	1995	1341	62	930	95		1					1
Inr.	Peugeot	406 SL	P	E1	1995	1762	81	1275	80							
Inr.	Renault	Clio 1.2L	P	E1	1995	1171	43	845	112		1					1
Inr.	Renault	Laguna 1.8 RN	P	E1	1994	1783	69	1225	114							
Inr.	Audi	A4 1.8 Turbo	P	E2	1998	1781	110	1283	24		1					1
Inr.	Ford	Fiesta 1.2	P	E2	2000	1242	55	989	10		1					1
Inr.	Renault	Clio 1.4RXT	P	E2	2000	1390	70	980	24		1					1
Inr.	Renault	Laguna RXE	P	E2	1995	1783	66	1255	62		1					1
Inr.	Renault	Mégane Coupe 1.6	P	E2	2000	1598	79	1060	4							
Inr.	Rover	414I	P	E2	1997	1396	76	1100	51		1					1
Inr.	Volkswagen	Polo 1.4	P	E2	1999	1390	44	967	15		1					1
Inr.	Peugeot	206 XS16S	P	E3	2001	1587	80	1013	3		1					1
Inr.	Peugeot	206XR	P	E3	2001	1124	44	910	17		1					1
Inr.	Renault	Laguna II 1.6 16V	P	E3	2001	1598	79	1270	7		1					1
Inr.	Renault	Scenic 1.6 16S	P	E3	2001	1598	79	1250	4		1					1
KTI	Mazda	E2200	D	E1	1993	2184	44	1335	3			LD				
KTI	Ford	Transit TD	D	E2	1996	2496	74	1845	3			LD				
KTI	Ford	Mondeo 1.8TD Est.	D	E2	1996	1753	65	1345	3		1					1
KTI	Lada	2110 1.5 16V	P	E2	2000	1499	69	1025	3							
KTI	Suzuki	Swift 1.3 GLX	P	E3	2001	1298	50	830	3		1					1

Lab.	Make	Model	Petrol / CNG / Diesel	Emis. standard	Year	Capacity (cm^3)	Max. power (kW)	Weight (kg)	Mileage (Mm)	instantaneous emis.	Unreg. pollutants PC	LD: Light Duty Veh.	G: gradient, H: humidity	L: load, T: temperature	A: auxiliaries, M: mileage	cold start
LAT	Volkswagen	Golf	D	E2	1996	1896	66	1120	95							
LAT	Renault	Laguna	D	E3	2001	1870	79	1310	30							
LAT	Citroen	Xsara	P	E2	1998	1587	67,1	1078	95							
LAT	Opel	Astra	P	E2	1999	1389	66	1180	95							
LAT	Rover	200	P	E2	1998	1396	76,1	1000	50							
LAT	Alfa Romeo	156	P	E3	2003	1598	88	1265	13							
LAT	Daewoo	Kalos	P	E3	2003	1150	53	982	11							
LAT	Daewoo	Lanos	P	E3	2001	1349	55	1030	88						M	
LAT	Daewoo	Matiz	P	E3	2001	796	37,5	835	6						M	
LAT	Fiat	Punto	P	E3	2002	1242	44	875	17							
LAT	Ford	Focus	P	E3	2002	1596	74	1208	6							
LAT	Opel	Corsa	P	E3	2001	1199	66	1073	14							
LAT	Peugeot	206	P	E3	2001	1360	55	1025	25							
LAT	Toyota	Corolla TS	P	E3	2002	1796	143	1232	19							
LAT	Toyota	Yaris	P	E3	2001	1298	64,2	948	23							
TNO	Opel	Omega 2.5 TD	D	E2	1999	2497	96	1650	43							
TNO	Volkswagen	Golf 1.9 TDI	D	E2	1999	1896	81	1306	46							
TNO	BMW	530D TOURING	D	E3	2001	2926	142	1713	17							
TNO	Toyota	Corolla	D	E3	2000	1900	51	1195	11							
TNO	Ford	Mondeo	P	E2	1999	1796	85	1325	10							
TNO	Opel	Omega Y22XE	P	E2	1999	2198	106	1655	22							
TNO	Volkswagen	Lupo 1.0	P	E2	1998	997	37	935	26							
TNO	Alfa Romeo	147 1.6	P	E3	2001	1598	77	1234	19							
TUG	Alfa Romeo	156 Estate	D	E3	2001	1910	81	1355	0	1					A	
TUG	Audi	A2 1.2 TDI	bioD	E3	2001	1191	45	940	25	1			G	L		
TUG	BMW	320D Limous. E46	D	E3	2003	1995	110	1415	0	1						
TUG	Ford	Mondeo T.TDCI 16V	D	E3	2002	1998	96	1505	3	1						
TUG	Nissan	Almera -N15	D	E3	2000	2184	81	1390	53	1			G	L	A	
TUG	Peugeot	307 XS HDI 90 5T	D	E3	2001	1997	66	1280	16	1						
TUG	Volkswagen	Golf 1.9 PD TDI	D	E3	2000	1896	85	1320	18	1						
TUG	Alfa Romeo	147 1.6 TS	P	E3	2001	1598	77	1190	13	1						
TUG	BMW	316I	P	E3	2000	1895	77	1385	0	1			G	L	A	
TUG	Chrysler	PT Cruiser	P	E3	2001	1598	85	1309	8	1						
TUG	Daewoo	Kalos 1.4 SE SOHC	P	E3	2003	1399	61	949	0	1						
TUG	Fiat	Multipla bipower	CNG	E3	2001	1581	76	1490	25	1						
TUG	Hyundai	Tiburon Coupe 2.7	P	E3	2001	2656	123	1370	4	1						
TUG	Mazda	323F 1.3I Evision	P	E3	2003	1324	53	1080	1	1			G	L		
TUG	Saab	95 4D 2,3T Auto	P	E3	2000	2290	136	1485	20	1						
TUG	Audi	A2 1.6 FSI	P	E4	2003	1599	81	995	0	1						
TUG	Opel	Vectra C	P	E4	2003	1796	90	1300	1	1						
TUG	Skoda	Fabia	P	E4	2001	1390	74	1081	12	1						
TUG	Toyota	Yaris 5-T. 1.0 VVTI	P	E4	2003	998	48	940	1	1						
TUG	Volvo	V70 2.4	CNG	E4	2002	2435	103	1606	30	1						
TUG	Volvo	V70 2.4	P	E4	2002	2435	103	1606	30	1						

Lab.	Make	Model	Petrol / CNG / Diesel	Emis. standard	Year	Capacity (cm^3)	Max. power (kW)	Weight (kg)	Mileage (Mm)	instantaneous emis.	Unreg. pollutants PC	LD: Light Duty Veh.	G: gradient, H: humidity	L: load, T: temperature	A: auxiliaries, M: mileage	cold start
VTT	Alfa Romeo	156 2.4 TD	D	E2	1998	2387	100	1425	136		1			T		1
VTT	Audi	A4TDI	D	E2	1996	1896	66	1395	38				H			
VTT	Peugeot	307 Hatc. 2.0 HDI-	D	E2	2001	1997	79	1354	13				H			
VTT	Volkswagen	Passat 1.9TDI Sal.	D	E2	1999	1896	85	1453	93		1			T		1
VTT	Volkswagen	Passat Var. 1.9 TDI	D	E2	1999	1890	66	1461	88							
VTT	Opel	Vectra 2.2DTI Sal.	D	E3	2001	2170	92	1450	3							
VTT	Volkswagen	Polo Classic 1.9 SDI	D	E3	2001	1896	50	1197	3		1			T		1
VTT	Alfa Romeo	147 Hatchback 1.6	P	E2	2001	1598	88	1295	46		1			T		1
VTT	Fiat	Bravo Hatchb. 1.2	P	E2	2000	1241	60	1085	40				H			
VTT	Fiat	Marea 1.6 Weekend	P	E2	1999	1581	76	1275	65		1			T		1
VTT	Ford	Mondeo 2.5	P	E2	1997	2540	125	1445	89							
VTT	Nissan	Almera Hatchb. 1.8	P	E2	2000	1760	84	1300	26							
VTT	Opel	Astra Caravan 1.6	P	E2	2001	1598	62	1235	13		1			T		1
VTT	Opel	Corsa 1.2	P	E2	1999	1190	48	950	41							
VTT	Peugeot	306 1.6l Break 5D	P	E2	2000	1587	65	1195	23		1			T		1
VTT	Peugeot	406 2.0l 4D Saloon	P	E2	1997	1998	97,4	1430	30				H			
VTT	Saab	95 Estate 2.0	P	E2	2001	1985	110	1680	17		1			T		1
VTT	Toyota	Avensis 1.6	P	E2	1999	1598	81	1270	66				H			
VTT	Volkswagen	Golf 1.6 4D Auto	P	E2	1999	1595	74	1295	23				H			
VTT	Volkswagen	Golf Variant 1.6 5D	P	E2	2000	1598	77	1396	30		1			T		1
VTT	Volkswagen	Polo Variant 1.4	P	E2	1998	1390	44	1105	23							
VTT	Volvo	S60 Saloon 2.4	P	E2	2001	2435	103	1548	59		1			T		1
VTT	Citroen	C5 Break 2.0l	P	E3	2002	1997	100	1442	7				H			
VTT	Honda	CIVIC Hatch. 1.6 4D	P	E3	2001	1590	81	1210	21				H			
VTT	Peugeot	307 Hatch. 1.6 l 4D	P	E3	2001	1587	80	1268	19				H			
VTT	Renault	Clio Hatchback 1.2	P	E3	2002	1149	43	955	2		1		H	T		1
VTT	Renault	Mégane Br. 1.4 16V	P	E3	2002	1390	70	1210	5				H			
VTT	Skoda	Octavia Hatchb. 2.0	P	E4	2002	1984	85	1310	2		1			T		1
VTT	Toyota	Corolla Saloon 1.4	P	E4	2002	1398	71	1185	3		1			T		1

Annex 5: Characteristics of the driving cycles used

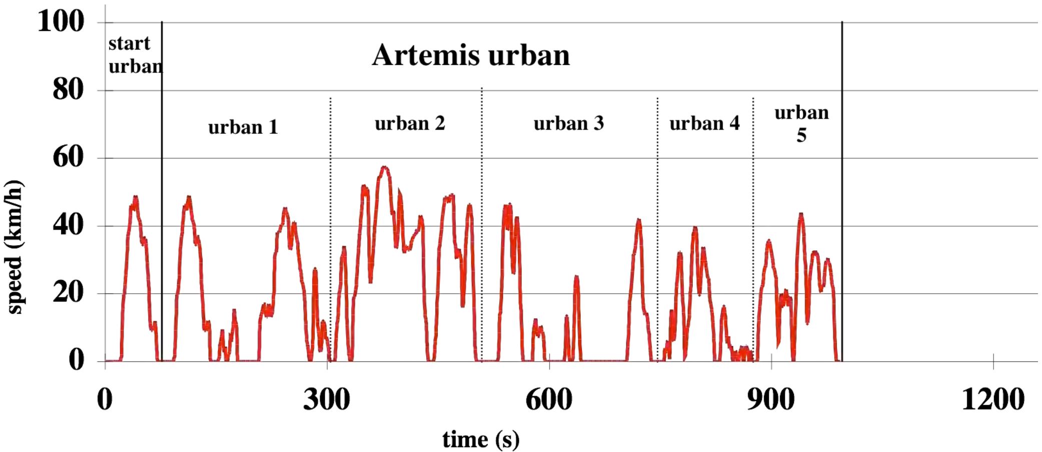
Cycles in italics and yellow are summation of cycles.

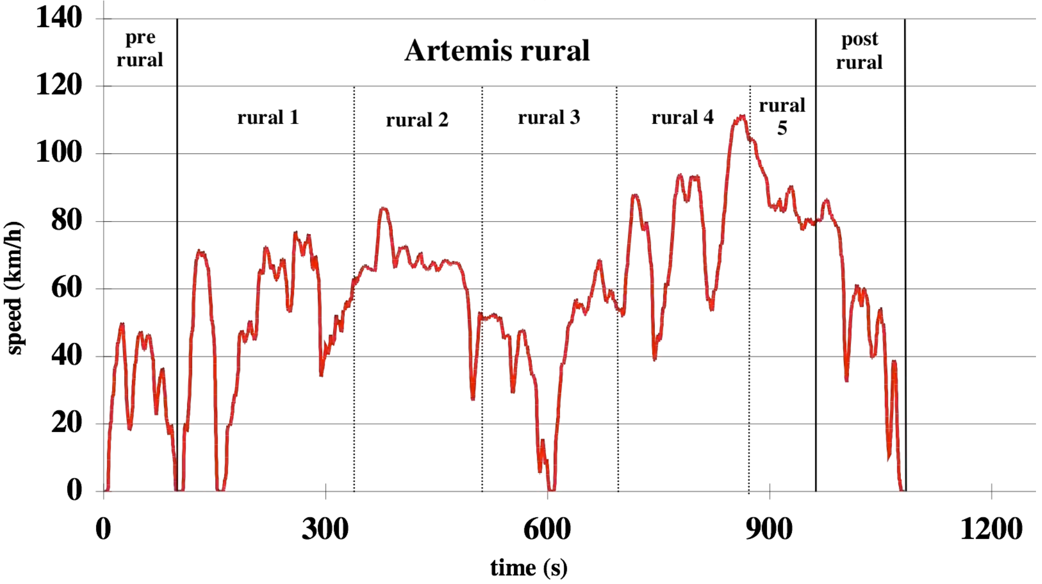
Driving cycle family	Cycle name (within the family)	Distance (km)	Duration (s)	Aver. speed (km/h)	Max. speed (km/h)	St. dev. accel. (m/s^2)	Max. accel. (m/s^2)
Artemis	urban	4.472	921	17.48	57.70	0.79	2.86
	rural	14.724	862	61.49	111.50	0.58	2.36
	motorway 130	23.793	736	116.38	131.80	0.39	1.28
	motorway	24.602	736	120.34	150.40	0.39	1.28
EMPA	BAB 1000	32.646	1000	117.53	160.85	0.15	0.32
Handbook	R4 = LE6+StGoAB+StGoIO	6.117	1340	16.43	60.90	0.40	1.39
	R3 = LE2u+LE3+LE5	14.140	1080	47.13	79.20	0.46	1.86
	R2 = A4+LE1+LE2s	22.342	1080	74.47	105.90	0.27	1.00
	R1 = AE1+AE2+AE3	41.157	1341	110.49	131.10	0.20	0.78
Inrets	urbain fluide court	0.985	189	18.76	44.00	0.81	
	route court	1.439	126	41.11	74.90	0.90	
legislative	ECE 15 (*or* UDC)	4.052	780	18.70	50.00	0.47	1.06
	EUDC	6.955	400	62.60	120.00	0.38	0.83
	NEDC = UDC + EUDC	*11.007*	*1180*	*33.58*	*120.00*	*0.44*	*1.06*
	US FTP 75 1st (*or* 3rd) part	5.779	505	41.20	91.20	0.65	1.50
	US FTP 75 2nd part	6.263	867	26.01	55.20	0.61	1.50
modem	urban 5+7+13	9.193	1426	23.21	82.40	0.86	3.08
modem Hyzem	pure road	10.682	743	51.75	103.40	0.75	2.42
Napoli	10-23	3.362	1081	11.20	49.96	0.52	1.90
	15-18-21	4.467	1070	15.03	52.00	0.57	1.80
	6-17	16.469	1038	57.12	105.51	0.54	2.09
PVU commerciale	grand routier	18.755	828	81.54	128.60	0.61	2.14
PVU fourgon 3.5 t (*or* LDV PVU 3.5 tons vans)	urbain lent (*or* slow urban) [a]	2.190	649	12.15	57.90	0.71	2.53
	urbain fluide (*or* free-flow urban)	2.893	467	22.30	52.50	0.73	2.17
	livraison (*or* delivery)	1.592	546	10.50	32.30	0.48	1.44
	route (*or* rural) [a]	9.646	544	63.83	86.20	0.37	0.97
	autoroute (*or* motorway) [a]	30.736	1226	90.25	130.40	0.43	1.44
TUG	Ries Road Gradient [b]	6.842	510	48.30	87.60	0.47	1.44
VP faible motorisation (*or* Artemis low motorisation)	urbain dense (*or* urban dense)	2.935	711	14.86	55.20	0.67	2.44
	urbain (*or* urban)	4.799	945	18.28	55.70	0.68	2.50
	urbain fluide (*or* free urban)	4.818	710	24.43	56.70	0.73	3.19
	route (*or* rural)	13.149	821	57.66	111.50	0.57	2.19
	autoroute (*or* motorway)	24.090	729	118.97	150.70	0.39	1.28
VP forte motorisation (*or* Artemis high motorisation)	urbain dense (*or* urban dense)	2.907	730	14.34	57.60	0.64	2.67
	urbain (*or* urban)	4.924	918	19.31	57.60	0.71	2.39
	urbain fluide (*or* free urban)	4.780	710	24.23	61.30	0.76	2.14
	route (*or* rural)	14.224	844	60.67	110.50	0.60	2.14
	autoroute (*or* motorway)	25.377	750	121.81	157.10	0.37	2.00

[a] slope: 10 or 50 % of full load

[b] average slope: 3 %, maximal slope: 14 %

Annex 6: Driving cycles used





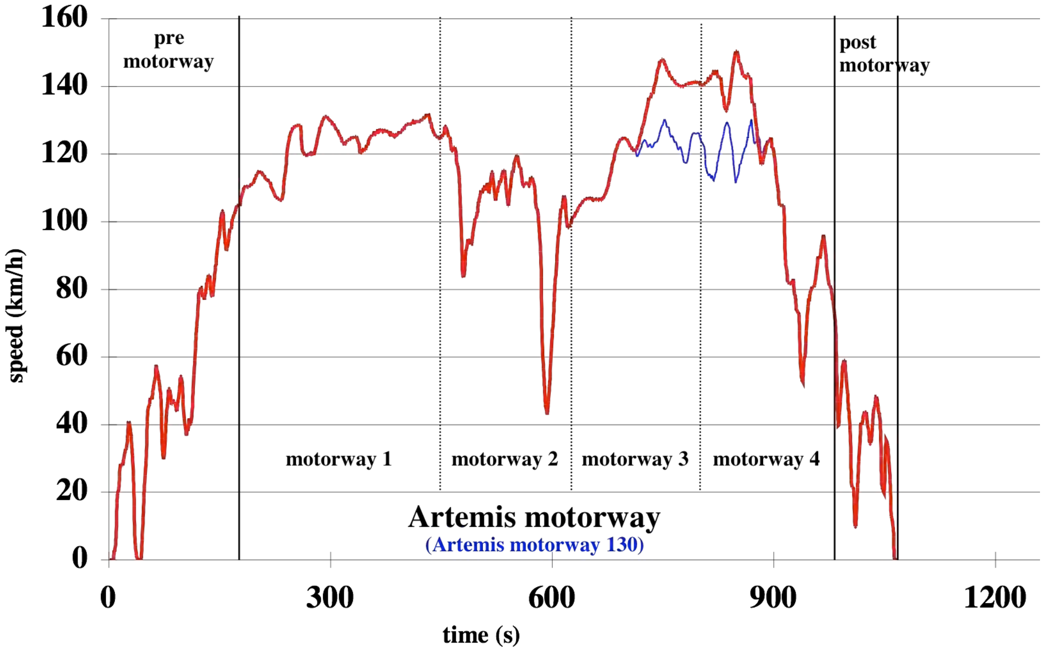


Figure 47: Shape of the driving cycles Artemis urban, rural and motorway (and motorway 130).

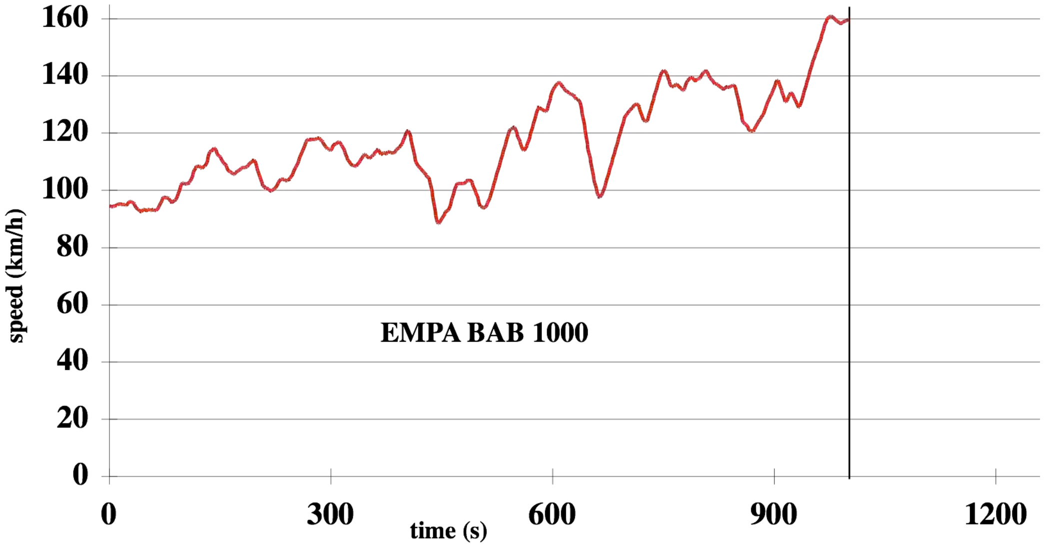
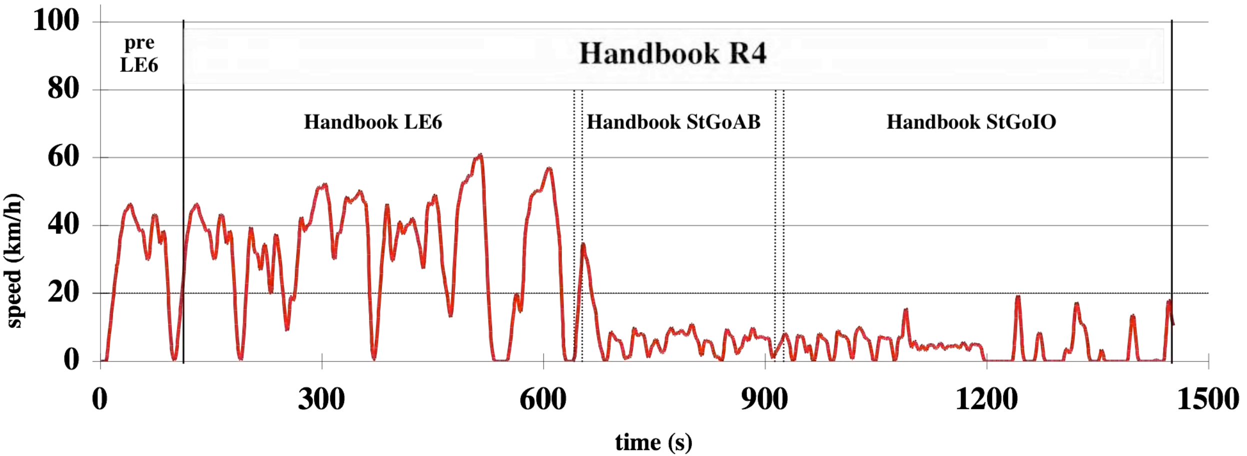
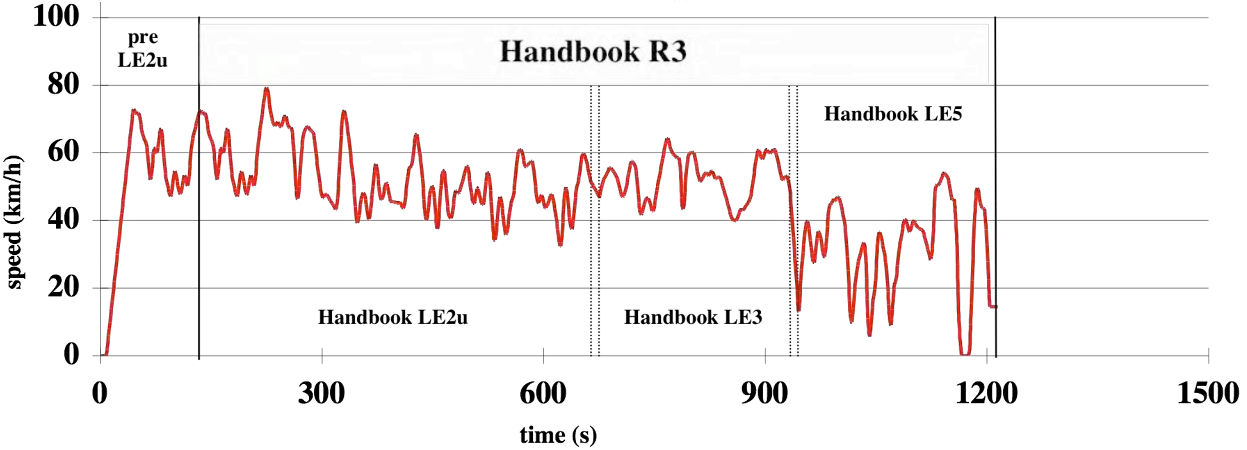
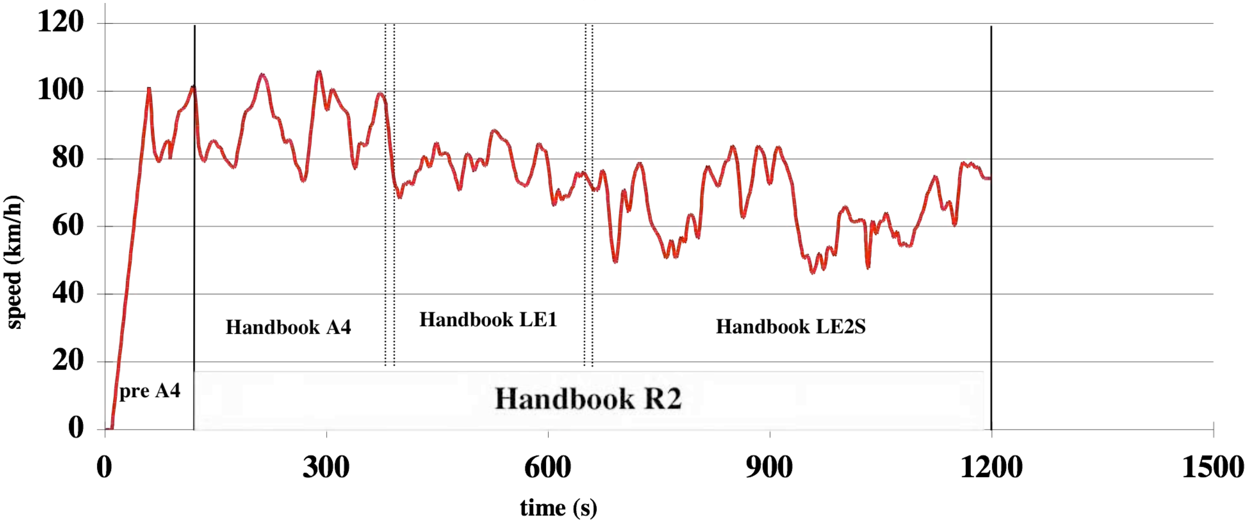


Figure 48: Shape of the driving cycle EMPA BAB 1000.


100
80
60
40
20
0
speed (km/h)
pre LE6
Handbook R4
Handbook LE6
Handbook StGoAB
Handbook StGoIO
0
300
600
900
1200
1500
time (s)


100
80
60
40
20
0
speed (km/h)
pre LE2u
Handbook R3
Handbook LE5
Handbook LE2u
Handbook LE3
0
300
600
900
1200
1500
time (s)


120
100
80
60
40
20
0
speed (km/h)
Handbook A4
Handbook LE1
Handbook LE2S
pre A4
Handbook R2
0
300
600
900
1200
1500
time (s)

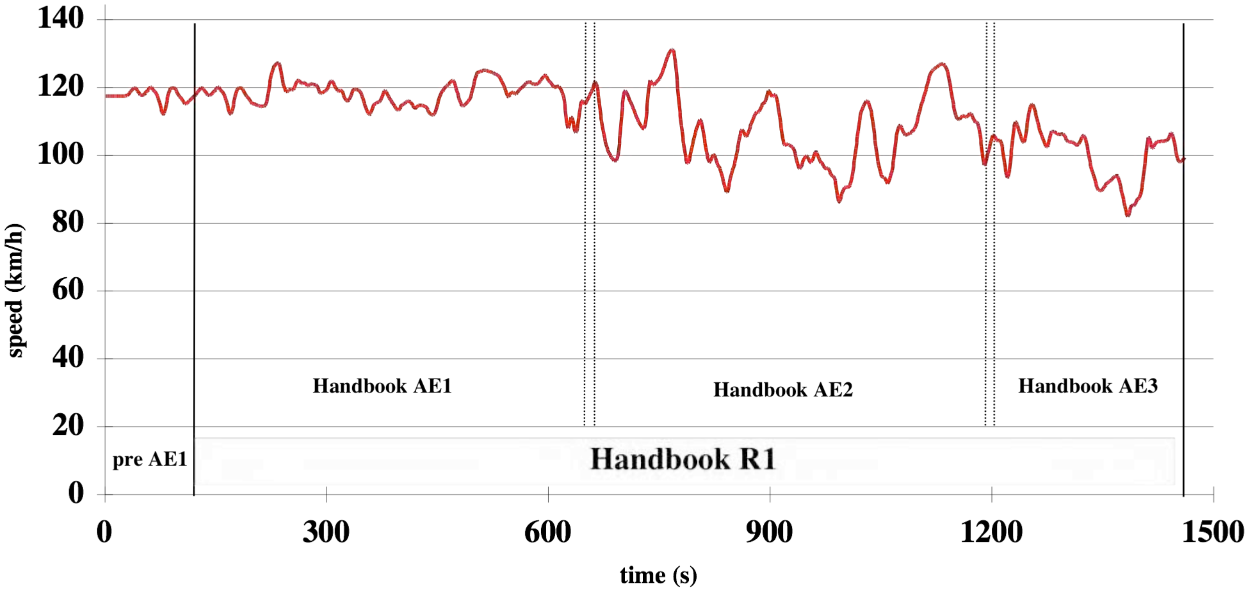


Figure 49: Shape of the driving cycles Handbook R1, R2, R3, and R4.

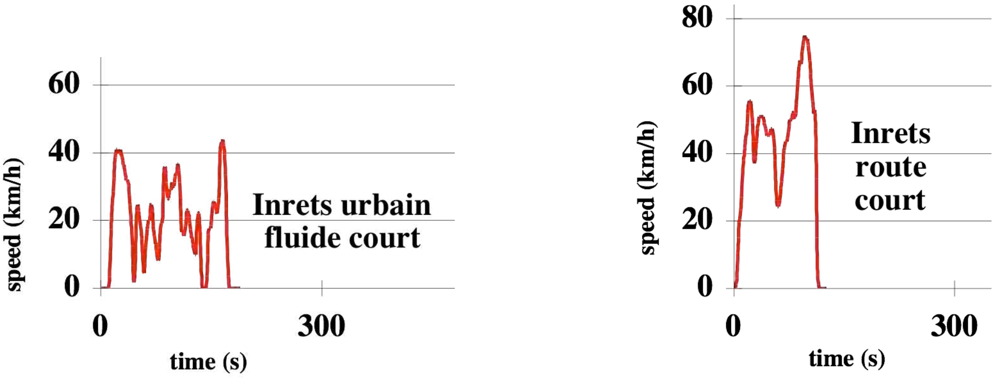


Figure 50: Shape of the driving cycles Inrets fluide court and Inrets route court.

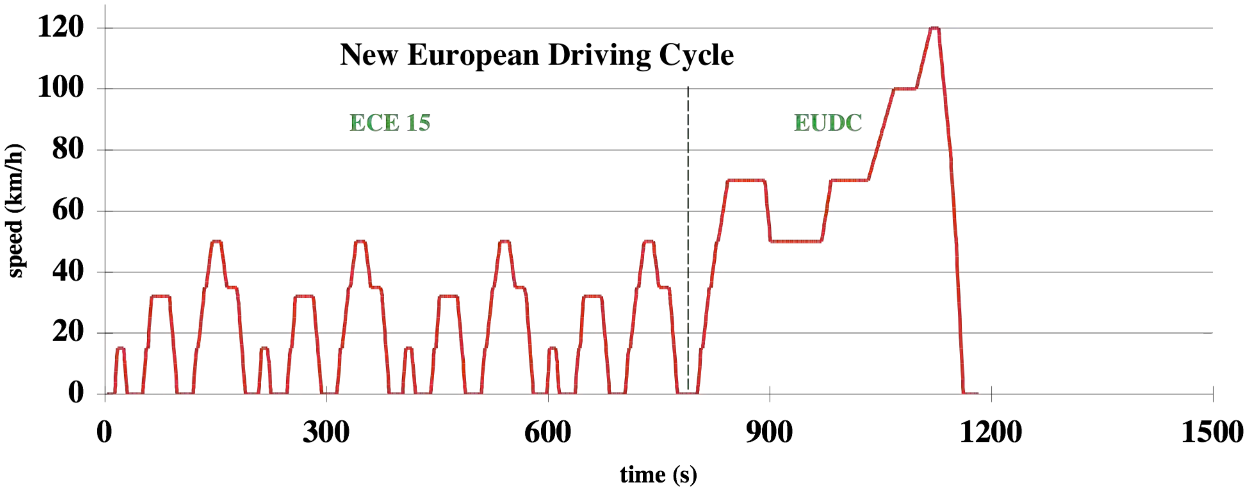


Figure 51: Shape of the legislative driving cycle NEDC (ECE 15 + EUDC).

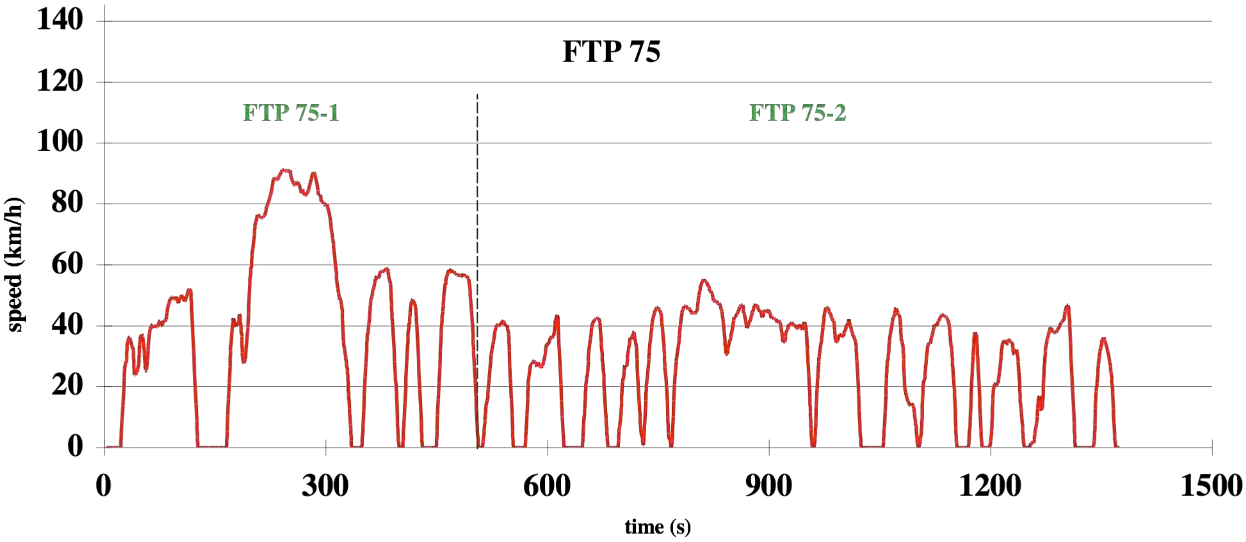


Figure 52: Shape of the legislative driving cycle FTP 75.

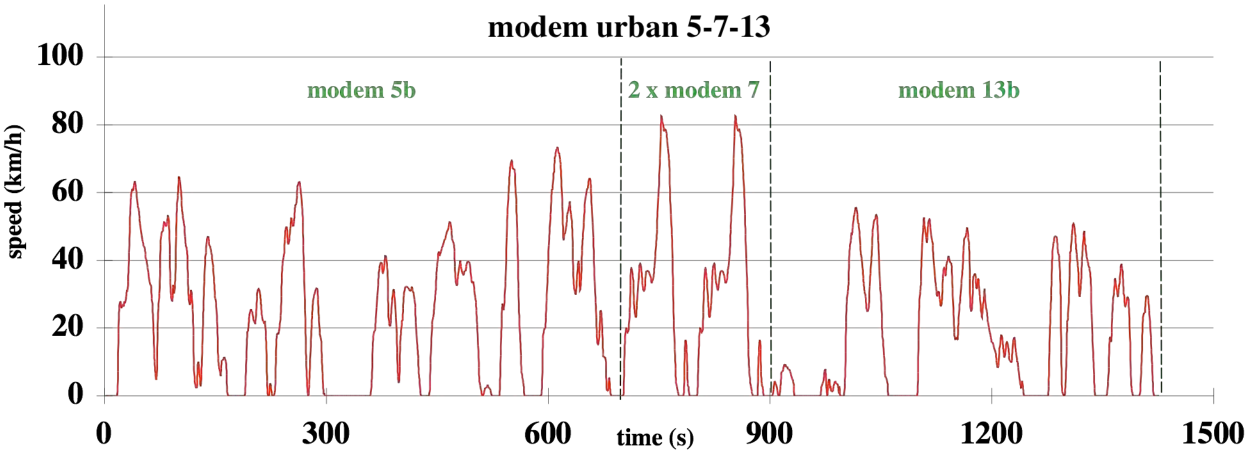


Figure 53: Shape of the driving cycle modem urban 5+7+13.

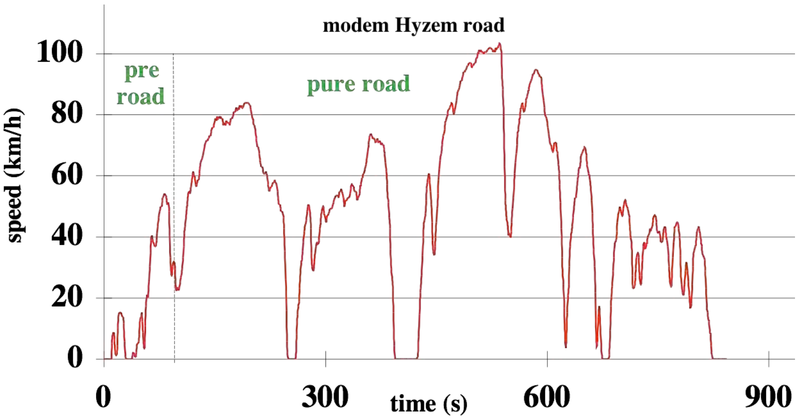


Figure 54: Shape of the driving cycle modem Hyzem pure road.

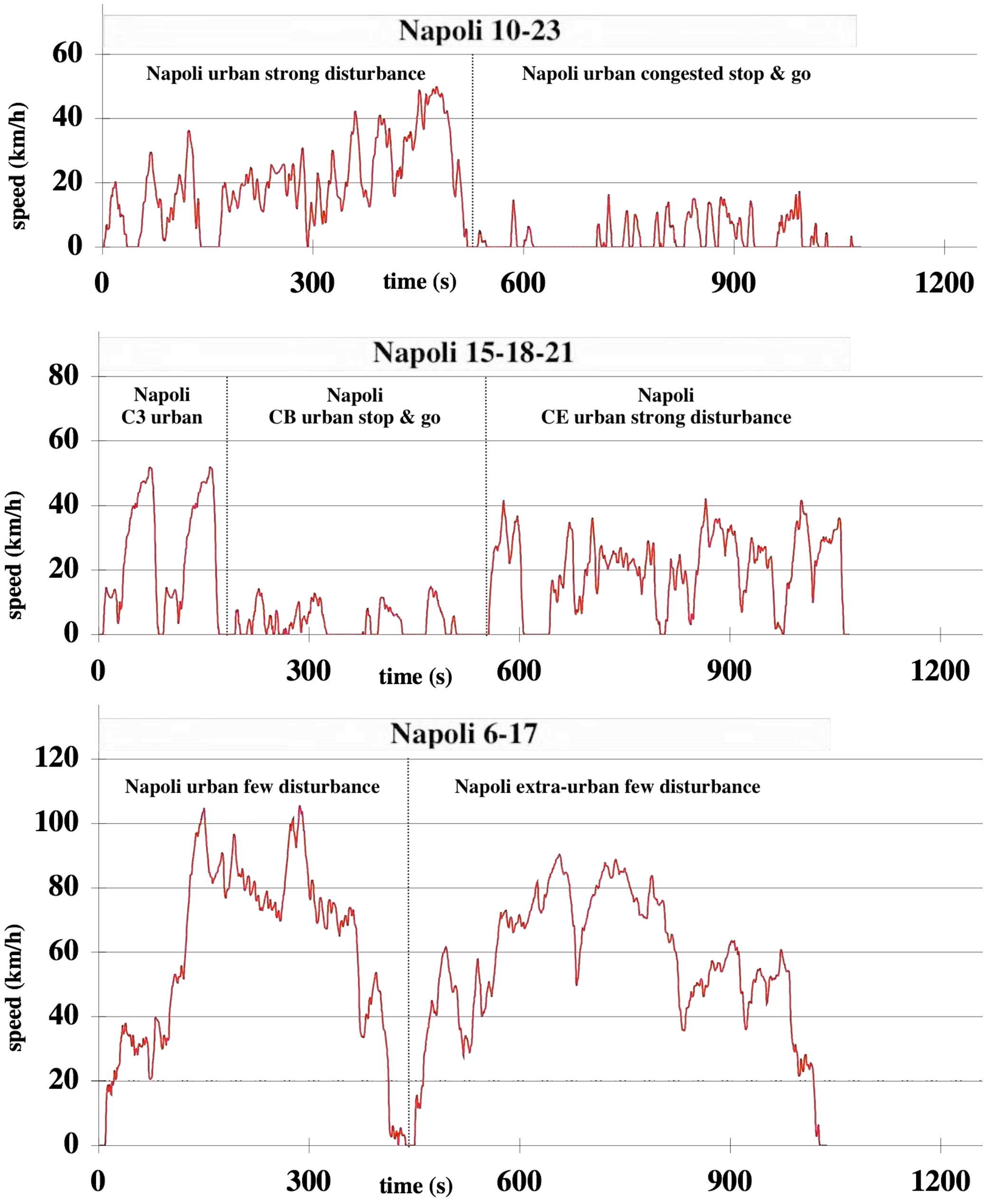


Figure 55: Shape of the driving cycles Napoli 10-23, 15-18-21, and 6-17.

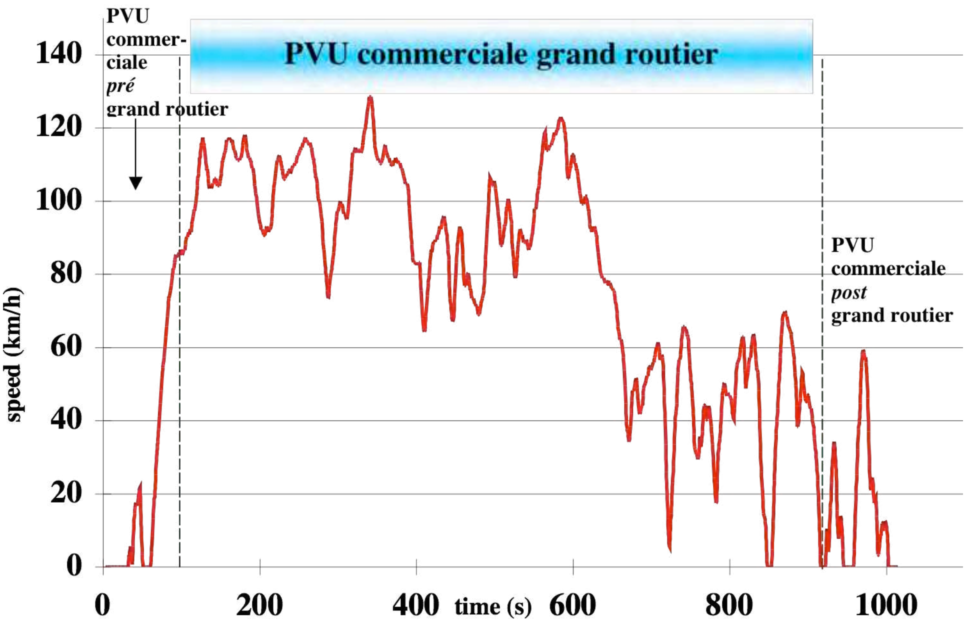
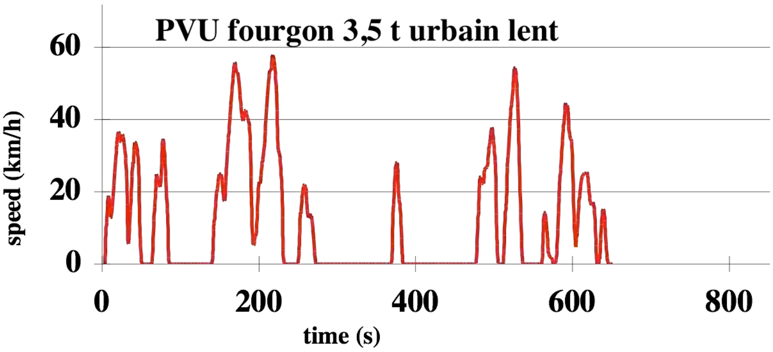
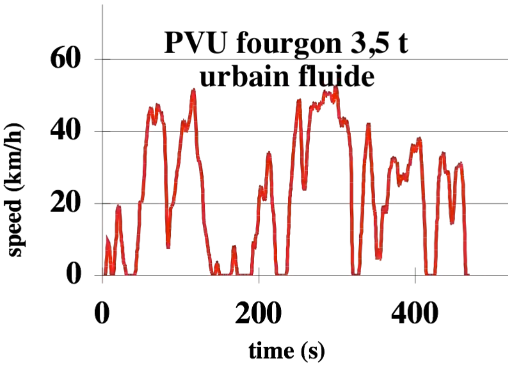
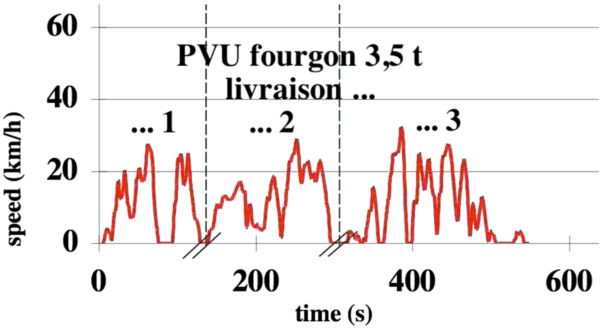


Figure 56: Shape of the driving cycle PVU commerciale grand routier (or LDV commercial cars motorway).







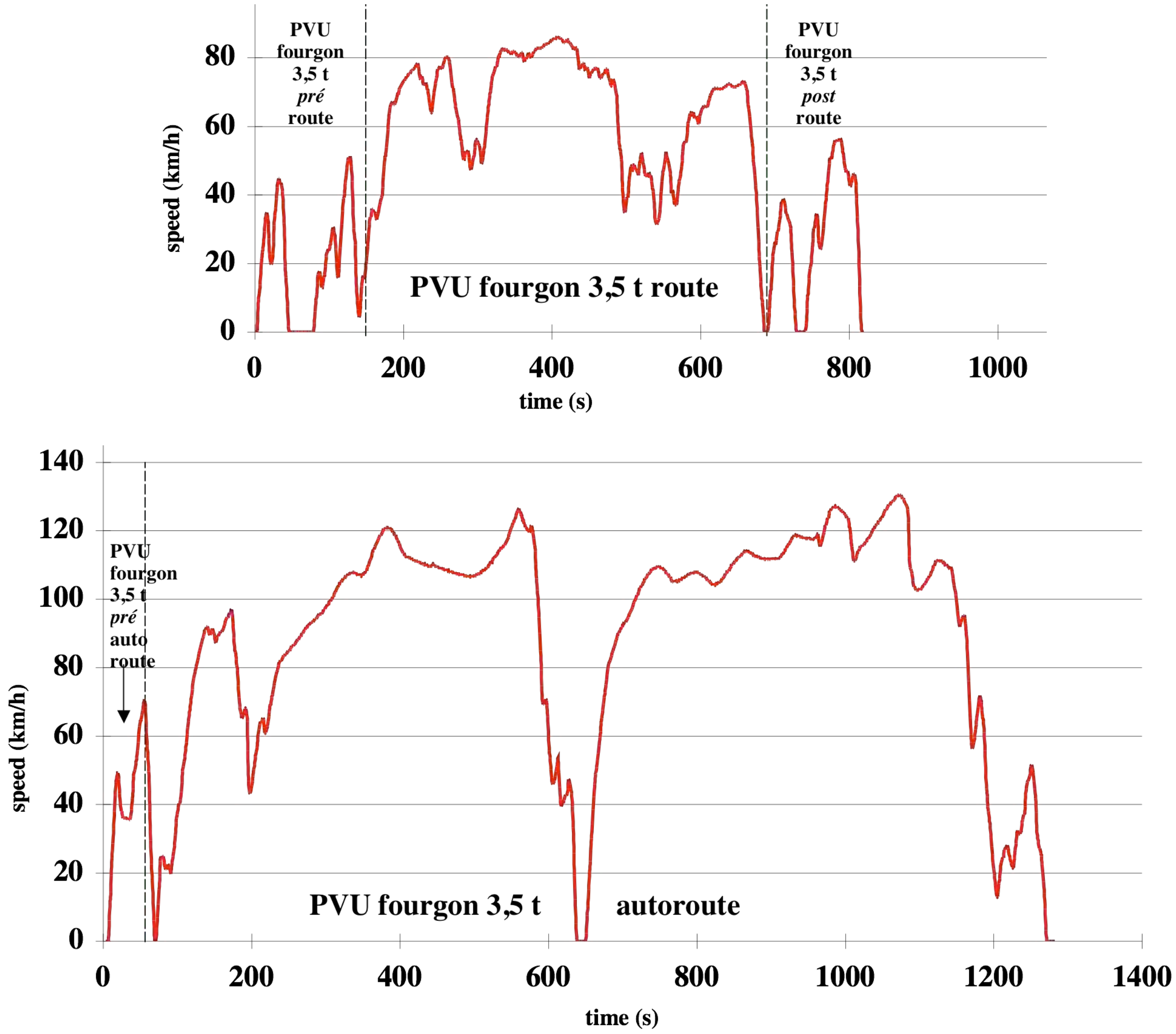


Figure 57: *Shape of the driving cycles PVU fourgon 3.5 t urbain lent, urbain fluide, livraison, route, and autoroute (or LDV 3.5 tons van slow urban, free-flow urban, delivery, rural, and motorway).*

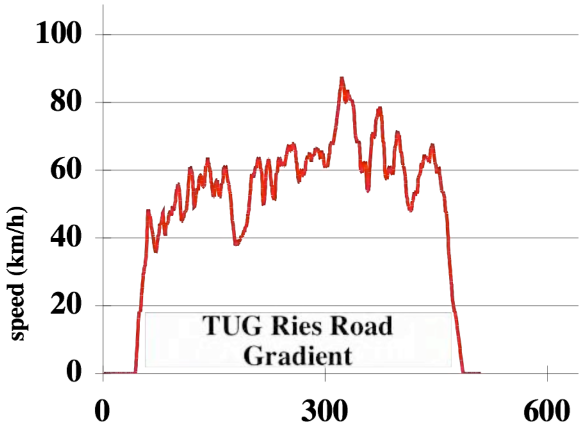
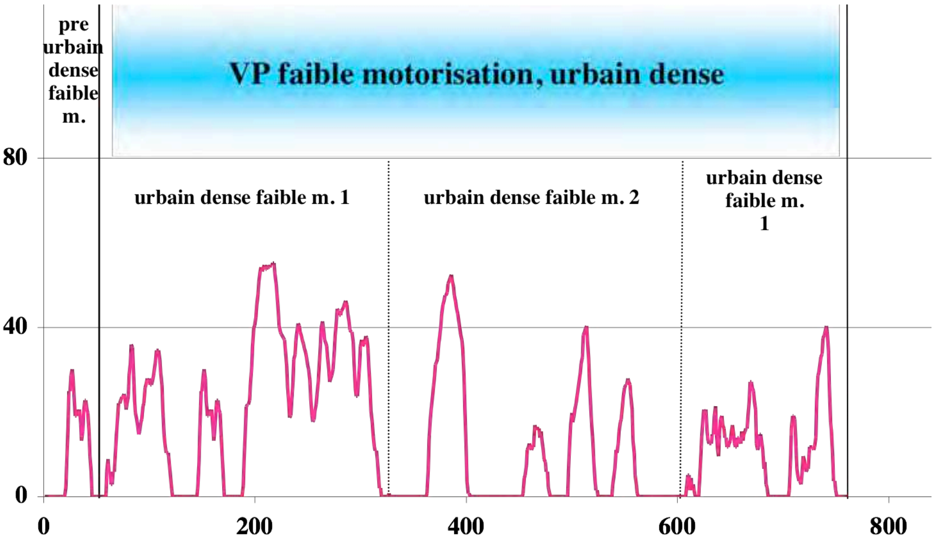
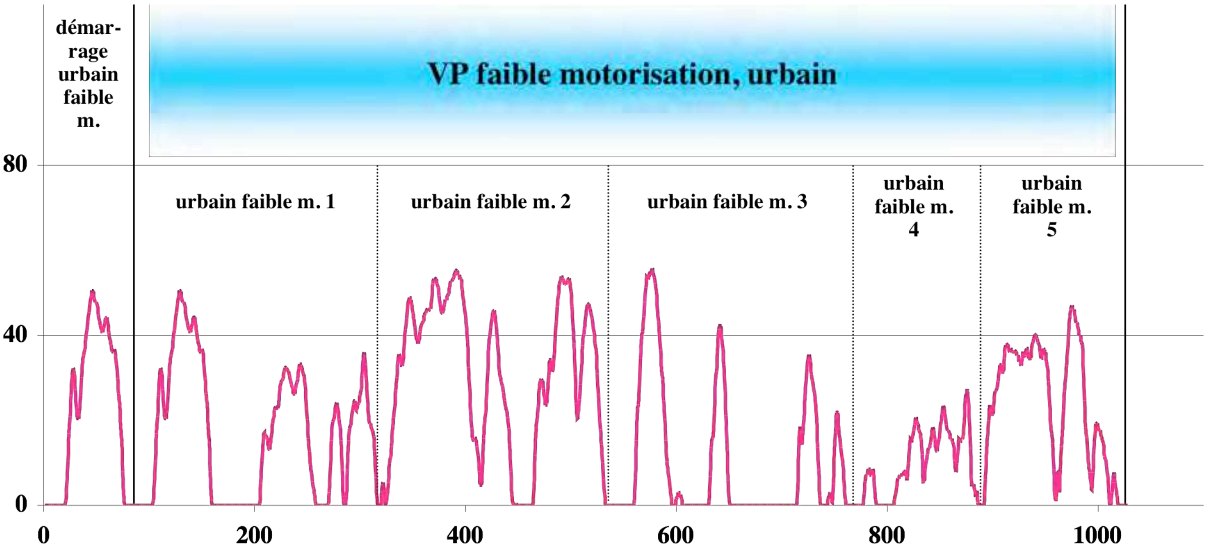
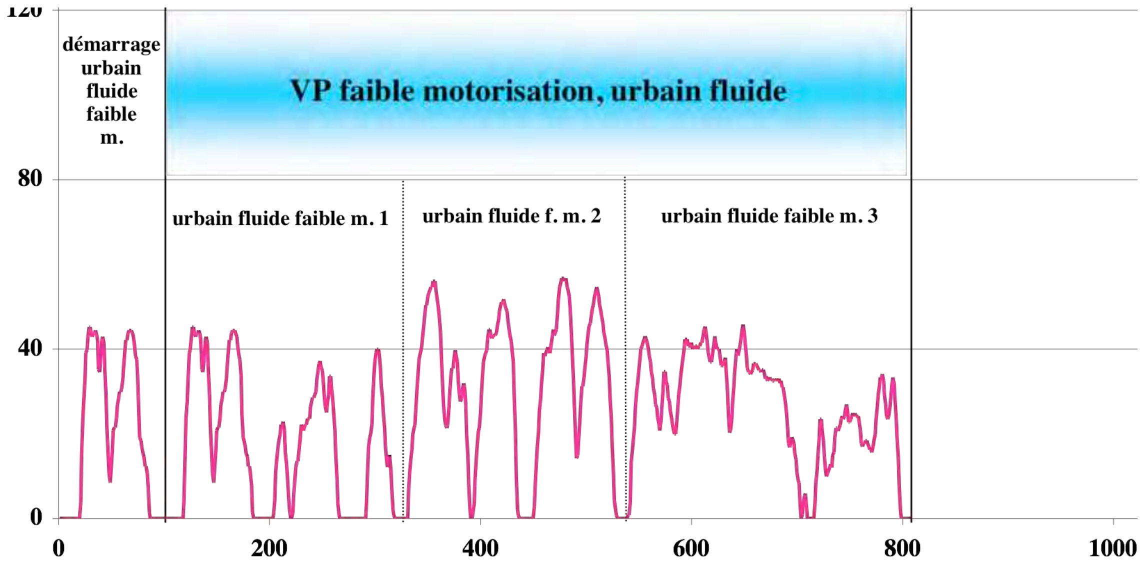
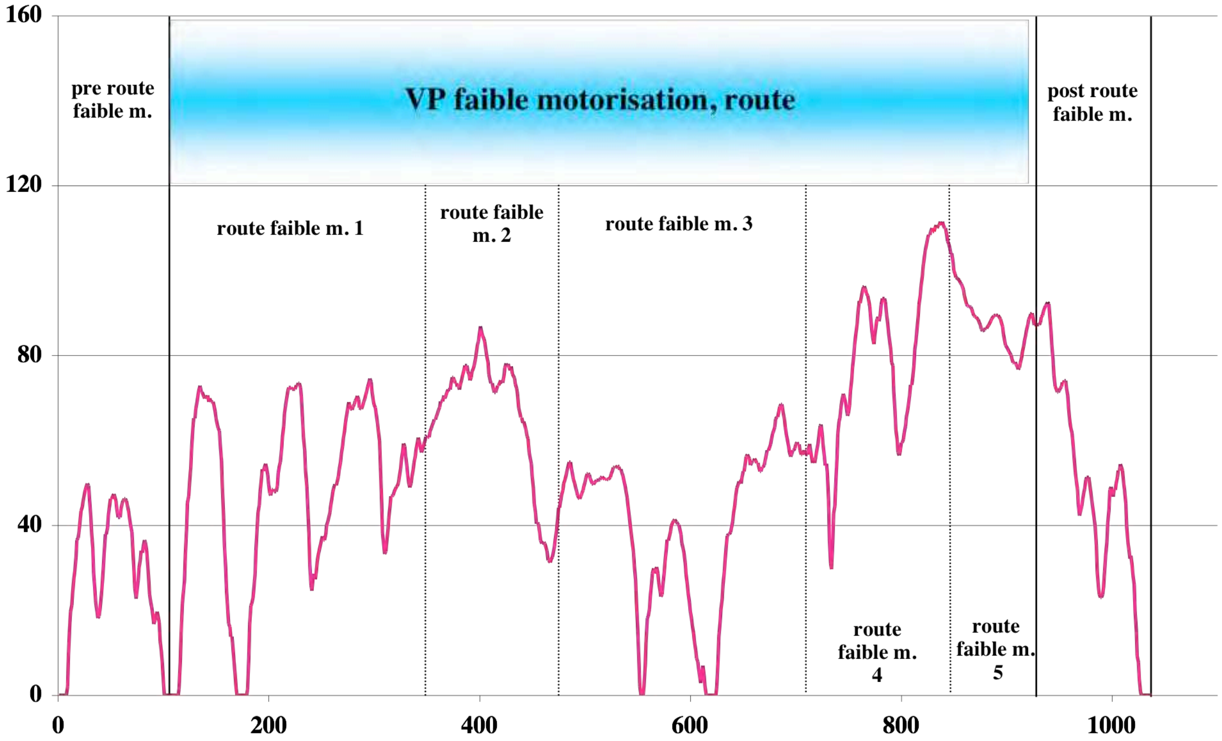


Figure 58: *Shape of the driving cycle TUG Ries Road Gradient used for determining the influence of the slope.*


pre urbain dense faible m.
VP faible motorisation, urbain dense
urbain dense faible m. 1
urbain dense faible m. 2
urbain dense faible m. 1
80
40
0
0
200
400
600
800


démar-rage urbain faible m.
VP faible motorisation, urbain
urbain faible m. 1
urbain faible m. 2
urbain faible m. 3
urbain faible m. 4
urbain faible m. 5
80
40
0
0
200
400
600
800
1000


120
démarrage urbain fluide faible m.
VP faible motorisation, urbain fluide
urbain fluide faible m. 1
urbain fluide f. m. 2
urbain fluide faible m. 3
80
40
0
0
200
400
600
800
1000



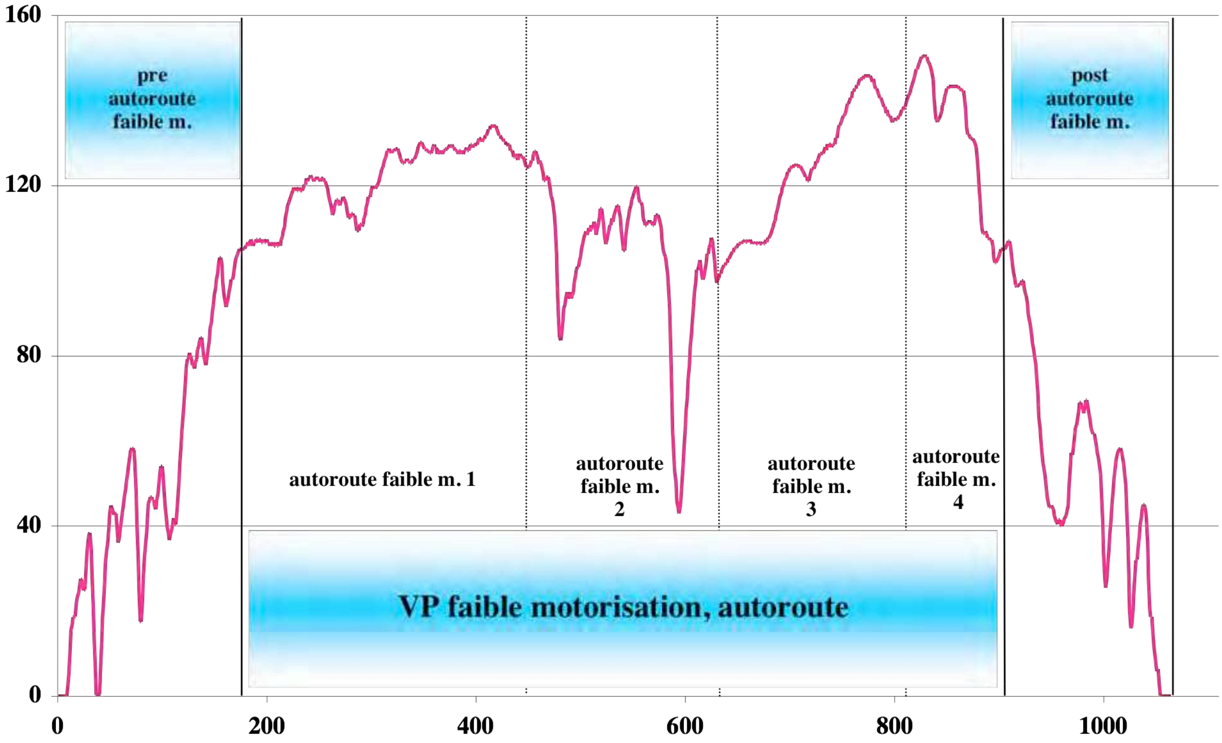
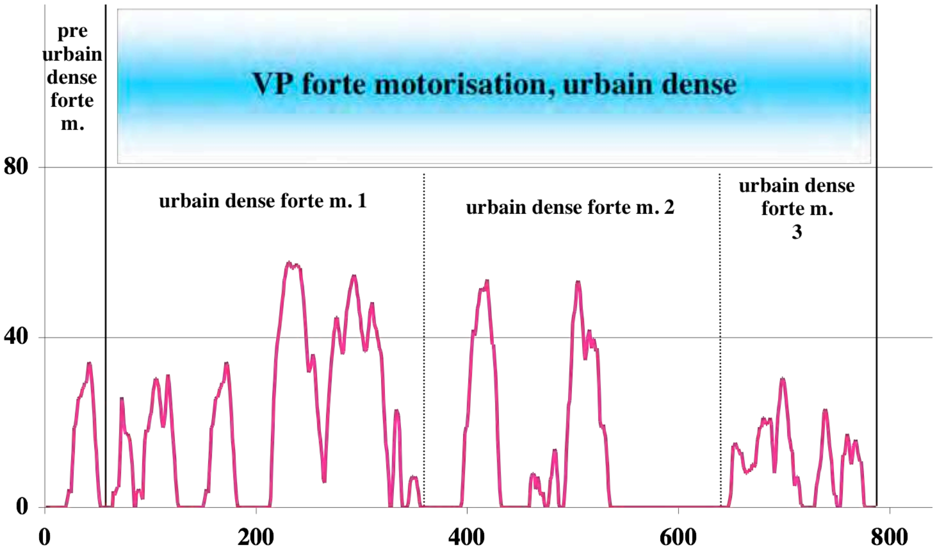
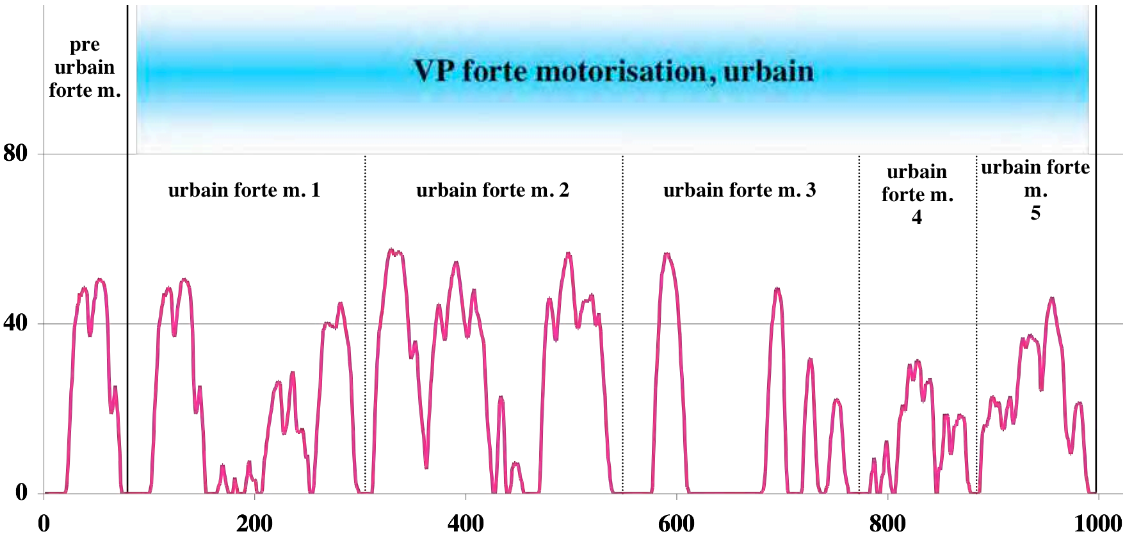
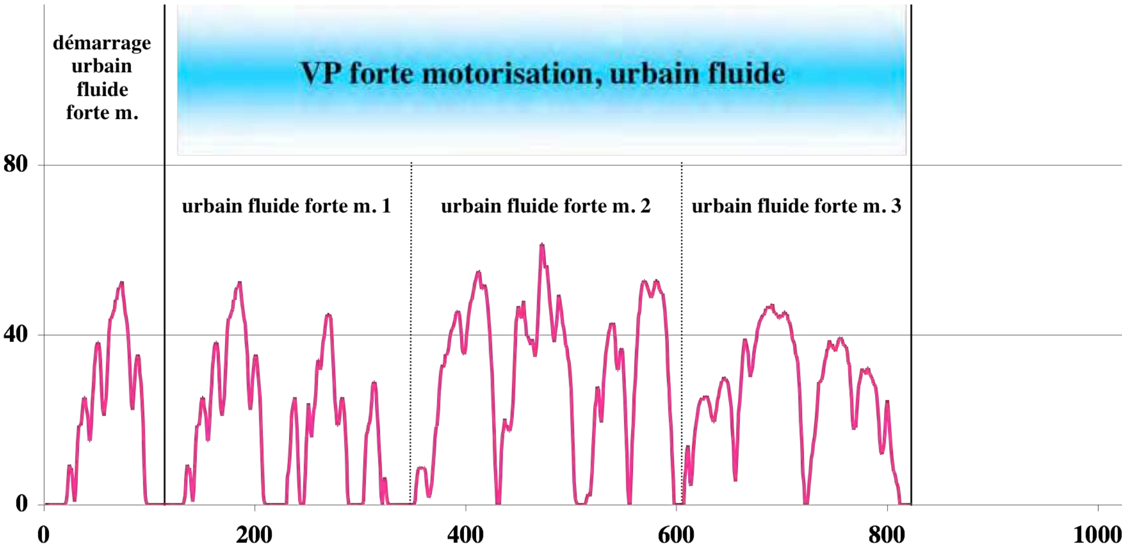
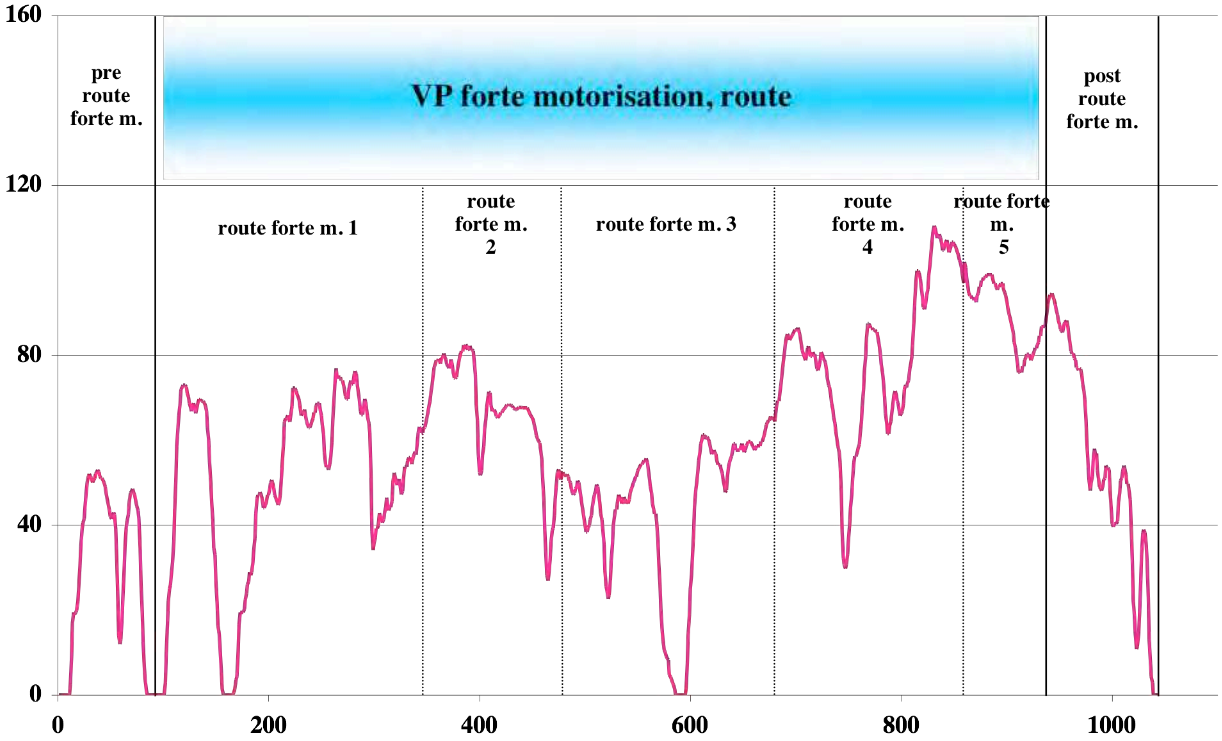


Figure 59: Shape of the driving cycle VP faible motorisation urbain dense, urbain, urbain fluide, route, and autoroute (or Artemis low motorisation urban dense, urban, free urban, rural, and motorway).


VP forte motorisation, urbain dense
pre urbain dense forte m.
urbain dense forte m. 1
urbain dense forte m. 2
urbain dense forte m. 3
80
40
0
0
200
400
600
800


VP forte motorisation, urbain
pre urbain forte m.
urbain forte m. 1
urbain forte m. 2
urbain forte m. 3
urbain forte m. 4
urbain forte m. 5
80
40
0
0
200
400
600
800
1000


VP forte motorisation, urbain fluide
démarrage urbain fluide forte m.
urbain fluide forte m. 1
urbain fluide forte m. 2
urbain fluide forte m. 3
80
40
0
0
200
400
600
800
1000



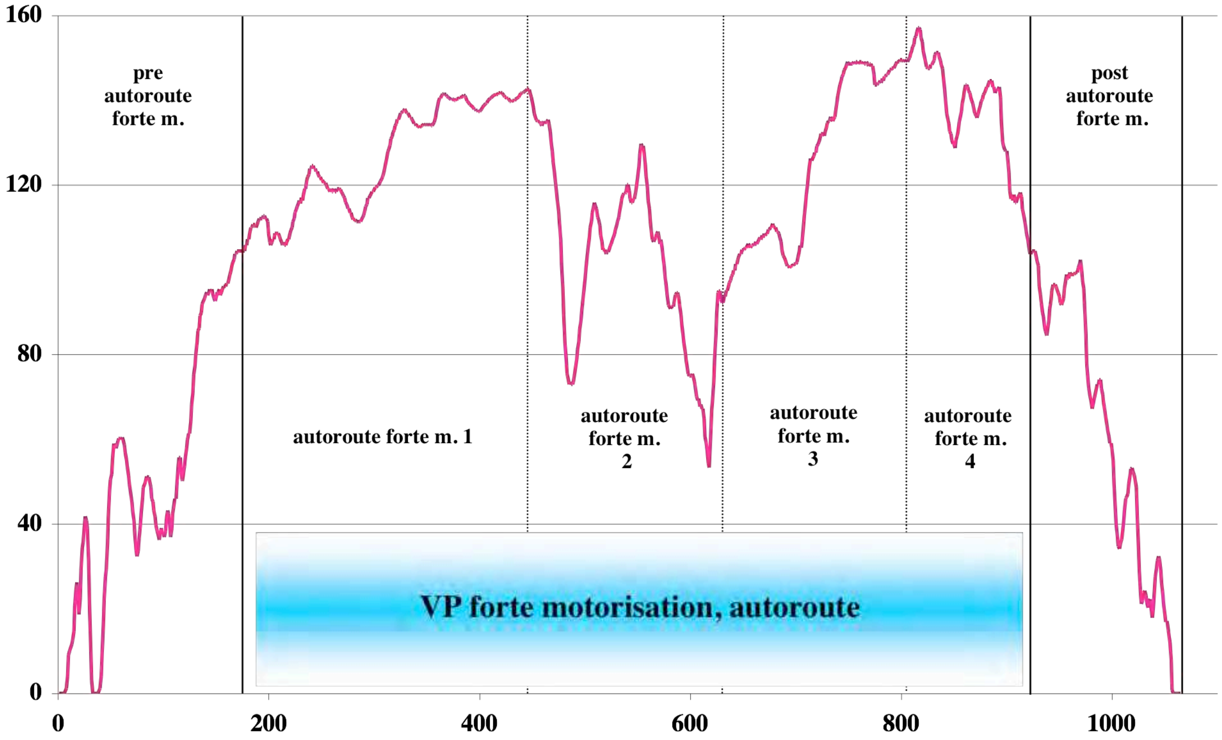
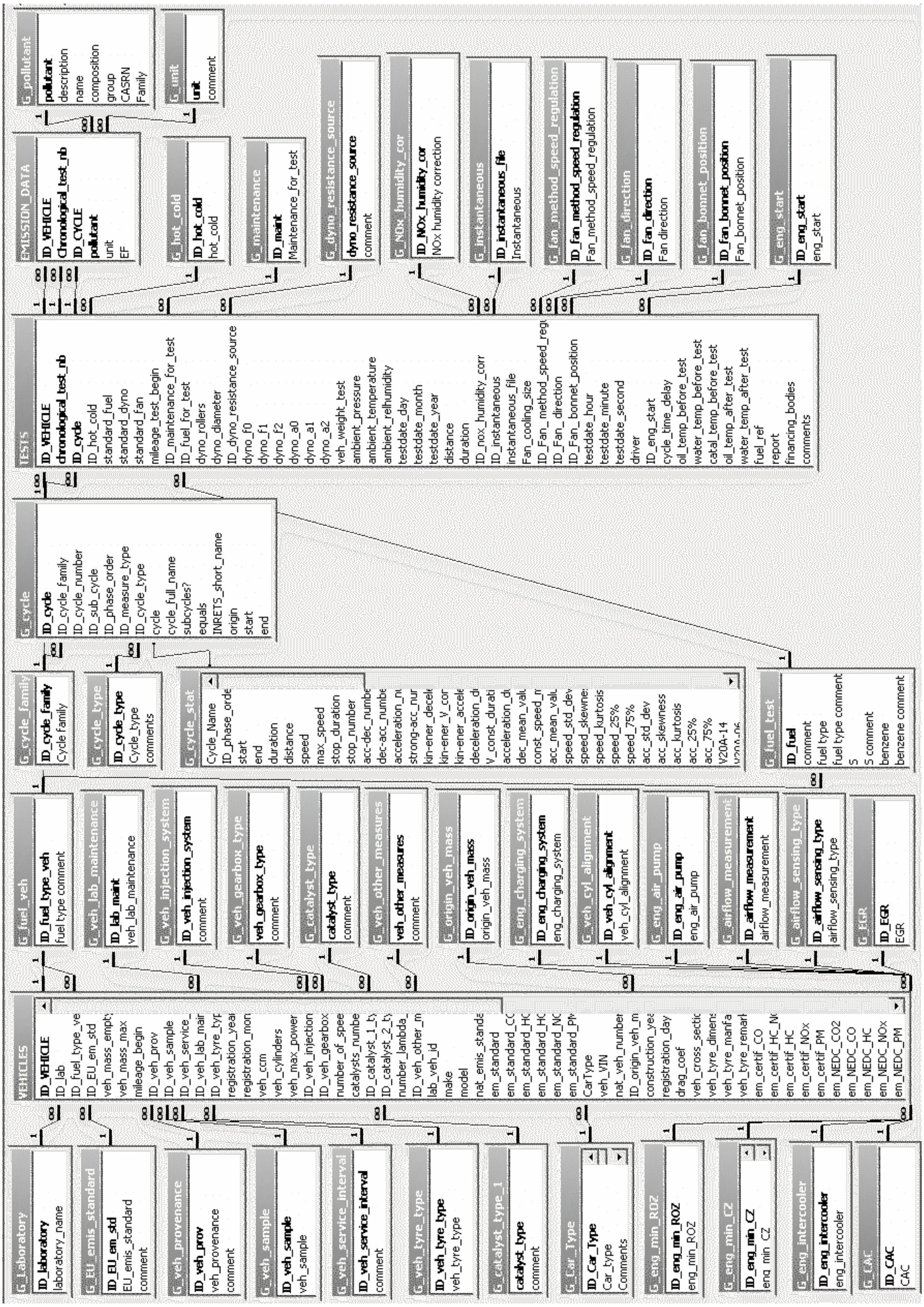


Figure 60: Shape of the driving cycle VP forte motorisation urbain dense, urbain, urbain fluide, route, and autoroute (or Artemis high motorisation urban dense, urban, free urban, rural, and motorway).

Annex 7: Design of the Artemis LVEM database



Annex 8: Artemis LVEM datasheet description

The Artemis LVEM datasheet provides the format that should be used when submitting data for the Artemis LVEM database. For every car involved, a separate copy of this Excel file should be used. Dark grey or red cells denote cells that need to be filled. A light grey background marks cells which can be filled optionally. The Artemis LVEM datasheet contains five sheets:

- *README*: provides additional information and help on how to use the datasheet.
- *car*: summarises the characteristics of the tested vehicle. The sheet is divided into eight sections:
  - laboratory name
  - vehicle data (e.g., make, model, fuel type)
  - official emission level data
  - chassis dynamometer and fan settings
  - engine data (e.g., capacity, number of cylinders)
  - gear box data (e.g., type, number of speeds)
  - aftertreatment system (information on catalysts)
  - emission units (for regulated and unregulated pollutants)
- *test xx*: describes the test characteristics of the tested car. One copy of this sheet is needed for each cycle tested. The sheet is divided into nine sections:
  - lab and car identification (linked to *car* sheet except for sulphur and benzene content)
  - chassis dynamometer (linked to *car* sheet, exceptions of *test xx* need to be entered manually)
  - ambient conditions (ambient pressure ,temperature and humidity)
  - fan (linked to *car* sheet, exceptions of *test xx* need to be entered manually)
  - test data (e.g., test number, test date)
  - test results (e.g., actual distance and duration, bag values. Add a row for each pollutant.)
  - drift measurements
  - instantaneous data (file format, content of the file)
  - additional questions (space for further comments)
- *instantaneous data test xx*: contains instantaneous data as a function of time. The use of this sheet for instantaneous data is recommended but not compulsory.
- *pollutant names*: lists the name convention for unregulated pollutants.

Annex 9: Atmospheric exhaust pollutants according to their toxicity

List of atmospheric pollutants emitted by exhaust pipes (Cassadou et al., 2004), with their classification of the Academy of sciences (CAS) from http://chemfinder.cambridgesoft.com/. On the left columns the main and secondary level pollutants are indicated, together with the PAH belonging to the groups of the 6 most carcinogenic, 12 least volatile, and 4 most volatile PAHs. All these pollutants are in a green line.

level of interest		**PAH group**			**NAME**	**Formulae**	**CAS**
1	**2**	**6**	**12**	**4**			
					Carbon oxides		(2 compounds)
					Carbon monoxide	CO	630-08-0
					Carbon dioxide	CO2	37210-16-5
					Nitrogen oxides		(7 compounds)
					Nitrogen monoxide	NO	10102-43-9
1					Nitrogen dioxide [2]	NO2	10102-44-0
					monoxyde de diazote	N2O	10024-97-2
					peroxyde d'azote	N2O4	10544-72-6
					acide nitrique [2]	HNO3	7697-37-2
					acide nitreux[2]	HNO2	7782-77-6
					nitrate de peroxyacyle [2]	$C_{15}H_{11}N_3O$	85-85-8
					Ammonia		(1 compound)
						NH3	7664-41-7
					Sulfur oxides		(5 compounds)
1					Sulfur dioxide	SO2	7446-09-5
					Sulfur trioxide [2]	SO3	7446-11-9
					acide sulfurique [2]	H2SO4	7664-93-9
					sulfate d'ammonium acide [2]	NH4HSO4	7803-63-6
					sulfate d'ammonium neutre [2]	(NH4)2SO4	7783-20-2
					Particles		(4 compounds)
1					PTS		
1					PM10		
1					PM2,5		
1					PM0,1		
					VOC - Alkanes		(64 compounds)

	methane	CH_4	74-82-8
	ethane	C_2H_6	74-84-0
	propane	C_3H_8	74-98-6
	isobutane	C_4H_{10}	75-28-5
	butane	C_4H_{10}	106-97-8
	dimethylpropane	C_5H_{12}	463-82-1
	isopentane	C_5H_{12}	78-78-4
	pentane	C_5H_{12}	109-66-0
	cyclopentane	C_5H_{10}	287-92-3
	methylcyclopentane	C_6H_{12}	96-37-7
	2,2-dimethylbutane	C_6H_{14}	75-83-2
	2,3-dimethylbutane	C_6H_{14}	79-29-8
	2-methylpentane	C_6H_{14}	107-83-5
	3-methylpentane	C_6H_{14}	96-14-0
2	hexane (n-hexane)	C_6H_{14}	110-54-3
	cyclohexane	C_6H_{12}	110-82-7
	2,4-dimethylpentane	C_7H_{16}	108-08-7
	2-methylhexane	C_7H_{16}	591-76-4
	2,3-dimethylpentane	C_7H_{16}	565-59-3
	2,2dimethylpentane	C_7H_{16}	590-35-2
	2,2,3-trimethylbutane	C_7H_{16}	464-06-2
	3,3-dimethylpentane	C_7H_{16}	562-49-2
	trimethylpentane	C_8H_{18}	29222-48-8
	3-methylhexane	C_7H_{16}	589-34-4
	3-ethylpentane	C_7H_{16}	617-78-7
	2,3-Dimethylhexane	C_8H_{18}	584-94-1
	2,2-dimethylhexane	C_8H_{18}	590-73-8
	2,4-dimethylhexane	C_8H_{18}	589-43-5
	2,5-dimethylhexane	C_8H_{18}	592-13-2
	3,4-dimethylhexane	C_8H_{18}	583-48-2
	methyloctane	C_9H_{20}	61193-19-9
	isooctane	C_8H_{18}	540-84-1
	heptane	C_7H_{16}	142-82-5
	2-methylheptane	C_8H_{18}	592-27-8
	3-methylheptane	C_8H_{18}	589-81-1
	4-methylheptane	C_8H_{18}	589-53-7
	methylcyclohexane	C_7H_{14}	108-87-2
	ethylcyclopentane	C_7H_{14}	1640-89-7
	1,3-dimethylcyclohexane	C_8H_{16}	591-21-9
	1,4-dimethylcyclohexane	C_8H_{16}	589-90-2
	1,2-dimethylcyclohexane	C_8H_{16}	583-57-3
	cycloheptane	C_7H_{14}	291-64-5
	butylcyclohexane	$C_{10}H_{20}$	1678-93-9
	methyl heptane	C_8H_{18}	50985-84-7
	methylnonane	$C_{10}H_{22}$	63335-87-5
	octane	C_8H_{18}	111-65-9

	nonane	C_9H_{20}	111-84-2
	decane	$C_{10}H_{22}$	124-18-5
	undecane	$C_{11}H_{24}$	1120-21-4
	dodecane	$C_{12}H_{26}$	112-40-3
	tridecane	$C_{13}H_{28}$	629-50-5
	tetradecane	$C_{14}H_{30}$	629-59-4
	pentadecane	$C_{15}H_{32}$	629-62-9
	hexadecane	$C_{16}H_{34}$	544-76-3
	heptadecane	$C_{17}H_{36}$	629-78-7
	octadecane	$C_{18}H_{38}$	593-45-3
	nonadecane	$C_{19}H_{40}$	629-92-5
	icosane	$C_{20}H_{42}$	112-95-8
	henicosane	$C_{21}H_{44}$	629-94-7
	docosane	$C_{22}H_{46}$	629-97-0
	tricosane	$C_{23}H_{48}$	638-67-5
2	1,2-dibromoethane (circ)	$C_2H_4Br_2$	106-93-4
2	monobromomethane	CH_3Br	74-83-9
	1,2-dichloroethane (circ)	$C_2H_4Cl_2$	1300-21-6
	VOC - Alkenes and alkynes		(46 compounds)
	ethylene (circ)	C_2H_4	74-85-1
	propene	C_3H_6	115-07-1
	propadiene	C_3H_4	463-49-0
	1-butene	C_4H_8	106-98-9
	isobutene	C_4H_8	115-11-7
1	1,3-butadiene (circ)	C_4H_6	106-99-0
	cis-2-butene	C_4H_8	590-18-1
	1-butyne	C_4H_6	107-00-6
	2-butyne	C_4H_6	503-17-3
	trans-2-butene	C_4H_8	624-64-6
	cyclopentadiene	C_5H_6	542-92-7
	isopentene	C_5H_{10}	563-45-1
	1-pentene	C_5H_{10}	109-67-1
	trans-2-pentene	C_5H_{10}	646-04-8
	cis-2-pentene	C_5H_{10}	627-20-3
	2-methyl-1-butene	C_5H_{10}	563-46-2
	1-hexene	C_6H_{12}	592-41-6
	cis-2-hexene (+1-hexyne)	C_6H_{12}	7688-21-3
	trans-2-hexene	C_6H_{12}	4050-45-7
	trans-3-hexene	C_6H_{12}	13269-52-8
	2-methyl,2-Pentene	C_6H_{12}	625-27-4
	3-methyl-1-Pentene	C_6H_{12}	760-20-3
	cis-4-methyl-2-pentene	C_6H_{12}	691-38-3
	cis-3-methyl,2-pentene	C_6H_{12}	922-62-3
	trans-3-methyl,2-pentene	C_6H_{12}	616-12-6

	2-methyl,1-pentene	C_6H_{12}	763-29-1
	2-methyl,1,4-pentadiene	C_6H_{10}	763-30-4
	trans-2-methyl-1,3-pentadiene	C_6H_{10}	926-54-5
	2,3,3-trimethyl,1-butene	C_7H_{14}	594-56-9
	cyclohexene	C_6H_{10}	110-83-8
	2-methyl,1-hexene	C_7H_{14}	6094-02-6
	trans-2-heptene	C_7H_{14}	14686-13-6
	cycloheptene	C_7H_{12}	628-92-2
	1-octene (+1,1-dimethylcyclohexane)	C_8H_{16}	111-66-0
	trans-2-octene	C_8H_{16}	13389-42-9
	cis-2-octene	C_8H_{16}	7642-04-8
	1-nonene	C_9H_{18}	124-11-8
	cis-4-nonene	C_9H_{18}	10405-84-2
	trans-4-nonene + trans-3-nonene	C_9H_{18}	10405-85-3 + 20063-92-7
	1-undecene	$C_{11}H_{22}$	821-95-4
	1-dodecene	$C_{12}H_{24}$	112-41-4
	acetylene	C_2H_2	74-86-2
	propyne	C_3H_4	74-99-7
	isoprene	C_5H_8	78-79-5
	2-methyl-2-butene	C_5H_{10}	513-35-9
	dimethylhexene	C_8H_{16}	78820-82-3
	VOC - Monocyclic Aromatic Hydrocarbons		(37 compounds)
1	benzene (circ)	C_6H_6	71-43-2
	toluene	C_7H_8	108-88-3
2	ethylbenzene	C_8H_{10}	100-41-4
2	m-xylene	C_8H_{10}	108-38-3
	p-xylene	C_8H_{10}	106-42-3
	o-xylene	C_8H_{10}	95-47-6
2	styrene	C_8H_8	100-42-5
	isopropylbenzene	C_9H_{12}	98-82-8
	propylbenzene	C_9H_{12}	103-65-1
	3-ethyltoluene	C_9H_{12}	620-14-4
	4-ethyltoluene	C_9H_{12}	622-96-8
	1,3,5-trimethylbenzene	C_9H_{12}	108-67-8
	2-ethyltoluene	C_9H_{12}	611-14-3
	1,2,4-trimethylbenzene	C_9H_{12}	95-63-6
	tert-butylbenzene	$C_{10}H_{14}$	98-06-6
	isobutylbenzene	$C_{10}H_{14}$	538-93-2
	sec-butylbenzene	$C_{10}H_{14}$	135-98-8
	butylbenzene	$C_{10}H_{14}$	104-51-8
	1,2,3-trimethylbenzene	C_9H_{12}	526-73-8
	cymene	$C_{10}H_{14}$	99-87-6
	indane	C_9H_{10}	496-11-7

				1,2-diethylbenzene	$C_{10}H_{14}$	135-01-3
				1,3-diethylbenzene	$C_{10}H_{14}$	141-93-5
				methylindane	$C_{10}H_{12}$	27133-93-3
				1,4-diethylbenzene	$C_{10}H_{14}$	105-05-5
				n-butylbenzene	$C_{10}H_{14}$	104-51-8
				1-methyl-3-propylbenzene	$C_{10}H_{14}$	1074-43-7
				1-methyl-3-isopropylbenzene	$C_{10}H_{14}$	535-77-3
				1-methyl-4-propylbenzene	$C_{10}H_{14}$	1074-55-1
				1,4-dimethyl-2-ethylbenzene	$C_{10}H_{14}$	1758-88-9
				1,3-dimethyl-4-ethylbenzene	$C_{10}H_{14}$	874-41-9
				1,2-dimethyl-4-ethylbenzene	$C_{10}H_{14}$	934-80-5
				1,3-dimethyl-2-ethylbenzene	$C_{10}H_{14}$	2870-04-4
				1,2-dimethyl-3-ethylbenzene	$C_{10}H_{14}$	933-98-2
				1,2,4,5-tetramethylbenzene	$C_{10}H_{14}$	95-93-2
				1,2,3,5-tetramethylbenzene	$C_{10}H_{14}$	527-53-7
				1,2,3,4-tetramethylbenzene	$C_{10}H_{14}$	488-23-3
				Polycyclic Aromatic Hydrocarbons "light"		(13 compounds)
2			**4**	naphtalene	$C_{10}H_8$	91-20-3
				2-methylnaphtalene	$C_{11}H_{10}$	91-57-6
				1-methylnaphtalene	$C_{11}H_{10}$	90-12-0
			4	acenaphthylene	$C_{12}H_8$	208-96-8
			4	fluorene (circ)	$C_{13}H_{10}$	86-73-7
				aromatique $C_{13}H_{12}$	$C_{13}H_{12}$	
		12		phenanthrene (circ)	$C_{14}H_{10}$	85-01-08
		12		anthracene (circ)	$C_{14}H_{10}$	120-12-7
			4	acenaphtene	$C_{12}H_{10}$	83-32-9
				1-nitronaphtalene (circ)	$C_{10}H_7NO_2$	86-57-7
				2-nitronaphtalene (circ)	$C_{10}H_7NO_2$	581-89-5
				2- nitrofluorene (circ)	$C_{13}H_9NO_2$	607-57-8
				9-nitroanthracene (circ)	$C_{14}H_9NO_2$	602-60-8
				Polycyclic Aromatic Hydrocarbons "heavy"		(42 compounds)
				anthanthrene (circ)	$C_{22}H_{12}$	191-26-4
		12		fluoranthene (circ)	$C_{16}H_{10}$	206-44-0
		12		pyrene (circ)	$C_{16}H_{10}$	129-00-0
		12		chrysene (circ)	$C_{18}H_{12}$	218-01-9
				benzo[a]fluorene (circ)		
				benzo[b]fluorene (circ)	$C_{17}H_{12}$	243-17-4
2	6	12		benzo[a]anthracene (circ)	$C_{18}H_{12}$	56-55-3
2	6	12		benzo[b]fluoranthene (circ)	$C_{20}H_{12}$	205-99-2
2	6	12		benzo[k]fluoranthene (circ)	$C_{20}H_{12}$	207-08-09
2				benzo[j]fluoranthene (circ)	$C_{20}H_{12}$	205-82-3

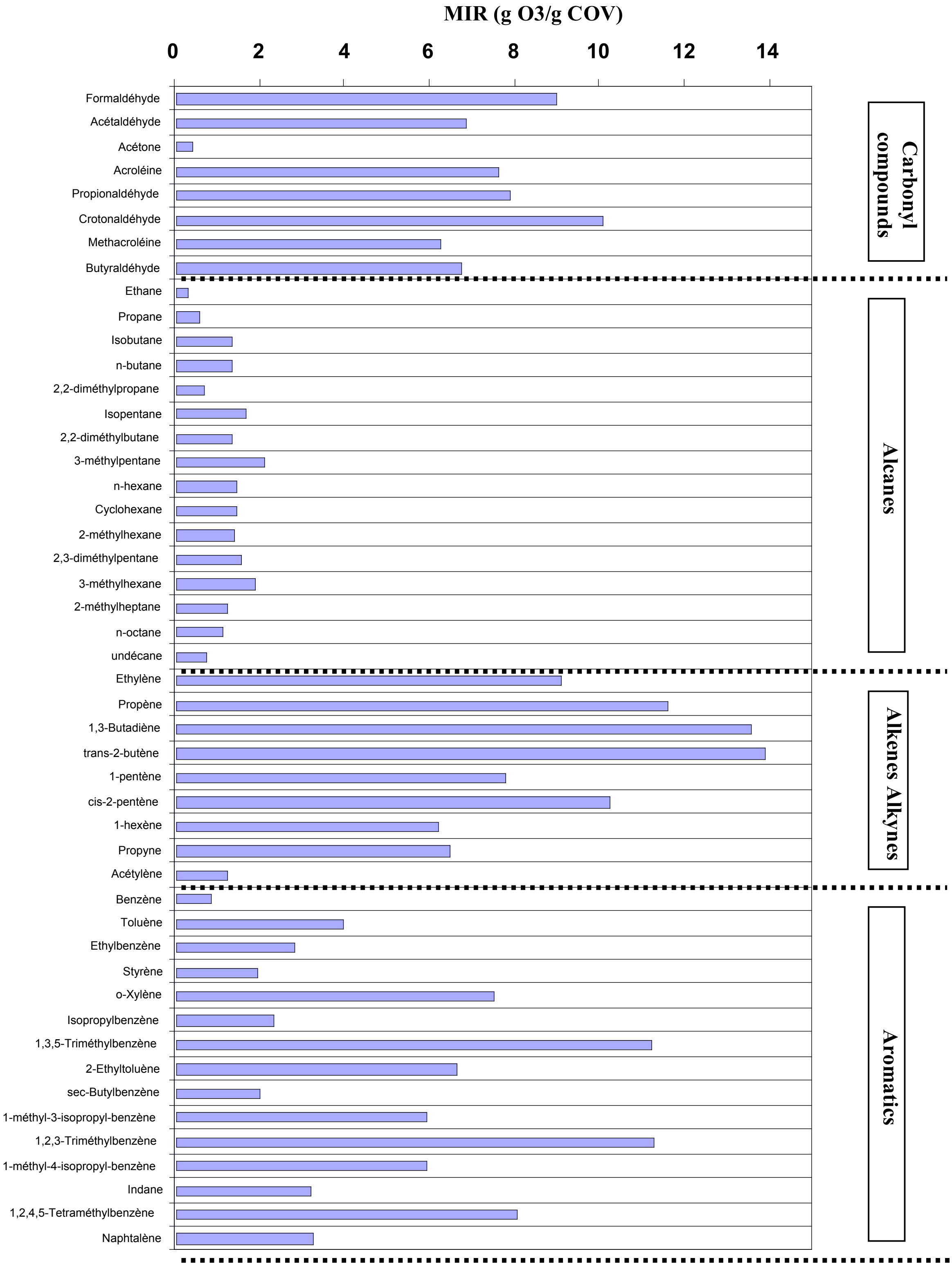
				benzo[ghi]fluoranthene (circ)	$C_{18}H_{10}$	203-12-3
				benzo[e]pyrene (circ)	$C_{20}H_{12}$	192-97-2
	2		12	benzo[ghi]perylene (circ)	$C_{22}H_{12}$	191-24-2
1		6	12	benzo[a]pyrene (circ)	$C_{20}H_{12}$	50-32-8
				benzo[c]phenanthrene (circ)	$C_{18}H_{12}$	195-19-7
				cyclopenta[cd]pyrene (circ)	$C_{18}H_{10}$	27208-37-3
	2	6	12	dibenzo[a,h]anthracene (circ)	$C_{22}H_{14}$	53-70-3
				dibenzo[a,j]anthracene	$C_{22}H_{14}$	224-41-9
				dibenzo[a,e]pyrene (circ)		
				dibenzo[a,h]pyrene (circ)		
				dibenzo[a,l]pyrene	$C_{24}H_{14}$	191-30-0
				1,4-dimethylphenantrene (circ)		
				3,6-dimethylphenantrene	$C_{16}H_{14}$	1576-67-6
				2-methylchrysene (circ)		
				3-methylchrysene (circ)		
				4-methylchrysene (circ)		
				5-methylchrysene (circ)		
				6-methylchrysene (circ)		
				1-methylphenanthrene (circ)		
				perylene (circ)	$C_{20}H_{12}$	198-55-0
				triphenylene (circ)	$C_{18}H_{12}$	217-59-4
				propylene (circ)	C_3H_6	115-07-1
	2	6	12	indeno[1,2,3-cd]pyrene (circ)	$C_{22}H_{12}$	193-39-5
				coronene (circ)	$C_{24}H_{12}$	191-07-1
				3,7-dinitrofluoranthene (circ)		
				3,9-dinitrofluoranthene (circ)		
				1-nitropyrene (circ)		
				3-nitrofluoranthene (circ)		
				1,3-dinitropyrene (circ)		
				1,6-dinitropyrene (circ)		
				1,8-dinitropyrene (circ)		
				6-nitrobenzo[a]pyrene (circ)		
				COV - Aldehydes and ketones (Carbonyl compounds)		(23 compounds)
1				formaldehyde (circ)	CH_2O	50-00-0
1				acetaldehyde (circ)	C_2H_4O	75-07-0
	2			acetone	C_3H_6O	67-64-1
1				acroleine (circ)	C_3H_4O	107-02-8
				propionaldehyde	C_3H_6O	123-38-6
				crotonaldehyde	C_4H_6O	4170-30-3
				2-butanone (methyl ethyle cketone)	C_4H_8O	78-93-3
				methacroleine	C_4H_6O	78-85-3
				butyraldehyde	C_4H_8O	123-72-8
				isobutanaldehyde	C_4H_8O	78-84-2
				benzaldehyde	C_7H_6O	100-52-7

	isovaleraldehyde	$C_5H_{10}O$	590-86-3
	valeraldehyde	$C_5H_{10}O$	110-62-3
	o-tolualdehyde	C_8H_8O	529-20-4
	m-tolualdehyde	C_8H_8O	620-23-5
	p-tolualdehyde	C_8H_8O	104-87-0
	hexaldehyde	$C_6H_{12}O$	66-25-1
	2,5-dimethylbenzaldehyde	$C_9H_{10}O$	5779-94-2
	1,2-ethanedione	$C_2H_2O_2$	107-22-2
	propanedione	$C_3H_4O_2$	78-98-8
	methylvinylcetone	C_4H_6O	78-94-4
	acide formique	CH_2O_2	64-18-6
	acide acetique	$C_2H_4O_2$	64-19-7
	COV - Ethers		(4 compounds)
	Methyl-Tertiobuthyl-Ether (MTBE)	$C_5H_{12}O$	1634-04-4
	Ethyl-Tertiobuthyl-Ether (ETBE)	$C_6H_{14}O$	637-92-3
	Methyl-Tertio-Amyl-Ether (TAME)	$C_6H_{14}O$	994-05-8
	thiofene	C_4H_4S	110-02-1
	Persistent Organic Pollutants		(8 compounds)
	chlordane		12789-03-6
	heptachlore		76-44-8
	hexachlorobenzene		118-74-1
	toxaphene		8001-35-2
	aldrine		309-00-02
	dieldrine		60-57-1
	endrine		72-20-8
	mirex		2385-85-5
	Dioxines and furanes		(5 + 5 compounds)
	Dioxines		
2	tetrachlorodibenzodioxines		
	pentachlorodibenzodioxines		
2	hexachlorodibenzodioxines		
	heptachlorodibenzodioxines		
	octachlorodibenzodioxines		
	Furanes		
	tetrachlorodibenzofuranes		
	pentachlorodibenzofuranes		
	hexachlorodibenzofuranes		
	heptachlorodibenzofuranes		
	octachlorodibenzofuranes		

	Metals		(12 compounds)
1	Lead (circ)	Pb	7439-92-1
1	Cadmium	Cd	7440-43-9
1	Chrome	Cr	7440-47-3
	Copper	Cu	7440-50-8
1	Nickel	Ni	7440-02-0
	Selenium	Se	7782-49-2
	Zinc	Zn	7440-66-6
	Manganese	Mn	7439-96-5
	Platine,	Pt,	7440-06-4,
	Palladium,	Pd,	7440-05-3,
	Rhodium	Rh	7440-16-6
1	Baryum	Ba	7440-39-3

Annex 10: MIR reactivity of VOC

Scale of MIR reactivity expressed in gram of formed ozone per gram of added VOC (Carter, 2000).



Annex 11: Ozone forming potential for different vehicle types

petrol cars Euro 0	decreasing OFP	petrol cars Euro 1 & 2	decreasing OFP
M+p xylene	.562	ethylene	.0442
ethylene	.453	M+p xylene	.0441
toluene	.438	toluene	.0338
3+4 ethyltoluene	.389	3+4 ethyltoluene	.0162
orthoxylene	.223	ethylbenzene	.0050
trimethylbenzene	.100	orthoxylene	.0035
1,3 butadiene	.059	trimethylbenzene	.0029
ethylbenzene	.053	1-3 butadiene	.0027
acetaldehyde	.048	acetaldehyde	.0014
propadiene	.035	isopentane	.0013
2-methylpentene	.035	acetylene	.0012
Trans-2-pentene	.037	n-hexane	.0012

diesel cars Euro 0 & 1	decreasing OFP	diesel cars Euro 2	decreasing OFP
ethylene	.0662	ethylene	.0445
acetaldehyde	.0212	formaldehyde	.0183
formaldehyde	.0172	acetaldehyde	.0121
1,3-butadiene	.0099	1,3-butadiene	.0067
acroleine	.0056	acetylene	.0062
1-pentene	.0049	1-pentene	.0034
acetylene	.0044	propionaldehyde	.0032
crotonaldehyde	.0037	toluene.00	.0033
butyraldehyde	.0037	butyraldehyde	.0016
toluene	.0034	acroleine	.0015
naphtalene	.0031	crotonaldehyde	.0013
methacroleine	.0016	naphtalene	.00098

Table 27: Calculated ozone forming potential OFP, in decreasing order, for different vehicle types on a Motorway driving cycle (Flandrin et al., 2002).

Annex 12: Comparison of emissions measured and modelled with instantaneous models

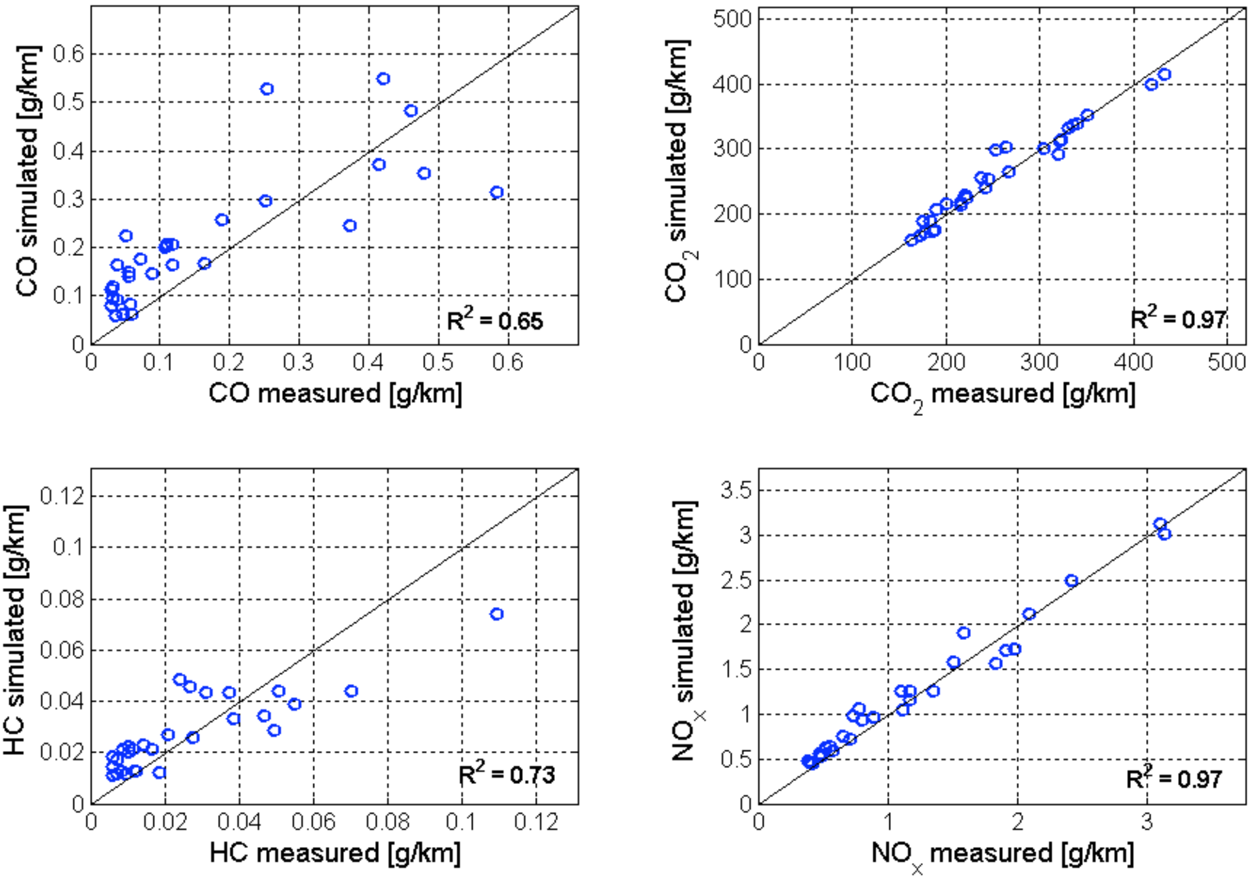


Figure 61: Simulation quality for the emission factors of the diesel vehicle with the EMPA instantaneous emission model. A point represents a driving pattern.

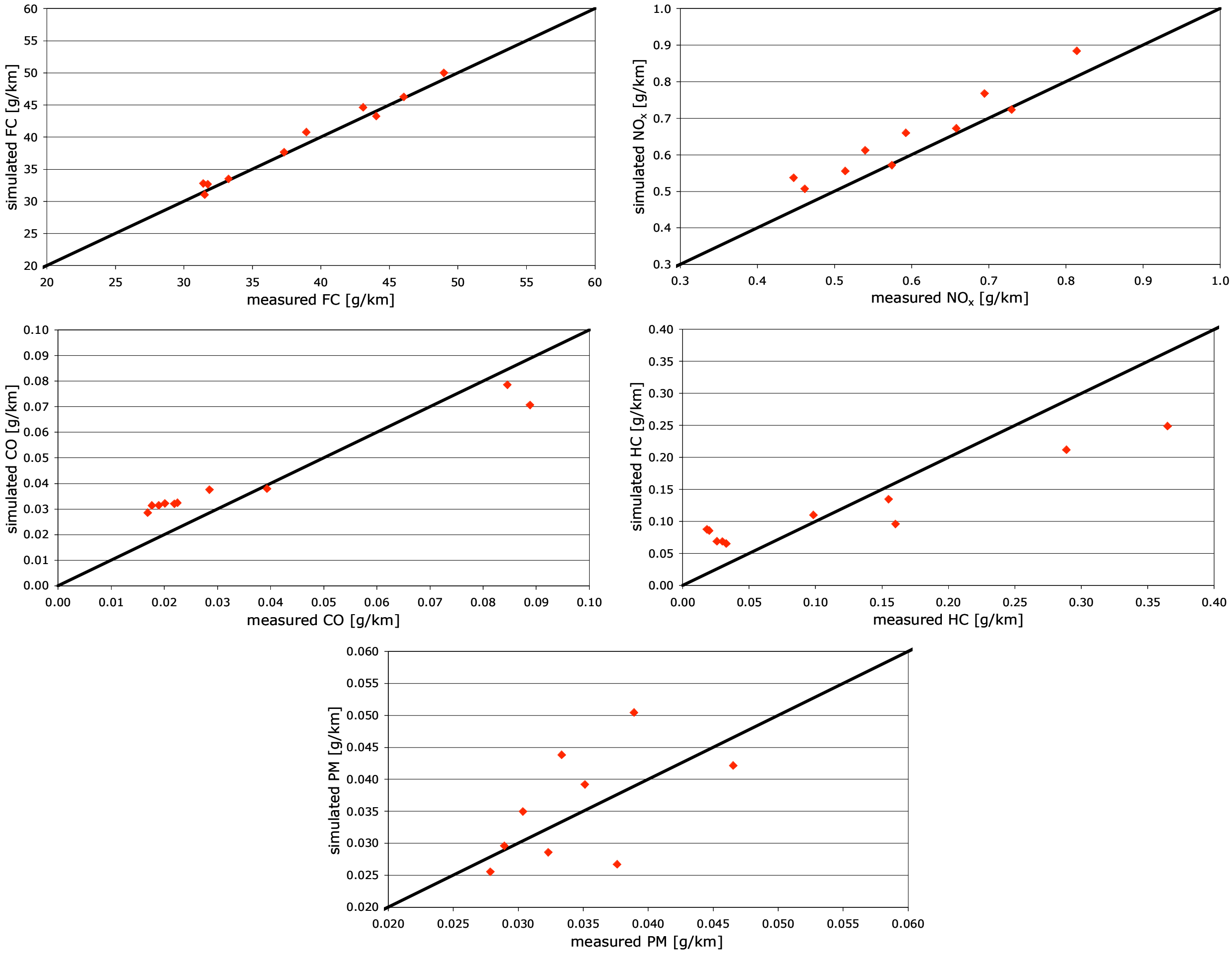


Figure 62: Simulation quality for the emission factors of the average Euro 2 diesel car with PHEM (engine maps from the Artemis driving cycle used for simulation of the Handbook driving cycles).

Annex 13: Kinematic models

The response considered by all models presented in this annexe is the unit emission mass of CO, HC, NO_X and CO_2 expressed in (g/km), a log-transform of Y was applied. Log transform of Y's observed data are scaled to unit variance (dividing by standard deviation) before model calculation. The basic idea and mathematics of models are illustrated into details in Rapone (1995).

Explicative variables characterize the kinematics of driving cycles, variables were divided into two conceptually meaningful blocks, then the following two basic regression equations were developed:

$$\ln Y = a_0 + a_1 MV + a_2 MV2 + a_3 MV3 + a_4 MVA\_POS + a_5 Trunning + a_6 Tidle + a_7 INVDIST + \varepsilon \tag{1}$$

$$\ln Y = b_0 + b_1 FS\_V20a1 + b_2 FS\_V20a2 + ... + b_{42} FS\_V101a7 + \varepsilon \tag{2}$$

where random noise ε is assumed to be a random variable normally distributed $\varepsilon \sim N(0,\sigma^2)$.

X's data are centred (subtracting mean) and scaled to unit variance (dividing by standard deviation).

Considering the number of X-variables, the most of which are correlated, it is convenient to utilize a regression method based on principal components (PC), which are latent variables function of original variables and orthogonal each other. In particular, the sparse matrix of data and the presence of missing values suggested to apply the Partial Least Square method and the NIPALS algorithm to estimate the regression model. Moreover, because response variables Y's may be correlated, a multivariate response Y (whose components are CO, CO_2, HC, NO_X) was considered and a multivariate PLS method applied (Tenenhaus,1998). To consider both the contributes of the two blocks in one model, a Hierarchical Multi-block PLS method (Westerhuis, 1998) is adopted. Following this approach, a set (t_1, t_2,…, t_k) of principal components (X-scores) is estimated separately for each block of variables, fitting a PLS base model to each block. Then, the super-block regression model (named top-model) is built, by applying the PLS regression of Y-variables on super-scores made by the union of scores of the two base models.

The regression equation for top model is the following:

$$\ln Y = C_1 M1.T_1 + C_2 M2.T_2 + .. + C_{k'} M1.T_{k'} + C_{k'+1} M2.T_1 + C_{k'+2} M2.T_2 + .. + C_K M2.T_{k''} + \varepsilon \tag{3}$$

where k' is the number of scores of the first block and k" is the number of scores of the second block, calculated by the fit of models to data as a function of X, and K= k'+k". Thus the top model estimates the coefficients C_K and the predicted values of regression of lnY on the full set of X-variables made of the two blocks, as it can be argued by the following equations:

$$M1.T_i = w_{i1} mv + w_{i2} mv2 + w_{i3} mv3 + ... + w_{i7}\ INVDIST + \varepsilon \quad \text{i=1, 2,..k'} \tag{4}$$

$$M2.T_i = w_{i1} 1FSv20a1 + w_{i2} FSv20a2 + w_{i3} FSv20a3 + ... + w_{i42} FSv101a7 + \varepsilon \quad \text{i=1, 2,…k''} \tag{5}$$

A logarithm transform was applied to the response Y , thus quantities predicted by model fit to data as lnY are to be retransformed in original scale to get emission factors. The following naïve estimate was used to calculate model expectations:

$$\text{e(p, veh. class) [g/km]} = \hat{Y} = \exp\left[\ln\hat{Y} + \left(\text{RMSE}\hat{E}\right)^2/2\right]$$

where $\ln\hat{Y}$ is the quantity calculated by putting coefficients calculated by model fit for each case and $RMSE\hat{E}$ is the root mean square error i.e. the standard deviation of model residuals.

Case study of Euro 3 petrol 1.4-2.0 l passenger car class

model 1

CO [g/km] = exp [-4,44416 + 0,00557634 · mv + 5,54E-05 · mv2 + 4,95E-07 · mv3 + 0,00165646 · tidle + 0,000397725 · trunning + 0,131082 · mva + 14,4737 1/d + (1,29265)^2/2];

CO2 [g/km] = exp [4,85823 - 0,00208098· mv + 3,74E-06· mv2 + 1,18E-07· mv3 + 0,00261577· tidle - 6,25E-05· trunning + 0,0288376· mva + 415,9681/d + (0,149323)^2/2];

HC [g/km] = exp [-6,02932 -0,00149716· mv + 3,37E-05· mv2 + 4,71E-07· mv3 + 0,00635325· tidle + 0,000138576· trunning + 0,126196· mva + 803,349 1/d + (0,986016)^2/2];

NOX [g/km] = exp [-4,22443 -0,00339366· mv+ 2,11E-06· mv2 + 1,47E-07· mv3 + 0,00539048· tidle + 0,000227761· trunning + 0,0645522· mva + 461,662 1/d + (0,971086)^2/2];

model 2

CO [g/km] = exp [-2,69653 - 0,0809634 · FS_V100xaccel1 - 0,0372766 · FS_V100xaccel2 - 0,0463132 · FS_V100xaccel3 - 0,0196432 · FS_V100xaccel4 - 0,0402573 · FS_V100xaccel + 50,040295 · FS_V100xaccel6 - 0,0708533 · FS_V100xaccel7 - 0,116826 · FS_V101xaccel + 10,0501926 · FS_V101xaccel2 + 0,101095 · FS_V101xaccel3 + 0,0771687 · FS_V101xaccel4 + 0,103904 · FS_V101xaccel5 + 0,0135185 · FS_V101xaccel6 - 0,0924244 · FS_V101xaccel7 - 0,0194603 · FS_V20xaccel1 - 0,0148916 · FS_V20xaccel2 - 0,0307388 · FS_V20xaccel3 - 0,00532937 · FS_V20xaccel4 - 0,038722 · FS_V20xaccel5 - 0,0190686 · FS_V20xaccel6 + 0,00451553 · FS_V20xaccel7 + 0,00433718 · FS_V40xaccel1 - 0,0104214 · FS_V40xaccel2 - 0,0555255 · FS_V40xaccel3 - 0,0657504 · FS_V40xaccel4 - 0,0332443 · FS_V40xaccel5 - 0,0323581 · FS_V40xaccel6 - 0,00303055 · FS_V40xaccel7 + 0,00172708 · FS_V60xaccel1 + 0,0103377 · FS_V60xaccel2 - 0,0258137 · FS_V60xaccel3 - 0,00246483 · FS_V60xaccel4 + 0,0139397 · FS_V60xaccel5 + 0,00256516 · FS_V60xaccel6 + 0,0184218 · FS_V60xaccel7 - 0,070793 · FS_V80xaccel1 + 0,0796336 · FS_V80xaccel2 - 0,0365832 · FS_V80xaccel3 - 0,0492469 · FS_V80xaccel4 - 0,0190527 · FS_V80xaccel5 + 0,0157882 · FS_V80xaccel6 + 0,0659957 · FS_V80xaccel7 + (1,27928)^2/2];

CO2 [g/km] = exp [5,33001 + 0,00320509 · FS_V100xaccel1 + 0,00274146 · FS_V100xaccel2 + -0,0208135 · FS_V100xaccel3 + -0,0169727 · FS_V100xaccel4 + -0,0151693 · FS_V100xaccel5 + 0,0406771 · FS_V100xaccel6 + 0,0484331 · FS_V100xaccel7 + -0,00421207 · FS_V101xaccel1 + -0,00699693 · FS_V101xaccel2 + -0,00512029 · FS_V101xaccel3 + -0,00942676 · FS_V101xaccel4 + 0,00528796 · FS_V101xaccel5 + 0,00925922 · FS_V101xaccel6 + -0,00393966 · FS_V101xaccel7 + 0,00134039 · FS_V20xaccel1 + 0,0149632 · FS_V20xaccel2 + 0,0285225 · FS_V20xaccel3 + 0,0274375 · FS_V20xaccel4 + 0,0324384 · FS_V20xaccel5 + 0,00247971 · FS_V20xaccel6 + 0,0193321 · FS_V20xaccel7 + 0,0453323 · FS_V40xaccel1 + 0,0148512 · FS_V40xaccel2 - 0,0276028 · FS_V40xaccel3 - 0,0136647 · FS_V40xaccel4 - 0,0155461 · FS_V40xaccel5 - 0,00961286 · FS_V40xaccel6 + 0,0330918 · FS_V40xaccel7 - 0,0884033 · FS_V60xaccel1 + 0,0112486 · FS_V60xaccel2 - 0,0449015 · FS_V60xaccel3 - 0,0263389 · FS_V60xaccel4 - 0,030274 · FS_V60xaccel5 + 0,0179473 · FS_V60xaccel6 - 0,0781766 · FS_V60xaccel7 + 0,021587 · FS_V80xaccel1 + 0,0740122 · FS_V80xaccel2 - 0,0160819 · FS_V80xaccel3 - 0,0242275 · FS_V80xaccel4 + 0,00723459 · FS_V80xaccel5 + 0,0407075 · FS_V80xaccel6 - 0,0685132 · FS_V80xaccel7 + (0,136814)2/2];

HC [g/km] = exp [-4,34117 - 0,0409743 · FS_V100xaccel1 - 0,0169436 · FS_V100xaccel2 - 0,0588976 · FS_V100xaccel3 - 0,0383996 · FS_V100xaccel4 - 0,0475969 · FS_V100xaccel5 + 0,081687 · FS_V100xaccel6 + 0,0193362 · FS_V100xaccel7 - 0,0735987 · FS_V101xaccel1 + 0,0184655 · FS_V101xaccel2 + 0,0484907 · FS_V101xaccel3 + 0,0291051 · FS_V101xaccel4 + 0,0649944 · FS_V101xaccel5 + 0,0208593 · FS_V101xaccel6 - 0,0617134 · FS_V101xaccel7 + 0,000213868 · FS_V20xaccel1 + 0,0208999 · FS_V20xaccel2 + 0,0309904 · FS_V20xaccel3 + 0,0416199 · FS_V20xaccel4 + 0,032574 · FS_V20xaccel5 + 0,00119606 · FS_V20xaccel6 + 0,0389355 · FS_V20xaccel7 + 0,0717529 · FS_V40xaccel1 + 0,0226889 · FS_V40xaccel2 -

0,0650945 · FS_V40xaccel3 - 0,0512134 · FS_V40xaccel4 - 0,035332 · FS_V40xaccel5 - 0,0265652 · FS_V40xaccel6 + 0,0588915 · FS_V40xaccel7 - 0,117034 · FS_V60xaccel1 + 0,0244123 · FS_V60xaccel2 - 0,0851562 · FS_V60xaccel3 - 0,0437449 · FS_V60xaccel4 - 0,0373423 · FS_V60xaccel5 + 0,0288276 · FS_V60xaccel6 - 0,11324 · FS_V60xaccel7 - 0,00873983 · FS_V80xaccel1 + 0,138059 · FS_V80xaccel2 - 0,0551315 · FS_V80xaccel3 - 0,0710085 · FS_V80xaccel4 - 0,0134046 · FS_V80xaccel5 + 0,0603888 · FS_V80xaccel6 - 0,0764631 · FS_V80xaccel7 + $(0,97709)^2/2$];

NOX [g/km] = exp [-3,84669 - 0,0312936 · FS_V100xaccel1 - 0,0172218 · FS_V100xaccel2 - 0,0359896 · FS_V100xaccel3 - 0,0248533 · FS_V100xaccel4 - 0,031327 · FS_V100xaccel5 + 0,0344145 · FS_V100xaccel6 - 0,0232601 · FS_V100xaccel7 - 0,0522676 · FS_V101xaccel1 + 0,00499107 · FS_V101xaccel2 + 0,0200052 · FS_V101xaccel3 + 0,0117509 · FS_V101xaccel4 + 0,0281851 · FS_V101xaccel5 + 0,00223383 · FS_V101xaccel6 - 0,0492098 · FS_V101xaccel7 + 0,00992933 · FS_V20xaccel1 + 0,0161572 · FS_V20xaccel2 + 0,017766 · FS_V20xaccel3 + 0,0236112 · FS_V20xaccel4 + 0,0176995 · FS_V20xaccel5 + 0,00824783 · FS_V20xaccel6 + 0,0273362 · FS_V20xaccel7 + 0,041514 · FS_V40xaccel1 + 0,0191147 · FS_V40xaccel2 - 0,0245991 · FS_V40xaccel3 - 0,0137067 · FS_V40xaccel4 - 0,00693182 · FS_V40xaccel5 - 0,00379126 · FS_V40xaccel6 + 0,0392298 · FS_V40xaccel7 - 0,0334126 · FS_V60xaccel1 + 0,0291515 · FS_V60xaccel2 - 0,0243012 · FS_V60xaccel3 - 0,010852 · FS_V60xaccel4 - 0,00105535 · FS_V60xaccel5 + 0,0332561 · FS_V60xaccel6 - 0,0620697 · FS_V60xaccel7 - 0,019655 · FS_V80xaccel1 + 0,0544703 · FS_V80xaccel2 - 0,0344784 · FS_V80xaccel3 - 0,039486 · FS_V80xaccel4 - 0,0155741 · FS_V80xaccel5 + 0,022913 · FS_V80xaccel6 - 0,0542544 · FS_V80xaccel7 + $(0,952002)^2/2$];

model 3

CO [g/km] = exp [-2,5151 + -0,253973 · M1.t1 + 0,25643 · M1.t2 + 0,0192314 · M1.t3 + -0,0900483 · M2.t1 + 0,0727555 · M2.t2 + 0,147771 · M2.t3 + 0,0140601 · M2.t4 + -0,167815 · M2.t5 + 0,0426933 · M2.t6 + 0,142154 · M2.t7 + $(1,26823)^2/2$];

CO2 [g/km] = exp [5,32258 + 0,0552223 · M1.t1 + 0,160689 · M1.t2 + -0,0285125 · M1.t3 + 0,0264709 · M2.t1 + 0,0322054 · M2.t2 + 0,0176457 · M2.t3 + 0,0401403 · M2.t4 + 0,0573429 · M2.t5 + 0,0318563 · M2.t6 + 0,013705 · M2.t7 + $(0,132317)^2/2$];

HC [g/km] = exp [-4,12042 + -0,0109236 · M1.t1 + 0,467298 · M1.t2 + -0,0175954 · M1.t3 + 0,0152887 · M2.t1 + 0,0941628 · M2.t2 + 0,130208 · M2.t3 + 0,0715776 · M2.t4 + 0,00547747 · M2.t5 + 0,0782761 · M2.t6 + 0,108391 · M2.t7 + $(0,962523)^2/2$];

NOX [g/km] = exp [-3,34465 + 0,0785951 · M1.t1 + 0,299503 · M1.t2 + 0,065518 · M1.t3 + 0,0560129 · M2.t1 + 0,0261385 · M2.t2 + 0,107069 · M2.t3 + 0,00155128 · M2.t4 + -0,0200644 · M2.t5 + 0,0231157 · M2.t6 + 0,0626605 · M2.t7 + $(0,944445)^2/2$];

Where M*.t* are the scores of the two model base. Moreover t* = X*w* where *w* is the weight matrix of X as detailed shown in the equation (4) and (5).

Variables	M1.w[1]	M1.w[2]	M1.w[3]
Tidle	0,359885	0,60193	0,517176
Trunning	-0,13029	0,0991421	0,464526
invDist	0,428067	0,461151	-0,63279
m_va_pos	-0,319455	0,431369	0,166457
mv	-0,491729	0,00302172	-0,073837
mv2	-0,428646	0,252471	-0,179092
mv3	-0,37773	0,406645	-0,226024

Table 28: Model 1 - weight matrix of X.

Variables	M2.w[1]	M2.w[2]	M2.w[3]	M2.w[4]	M2.w[5]	M2.w[6]	M2.w[7]
FS_V100xaccel1	-0,0601457	0,171516	-0,215116	-0,088999	0,183235	0,0642824	-0,241913
FS_V100xaccel2	-0,14579	0,111674	-0,00639852	0,00225961	0,152912	-0,227425	-0,0163727
FS_V100xaccel3	-0,17877	-0,0504258	-0,128454	-0,00634528	0,0600539	-0,309946	0,0997569
FS_V100xaccel4	-0,182547	-0,0591483	-0,126135	-0,000434923	0,0100756	-0,2538	0,181222
FS_V100xaccel5	-0,18419	-0,0182767	-0,12768	-0,0066852	0,0908313	-0,249793	0,0842607
FS_V100xaccel6	-0,132899	0,16862	0,210052	0,0879018	0,216464	-0,0993568	0,0422321
FS_V100xaccel7	-0,0265885	0,0705269	-0,357088	0,149617	0,112532	0,320831	-0,0402255
FS_V101xaccel1	-0,0583485	0,154504	-0,282579	-0,0604535	0,124475	0,0832292	-0,321722
FS_V101xaccel2	-0,078063	0,213259	-0,0659814	-0,160076	-0,0592438	0,168383	0,00980888
FS_V101xaccel3	-0,151354	0,211423	0,0828917	-0,0993271	-0,209744	0,152257	0,249583
FS_V101xaccel4	-0,1523	0,200459	0,061751	-0,132611	-0,262248	0,133923	0,243858
FS_V101xaccel5	-0,138176	0,238932	0,133972	-0,0598309	-0,166677	0,23636	0,218943
FS_V101xaccel6	-0,128729	0,204696	0,0194507	-0,0500324	0,098282	-0,00823522	-0,117535
FS_V101xaccel7	-0,0564239	0,119683	-0,322545	-0,0405908	0,0877616	0,150958	-0,1929
FS_V20xaccel1	0,21927	0,0455544	0,00433808	-0,00643456	-0,084633	-0,06345	-0,0657055
FS_V20xaccel2	0,221706	0,0583298	-0,015713	0,0622586	-0,00929679	-0,0413543	0,0290278
FS_V20xaccel3	0,221454	0,0749062	-0,0458631	0,151216	0,0522385	-0,0194223	-0,0154522
FS_V20xaccel4	0,22108	0,076818	0,0795298	0,189665	0,0361079	0,0142898	-0,0555318
FS_V20xaccel5	0,225257	0,0950052	-0,056727	0,169972	0,0735292	-0,0268814	-0,0446116
FS_V20xaccel6	0,214599	0,0391855	-0,0118333	0,0323605	-0,0967328	-0,0933008	-0,0248955
FS_V20xaccel7	0,216228	0,0620314	0,0499604	0,0699184	-0,0654156	0,0142758	-0,0324987
FS_V40xaccel1	0,146101	-0,0529273	0,0988936	0,15499	0,0999095	0,0348877	0,109072
FS_V40xaccel2	0,209811	-0,0260104	-0,0415329	0,0303145	0,0283379	0,0097466	0,170482
FS_V40xaccel3	0,168838	-0,0901547	-0,22589	-0,15035	-0,0237935	-0,135346	0,175551
FS_V40xaccel4	0,182966	-0,112923	-0,0450108	-0,0676074	0,00362612	-0,087022	-0,0835503
FS_V40xaccel5	0,189756	-0,0844929	-0,0570412	-0,0692074	-0,0789497	-0,0568584	0,0112568
FS_V40xaccel6	0,18779	-0,093744	-0,035285	-0,0106232	-0,0765537	-0,0931001	0,0329324
FS_V40xaccel7	0,216305	0,142269	0,139618	0,0957977	-0,0163286	-0,0911782	-0,124834
FS_V60xaccel1	-0,0823345	0,0207001	0,235537	-0,28666	-0,071278	-0,401371	-0,107069
FS_V60xaccel2	0,0184065	-0,00996134	0,299513	-0,170426	0,200887	0,0427092	-0,216564
FS_V60xaccel3	0,00773456	-0,271901	0,0304987	-0,33387	0,111182	0,184222	-0,0519018
FS_V60xaccel4	0,0395875	-0,30303	0,0365384	-0,207489	-0,0112164	0,184544	0,0089723
FS_V60xaccel5	0,054947	-0,157467	0,119555	-0,32145	0,021902	0,221838	-0,142196
FS_V60xaccel6	0,0435389	-0,0811564	0,274847	-0,175332	0,285657	0,0829547	-0,0988931
FS_V60xaccel7	-0,0940662	-0,0404515	0,0799789	0,0886469	-0,449371	-0,0667802	-0,444941
FS_V80xaccel1	-0,136739	0,166535	-0,0128682	0,02164	0,193773	-0,151076	-0,163228
FS_V80xaccel2	-0,137073	-0,11237	0,263839	0,436268	0,0824722	0,195137	0,0649798
FS_V80xaccel3	-0,167882	-0,328256	-0,107333	0,134418	-0,0418911	0,0123108	0,000641246
FS_V80xaccel4	-0,167647	-0,346333	-0,135514	0,0720638	-0,0578164	-0,106407	-0,0500598
FS_V80xaccel5	-0,155134	-0,300871	-0,0391485	0,206091	0,0589178	0,161089	0,00723368
FS_V80xaccel6	-0,163674	-0,0261229	0,259459	0,227104	0,187194	0,0111906	-0,133109
FS_V80xaccel7	-0,108869	-0,0170015	0,0282064	0,133633	-0,459025	0,0075367	-0,340058

Table 29: Model 2 - weight matrix of X.

Annex 14: Traffic situation description

Main function	Comments	Le-vel	Characteristics	Speed limit (km/h)	Number of lanes and geometry		Junction type & density: order of magnitude of dist. between junctions		Parking	Pedestrians, cycles, mopeds	Bus circulation and stops
Through-traffic – Primary distributor - National and regional network	High-speed or major road through an urban area. Concerns Regional or national traffic	5a	Motorway	110-130	At least 2*2, separate road ways	Wide	Always grade separated	Low (10 km)	Specific area	Always prohibited	Authorized, no bus stops
		5b	Not motorway (trunk road)	80-90/97*	At least 2*1, separate road ways or no	Wide	Grade separated	Low	Specific area	Prohibited	Authorized, no bus stops
Primary distributor - Agglomeration network, city primary roads	High-speed or major roads through the urban area, major arterials. Quick exchanges at the city scale	4a	Motorway (ring road)	80-113*	At least 2*2, separate road ways or no	Wide	Always grade separated	High (1 km)	Specific area	Always prohibited	Authorized, no bus stops
		4b	Not motorway (trunk road)	48*/50-90/97*	At least 2*1, separate road ways or no	Wide	Grade separated, roundabout, traffic lights	High	Specific area or on road side	Prohibited or on pavement, and cycle lane	Authorized, separate stops or on road side
Districts distributors	Connection between districts or poles and access to/from primary distributors	3	road	48*/50 - 70	At least 2*1 or 1*2, separate road ways or no, (perhaps 1*1 when one way road)	Lanes can be narrowed to limit the speed	Traffic lights, roundabout or grade separated	High	On road side	Pavement, cycles and mopeds on road or on a specific lane	Authorized, possibly on a specific lane, separate stops or on road side
Local distributors - Inner exchange and local traffic	Connection between communities and within districts. Access to/from district distributors – Neighbourhood traffic	2	road	50/48*	At least 2*1 or 1*1 lane if one way road	Narrow lanes	Traffic lights, priority rule or roundabout	High	On road side	Pavement, cycles and mopeds on road or on a specific lane	Authorized, possibly on a specific lane, separate stops or on road side
Access roads - Local traffic.	Access to housing and business places.	1	road, cul-de-sac, side road	5-10-30-50/48*	At best 2*1 or 1*2 lanes	Narrow lanes	Mostly priority rule, traffic lights and small roundabout	High (100 m)	On road side or on the street	Pavement, cycles and mopeds on road	Authorized, stops on road side

Table 30: Urban road classification.

Main function	Comments	Le-vel	Characteristics	Speed limit (km/h)	Number of lanes and geometry		Junction type & density: order of magnitude of dist. between junctions		Parking	Pedestrians, cycles, mopeds	Bus circulation and stops
Through and distribution traffic – National and regional network	High speed or major road through the rural area. Concerns Regional or national traffic	5	Motorway	110->130	At least 2*2, separate road ways	Wide	Always grade separated	Low (20 km)	Specific area	Always prohibited	Authorized, no bus stop
		5s	*Semi-motorway (1)*		(1)						
	Road network in the rural area, connecting villages, towns	4	Not motorway (trunk road)	70-113*	At least 2*1, separate road ways or no	Wide	Roundabout, traffic lights, or grade separated	Low (5 km)	Specific area or on road side	Prohibited or on pavement, and cycle lane	Authorized, separate stops or on road side
Distributors	Connection between villages/towns and access to/from national/regional network	3	Road	48*/50 – 90/97*	At least 2*1 or 1*2, separate road ways or no	Lanes can be narrowed to limit the speed	Traffic lights, roundabout, priority rule	High	On road side	Pavement, cycles and mopeds on road or on a specific lane	Authorized, separate stops or on road side
Local distributors - Inner exchange and local traffic	Roads through villages, and occasional access to properties such as farms	2	Road	50/48*, 70	At least 2*1 or 1*1 lane if one way road	Narrow	Roundabout, priority rule or traffic lights	High	On road side	Pavement, cycles and mopeds on road	Authorized, stops on road side or on road
Access roads - Local traffic.	Access to properties, residential roads	1	Road, cul-de-sac, side road	≤ 50/48*	At best 2*1 lanes	Narrow	Priority rule	-	On the street	Pavement, cycles and mopeds on road	No

(1) the “semi-motorway” is a particular case of the rural motorway. It presents an alternation of road segments (distance of 2-3 km), with 2 lanes in one way and 1 lane in the opposite way.

Table 31: Rural road classification.

Annex 15: Illustrative photographs of traffic situations

Rural 5: National / regional motorway

Motorway (2x3)

Motorway (2x4) (can be also Urban 5a:National / regional motorway in an urban area, strategic network)

Rural 4: National / regional trunk road

2x1 A-road

2x2 trunk road

Rural 3: Distributor, inter-village road

Rural minor road
(2x1)

Rural 2: Local distributor, through-village road

(2x1) road

Rural 1: Access road

Rural minor road
(1x1)

Urban 5a: National / regional motorway in an urban area (strategic network)

Speed limit:
110 to 130 km/h
2*3 lanes
Grade separated junctions,
Grade separated road ways ,
Street lighting,
Capacity around 2000 vehicles per lane per hour.

Speed limit:
110 to 130 km/h
2*2 lanes
Grade separated junctions,
Grade separated road ways
No lighting
Capacity around 1800 vehicles per lane per hour

Motorway (2x4) (can be also Rural 5:National / regional motorway in an urban area, strategic network)

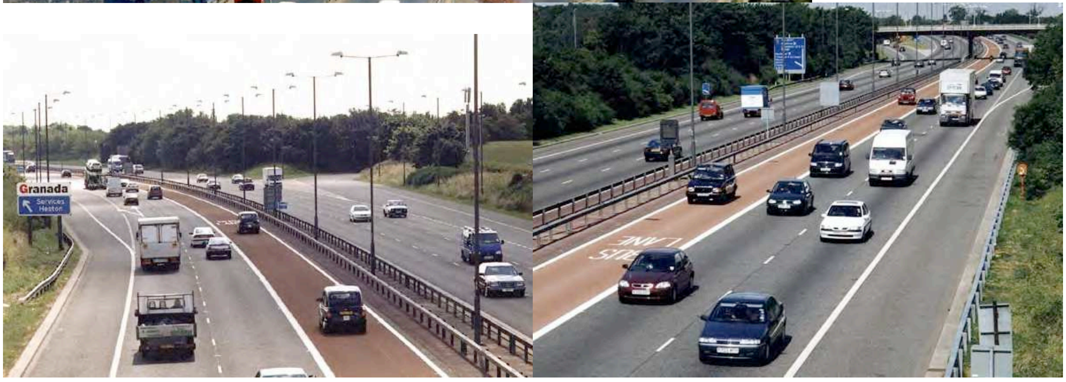
Urban 5b: National/regional trunk road (strategic network)

N74, Belgium

Urban 4a: Urban motorway (city scale network)

Speed limit:
90 to 110 km/h
2*5 lanes (left)
2*2 lanes (right)
Grade separated junctions,
Grade separated road ways with trees
Street lighting
Capacity around 1800 vehicles per lane per hour

4a (could be also 5a National / regional motorway through an urban area)

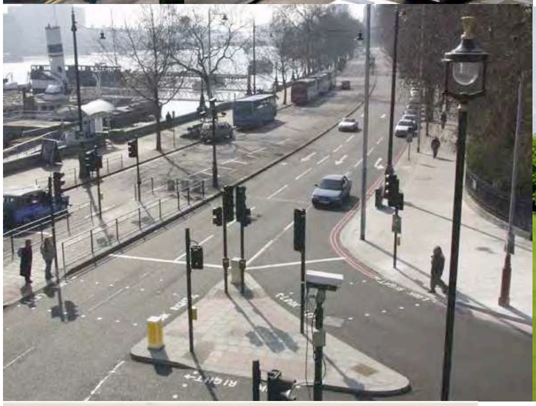


(Rural/urban) motorway (2x2 with bus lane) - It is a motorway M6 in the approach of London

Urban 4b: City primary road, major arterial (city scale network)

Speed limit:
90 to 110 km/h
2*2 lanes
Junction not grade- separated,
Grade-separated road ways
Street lighting
Capacity around 1500 vehicles per lane per hour

4b – trunk road



4b urban trunk road, major arterial

(Left: could be also an Urban 3 road category)

Other illustrations

Urban 3: District distributor, inter-district road

Speed limit:
50 km/h
2*2 lanes (left)
2*1 lanes (right)
Grade separated road ways
Sidewalks
Parking area on road side
Capacity around 800 vehicles per lane per hour

Speed limit:
50 to 70 km/h
2*2 lanes
Sidewalk
Grade separated road ways (right)
No parking
Capacity around 1000 vehicles per lane per hour

Speed limit:
50 km/h
1*2 lanes in one way
Sidewalks
Parking area on road side
Specific cycles lane
Bus lane
Capacity around 800 vehicles per lane per hour

Urban 3: District distributor, inter-district road (cont.)

Other illustrations

Urban 2: Local distributor

Speed limit:
30 to 50 km/h
Capacity maximum 600 vehicles per hour
One way road
Parking area on road side
Sidewalks

Speed limit:
50 km/h
Capacity maximum in vehicles per hour:
- Left: 800
- Right: 2000

2*1 lanes
Parking area on road side
Sidewalks

Speed limit:
50 km/h
Capacity maximum 1600 vehicles per hour
2*1 lanes (road ways separated with a mark)
Parking on road side
Sidewalks

With traffic calming

Urban 2: Local distributor (cont.)

in fact a trunk road (A-road)

Other illustrations

Urban 1: Access road

Speed limit:
30 km/h
Capacity around 300 vehicles per hour
One way road
Parking on road side
Sidewalks

Speed limit 50 km/h
Capacity around 700 vehicles per hour
2*1 lanes
- Left: No parking area, sidewalks, cycles on a specific lane
- Middle: Parking on road side,, sidewalks
- Right: No marks, parking on road side

Residential roads (2x1)

With traffic calming

Urban 1: Access road (cont.)

Others illustrations

Annex 16: Description of reference test patterns and cycles

Reference Test Pattern number and characteristics			Reference test cycle	Average speed (km/h)	Average positive acceleration (m/s²)	Stop duration (%)	Stop/km
7	Urban	Stop&go	OSCAR.H1, OSCAR.H2, OSCAR.H3, TRL.WSL_CongestedTraffic	7	0,70	35	16,3
3	Urban	Congested, stops	Artemis.urban_3	9	0,98	58	10,2
2	Urban	Congested, low speeds	Artemis.urban_4	12	0,83	19	16,7
1	Urban	Dense	Artemis.urban, Artemis.urban_1	17	0,82	29	5,2
4	Urban	Free-flowing	Artemis.urban_5	22	0,80	10	4,3
5	Urban	Free-flow, unsteady	Artemis.urban_2	32	0,84	9	2,3
6	Rural	Low speed	Artemis.rural_3	43	0,62	3	0,5
11	Rural	Unsteady	Artemis.rural, Artemis.rural_1	58	0,71	3	0,3
9	Rural	Steady	Artemis.rural_2	66	0,69	0	0,0
10	Rural	Main roads, unsteady	Artemis.rural_4	79	0,58	0	0,0
8	Rural	Main roads	Artemis.rural_5	88	0,38	0	0,0
14	Motorway	Unsteady	Artemis.motorway_150_2	104	0,63	0	0,0
15	Motorway	Stable	EMPA.BAB, modemHyzem.motorway, TRL.MotorwayM113	115	0,32	0	0,0
13	Motorway		Artemis.motorway_130, Artemis.motorway_150_1	119	0,53	0	0,0
12	Motorway	High speed	Artemis.motorway_150, Artemis.motorway_150_3, Artemis.motorway_150_4	125	0,48	0	0,0

Table 32: *Definition and average characteristics of the reference test patterns and corresponding reference test cycles, sorted by the average speed. Stable cycles are in blue, unstable ones in red.*

Reference Test Pattern number and characteristics			Speed (km/h)			Stops		Accelerations		
			Average	Running speed	Max. Speed	duration (%)	Frequency / km	Average positive acc.	Acc. /km	Strong acc./km
7	Urban	Stop&go	7,1	11,1	41	35,4	16,3	0,70	10,6	1,7
3	Urban	Congested, stops	8,7	20,8	46	58,2	10,2	0,98	6,8	5,1
2	Urban	Congested, low speeds	11,7	14,4	40	18,6	16,7	0,83	16,7	4,8
1	Urban	Dense	16,9	23,7	55	28,7	5,2	0,82	8,0	2,2
4	Urban	Free-flowing	21,5	23,9	44	10,3	4,3	0,80	11,5	4,3
5	Urban	Free-flow, unsteady	31,6	34,6	58	8,5	2,3	0,84	5,2	1,7
6	Rural	Low speed	43,1	44,3	69	2,7	0,5	0,62	3,6	0,5
11	Rural	Unsteady	58,0	60,0	101	3,4	0,3	0,71	3,1	0,5
9	Rural	Steady	65,9	65,9	84	0,0	0,0	0,69	0,6	0,0
10	Rural	Main roads, unsteady	78,5	78,5	112	0,0	0,0	0,58	1,3	0,0
8	Rural	Main roads	87,6	87,6	104	0,0	0,0	0,38	0,5	0,0
14	Motorway	Unsteady	103,5	103,5	128	0,0	0,0	0,63	1,8	0,2
15	Motorway	Stable	115,3	115,3	146	0,1	0,02	0,13	0,06	0,0
13	Motorway		118,8	118,8	132	0,0	0,0	0,53	0,4	0,02
12	Motorway	High speed	124,6	124,6	150	0,0	0,0	0,48	0,5	0,02

Table 33: *Detailed characteristics of the references test cycles (combination of one or several cycles), sorted by the average speed.*

Annex 17: Reference emissions according to the Reference Test Patterns

Reference Test Patterns	Av. speed	**diesel**					**petrol**				
		pre-Euro 1	Euro 1	Euro 2	Euro 3	Euro 4	pre-Euro 1	Euro 1	Euro 2	Euro 3	Euro 4
CO [g/km]	km/h										
1 Urban dense	17	0.898	0.455	0.470	0.210	0.342	21.873	4.348	1.618	0.747	0.151
2 Congested urban, low speeds	12	0.826	0.400	0.534	0.316	0.128	26.857	2.318	2.098	0.965	0.297
3 Congested urban, stops	9	1.166	0.926	0.858	0.549	0.057	33.682	3.069	1.235	1.249	0.341
4 Free-flowing urban	22	0.859	0.535	0.420	0.225	0.076	19.936	3.760	1.686	0.776	0.255
5 Free-flow urban, unsteady	32	0.641	0.504	0.454	0.199	0.072	16.434	2.617	1.022	0.504	0.117
6 Rural	43	0.480	0.299	0.214	0.154	0.013	8.969	0.676	0.320	0.297	0.093
7 Stop and go	7	2.370	0.859	0.839	0.239	0.251	49.482	9.969	2.117	0.363	0.220
8 Main roads	88	0.295	3.469	0.061	0.017	0.001	3.326	0.907	0.388	0.371	0.236
9 Rural steady	66	0.436	0.234	0.145	0.090	0.008	6.678	0.582	0.267	0.317	0.123
10 Main roads, unsteady	79	0.414	0.265	0.125	0.034	0.003	11.199	1.652	1.087	1.212	0.858
11 Rural unsteady	58	0.423	0.234	0.144	0.055	0.005	11.039	2.265	1.461	0.785	1.382
12 Motorway, high speed	125	0.380	0.352	0.051	0.023	0.019	14.800	2.861	3.299	3.892	5.236
13 Motorway	119	0.401	0.155	0.064	0.013	0.011	16.141	1.088	2.618	3.196	0.543
14 Motorway, unsteady	104	0.399	0.292	0.076	0.016	0.013	14.569	1.343	1.034	2.875	0.681
15 Motorway, stable	115	0.419	0.290	0.066	0.012	0.010	9.650	4.279	1.667	2.011	0.348
Number of data		*226*	*191*	*1029*	*815*	*26*	*1123*	*735*	*1856*	*3190*	*293*
HC [g eq. C_3H_8 / km]											
1 Urban dense	17	0.177	0.077	0.073	0.030	0.030	3.221	0.387	0.161	0.029	0.005
2 Congested urban, low speeds	12	0.137	0.069	0.117	0.072	0.024	3.327	0.511	0.228	0.035	0.006
3 Congested urban, stops	9	0.225	0.108	0.137	0.079	0.028	4.234	0.527	0.173	0.050	0.002
4 Free-flowing urban	22	0.222	0.050	0.079	0.043	0.009	2.456	0.425	0.136	0.027	0.004
5 Free-flow urban, unsteady	32	0.147	0.042	0.059	0.030	0.015	2.344	0.284	0.085	0.017	0.001
6 Rural	43	0.055	0.026	0.047	0.028	0.018	1.020	0.108	0.037	0.012	0.000
7 Stop and go	7	0.437	0.093	0.142	0.078	0.036	4.530	0.748	0.192	0.012	0.012
8 Main roads	88	0.054	0.029	0.021	0.013	0.008	0.377	0.041	0.035	0.014	0.005
9 Rural steady	66	0.045	0.018	0.034	0.021	0.013	0.769	0.086	0.032	0.013	0.003
10 Main roads, unsteady	79	0.065	0.024	0.026	0.016	0.010	1.189	0.134	0.060	0.032	0.016
11 Rural unsteady	58	0.075	0.041	0.027	0.013	0.008	1.434	0.153	0.048	0.019	0.004
12 Motorway, high speed	125	0.038	0.024	0.014	0.004	0.005	0.795	0.139	0.039	0.036	0.002
13 Motorway	119	0.036	0.024	0.017	0.006	0.007	1.071	0.072	0.034	0.085	0.017
14 Motorway, unsteady	104	0.046	0.023	0.017	0.009	0.011	1.198	0.109	0.036	0.057	0.011
15 Motorway, stable	115	0.069	0.032	0.022	0.014	0.017	0.586	0.150	0.052	0.020	0.010
Number of data		*242*	*254*	*1215*	*935*	*26*	*1123*	*745*	*1953*	*3264*	*296*

The extrapolated figures are coloured:

- Yellow: urban cases and corresponding extrapolations
- Green: rural cases and corresponding extrapolations
- Blue: motorway cases and corresponding extrapolations
- In red: other extrapolation by similarity between close vehicle categories

Reference Test Patterns	Av. speed km/h	**diesel**					**petrol**				
		pre-Euro 1	Euro 1	Euro 2	Euro 3	Euro 4	pre-Euro 1	Euro 1	Euro 2	Euro 3	Euro 4
NOx [g eq. NO_2 / km]											
1 Urban dense	17	0.781	1.000	1.060	0.970	0.566	1.447	0.465	0.543	0.130	0.075
2 Congested urban, low speeds	12	1.452	1.017	1.308	1.448	0.665	1.217	0.412	0.428	0.125	0.039
3 Congested urban, stops	9	1.463	1.417	1.685	1.744	0.618	1.768	0.464	0.638	0.129	0.072
4 Free-flowing urban	22	1.102	0.813	0.888	1.004	0.339	1.051	0.239	0.368	0.100	0.045
5 Free-flow urban, unsteady	32	0.838	0.742	0.778	0.925	0.441	1.241	0.304	0.419	0.097	0.041
6 Rural	43	0.611	0.506	0.500	0.652	0.394	0.641	0.233	0.159	0.043	0.024
7 Stop and go	7	1.538	1.456	1.406	1.562	0.633	1.166	0.678	0.244	0.071	0.046
8 Main roads	88	0.550	0.571	0.459	0.616	0.373	1.019	0.259	0.188	0.044	0.020
9 Rural steady	66	0.556	0.479	0.492	0.616	0.372	1.010	0.228	0.131	0.040	0.015
10 Main roads, unsteady	79	0.690	0.599	0.815	1.119	0.677	2.041	0.394	0.344	0.095	0.021
11 Rural unsteady	58	0.559	0.581	0.652	0.664	0.401	1.413	0.378	0.318	0.079	0.071
12 Motorway, high speed	125	0.912	0.838	1.145	1.187	1.115	3.073	0.511	0.152	0.091	0.083
13 Motorway	119	0.900	0.807	0.963	0.787	0.740	2.700	0.437	0.355	0.064	0.017
14 Motorway, unsteady	104	0.677	0.661	0.857	1.077	1.012	2.220	0.403	0.300	0.067	0.008
15 Motorway, stable	115	0.799	0.785	0.727	0.957	0.899	1.901	0.543	0.270	0.047	0.024
Number of data		*228*	*254*	*1205*	*934*	*26*	*1122*	*740*	*1944*	*3262*	*296*
PM mass [g/km]											
1 Urban dense	17	0.114	0.090	0.095	0.044	0.041	0.004	0.004	0.002	0.006	0.002
2 Congested urban, low speeds	12	0.125	0.099	0.061	0.042	0.038	0.004	0.004	0.002	0.003	0.001
3 Congested urban, stops	9	0.098	0.078	0.051	0.051	0.038	0.004	0.004	0.002	0.003	0.001
4 Free-flowing urban	22	0.240	0.040	0.072	0.044	0.024	0.004	0.004	0.002	0.001	0.001
5 Free-flow urban, unsteady	32	0.195	0.081	0.073	0.044	0.044	0.005	0.005	0.002	0.002	0.001
6 Rural	43	0.033	0.027	0.029	0.012	0.014	0.004	0.004	0.003	0.003	0.002
7 Stop and go	7	0.524	0.086	0.069	0.044	0.046	0.021	0.021	0.012	0.035	0.015
8 Main roads	88	0.069	0.056	0.047	0.036	0.039	0.004	0.004	0.005	0.002	0.001
9 Rural steady	66	0.035	0.029	0.031	0.013	0.015	0.004	0.004	0.003	0.003	0.002
10 Main roads, unsteady	79	0.080	0.066	0.070	0.030	0.033	0.004	0.004	0.003	0.003	0.002
11 Rural unsteady	58	0.105	0.066	0.070	0.030	0.033	0.004	0.004	0.003	0.003	0.002
12 Motorway, high speed	125	0.207	0.224	0.085	0.088	0.135	0.026	0.026	0.014	0.009	0.006
13 Motorway	119	0.096	0.088	0.091	0.037	0.105	0.002	0.002	0.006	0.004	0.002
14 Motorway, unsteady	104	0.148	0.088	0.085	0.037	0.057	0.011	0.011	0.006	0.004	0.002
15 Motorway, stable	115	0.148	0.088	0.067	0.049	0.076	0.018	0.018	0.010	0.003	0.002
Number of data		*108*	*71*	*424*	*460*	*26*	*(3)*	*102*	*277*	*202*	*36*

The extrapolated figures are coloured:

- Yellow: urban cases and corresponding extrapolations
- Green: rural cases and corresponding extrapolations
- Blue: motorway cases and corresponding extrapolations
- Red: other extrapolation by similarity between close vehicle categories
- Brown: use of another vehicle category by lack of data

Reference Test Patterns	Av. speed	**diesel**					**petrol**				
		pre-Euro 1	Euro 1	Euro 2	Euro 3	Euro 4	pre-Euro 1	Euro 1	Euro 2	Euro 3	Euro 4
CO₂ [g/km]	km/h										
1 Urban dense	17	219	220	233	232	205	236	237	262	264	281
2 Congested urban, low speeds	12	292	251	290	298	233	375	345	344	347	381
3 Congested urban, stops	9	372	336	356	359	219	482	372	422	415	447
4 Free-flowing urban	22	205	191	203	203	151	236	225	237	237	267
5 Free-flow urban, unsteady	32	178	191	192	187	156	205	186	195	210	235
6 Rural	43	149	131	138	146	130	153	151	163	154	156
7 Stop and go	7	358	282	327	302	269	416	397	460	370	378
8 Main roads	88	130	142	125	119	106	136	140	138	136	139
9 Rural steady	66	141	125	131	130	116	136	136	138	140	143
10 Main roads, unsteady	79	190	179	179	165	147	174	165	189	179	183
11 Rural unsteady	58	143	147	151	143	128	151	155	156	165	170
12 Motorway, high speed	125	216	209	186	171	181	197	185	195	197	190
13 Motorway	119	220	173	187	153	162	184	174	156	177	198
14 Motorway, unsteady	104	198	177	171	149	158	170	158	155	169	189
15 Motorway, stable	115	181	184	179	162	172	173	172	172	171	182
Number of data		*238*	*254*	*1208*	*935*	*26*	*1123*	*745*	*1948*	*3264*	*293*

The extrapolated figures are coloured:

- Green: rural cases and corresponding extrapolations
- Blue: motorway cases and corresponding extrapolations

CO$_2$ according to the engine size (liter)

Reference Test Patterns	Av. speed	diesel								
		pre-Euro 1		Euro 1		Euro 2		Euro 3		Euro 4
		<2 l	>2 l	<2 l	>2 l	<2 l	>2 l	<2 l	>2 l	<2 l
CO₂ [g/km]	km/h									
1 Urban dense	17	205	275	215	267	229	267	219	275	205
2 Congested urban, low speeds	12	258	327	251	360	280	366	296	362	233
3 Congested urban, stops	9	322	397	336	446	348	423	360	322	219
4 Free-flowing urban	22	201	222	191	262	194	256	203	205	151
5 Free-flow urban, unsteady	32	169	209	191	249	187	232	186	198	156
6 Rural	43	129	169	131	175	133	168	146	179	130
7 Stop and go	7	356	367	282	398	311	400	273	409	269
8 Main roads	88	116	157	122	211	118	162	119	151	106
9 Rural steady	66	123	158	125	168	127	162	130	159	116
10 Main roads, unsteady	79	165	216	179	235	174	219	165	202	147
11 Rural unsteady	58	129	200	143	176	148	177	138	164	128
12 Motorway, high speed	125	157	227	209	254	182	218	170	174	181
13 Motorway	119	234	215	173	234	185	227	150	164	162
14 Motorway, unsteady	104	132	198	177	228	166	210	149	183	158
15 Motorway, stable	115	158	238	162	283	158	227	162	160	172
Number of data		*166*	*72*	*238*	*16*	*1060*	*148*	*812*	*123*	*26*

The extrapolated figures are coloured:

- Green: as RTP 15
- Red: based on the shapes of Euro 1 <2 l and of Euro 2 >2 l
- blue: based on the engine size influence of Euro 2 and Euro 3
- Yellow: as Euro 4 all capacities considered

CO_2 according to the engine size (liter)

Reference Test Patterns	Av. speed	petrol								
		pre-Euro 1			Euro 1			Euro 2		
		<1.4 l	1.4-2 l	>2 l	<1.4 l	1.4-2 l	>2 l	<1.4 l	1.4-2 l	>2 l
CO_2 [g/km]	km/h									
1 Urban dense	17	175	242	366	211	272	287	220	283	351
2 Congested urban, low speeds	12	284	322	496	285	397	418	302	373	467
3 Congested urban, stops	9	355	406	655	308	455	479	363	485	642
4 Free-flowing urban	22	174	225	335	198	240	264	199	256	303
5 Free-flow urban, unsteady	32	160	200	273	174	197	193	175	209	208
6 Rural	43	125	139	191	131	180	190	150	163	214
7 Stop and go	7	301	434	683	380	430	453	355	476	671
8 Main roads	88	112	138	176	122	139	175	120	143	187
9 Rural steady	66	109	125	168	119	159	167	124	141	187
10 Main roads, unsteady	79	136	153	224	145	191	201	191	187	228
11 Rural unsteady	58	120	162	211	143	165	184	138	168	190
12 Motorway, high speed	125	154	169	253	177	193	268	184	207	196
13 Motorway	119	159	155	243	154	195	271	149	186	252
14 Motorway, unsteady	104	140	142	221	145	175	244	145	181	245
15 Motorway, stable	115	142	179	234	154	177	246	147	160	250
Number of data		*375*	*544*	*204*	*333*	*373*	*39*	*878*	*885*	*185*

Reference Test Patterns	Av. speed	petrol					
		Euro 3			Euro 4		
		<1.4 l	1.4-2 l	>2 l	<1.4 l	1.4-2 l	>2 l
CO_2 [g/km]	km/h						
1 Urban dense	17	235	280	332	225	266	340
2 Congested urban, low speeds	12	311	373	449	305	342	563
3 Congested urban, stops	9	377	437	552	362	388	675
4 Free-flowing urban	22	212	253	312	216	233	404
5 Free-flow urban, unsteady	32	190	223	271	192	214	339
6 Rural	43	143	162	184	131	152	229
7 Stop and go	7	289	405	452	270	378	421
8 Main roads	88	123	147	150	126	136	180
9 Rural steady	66	131	147	159	124	141	197
10 Main roads, unsteady	79	164	190	211	162	185	236
11 Rural unsteady	58	152	172	203	147	169	190
12 Motorway, high speed	125	179	200	207	164	184	198
13 Motorway	119	164	193	204	179	194	242
14 Motorway, unsteady	104	154	183	197	163	192	236
15 Motorway, stable	115	144	180	195	145	182	197
Number of data		*1460*	*1618*	*186*	*104*	*107*	*82*

The extrapolated figures are coloured:

- Blue: based on 1.4–2 l and on the global ratio 1.4-2 l / >2 l
- Purple: based on 1.4 – 2 l and RTP 15
- Green: based on 1.4 – 2 l and RTP 1 and 7
- Brown: based on 1.4 – 2 l and RTP 9 and 11
- Red: based on Euro 3 and ratio with 1.4 – 2 l.

Annex 18: Conversion ratios between standards based on Reference Test Pattern emissions

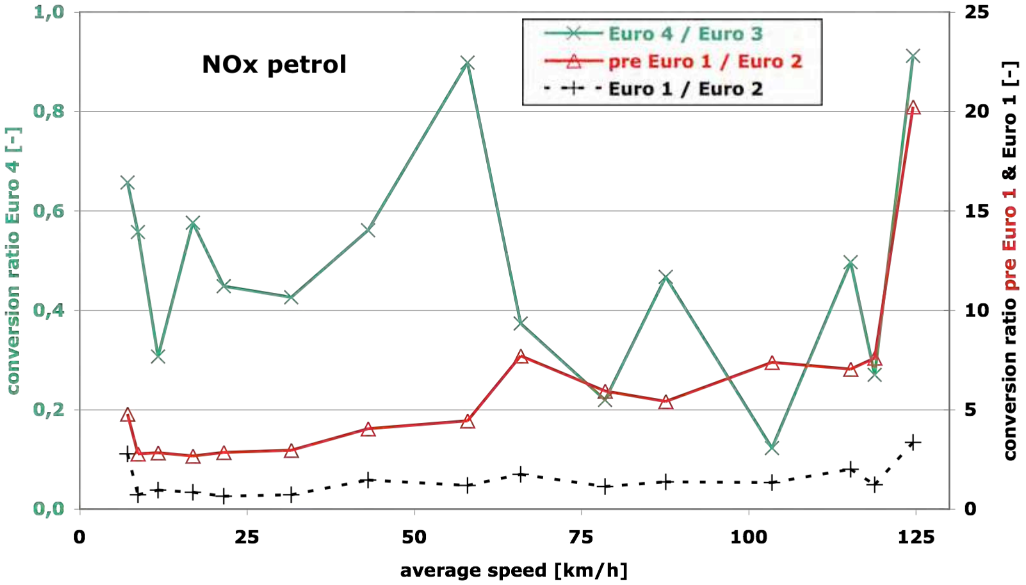


Figure 63: *Conversion ratios of NOx emission factors of Reference test patterns for petrol cars between pre Euro 1, Euro 1, Euro 4, and resp. Euro 2, Euro 2, Euro 3 categories. Emission factors are in Annex 17.*

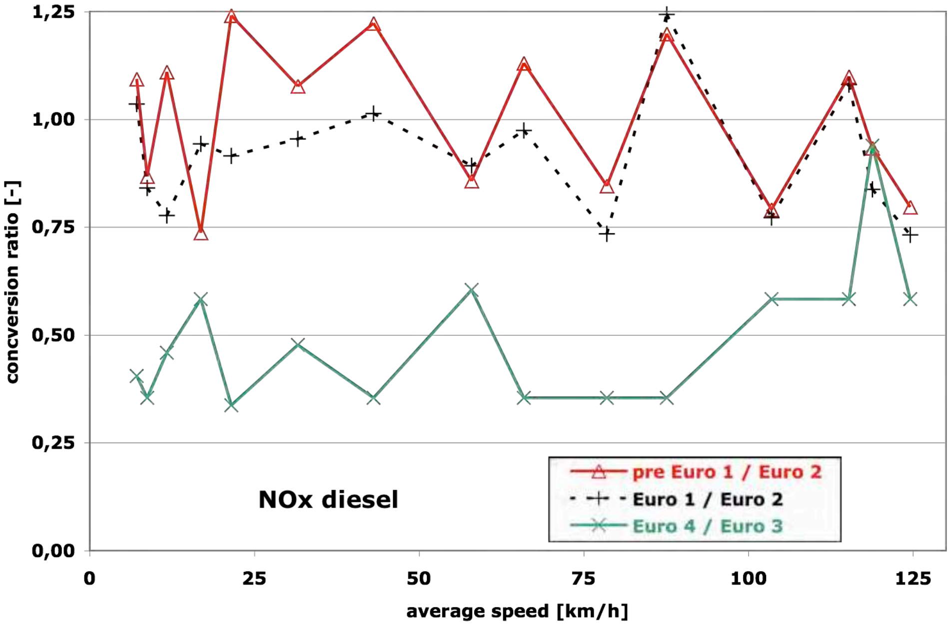


Figure 64: *Conversion ratios of NOx emission factors of Reference test patterns for diesel cars between pre Euro 1, Euro 1, Euro 4, and resp. Euro 2, Euro 2, Euro 3 categories. Emission factors are in Annex 17.*

Annex 19: Traffic Situations according to Reference Test Patterns

Description and then weighting coefficients of the Reference Test Patterns of each of the 69 traffic situation for which speed data are available, and for the 19 additional traffic situations corresponding to each of the Artemis driving cycles or sub-cycles, for the emission computation.

The traffic situations 1002, 1009 and 1016 are macro traffic situations (in red) resp. for urban, rural and motorway situations. They are composed of one or two Reference test patterns. A last traffic situation is the most macroscopic situation corresponding to the European traffic situation. Alternative macro traffic situations are composite ones.

ID speed curve	Area	Road Category	Speed limit (km/h)	Gradient, sinuosity	Traffic condition	Identification
40	Rural	national/regional motorway	130	Flat, non-sinuous	Free-flow	110131
87	Rural	national/regional motorway	150	Flat, non-sinuous	Free-flow	110141
88	Rural	national/regional motorway	150	Flat, non-sinuous	Free-flow	110141
89	Rural	national/regional motorway	150	Flat, non-sinuous	Free-flow	110141
84	Rural	Semi-motorway	90	Flat, non-sinuous	Free-flow	112091
75	Rural	Semi-motorway	90	Flat, non-sinuous	Heavy traffic	112092
77	Rural	Semi-motorway	90	Flat, non-sinuous	Saturated	112093
74	Rural	Semi-motorway	110	Flat, non-sinuous	Free-flow	112111
67	Rural	Semi-motorway	110	Flat, non-sinuous	Heavy traffic	112112
68	Rural	Semi-motorway	110	Flat, non-sinuous	Saturated	112113
43	Rural	national/regional trunk road	70	Flat, non-sinuous	Free-flow	120071
41	Rural	national/regional trunk road	90	Flat, non-sinuous	Free-flow	120091
51	Rural	national/regional trunk road	90	Hilly, sinuous	Free-flow	120091
52	Rural	national/regional trunk road	90	Hilly, sinuous	Free-flow	120091
42	Rural	national/regional trunk road	90	Hilly, sinuous	Free-flow	120091
46	Rural	distributor, inter village road	50	Flat, non-sinuous	Free-flow	130051
45	Rural	distributor, inter village road	70	Mountainous, sinuous	Free-flow	130071
53	Rural	distributor, inter village road	90	Mountainous, sinuous	Free-flow	130091
54	Rural	distributor, inter village road	90	Mountainous, sinuous	Free-flow	130091
55	Rural	distributor, inter village road	90	Mountainous, sinuous	Free-flow	130091
56	Rural	distributor, inter village road	90	Mountainous, sinuous	Free-flow	130091
44	Rural	distributor, inter village road	90	Mountainous, sinuous	Free-flow	130091
57	Rural	distributor, inter village road	90	Mountainous, sinuous	Free-flow	130091
58	Rural	distributor, inter village road	90	Mountainous, sinuous	Free-flow	130091
59	Rural	distributor, inter village road	90	Mountainous, sinuous	Free-flow	130091
60	Rural	distributor, inter village road	90	Mountainous, sinuous	Free-flow	130091

ID speed curve	Area	Road Category	Speed limit (km/h)	Gradient, sinuosity	Traffic condition	Identification
2	Urban	national/regional motorway	110	Flat, non-sinuous	Free-flow	210111
3	Urban	national/regional motorway	110	Flat, non-sinuous	Heavy traffic	210112
4	Urban	national/regional motorway	110	Flat, non-sinuous	Stop and go	210114
1	Urban	national/regional motorway	130	Flat, non-sinuous	Free-flow	210131
8	Urban	City or urban motorway	80	Flat, non-sinuous	Heavy traffic	211082
7	Urban	City or urban motorway	90	Flat, non-sinuous	Free-flow	211091
5	Urban	City or urban motorway	100	Flat, non-sinuous	Free-flow	211101
6	Urban	City or urban motorway	100	Flat, non-sinuous	Heavy traffic	211102
16	Urban	City primary road, major arterial	50	Flat, non-sinuous	Free-flow	221051
17	Urban	City primary road, major arterial	50	Flat, non-sinuous	Heavy traffic	221052
18	Urban	City primary road, major arterial	50	Flat, non-sinuous	Saturated	221053
19	Urban	City primary road, major arterial	50	Flat, non-sinuous	Stop and go	221054
12	Urban	City primary road, major arterial	60	Flat, non-sinuous	Free-flow	221061
13	Urban	City primary road, major arterial	60	Flat, non-sinuous	Heavy traffic	221062
14	Urban	City primary road, major arterial	60	Flat, non-sinuous	Saturated	221063
15	Urban	City primary road, major arterial	60	Flat, non-sinuous	Stop and go	221064
9	Urban	City primary road, major arterial	80	Flat, non-sinuous	Free-flow	221081
10	Urban	City primary road, major arterial	80	Flat, non-sinuous	Heavy traffic	221082
11	Urban	City primary road, major arterial	80	Flat, non-sinuous	Stop and go	221084
28	Urban	Districts distributor, inter district road	50	Flat, non-sinuous	Free-flow	230051
29	Urban	Districts distributor, inter district road	50	Flat, non-sinuous	Heavy traffic	230052
30	Urban	Districts distributor, inter district road	50	Flat, non-sinuous	Saturated	230053
31	Urban	Districts distributor, inter district road	50	Flat, non-sinuous	Stop and go	230054
24	Urban	Districts distributor, inter district road	60	Flat, non-sinuous	Free-flow	230061
25	Urban	Districts distributor, inter district road	60	Flat, non-sinuous	Heavy traffic	230062
26	Urban	Districts distributor, inter district road	60	Flat, non-sinuous	Saturated	230063
27	Urban	Districts distributor, inter district road	60	Flat, non-sinuous	Stop and go	230064
20	Urban	Districts distributor, inter district road	70	Flat, non-sinuous	Free-flow	230071
21	Urban	Districts distributor, inter district road	70	Flat, non-sinuous	Heavy traffic	230072
22	Urban	Districts distributor, inter district road	70	Flat, non-sinuous	Saturated	230073
23	Urban	Districts distributor, inter district road	70	Flat, non-sinuous	Stop and go	230074
32	Urban	Local distributor	50	Flat, non-sinuous	Free-flow	240051
47	Urban	Local distributor	50	Flat, non-sinuous	Saturated	240053
33	Urban	Local distributor	50	Flat, non-sinuous	Stop and go	240054

ID speed curve	Area	Road Category	Speed limit (km/h)	Gradient, sinuosity	Traffic condition	Identification
38	Urban	Local access	30	Flat, non-sinuous	Free-flow	250031
50	Urban	Local access	30	Flat, non-sinuous	Saturated	250033
39	Urban	Local access	30	Flat, non-sinuous	Stop and go	250034
36	Urban	Local access	40	Flat, non-sinuous	Free-flow	250041
49	Urban	Local access	40	Flat, non-sinuous	Saturated	250043
37	Urban	Local access	40	Flat, non-sinuous	Stop and go	250044
34	Urban	Local access	50	Flat, non-sinuous	Free-flow	250051
48	Urban	Local access	50	Flat, non-sinuous	Saturated	250053
35	Urban	Local access	50	Flat, non-sinuous	Stop and go	250054

Description of the traffic situation corresponding to the Artemis driving cycles or sub-cycles, and weighting factors of macro traffic situations according to these cycles.

ID speed curve	Name of the cyle or sub-cycle	Area	Road Category	Speed limit (km/h)	Gradient, sinuosity	Traffic condition	absolute weight (André, 2004a)			
							European	European composite	European 130	European 130 composite
1002	TS_Artemis.urban	*Urban*	*Districts distributor, inter district road*	*50*	*Flat, non-sinuous*	*Heavy traffic*	0.292		0.292	
1003	TS_Artemis.urban_1	*Urban*	*Districts distributor, inter district road*	*50*	*Flat, non-sinuous*	*Saturated*		0.059		0.059
1004	TS_Artemis.urban_2	*Urban*	*Districts distributor, inter district road*	*50*	*Flat, non-sinuous*	*Saturated*		0.122		0.122
1005	TS_Artemis.urban_3	*Urban*	*Districts distributor, inter district road*	*50*	*Flat, non-sinuous*	*Stop and go*		0.037		0.037
1006	TS_Artemis.urban_4	*Urban*	*Districts distributor, inter district road*	*50*	*Flat, non-sinuous*	*Stop and go*		0.024		0.024
1007	TS_Artemis.urban_5	*Urban*	*Districts distributor, inter district road*	*50*	*Flat, non-sinuous*	*Heavy traffic*		0.051		0.051
1009	TS_Artemis.road	*Rural*	*distributor, inter village road*	*90*	*Flat, non-sinuous*	*Heavy traffic*	0.449		0.449	
1010	TS_Artemis.road_1	*Rural*	*distributor, inter village road*	*90*	*Flat, non-sinuous*	*Heavy traffic*		0.108		0.108
1011	TS_Artemis.road_2	*Rural*	*distributor, inter village road*	*90*	*Flat, non-sinuous*	*Heavy traffic*		0.072		0.072
1012	TS_Artemis.road_3	*Rural*	*distributor, inter village road*	*90*	*Flat, non-sinuous*	*Heavy traffic*		0.088		0.088
1013	TS_Artemis.road_4	*Rural*	*distributor, inter village road*	*90*	*Flat, non-sinuous*	*Heavy traffic*		0.118		0.118
1014	TS_Artemis.road_5	*Rural*	*national/regional trunk road*	*90*	*Flat, non-sinuous*	*Heavy traffic*		0.062		0.062
1016	TS_Artemis.motorway	*Rural*	*national/regional motorway*	*130*	*Flat, non-sinuous*	*Heavy traffic*	0.259			
1017	TS_Artemis.motorway_1	*Rural*	*national/regional motorway*	*130*	*Flat, non-sinuous*	*Heavy traffic*		0.093		0.095
1018	TS_Artemis.motorway_2	*Rural*	*national/regional motorway*	*130*	*Flat, non-sinuous*	*Heavy traffic*		0.060		0.063
1019	TS_Artemis.motorway_3	*Rural*	*national/regional motorway*	*130*	*Flat, non-sinuous*	*Heavy traffic*		0.062		
1020	TS_Artemis.motorway_4	*Rural*	*national/regional motorway*	*130*	*Flat, non-sinuous*	*Heavy traffic*		0.044		
1022	TS_Artemis.motorway130	*Rural*	*national/regional motorway*	*130*	*Flat, non-sinuous*	*Heavy traffic*			0.259	
1023	TS_Artemis.motorway130_3	*Rural*	*national/regional motorway*	*130*	*Flat, non-sinuous*	*Heavy traffic*				0.061
1024	TS_Artemis.motorway130_4	*Rural*	*national/regional motorway*	*130*	*Flat, non-sinuous*	*Heavy traffic*				0.040

Weighting coefficients of the Reference Test Patterns

ID speed curve	Identification	Number of coefficients	Reference test patterns														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
			Urban, Dense	Urban, Congested, low speeds	Urban, Congested, stops	Urban, Free-flowing	Urban, Free-flow, unsteady	Rural, Low speed	Urban, Stop&go	Rural, Main roads	Rural, Steady	Rural, Main roads, unsteady	Rural, Unsteady	Motorway, High speed	Motorway,	Motorway, Unsteady	Motorway, Stable
40	110131	1													1.00		
87	110141	1												1.00			
88	110141	1												1.00			
89	110141	1												1.00			
84	112091	1								1.00							
75	112092	2								0.84			0.16				
77	112093	2								0.68			0.32				
74	112111	1															1.00
67	112112	3										0.11	0.11				0.79
68	112113	4								0.18		0.19				0.27	0.37
43	120071	1									1.00						
41	120091	2								0.75			0.25				
51	120091	2										0.34	0.66				
52	120091	2									0.25		0.75				
42	120091	2									0.60		0.40				
46	130051	1						1.00									
45	130071	2									0.20		0.80				
53	130091	2					0.42						0.58				
54	130091	2					0.39						0.61				
55	130091	1											1.00				
56	130091	2					0.17						0.83				
44	130091	1								1.00							
57	130091	2									0.18		0.82				
58	130091	2									0.78		0.22				
59	130091	2						0.42					0.58				
60	130091	2									0.13		0.87				

ID speed curve	Identification	Number of coefficients	Reference test patterns														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
			Urban, Dense	Urban, Congested, low speeds	Urban, Congested, stops	Urban, Free-flowing	Urban, Free-flow, unsteady	Rural, Low speed	Urban, Stop&go	Rural, Main roads	Rural, Steady	Rural, Main roads, unsteady	Rural, Unsteady	Motorway, High speed	Motorway,	Motorway, Unsteady	Motorway, Stable
2	210111	3								0.17		0.12					0.72
3	210112	2								0.52		0.48					
4	210114	3	0.25	0.37		0.38											
1	210131	2													0.32		0.68
8	211082	1									1.00						
7	211091	2								0.47			0.53				
5	211101	4								0.55		0.21	0.11				0.13
6	211102	3								0.23		0.50	0.27				
16	221051	1						1.00									
17	221052	3	0.15				0.66						0.20				
18	221053	3	0.38	0.35					0.28								
19	221054	3	0.44		0.11				0.45								
12	221061	1									1.00						
13	221062	2					0.25						0.75				
14	221063	2				0.47	0.53										
15	221064	2		0.18		0.82											
9	221081	3								0.64		0.14	0.22				
10	221082	2					0.14						0.86				
11	221084	2				0.22			0.78								
28	230051	2					0.26	0.74									
29	230052	2					0.32	0.68									
30	230053	3	0.45		0.17		0.38										
31	230054	2	0.71		0.29												
24	230061	2					0.26						0.74				
25	230062	2					0.37	0.64									
26	230063	2	0.33				0.68										
27	230064	2	0.89		0.11												
20	230071	2									0.70		0.30				
21	230072	2									0.19		0.82				
22	230073	2	0.51				0.49										
23	230074	2	0.29		0.71												
32	240051	2					0.79	0.21									
47	240053	2	0.88			0.12											
33	240054	2	0.27		0.73												

ID speed curve	Identification	Number of coefficients	Reference test patterns														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
			Urban, Dense	Urban, Congested, low speeds	Urban, Congested, stops	Urban, Free-flowing	Urban, Free-flow, unsteady	Rural, Low speed	Urban, Stop&go	Rural, Main roads	Rural, Steady	Rural, Main roads, unsteady	Rural, Unsteady	Motorway, High speed	Motorway,	Motorway, Unsteady	Motorway, Stable
38	250031	2		0.43		0.57											
50	250033	2	0.25	0.75													
39	250034	2	0.57	0.43													
36	250041	2					0.44	0.57									
49	250043	2	0.25		0.75												
37	250044	2	0.46		0.55												
34	250051	3				0.26	0.55	0.19									
48	250053	1				1.00											
35	250054	2			0.82				0.18								
1002	(urban)	1	1.00														
1003		2	0.83	0.18													
1004		1					1.00										
1005		1			1.00												
1006		1		1.00													
1007		1				1.00											
1009	(rural)	1											1.00				
1010		1											1.00				
1011		1									1.00						
1012		1						1.00									
1013		1										1.00					
1014		1								1.00							
1016	(motorw.)	2												0.66	0.34		
1017		1													1.00		
1018		1														1.00	
1019		1												1.00			
1020		1												1.00			
1022		1													1.00		
1023		2													0.86		0.14
1024		4												0.15	0.39	0.19	0.27
(European)		4	0.292										0.449	0.171	0.088		
(urban composite)		5	0.167	0.118	0.127	0.175	0.418										
(rural composite)		5						0.196		0.138	0.160	0.263	0.241				
(motorway comp.)		3												0.409	0.359	0.232	
(European comp.)		13	0.049	0.034	0.037	0.051	0.122	0.088		0.062	0.072	0.118	0.108	0.106	0.093	0.060	

Annex 20: First emission functions according to speed

Fuel	Pol.	Em. Std.	Eng. cap.	Equation	a	b	c	d	e	f
Petrol	CO	Euro 1	All	(a+cx+ex^2)/(1+bx+dx^2)	11.15320657	0.128685358	-0.101503184	-0.000946631	0.000676883	
		Euro 2	All	(a+cx+ex^2)/(1+bx+dx^2)	60.5256484	3.499185561	0.152041368	-0.025212142	-0.000168436	
		Euro 3	All	(a+cx)/(1+bx+dx^2)	71.70537699	35.40666116	11.44056269	-0.248305435		
		Euro 4	All	(a+cx)/(1+bx+dx^2)	0.136241403	-0.014097785	-0.000890931	4.98989E-05		
	HC	Euro 1	All	(a+cx)/(1+bx+dx^2)	1.349382393	0.177893263	-0.006773162	-0.001272345		
		Euro 2	All	(a+cx)/(1+bx+dx^2)	4108199.712	1659966.156	-14511.33287	-10274.30718		
		Euro 3	All	(a+cx+ex^2)/(1+bx+dx^2)	0.055738489	0.036523691	-0.001102637	-0.000187725	1.25168E-05	
		Euro 4	All	a+cx+ex^2	0.011794753		-3.47291E-05		8.83984E-07	
	NOx	Euro 1	All	a+cx+ex^2	0.524738843		-0.010032005		9.3607E-05	
		Euro 2	All	(a+cx+ex^2)/(1+bx+dx^2)	0.283553945	-0.023390896	-0.008689173	0.000443086	0.000114496	
		Euro 3	All	(a+cx+ex^2)/(1+bx+dx^2)	0.092949654	-0.012205513	-0.001490763	3.97074E-05	6.52593E-06	
		Euro 4	All	a+cx+ex^2	0.106315088		-0.001583401		7.09522E-06	
	FC	Euro 1	<1.4	(a+cx)/(1+bx+dx^2)	190.507552	0.12906099	1.168450492	-0.000723245		
			1.4-2	(a+cx)/(1+bx+dx^2)	199.4956409	0.089245234	0.346249391	-0.00053801		
			>2.0	(a+cx)/(1+bx+dx^2)	230.0493812	0.069360039	-0.042598666	-0.000446338		
		Euro 2	<1.4	(a+cx+ex^2)/(1+bx+dx^2)	207.5258849	0.106724999	-0.565372973	-0.000500018	0.014269811	
			1.4-2	(a+cx+ex^2)/(1+bx+dx^2)	346.7895261	0.216777874	2.725507153	-0.000910501	0.004281619	
			>2.0	(a+cx)/(1+bx+dx^2)	1539.083363	0.869030335	19.07516558	-0.003625444		
		Euro 3	<1.4	(a+cx+ex^2)/(1+bx+dx^2)	169.5677149	0.092836318	0.418324779	-0.000451903	0.004986675	
			1.4-2	(a+cx+ex^2)/(1+bx+dx^2)	217.0507554	0.095972866	0.253496927	-0.000421365	0.009651816	
			>2.0	(a+cx)/(1+bx+dx^2)	253.2315995	0.090248921	0.501611867	-0.000468596		
		Euro 4	<1.4	(a+cx+ex^2)/(1+bx+dx^2)	136.2596257	0.026010686	-1.6475393	0.000227505	0.031222313	
			1.4-2	(a+cx+ex^2)/(1+bx+dx^2)	173.7871418	0.068499485	0.364000835	-0.000246809	0.008739103	
			>2.0	(a+cx)/(1+bx+dx^2)	285.0309931	0.072817643	-0.137181957	-0.000416216		

Fuel	Pol.	Em. Std.	Eng. cap.	Equation	a	b	c	d	e	f
diesel	CO	Euro 1	All	a+cx+ex^2	0.995787107		-0.018772272		0.000108897	
		Euro 2	All	a+cx+ex^2	0.899711748		-0.017417942		8.77264E-05	
		Euro 3	All	a+cx+ex^2+f/x	0.168637914		-0.002924642		1.24692E-05	1.095523771
	HC	Euro 1	<2.0	(a+cx+ex^2)/(1+bx+dx^2)	0.142282293	0.013776793	-0.002007015	-1.89805E-05	1.14818E-05	
			>2.0	a+cx+ex^2	0.159093324		-0.002460623		1.2138E-05	
		Euro 2	<2.0	(a+cx+ex^2)/(1+bx+dx^2)	0.161234564	0.074607063	-0.001206231	-0.000335154	3.6292E-06	
			>2.0	(a+cx+ex^2)/(1+bx+dx^2)	50057.71156	38026.82833	8033.150994	1150.215685	-26.61240156	
		Euro 3	<2.0	(a+cx+ex^2)/(1+bx+dx^2)	0.096521338	0.103000188	-0.000238314	-7.23554E-05	1.93331E-06	
			>2.0	a+cx+ex^2	0.09124181		-0.001682045		8.93739E-06	
	NOx	Euro 1	All	(a+cx+ex^2)/(1+bx+dx^2)	3.095607924	0.141192269	-0.006175676	-0.000503115	0.000421523	
		Euro 2	All	(a+cx+ex^2)/(1+bx+dx^2)	2.398097386	0.076699891	-0.011576236	-0.000499938	0.000119971	
		Euro 3	All	(a+cx+ex^2)/(1+bx+dx^2)	2.816405992	0.198187904	0.066873591	-0.001431755	-0.000463021	
	PM	Euro 1	All	a+cx+ex^2	0.113797282		-0.00232673		2.2605E-05	
		Euro 2	All	a+cx+ex^2	0.086648957		-0.001421038		1.05592E-05	
		Euro 3	All	a+cx+ex^2	0.051499481		-0.000880012		8.11743E-06	
	FC	Euro 1	<2.0	(a+cx+ex^2)/(1+bx+dx^2)	144.6558266	0.067270936	-0.187518726	-0.000316808	0.009469874	
			>2.0	(a+cx+ex^2)/(1+bx+dx^2)	194.8899162	0.071928682	0.18722555	-0.000332188	0.009988524	
		Euro 2	<2.0	(a+cx+ex^2)/(1+bx+dx^2)	142.2433943	0.049847679	-0.651010459	-0.000169078	0.013231348	
			>2.0	(a+cx+ex^2)/(1+bx+dx^2)	194.8899162	0.071928682	0.18722555	-0.000332188	0.009988524	
		Euro 3	<2.0	(a+cx+ex^2)/(1+bx+dx^2)	161.9413328	0.122981533	2.183647639	-0.000775895	-0.012779891	
			>2.0	(a+cx+ex^2)/(1+bx+dx^2)	194.8899162	0.071928682	0.18722555	-0.000332188	0.009988524	

Fuel	Pol.	Em. Std.	Eng. cap.	Equation	a	b	c	d	e	f
hybrid	CO	Euro 4	All	a+cx+ex^2	0.000195394		3.80498E-05		-2.639E-07	
	HC	Euro 4	All	a+cx+ex^2	0.000550112		-8.5364E-06		4.94E-08	
	NOx	Euro 4	All	a+cx+ex^2	0.014777397		-0.000419555		4.2874E-06	
	FC	Euro 4	All	a+cx+ex^2	19.36416487		0.060648361		0.000753966	

Annex 21: Emission functions acc. to speed based on RTP

Poll.	fuel	emis. st.	shape	order	a_0	a_1 (x 100) but power: a_1	a_2 (x 10^4)	a_3 (x 10^6)	a_4 (x 10^8)	a_5 (x 10^{10})
CO	petrol	pre Euro	Polyn.	4	58.406	-285.959	596.918	-536.230	176.000	
		Euro 1	Polyn.	4	8.745	-41.392	83.669	-73.635	24.200	
		Euro 2	Polyn.	3	1.881	-0.626	-5.965	5.793		
		Euro 3	Polyn.	2	1.290	-4.327	4.914			
		Euro 4	Polyn.	2	0.635	-2.808	3.343			
	diesel	pre Euro	Power		3.96601	-0.51532				
		Euro 1	Power		1.19086	-0.27682				
		Euro 2	Power		7.40303	-0.98045				
		Euro 3	Polyn.	3	0.43407	-1.03732	0.87366	-0.24979		
		Euro 4	Power		2.77591	-1.29524				
HC	petrol	pre Euro	Polyn.	4	5.57576	-19.06828	29.83329	-21.15120	5.66600	
		Euro 1	Polyn.	4	0.86030	-3.33338	5.62091	-4.33858	1.28345	
		Euro 2	Polyn.	3	0.26336	-0.80892	0.93837	-0.34909		
		Euro 3	Polyn.	3	0.04445	-0.14022	0.19680	-0.06000		
		Euro 4	Polyn.	2	0.00531	-0.00402	0.00697			
	diesel	pre Euro	Power		1.25580	-0.70775				
		Euro 1	Polyn.	4	0.13189	-0.52432	0.95521	-0.75054	0.21400	
		Euro 2	Power		0.77744	-0.79025				
		Euro 3	Power		0.49531	-0.84573				
		Euro 4	Power		0.07700	-0.46350				
NOx	petrol	pre Euro	Polyn.	3	1.53321	-1.47482	0.82264	0.98000		
		Euro 1	Polyn.	4	0.75701	-3.02899	6.51466	-5.75000	1.90000	
		Euro 2	Polyn.	3	0.55040	-1.05604	1.20798	-0.44300		
		Euro 3	Polyn.	2	0.12700	-0.16341	0.09709			
		Euro 4	Polyn.	3	0.04399	0.12464	-0.39284	0.24000		
	diesel	pre Euro	Polyn.	5	2.09128	-9.00145	22.72120	-29.65980	19.29000	-5.00000
		Euro 1	Polyn.	5	2.02150	-9.98383	27.72528	-38.90979	26.93542	-7.14000
		Euro 2	Polyn.	4	2.12341	-8.88250	18.62007	-16.94811	5.77800	
		Euro 3	Polyn.	4	2.25413	-9.34458	19.32741	-16.37522	5.03116	
		Euro 4	Polyn.	3	0.78737	-1.91047	2.56467	-0.70976		
PM	petrol	pre Euro	Polyn.	2	0.01217	-0.03603	0.03265			
		Euro 1	Polyn.	2	0.01217	-0.03603	0.03265			
		Euro 2	Polyn.	3	0.00733	-0.02552	0.03021	-0.00589		
		Euro 3	Power		0.00823	-0.22603				
		Euro 4	Power		0.00223	-0.04700				
	diesel	pre Euro	Polyn.	4	0.40498	-1.87681	3.91769	-3.57870	1.23000	
		Euro 1	Polyn.	3	0.08428	0.01414	-0.30544	0.27900		
		Euro 2	Polyn.	2	0.07940	-0.08685	0.07496			
		Euro 3	Polyn.	2	0.05995	-0.12415	0.10291			
		Euro 4	Polyn.	4	0.05030	-0.11472	0.28151	-0.40400	0.24000	

Formulae polynomial functions: See next page
Formulae of power function is: emis. factor [g/km] = $a_0 . V^{a1}$
with V [km/h]

For V > 125 km/h, EF(V) = EF(125)

poll.	fuel	eng. size	emis. st.	shape	order	a_0	a_1 (x 100)	a_2 (x 10^4)	a_3 (x 10^6)	a_4 (x 10^8)	a_5 (x 10^{10})
CO_2	petrol	all	pre Euro	Polyn.	5	675.3	-3704.9	10309.8	-13928.8	9050.0	-2240.0
			Euro 1	Polyn.	5	571.3	-2888.2	7817.7	-10321.3	6574.8	-1600.8
			Euro 2	Polyn.	5	666.4	-3654.8	10057.5	-13086.5	8002.0	-1835.4
			Euro 3	Polyn.	4	521.9	-1982.3	3928.5	-3390.2	1080.3	
			Euro 4	Polyn.	4	523.7	-1654.4	2635.4	-1771.5	442.9	
	diesel	all	pre Euro	Polyn.	5	541.5	-2914.5	8401.0	-11717.0	7895.2	-2032.0
			Euro 1	Polyn.	4	389.9	-1337.6	2561.0	-2081.5	633.9	
			Euro 2	Polyn.	4	444.3	-1623.8	3124.2	-2562.1	779.4	
			Euro 3	Polyn.	4	429.7	-1516.1	2930.1	-2480.6	780.2	
			Euro 4	Polyn.	4	313.2	-959.4	1756.5	-1407.2	439.8	
	petrol	<1.4 l	pre Euro	Polyn.	5	497.2	-2768.1	8112.8	-11624.8	8031.3	-2117.7
			Euro 1	Polyn.	4	476.9	-2085.1	4515.6	-4151.0	1377.7	
			Euro 2	Polyn.	4	505.9	-2304.4	5188.9	-4898.6	1645.6	
			Euro 3	Polyn.	4	434.0	-1508.0	2919.6	-2507.4	804.4	
			Euro 4	Polyn.	4	395.0	-1136.0	1731.8	-1086.0	248.5	
		1.4-2 l	pre Euro	Polyn.	5	651.7	-3857.4	11781.8	-17414.1	12247.4	-3265.0
			Euro 1	Polyn.	5	670.9	-3566.4	9913.8	-13327.0	8578.9	-2105.0
			Euro 2	Polyn.	5	709.2	-3739.9	9864.6	-12420.5	7413.7	-1667.0
			Euro 3	Polyn.	4	561.3	-2131.9	4130.1	-3447.4	1060.1	
			Euro 4	Polyn.	4	497.8	-1728.7	3078.9	-2307.1	634.8	
		>2 l	pre Euro	Polyn.	5	1052.7	-6376.0	18827.6	-26956.0	18485.8	-4829.1
			Euro 1	Polyn.	4	644.8	-2708.0	5396.3	-4487.5	1374.7	
			Euro 2	Polyn.	4	931.8	-4584.3	9521.8	-8018.4	2382.1	
			Euro 3	Polyn.	4	649.8	-2267.5	4049.3	-3182.1	935.8	
			Euro 4	Polyn.	3	672.0	-1723.5	2025.0	-755.0	0.0	
	diesel	<2 l	pre Euro	Polyn.	4	456.0	-1942.3	4084.8	-3634.5	1181.3	
			Euro 1	Polyn.	4	393.5	-1404.4	2833.6	-2476.7	808.3	
			Euro 2	Polyn.	4	433.5	-1642.2	3290.2	-2819.0	890.1	
			Euro 3	Polyn.	4	412.0	-1449.1	2818.8	-2388.6	750.2	
			Euro 4	Polyn.	4	313.2	-959.4	1756.5	-1407.2	439.8	
		>2 l	pre Euro	Polyn.	5	549.9	-2691.2	7720.0	-10806.3	7315.9	-1892.0
			Euro 1	Polyn.	4	539.9	-1888.4	3346.0	-2344.2	584.6	
			Euro 2	Polyn.	4	542.1	-2003.9	3796.4	-2993.4	863.3	
			Euro 3	Polyn.	5	534.9	-2403.7	5923.5	-6819.5	3685.9	-752.0
			Euro 4								

Formulae of 2nd order polynomial function is: emis. factor [g/km] = $a_0+a_1V+a_2V^2$
Formulae of 3rd order polynomial function is: emis. factor [g/km] = $a_0+a_1V+a_2V^2+a_3V^3$
Formulae of 4th order polynomial function is: emis. factor [g/km] = $a_0+a_1V+a_2V^2+a_3V^3+a_4V^4$
Formulae of 5th order polynomial function is: emis. factor [g/km] = $a_0+a_1V+a_2V^2+a_3V^3+a_4V^4+a_5V^5$
with V [km/h]

For V > 125 km/h, EF(V) = EF(125)

Annex 22: Hot emission factors for unregulated VOCs and PAHs

Only ambient temperatures >18°C are considered.

	petrol			diesel		
EU emis. standard	Average (mg/km)	SD (mg/km)	Nber tests	Average (mg/km)	SD (mg/km)	Nber tests
			benzene			
pre-Euro 1	47.5	58.9	147	*8.7*	*0.0*	*1*
Euro 1	16.0	18.5	14	*5.3*	*9.0*	*8*
Euro 2	7.8	10.0	55	1.4	2.1	174
Euro 3	1.4	3.3	190	3.3	5.3	10
Euro 4	0.3	0.7	10	na	na	na
			1.3-butadiene			
pre-Euro 1	*69.3*	*37.4*	*8*	na	na	na
Euro 1	0.38	0.53	10	*0.21*	*0.13*	*4*
Euro 2	0.00	0.00	29	0.00	0.00	8
Euro 3	0.03	0.10	61	0.00	0.00	7
Euro 4	0.0	0.0	10	na	na	na
			ethylbenzene			
pre-Euro 1	na	na	na	*11.2*	*6.9*	*5*
Euro 1	*4.0*	*4.5*	*8*	*0.9*	*1.3*	*10*
Euro 2	12.1	23.6	36	6.3	8.7	38
Euro 3	4.4	13.1	34	*22.6*	*15.3*	*3*
Euro 4	0.0	0.0	10	na	na	na
			toluene			
pre-Euro 1	208.1	204.4	147	*31.7*	*27.9*	*5*
Euro 1	15.6	12.5	14	*12.7*	*18.3*	*11*
Euro 2	16.0	32.9	60	3.0	10.0	187
Euro 3	2.5	9.8	191	*6.2*	*7.1*	*9*
Euro 4	0.2	0.5	10	na	na	na
			hexane			
pre-Euro 1	*67.5*	*44.8*	*8*	*na*	*na*	*na*
Euro 1	3.7	3.6	10	*na*	*na*	*na*
Euro 2	1.0	1.1	25	*0.3*	*0.7*	*8*
Euro 3	0.1	0.3	49	*0.7*	*1.6*	*7*
			formaldehyde			
pre-Euro 1	32.0	14.4	18	*11.4*	*10.0*	*13*
Euro 1	0.8	1.0	31	*6.4*	*10.0*	*20*
Euro 2	1.0	1.4	51	4.8	6.8	52
Euro 3	0.4	0.5	65	3.6	4.1	20

	petrol			diesel		
EU emis. standard	Average (mg/km)	SD (mg/km)	Nber tests	Average (mg/km)	SD (mg/km)	Nber tests
acetaldehyde						
pre-Euro 1	11.5	11.4	18	*7.7*	*6.1*	*13*
Euro 1	0.7	0.6	31	*6.6*	*8.3*	*20*
Euro 2	0.7	0.9	50	4.1	5.5	52
Euro 3	0.2	0.2	65	1.7	2.4	20
acrolein						
pre-Euro 1	*2.6*	*0.1*	*3*	*1.5*	*2.0*	*12*
Euro 1	0.0	0.1	9	*0.8*	*1.2*	*6*
Euro 2	0.4	1.2	13	0.3	0.7	29
Euro 3	0.0	0.0	12	na	na	na
Sum of considered VOCs (from data above)						
Pre-Euro 1	438	371	na	*72*	*53*	*na*
Euro 1	41	41	127	*33*	*48*	*na*
Euro 2	39	71	319	20	35	548
Euro 3	8.9	27	667	38	36	na
Euro 4	0.6	1.3	na	na	na	na
benzo(a)pyrene						
Pre-Euro 1	0.025	0.027	8	*	*	*3*
Euro 1	0.002	0.003	11	*	*	*8*
Euro 2	0.007	0.002	39	0.000	0.001	53
Euro 3	0.007	0.001	47	0.001	0.001	24
Sum of the 6 most carcinogenic PAHs						
Pre-Euro 1	*0.112*	*0.104*	*8*	*	*	*3*
Euro 1	0.008	0.007	11	*	*	*8*
Euro 2	0.004	0.010	23	0.002	0.006	37
Euro 3	0.005	0.007	47	0.003	0.003	24
Euro 4	na	na	na	na	na	na

* average emission factor is not representative

Font in red italic means low sample size, average emission factor may not be representative

na: no data available

Annex 23: Emission factors for particle properties

Total particle population		Active surface area [m^2/km]			Total particle number [#/km] ×10^{-14}		
Category	Fuel specs (EN590)	Urban	Rural	Motorway	Urban	Rural	Motorway
PC diesel Euro-1	2000-2009	20.97	19.13	29.36	4.0	3.0	3.2
PC diesel Euro-2	2005-2009	16.82	17.05	27.77	2.1	2.0	4.3
	2000			36.19			7.1
PC diesel Euro-3	2005-2009	15.31	13.43	18.51	1.6	1.7	2.8
	2000			39.31			12.3
PC diesel Euro-3 DPF	2005-2009	0.012	0.013	0.22	0.00067	0.09	1.8
	2000		4.03	44.62		1.7	13.4
PC petrol Euro-1	later than 2000	0.68	0.43	0.50	0.088	0.073	0.18
PC petrol Euro-3	later than 2000	0.024	0.033	0.074	0.007	0.053	0.056
PC petrol Euro-3 DISI	later than 2000	2.04	1.77	2.48	0.15	0.11	0.90

Table 34: Emission factors for active surface area and particle number of the total particle population.

Solid particle population [#/km] ×10^{-13}	Number of solid particles <50 nm			Number of solid particles 50-100 nm		
Category	Urban	Rural	Motorway	Urban	Rural	Motorway
PC diesel Euro-1	8.5	8.6	7.2	9.3	7.8	7.3
PC diesel Euro-2	7.6	7.6	6.1	8.8	7.7	7.2
PC diesel Euro-3	7.9	7.1	5.8	8.7	6.8	6.9
PC diesel Euro-3 DPF	0.0055	0.0040	0.023	0.0023	0.0016	0.0094
PC petrol Euro-1	0.32	0.24	0.086	0.14	0.10	0.034
PC petrol Euro-3	0.0096	0.011	0.0055	0.0044	0.0054	0.0028
PC petrol Euro-3 DISI	0.81	0.61	0.28	0.65	0.36	0.19

Solid particle population [#/km] ×10^{-13}	Number of solid particles 100-1000 nm		
Category	Urban	Rural	Motorway
PC diesel Euro-1	5.4	3.8	4.0
PC diesel Euro-2	5.1	3.6	4.0
PC diesel Euro-3	4.5	3.2	3.5
PC diesel Euro-3 DPF	0.0016	0.0012	0.0028
PC petrol Euro-1	0.052	0.037	0.012
PC petrol Euro-3	0.0026	0.0034	0.0051
PC petrol Euro-3 DISI	0.41	0.21	0.15

Table 35: Emission factors for solid particle number in the size ranges 7-50 nm, 50-100 nm and 100 nm - 1 µm (aerodynamic diameter) - Fuel specifications later or equal to EN590:2000.

Annex 24: Equation of emission factors for LDVs

Fuel	Weight cat.	Standard Cat.	Poll.	Load range (%)	Equation factor E [g/km]; v = average speed [km/h]; p = load [%]
Diesel	N1-I	Pre-Euro-1	CO		$E= 5{,}83\times10^{-4}v^2 - 6{,}99\times10^{-2}v + 2{,}53$
			CO_2		$E= 0{,}146v^2 - 15{,}6v + 590$
			FC		$E= 4{,}75\times10^{-2}v^2 - 5{,}05v + 191$
			HC		$E= 9{,}92\times10^{-5}v^2 - 1{,}15\times10^{-2}v + 0{,}485$
			NOx		$E= 4{,}41\times10^{-4}v^2 - 4{,}46\times10^{-2}v + 1{,}69$
			PM [1]		$E= 5.8\times10^{-5}v^2-0.0086v+0.45$
		Euro-1	CO	0-25	$E= (-3{,}83\times10^{-6}v^2 + 3{,}30\times10^{-4}v + 1{,}28\times10^{-2})p+1{,}84\times10^{-4}v^2 - 2{,}50\times10^{-2}v + 1{,}26$
			CO_2	0-25	$E= (-0{,}0012v^2 + 0{,}0654v + 6{,}0995)p+(0{,}0249v^2 - 2{,}3223v + 176{,}92)$
			FC	7-25	$E= (-5{,}86\times10^{-5}v^2 + 8{,}84\times10^{-3}v - 4{,}91\times10^{-1})p^2+(0{,}0019v^2 - 0{,}2989v + 18{,}565)p+ 0{,}4963v - 32{,}605$
			HC [3]	7-25	$E= (2{,}42\times10^{-5}v - 2{,}43\times10^{-3})p^2+(-8{,}44\times10^{-4}v + 8{,}41\times10^{-2})p+ 0{,}0041v - 0{,}3375;\ E\geq0{,}04$
			NOx	7-25	$E= (4{,}80\times10^{-5}v - 6{,}80\times10^{-3})p^2+(-1{,}73\times10^{-3}v + 0{,}246)p+1{,}02\times10^{-2}v - 0{,}955$
			PM [2]		$E= -1{,}71\times10^{-5}v^2 + 2{,}419\times10^{-3}v + 2{,}31\times10^{-2}$
		Euro-2	CO		$E= 8{,}66\times10^{-5}v^2 - 1{,}56\times10^{-2}v + 0{,}912$
			CO_2		$E= 0{,}0245v^2 - 3{,}4055v + 273{,}56$
			FC		$E= 8{,}35\times10^{-3}v^2 - 1{,}20v + 84{,}3$
			HC		$E= 3{,}47\times10^{-5}v^2 - 6{,}17\times10^{-3}v + 0{,}293$
			NOx		$E= 2{,}23\times10^{-4}v^2 - 2{,}89\times10^{-2}v + 1{,}47$
			PM		$E= 1{,}50\times10^{-5}v^2 - 2{,}19\times10^{-3}v + 0{,}113$
	N1-II	Pre-Euro-1	CO	0-62	$E= (-2{,}11\times10^{-7}v^2 + 3{,}76\times10^{-5}v - 2{,}03\times10^{-3})p^2+(1{,}33\times10^{-5}v^2 - 2{,}70\times10^{-3}v + 0{,}161)p+(1{,}46\times10^{-4}v^2 - 1{,}14\times10^{-2}v + 0{,}398)$
			CO_2	0-62	$E= (6{,}21\times10^{-6}v^2 - 2{,}35\times10^{-3}v + 7{,}58\times10^{-2})p^2+(2{,}49\times10^{-4}v^2 + 7{,}25\times10^{-2}v - 4{,}04)p+0{,}0211v^2 - 3{,}7377v + 357{,}35$
			FC	0-62	$E= (2{,}45\times10^{-6}v^2 - 6{,}32\times10^{-4}v + 2{,}72\times10^{-2})p^2+(2{,}25\times10^{-2}v - 1{,}77)p+(7{,}98\times10^{-3}v^2 - 1{,}31 v + 125)$
			HC [3]	6-62	$E= (-5{,}29\times10^{-8}v^2 + 1{,}09\times10^{-5}v - 8{,}56\times10^{-4})p^2+(3{,}48\times10^{-6}v^2 - 7{,}24\times10^{-4}v + 5{,}76\times10^{-2})p -4{,}39\times10^{-5}*v^2 + 5{,}54\times10^{-3}v - 0{,}138;\ E\geq0{,}05$
			NOx [3]	0-62	$E= (-3{,}23\times10^{-5}v + 2{,}42\times10^{-3})p^2+(1{,}41\times10^{-3}v - 6{,}83\times10^{-2})p-1{,}17\times10^{-2}v + 1{,}61;\ E\geq0{,}5$
			PMm	6-50 [4]	$E= (-1{,}33\times10^{-8}v^2 + 9{,}48\times10^{-6}v - 1{,}02\times10^{-3})p^2+(4{,}72\times10^{-6}v^2 - 1{,}19\times10^{-3}v + 8{,}35\times10^{-2})p+2{,}82\times10^{-6}v^2 + 5{,}36\times10^{-3}v - 0{,}341$

[1]: MEET equation was used because of the lack of data for Artemis project

[2]: equation only according to the mean speed to avoid negative value

[3]: E limited by a minimum to avoid negative value

[4]: load range limited to avoid negative value

Fuel	Weight cat.	Standard Cat.	*Poll.*	Load range (%)	Equation factor E [g/km]; v = average speed [km/h]; p = load [%]
Diesel	N1-II	Euro-1	CO	5-32	$E=(4,998\times10^{-8}v^2 + 1,830\times10^{-5}v - 2,301\times10^{-3})p^2+(5,086\times10^{-6}v^2 - 1,822\times10^{-3}v + 0,1435)p+9,10\times10^{-5}v^2 - 1,48\times10^{-2}v + 0,499$
			CO_2	0-32	$E=(1,70\times10^{-4}v^2 - 1,37\times10^{-2}v + 1,38)p+2,81\times10^{-2}v^2 - 4,13v + 306$
			FC	0-32	$E=(-2,99\times10^{-6}v^2 + 7,84\times10^{-4}v - 8,45\times10^{-3})p^2+(8,33\times10^{-5}v^2 - 2,16\times10^{-2}v + 0,359)p+1,17\times10^{-2}v^2 - 1,60v + 108$
			HC [2]		$E= 2,51\times10^{-5} v^2 - 5,56\times10^{-3}v + 0,342$
			NOx	0-32	$E=(-6,47\times10^{-7}v^2 + 1,01\times10^{-4}v - 2,49\times10^{-3})p^2+(2,85\times10^{-5}v^2 - 4,14\times10^{-3}v + 0,106)p+1,83\times10^{-5}v^2 + 2,66\times10^{-3}v + 0,640$
			PM	0-32	$E=(4,85\times10^{-6}v - 1,03\times10^{-4})p^2+(-1,85\times10^{-4}v + 6,48\times10^{-3})p+1,17\times10^{-3}v + 2,88\times10^{-2}$
		Euro-2	CO		$E= 1,65\times10^{-5}v^2 - 5,19\times10^{-3}v + 0,412$
			CO_2		$E= 0,0343v^2 - 5,1159v + 367,86$
			FC		$E= 0,0105v^2 - 1,513v + 107,74$
			HC		$E= -5,49\times10^{-7}v^2 - 4,38\times10^{-4}v + 7,29\times10^{-2}$
			NOx		$E= 1,85\times10^{-4}v^2 - 2,16\times10^{-2}v + 1,42$
			PM		$E=5,03\times10^{-6}v^2-7\times10^{-4}v+0,049$
		Euro-3	Only one vehicle		
	N1-III	Pre-Euro-1	CO	0-100	$E=(1,37\times10^{-7}v^2 - 1,27\times10^{-5}v + 3,98\times10^{-4})p^2+(-1,22\times10^{-5}v^2 + 1,12\times10^{-3}v - 3,73\times10^{-2})p+ 4,12\times10^{-4}v^2 - 4,86\times10^{-2}v + 2,25$
			CO_2	0-100	$E=(-4,06\times10^{-6}v^2 + 7,71\times10^{-4}v + 2,86\times10^{-2})p^2+(3,84\times10^{-4}v^2 - 6,11\times10^{-2}v - 4,07)p+ 0,0444v^2 - 6,1129v + 509,84$
			FC	0-100	$E=(-2,74\times10^{-6}v^2 + 3,79\times10^{-4}v + 7,49\times10^{-3})p^2+(2,52\times10^{-4}v^2 - 3,25\times10^{-2}v - 1,11)p+ 0,0115v^2 - 1,6528v + 161,8$
			HC	0-100	$E=(6,67\times10^{-9}v^2 - 6,78\times10^{-7}v + 5,95\times10^{-5})p^2+(-6,16\times10^{-7}v^2 + 9,76\times10^{-5}v - 8,61\times10^{-3})p+3,77\times10^{-5}v^2 - 6,82\times10^{-3}v + 0,436$
			NOx	0-100	$E=(2,66\times10^{-7}v^2 - 4,83\times10^{-5}v + 2,66\times10^{-3})p^2+(-2,62\times10^{-5}v^2 + 4,79\times10^{-3}v - 0,262)p+(0,0009v^2 - 0,1511v + 8,3427)$
			PM	0-100	$E=(1,34\times10^{-6}v + 2,89\times10^{-5})p^2+(-1,36\times10^{-4}v - 3,88\times10^{-3})p+1,49\times10^{-5}v^2 + 6,51\times10^{-4}v + 0,352$
		Euro-1	CO	7-50	$E=(1,79\times10^{-7}p^2-1,87\times10^{-5}p+4,3\times10^{-4})v^2+(-2,1\times10^{-5}p^2+2,66\times10^{-3}p-6,94\times10^{-2})v+(2,88\times10^{-3}p^2-0,195p+4,05)$
			CO_2	7-50	$E=(2,56\times10^{-5}p^2-1,89\times10^{-3}p+0,0654)v^2+(7,4\times10^{-4}p^2+0,108p-7,2126)v+(0,304p^2-19,8p+662,1)$
			FC	7-50	$E=(2,37\times10^{-5}p^2-1,3\times10^{-3}p+0,0279)v^2+(-2,73\times10^{-3}p^2+0,176p-3,8935)v+(0,193p^2-11,1p+262,46)$
			HC [3]	7-50	$E=(1,219\times10^{-7}v^2 - 2,872\times10^{-5}v + 2,059\times10^{-3})p^2+(-7,883\times10^{-6}v^2 + 1,743\times10^{-3}v - 1,157\times10^{-1})p+ 1,357\times10^{-4}v^2 - 2,788\times10^{-2}v + 1,679;\ E\geq0$
			NOx		$E= 3,75\times10^{-4}v^2 - 4,51\times10^{-2}v + 2,24$
			PM [3]	0-50	$E=(-2,176\times10^{-6}v^2 + 3,695\times10^{-4}v - 1,760\times10^{-2})p+(8,98\times10^{-5}v^2 - 1,33\times10^{-2}v + 0,642);\ E\geq0,03$
		Euro-2	CO [3]	0-30	$E=(9,25\times10^{-7}v^2 - 1,40\times10^{-4}v + 4,75\times10^{-3})p^2+(-3,36\times10^{-5}v^2 + 5,14\times10^{-3}v - 1,90\times10^{-1})p+2,49\times10^{-4}v^2 - 4,00\times10^{-2}v + 1,88;\ E\geq0,01$
			CO_2	0-30	$E=(2,08\times10^{-4}v^2 - 2,51\times10^{-2}v + 0,331)p^2+(-4,08\times10^{-3}v^2 + 5,83\times10^{-1}v - 9,10)p+5,49\times10^{-2}v^2 - 7,89v + 436$
			FC	0-30	$E=(-1,74\times10^{-5}v^2 + 2,24\times10^{-3}v - 0,111)p^2+(6,85\times10^{-4}v^2 - 8,21\times10^{-2}v + 4,54)p+8,66\times10^{-3}v^2 - 1,19v + 87,6$
			HC [3]	0-30	$E=(1,85\times10^{-7}v^2 - 2,67\times10^{-5}v + 1,08\times10^{-3})p^2+(-6,87\times10^{-6}v^2 + 1,02\times10^{-3}v - 4,35\times10^{-2})p+ 5,81\times10^{-5}v^2 - 8,99\times10^{-3}v + 0,427;\ E\geq0,01$
			NOx		$E= 4,03\times10^{-4}v^2 - 4,82\times10^{-2}v + 2,25$
			PM	0-30	$E=(-8,52\times10^{-8}v^2 + 1,26\times10^{-5}v - 3,42\times10^{-4})p^2+(2,49\times10^{-6}v^2 - 3,36\times10^{-4}v + 8,83\times10^{-3})p+8,98\times10^{-6}v^2 - 1,25\times10^{-3}v + 0,114$

[2]: equation only according to the mean speed to avoid negative value

[3]: E limited by a minimum to avoid negative value

Fuel	Weight cat.	Standard Cat.	Poll.	Load range (%)	Equation factor E [g/km]; v = average speed [km/h]; p = load [%]
Petrol	N1-I	Pre-Euro-1	CO		$E= 7,75x10^{-3}v^2 -0,889v + 32,4$ (Only hot cycles)
			CO_2		$E= 0,0219v^2 - 3,388v + 307,69$
			FC		$E= 0,0092v^2 - 1,233v + 103,07$
			HC		$E= 1,95x10^{-4}v^2 - 4,51x10^{-2}v + 3,22$
			NOx		$E= -2,24x10^{-5}v^2 + 2,71x10^{-2}v + 1,04$
		Euro-1	CO		$E= 3,09x10^{-3}v^2 - 0,273v + 8,07$
			CO_2		$E= 0,0372v^2 - 5,3731v + 398,66$
			FC		$E= 0,0092v^2 - 1,233v + 103,07$
			HC		$E= 5,13x10^{-5}v^2 - 7,93x10^{-3}v + 0,422$
			NOx		$E= -8,15x10^{-6}v^2 - 1,03x10^{-3}v +0, 729$
	N1-II	Pre-Euro-1	CO	0-100	$E=(1,97x10^{-5}v^2 - 4,42x10^{-3}v + 0,35)p+0,0087v^2 - 1,2106v + 42,747$
			CO_2		$E= 0,055v^2 - 8,0246v + 486,46$
			FC		$E= 0,023v^2 - 3,3138v + 182,39$
			HC		$E= 8,91x10^{-4}v^2 - 0,142v + 5,80$
			NOx	0-100	$E=(-8,80x10^{-6}v^2 + 1,43x10^{-3}v + 4,47x10^{-3})p+3,38x10^{-4}v^2 - 3,94x10^{-2}v + 1,83$
		Euro-1	CO [3]	12-43	$E=(-7,56x10^{-6}*v^2 + 6,92x10^{-4}v - 1,29x10^{-2})p^2+(4,86x10^{-4}*v^2 - 4,64x10^{-2}v + 0,974)p+(-5,08x10^{-3}v^2 + 0,497v - 9,28); E\geq 0,01$
			CO_2	0-100	$E=(-1,96x10^{-5}v^2 + 3,18x10^{-3}v - 0,111)p^2+(1,57x10^{-3}v^2 - 0,244v + 8,82)p+4,21x10^{-2}v^2 - 5,70v + 371$
			FC		$E= 0,0587v^2 - 8,578v + 501,9$
			HC		$E= 5,81x10^{-5}v^2 - 8,35x10^{-3}v + 0,396$
			NOx		$E= 9,43x10^{-5}v^2 – 6,58x10^{-3}v + 0,484$
		Euro-2	CO	4-56	$E=(8,37x10^{-7}v^2 - 1,43x10^{-4}v + 6,56x10^{-3})p^2+(-1,19x10^{-5}v^2 + 5,52x10^{-3}v - 0,255)p+6,86x10^{-4}v^2 – 0,112v + 4,63$
			CO_2		$E= 8,48x10^{-2}v^2 - 12,8v + 635$
			FC		$E= 0,0248v^2 - 3,719v + 191,22$
			HC	4-56	$E=(1,69x10^{-7}v^2 - 3,32x10^{-5}v + 1,83x10^{-3})p^2+(-5,85x10^{-6}v^2 + 1,24x10^{-3}v - 6,60x10^{-2})p+7,10x10^{-5}v^2 - 1,33x10^{-2}v +0,641$
			NOx	0-56	$E=(4,29x10^{-7}v^2 - 3,58x10^{-5}v + 1,45x10^{-3})p^2+(-1,56x10^{-5}v^2 + 1,46x10^{-3}v - 5,16x10^{-2})p+1,52x10^{-4}v^2 - 1,61x10^{-2}v + 0,684$
	N1-III	Euro-1	CO [3]	7-87	$E=(-1,41x10^{-4}v^2 + 1,27x10^{-2}v + 5,24x10^{-2})p+(6,31x10^{-3}v^2 - 0,642v + 15,3); E\geq 1$
			CO_2		$E= 0,0803v^2 - 11,572v + 632,69$
			FC		$E= 0,0272v^2 - 3,8434v + 208,16$
			HC [2]		$E= 1,14x10^{-4}v^2 - 1,41x10^{-2}v + 0,692$
			NOx [2]		$E= 9,52x10^{-5}v^2 - 8,96x10^{-3}v + 0,565$
		Euro-2	CO		$E= 7,40x10^{-4}v^2 – 0,122v + 6,16$
			CO_2		$E= 0,0876v^2 - 13,253v + 644,56$
			FC		$E= 0,0275v^2 - 4,1999v + 207,56$
			HC [3]		$E= 1,01x10^{-5}v^2 - 5,56x10^{-3}v + 0,484; E\geq 0,01$
			NOx		$E= 1,20x10^{-5}v^2 - 5,43x10^{-3}v + 0,535$

[2]: equation only according to the mean speed to avoid negative value

[3]: E limited by a minimum to avoid negative value

In the load range: use of the equation E(v,p)
Between 0 % and the minimal border: use the value of the inferior border
Between the maximal border and 100 %: use the value of the superior border

Annex 25: Equation of the mileage influence for petrol cars

Petrol Euro 1 & 2		Capacity class [l]	Average mileage [km]	a	b	Value at ≥ 120 000 km
y(urban) for V≤19 km/h (urban situation)	CO	≤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
	HC	≤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
	NOx	all	44 931	1.598E-05	0.282	2.20
y(rural) for V≥63 km/h (rural situation)	CO	≤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
	HC	≤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
	NOx	all	47 186	1.220E-05	0.424	1.89

Table 36: Emission degradation correction factor y = a x Mileage + b, for Euro 1 and Euro 2 petrol vehicles. Mileage expressed in km, y normalised for the corresponding average mileage.

Petrol Euro 3 & 4		Capacity class [l]	Average mileage [km]	a	b	Value at ≥ 160 000 km
y(urban) for V≤19 km/h (urban situation)	CO	≤1.4	32 407	7.129E-06	0.769	1.91
		>1.4	16 993	2.670E-06	0.955	1.38
	HC	≤1.4	31 972	3.419E-06	0.891	1.44
		>1.4	17 913	0	1	1
	NOx	≤1.4	31 313	0	1	1
		>1.4	16 993	3.986E-06	0.932	1.57
y(rural) for V≥63 km/h (rural situation)	CO	≤1.4	30 123	1.502E-06	0.955	1.20
		>1.4	26 150	0	1	1
	HC	all	28 042	0	1	1
	NOx	all	26 150	0	1	1

Table 37: Emission degradation correction factor y = a x Mileage + b, for Euro 3 and Euro 4 petrol vehicles. Mileage expressed in km, y normalised for the corresponding average mileage.

Annex 26: Equations of the influence of air temperature

			urban		rural		motorway	
			a	b	a	b	a	b
CO	petrol	Euro 0	0.0021	0.95	0.003	0.93	0.0054	0.88
		Euro 2	-0.0115	1.3	0.002	0.95	-	-
		Euro 3	-0.0087	1.2	0.0053	0.88	-0.0008	1.02
		Euro 4	No correction		0.017	0.61	-	-
	diesel	Euro 2	-0.034	1.784	-0.075	2.72	-0.024	1.56
HC	petrol	Euro 0	-0.001	1.02	-0.0027	1.066	No correction	
		Euro 2	-0.016	1.37	No correction		-	-
		Euro 3	-0.0525	2.21	-0.025	1.57	-0.001	1.02
		Euro 4	***3.4627***	***-0.0544***	0.0107	0.7442	-	-
			$y = a\,e^{bT}$				$y = a\,e^{bT}$	
	diesel	Euro 2	-0.027	1.62	-0.032	1.75	***1.43***	***-0.015***
NOx	petrol	Euro 0	-0.0075	1.17	-0.0063	1.14	-0.0035	1.08
		Euro 2	-0.0091	1.21	0.0045	0.895	-	-
		Euro 3	-0.0084	1.19	-0.0027	1.065	-0.002	1.05
		Euro 4	-0.01	1.23	0.0013	0.97	-	-
	diesel	Euro 2	-0.0015	1.05	-0.0015	1.05	-0.0006	1.016
CO_2	petrol	Euro 0	-0.0038	1.09	-0.0038	1.09	-0.0033	1.08
		Euro 2	-0.0013	1.03	-0.0017	1.04	-	-
		Euro 3	-0.001	1.03	-0.0013	1.03	-0.0015	1.0342
		Euro 4	-0.0028	1.0619	-0.0016	1.0334	-	-
	diesel	Euro 2	-0.0015	1.03	-0.0017	1.04	-0.0009	1.0205
PM	diesel	Euro 2	0.005	0.88	No correction		-0.005	1.11

Table 38: Correction factor $y = a \times Temperature + b$, or $y = a\,e^{b \times Temperature}$ when in blue italics bold, for urban, rural or motorway driving behaviour. Temperature in °C. y normalised at 23°C.

Annex 27: Equations of the influence of air humidity on NOx emissions

				urban		rural	
				a	b	a	b
Uncorrected emissions	NOx	petrol	Euro 2	-0.052	1.5592	-0.0293	1.31
			Euro 3	-0.081	1.8669	-0.0284	1.3
		diesel	Euro 2	-0.0249	1.2668	-0.0307	1.325
Already corrected emissions	NOx	petrol	Euro 2	-0.0182	1.1944	0.004	0.9571
			Euro 3	-0.0529	1.5654	-0.0093	1.0996
		diesel	Euro 2	0.0067	0.9281	0.0106	0.8869

Table 39: Correction factor y = a x Humidity + b, for NOx emissions already corrected or not by using the standard (or legislative) method, and for urban or rural driving behaviour. Humidity in g H_2O/kg dry air, y normalised at 10.71 g H_2O/kg dry air.

It is recommended to use the rural figures for motorway driving behaviour, and to use the petrol Euro 2 figures for petrol Euro 0 and 1, petrol Euro 3 figures for petrol Euro 4, and diesel Euro 2 figures for the other diesel cases. For other pollutants, no correction factors are proposed.

Annex 28: Road gradient factors

		Diesel vehicle					Petrol vehicle			
	gradient	FC	NOx	HC	CO	PM	FC	NOx	HC	CO
urban	0%	1	1	1	1	1	1	1	1	1
	2%	1.241	1.345	0.981	1.037	1.083	1.129	1.359	1.048	1.099
	-2%	0.773	0.692	1.006	0.971	0.921	0.869	0.689	0.968	0.910
	4%	1.534	1.783	0.995	1.067	1.263	1.291	1.883	1.128	1.203
	-4%	0.578	0.453	1.035	0.953	0.876	0.767	0.490	1.013	0.842
	6%	1.902	2.382	1.045	1.655	1.550	1.460	2.459	1.176	1.277
	-6%	0.386	0.265	0.918	0.814	0.699	0.680	0.332	1.015	0.775
rural	0%	1	1	1	1	1	1	1	1	1
	2%	1.308	1.424	0.975	1.109	1.156	1.183	1.335	1.111	1.281
	-2%	0.818	0.735	1.292	1.153	1.165	0.868	0.759	0.951	0.793
	4%	1.656	1.897	0.958	1.129	1.384	1.381	1.699	1.263	1.656
	-4%	0.577	0.451	1.293	1.105	1.043	0.699	0.494	0.962	0.675
	6%	2.065	2.448	1.112	1.097	1.819	1.576	2.001	1.424	1.956
	-6%	0.321	0.214	1.043	0.836	0.686	0.582	0.302	1.046	0.595
	8%	2.437	2.888	1.280	1.316	2.102	1.827	2.475	1.656	1.935
	-8%	0.174	0.085	1.109	0.839	0.610	0.529	0.147	1.191	0.576
	10%	2.905	3.325	1.821	1.897	2.609	2.070	2.569	1.981	1.755
	-10%	0.109	0.046	0.994	0.726	0.471	0.481	0.097	1.132	0.528
motorway	0%	1	1	1	1	1	1	1	1	1
	2%	1.354	1.485	0.885	0.874	1.180	1.248	1.148	1.323	1.791
	-2%	0.663	0.584	1.127	1.206	0.790	0.775	0.748	0.754	0.554
	4%	1.667	1.946	0.824	0.974	1.278	1.432	1.278	1.571	2.192
	-4%	0.339	0.218	1.130	1.131	0.588	0.564	0.394	0.620	0.360
	6%	2.057	2.620	0.810	0.946	1.578	1.703	1.546	1.856	2.887
	-6%	0.134	0.047	1.074	0.975	0.474	0.416	0.194	0.587	0.282

Table 40: Road gradient factors for Euro 0 diesel and petrol vehicles

		Diesel vehicle					Petrol vehicle			
	gradient	FC	NOx	HC	CO	PM	FC	NOx	HC	CO
urban	0%	1	1	1	1	1	1	1	1	1
	2%	1.243	1.368	0.961	1.025	1.124	1.1287	1.3586	1.0477	1.0985
	-2%	0.771	0.674	1.029	0.983	0.878	0.8688	0.6886	0.9683	0.9096
	4%	1.537	1.829	0.965	1.054	1.346	1.2907	1.8826	1.1282	1.2035
	-4%	0.576	0.425	1.085	0.980	0.789	0.7672	0.4900	1.0129	0.8421
	6%	1.905	2.451	1.008	1.633	1.670	1.4604	2.4592	1.1759	1.2767
	-6%	0.384	0.241	0.984	0.846	0.581	0.6796	0.3315	1.0154	0.7752
rural	0%	1	1	1	1	1	1	1	1	1
	2%	1.309	1.443	0.930	1.089	1.205	1.183	1.335	1.111	1.281
	-2%	0.816	0.711	1.396	1.216	1.089	0.868	0.759	0.951	0.793
	4%	1.658	1.932	0.882	1.098	1.474	1.381	1.699	1.263	1.656
	-4%	0.574	0.423	1.439	1.183	0.918	0.699	0.494	0.962	0.675
	6%	2.067	2.488	1.051	1.084	1.923	1.576	2.001	1.424	1.956
	-6%	0.319	0.198	1.190	0.897	0.529	0.582	0.302	1.046	0.595
	8%	2.439	2.939	1.210	1.307	2.226	1.827	2.475	1.656	1.935
	-8%	0.172	0.074	1.315	0.922	0.390	0.529	0.147	1.191	0.576
	10%	2.907	3.375	1.779	1.906	2.711	2.070	2.569	1.981	1.755
	-10%	0.108	0.039	1.209	0.805	0.245	0.481	0.097	1.132	0.528
motorway	0%	1	1	1	1	1	1	1	1	1
	2%	1.355	1.497	0.814	0.836	1.228	1.248	1.148	1.323	1.791
	-2%	0.663	0.573	1.191	1.238	0.742	0.775	0.748	0.754	0.554
	4%	1.669	1.972	0.671	0.891	1.375	1.432	1.278	1.571	2.192
	-4%	0.338	0.200	1.270	1.195	0.483	0.564	0.394	0.620	0.360
	6%	2.060	2.659	0.616	0.851	1.716	1.703	1.546	1.856	2.887
	-6%	0.132	0.037	1.277	1.061	0.318	0.416	0.194	0.587	0.282

Table 41: Road gradient factors for Euro 1 diesel and petrol vehicles

		Diesel vehicle					Petrol vehicle			
	gradient	FC	NOx	HC	CO	PM	FC	NOx	HC	CO
urban	0%	1	1	1	1	1	1	1	1	1
	2%	1.245	1.352	0.945	0.987	1.235	1.190	1.125	1.312	1.354
	-2%	0.770	0.687	1.047	1.019	0.764	0.807	0.819	0.728	0.716
	4%	1.540	1.797	0.941	1.013	1.577	1.438	1.231	1.918	2.118
	-4%	0.572	0.444	1.125	1.066	0.575	0.637	0.623	0.564	0.524
	6%	1.909	2.403	0.979	1.568	2.003	1.722	1.414	2.798	3.423
	-6%	0.380	0.257	1.036	0.947	0.338	0.511	0.512	0.438	0.376
rural	0%	1	1	1	1	1	1	1	1	1
	2%	1.311	1.430	0.890	1.011	1.313	1.229	1.236	1.445	1.488
	-2%	0.813	0.727	1.491	1.464	0.922	0.822	0.815	0.708	0.709
	4%	1.661	1.908	0.814	0.979	1.675	1.469	1.469	2.097	2.276
	-4%	0.570	0.442	1.573	1.493	0.649	0.601	0.536	0.463	0.431
	6%	2.070	2.460	0.995	1.030	2.154	1.702	1.654	2.663	2.920
	-6%	0.316	0.209	1.326	1.141	0.283	0.448	0.397	0.299	0.258
	8%	2.443	2.904	1.147	1.265	2.503	2.110	2.537	2.988	3.396
	-8%	0.169	0.082	1.505	1.251	0.127	0.337	0.311	0.189	0.138
	10%	2.911	3.340	1.740	1.929	2.938	2.471	2.699	2.532	2.461
	-10%	0.106	0.044	1.408	1.119	0.067	0.272	0.256	0.152	0.092
motorway	0%	1	1	1	1	1	1	1	1	1
	2%	1.356	1.489	0.745	0.666	1.331	1.271	1.735	1.786	2.048
	-2%	0.661	0.581	1.253	1.381	0.643	0.732	0.540	0.537	0.493
	4%	1.672	1.954	0.524	0.519	1.579	1.474	1.701	2.593	3.022
	-4%	0.335	0.213	1.406	1.488	0.276	0.461	0.361	0.244	0.220
	6%	2.065	2.632	0.432	0.451	2.006	1.665	1.972	3.882	4.465
	-6%	0.129	0.044	1.474	1.453	0.081	0.265	0.227	0.130	0.120

Table 42: Road gradient factors for Euro 2 diesel and petrol vehicles

		Diesel vehicle					Petrol vehicle			
	gradient	FC	NOx	HC	CO	PM	FC	NOx	HC	CO
urban	0%	1	1	1	1	1	1	1	1	1
	2%	1.197	1.404	1.075	1.650	1.207	1.190	1.125	1.312	1.354
	-2%	0.827	0.673	0.905	0.655	0.855	0.807	0.819	0.728	0.716
	4%	1.440	1.954	1.192	2.226	1.426	1.438	1.231	1.918	2.118
	-4%	0.686	0.411	0.794	0.504	0.772	0.637	0.623	0.564	0.524
	6%	1.715	2.686	1.315	2.642	1.564	1.722	1.414	2.798	3.423
	-6%	0.544	0.253	0.591	0.424	0.635	0.511	0.512	0.438	0.376
rural	0%	1	1	1	1	1	1	1	1	1
	2%	1.271	1.481	1.114	1.622	1.503	1.229	1.236	1.445	1.488
	-2%	0.766	0.642	0.880	0.560	0.681	0.822	0.815	0.708	0.709
	4%	1.573	2.030	1.235	1.873	1.892	1.469	1.469	2.097	2.276
	-4%	0.587	0.387	0.721	0.332	0.489	0.601	0.536	0.463	0.431
	6%	1.915	2.468	1.515	1.552	2.102	1.702	1.654	2.663	2.920
	-6%	0.471	0.207	0.570	0.210	0.392	0.448	0.397	0.299	0.258
	8%	2.244	2.855	1.784	1.862	2.586	2.110	2.537	2.988	3.396
	-8%	0.383	0.074	0.471	0.139	0.369	0.337	0.311	0.189	0.138
	10%	2.691	3.274	2.390	2.501	3.550	2.471	2.699	2.532	2.461
	-10%	0.313	0.040	0.383	0.104	0.438	0.272	0.256	0.152	0.092
motorway	0%	1	1	1	1	1	1	1	1	1
	2%	1.315	1.715	1.124	3.223	1.287	1.271	1.735	1.786	2.048
	-2%	0.706	0.527	0.922	0.104	0.762	0.732	0.540	0.537	0.493
	4%	1.602	2.428	1.232	5.862	1.548	1.474	1.701	2.593	3.022
	-4%	0.434	0.192	0.736	0.040	0.554	0.461	0.361	0.244	0.220
	6%	1.919	3.335	1.458	6.940	1.905	1.665	1.972	3.882	4.465
	-6%	0.277	0.045	0.381	0.013	0.429	0.265	0.227	0.130	0.120

Table 43: Road gradient factors for Euro 3 diesel and petrol vehicles

		Diesel vehicle					Petrol vehicle			
	gradient	FC	NOx	HC	CO	PM	FC	NOx	HC	CO
urban	0%	1	1	1	1	1	1	1	1	1
	2%	1.197	1.404	1.075	1.650	1.207	1.180	1.127	1.100	1.296
	-2%	0.827	0.673	0.905	0.655	0.855	0.831	0.842	0.930	0.781
	4%	1.440	1.954	1.192	2.226	1.426	1.400	1.120	1.207	1.820
	-4%	0.686	0.411	0.794	0.504	0.772	0.662	0.662	0.896	0.614
	6%	1.715	2.686	1.315	2.642	1.564	1.659	1.203	1.396	2.693
	-6%	0.544	0.253	0.591	0.424	0.635	0.537	0.535	0.893	0.411
rural	0%	1	1	1	1	1	1	1	1	1
	2%	1.271	1.481	1.114	1.622	1.503	1.229	1.061	1.214	1.278
	-2%	0.766	0.642	0.880	0.560	0.681	0.804	0.852	0.826	0.837
	4%	1.573	2.030	1.235	1.873	1.892	1.474	1.116	1.484	1.553
	-4%	0.587	0.387	0.721	0.332	0.489	0.624	0.699	0.687	0.665
	6%	1.915	2.468	1.515	1.552	2.102	1.709	1.281	1.698	1.659
	-6%	0.471	0.207	0.570	0.210	0.392	0.486	0.579	0.593	0.502
	8%	2.244	2.855	1.784	1.862	2.586	2.035	1.362	2.060	2.692
	-8%	0.383	0.074	0.471	0.139	0.369	0.384	0.482	0.648	0.294
	10%	2.691	3.274	2.390	2.501	3.550	2.399	2.100	2.190	2.935
	-10%	0.313	0.040	0.383	0.104	0.438	0.312	0.413	0.678	0.178
motorway	0%	1	1	1	1	1	1	1	1	1
	2%	1.315	1.715	1.124	3.223	1.287	1.281	0.922	1.415	1.235
	-2%	0.706	0.527	0.922	0.104	0.762	0.740	0.989	0.737	0.722
	4%	1.602	2.428	1.232	5.862	1.548	1.530	1.030	1.902	1.364
	-4%	0.434	0.192	0.736	0.040	0.554	0.483	0.898	0.543	0.435
	6%	1.919	3.335	1.458	6.940	1.905	1.923	1.006	2.763	1.785
	-6%	0.277	0.045	0.381	0.013	0.429	0.299	0.584	0.376	0.325

Table 44: Road gradient factors for Euro 4 diesel and petrol vehicles

Annex 29: Cities considered for auxiliary emission modelling and Köppen classes

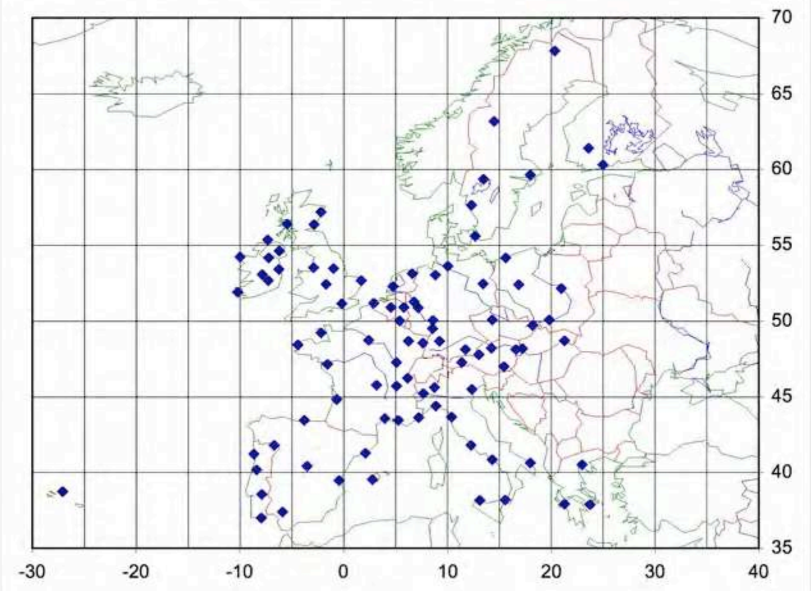


Figure 65: Localization of the 91 European cities considered for auxiliary emission modelling.

Id	country	city	longitude	latitude	Köppen class	average temperature
1	AUT	GRAZ	15.43	47	Dfb	9.5
2	AUT	INNSBRUCK	11.35	47.27	Dfb	9.0
3	AUT	LINZ	14.2	48.23	Dfb	9.2
4	AUT	SALZBURG	13	47.8	Dfb	9.3
5	AUT	VIENNA_ SCHWECHAT	16.57	48.12	Dfb	10.0
6	BEL	BRUSSELS	4.53	50.9	Cfb	10.3
7	BEL	OOSTENDE	2.87	51.2	Cfb	10.3
8	BEL	SAINT HUBERT	5.4	50.03	Dfb	7.5
9	CHE	GENEVA	6.13	46.25	Cfb	10.4
10	CZE	OSTRAVA	18.18	49.72	Dfb	8.5
11	CZE	PRAGUE	14.28	50.1	Dfb	8.1
12	DEU	BERLIN	13.4	52.47	Cfb	9.8
13	DEU	BREMEN	8.8	53.05	Cfb	8.9
14	DEU	DUSSELDORF	6.78	51.28	Cfb	10.5
15	DEU	FRANKFURT AM MAIN	8.6	50.05	Cfb	10.1
16	DEU	HAMBURG	10	53.63	Cfb	9.0
17	DEU	KOLN	7.17	50.87	Cfb	9.9
18	DEU	MANNHEIM	8.55	49.52	Cfb	11.1
19	DEU	MUNICH	11.7	48.13	Dfb	8.0
20	DEU	STUTTGART	9.22	48.68	Dfb	9.1

21	DNK	COPENHAGEN	12.67	55.63	Cfb	8.3
22	ESP	BARCELONA	2.07	41.28	Cfa	15.7
23	ESP	MADRID	-3.55	40.45	Cfa	14.3
24	ESP	PALMA	2.73	39.55	Cfa	16.7
25	ESP	SANTANDER	-3.82	43.47	Cfb	14.8
26	ESP	SEVILLA	-5.9	37.42	Csa	18.4
27	ESP	VALENCIA	-0.47	39.5	Cfa	17.3
28	FIN	HELSINKI	24.97	60.32	Dfb	5.2
29	FIN	TAMPERE	23.58	61.42	Dfb	4.3
30	FRA	BORDEAUX	-0.7	44.83	Cfb	13.2
31	FRA	BREST	-4.42	48.45	Cfb	11.2
32	FRA	CLERMONT-FERRAND	3.17	45.78	Cfb	11.4
33	FRA	DIJON	5.08	47.27	Cfb	10.7
34	FRA	LYON	5.08	45.73	Cfb	11.9
35	FRA	MARSEILLE	5.23	43.45	Cfa	14.8
36	FRA	MONTPELLIER	3.97	43.58	Cfa	14.8
37	FRA	NANCY	6.22	48.68	Cfb	10.2
38	FRA	NANTES	-1.6	47.17	Cfb	12.2
39	FRA	NICE	7.2	43.65	Cfa	15.5
40	FRA	PARIS_ ORLY	2.4	48.73	Cfb	11.1
41	FRA	STRASBOURG	7.63	48.55	Cfb	10.3
42	GBR	ABERDEEN/DYCE	-2.22	57.2	Cfb	8.4
43	GBR	AUGHTON	-2.92	53.55	Cfb	9.5
44	GBR	BELFAST	-6.22	54.65	Cfb	9.1
45	GBR	BIRMINGHAM	-1.73	52.45	Cfb	9.7
46	GBR	FINNINGLEY	-1	53.48	Cfb	9.5
47	GBR	HEMSBY	1.68	52.68	Cfb	9.9
48	GBR	JERSEY/CHANNEL ISLANDS	-2.2	49.22	Cfb	11.2
49	GBR	LEUCHARS	-2.87	56.38	Cfb	8.7
50	GBR	LONDON/GATWICK	-0.18	51.15	Cfb	10.2
51	GBR	OBAN	-5.47	56.42	Cfb	9.3
52	GRC	ANDRAVIDA	21.28	37.92	Csa	16.7
53	GRC	ATHENS	23.73	37.9	Cfa	17.9
54	GRC	THESSALONIKI	22.97	40.52	Cfa	15.4
55	IRL	BELMULLET	-10	54.23	Cfb	10.3
56	IRL	BIRR	-7.88	53.08	Cfb	9.6
57	IRL	CLONES	-7.23	54.18	Cfb	9.1
58	IRL	DUBLIN	-6.25	53.43	Cfb	9.8
59	IRL	KILKENNY	-7.27	52.67	Cfb	9.7
60	IRL	MALIN	-7.33	55.37	Cfb	9.7
61	IRL	VALENTIA OBSERVATORY	-10.25	51.93	Cfb	11.0
62	ITA	BRINDISI	17.95	40.65	Cfa	17.1
63	ITA	GENOVA	8.85	44.42	Cfa	16.1
64	ITA	MESSINA	15.55	38.2	Cfa	18.9
65	ITA	MILAN	8.73	45.62	Cfa	11.8
66	ITA	NAPLES	14.3	40.85	Cfa	16.3
67	ITA	PALERMO	13.1	38.18	Cfa	18.8
68	ITA	PISA	10.38	43.68	Cfa	14.6
69	ITA	ROME	12.23	41.8	Cfa	15.8

70	ITA	TORINO	7.65	45.22	Cfa	12.2
71	ITA	VENICE	12.33	45.5	Cfa	13.2
72	NLD	AMSTERDAM	4.77	52.3	Cfb	10.0
73	NLD	BEEK	5.78	50.92	Cfb	10.1
74	NLD	GRONINGEN	6.58	53.13	Cfb	9.1
75	POL	KOLOBRZEG	15.58	54.18	Dfb	8.5
76	POL	KRAKOW	19.8	50.08	Dfb	8.2
77	POL	POZNAN	16.83	52.42	Dfb	8.6
78	POL	WARSAW	20.97	52.17	Dfb	8.4
79	PRT	BRAGANCA	-6.73	41.8	Cfb	12.4
80	PRT	COIMBRA	-8.42	40.2	Csb	15.3
81	PRT	EVORA	-7.9	38.57	Cfa	15.8
82	PRT	FARO	-7.97	37.02	Cfa	17.8
83	PRT	LAJES	-27.1	38.77	Cfa	17.5
84	PRT	PORTO	-8.68	41.23	Csb	14.3
85	SVK	BRATISLAVA	17.2	48.2	Dfb	10.4
86	SVK	KOSICE	21.27	48.7	Dfb	9.1
87	SWE	GOTEBORG_ LANDVETTER	12.3	57.67	Dfb	6.5
88	SWE	KARLSTAD	13.47	59.37	Dfb	5.9
89	SWE	KIRUNA	20.33	67.82	Dfc	-1.1
90	SWE	OSTERSUND/FROSON	14.5	63.18	Dfc	3.1
91	SWE	STOCKHOLM_ ARLANDA	17.95	59.65	Dfb	6.5

Table 45: Characteristics of the 91 European locations considered for auxiliary emission modelling, in terms on longitude, latitude, temperature and Köppen class.

Cfa	mild mid-latitude, moist with an average temperature of the warmest month above 22°C
Cfb	similar to Cfa with a cooler warmest month
Csa	Mediterranean climate, with an average temperature of the warmest month above 22°C
Csb	similar to Csa with a cooler warmest month
Dfb	moist continental mid-latitude climates, wet at all seasons with an average temperature of warmest month below 22°C and an average temperature of the 4 warmest months above 10°C
Dfc	close to Dfb, with an average temperature of 1 to 3 warmest months above 10°C

Table 46: Modified Köppen climate classes of European locations.

Annex 30: Values of hourly fuel consumption of the auxiliaries simplified model

Id (see Annex 29)	a_1	a_2	a_3	a_4	a_5
1	-0.863	0.0402	-0.0376	0.0334	-0.00164
2	-0.722	0.0312	-0.0294	0.0355	-0.00160
3	-0.731	0.0332	-0.0326	0.0348	-0.00168
4	-0.834	0.0362	-0.0339	0.0383	-0.00176
5	-0.808	0.0355	-0.0329	0.0360	-0.00164
6	-0.890	0.0386	-0.0349	0.0391	-0.00171
7	-0.946	0.0370	-0.0330	0.0556	-0.00226
8	-0.818	0.0302	-0.0281	0.0536	-0.00217
9	-0.799	0.0346	-0.0333	0.0386	-0.00172
10	-0.831	0.0364	-0.0336	0.0377	-0.00176
11	-0.799	0.0345	-0.0323	0.0385	-0.00176
12	-0.732	0.0319	-0.0300	0.0344	-0.00155
13	-0.842	0.0363	-0.0355	0.0406	-0.00182
14	-0.761	0.0322	-0.0306	0.0356	-0.00154
15	-0.797	0.0345	-0.0322	0.0377	-0.00170
16	-0.829	0.0353	-0.0324	0.0399	-0.00174
17	-0.755	0.0326	-0.0315	0.0367	-0.00166
18	-0.786	0.0342	-0.0335	0.0359	-0.00163
19	-0.799	0.0334	-0.0319	0.0440	-0.00197
20	-0.763	0.0328	-0.0319	0.0396	-0.00181
21	-0.794	0.0307	-0.0284	0.0484	-0.00201
22	-1.110	0.0461	-0.0416	0.0481	-0.00192
23	-0.822	0.0331	-0.0338	0.0437	-0.00185
24	-1.182	0.0504	-0.0450	0.0471	-0.00192
25	-0.968	0.0393	-0.0344	0.0484	-0.00189
26	-0.924	0.0383	-0.0391	0.0407	-0.00176
27	-1.060	0.0454	-0.0408	0.0408	-0.00169
28	-0.793	0.0291	-0.0292	0.0517	-0.00211
29	-0.729	0.0277	-0.0283	0.0461	-0.00190
30	-0.877	0.0355	-0.0354	0.0458	-0.00192
31	-1.192	0.0370	-0.0328	0.0888	-0.00332
32	-0.802	0.0336	-0.0332	0.0408	-0.00178
33	-0.927	0.0400	-0.0377	0.0440	-0.00196
34	-0.898	0.0375	-0.0373	0.0442	-0.00191
35	-0.989	0.0408	-0.0384	0.0469	-0.00195
36	-0.924	0.0390	-0.0375	0.0413	-0.00172
37	-0.871	0.0377	-0.0342	0.0406	-0.00182
38	-0.855	0.0343	-0.0345	0.0477	-0.00200
39	-1.143	0.0468	-0.0413	0.0536	-0.00215
40	-0.861	0.0367	-0.0346	0.0416	-0.00183
41	-0.923	0.0416	-0.0365	0.0389	-0.00181
42	-1.062	0.0394	-0.0327	0.0662	-0.00274
43	-0.791	0.0308	-0.0264	0.0491	-0.00203
44	-0.786	0.0313	-0.0271	0.0462	-0.00192
45	-0.804	0.0305	-0.0289	0.0523	-0.00223

Id (see Annex 29)	a_1	a_2	a_3	a_4	a_5
46	-0.735	0.0294	-0.0264	0.0428	-0.00186
47	-0.901	0.0358	-0.0311	0.0539	-0.00228
48	-0.987	0.0366	-0.0332	0.0672	-0.00277
49	-0.814	0.0330	-0.0279	0.0458	-0.00191
50	-0.840	0.0333	-0.0310	0.0500	-0.00218
51	-0.725	0.0263	-0.0229	0.0494	-0.00198
52	-0.967	0.0419	-0.0404	0.0380	-0.00163
53	-0.947	0.0374	-0.0382	0.0483	-0.00197
54	-0.903	0.0368	-0.0377	0.0461	-0.00195
55	-0.786	0.0296	-0.0237	0.0502	-0.00199
56	-0.867	0.0339	-0.0285	0.0504	-0.00207
57	-1.031	0.0362	-0.0307	0.0681	-0.00269
58	-0.883	0.0332	-0.0284	0.0548	-0.00220
59	-0.913	0.0341	-0.0305	0.0575	-0.00236
60	-0.682	0.0217	-0.0243	0.0541	-0.00213
61	-0.910	0.0338	-0.0283	0.0594	-0.00234
62	-1.262	0.0543	-0.0461	0.0495	-0.00209
63	-1.195	0.0488	-0.0426	0.0523	-0.00208
64	-1.106	0.0468	-0.0443	0.0461	-0.00191
65	-0.953	0.0411	-0.0388	0.0409	-0.00179
66	-1.018	0.0448	-0.0422	0.0382	-0.00166
67	-1.174	0.0485	-0.0441	0.0527	-0.00213
68	-0.945	0.0415	-0.0405	0.0399	-0.00172
69	-1.105	0.0478	-0.0436	0.0420	-0.00172
70	-1.033	0.0458	-0.0411	0.0410	-0.00180
71	-1.065	0.0468	-0.0411	0.0367	-0.00158
72	-0.900	0.0358	-0.0323	0.0502	-0.00206
73	-0.852	0.0369	-0.0345	0.0394	-0.00173
74	-0.927	0.0398	-0.0350	0.0443	-0.00192
75	-0.772	0.0295	-0.0314	0.0515	-0.00218
76	-0.801	0.0362	-0.0338	0.0359	-0.00174
77	-0.753	0.0342	-0.0323	0.0319	-0.00152
78	-0.792	0.0359	-0.0338	0.0352	-0.00169
79	-0.721	0.0299	-0.0314	0.0412	-0.00180
80	-0.993	0.0400	-0.0376	0.0544	-0.00231
81	-0.776	0.0305	-0.0336	0.0472	-0.00199
82	-0.970	0.0384	-0.0375	0.0552	-0.00224
83	-1.128	0.0472	-0.0393	0.0442	-0.00174
84	-0.963	0.0368	-0.0347	0.0596	-0.00240
85	-0.869	0.0384	-0.0367	0.0373	-0.00173
86	-0.818	0.0362	-0.0345	0.0375	-0.00175
87	-0.783	0.0265	-0.0255	0.0582	-0.00234
88	-0.860	0.0324	-0.0316	0.0564	-0.00235
89	-0.620	0.0221	-0.0227	0.0441	-0.00183
90	-0.670	0.0263	-0.0273	0.0421	-0.00178
91	-0.729	0.0296	-0.0280	0.0421	-0.00185

Table 47: Values of hourly fuel consumption simplified model for hourly weather format for each location, as described in Annex 29.

Id (see Annex 29)	a_1	a_2	a_3	a_4	a_5
1	-1.286	0.0342	-0.0321	0.1281	-0.00477
2	-0.869	0.0256	-0.0224	0.0825	-0.00300
3	-1.119	0.0311	-0.0272	0.1071	-0.00394
4	-1.189	0.0326	-0.0279	0.1157	-0.00429
5	-1.099	0.0333	-0.0290	0.0971	-0.00364
6	-1.245	0.0385	-0.0282	0.1039	-0.00375
7	-1.071	0.0356	-0.0259	0.0894	-0.00331
8	-0.873	0.0244	-0.0223	0.0836	-0.00302
9	-1.118	0.0313	-0.0278	0.1043	-0.00375
10	-1.125	0.0324	-0.0265	0.1141	-0.00440
11	-1.296	0.0332	-0.0270	0.1311	-0.00488
12	-0.952	0.0298	-0.0252	0.0817	-0.00303
13	-1.390	0.0359	-0.0299	0.1353	-0.00490
14	-0.891	0.0273	-0.0237	0.0785	-0.00287
15	-1.039	0.0304	-0.0253	0.0945	-0.00341
16	-1.079	0.0310	-0.0258	0.0996	-0.00363
17	-1.115	0.0301	-0.0244	0.1073	-0.00386
18	-1.135	0.0325	-0.0277	0.1057	-0.00389
19	-1.194	0.0308	-0.0263	0.1244	-0.00459
20	-1.318	0.0318	-0.0264	0.1340	-0.00481
21	-0.936	0.0273	-0.0230	0.0892	-0.00338
22	-1.069	0.0355	-0.0345	0.0887	-0.00331
23	-1.040	0.0288	-0.0282	0.0982	-0.00346
24	-1.266	0.0399	-0.0374	0.1188	-0.00449
25	-0.945	0.0333	-0.0279	0.0709	-0.00265
26	-1.301	0.0358	-0.0326	0.1179	-0.00418
27	-1.110	0.0361	-0.0333	0.0934	-0.00344
28	-1.118	0.0287	-0.0247	0.1105	-0.00401
29	-0.993	0.0251	-0.0236	0.0992	-0.00355
30	-1.150	0.0325	-0.0292	0.1063	-0.00381
31	-1.559	0.0330	-0.0244	0.1633	-0.00576
32	-1.136	0.0306	-0.0277	0.1104	-0.00399
33	-1.319	0.0366	-0.0315	0.1235	-0.00446
34	-1.207	0.0348	-0.0317	0.1100	-0.00401
35	-1.133	0.0344	-0.0328	0.1032	-0.00386
36	-1.128	0.0349	-0.0325	0.1009	-0.00378
37	-1.146	0.0327	-0.0269	0.1089	-0.00394
38	-1.195	0.0325	-0.0294	0.1118	-0.00399
39	-1.169	0.0386	-0.0366	0.0958	-0.00362
40	-1.129	0.0333	-0.0280	0.0990	-0.00355
41	-1.377	0.0392	-0.0296	0.1269	-0.00460
42	-1.458	0.0378	-0.0243	0.1503	-0.00576
43	-0.873	0.0265	-0.0188	0.0794	-0.00296
44	-0.768	0.0197	-0.0171	0.0776	-0.00283
45	-1.317	0.0305	-0.0239	0.1376	-0.00504
46	-1.135	0.0275	-0.0204	0.1190	-0.00436

Id (see Annex 29)	a_1	a_2	a_3	a_4	a_5
47	-0.953	0.0300	-0.0242	0.0891	-0.00352
48	-1.098	0.0352	-0.0254	0.0986	-0.00381
49	-1.010	0.0285	-0.0201	0.0974	-0.00360
50	-1.441	0.0335	-0.0258	0.1507	-0.00551
51	-0.769	0.0197	-0.0127	0.0760	-0.00267
52	-1.249	0.0383	-0.0360	0.1096	-0.00411
53	-1.059	0.0327	-0.0351	0.0923	-0.00350
54	-1.075	0.0320	-0.0336	0.0970	-0.00359
55	-0.632	0.0177	-0.0132	0.0655	-0.00252
56	-1.035	0.0284	-0.0187	0.0977	-0.00350
57	-1.244	0.0267	-0.0208	0.1318	-0.00469
58	-0.919	0.0262	-0.0208	0.0841	-0.00303
59	-1.042	0.0250	-0.0190	0.1101	-0.00399
60	-0.749	0.0227	-0.0195	0.0700	-0.00273
61	-0.792	0.0249	-0.0190	0.0723	-0.00270
62	-1.430	0.0496	-0.0415	0.1031	-0.00393
63	-1.182	0.0419	-0.0380	0.0806	-0.00304
64	-1.195	0.0438	-0.0419	0.0782	-0.00305
65	-1.057	0.0300	-0.0330	0.1060	-0.00392
66	-1.223	0.0394	-0.0376	0.1024	-0.00389
67	-1.214	0.0445	-0.0408	0.0790	-0.00302
68	-1.148	0.0365	-0.0349	0.0997	-0.00369
69	-1.205	0.0396	-0.0371	0.1017	-0.00385
70	-1.169	0.0373	-0.0353	0.0989	-0.00361
71	-1.218	0.0417	-0.0363	0.0857	-0.00316
72	-1.122	0.0347	-0.0246	0.0999	-0.00371
73	-1.081	0.0346	-0.0275	0.0913	-0.00337
74	-1.189	0.0359	-0.0259	0.1104	-0.00410
75	-0.944	0.0310	-0.0261	0.0836	-0.00330
76	-1.339	0.0364	-0.0288	0.1328	-0.00503
77	-1.086	0.0323	-0.0270	0.1008	-0.00379
78	-1.185	0.0340	-0.0284	0.1162	-0.00445
79	-1.066	0.0280	-0.0269	0.1079	-0.00391
80	-1.438	0.0370	-0.0312	0.1448	-0.00532
81	-1.109	0.0300	-0.0293	0.1070	-0.00389
82	-1.051	0.0335	-0.0332	0.0945	-0.00361
83	-1.021	0.0382	-0.0312	0.0670	-0.00257
84	-1.127	0.0335	-0.0293	0.1087	-0.00412
85	-1.284	0.0368	-0.0331	0.1225	-0.00467
86	-1.199	0.0335	-0.0308	0.1202	-0.00467
87	-1.129	0.0271	-0.0206	0.1193	-0.00441
88	-1.008	0.0257	-0.0261	0.1027	-0.00376
89	-0.715	0.0175	-0.0183	0.0773	-0.00290
90	-0.930	0.0230	-0.0223	0.0940	-0.00336
91	-1.065	0.0281	-0.0241	0.1055	-0.00393

Table 48: Values of hourly fuel consumption simplified model for daily weather format for each location, as described in Annex 29.

Id (see Annex 29)	a_1	a_2	a_3	a_4	a_5
1	-0.403	0.0138	-0.0067	0.0493	-0.00186
2	-0.219	0.0090	-0.0043	0.0259	-0.00096
3	-0.345	0.0132	-0.0058	0.0381	-0.00142
4	-0.301	0.0106	-0.0047	0.0381	-0.00142
5	-0.371	0.0148	-0.0060	0.0392	-0.00148
6	-0.258	0.0114	-0.0041	0.0252	-0.00091
7	-0.293	0.0126	-0.0049	0.0267	-0.00098
8	-0.149	0.0057	-0.0034	0.0182	-0.00068
9	-0.425	0.0160	-0.0063	0.0443	-0.00163
10	-0.322	0.0129	-0.0051	0.0375	-0.00144
11	-0.289	0.0107	-0.0050	0.0352	-0.00134
12	-0.279	0.0118	-0.0051	0.0286	-0.00107
13	-0.254	0.0107	-0.0045	0.0284	-0.00106
14	-0.235	0.0101	-0.0043	0.0248	-0.00093
15	-0.307	0.0123	-0.0051	0.0331	-0.00122
16	-0.216	0.0092	-0.0044	0.0243	-0.00091
17	-0.247	0.0100	-0.0048	0.0275	-0.00101
18	-0.386	0.0150	-0.0060	0.0409	-0.00152
19	-0.336	0.0120	-0.0054	0.0416	-0.00157
20	-0.364	0.0132	-0.0055	0.0407	-0.00149
21	-0.246	0.0106	-0.0044	0.0246	-0.00096
22	-0.705	0.0260	-0.0110	0.0655	-0.00239
23	-0.629	0.0201	-0.0084	0.0648	-0.00222
24	-0.796	0.0304	-0.0120	0.0764	-0.00285
25	-0.394	0.0171	-0.0061	0.0322	-0.00119
26	-0.833	0.0273	-0.0113	0.0779	-0.00271
27	-0.803	0.0290	-0.0115	0.0718	-0.00256
28	-0.220	0.0088	-0.0043	0.0253	-0.00095
29	-0.213	0.0084	-0.0042	0.0243	-0.00090
30	-0.495	0.0177	-0.0070	0.0520	-0.00189
31	-0.368	0.0134	-0.0050	0.0355	-0.00128
32	-0.383	0.0138	-0.0057	0.0445	-0.00163
33	-0.485	0.0176	-0.0070	0.0523	-0.00192
34	-0.444	0.0168	-0.0067	0.0472	-0.00173
35	-0.641	0.0232	-0.0094	0.0656	-0.00245
36	-0.623	0.0227	-0.0089	0.0639	-0.00239
37	-0.372	0.0154	-0.0057	0.0384	-0.00143
38	-0.414	0.0157	-0.0063	0.0420	-0.00153
39	-0.702	0.0271	-0.0105	0.0641	-0.00241
40	-0.425	0.0160	-0.0062	0.0417	-0.00151
41	-0.503	0.0189	-0.0067	0.0515	-0.00190
42	-0.278	0.0069	-0.0029	0.0363	-0.00139
43	-0.123	0.0061	-0.0024	0.0110	-0.00042
44	-0.122	0.0055	-0.0026	0.0115	-0.00043
45	-0.329	0.0119	-0.0045	0.0346	-0.00128
46	-0.272	0.0110	-0.0040	0.0280	-0.00106

Id (see Annex 29)	a_1	a_2	a_3	a_4	a_5
47	-0.233	0.0118	-0.0043	0.0196	-0.00080
48	-0.301	0.0131	-0.0052	0.0282	-0.00110
49	-0.283	0.0084	-0.0031	0.0321	-0.00118
50	-0.508	0.0149	-0.0054	0.0548	-0.00193
51	-0.133	0.0049	-0.0020	0.0129	-0.00045
52	-0.722	0.0266	-0.0101	0.0683	-0.00254
53	-0.755	0.0269	-0.0116	0.0707	-0.00263
54	-0.676	0.0230	-0.0104	0.0705	-0.00259
55	-0.212	0.0053	-0.0027	0.0256	-0.00096
56	-0.193	0.0085	-0.0033	0.0177	-0.00066
57	-0.304	0.0084	-0.0034	0.0337	-0.00118
58	-0.170	0.0079	-0.0034	0.0152	-0.00057
59	-0.240	0.0124	-0.0042	0.0191	-0.00073
60	-0.180	0.0052	-0.0021	0.0202	-0.00076
61	-0.154	0.0078	-0.0036	0.0125	-0.00047
62	-0.852	0.0344	-0.0127	0.0702	-0.00265
63	-0.585	0.0256	-0.0104	0.0469	-0.00177
64	-0.729	0.0329	-0.0130	0.0497	-0.00195
65	-0.666	0.0212	-0.0101	0.0755	-0.00278
66	-0.820	0.0302	-0.0119	0.0760	-0.00286
67	-0.691	0.0319	-0.0120	0.0461	-0.00176
68	-0.589	0.0228	-0.0097	0.0579	-0.00212
69	-0.712	0.0275	-0.0109	0.0674	-0.00253
70	-0.632	0.0225	-0.0099	0.0646	-0.00233
71	-0.645	0.0253	-0.0109	0.0553	-0.00203
72	-0.252	0.0106	-0.0043	0.0266	-0.00100
73	-0.282	0.0117	-0.0049	0.0289	-0.00105
74	-0.221	0.0097	-0.0041	0.0240	-0.00089
75	-0.187	0.0081	-0.0044	0.0207	-0.00080
76	-0.294	0.0120	-0.0052	0.0347	-0.00134
77	-0.262	0.0111	-0.0050	0.0298	-0.00114
78	-0.328	0.0132	-0.0054	0.0371	-0.00143
79	-0.504	0.0178	-0.0065	0.0547	-0.00200
80	-0.538	0.0211	-0.0073	0.0527	-0.00197
81	-0.646	0.0232	-0.0080	0.0606	-0.00221
82	-0.717	0.0275	-0.0109	0.0637	-0.00240
83	-0.597	0.0275	-0.0087	0.0358	-0.00137
84	-0.536	0.0226	-0.0067	0.0474	-0.00182
85	-0.523	0.0176	-0.0073	0.0614	-0.00232
86	-0.473	0.0178	-0.0069	0.0516	-0.00200
87	-0.208	0.0045	-0.0034	0.0291	-0.00105
88	-0.252	0.0090	-0.0050	0.0300	-0.00112
89	-0.103	0.0028	-0.0018	0.0145	-0.00055
90	-0.116	0.0055	-0.0022	0.0125	-0.00045
91	-0.196	0.0069	-0.0039	0.0250	-0.00093

Table 49: Values of hourly fuel consumption simplified model for monthly weather format for each location, as described in Annex 29.

Köppen classes	a1	a2	a3	a4	a5
Cfa	-1.0368	0.0436	-0.0404	0.0455	-0.00189
Cfb	-0.8575	0.0343	-0.0315	0.0480	-0.00202
Csa/Csb	-0.9618	0.0393	-0.0380	0.0482	-0.00203
Dfb	-0.7937	0.0333	-0.0319	0.0417	-0.00185
Dfc	-0.6450	0.0242	-0.0250	0.0431	-0.00181

Table 50: Values of hourly fuel consumption simplified model for hourly weather format for Köppen classes

Köppen classes	a1	a2	a3	a4	a5
Cfa	-1.1486	0.0372	-0.0352	0.0951	-0.00356
Cfb	-1.0914	0.0305	-0.0243	0.1032	-0.00378
Csa/Csb	-1.2800	0.0362	-0.0323	0.1205	-0.00443
Dfb	-1.1300	0.0309	-0.0267	0.1110	-0.00414
Dfc	-0.8225	0.0203	-0.0203	0.0857	-0.00313

Table 51: Values of hourly fuel consumption simplified model for daily weather format for Köppen classes

Köppen classes	a1	a2	a3	a4	a5
Cfa	-0.6914	0.0264	-0.0106	0.0629	-0.00233
Cfb	-0.3029	0.0117	-0.0046	0.0313	-0.00116
Csa/Csb	-0.6573	0.0244	-0.0088	0.0616	-0.00226
Dfb	-0.2979	0.0111	-0.0051	0.0349	-0.00132
Dfc	-0.1095	0.0041	-0.0020	0.0135	-0.00050

Table 52: Values of hourly fuel consumption simplified model for monthly weather format for Köppen classes

a1	a2	a3	a4	a5
-0.886	0.0363	-0.0339	0.0458	-0.00195

Table 53: Average values of hourly fuel consumption simplified model for hourly weather format

a1	a2	a3	a4	a5
-1.116	0.0322	-0.0278	0.1034	-0.00382

Table 54: Average values of hourly fuel consumption simplified model for daily weather format

a1	a2	a3	a4	a5
-0.407	0.0155	-0.0063	0.0407	-0.00151

Table 55: Average values of hourly fuel consumption simplified model for monthly weather format

Annex 31: Detailed model of excess fuel consumption for a fleet due to AC

The general equation to calculate the excess fuel consumption fc_f for a fleet f due to the use of air conditioning is:

$$fc_f = \sum_{loc}\sum_{T}\sum_{TS}\sum_{i} n_{AC,i,TS,T,loc} \cdot hfc(h, T_{ext}, T_{\mathrm{int}})$$

Excess CO_2 emission is:

$$eCO_{2f} = \sum_{loc}\sum_{T}\sum_{TS}\sum_{i} n_{AC,i,TS,T,loc} \cdot c_{CO_2,i} \cdot hfc(h, T_{ext}, T_{\mathrm{int}})$$

with:

$n_{ac,i,TS,T,loc}$: number of vehicles with AC running for segment i, at the traffic situation TS (i.e. urban, rural, highway), at the time T, at the location loc, expressed in number of vehicle per hour.

$$n_{AC,i,TS,T,loc} = n_{i,TS,T,loc} \cdot f_{clim,i}$$

hfc: hourly fuel consumption depending on the hour of the day, external temperature and internal temperature (l/h).

$c_{CO_2,i}$: transformation factor from fuel to CO_2 depending on vehicle segment i. The transformation factor is deduced from carbon balance equation and density of fuel. To calculate this factor, we neglected the mass of non-CO_2 pollutants in comparison with the mass of CO_2.

$$c_{CO_2,i} = \frac{m_{CO_2}}{v_{fuel}} = \frac{44.011}{12.011 + 1.008 \cdot r_{H/C,i}} \cdot \rho_{fuel,i}$$

with:

$r_{H/C,i}$: Hydrogen Carbon ratio depending of the type of fuel: 1.8 for petrol and 2 for diesel.

$\rho_{fuel,i}$: density of fuel (kg/l): 0.766 kg/l for petrol and 0.8414 kg/l for diesel.

$f_{clim,i}$: fraction of vehicles equipped with air conditioning in segment i. The fraction of vehicles equipped with AC is calculated with the penetration rate ($pr_{AC,i}$). Value of $pr_{AC,I}$ are given for the France in Annex 3 (Hugrel and Joumard, 2004).

$n_{i,TS,T,loc}$: number of vehicles belonging to segment i, at the situation of traffic TS, at time T, and at location loc:

$$n_{i,TS,T,loc} = \frac{n_{i,loc} \cdot k_{i,loc,TS}}{v_{TS}} \cdot d_{i,TS,T,loc}$$

with:

$n_{i,loc}$: total number of vehicles belonging to the segment i, at the location loc

$k_{i, TS, loc}$: annual mileage of a vehicle belonging to the segment i, in the traffic situation TS, at the location loc (km)

v_{TS}: mean velocity in traffic situation TS (km/h)

$d_{i,TS,T,loc}$: traffic distribution coefficient (see some examples in Annex 37)

Annex 32: Model of excess emission due to auxiliaries at full load

Annex 32.1: Model of CO excess emission at full load

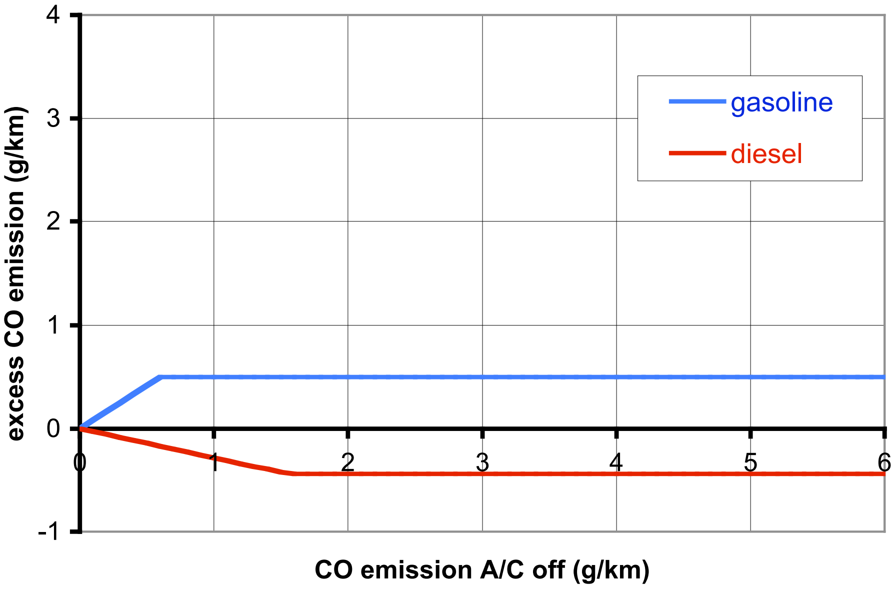


Figure 66: CO excess emission due to auxiliaries at full load for diesel and petrol vehicles.

<u>petrol:</u>

if $ef_{CO,ACoff}<0.6$ $\quad cf_{AC,CO,diesel}\left(ef_{CO,ACoff}\right)=5/6\cdot ef_{CO,ACoff}$

else $\quad cf_{AC,CO,gasoline}\left(ef_{CO,ACoff}\right)=0.5$

<u>diesel:</u>

if $ef_{CO,ACoff}<1.56$ $\quad cf_{AC,CO,diesel}\left(ef_{CO,ACoff}\right)=-0.2825\cdot ef_{CO,ACoff}$

else $\quad cf_{AC,CO,diesel}\left(ef_{CO,ACoff}\right)=-0.2825\cdot 1.56=-0.441$

Annex 32.2: Model of HC excess emission at full load

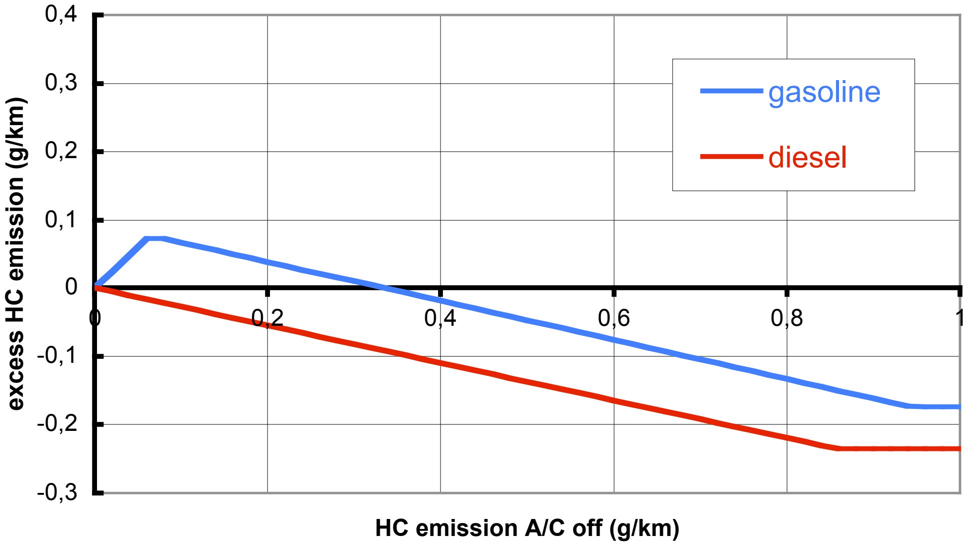


Figure 67: HC excess emission due to auxiliaries at full load for diesel and petrol vehicles.

petrol:

if $ef_{HC,ACoff} < 0.06$ g/km $\quad cf_{AC,HC,gasoline}(ef_{HC,ACoff}) = 1.21646 \cdot ef_{HC,ACoff}$

if $ef_{HC,ACoff} > 0.06$ g/km and < 0.08 $\quad cf_{AC,HC,gasoline}(ef_{HC,ACoff}) = 0.072988$

if $ef_{HC,ACoff} > 0.08$ and < 0.944 g/km $\quad cf_{AC,HC,gasoline}(ef_{HC,ACoff}) = -0.2864 \cdot ef_{HC,ACoff} + 0.0959$

if $ef_{HC,ACoff} > 0.944$ g/km $\quad cf_{AC,HC,gasoline}(ef_{HC,ACoff}) = -0.2864 \cdot 0.944 + 0.0959 = -0.174$

diesel:

if $ef_{HC,ACoff} < 0.857$ g/km $\quad cf_{AC,HC,diesel}(ef_{HC,ACoff}) = -0.2743 \cdot ef_{HC,ACoff}$

else $\quad cf_{AC,HC,diesel}(ef_{HC,ACoff}) = -0.2743 \cdot 0.855 = -0.235$

Annex 32.3: Model of NOx excess emission at full load

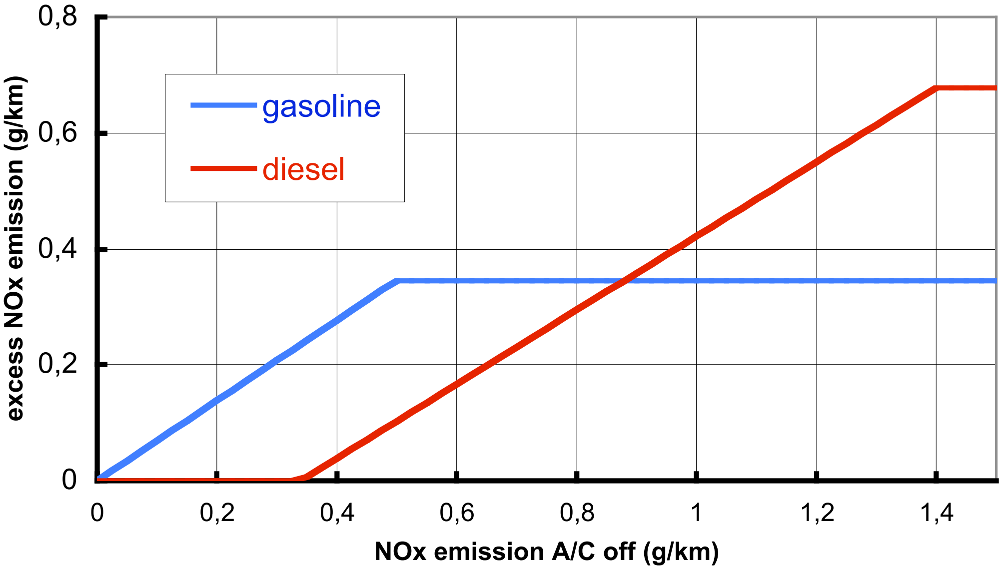


Figure 68: NOx excess emission due to auxiliaries at full load for diesel and petrol vehicles.

<u>petrol:</u>

if $ef_{NOx,\ ACoff} < 0.5$g/km $\quad cf_{AC,NOx,gasoline}\left(ef_{NOx,ACoff}\right) = 0.6918 \cdot ef_{NOx,ACoff}$

else $\quad cf_{AC,NOx,gasoline}\left(ef_{NOx,ACoff}\right) = 0.6918 \cdot 0.5 = 0.3459$

<u>diesel:</u>

if $ef_{NOx,ACoff} < 0.3397$ $\quad cf_{AC,NOx,diesel}\left(ef_{NOx,ACoff}\right) = 0$

else if $ef_{NOx,ACoff} > 0.3397$

and $ef_{NOx,ACoff} < 1.4$ $\quad cf_{AC,NOx,diesel}\left(ef_{NOx,ACoff}\right) = 0.6395 \cdot ef_{NOx,ACoff} - 0.2172$

else $\quad cf_{AC,NOx,diesel}\left(ef_{NOx,ACoff}\right) = 0.6395 \cdot 1.4 - 0.2172 = 0.6781$

Annex 32.4: Model of particulates excess emissions

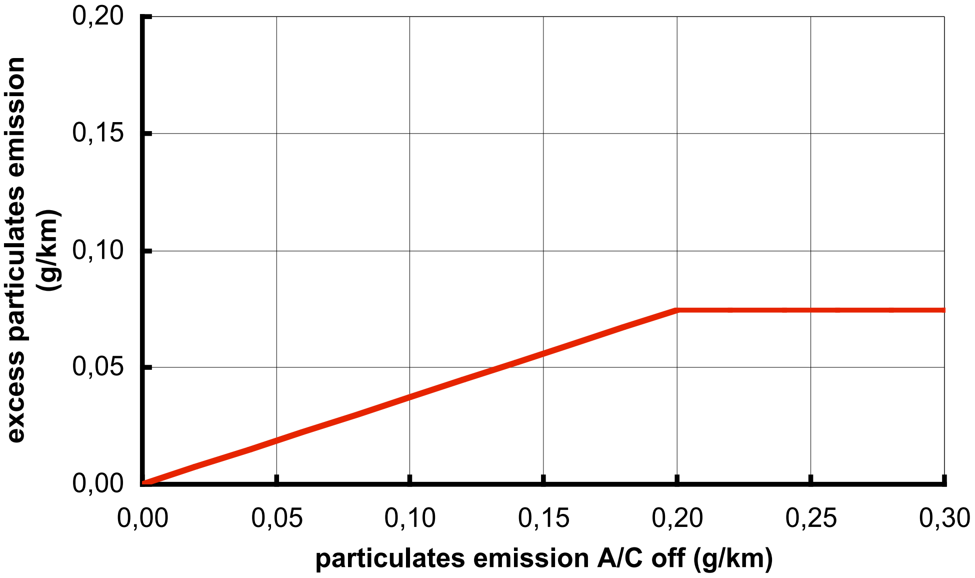


Figure 69: PM excess emission due to auxiliaries for diesel vehicles.

petrol:

$$cf_{AC,Pa,gasoline}\left(ef_{NOx,ACoff}\right)=0$$

diesel:

if $ef_{HC,ACoff} < 0.2$ g/km $\quad cf_{AC,Pa,diesel}\left(ef_{HC,ACoff}\right)=0.3722\cdot ef_{HC,ACoff}$

else $\quad cf_{AC,Pa,diesel}\left(ef_{HC,ACoff}\right)=0.07444$

Annex 33: Cold distance as a function of the average speed and temperature

The formula below describes the cold distance d_c (km) as a function of the average speed V (km/h) and the temperature T (°C). The results of this formula must be positive.

Pollutant	Emission standard	Fuel Type	# of points	$d_c(T,V)$
CO	Euro 0 w/o cat.	Diesel	27	10.17 - 0.167*T - 0.049*V
		Petrol	350	2.826 + 0.116*V
	Euro 0 cat.	Petrol	95	1.639 - 0.019*T + 0.054*V
	Euro 1	Diesel	8	9.553 - 0.042*V
		Petrol	12	8.805 - 0.132*V
	Euro 2	Diesel	466	4.916 - 0.039*T + 0.091*V
		Petrol	79	4.409 - 0.002*T + 0.024*V
	Euro 3	Diesel	18	4.891 + 0.078*V
		Petrol	721	4.284 - 0.025*T - 0.004*V
	Euro 4	Petrol	14	6.716 - 0.06*T
CO_2	Euro 0 w/o cat.	Diesel	27	-2.27 + 0.321*V
		Petrol	333	2.807 - 0.024*T + 0.141*V
	Euro 0 cat.	Petrol	102	2.172 + 0.126*V
	Euro 1	Diesel	18	3.474 + 0.163*V
		Petrol	18	3.838 + 0.081*V
	Euro 2	Diesel	617	4.31 - 0.04*T + 0.125*V
		Petrol	142	4.048 - 0.124*T + 0.145*V
	Euro 3	Diesel	32	9.093 - 0.064*V
		Petrol	781	2.461 - 0.057*T + 0.173*V
	Euro 4	Petrol	14	5.398 - 0.142*T
HC	Euro 0 w/o cat.	Diesel	27	6.834 + 0.022*V
		Petrol	350	3.578 - 0.052*T + 0.093*V
	Euro 0 cat.	Petrol	91	2.087 - 0.042*T + 0.099*V
	Euro 1	Diesel	18	3.444 + 0.226*V
		Petrol	14	7.972 - 0.048*V
	Euro 2	Diesel	617	4.79 - 0.021*T + 0.116*V
		Petrol	62	5.201 - 0.037*T + 0.065*V
	Euro 3	Diesel	32	7.341 + 0.07*V
		Petrol	633	3.552 - 0.092*T + 0.135*V
	Euro 4	Petrol	14	6.97 - 0.16*T

Pollutant	Emission standard	Fuel Type	# of points	$d_c(T,V)$
NOx	Euro 0 w/o cat.	Diesel	27	3.18 + 0.087*V
		Petrol	350	2.879 + 0.081*V
	Euro 0 cat.	Petrol	102	1.92 - 0.026*T + 0.101*V
	Euro 1	Diesel	13	-4.392 + 0.317*V
		Petrol	18	4.318 - 0.016*V
	Euro 2	Diesel	617	0.76 - 0.033*T + 0.158*V
		Petrol	105	-2.515 + 0.238*V
	Euro 3	Diesel	32	9.809 - 0.094*V
		Petrol	708	1.922 + 0.091*V
	Euro 4	Petrol	14	4.523

Annex 34: Equation of the cold start excess emission ω(T,V) and correction coefficients f(V,T)

The equation describes the influence of the mean speed V [km/h] and the ambient temperature T [°C] on excess emission ω(T,V) [g] and the associated dimensionless correction coefficients f(V,T). This equation results in a 3D linear regression (best fitted plan).

Pollutant	Emission Standard	Fuel Type	# of points	Excess Emission Equation ω(T,V)	Correction Coefficient f(T,V)
CO	Euro 0 w/o cat.	Diesel	77	5.102 -0.044*T -0.074*V	1.851 -0.016*T -0.027*V
		Petrol	655	129.521 -5.361*T + 1.285*V	2.698 -0.112*T + 0.027*V
	Euro 0 cat.	Petrol	1561	128.022 -5.731*T + 0.126*V	8.044 -0.36*T + 0.008*V
	Euro 1	Diesel	13	4.662 -0.067*T -0.061*V	2.198 -0.031*T -0.029*V
		Petrol	51	30.369 -1.221*T + 0.437*V	2.068 -0.083*T + 0.03*V
	Euro 2	Diesel	481	7.711 -0.199*T -0.05*V	2.824 -0.073*T -0.018*V
		Petrol	110	32.873 -0.74*T -0.051*V	1.927 -0.043*T -0.003*V
	Euro 3	Diesel	20	2.455 -0.02*V	1.194 -0.01*V
		Petrol	731	35.45 -1.455*T + 0.096*V	4.291 -0.176*T + 0.012*V
	Euro 4	Petrol	14	31.627 -1.338*T	6.488 -0.274*T
CO$_2$	Euro 0 w/o cat.	Diesel	76	206.96 -1.934*V	1.23 -0.011*V
		Petrol	617	214.922 -6.528*T -0.088*V	2.602 -0.079*T -0.001*V
	Euro 0 cat.	Petrol	1568	133.024 -0.306*V	1.048 -0.002*V
	Euro 1	Diesel	24	206.07 -2.606*V	1.338 -0.017*V
		Petrol	57	162.937 -5.435*T + 0.358*V	2.654 -0.089*T + 0.006*V
	Euro 2	Diesel	633	362.34 -10.921*T -0.14*V	2.567 -0.077*T -0.001*V
		Petrol	173	194.662 -3.546*T + 0.504*V	1.454 -0.026*T + 0.004*V
	Euro 3	Diesel	34	171.52-0.381*V	1.047-0.002*V
		Petrol	791	186.055 -5.365*T + 2.283*V	1.496 -0.043*T + 0.018*V
	Euro 4	Petrol	14	168.005 -5.165*T	2.597 -0.08*T
HC	Euro 0 w/o cat.	Diesel	77	1.607-0.028*V	1.538-0.027*V
		Petrol	645	27.712 -1.278*T + 0.233*V	4.068 -0.188*T + 0.034*V
	Euro 0 cat.	Petrol	1557	10.853 -0.439*T + 0.035*V	3.893 -0.157*T + 0.013*V
	Euro 1	Diesel	24	0.75 -0.007*T -0.011*V	1.835 -0.016*T -0.026*V
		Petrol	53	8.653 -0.114*V	1.357 -0.018*V
	Euro 2	Diesel	632	2.38 -0.094*T -0.006*V	6.247 -0.247*T -0.015*V
		Petrol	93	6.997 -0.059*T -0.071*V	1.597 -0.014*T -0.016*V
	Euro 3	Diesel	34	0.129 + 0.001*V	0.863 + 0.007*V
		Petrol	643	8.229 -0.415*T + 0.049*V	9.093 -0.459*T + 0.054*V
	Euro 4	Petrol	14	5.184 -0.247*T	21.246 -1.012*T
NOx	Euro 0 w/o cat.	Diesel	77	-0.489 + 0.015*V	2.472 -0.074*V
		Petrol	656	0.547 -0.022*V	5.523 -0.226*V
	Euro 0 cat.	Petrol	1568	2.159 -0.094*T + 0.023*V	2.894 -0.126*T + 0.031*V
	Euro 1	Diesel	19	2.672 -0.074*V	2.244 -0.062*V
		Petrol	57	0.053 + 0.04*V	0.063 + 0.047*V
	Euro 2	Diesel	633	1.686 -0.082*T + 0.002*V	20.076 -0.978*T + 0.024*V
		Petrol	136	0.287 + 0.021*V	0.406 + 0.03*V
	Euro 3	Diesel	34	-0.909 + 0.04*V	8.335 -0.367*V
		Petrol	718	0.282 -0.002*T + 0.005*V	0.808 -0.005*T + 0.015*V
	Euro 4	Petrol	14	0.186	1

Annex 35: Coefficient a in the equation of the dimensionless cold start excess emission h(δ)

$h(\delta) = \frac{1-e^{a.\delta}}{1-e^{a}}$, with δ = dimensionless distance = d/d_c. dc is given in Annex 33.

pollutant	Emission standard	Fuel type	a
CO	Euro 0 w/o cat.	Diesel	-3.050
		Petrol	-6.066
	Euro 0 cat.	Petrol	-5.579
	Euro 1	Diesel	-3.083
		Petrol	-4.533
	Euro 2	Diesel	-6.731
		Petrol	-9.007
	Euro 3	Diesel	-9.503
		Petrol	-7.280
	Euro 4	Petrol	-5.544
CO_2	Euro 0 w/o cat.	Diesel	-3.432
		Petrol	-2.330
	Euro 0 cat.	Petrol	-2.680
	Euro 1	Diesel	-4.078
		Petrol	-2.714
	Euro 2	Diesel	-3.767
		Petrol	-2.563
	Euro 3	Diesel	-3.389
		Petrol	-3.662
	Euro 4	Petrol	-2.686
HC	Euro 0 w/o cat.	Diesel	-3.352
		Petrol	-5.204
	Euro 0 cat.	Petrol	-10.737
	Euro 1	Diesel	-3.242
		Petrol	-8.923
	Euro 2	Diesel	-4.388
		Petrol	-10.209
	Euro 3	Diesel	-12.140
		Petrol	-8.624
	Euro 4	Petrol	-11.898
NOx	Euro 0 w/o cat.	Diesel	-2.926
		Petrol	-2.615
	Euro 0 cat.	Petrol	-2.246
	Euro 1	Diesel	-1.776
		Petrol	-5.752
	Euro 2	Diesel	-4.729
		Petrol	-3.765
	Euro 3	Diesel	-2.479
		Petrol	-0.739
	Euro 4	Petrol	-0.432

Annex 36: Equations describing the parking time influence on the cold start excess emission

The parking time t is in min. g(720) = 1.

	Pollutant	Equation
Catalyst petrol cars	CO	• $g(t) = 4.614*10^{-3}*t-2.302*10^{-6}*t^2 -2.966*10^{-9}*t^3$ $(t \le 720)$ • $g(t) = 1$ (t>720 min)
	CO_2	• $g(t) =0.1349*10^{-2}*t-2.915*10^{-4}*t^2$ $(t \le 20)$ • $g(t) = 0.136+0.0012*t$ $(21 \le t \le 720)$ • $g(t) = 1$ $(t \ge 720)$
	HC	• $g(t) = 7.641*10^{-3}*t-2.639*10^{-5}*t^2 +3.128*10^{-8}*t^3$ $(t \le 240)$ • $g(t) = 0.625+5.208*10^{-4}*t$ $(241 \le t \le 720)$ • $g(t) = 1$ $(t \ge 720)$
	NOx	• $g(t) =7.141*10^{-3}*t+1.568*10^{-3}*t^2 -3.204*10^{-5}*t^3+1.594*10^{-7}*t^4$ $(t \le 50$ min) • $g(t) = 1.290-4.030*10^{-4}*t$ $(51 \le t \le 720)$ • $g(t) = 1$ $(t \ge 720)$
Petrol cars without catalyst	CO	• $g(t) = -1.504*10^{-2}*t+1.406*10^{-4}*t^2 -2.547*10^{-7}*t^3$ $(t \le 240)$ • $g(t) = 1$ (t>240 min)
	CO_2	• $g(t) =5.287*10^{-9}*t^3-8.864*10^{-6}*t^2 +5.035*10^{-3}*t$ (t<720 min) • $g(t) = 1$ (t>720 min)
	HC	• $g(t) = 1.039*10^{-3}*t-7.918*10^{-6}*t^2 +4.211*10^{-8}*t^3-6.856*10^{-11}*t^4 +3.650*10^{-14}*t^5$ $(t \le 720)$ • $g(t) = 1$ $(t \ge 720)$
	NOx	• $g(t) = 3.52*10^{-2}**t-3.705*10^{-4}*t^2$ $(t \le 50)$ • $g(t) = 0.8170+2.537*10^{-4}*t$ $(51 \le t \le 720)$ • $g(t) = 1$ $(t \ge 720)$
Diesel cars	CO	• $g(t) = 4.167*10^{-3}*t$ $(t \le 240$ min) • $g(t) = 1$ $(t \ge 240$ min)
	CO_2	• $g(t) = 4.339*10^{-3}*t-4.747*10^{-6}*t^2$ $(t \le 460)$ • $g(t) = 0.978+3.077*10^{-5}*t$ $(461 \le t \le 715)$ • $g(t) = 1$ $(t \ge 715$ min)
	HC	• $g(t) = 3.070*10^{-4}*t+4.402*10^{-6}*t^2 -4.030*10^{-9}*t^3$ $(t \le 720)$ • $g(t) = 1$ (t>720 min)
	NOx	• $g(t) = 0$ $(t \le 300$ min) • $g(t) = -1.11+3.703*10^{-3}*t$ (300 min<t<570 min) • $g(t) = 1$ $(t \ge 570$ min)
	PM	• $g(t) = 0$ $(t \le 60$ min) • $g(t) = -0.323+6.488*10^{-3}*t-1.116*10^{-5}*t^2+6.545*10^{-9}*t^3$ (60 min<t<420 min) • $g(t) = 0.808+2.667*10^{-4}*t$ $(t \ge 420$ min)

Annex 37: Base traffic distribution used in the design of the third cold start model

Here is the relative traffic distribution $ptf_{i,h}$ along the day used in the design of the third model, the so-called base distribution, showed in Figure 70.

hour	$ptf_{i,h}$
1	*0.12*
2	*0.08*
3	*0.05*
4	*0.08*
5	*0.13*
6	*0.32*
7	*1.29*
8	*1.78*
9	*1.16*
10	*1.33*
11	*1.50*
12	*1.71*
13	*1.40*
14	*1.60*
15	*1.93*
16	*2.17*
17	*1.99*
18	*1.76*
19	*1.28*
20	*0.86*
21	*0.58*
22	*0.39*
23	*0.31*
24	*0.18*
average	*1.00*

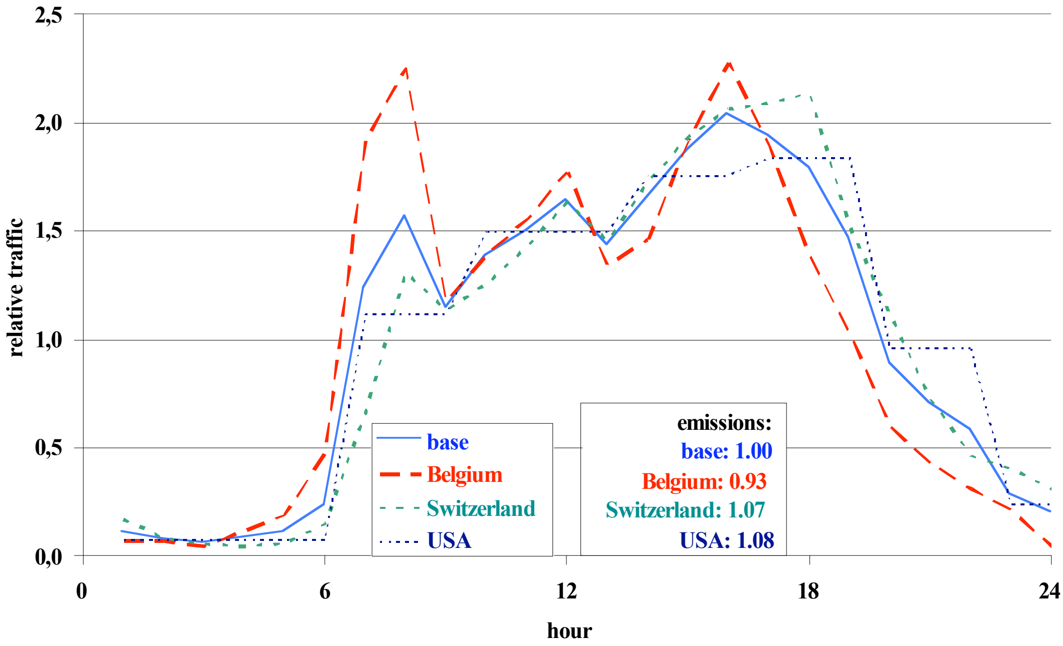


Figure 70: Average traffic distributions representative of 3 countries (relative to the hourly average), and relative base distribution (average) used in the third model design. Relative influence of the using of the different distributions on the daily emissions.

Annex 38: Examples of influence of the temperature, season and hour on the cold start emission (3^{rd} model)

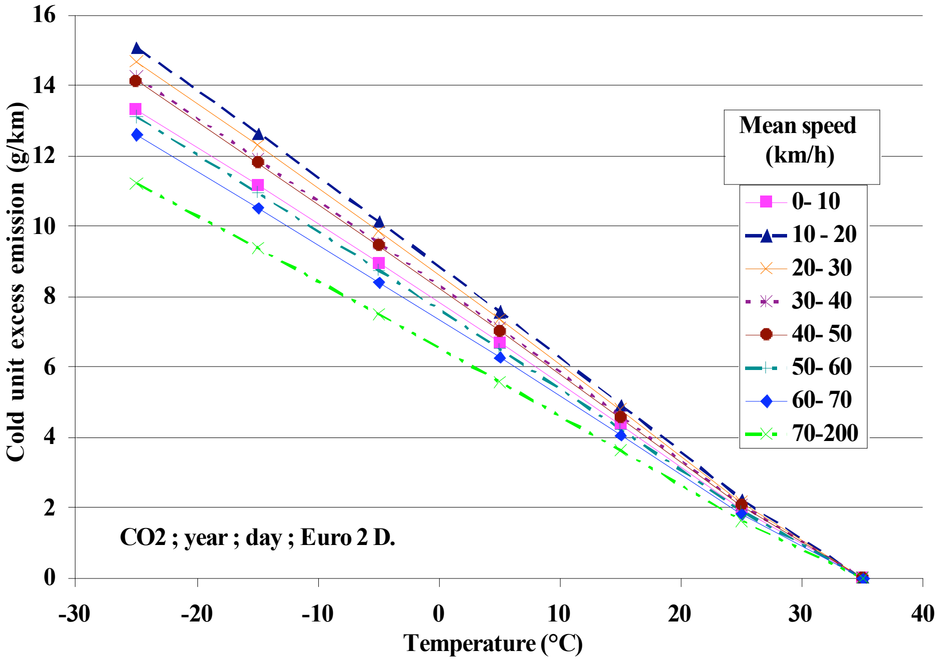


Figure 71: CO_2 cold start unit excess emission according to the ambient temperature and average speed.

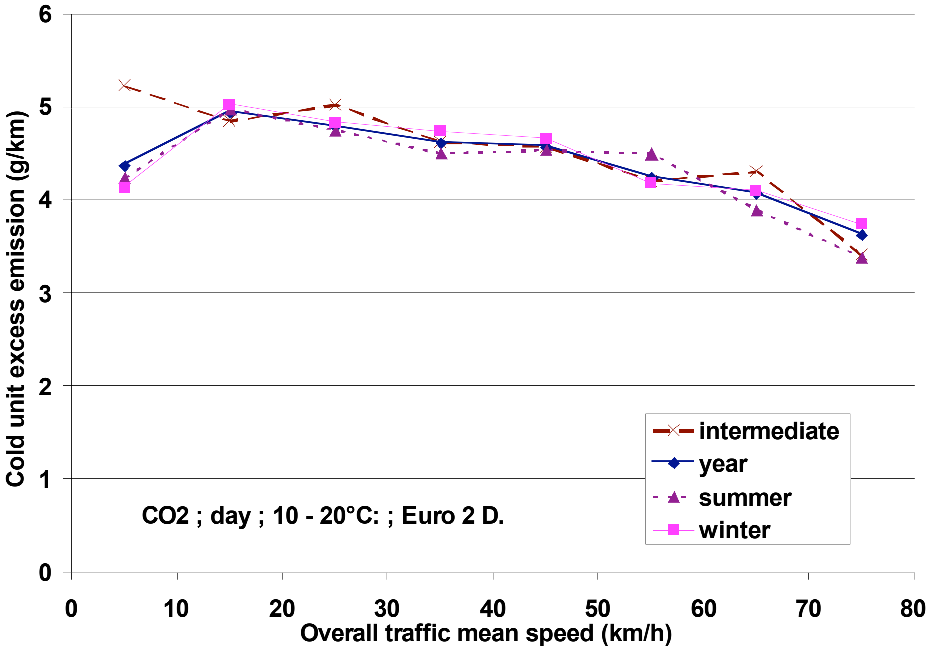


Figure 72: *CO_2 cold start unit excess emission according to the season and average speed.*

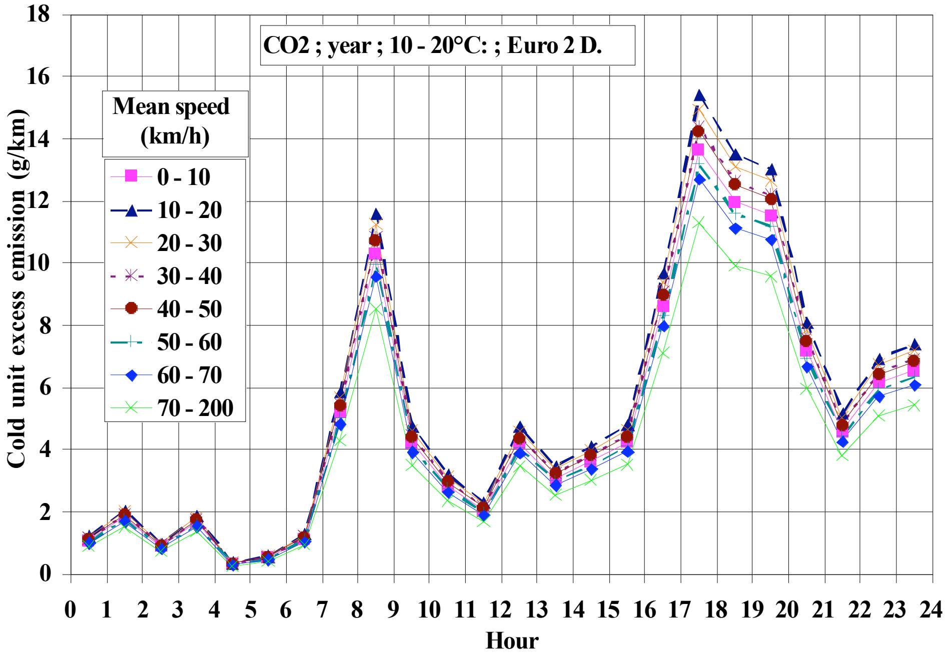


Figure 73: *CO_2 cold start unit excess emission according to the hour and average speed.*

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Literature

References in bold are Artemis deliverables.

References in dark green are specific Artemis reports presenting parts of the research synthetised in this report.

References in blue are articles or communications presenting parts of the research synthetised in this report.

Aakko P., J. Laurikko, M. Weilenmann, P. Mattrel, R. Joumard, J.M. André, M.V. Prati, M.A. Costagliola, T. Merétei, F. Cazier, A. Mercier, H. Nouali, L. Paturel, E. Combet, O. Devos, J.C. Déchaux, I. Caplain & V. Nollet (2005): Emission factors of unregulated atmospheric pollutants for passenger cars. *VTT Processes report*, PRO3/P3016/05, Espoo, Finland, 56 p.

Aakko P., J. Laurikko, M. Weilenmann, R. Joumard, J.-M. André, M. V. Prati, M. A. Costagliola, T. Merétei, F. Cazier, A. Mercier, H. Nouali, L. Paturel, E. Combet, O. Devos, J. C. Dechaux, I. Caplain & V. Nollet (2006): Emission factors of unregulated atmospheric pollutants for passenger cars - Task 320 of the EU ARTEMIS Project. 2nd conf. *Environment & Transport*, incl. 15th conf. *Transport and Air Pollution*, 12-14 June 2006, Reims, France. Proceedings, actes Inrets, n°107, vol. 1, Arcueil, France, p. 231-238.

Ajtay D. (2005): Modal Pollutant Emissions Model of Diesel and Gasoline Engines. *Doctoral thesis*, n°16302, 25 Aug. 2005, ETH, Zurich, Switzerland, 110 p.

Ajtay D., M. Weilenmann & P. Soltic (2003): Towards Accurate Instantaneous Emission Models, 12th int. symp. *Transport and Air Pollution*, 16-18 June 2003, Avignon, Proceedings Volume 1, pp 137-144, Inrets, 2003

Ajtay D. & M. Weilenmann (2004a): Static and Dynamic Instantaneous Emission Modelling, *Intern. J. of Environ. and Pollution*, Vol. 22, No 3, 2004.

Ajtay D. & M. Weilenmann (2004b): Compensation of the exhaust gas transport dynamics for accurate instantaneous emission measurements. *Environ. Sci. & Technol.*, 2004, 38(19), 5141-5148.

Ajtay D., M. Weilenmann & T. Auckenthaler (2004): Modelling catalyst-out NO_x emissions based on the relative oxygen level in the catalyst. Poster, 13th int. symp. *Transport and Air Pollution*, 13-15 September 2004, Boulder, USA.

Ajtay D., M. Weilenmann & P. Soltic (2005): Towards Accurate Instantaneous Emission Models, *Atmos. Environ.*, Vol 39/13 pp 2443-2449, April 2005.

Ajtay D. & M. Weilenmann (2005a): Validation of instantaneous emission model for different loads, slopes and gear-shift strategies. Poster, 14th int. symp. *Transport and Air Pollution*, 1-4 June 2005, Graz, Austria.

Ajtay D. & M. Weilenmann (2005b): Application of vehicle instantaneous emission models at fleet level. Environmental Modelling and Software, presentation at *Urban Air Quality Congress*, 29. Mar – 1. Apr. 2005, Valencia.

André M. (2002a): ARTEMIS and COST346 projects: Road traffic characteristics. COST346-54. *COST346 workshop*, Brussels, 22-23 Oct. 2002, 18 p.

André M. (2002b): The ARTEMIS European driving cycles for measuring car pollutant emissions. 7th Int. Symp. *Highway and Urban Pollution*, Barcelona, 20-23 May 2002. Sci. Total Environ., 2004, vol. 334-335, p. 73-84.

André M. (2004a): Real-world driving cycles for measuring cars pollutant emissions - Part A : The Artemis European driving cycles. *INRETS report*, Bron, France, n°LTE 0411, 97 p

André M. (2004b): The ARTEMIS European driving cycles for measuring car pollutant emissions. *Sci. Total Environ.*, n°334-335, p. 73-84.

André J.M. (2005): Vehicle emission measurement collection of the Artemis database - Artemis 3312 report. *Inrets report*, LTE 0504, Bron, France, 25 p.

André M., R. Vidon, C. Pruvost & P. Tassel (2000) : Cycles de conduite pour la mesure des émissions de polluants des petits véhicules utilitaires. *INRETS report*, n° LTE 2014, Bron, France, 87 pp.

André M. & R. Joumard (2004): Real-world and specific to vehicle driving cycles for measuring car pollutant emissions. 13th Int. Symp. *Transport and Air Pollution*, Sept. 13-15, Boulder, Colorado USA, proceedings, NCAR, Boulder, p. 115-124.

André JM., R. Joumard & M. André (2004): Modelling of cold start emissions for passenger cars. Poster, 13th Int. Symp. *Transport and Air Pollution*, Sept. 13-15, Boulder, Colorado USA, proceedings, NCAR, Boulder, p. 231-238.

André J.M. & R. Joumard (2005): Modelling of cold start excess emissions for passenger cars. *Inrets report*, Bron, France, n°LTE 0509, 239 p.

André J.M. & R. Joumard (2006): Modelling of cold start excess emissions for passenger cars in the Artemis model. 2nd conf. *Environment & Transport*, incl. 15th conf. *Transport and Air Pollution*, 12-14 June 2006, Reims, France. Proceedings, actes Inrets, n°107, vol. 1, Arcueil, France, p. 103-110.

André M. & M. Rapone (2006): Driving cycles and pollutant emissions estimation. 2nd conf. *Environment & Transport*, incl. 15th conf. *Transport and Air Pollution*, 12-14 June 2006, Reims, France. Proceedings, actes Inrets, n°107, vol. 1, Arcueil, France, p. 327-334.

André M., M. Rapone, N. Adra, I. Pollak, M. Keller & I. McCrae (2006a): Traffic characteristics for the estimation of pollutant emissions from road transport – Artemis deliverable 10. *Inrets report*, Bron, France, LTE 0606, 89 p.

André M., M. Rapone & R. Joumard (2006b): Analysis of the car pollutant emissions as regards driving cycles and kinematic parameters. *Inrets report*, Bron, n°LTE 0607, 136 p., ISBN N° INRETS/RR/06-509-ENG.

André M., C. Fantozzi & N. Adra (2006c): Development of an approach for estimating the pollutant emissions from road transport at a street level. *Inrets report*, Bron, France, LTE 0628, 153 p.

AQEG – Air quality expert group (2006): Trends in primary nitrogen dioxide in the UK. *DEFRA report*, London, 71 p.

ASHRAE (1992) (American Society of Heating Refrigerating and Air Conditioning Engineers): Thermal environmental conditions for human occupancy, ASHRAE standard 55-1992.

Barbusse S., D. Clodic & J.-P. Roumegoux (1998) : Climatisation automobile, énergie et environnement. *Recherche Transport Sécurité*, n°60, p. 3-18.

Barbusse S. & L. Gagnepain (2003) : La climatisation automobile, impact énergétique et environnemental. *Données et Références*, Ademe, Paris.

Barth, M., An, F., Norbeck, J. and Ross, M., (1996): Modal emissions modeling: A physical approach. *Transportation Research Record*, Vol. 1520, p. 81-88.

Benouali J, D. Clodic & C. Malvicino (2002): External and internal control compressors for mobile air-conditioning systems. Proc. Int. *Refrigeration and air conditioning* conf., Purdue, West Lafayette, Indiana, 16-19 July.

Benouali J., D. Clodic, S. Mola, G. Lo Presti, M. Magini & C. Malvicino (2003): Fuel consumption of Mobile air conditioning - Method of testing and results. *Earth Technology Forum*, Washington DC, April 2003, 10 p.

Bolher A., R. Casari, B. Collignan, E. Fleury, D. Marchio, J.R. Millet & O. Morisot (2000) : Méthode de calcul des consommations des bâtiments climatisés ConsoClim. *CSTB/ENEA report*, DDD/CVA-99-176R, Marne-la-Vallée, France.

Boulter P. (ed.) (2007): ARTEMIS: Assessment and reliability of transport emission models and inventory systems: final report. *TRL report*, Wokingham, UK.

Caplain I., F. Cazier, H. Nouali, A. Mercier, JC. Déchaux, V. Nollet, R. Joumard, JM. André and R. Vidon (2004): Measurement of non regulated pollutants from gasoline and diesel passengers cars. Poster, 13th Int. Symp. *Transport and Air Pollution*, Sept. 13-15, Boulder, Colorado USA, proceedings, NCAR, Boulder, p. 243-249.

Caplain I., F. Cazier, H. Nouaki, A. Mercier, JC. Déchaux, V. Nollet, R. Joumard R., JM. André & R. Vidon (2006): Emissions of unregulated pollutants from European gasoline and diesel passengers cars. *Atmos. Environ.*, 40, p. 5954-5966.

Carslaw D C (2005): Evidence of an increasing NO_2/NOx emissions ratio from road traffic emissions. *Atmos. Environ.*, Vol. 39, pp. 4793-4802.

Carslaw D.C. & S.D. Beevers (2004): Investigating the potential importance of primary NO_2 emissions in a street canyon. *Atmos. Environ.,* Vol. 38, pp. 3585-3594.

Carter W.P.L. (2000) : The SAPRC 99 chemical mechanism and updated VOC reactivity scales. http://cert.ucr.edu/~carter/reactdat.htm

Cassadou S., I. Nicoulet, J. Noppe, M. Chiron, A. Rouhan, A. Barneaud, C. Bassi, L. Calovi, J.P. Vinot & H. Desqueyroux (2004) : Selection des agents dangereux à prendre en compte dans l'evaluation des risques sanitaires lies aux infrastructures routieres *(selection of hazardeous compounds to take into account for the health risk assessment from road infrastructures)*. *Ministère Santé*, DGS, Paris, 77 p and 163 p (annexes).
http://www.sante.gouv.fr/htm/dossiers/etud_impact

Charles K.E. (2003): Fanger's Thermal comfort and draught models. *Institute for Research in Construction*, IRC RR 162 report, Ottawa, Canada, 29 p.

Della Ragione L., G. Meccariello, M. V. Prati, M. Rapone (2003): The effect of different kinematic aspects on emission factors of Diesel cars, *6th International Conference on Engines for Automobile - ICE 2003*, Paper SAE-NA 2003-01-62

Devos O., E. Combet, P. Tassel & L. Paturel (2006): Exhaust emissions of PAHs of passenger cars. *Polycyclic Aromatic Compounds*, 26 ,69-78.

DOE - Department of Energy (2004): EnergyPlus. Washington. Available from:
http://www.eren.doe.gov/buildings/energy_tools/energyplus/

Duan N. (1983): Smearing Estimate: A Nonparametric retransformation Method. *J. American Statistical Assoc.*, September 1983, 78-383.

Duboudin C. & C. Crozat (2002): Analyse de la méthodologie COPERT III (Analysis of the Copert III methodology). *SCM report*, Paris, 152 p.

EC (2005a): CAFÉ programme - Clean Air for Europe. www.europa.eu.int/comm/environment/air/cafe/index.htm (30 June 2005)

EC (2005b): European Climate Change Programme (ECCP). europa.eu.int/comm/environment/climat/eccp.htm (16 August 2005)

ECCP (2003): How to considerably reduce greenhouse gas emissions due to mobile air conditioners. Consultation paper, *European Commission*, DG Environment, Brussels.

EEC (1991): Council directive of 20 March 1970, on the approximation of the laws of the Member States on measures to be taken against air pollution by emissions from motor vehicles (70/220/EEC), as amended by Council Directive 91/441/EEC of 26 June 1991, Appendix 8, Item 1.4 ("Determination of the NO humidity correction factor"), in 1970L0220 - EN —-31.10.2002 —-020.001, p. 106, 1991.

Eggleston HS., D. Gaudioso, N. Gorissen, R. Joumard, R.C. Rijkeboer, Z. Samaras & K.H. Zierock (1993): CORINAIR working group on emission factors for calculating 1990 emissions from road traffic - volume 1 : methodology and emission factors. *CEC report*, Luxembourg, ISBN 92-826-5571-X, 116 p.

Fanger P.O. (1972): Thermal comfort. *McGraw-Hill Book.*

Fantozzi C., André M., N. Adra (2005): Development of a new approach for the estimation of the pollutant emissions from the road transport at the street level. 14th Int. Conf. *Transport and Air Pollution*, 2005, Graz. Proceedings Vol. 1, p. 289-298.

Farrington R.B, D.L. Brodt, S.D. Burch & M. A. Keyser (1998): Opportunities to reduce vehicle climate control loads. Proc. 15th *Electric Vehicle* Symp., Brussels, Sept. 30-Oct. 3.

Farrington R.B., R. Anderson, D.M. Blake, S.D. Burch, M.R. Cuddy, M. A. Keyser & J.P. Rugh (1999): Challenges and potentials solutions for reducing climate control loads in conventional and hybrid electric vehicles. NREL/CP-540-25975, *Nal Renewable Energy Lab.*, Golden, CO, presented at the VTMS4, London, May 26, 1999.

Flandrin Y., R. Vidon, P. Tassel, J.C. Dechaux, V. Nollet, F. Cazier & R. Joumard (2002) : Mesure des emissions automobiles de composes organiques volatils et de derives carbonyles. *INRETS report*, Bron, France, n°LTE 0210, 269 p.

Fontaine H. (2000) : Les Composés Organiques Volatils dans les gaz d'échappement des automobiles : Etablissement de profils d'émission representatifs de différentes conditions de conduite. *These de Doctorat*, Université de Technologie de Compiegne, 359 p.

Fontaras G., Geivanidis S. & Samaras Z. (2006): Development and evaluation of hybrid vehicle emission and fuel consumption factors based on measurements over real world cycles, 2nd conf. *Environment & Transport*, incl. 15th conf. *Transport and Air Pollution*, 12-14 June 2006, Reims, France. Proceedings, actes Inrets, n°107, vol. 1, Arcueil, France, p. 215-222.

Fraisse G. & J. Virgone (2001) : Modélisation numérique d'un bâtiment multizone sous TRNSYS. 4es *Journées TRNSYS Francophones*, Lyon, France, 10 sept. 2001, 19 p.

Geivanidis S. & Z. Samaras (2004): Investigation of the emission degradation of petrol vehicles. *LAT Report*, n°0415, Thessaloniki, Greece, 34 p.

Geivanidis S. & Samaras Z. (2005): Investigation of the emission degradation of Euro III and Euro IV gasoline vehicles, Proceedings of the 14th Int. Symp. *Transport and Air Pollution*, Graz, Austria.

Gense N. L. J. (2000): Driving style, fuel consumption and tail pipe emissions - Final report. *TNO report*, Delft, the Netherlands.

Gense R., R. Vermeulen, M. Weilenmann & I. McCrae (2006): NO_2 emission from passenger cars. 2nd conf. *Environment & Transport*, incl. 15th conf. *Transport and Air Pollution*, 12-14 June 2006, Reims, France. Proceedings, actes Inrets, n°107, vol. 1, Arcueil, France, p. 175-182.

Hammarström U. (2002): Betydelsen av korta motoravstängningar och körtid för avgasemissioner fran bensindrivna bilar med och utan katalysator. *VTI meddelande*, 931, Sweden.

Hassel D., P. Jost, F.-J. Weber, F. Dursbeck, K.-S. Sonnborn & D. Plettau (1994): Abgas-Emissionsfaktoren von Pkw in der Bundesrepublik Deutschland - Abgasemissionen von Fahrzeugen der Baujahre 1986 bis 1990. *UBA-Forschungsbericht* 104 05 152 & 104 05 509, TÜV Rheinland, Cologne, Germany, and Berichte 8/94, Erich Schmidt Verlag, Berlin, ISBN 3-503-03683-0, 343 p, and: Exhaust emission factors for motor vehicles in the Federal Republic of Germany for the reference year 1990 (English translation). COST secretariat, CEC DG VII, Brussels.

Hausberger S. (1997): Globale Modellbildung für Emissions- und Verbrauchsszenarien im Verkehrssektor (Global Modelling of Scenarios Concerning Emission and Fuel Consumption in the Transport Sector); *Dissertation am Institut für Verbrennungskraftmaschinen und Thermodynamik der TU-Graz*; Graz,

Hausberger S., W. Tripolt, J. Brenner, J. Wiesmayr & E. Bukvarevic (2005): Evaporative emissions of vehicles. Artemis deliverable 6, *TUG report*, Graz, Austria, 70 p.

Heeb NV., A.-M. Forss, C.J. Saxer & P. Wilhelm (2002): Methane, Benzene and Alkyl Benzene Cold Start Data of gasoline-driven Passenger Cars representing the Vehicle Technology of the last two Decades, Publication, in Proceedings of 11th Int. Symp. *Transport and Air Pollution* (ISBN 3-901351-59-0), Graz, Austria, Vol. 1, p 171-178, 2002.

Heeb N., AM. Forss, C. Saxer, P. Wilhelm, S. Brühlmann, C. Rüedy & M. Weilenmann (2004): The benzene problem – impact of three-way catalyst technology – potential for further improvement. *Intern. J. Environ. Pollution*, Vol. 22, n°3, p 287-300.

Hickman J., D. Hassel, R. Journard, Z. Samaras & S. Sorenson (1999): MEET - Methodology for calculating transport emissions and energy consumption. *European Commission*, DG VII, ISBN 92-828-6785-4, Luxembourg, 362 p. www.inrets.fr/infos/cost319/M22.pdf

Hugrel C. & R. Joumard (2004): The contribution of passenger cars to the greenhouse effect : influence of air-conditioning and ACEA's commitment (JAMA and KAMA included) on the CO_2 emissions. Proc. 13th Symp. *Transport and Air Pollution*, Boulder, USA, Sept. 13-15, 2004, NCAR ed., Boulder, p. 305-313.

IARC (1983): Polynuclear Aromatic Compounds. Part 1 Chemical, Environmental and Experimental data. *IARC monographs*, 32, 1983. http://193.51.164.11/htdocs/Indexes/Vol32Index.html

IARC (1987): Overall Evaluations of Carcinogenicity: An updating of *IARC Monographs*, vol.1-42, supplement n°7, 1987. http://193.51.164.11/htdocs/Indexes/Suppl7Index.html

IARC (2002): Some Traditional Herbal Medicines, Some Mycotoxins, Naphthalene and Styrene. *IARC monograph*, vol. 82, 590 p., ISBN 92 832 1282 7. http://monographs.iarc.fr/

IARC (2006): Polynuclear Aromatic Compounds. *IARC monograph*, vol. 32, suppl. 7, 92, in prep. http://monographs.iarc.fr/

Jenkin M.E. (2004): Analysis of sources and partitioning of oxidant in the UK—Part 2: contributions of nitrogen dioxide emissions and background ozone at a kerbside location in London. *Atmos. Environ.*, Vol. 38, pp. 5131–5138.

Jimenez J.L., G.J. McCrae, D.D. Nelson, M.S. Zahniser & C.E. Kolb (2000): Remote sensing of NO and NO_2 emissions from heavy-duty diesel trucks using tunable diode lasers. *Environ. Sci. and Tech.*, Vol. 34(12), pp. 2380-2387.

Joumard R. (ed.) (1999): COST 319 - Estimation of pollutant emissions from transport: Scientific state-of-the-art and network of European scientists. *European Commission*, DG Transport, n°EUR 18902, ISBN 92-828-6797-8, Luxembourg, 174 p. www.inrets.fr/infos/cost319/index.html

Joumard R., P. Jost, A.J. Hickman & D. Hassel (1995a): Hot passenger car emissions modelling as a function of instantaneous speed and acceleration. 3rd Int. Symp. *Transport and Air Pollution*, Avignon, France, 6-10 June, 1994, and Sc. Total Environ., vol. 69, p. 167-174.

Joumard R., R. Vidon, L. Paturel, C. Pruvost, P. Tassel, G. De Soete & A. Saber (1995b): Changes in pollutant emissions from passenger cars under cold start conditions. *INRETS report*, n° 197 bis, Bron, France, 75 p.

Joumard R. & É. Sérié (1999): Modelling of cold start emissions for passenger cars. *INRETS report*, LTE 9931, Bron, France, 86 p.

Joumard R., R. Vidon & P. Tassel (2001) : Émissions unitaires de polluants des véhicules utilitaires légers. *INRETS report*, n°LTE 0101, Bron, France, 65 p.

Joumard R. & M. André (2003) : Le projet européen Artemis : nouveautés structurelles envisagées pour la modélisation des émissions du transport routier. Séminaire Ademe *Modélisation des émissions de polluants du transport routier*, Paris, 1er avril 2003.

Joumard R., M. André, R. Vidon & P. Tassel (2003): Characterizing real unit emissions for light duty goods vehicles. *Atmos. Environ.*, vol. 37, p. 5217-5225.

Joumard R., J.M. André, I. Caplain, L. Paturel, F. Cazier, A. Mercier, E. Combet, O. Devos, H. Nouali, R. Vidon, P. Tassel, P. Perret, S. Lacour, M. Hugot & J.C. Déchaux (2004a) : Campagne de mesure des émissions unitaires de polluants non réglementés des véhicules particuliers. *Inrets report*, Bron, France, n°LTE 0408, 151 p.

Joumard R., J.M. André, M. André, L. Paturel, F. Cazier & J.C. Déchaux (2004b): Exhaust emissions of regulated and unregulated pollutants of passenger cars. 10th CONAT congress, *Automotive and future technologies*, 20-22 Oct., 2004, Brasov, Romania, paper 20042079.

Joumard R., M. André, J. Laurikko, T. Le Anh, S. Geivanidis, Z. Samaras, Z. Oláh, P. Devaux, J.M. André, E. Cornelis, P. Rouveirolles, S. Lacour , M.V. Prati, R. Vermeulen & M. Zallinger (2006a): Accuracy of exhaust emissions measurements on vehicle bench - Artemis deliverable 2. *Inrets report*, Bron, France, n°LTE 0522, 140 p.

Joumard R., J. Laurikko, S. Geivanidis, Z. Samaras, Z. Oláh, M. Weilenman, JM. André, E. Cornelis, M. Gribe, S. Lacour, MV. Prati, R. Vermeulen & M. Zallinger (2006b): Accuracy of exhaust emissions measurements on vehicle bench. 2nd conf. *Environment & Transport*, incl. 15th conf. *Transport and Air Pollution*, 12-14 June 2006, Reims, France. Proceedings, actes Inrets, n°107, vol. 1, Arcueil, France, p. 119-126.

Joumard R., J. Laurikko, S. Geivanidis, Z. Samaras, Z. Oláh, M. Weilenman, JM. André, E. Cornelis, M. Gribe, S. Lacour, MV. Prati, R. Vermeulen & M. Zallinger (2006c): Accuracy of exhaust emissions measurements on vehicle bench. Poster, *FISITA 2006*, 22-27 October, 2006, Yokohama, Japan.

Kadenko A. (2001): Statistical syntheses of the vehicles emissions factor measurements results. *INRETS report*, LTE 0132, Bron, France, 60 p.

Keller M. (2004): Handbook emission factors for road traffic (HBEFA, version 2.1). Software, Infras, Bern.

www.umwelt-schweiz.ch/buwal/eng/fachgebiete/fg_luft/quellen/verkehr/emission/ (16 August 2005)

Keller M., R. Evéquoz, J. Heldstab & H. Kessler (1995): Émissions polluantes du trafic routier de 1950 à 2010. *Cahier de l'environnement*, n° 255, OFEFP, Berne, Switzerland, 430 p.

Kljun N., M. Keller & P. de Haan (2005): Design of the A300 data base. *Infras report*, Zurich, 9 p.

Kljun N. & M. Keller (2006): Emission factors PC, internal working paper (WP 330). *Infras report*, Bern, 64 p

Koupal J.W. (2001): Air Conditioning Activity Effects in MOBILE6. M6.ACE.001, USEPA.

Koupal J.W. & J. Kremer (2001): Air Conditioning Corrections Factors in MOBILE6. M6.ACE.002 USEPA.

Kurtenbach R., K.H. Becker, J.A.G. Gomes, J. Kleffmann, J.C. Lorzer, M. Spittler, P. Wiesen, R. Ackermann, A. Geyer & U. Platt (2001): Investigations of emissions and heterogeneous formation of HONO in a road traffic tunnel. *Atmos. Environ.*, Vol. 35, pp. 3385–3394.

Latham S., S. Kollamthodi, P.G. Boulter, P.M. Nelson & A.J. Hickman (2001): Assessment of primary NO_2 emissions, hydrocarbon speciation and particulate sizing on a range of road vehicles. TRL Report PR/SE/353/2001, Transport Research Laboratory, Crowthorne, UK.

Laurikko J. (2005a): The Effect of Ambient Temperature on Emissions. *VTT Processes report* PRO3/P3030/05, Espoo, Finland, 23 p + App 4 p.

Laurikko J. (2005b): The Effect of Ambient Humidity on Emissions. *VTT Processes report* PRO3/P3031/05, Espoo, Finland, 16 p + App. 3 p.

Le Anh T., S. Hausberger, D. Ajtaj & M. Weilenmann (2005a): Response time in instantaneous emission measurement. *EMPA & TUG report*, Dübendorf, Switzerland, Graz, Austria, 44 p.

Le Anh T., S. Hausberger & M. Zallinger M. (2005b): Correction for accurate instantaneous emission measurements of passenger cars. 13th Conf. *Air pollution*, Wessex Institute of Technology- WIT express, 1-84564-014-4, Cordoba 2005.

Lhuillier J.P. (2004) : Le projet routier, acte d'aménagement : de l'analyse des données à la prise de décision. Cycle de formation ENPC – IAO, CERTU, 17 Novembre 2004, Marseille, France.

Markewitz K. & R. Joumard (2005): Atmospheric pollutant emission factors of light duty vehicles. *Inrets report*, n°LTE0508A, Bron, France, 65 p.

Markewitz K. & R. Joumard (2006): Atmospheric pollutant emission factors of light duty vehicles within the Artemis model. 2nd conf. *Environment & Transport*, incl. 15th conf. *Transport and Air Pollution*, 12-14 June 2006, Reims, France, poster. Proceedings, actes Inrets, n°107, vol. 2, Arcueil, France, p. 84-89.

Millbrook (2005): The effects of emerging technologies on certain vehicle emissions not currently regulated. Millbrook Proving Ground Ltd & AEA Technology, CFV project S0426/T4, *MBK report*, MBK 05/0832.

Morisot O., D. Marchio & P. Stabat (2002): Simplified model for the operation of chilled water cooling coils under non-nominal conditions. *HVAC & R Research*, Vol. 8, No. 2.

Ntziachristos L.& Z. Samaras (2000a): Copert III, Methodology and Emissions Factors. Final draft report with contributions from S. Eggleston, N. Gorissen, D. Hassel, A.-J. Hickman, R. Joumard & K.-H. Zierock, *European Environment Agency*, ETC/AE, 83 pp.

Ntziachristos L. & Z Samaras (2000b): Copert III, Computer Program to Calculate Emissions from Road Transport. *European Environment Agency*, Copenhagen.

Park Y.C., R. McEnaney, D. Boewe, J.M. Yin & P.S. Hrnjak (1999): Steady state and cycling performance of a typical R134a Mobile A/C System. *SAE paper*, 1999-01-1190, Warrendale, USA.

Paturel L., E. Combet, O. Devos & P. Tassel (2003): Unit PAH emissions at exhausts of recent-technology light vehicles in Europe. Affiche, 12e colloque *Transports et pollution de l'air*, Avignon, 16-18 juin 2003. Actes, Inrets, Arcueil, France, n°92, vol. 2, p. 177-182.

Paturel L., E. Combet, O. Devos & P. Tassel (2005): Exhaust emissions of PAHs of passenger cars. Proceedings of the 20th Int. Symp. on *Polycyclic Aromatic Compounds*, Toronto, Canada, August 21-26.

Pelkmans L, G. Lenaers, P. Debal, M. Van Poppel, T. Hood, G. Hauser & M. R. Delgado (2003): Impact of air conditioning, ambient temperature and humidity on emissions of modern passenger cars. Proc. 12^{th} Symp. *Transport and Air Pollution*, Avignon, France, June 16-18, 2003, vol. 2,Inrets ed. Arcueil, France, p. 145-152.

Prati M.V., M. Rapone, M. A. Costagliola (2003a): Unregulated emissions of European different technology gasoline cars. 12th Int. Sci. Symp. *Transport and Air Pollution*, Avignon, France.

Prati M.V., M. Rapone, M.A. Costagliola (2003b): Unregulated emissions of different technology Diesel cars. Proceedings, 6th Int. Conf. *Engines for Automobile - ICE 2003,* Paper SAE-NA 2003-01-60

Prati M.V., Costagliola M.A., Rapone M. (2005): Unregulated emissions of Euro I, II and III gasoline cars, 7th Int. Conf. *Engines for Automobile, ICE2005*, Capri (Napoli) 2005, SAE Paper 2005-24-025 (ISBN 88-9000399-2-2).

Rapone M. (2005): A Multiblock Regression Model For The Determination Of Emission Factors. Application To A Case Study. *CNR IM report*, n° 2005 P 1570, Napoli, Italy, proposed for publication.

Rapone M., L. Della Ragione, M. V. Prati, G. Meccariello (2003): Influence of the driving cycle on average emissions: development of the regression model for a case study, 12th Int. Sci. Symp. *Transport and Air Pollution,* Avignon, France.

Rapone M., L. Della Ragione, G. Meccariello, M.V. Prati & M.A. Costagliola (2005a): effect of vehicle class and driving behavior on emission factors of gasoline passenger cars. *CNR-IM report*, 2005RR1657, Naples, Italy, 55 p.

Rapone M., L. Della Ragione, G. Meccariello, M.V. Prati & M.A. Costagliola (2005b): effect of vehicle class and driving behavior on emission factors of diesel passenger cars. *CNR-IM report*, 2005RR1658, Naples, Italy, 44 p.

Rapone M., Della Ragione L., Meccariello G, M.V. Prati, Costagliola M.A. (2005c): Effect of vehicle class and driving behavior on emission factors of gasoline passenger cars. Poster, 14th Int. Symp. *Transport and Air Pollution*, Graz, Austria, 1-3 June 2005, Vol. II, p. 198-205.

Rapone M., M.V. Prati, Costagliola M.A.,Della Ragione L., Meccariello G. (2005d): Emission factors determination of Euro III 1200-1400 cc petrol passenger cars by a PLS multivariate regression model. 5th Int. Conf. *Urban Air Quality*, Valencia (Spain) 2005, p. 37-40 (ISBN 1-898543-92-5)

Rapone M., M.V. Prati, Della Ragione L., Meccariello G, Costagliola M.A. (2005e): A novel statistical model for the evaluation of vehicle emission factors. Application to a Euro III gasoline car fleet, 7th Int. Conf. *Engines for Automobile, ICE2005*, Capri (Napoli) 2005, SAE Paper 2005-24-024 (ISBN 88-9000399-2-2).

Rapone M., MV. Prati, I. Iaccio, L. Della Ragione, G. Meccariello & M. Costagliola (2006a): Per la determinazione di consumi e fattori di emissione di autovetture, veicoli heavy-duty e veicoli a due ruote (Determination of fuel consumption and emission factors of passenger cars, heavy duty vehicles and two wheels vehicles). *IM report* (in Italian), 2006RR1718, Napoli, Italy, 196 p.

Rapone M., L. Della Ragione, G. Meccariello, M. V. Prati & M.A. Costagliola (2006b): Validation of a hierarchical emission model: a statistical analysis of Artemis data base. 2nd conf. *Environment & Transport*, incl. 15th conf. *Transport and Air Pollution*, 12-14 June 2006, Reims, France. Proceedings, actes Inrets, n°107, vol. 1, Arcueil, France, p. 247-254.

Rexeis M., S. Hausberger, I. Riemersma, L. Tartakovsky, Y. Zvirin, M. Van poppel & E. Cornelis (2005): Heavy duty vehicle emission. Artemis deliverable 4, *TUG report*, Graz, Austria, 176 p.

Ricardo (2003): Emission factors for cars. Q40240 / VSE project S0135/VB, *Ricardo report*, UK.

Roujol S. (2005): Influence of passenger car auxiliaries on pollutant emissions - Artemis 324 report. *Inrets report*, LTE 0502, Bron, France, 58 p.

Roujol S. & R. Joumard (2006): Influence of passenger car auxiliaries on pollutant emission factors within the Artemis model. 2nd conf. *Environment & Transport*, incl. 15th conf. *Transport and Air Pollution*, 12-14 June 2006, Reims, France. Proceedings, actes Inrets, n°107, vol. 1, Arcueil, France, p. 207-214.

Roumégoux J-P., M. André, R. Vidon, P. Perret & P. Tassel (2004) : Consommation de carburant et émission de CO_2 des auxiliaires : climatisation et alternateur, impact des optimisations. *INRETS report*, n°LTE 0428, Bron, France, p.

Sabate S. (1996): Methodology for calculating and redefining cold and hot start emissions, *CARB report*.

Samaras Z. & L. Ntziachristos (1998): Average hot emission factors for passenger cars and light duty trucks. *LAT report*, n°9811, Thessaloniki, Greece, 112 p.

www.inrets.fr/infos/cost319/index.html

Samaras Z., N. Kyriakis, M. Giannouli, E. Tourlou & L. Ntziachristos (2001): Modelling of cold start emissions: Comparative assessment of existing methodologies. *LAT report*, Thessaloniki, Greece, 52 p.

Samaras S. & S. Geivanidis (2005): Speed dependent emission factors for Euro I and onwards petrol and diesel passenger cars. *LAT report*, 0417, Univ. Thessaloniki, Greece, 41 p.

Samaras Z., N. Kyriakis, S. Geivanidis, G. Mellios, M. Zallinger & S. Hausberger (2005a): Influence of the Technical Characteristics of the Vehicles on their Real World Emission Behavior. *TUG report*, Graz, Austria, 17 p.

Samaras Z., L. Ntziachristos, N. Thompson, D. Hall, R. Westerholm & P. Boulter (2005b): Characterisation of exhaust particulate emissions from road vehicles (PARTICULATES). *LAT report*, Thessaloniki, Greece, 114 p. http://lat.eng.auth.gr/particulates/deliverables/Particulates_D16.pdf

Saxer CJ., A.-M. Forss & N. V. Heeb (2002): Temperature-dependent Methane, Benzene and Alkyl Benzene Cold Start Emissions of 3 conventional Passenger Cars (Euro 0), Poster, Proc. 11th Int. Symp. *Transport and Air Pollution* (ISBN 3-901351-59-0), Graz, Austria, Vol. 2, p 35-40, 2002

Saxer C., AM. Forss, M. Weilenmann & N.V. Heeb (2003): Benzene Emission Factors of the latest Diesel- and Gasoline-fueled Passenger Cars within the Common Artemis Driving Cycle, 12th Int. Symp. *Transport and Air pollution*, Avignon, Proceedings Vol. 2, INRETS Acte No 92, pp 153-158.

Schweizer Th., Ch. Rytz, N. Heeb & P. Mattrel (1997): Nachführung der Emissionsgrundlagen Strassenverkehr - Teilprojekt Emissionsfaktoren - Arbeiten 1996. *EMPA Bericht*, Nr. 161’150.

Sjödin A., M. Ekström, U. Hammarström, M.-R. Yahya, E. Ericsson, H. Larsson, J. Almén, C. Sandström & H. Johansson (2006): Implementation and Evaluation of the ARTEMIS Road Model for Sweden's International Reporting Obligations on Air Emissions. 2nd conf. *Environment & Transport*, incl. 15th conf. *Transport and Air Pollution*, 12-14 June 2006, Reims, France. Proceedings, actes Inrets, n°107, vol. 1, Arcueil, France, p. 375-382.

Soltic P. & M. Weilenmann (2002): Influence of Electric Load on the Exhaust Gas Emissions of Passenger Cars. 11th int. symp. *Transport and Air Pollution*, 19-21 June 2002, Proceedings Volume I, pp 179-186, Graz University of Technology.

Settler P., M. Weilenmann, A.M. Forss, M. Mohr, P. Mattrel, C. Saxer & N. Heeb (2004): Nachführung der Emissionsgrundlagen Strassenverkehr: Messungen 01 – 02 Benzinpersonenwagen Euro-0 und Euro-3 sowie Dieselpersonenwagen Euro-2. *EMPA Untersuchungsbericht*, Nr. 202 114, Empa, Duebendorf, Switzerland, 227 p, ISSN 1424-2532.

Sturm P.J., P. Boulter, P. de Haan, R. Joumard, S. Hausberger, J. Hickmann, M. Keller, W. Niederle, L. Ntziachristos, C. Reiter, Z. Samaras, G. Schinagl, T. Schweizer & R. Pischinger (1998): Instantaneous emission data and their use in estimating passenger car emissions. *VKM-THD Report*, Vol. 74, Verlag der Techn. Univ. Graz, Graz, Austria, 42 p., ISBN 3-901351-24-8.

Sturm P., M. Keller, M. André, H. Steven, S. Hausberger, M. Rexeis, E. Cornelis, I. de Vlieger, M. van Poppel, U Hammarström, O. Koskinen, I. McCrae, I. Pollak, I. Riemersma, L. Tartakovski, Y. Zwirin, P. Soltic & M. Weilenmann (2006): Emissions and Fuel Consumption from Heavy Duty Vehicles – Final report of the COST346 action. *Graz Univ. Techn.*, Austria, 130 p.

Tenenhaus M (1998): La regression PLS - Théorie et Pratique. *Editions Technip*, Paris.

Türler D., D. Hopkins & H. Goudey (2003): Reducing vehicle auxiliary loads using advanced thermal insulation and window technologies. *SAE paper*, 2003-01-1076, in Advances in Automotive Climate Control Technologies, SP-1733, Warrendale, USA.

US EPA (2000): Mobile Source Air Toxics. July 20, 2000. (http://www.epa.gov/otaq/regs/toxics/msatlist.pdf)

Weilenmann M.F. (2001): Cold Start and cold ambient Emissions of Euro II cars. Proceedings 10th Int. Symp. *Transport and Air Pollution*, Boulder, USA.

Weilenmann M., P. Soltic & D. Steffen (2002a): Cold Start Emissions at Cold Ambient Temperatures from Euro-0 to Euro-3 Light Duty Vehicles, 11th int. symp. *Transport and Air Pollution,* 19-21 June 2002, Graz, Proceedings Volume II, pp 365-382, Graz University of Technology.

Weilenmann M., P. Soltic & D. Ajtay (2002b): *Describing and Compensating Gas Transport Dynamics for Accurate Instantaneous Emission Measurement*, 11th int. symp. *Transport and Air Pollution,* 19-21 June 2002, Graz, Proceedings Volume II, pp 155-162, Graz University of Technology.

Weilenmann M., P. Soltic & D. Ajtay (2003a): Describing and compensating gas transport dynamics for accurate instantaneous emission measurement. *Atmos. Environ.*, 37, pp. 5137 – 5145.

Weilenmann M., P. Soltic, C. Saxer & AM. Forss (2003b): Regulated and Nonregulated Diesel and Gasoline Cold Start Emissions at different Temperatures, 12th Int. Symp. *Transport and Air pollution*, Proceedings Vol. 1, INRETS Acte No 92, pp 129- 136.

Weilenmann M., A.M. Vasic & P. Stettler (2004): Effect of air conditioning activity on fuel consumption and CO2 emissions in Europe. Proc. 13th Symp. *Transport and Air Pollution*, Boulder, USA, Sept. 13-15, 2004, NCAR ed., Boulder, p. 395-402.

Weilenmann M., P. Soltic, C. Saxer & AM. Forss (2005): Regulated and Nonregulated Diesel and Gasoline Cold Start Emissions at different Temperatures. *Atmos. Environ*., Vol 39, No 13, pp 2433-2441, April 2005.

Westerhuis J. A., T. Kourti & J.F. Macgregor (1998): Analysis of Multiblock and Hierarchical PCA and PLS Models. J. Chemometrics, 12, p. 301-321.

Zallinger M. & S. Hausberger (2004): WP300, Task 321: Road gradient and vehicle load. *TUG report*, Graz, Austria, 23 p.

Zallinger M., S. Hausberger, D. Ajtay & M. Weilenmann (2005a): Instantaneous emission modeling applications. *EMPA & TUG report*, Dübendorf, Switzerland & Graz, Austria, 53 p.

Zallinger M., Le Anh T., Hausberger S. (2005b): Improving an instantaneous emission model for passenger cars. *Transport and Air Pollution* conf., ISBN: 3-902465-16-6, Graz, Austria.