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## **ACCURACY OF EXHAUST EMISSION FACTOR MEASUREMENTS ON CHASSIS DYNAMOMETER**

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### **ABSTRACT**

In order to improve the accuracy, reliability and representativeness of emission factors, 10 European laboratories worked together to study the influence of 20 parameters on the measurement of light vehicle emission factors on chassis dynamometer of 4 main categories: driving patterns, vehicle related parameters, vehicle sampling and laboratory related parameters. The results are based i) on literature synthesis, ii) on about 2700 specific tests with 183 vehicles and iii) on the reprocessing of more than 900 tests. These tests concern the regulated atmospheric pollutants and pre-Euro to Euro 4 vehicles. Of the 20 parameters analyzed, 7 seemed to have no effect, 7 were qualitatively influential, and 6 were highly influential: gearshift strategy, vehicle mileage, ambient temperature, humidity, dilution ratio and driving cycle. The first 4 of the 6 were able to have correction factors developed for them. The results allow the design of recommendations or guidelines for the emission factor measurement method.

### **KEYWORDS**

emission factor, light vehicle, model, inventory, regulated pollutant, recommendations, measurement conditions, method.

## **IMPLICATIONS**

The accuracy of most air pollution modeling and the efficiency of emission standard reinforcement depend on the accuracy of emission factor measurements. The understanding of the role of various emission parameters allows the improvement of the standard emission measurement method and the quality of the emission calculations at local, regional or national level.

## **INTRODUCTION**

Calculation of emissions has therefore gained institutional importance in the European Community, particularly with the development of the CAFÉ<sup>1,2</sup> programs. Reliable and credible emission estimates are a central prerequisite, but comparisons of the results from emission models such as COPERT<sup>3,4</sup>, FOREMOVE<sup>5</sup>, TREMOVE<sup>6</sup>, RAINS<sup>7,8</sup>, Handbook<sup>9</sup> and national models have shown substantial differences<sup>10-13</sup> (See Figure 1). This causes doubts about the credibility of the underlying data and methodologies and might mislead the political discussions.

The European MEET (Methodologies for Estimating air pollutant Emissions from Transport) project<sup>14</sup>, the COST 319 action<sup>15</sup> and other research programs raised a main question in relation to passenger car emissions, summarized as follows: large differences in measured emission levels occurred between the different laboratories in Europe; these differences appeared to be more pronounced for more recent (at this time) vehicle technologies (i.e. Euro 1), irrespective of the way the emissions modeling is conducted (i.e. average speed dependency approach, traffic situation approach).

In order to be able to produce accurate emission factors for current and near-future technology, taking into consideration the aforementioned observations for modern car categories, a two-fold strategy is proposed in the present study: i) investigating and reducing the measurement differences between laboratories, ii) investigating, understanding and modeling the emission differences among comparable vehicles. The first aim is to study the sensitivity of pollutant emissions to the key parameters. The second aim is to develop methods that allow the harmonization of any European emission measurements.

This study, detailed in<sup>16</sup> is a part of the ARTEMIS project "Assessment and Reliability of Transport Emission Models and Inventory Systems", whose purpose is to arrive at a harmonized methodology and to develop software that calculates emissions of any transport mode, at local, national and international level - described for the light vehicles in<sup>17</sup>.

## **METHODOLOGY**

The influence of all the potential parameters on the exhaust emission level and accuracy is studied first with a literature review and then by laboratory tests on vehicles. Four types of parameters of

the measurement conditions are studied:

- Driving patterns: driving cycles, gear choice behavior, driver type, cycle following
- Vehicle related parameters: technical characteristics of the vehicles, short term emission stability, long term emission degradation (mileage), fuel properties, vehicle cooling, vehicle preconditioning
- Vehicle sampling method: method of vehicle sampling, number of vehicles
- Laboratory related parameters: ambient temperature, ambient humidity, dynamometer setting, dilution ratio, heated line sampling temperature, PM filter preconditioning, response time, instantaneous versus bag value, dilution air conditions

Parallel to the study of the impact of different parameters on emissions, 9 roller test bench laboratories were compared to each other by performing a round robin test with a Euro 3 petrol vehicle rented through a rental company and reference gases.

A specific test program was built-up for each parameter studied, except the vehicle running conditions and the method of vehicle sampling, where only literature review or inquiries were performed.

Emissions of CO, CO<sub>2</sub>, HC, NO<sub>x</sub>, and PM are considered. Although a wide variety of driving cycles were tested for the whole study (65 cycles), most of them have been used either to study specifically the influence of the driving patterns, or in the case of already existing data (case of the minimum size of a vehicle sample). For the influence of the vehicle and laboratory related parameters, the 3 Artemis driving cycles<sup>18</sup> (See Figure 2) have generally been tested with hot start, but in a few cases without the rural or motorway cycles. In many cases cold and/or hot NEDC have been tested in addition. All the tested driving cycles are analyzed in<sup>19</sup>. The tests shared between the different partner laboratories.

Globally 2753 tests were carried out (1 test = 1 vehicle x 1 driving cycle: See Table 1), i.e. 537 tests to study the influence of the driving patterns (48 vehicles), 1334 tests to study the influence of the vehicle parameters (70 vehicles), 672 tests to study the influence of the laboratory related parameters (64 vehicles), and 210 tests are part of the round robin test conducted within 9 laboratories with a petrol passenger car. In addition at least 910 tests (81 vehicles) from the European ARTEMIS data base but not carried out within the project are processed in order to study the influence of the driver and mainly the vehicle sample size.

In all, 183 vehicles were tested, resp. 119 and 64 petrol and diesel ones, 2 pre-Euro 1, 13 Euro 1, 77 Euro 2, 75 Euro 3, and 9 Euro 4.

## **RESULTS**

According to the outputs of the above studies and in test conditions, some parameters have no

influence on the emission measurements, or have a qualitative or quantitative influence. The parameters which were not found to have an influence on the emission measurements are those without any statistically significant influence on the emissions, usually with a margin of error of 5 %, but the statistical tests depend on the parameter studied and can be more sophisticated: See 16. Parameters found to have a qualitative or quantitative influence on the emission measurements have a statistically significant influence. The influence is a qualitative one when the parameters are qualitative; the only exception is the driver (human / robot) where the difference cannot be explained by the driving characteristics. The difference is quantitative when quantitative correction factors or functions are available.

### **Non-Influencing Parameters**

No statistically significant influence on emission measurement was found for some vehicle and laboratory related parameters. This does not mean that these parameters have no influence on the emission measurements, but only that no influence can be proved, taking into account the small data sample or the contradictory results.

- *Short term emission stability* or driving cycle repetition
- Inspection-maintenance
- *Fuel properties*. The results confirm the influence of fuel on exhaust emissions, but in spite of observing significant differences, especially for PM emissions with diesel vehicle, it was not possible to propose an explanation based on the today knowledge of fuel effect
- *Vehicle cooling*. The open and closed bonnet, the height of a small blower have no influence on the emissions measured. The cooling power, i.e. the flow of the cooling air, does not have a clear influence on the measured emissions
- *Heated line temperature*, because the observed emission change contradicts what is expected from the physico-chemical characteristics of the diluted emissions
- PM filter conditions
- Dilution air condition

### **Parameters With Qualitative Influence**

Some parameters of the 4 broad categories have a qualitative influence: There is an influence but that it is not quantifiable within the limits of the available data. Therefore recommendations are made concerning these parameters:

- The driver can be a *human driver or a robot*. Only the CO<sub>2</sub> emission was significantly higher by +4 % with human driver than with a robot driver, but the difference cannot be explained by the driving characteristics.
- The *vehicle classification*, through the type approval category (Euro 1 to 4) and the fuel, has a clear influence on the emissions, together with the engine capacity in some cases. But no

correlation between emission behavior and emission control technologies was found as long as the cars belong to the same type approval category. Therefore the additional introduction of technological characteristics wouldn't improve the accuracy of emission data bases of conventional cars up to Euro 4.

- The *vehicle preconditioning* conditions have an influence in some cases, but very few for modern close loop vehicles. A 10-minute cycle at a constant speed of 80 km/hr can be considered as the most suitable preconditioning cycle. It resulted in the lowest emission levels and the lowest standard deviation for the majority of the measurements.
- The *sample characteristics* influence the emission levels: the vehicle classes given above, but also the size and engine power at the maximum power of the vehicle, which strongly influence the CO<sub>2</sub> emission and fuel consumption.
- *Minimum size of vehicle sample*. Usually 10 to 15 vehicles are required for all the pollutants, in order to build-up an emission model which is representative of an average vehicle's behavior. Below these prescribed numbers, the weight of the individual behavior of some vehicles is too significant to obtain a mean, which is representative of an average behavior.
- The *dynamometer setting* has a clear influence on all emissions, but significantly only on CO<sub>2</sub> and fuel consumption, and on NO<sub>x</sub> for diesel vehicles. It cannot be excluded, however, that altered settings might affect these other pollutants too.
- *Response time including instantaneous versus bag value*. The measured instantaneous emission level must be corrected using specific functions, before building an instantaneous emission model<sup>20-22</sup>.

### **Influencing Parameters**

6 parameters have a clear and statistically significant influence on the emissions measured. The influence of 4 parameters can be quantified and quantitative correction factors were derived from the test data and are available in order to standardize emission measurements for the gearshift strategy, vehicle mileage, ambient air temperature and ambient air humidity parameters.

- *Driving cycle*. The variation induced by the driving type or cycle was more significant than the variation induced by the fuel type (for HC, CO<sub>2</sub>), or by the emission standard (NO<sub>x</sub>, CO<sub>2</sub>), or even between the vehicles (CO<sub>2</sub>), with quite contrasted behavior between diesel (rather sensitive to speed and stop parameters) and petrol cars (rather sensitive to accelerations). However, it was not possible to design a satisfying model or correction function that would enable a systematic correction, but an harmonization approach was then developed, based on the similarities between cycles from a kinematic point of view<sup>19</sup>.
- *Gearshift strategy*. It is possible to classify the gearshift strategies according to their CO<sub>2</sub> emission (the only pollutant always influenced by the strategy). The most polluting strategy is the gear change at given engine speeds whatever the cycle. The least polluting strategy seems to

be the gear change at given vehicle speeds (defined in the NEDC cycle). The ratio between these two strategies is around 15 %. For urban cycle, the strategy depending on the vehicle power-to-mass ratio and on the 3<sup>rd</sup> gear ratio (part of the Artemis cycles) pollutes as the gear change at given vehicle speeds. For rural cycle, the Artemis strategy pollutes less than given engine speed strategy (9 %) but more than the given vehicle speed strategy (6 %). The correction factor (CF = emission CO<sub>2</sub> (Artemis strategy) / emission CO<sub>2</sub> (other strategy)) equals 1, except in the case of CO<sub>2</sub> for the NEDC gearshift strategy, for motorway (CF = 1.03) and rural (CF = 1.08) driving behavior.

- The *mileage* has no influence on the CO<sub>2</sub> emission nor on the emissions of diesel vehicles, but increases CO, HC and NOx emissions of petrol cars: between 0 and 100 000 km, these emissions increase by a factor 3.6 on average for Euro 1 and 2 vehicles, and by 15 % for Euro 3 and 4 vehicles. Figure 3 shows that, all vehicles together, the mileage influence is important especially for engine capacity higher than 2 liters. The influence of the mileage M<sub>1</sub> or M<sub>2</sub> [km] is expressed by

$$\frac{emission(M_1)}{emission(M_2)} = \frac{y(M_1)}{y(M_2)} \quad (1)$$

y is available for Euro 1 to Euro 4 petrol cars in Table 2, 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:

$$y(V) = y(urban) + \frac{(V - 19) \cdot (y(rural) - y(urban))}{44} \quad (2)$$

- *Ambient air temperature*. 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<sub>2</sub> emissions by 2 %, and PM is constant. The influence of the ambient temperature is usually a linear function and sometimes an exponential one. The influence of the temperature T<sub>1</sub> or T<sub>2</sub> [°C] is expressed by:

$$\frac{emission(T_1)}{emission(T_2)} = \frac{y(T_1)}{y(T_2)} \quad (3)$$

y is available for urban, rural and motorway driving behavior in Table 3.

- The influence of the *ambient humidity* exists only for NOx and for some vehicle classes. It is a linear function. An increase in ambient humidity lowers the NOx emissions, which is also the expected general trend according to the humidity correction established in legislative testing<sup>23</sup>. Figure 4 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. ). The influence of the humidity on NOx emission is expressed by:

$$\frac{emission(H_1)}{emission(H_2)} = \frac{y(H_1)}{y(H_2)} \quad (4)$$

y is available for some vehicle classes and for urban and rural driving behavior in Table 4. It is recommended to use the rural figures for motorway driving behavior, 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.

- *Exhaust gas dilution ratio*. A higher dilution ratio increases only the diesel PM emission measurement.

### **Round Robin Test**

The best accuracy (i.e. lowest spread in results) was encountered for CO<sub>2</sub>, where the average coefficient of variation was around 5 %. This latter is around 40 % for CO, below 40 % for NOx, and around 60 % for HC. When comparing these variations to those values calculated on the basis of the repeated tests at the begin and at the end of the whole round robin test in a same laboratory, the overall variability recorded for CO in the round robin test was roughly at the same order of magnitude than the “basic” repeatability combining the repeatability of the laboratory and fluctuations in the car performance. However, with HC the overall spread of results over the whole round robin test was higher (the coefficient of variation is only 40 % for repeated tests), suggesting that some external factors, like the change in fuel quality, affected and lowered the repeatability. In terms of NOx, the overall round robin test variability was also somewhat higher than the basic value obtained from one laboratory alone, but no speculations were made over the probable reasons for this.

This result means that the accuracy of an emission measurement with one vehicle and one driving cycle, in given conditions, has an inaccuracy of 5, 40, 10-40, and 40-60 % for CO<sub>2</sub>, CO, NOx and HC resp. It does not mean that it is the inaccuracy of the emission factors of a given vehicle class, because such emission factors are always based on several individual measurements, often on many, highly reducing the inaccuracy. The ranges of accuracy for NOx and HC mean that some parameters of inaccuracy are not well-understood, especially for NOx.

### **RECOMMENDATIONS**

The knowledge of the sensitivity of vehicle pollutant emissions to the key parameters identified above allows the design of better practice for measuring emissions of the European passenger car traffic. These recommendations can be shown in four directions: Which cars to measure? In which conditions to test the cars? How to sample and analyze the pollutants? How to manage the data?

## Vehicle Sampling

It is recommended to choose as far as possible a vehicle sample with similar distributions as the in-use fleet of the fuels, emission standard, vehicle size, maximum engine power. At least the means or medians of the cubic capacity, maximum power and mileage should be similar.

The variability between vehicles is also identified as a significant and preponderant factor, together with the emitter status (high/ or normal emitter). It is not possible to know a priori the emitter status before measuring, but the high variability between vehicles of a same category obliges the random choice of cars within a category and to sample a minimum number of vehicles. The minimum sample size per vehicle category, with the aim of calculating only an emission average per vehicle category, seems to be not less than 10 vehicles. It is recommended to carry out only a limited number of repetition tests on these cars instead of taking a smaller sample tested many times. The vehicles to test should be chosen as randomly as possible in a list created by an official body such as the government, because it will give results closest to the fleet representativeness. If an official list cannot be obtained, the list created in laboratories should be completed by vehicle owners, whose the profession is not linked with pollution, such as laboratory staff.

## Usage Conditions Of The Vehicles

The vehicle conditions in the measuring laboratory should correspond to the range of traffic conditions observed in Europe: it concerns not only the driving patterns, but also the environmental conditions, the vehicle load, the fuel used...

*Driving Cycle:* It is highly recommended to test the passenger cars with real-world driving cycles. Many such driving cycles are available in Europe. The so-called Artemis driving cycles now widely used in Europe to measure passenger cars emissions<sup>18</sup> (See Figure 2) are recommended, or vehicle-specific driving cycles<sup>24</sup> to measure actual European pollutant emission factors.

*Gearshift Strategy:* The gearshift strategy depending on the vehicle power-to-mass ratio and on the 3<sup>rd</sup> gear ratio, i.e. foreseen in the Artemis and vehicle-adapted driving cycles, seems to be the most appropriate. But the strategy impact remains nevertheless relatively low as soon as realistic patterns are selected.

*Vehicle Preconditioning:* As preconditioning cycle for hot start emission measurement, a constant speed cycle is recommended, with a reasonable vehicle speed level, especially for petrol cars: a 10-minute cycle at a constant speed of 80 km/hr for instance.

*Driver:* The robot does not give more stable emissions and some driving cycles are too aggressive for it. There is therefore no reason to prefer a robot to a human driver. A cycle following should be in the tolerance band ( $\pm 2$  km/hr and  $\pm 1$  sec) for more than 99% of time and with a driven distance within 1 % to the reference distance. A test is accepted with remark if it fails these values due to

insufficient power, wheel slip, difficult gear box, in NEDC if deceleration is steeper than reference or if the engine stalls or does not activate immediately at test start. In all other cases a test should be rejected.

*Fuel Characteristics:* Both diesel and petrol fuels strongly influence the emissions, but not CO<sub>2</sub>. Therefore it is recommended to use common fuels rather than laboratory fuels.

*Ambient Air Temperature And Humidity:* It is recommended to measure the emissions close to the average ambient temperature and humidity rather than at the "standard" one when this one is far from the reality.

*Vehicle Cooling:* The use a high power cooling system is recommended, in order to reproduce as far as possible the real-world cooling.

*Dynamometer Setting:* Although only few effects were found significant, the chassis dynamometer settings should lead to a load applied to the driving wheels of a vehicle that is equivalent to the load experienced on the road at all speeds and accelerations. For the testing to be performed for the determination of real world emission factors, it is therefore primarily recommended to use road load information derived from the coast down method performed by the laboratory, and an inertia setting as close to the actual on-road inertia as possible, which is also determined by the laboratory.

## **CONCLUSION**

The study was designed to study the influence of many of parameters of the measurement of light vehicle emission factors: driving patterns, vehicle related parameters, vehicle sampling method and laboratory related parameters.

In test conditions, some parameters were not found to have an influence. For some other parameters, a qualitative influence was found but not quantifiable. Finally some parameters have a clear and quantifiable influence and can be used to normalize emission measurements when the level of these parameters during the experiment is known, by using correction factors: gearshift strategy, vehicle mileage, ambient air temperature and humidity, exhaust gas dilution ratio. The results allow the design of recommendations or guidelines for the real-world emission factor measurement method. All these outputs have been used to design the ARTEMIS emission inventorying tools for light vehicles, on a better basis than the previous European models.

The outputs of this study are nevertheless not fully positive, mainly because of the low number of tests performed to study the influence of some parameters, which did not allow any significant influence to be found. Some parameters could therefore be studied again.

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Table 1. Description of the tests carried out, per parameter and laboratory.

Parameter		lab.	N. veh.	N. driving cycles	Tested cases	N. tests
Driving patterns	Driving cycles	IM	1	14	Large range of driving conditions	14
		Inrets	24	8		192
			6	18		108
		KTI	1	14		14
	TNO	1	14	14		
	Gear choice	Inrets	9	3	5 strategies	195
			4	2		
KTI	2	2				
Driver	Empa	1	15	4 times 1 robot driver, 4 human drivers	120	
Vehicle parameters	Techn. char. veh.	LAT, Renault & TUG	43	6	Tests repeated twice	516
	Emission stability	all	12 <sup>a</sup>	2	Tests repeated 5 times	120
	Emis. degradation	LAT	2	6	Test every 20 000 km, before and after maintenance; 1, 2 or 3 repetitions	174
	Fuel properties	Renault	2	6	4 fuels, tests repeated twice	96
	Vehicle cooling	VTT	6	2	A small fan at 2 heights, a large fan with 3 air speeds, with open air closed bonnet	108
	Vehicle precondition.	IM & KTI	5	4	4 preconditioning cycles, driving cycle repeated 4 times	320
	Veh. sample size <sup>b</sup>	Inrets	80 <sup>c</sup>	29 <sup>c</sup>		790
Laborat. related parameters	Ambient temp.	Empa	18	3	3 ambient temperatures: -20, -7 and +23°C	240
		VTT	13	2		
	Ambient humidity	VTT	11	2	3 ambient humidity levels, tests repeated	131
	Dynamo. setting	TNO	5	5	3 settings for road load and inertia	75
		KTI	2	2		
	Dilution ratio	IM	3	5	3 dilution ratios	91
		LAT	3	5		
	Heated line temp.	KTI	1	2	2 dilution factors	4
	PM filter precondition.	TNO	1	4	2 temperatures	20
Response time	Empa, TUG & LAT	5	30	3 temperatures and 3 humidity levels	75	
Dilution air cond.	IM	2	3	Specific tests	36	
	Round robin test	Most <sup>d</sup>	1	6	3 levels of polluted dilution levels, tests repeated twice	210
					2 to 10 repetitions	

a TUG: 3, IM: 2, Empa, Inrets, KTI, LAT, Renault, TNO, VTT: 1 each

b corresponds to existing data, not measured within the project

c all vehicles have not been tested with all driving cycles

d Empa, IM, Inrets, KTI, LAT, MTC, TNO, TUG, VTT

Table 2. Emission degradation correction factor  $y = a \times \text{Mileage} + b$ , for petrol vehicles. Mileage expressed in km,  $y$  normalized for the corresponding average mileage.

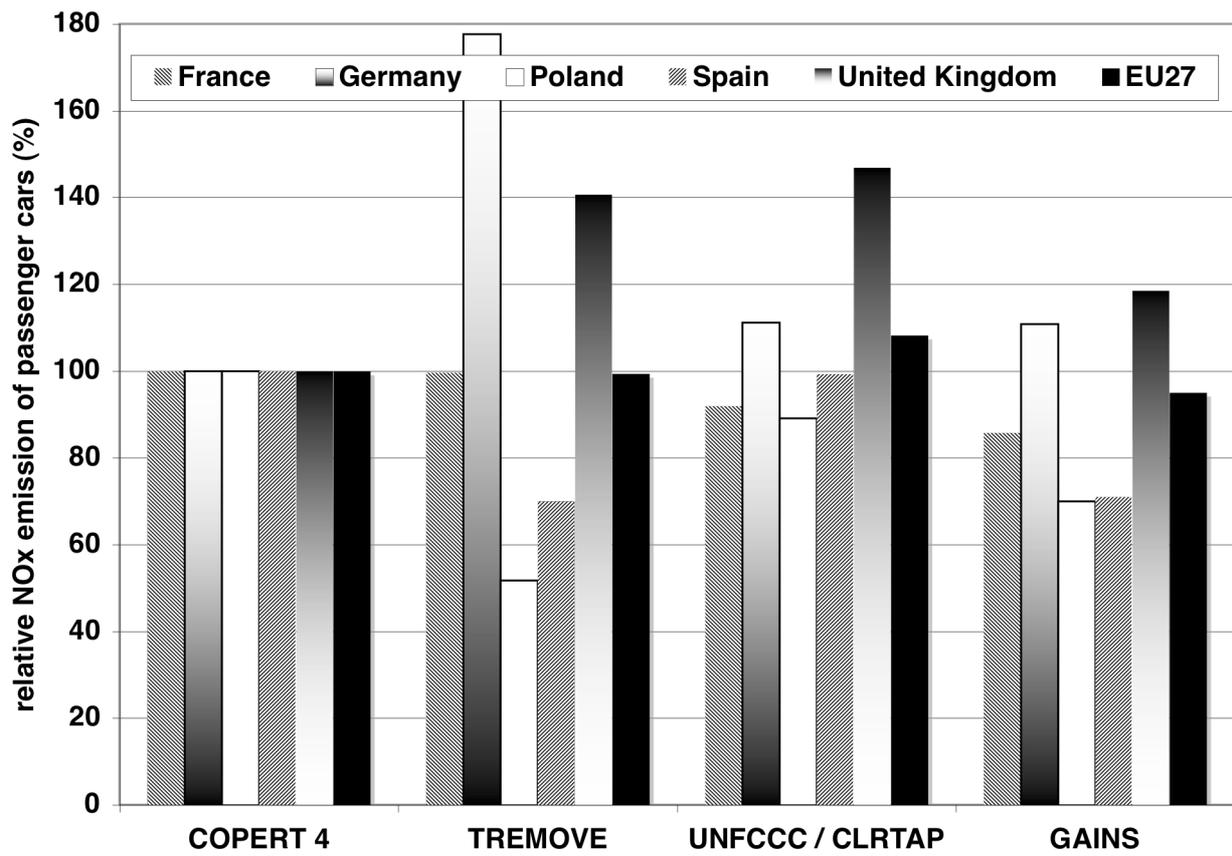
			Capacity class [l]	Average mileage [km]	a	b	Value at $\geq$ 120 000 km (Euro 1 & 2), or 160 000 km (Euro 3 & 4)	
Petrol Euro 1 & 2	y(urban) for $V \leq 19$ km/h	CO	$\leq 1.4$	29 057	1.523E-05	0.557	2.39	
			1.4-2.0	39 837	1.148E-05	0.543	1.92	
			$> 2.0$	47 028	9.243E-06	0.565	1.67	
	(urban situation)	HC	$\leq 1.4$	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 $V \geq 63$ km/h (rural situation)	CO	$\leq 1.4$	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	$\leq 1.4$	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	
Petrol Euro 3 & 4	y(urban) for $V \leq 19$ km/h (urban situation)	CO	$\leq 1.4$	32 407	7.129E-06	0.769	1.91	
			$> 1.4$	16 993	2.670E-06	0.955	1.38	
	HC	$\leq 1.4$	31 972	3.419E-06	0.891	1.44		
		$> 1.4$	17 913	0	1	1		
	NOx	$\leq 1.4$	31 313	0	1	1		
		$> 1.4$	16 993	3.986E-06	0.932	1.57		
	y(rural) for $V \geq 63$ km/h (rural situation)	CO	$\leq 1.4$	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 3.** Correction factor  $y = a \times \text{Temperature} + b$ , or  $y = a e^{b \times \text{Temperature}}$  when in italics, for urban, rural or motorway driving behavior. Temperature in °C. y normalized at 23°C.

			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	<i>3.4627</i>	<i>-0.0544</i>	0.0107	0.7442	-	-
	diesel	Euro 2	<i><math>y = a e^{bT}</math></i>		-0.032	1.75	<i><math>y = a e^{bT}</math></i>	
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 <sub>2</sub>	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 4.** Correction factor  $y = a \times \text{Humidity} + b$ , for NOx emissions corrected or not using the current method, and for urban or rural driving behavior. Humidity in g H<sub>2</sub>O/kg dry air, y normalized at 10.71 g H<sub>2</sub>O/kg dry air.

			urban		rural	
			a	b	a	b
Uncorrected emissions	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
Corrected emissions	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



**Figure 1.** Comparison of emission calculations performed for several European countries and the European Union by using 4 emission models<sup>13</sup>.

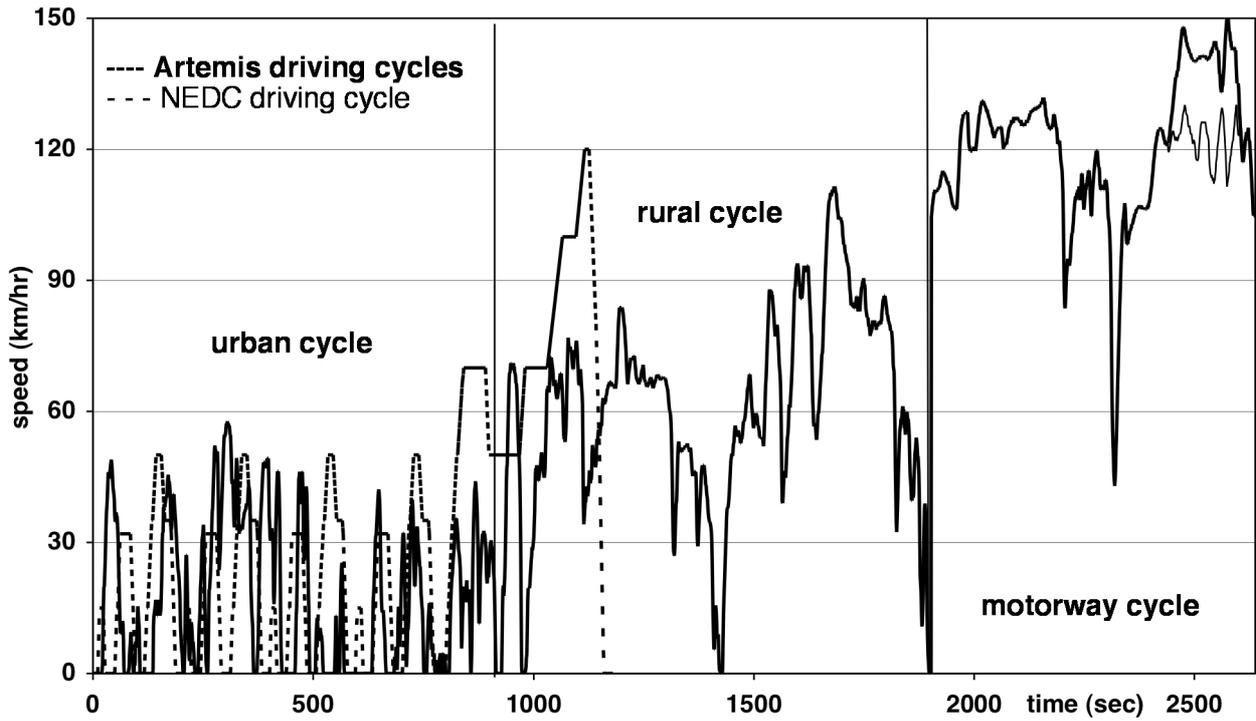


Figure 2. Artemis driving cycle compared with the New European Driving Cycle.

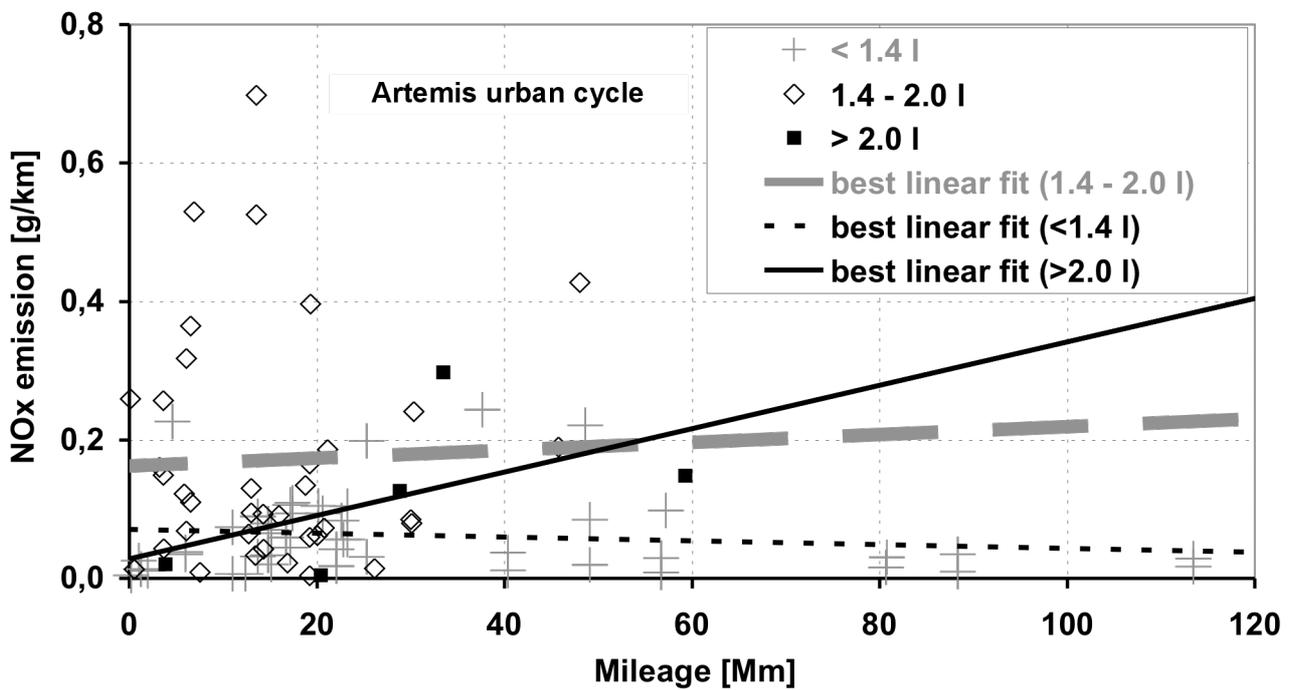
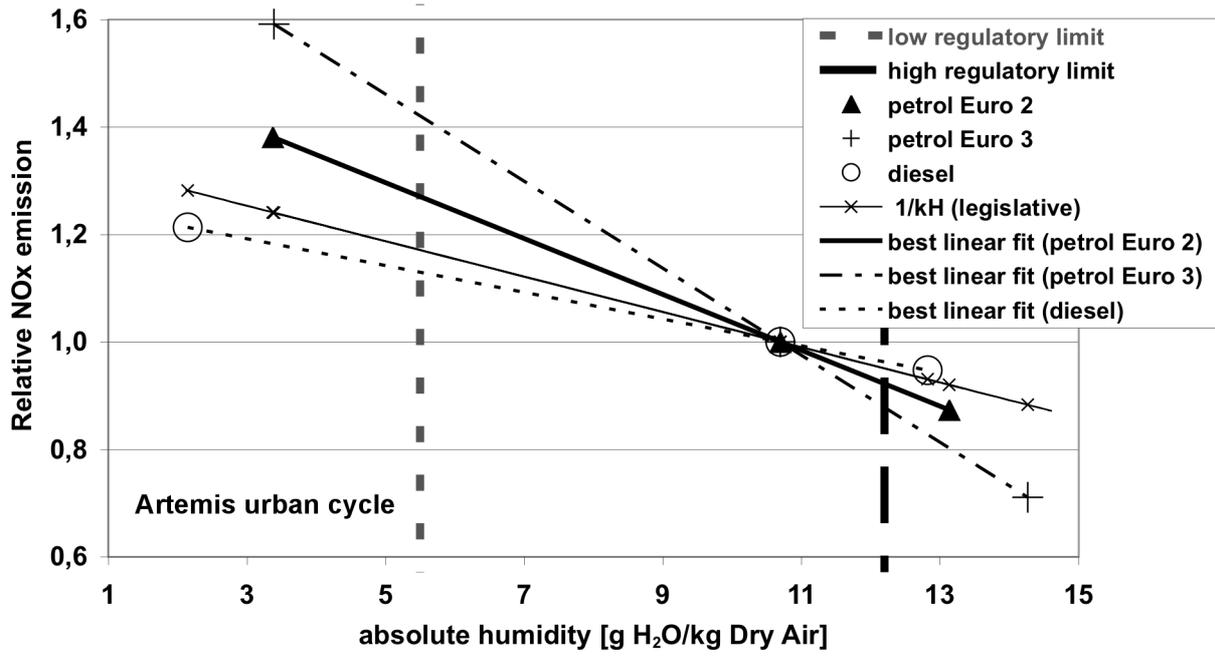


Figure 3. NO<sub>x</sub> degradation in urban driving behavior for petrol vehicles.



**Figure 4.** 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).