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Description of new elements in COPERT 4 v10.0

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Summary

This report presents the methodological revisions of COPERT 4 version 10.0, compared to version 9.1.

Keywords

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Contents

1 Gasoline and diesel PCs: CO_2 correction option

CO_2 emissions of new passenger cars (PCs) registered in Europe are monitored in order to meet the objectives of Regulation EC 443/2009. CO_2 emissions of new vehicle types are determined during the vehicle type-approval by testing over the New European Driving Cycle (NEDC). Worries have been expressed that this driving cycle is not representative of real-world driving conditions. It is considered that fuel consumption, and hence CO_2 emissions (and air pollutant emissions), measured over this cycle under-represent reality. The main objective was to develop functions that may enable prediction of in-use fuel consumption values, based on vehicle specifications.

1.1 Models

Simple empirical models were constructed to check how well measured in-use fuel consumption of PCs can be predicted on the basis of independent variables. The models were built on the basis of linear combinations of the variables mass, engine capacity, rated power, and power to mass ratio. In addition, type-approval fuel consumption was used as an independent variable and, in some cases, the manual and automatic transmission and the vehicle emission concept (Euro standard) were used as independent variables as well. The models were first applied to all measured in-use fuel consumption data that became available to the project.

The set of models based on type-approval FC, only require vehicle mass in addition to predict real-world fuel consumption. Moreover, this set of models does not distinguish between vehicle types. This set of model is ideal to predict consumption of new car registrations because both vehicle mass and type-approval CO_2 are readily available from the CO_2 monitoring database. The model equations are (FC_{TA} stands for type-approval fuel consumption, m stands for the vehicle reference mass (empty weight + 75 kg for driver and 20 kg for fuel), and CC stands for the engine capacity in cm^3):

Petrol Euro 5 PCs:

$$\mathrm{FC_{InUse,\,Gasoline}}[\mathrm{l/100\,km}] = 1.15 + 0.000392 \times \mathrm{CC} + 0.00119 \times \mathrm{m} + 0.643 \times \mathrm{FC_{TA}}$$

Diesel Euro 5 PCs:

$$\mathrm{FC_{InUse,\,Diesel}}[\mathrm{l/100\,km}] = 0.133 + 0.000253 \times \mathrm{CC} + 0.00145 \times \mathrm{m} + 0.654 \times \mathrm{FC_{TA}}$$

Compared to the FC TA the CADC leads to 25% higher fuel consumption values.

Furthermore the CADC 1/3 mix tends to overestimate the fuel consumption of large cars more significantly than that of smaller cars.

1.2 CO_2 correction option

In order to introduce the CO_2 correction option average mass, engine capacity and Type Approval CO2 values are required user input per passenger car category. COPERT first calculates emissions normally, based on custom input circulation data. If the CO_2 correction option is selected, a calibration process introduces a correction coefficient.

The mean FC_{Sample} was calculated as the average FC of the vehicle sample used in developing COPERT EFs over the three CADC parts (Urban, Road and Motorway). The sum of FC of the three CADC parts was used, each weighted by a 1/3 factor. It should be noted that this 'average' FC was computed using actual vehicle performance (measurements), not COPERT emission factors. The correction factor is then calculated as:

$$Correction = \frac{FC_{InUse}}{FC_{Sample}}$$

This coefficient is then used to calculate the modified FC and respective CO_2 emission factors for hot emissions only.

Table 1: COPERT Sample mean FC (CADC 1/3 mix)

Subsector	**FC sample (COPERT)**
G < 0.8l	47.02
G 0.8 - 1.4l	59.48
G1.4-2l	66.22
G >2l	72.84
D<1.4l	38.77
D1.4-2l	54.43
D >2l	67.76

1.3 Example

Let us assume that the correction process is applied to an average Gasoline<1.4, Euro 5 technology with the following statistics:

- average mass: 1200 kg
- average capacity: 1150cc
- average type-approval FC: 40 g/km (~5.26 l/100km)

Applying the model fuel consumption for Euro 5 cars yields a FC of 6.41 l/100km or **48.1 g/km. This reflects mean consumption over CADC.**

COPERT information is summarised in the following table:

Table 2: COPERT information

COPERT Stats	Urban	Rural	Highway
Speed profile	40 km/h	60 km/h	100 km/h
Share profile	20%	40%	40%
Average FC	50.0 g/km	44.3 g/km	48.2 g/km

The average consumption of vehicles over CADC on which the COPERT 4 emission factors is based is **59.5 g/km**. Hence a correction coefficient has to be introduced equal to **48.1/ 59.5 = 0.808**. Applying the coefficient will produce modified FCs:

- 0.808 x 50.0 = 40.4 g/km for urban (was 50 g/km)
- 0.808 x 44.3 = 35.8 g/km for rural (was 44.3 g/km)
- 0.808 x 48.2 = 39.0 g/km for highway (was 48.2 g/km)

CO2 calculation proceeds as normal, based on this modified FC.

1.4 Validation

The CO_2 monitoring database (2011, v3) specifications were used to estimate the corrected FC (mass, capacity and type-approval FC) and compare it to the average FC (1/3 Artemis mix). The correction modification can vary. Four countries were used for comparison. The difference was calculated as shown in the next equation:

$$Difference = \frac{FC_{InUse} - FC_{Sample}}{FC_{Sample}} \cdot 100\%$$

The results are summarized in the tables below.

Table 3: Correction difference (%) for gasoline vehicles. G<0.8l value refers to total database due to the low number of available vehicles (reported per country).

Country/Subsector	G<0.8l	G0.8-1.4l	G1.4-2l	G>2l
Austria	-13.8	-16.0	-11.5	13.6
Germany	-13.8	-15.2	-10.1	10.5
Italy	-13.8	-20.4	-12.8	19.5
UK	-13.8	-18.3	-12.7	16.8

Table 4: Correction difference (%) for diesel vehicles.

Country/Subsector	D<1.4l	D1.4-2l	D>2l
Germany	3.22	-3.34	-2.17
Italy	5.02	-7.38	-0.29
Great Britain	5.61	-7.89	-2.11
Austria	9.06	-3.91	-2.84

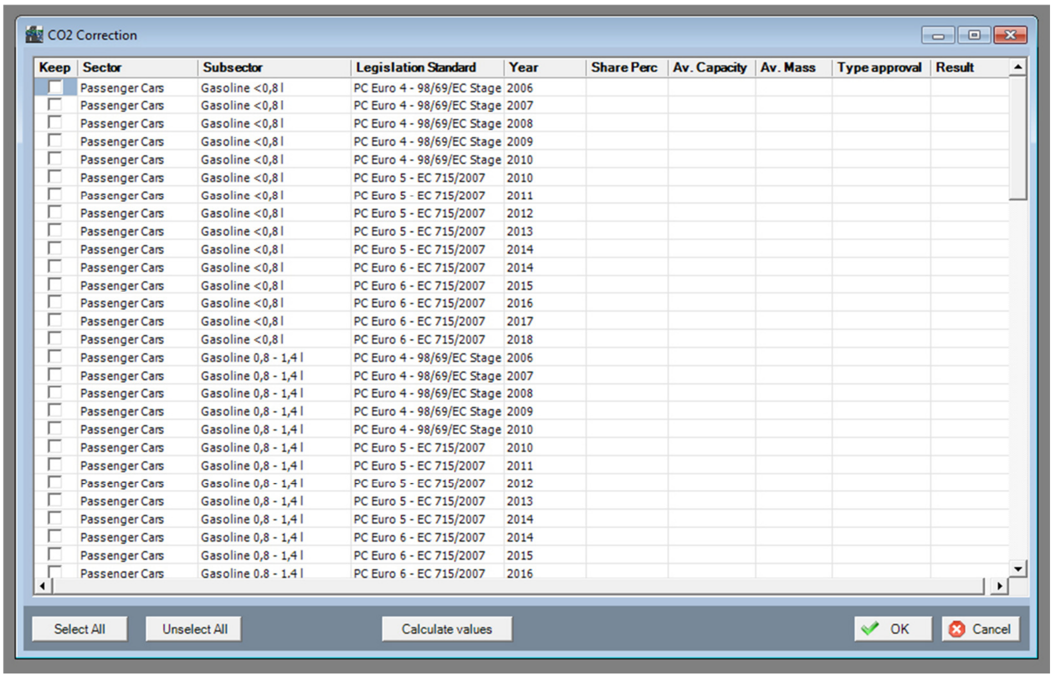
1.5 Implementation to COPERT

The correction model is implemented for passenger cars of all subsectors for technologies Euro 4 to Euro 6.

The Annual correction factor (2005-2020) was calculated on the basis of mean mass, capacity, $CO_{2,TA}$, new registrations, available in both the:

- 1753/2000/EC database and the,
- 443/2009 database

The weighted average correction factor per emission standard is calculated and used per emission standard.



Keep	Sector	Subsector	Legislation Standard	Year	Share Perc	Av. Capacity	Av. Mass	Type approval	Result
☐	Passenger Cars	Gasoline <0,8 l	PC Euro 4 - 98/69/EC Stage	2006					
☐	Passenger Cars	Gasoline <0,8 l	PC Euro 4 - 98/69/EC Stage	2007					
☐	Passenger Cars	Gasoline <0,8 l	PC Euro 4 - 98/69/EC Stage	2008					
☐	Passenger Cars	Gasoline <0,8 l	PC Euro 4 - 98/69/EC Stage	2009					
☐	Passenger Cars	Gasoline <0,8 l	PC Euro 4 - 98/69/EC Stage	2010					
☐	Passenger Cars	Gasoline <0,8 l	PC Euro 5 - EC 715/2007	2010					
☐	Passenger Cars	Gasoline <0,8 l	PC Euro 5 - EC 715/2007	2011					
☐	Passenger Cars	Gasoline <0,8 l	PC Euro 5 - EC 715/2007	2012					
☐	Passenger Cars	Gasoline <0,8 l	PC Euro 5 - EC 715/2007	2013					
☐	Passenger Cars	Gasoline <0,8 l	PC Euro 5 - EC 715/2007	2014					
☐	Passenger Cars	Gasoline <0,8 l	PC Euro 6 - EC 715/2007	2014					
☐	Passenger Cars	Gasoline <0,8 l	PC Euro 6 - EC 715/2007	2015					
☐	Passenger Cars	Gasoline <0,8 l	PC Euro 6 - EC 715/2007	2016					
☐	Passenger Cars	Gasoline <0,8 l	PC Euro 6 - EC 715/2007	2017					
☐	Passenger Cars	Gasoline <0,8 l	PC Euro 6 - EC 715/2007	2018					
☐	Passenger Cars	Gasoline 0,8 - 1,4 l	PC Euro 4 - 98/69/EC Stage	2006					
☐	Passenger Cars	Gasoline 0,8 - 1,4 l	PC Euro 4 - 98/69/EC Stage	2007					
☐	Passenger Cars	Gasoline 0,8 - 1,4 l	PC Euro 4 - 98/69/EC Stage	2008					
☐	Passenger Cars	Gasoline 0,8 - 1,4 l	PC Euro 4 - 98/69/EC Stage	2009					
☐	Passenger Cars	Gasoline 0,8 - 1,4 l	PC Euro 4 - 98/69/EC Stage	2010					
☐	Passenger Cars	Gasoline 0,8 - 1,4 l	PC Euro 5 - EC 715/2007	2010					
☐	Passenger Cars	Gasoline 0,8 - 1,4 l	PC Euro 5 - EC 715/2007	2011					
☐	Passenger Cars	Gasoline 0,8 - 1,4 l	PC Euro 5 - EC 715/2007	2012					
☐	Passenger Cars	Gasoline 0,8 - 1,4 l	PC Euro 5 - EC 715/2007	2013					
☐	Passenger Cars	Gasoline 0,8 - 1,4 l	PC Euro 5 - EC 715/2007	2014					
☐	Passenger Cars	Gasoline 0,8 - 1,4 l	PC Euro 6 - EC 715/2007	2014					
☐	Passenger Cars	Gasoline 0,8 - 1,4 l	PC Euro 6 - EC 715/2007	2015					
☐	Passenger Cars	Gasoline 0,8 - 1,4 l	PC Euro 6 - EC 715/2007	2016					

Figure 1: COPERT implementation

1.6 Discussion

Large Gasoline fuel consumption increases by 10-20% due the high average capacity in the CO_2 monitoring database (>3500cc). All the other subsectors have a 10-20% decrease in fuel consumption. The G<0.8l subsector was non-existent, when the CO2 correction model was compiled. The G0.8-1.4l subsector FC average was extracted for capacity around 1390cc while the country averages in the CO_2 monitoring database are ~1250cc. The G1.4-2l subsector FC average was extracted for capacity close to the CO2 monitoring database which can explain the smaller corrections. The FC_{Sample} was generally based on Euro 4 measurements, so it is expected to be somewhat higher than the 2011 database.

Diesel vehicles have much lower correction factors. D<1.4l and D1.4-2l show opposite trends; the correction was compiled with the old COPERT classification (only D<2.0l). High capacity (D>2.0l) vehicles have very small corrections; the capacity average in this case is much closer to 2.0l (less than 2500cc), which can explain the slight differences.

Note that a mix of the three CADC parts Urban, Road and Motorway, each weighted by a 1/3 factor, was used for comparison. The CADC 1/3-Mix lead on average to 4% higher fuel consumption values than the FC_{InUse} data for the tested vehicles according to the report.

1.7 References

G. Mellios, S. Hausberger, M. Keller, C. Samaras, L. Ntziachristos, 2012, Parameterisation of fuel consumption and CO_2 emissions of passenger cars and light commercial vehicles for modelling purposes, JRC Report

Monitoring of CO_2 emissions from passenger cars – Regulation 443/2009 (2012), http://www.eea.europa.eu/data-and-maps/data/co2-cars-emission-2, accessed September 2012

2 Gasoline and diesel PCs: new subsector classification

The increased penetration of low-capacity passenger cars in the European Market recently has been the driving force for the introduction of new passenger car subsectors for COPERT. Under this scope the following changes have taken place:

- The Gasoline<0.8 l subsector has been added for gasoline passenger cars for Euro 4-6 technologies
- Gasoline<1.4 l subsector will become Gasoline 0.8-1.4l
- The Diesel<1.4 l subsector has been added for diesel passenger cars for Euro 4-6 technologies
- Diesel <2l subsector will become Diesel 1.4-2.0l

2.1 Modelling

The goal of the modelling procedure was to provide FC emission factors using simulated vehicle models. Emission factors for these new vehicle subsectors have remained the same. Towards this end, specific vehicle features (where available) were used to design powertrain system level simulations (AVL CRUISE). The collection (or estimation) of vehicle technical specifications focused on physical characteristics (weight, wheel base, drag coefficient, tyre dimensions, etc.) as well as vehicle architecture and control systems data.

In order to build the vehicle model, the embedding of performance (energy, emission, output, etc.) maps for main components (engine, motor, battery, transmission) based on available data or expected improvements was necessary.

Finally, vehicle model performance was calibrated by using type approval cycle testing (NEDC, EUDC, UDC) and acceleration data based on official available data. The ARTEMIS cycles were then used for real-world fuel consumption estimation. Results were validated where chassis models or similar simulations were available.

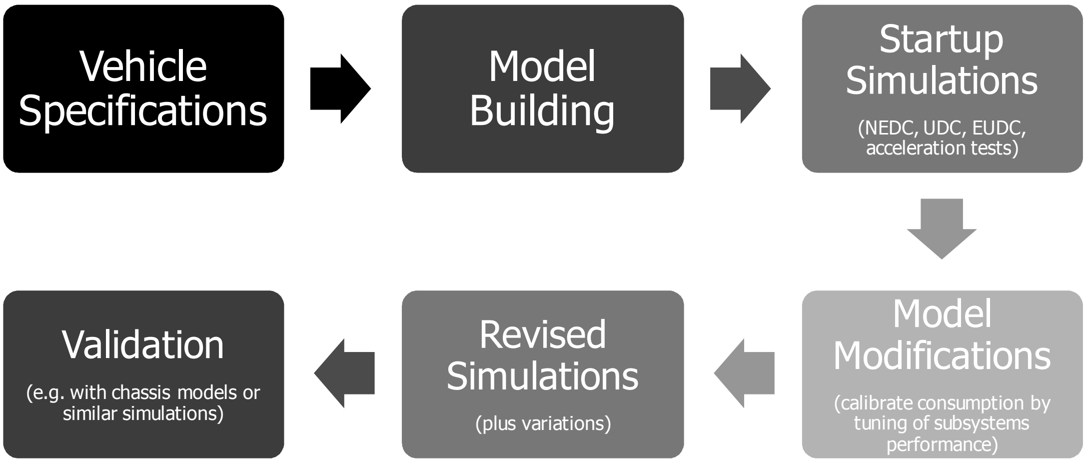


Figure 2: Modelling Approach

2.1.1 Gasoline <0.8l modeling

Starting with the CO_2 monitoring database, three representative passenger cars with an engine capacity of less than 800cc were chosen (based on their popularity and engine capacity distribution). This subsector contained a very limited choice of passenger cars.

Table 5: Gasoline <0.8l vehicles

Model	Engine Capacity	NEDC consumption (lt/100km)
Smart Fortwo Coupe	698 cm^3	5.21
Chevrolet Matiz	796 cm^3	5.04
Fiat 500	875 cm^3	4.11

The Fiat 500 vehicle typically exceeds the 0.8l range. However, due to the limited of vehicles in the CO_2 database and the low-consumption performance of this vehicle, it was still included in the simulation.

2.1.2 Simulation results

Simulation was weighted based on vehicle registration numbers.

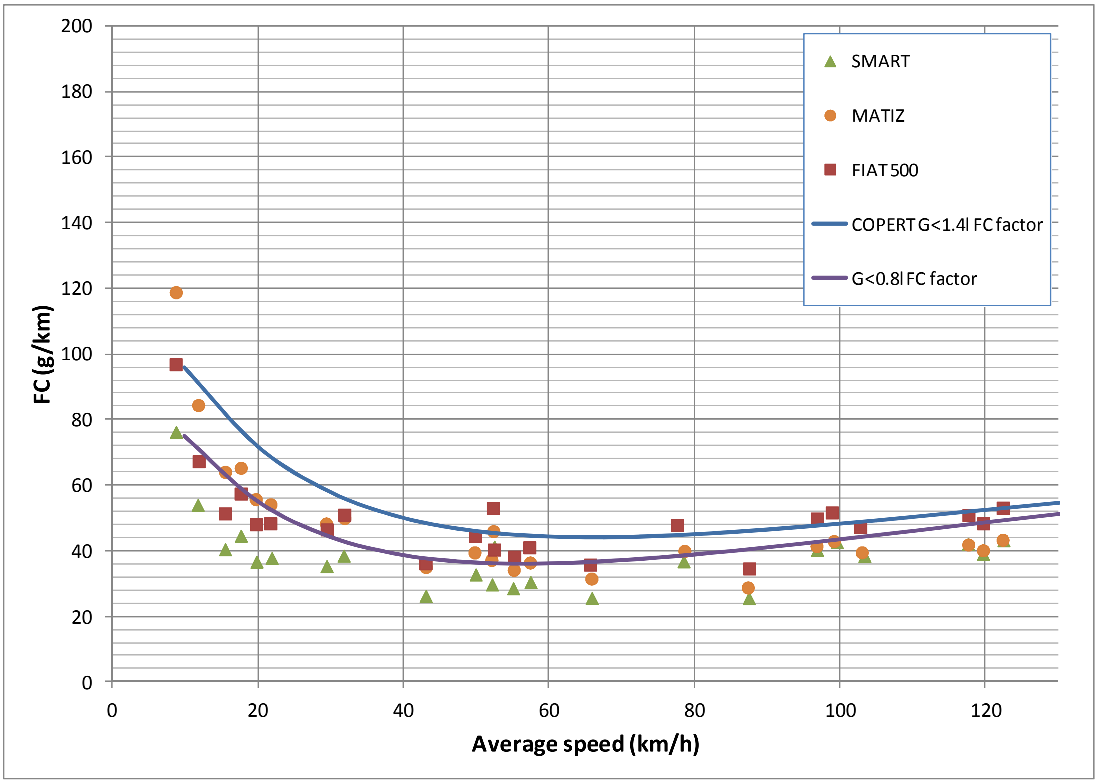


Figure 3: Gasoline <0.8l simulation results and FC factors.

In this figure, the discrete Artemis subcycles can be observed and compared to the original COPERT G<1.4l FC factor and the new, proposed G<0.8l FC factor.

2.1.3 Fitting

The fitting equation type was based on the Gasoline <1.4l one, since this subsector is a subset of the previous subsector:

$$\mathrm{FC} = (\mathrm{alpha} + \mathrm{gamma} * \mathrm{v} + \mathrm{epsilon} * \mathrm{v}^2 + \mathrm{z}/\mathrm{v}) * (1 - \mathrm{RF})/(1 + \mathrm{beta} * \mathrm{v} + \mathrm{delta} * \mathrm{v}^2) \ ,$$

Instead of the old coefficients, using the ones from the table below were used.

Table 6: Coefficients for G<0.8l

alpha	beta	gamma	delta	epsilon	z	RF
110	0.0261	-1.67	0.000225	0.0312	0	0

The goodness of fit statistics are:

- Adjusted R-square: 0.884
- RMSE: 3.558

This curve seems to show a reduced overall fuel consumption which becomes more pronounced for low speeds while it approaches the performance of the G<1.4l fuel consumption for high speeds.

2.1.4 Diesel <1.4l modeling

In this case six representative passenger cars with an engine capacity of less than 1400cc were chosen from the CO_2 monitoring database, based on their popularity and engine capacity distribution.

Table 7: Diesel <1.4l vehicles

Model	Engine Capacity (cm^3)	NEDC consumption (lt/100km)
Smart Coupe cdi	799	3.4
Ford Fiesta TDCi 1.4	1398	4.3
VW Polo 1.2 TDI	1199	3.76
Lancia Ypsilon 1.3 MJ	1248	4.6
Fiat Grande Punto 1.3 MJ	1248	4.5
Toyota Yaris 1.4D	1364	4.5

2.1.5 Simulation results

Simulations were again weighted based on vehicle registration numbers. Results can be seen on Figure 4: Diesel <1.4l simulation results and FC factors.

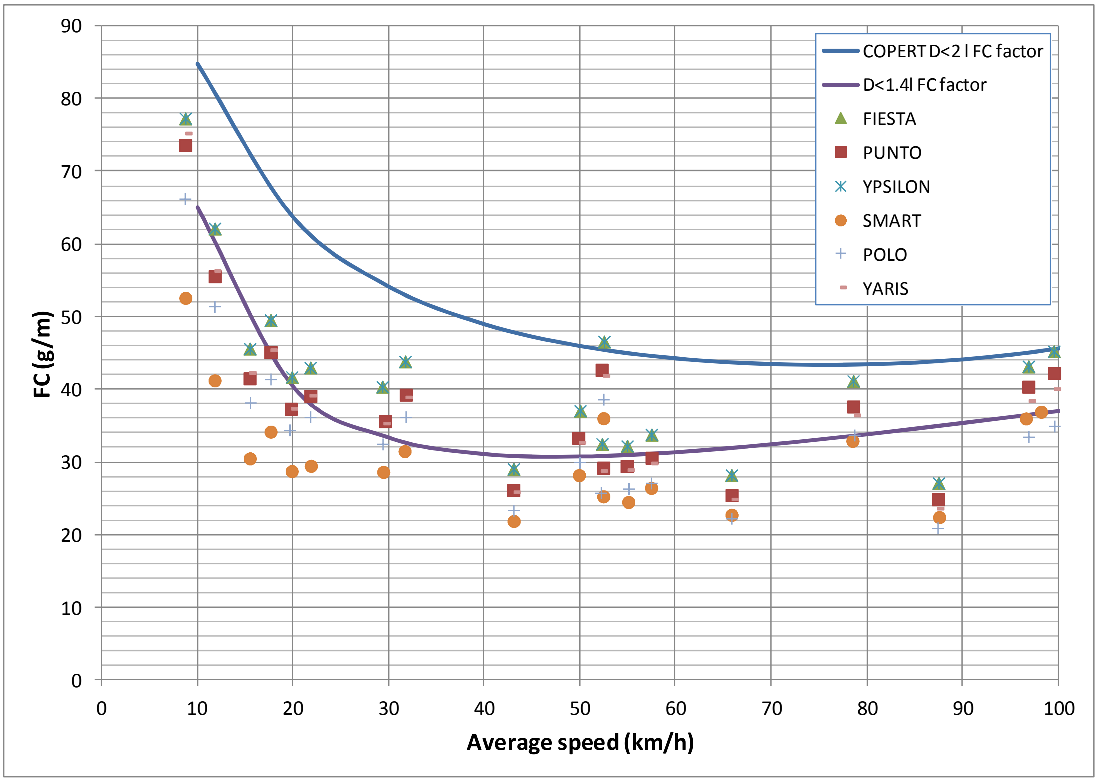


Figure 4: Diesel <1.4l simulation results and FC factors.

2.1.6 Fitting

The fitting equation type was based on the Gasoline <1.4l one, since this subsector is a subset of the previous subsector:

$$FC = (alpha + gamma * v + epsilon * v^2 + z/v) * (1 - RF)/(1 + beta * v + delta * v^2) \ ,$$

using the coefficients from the table below.

Table 8: Coefficients for G<0.8l

alpha	beta	gamma	delta	epsilon	z	RF
500	0.74	3.04	0.001515	0.253	0	0

The goodness of fit statistics are:

- Adjusted R-square: 0.6971
- RMSE: 2.456

This curve seems to show a significant reduction in fuel consumption compared to the D<1.4l subsector which is clearer for low to medium speeds.

2.1.7 Validation

Average Diesel <1.4l vehicle results as well as the FC emission factors were compared to the A300DB content on Diesel<1,4 l Euro 4 & 5 cars for validation purposes.

Table 9: Comparison between simulated vehicles, proposed emission factor and A300DB content factors (g/km)

FC in g/km	**Artemis Urban hot**	**Artemis Rural hot**	**Artemis MW150 hot**
Average Vehicle (simulation)	44.2	30.3	40.8
Emission factor	43.8	31.5	40.3
A300DB content	44.2	29.2	44.3

It appears that the urban and rural emissions are a very good match and only the highway emissions are underestimated by about 10% compared to the A300DB. However, the difference is similar to differences occurring between the A300DB database and higher capacity diesel vehicles in COPERT.

2.1.8 References

AVL CRUISE, powertrain system level simulation tool, https://www.avl.com/cruise1

A300DB (2012), Infras

3 Diesel PCs Euro 5/6: Updated Emission factors

Diesel Euro 5 cars are known of largely exceeding their type approval limits for NOx, in real world operation. This is the result of tuned engine and aftertreatment components only towards meeting the type approval limits. In real world driving emission control becomes more relaxed to the benefit of reducing fuel consumption and greenhouse gas emissions.

Although Euro 5 has been mandatory in Europe already since September 2009, it takes a lot of time to collect and measure a sufficient number of vehicles in order to develop reliable emission factors. All this testing is coordinated in the framework of the ERMES activity. Table Table **10** shows the vehicle sample that has been collected so far. Detailed emission factors based on this sample are currently being processed. However, due to the urgency in developing representative NOx emission factors, we need to introduce some corrections in COPERT at this stage, even before the final dataset becomes available.

Table 10: Available measurements at different labs collected in the framework of ERMES

Lab	EU5 SI	EU5 CI	EU6 SI	EU6 CI
TNO	5	7	-	3
ADAC	1	3	-	1
TUG	5	5	-	5
EMPA	10	4		
JRC	8	4		
LAT	3	1		
Total	**32**	**24**	**0**	**8 (7 diff. Models)**

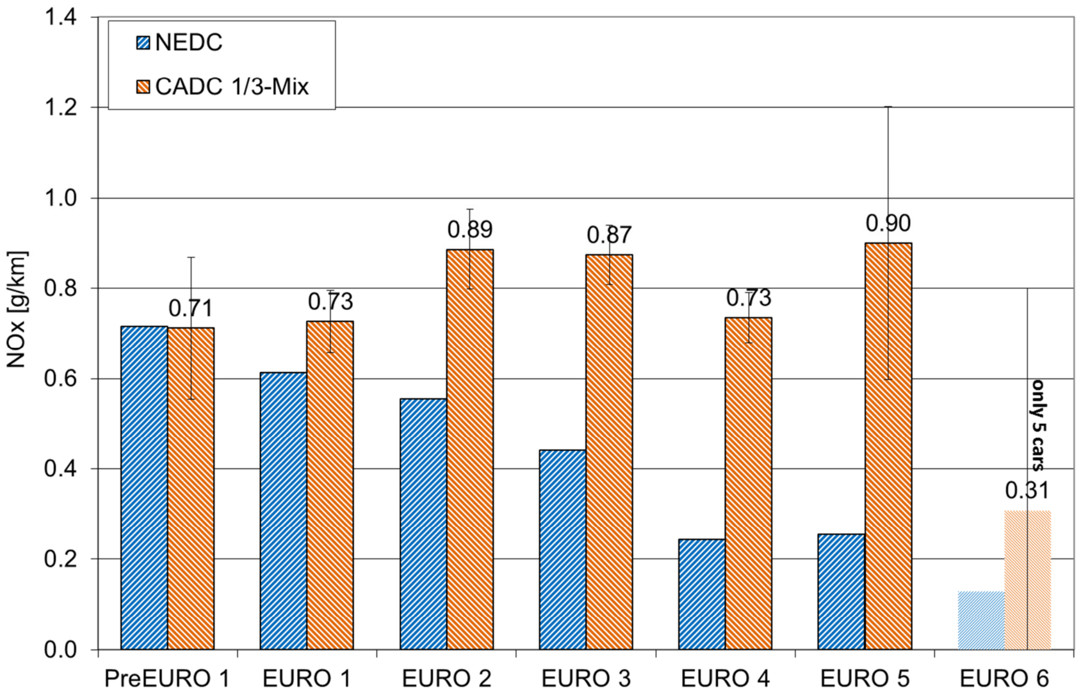


Figure 5: Average NOx emission levels of diesel passenger cars tested in the framework of ERMES.

Having this in mind, Figure 5 shows average NOx emission levels over the type approval and a real-world driving cycle mix (average of Artemis Urban, Rural, and Highway) for different diesel technologies included in the ERMES database. The data available shows that Euro 5 is the highest NOx emission technology ever (within the high uncertainty provided) and it even slightly exceeds the Euro 2 and Euro 3 emission levels. Considerably lower NOx emissions are shown for the small sample of Euro 6 cars tested (8 vehicles). These have to be treated with care: These first Euro 6 models are of advanced emission control technology which is not yet known whether it will be applied to all available models in the future. Also, the exact type-approval procedure for Euro 6 cars – including real drive emissions – has not been decided yet. Hence, this emission level should still be considered as a preliminary indication. Better estimates of the Euro 6 level will be produced in the future.

With respect to PM, Figure 6 shows the average emission rates at different technology level. A much better picture is shown here with the real world driving mix to be consistent with the expected type approval reductions and the current COPERT emission factors. This is the result of the use of the very efficient diesel particle filters (DPFs) in all diesel cars post Euro 5. Based on this figure only, no change in the existing COPERT emission factors is necessary. When detailed emission factors are produced then some correction may be necessary but this will not substantially change the emission levels as they are calculated today.

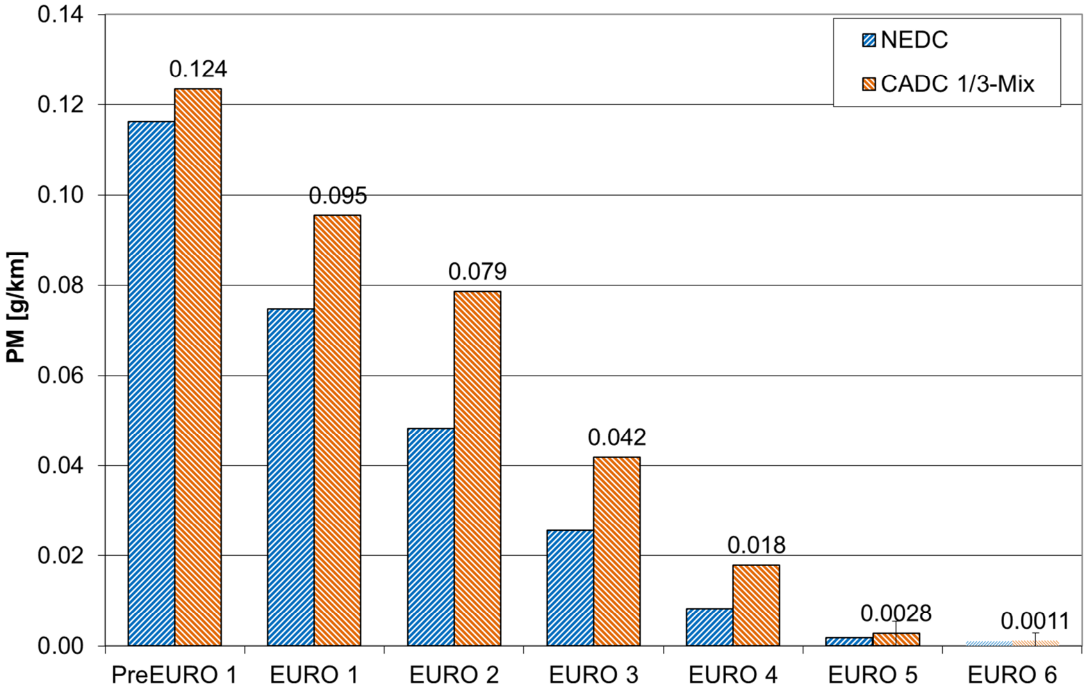


Figure 6: Average PM emission levels of diesel passenger cars tested in the framework of ERMES

Hence, for the time being, only a correction in diesel NOx emission factors is necessary in COPERT. The latest technology for which detailed emission factors exist in COPERT is Euro 4. Hence, on the basis of Euro 4, the following reduction factors are proposed:

RF_{EURO5} = 1 – 0,90/ 0,73 = -0,23 (negative reduction factor which actually means an increase)

RF_{EURO6} = 1 – 0,31/ 0,73 = 0,57

The proposed 'reduction factor' will lead to a substantial increase in NOx emissions compared to the previous COPERT version. The increase will be more important to countries where the stock of Euro 5 cars is relatively more important.

Detailed emission factors for Euro 5 and Euro 6 will be made available in Spring 2013 through ERMES. These will be introduced in the next COPERT version. They will also lead to some adjustment of the emissions calculated with COPERT 4 v10.0 but will not lead to a dramatic change in the emissions as the one from v9.0 to v10.0.

4 PCs: E85 subsector (new)

This is a report summarizing the results of a study for comparing emission factors of ethanol E85 vs. E0/E5/E10 in Euro4 – Euro5 passenger cars. The report firstly provides an overview of the study. Then, some general information about the tests performed is given (vehicle characteristics, fuel used, test cycles, etc), together with a summary of emission measurements and some notes to be considered. Finally, numerical results with corresponding graphs are presented, as well as some conclusions that can be drawn from these graphs.

4.1 Introduction

Bioethanol is the most widely used biofuel in the world. This fuel is particularly popular in Brazil, in USA and in Sweden. The use of ethanol as transport fuel is considered also the most important option to achieve the ambitious target of reaching the 10% market share of fuels from renewable sources by 2020. In fact, compared to biodiesel, ethanol has a higher production potential due to a larger range of possible biomass sources from which this product can be obtained. Unless second generation biofuels are developed in the next future, it seems difficult to achieve the above mentioned target without large recourse to ethanol. Although ethanol can be a very good fuel for thermal engines, it also has some disadvantages which limit its maximum content in ethanol/gasoline blends. In order to overcome the problems associated with the use of blends containing high levels of ethanol, the car manufacturers have developed flexible fuel vehicles able to run with ethanol levels ranging from 0% to 85% (Martini et al., 2009).

The most popular blend is E85 which consists of 85% ethanol and 15% gasoline by volume. Although E85 has been extensively used worldwide, engine manufacturers guarantee problem-free operation without any modification only to catalyst equipped cars fuelled with gasoline containing no more than 5% ethanol. However, modern catalyst-equipped cars are probably able to run without any problem with up to 20% ethanol, which seems to be the upper limit for cold climates. Mixture preparation is also important to achieve low exhaust emissions with engines fuelled with ethanol/gasoline blends, especially at cold start.

This report from EMISIA SA summarizes the results of a study carried out to compare emission factors of ethanol E85 vs. E0/E5/E10 in Euro4 – Euro5 passenger cars in the framework of the ERMES activities and mostly based on a database held by AVL MTC. The details of the work and the complete results are described in Sections 2-4 (Experimental work, Results and graphs, Conclusions). Specifically, in Section 2 some general information is provided about the tests performed (vehicle characteristics, fuel used, test cycles, etc.) and a summary of emission measurements with some notes to be considered. In Section 3, the numerical results and corresponding graphs are presented. Finally, in Section 4, the conclusions that can be drawn from these graphs are provided.

4.2 Experimental work

In this section, general information about the tests performed is provided. This information concerns the characteristics of the test vehicles used, the test fuels, and driving cycles. A summary of emission measurements with some notes to be considered is also presented. There are two subsections, one for Euro 4 vehicles and one for Euro 5 vehicles.

4.2.1 Euro 4 vehicles

Test vehicles

Six different types of passenger cars, complying with the Euro 4 emission limits, were tested. All vehicles were from the AVL MTC. Their technical characteristics are given in the table below. It can be seen that all vehicles belong to engine size category of '1.4 – 2.0 lt'.

Table 11: Euro 4 test vehicles' characteristics

Type	Engine (cm^3)	Technology	Fuel
Volvo V50	1798	Euro 4	petrol / E85
Saab 9-5 Biopower	1985	Euro 4	petrol / E85
Ford Focus FFV	1798	Euro 4	petrol / E85
Renault Megane FFV	1598	Euro 4	petrol / E85
Peugeot 307 Bio flex	1587	Euro 4	petrol / E85
Volkswagen Golf 1.6	1595	Euro 4	petrol / ethanol

Test fuels

The objective was to compare the emission rates of the above vehicles when running on three different fuels:

- Neat gasoline, with no ethanol blend, referred to as **E0** hereinafter.
- **E5**, consisting of standard gasoline fuel containing 5% of ethanol.
- A blend of 15% gasoline and 85% ethanol, referred to as **E85** hereinafter.

The three test fuels were produced by using the same base fuel which was a standard commercial unleaded gasoline that can be found on the market.

The following table shows which vehicle was tested with the above test fuels.

Table 12: Test fuels used

Type	Test fuel
Volvo V50	E5 and E85
Saab 9-5 Biopower	E5 and E85
Ford Focus FFV	E5 and E85

Renault Megane FFV	E5 and E85
Peugeot 307 Bio flex	E0 and E85
Volkswagen Golf 1.6	E0 and E85

Test driving cycles

The emission tests were carried out using the Common Artemis Driving Cycle (CADC), consisting of the three parts Urban – Rural – Motorway 150, which are shown in the following figure.

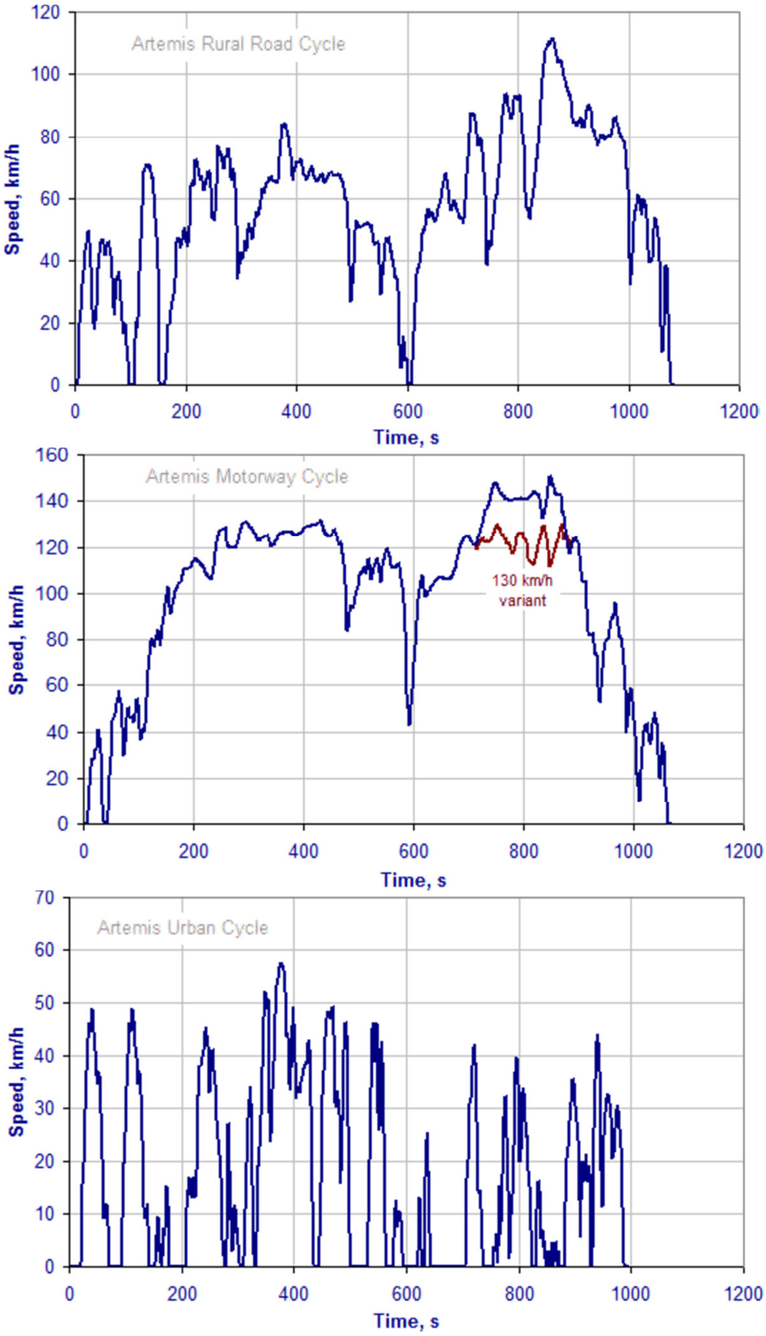


Figure 7: The three parts of the CADC cycle (urban, rural, motorway)

Only the ‘hot’ phase of the urban part of the cycle was considered (the results of the ‘cold’ phase are not included in this study). There are separate measurements for each part of the cycle, that is, there are separate values of emission factors for:

- The ‘urban’ part of the cycle (average speed 17.5 km/h).
- The ‘rural’ part of the cycle (average speed 57.5 km/h).
- The ‘Motorway 150’ part of the cycle (average speed 99.7 km/h).
- There are also measurements for the whole cycle with all three parts (urban_hot, rural, motorway 150), referred to as cycle ‘Artemis_total_hot’ hereinafter (with average speed 60.2 km/h).

More than one vehicles of the same type were tested using the CADC and Artemis_total_hot cycles. The following table shows how many vehicles of the same type were tested.

Table 13: Test cycles and number of vehicles of the same type

Type	Test cycle	Number of vehicles
Volvo V50	CADC	1
Saab 9-5 Biopower	CADC	4
Ford Focus FFV	CADC	3
-//-	Artemis_total_hot	2
Renault Megane FFV	CADC	3
-//-	Artemis_total_hot	3
Peugeot 307 Bio flex	CADC	3
-//-	Artemis_total_hot	3
Volkswagen Golf 1.6	CADC	2

Summary of emission measurements

The following table shows how many measurements are available for creating the graphs presented in the next section. Since the objective was to compare E85 against E0 or E5, the table shows the number of available values for E85/E5 and E85/E0 comparison.

Table 14: Pollutants and number of measurements available

Pollutant	# of values for E85/E5 comparison	# of values for E85/E0 comparison
CO	38	18
HC	38	18
NOx	38	18
NO2	-	18
CO2	32	18
Fuel Consumption	38	18
PM	32	18
PM (PMP)	-	15

PN	32	18
CH4	9	12
NMHC	9	12

All values of the above table are in g/km except for fuel consumption (lt/100km) and PN (nr/km).

Notes to be considered

The following notes concern the tests performed in the framework of this study.

- The ambient temperature for all tests was around 22-25 °C. Some tests were also performed with temperatures below zero (-5, -7 °C), but these results are not included in this study.
- There are also measurements from the 'cold' phase of the urban part of the CADC cycle, as well as measurements from the New European Driving Cycle (NEDC), consisting of the UDC (Urban) and EUDC (Extra-Urban) parts. These measurements are not presented in this study.

4.2.2 Euro 5 vehicles

Test vehicles

Three different types of passenger cars, complying with the Euro 5 emission limits, were tested. One vehicle was from AVL MTC / JRC (Audi A4 2.0 TFSI Flex) and two from TÜV (Opel Insignia 2.0 Turbo Bifuel and Passat 1.4 TSI Multifuel). Their technical characteristics are given in the table below.

Table 15: Euro 5 test vehicles' characteristics

Type	Engine (cm^3)	Technology	Fuel
Audi A4 2.0 TFSI Flex	1984	Euro 5	petrol / E85
Opel Insignia 2.0 Turbo Bifuel	1998	Euro 5	petrol / E85
Passat 1.4 TSI Multifuel	1390	Euro 5	petrol / E85

Test fuels

The objective was to compare the emission rates of the above vehicles when running on three different fuels:

- **E5**, consisting of standard gasoline fuel containing 5% of ethanol.
- **E10**, consisting of standard gasoline fuel containing 10% of ethanol.
- A blend of 15% gasoline and 85% ethanol, referred to as **E85** hereinafter.

The following table shows which vehicle was tested with the above test fuels.

Table 16: Test fuels used

Type	Test fuel
Audi A4 2.0 TFSI Flex	E5 and E85
Opel Insignia 2.0 Turbo Bifuel	E10 and E85

Passat 1.4 TSI Multifuel	E10 and E85

Test driving cycles

The emission tests for Audi A4 2.0 TFSI Flex were carried out using the CADC driving cycle, as described in the previous subsection for Euro 4 vehicles.

The other two vehicle types, Opel Insignia 2.0 Turbo Bifuel and Passat 1.4 TSI Multifuel, were tested with CADC and the ERMES driving cycle, shown in the figure below, which is basically foreseen as hot cycle in course of the elaboration of engine emission maps for emission factors (average cycle speed 65.5 km/h).

The ERMES cycle is mainly developed to offer a short test which can provide data to fill an engine emission map for simulation of emission factors and to provide emission levels for real world cycles from the HBEFA. It is noticed that the ERMES cycle includes full load acceleration ramps. These are realized by increasing the target speed within 1 second to a clearly higher velocity level (the driver just makes full load acceleration in the defined gear until he reaches the target speed curve again).

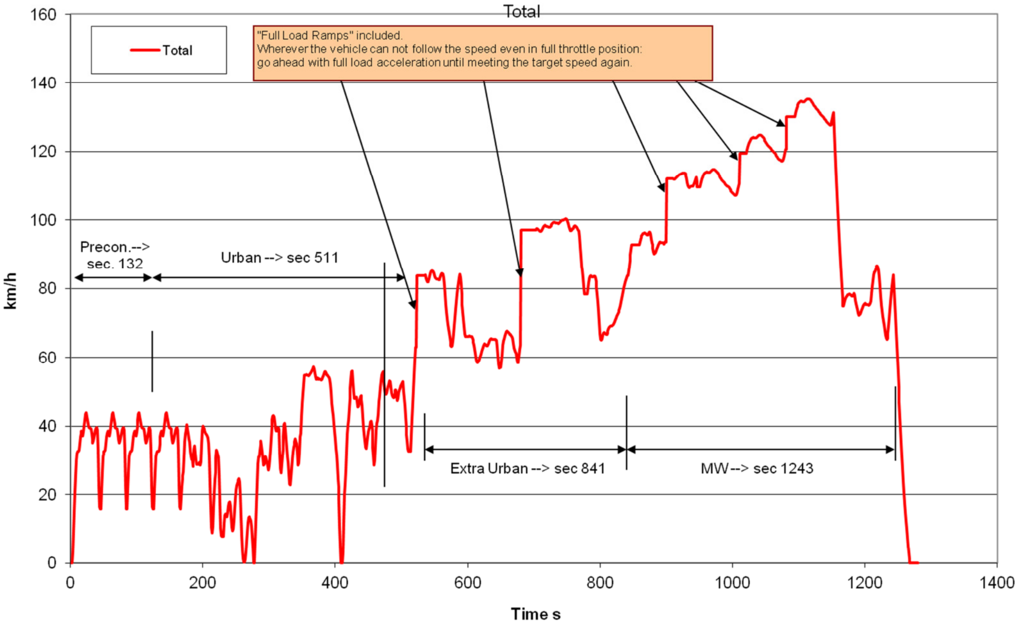


Figure 8: The ERMES driving cycle

For every one of the three abovementioned vehicle types of Euro 5 technology (Audi A4 2.0 TFSI Flex, Opel Insignia 2.0 Turbo Bifuel, Passat 1.4 TSI Multifuel), only one vehicle of each type was tested.

Summary of emission measurements

Audi A4 2.0 TFSI Flex

For each part of CADC (urban_hot, rural, motorway 150) there were four measurements for E5 and three measurements for E85 for CO, HC, NOx, CO2, Fuel Consumption, PN, NMHC. The averages were calculated from these measurements, and then the quotients Avg.E85/Avg.E5 were produced (one for every part of the cycle). The following table shows the number of available measurements.

Table 17: Pollutants and number of measurements available

Pollutant	# of values for E5	# of values for E85
CO	12	9
HC	12	9
NOx	12	9
CO2	12	9
Fuel Consumption	12	9
PN	12	9
NMHC	12	9

All values of the above table are in g/km except for fuel consumption (lt/100km) and PN (nr/km).

Opel Insignia 2.0 Turbo Bifuel – Passat 1.4 TSI Multifuel

For the ERMES driving cycle and for every part of CADC there was one measurement for E10 and one for E85 for CO, HC, NOx, NO, CO2, Fuel Consumption, PN. Therefore, in total for the two vehicles, the numbers of available measurements are the following.

Table 18: Pollutants and number of measurements available

Pollutant	# of values for E85/E10 comparison
CO	8
HC	8
NOx	8
NO	8
CO2	8
Fuel Consumption	8
PN	8

All values of the above table are in g/km except for PN (nr/km).

Notes to be considered

Audi A4 2.0 TFSI Flex

Same as in previous subsection for Euro 4 vehicles.

4.3 Results and graphs

In this section, numerical results of the emission ratios when using two different fuels on the same vehicle, and their corresponding graphs are presented. Again, the section is divided in two subsections, one for Euro 4 vehicles and one for Euro 5 vehicles. Results are presented (in order of appearance) for CO, HC, NO_x, CO_2, and fuel consumption.

We are using both the arithmetic average and the geometric average of the ratio E85/E5 or E85/E0 as the characteristic number to express the difference between the two fuels. The arithmetic average is more popular but could lead to some artifacts. In fact, emission ratios cannot be uniformly dispersed around 1, because emissions cannot decrease below 0. Therefore a lognormal distribution which ranges from 0 to infinite better approximates the probability density function of emission ratios when using different fuels. In this case, geometric rather than arithmetic statistics are better descriptors. The tables which are shown in the remaining of the chapter show both values and one can identify that arithmetic and geometric averages may vary substantially. Our recommendation is therefore to use the geometric average as a more representative value.

4.3.1 Euro 4 vehicles

CO emission rates for E85/E5 and E85/E0 comparison

The following table shows the CO emission rates in g/km for E85 and E5, as well the quotients of E85/E5.

Table 19: CO emission rates (g/km) for E85 and E5 and their ratio (-)

Average cycle speed (km/h)	E85	E5	E85/E5
17.5	0.2600	0.7900	0.329
	0.0600	0.0300	2.000
	0.8780	0.5380	1.632
	0.3170	1.0930	0.290
	0.2220	0.5830	0.381
	0.0230	0.0410	0.561
	0.0140	0.0170	0.824
	0.0280	0.0200	1.400
	0.1060	0.0310	3.419
	0.0230	0.0650	0.354
	0.1290	0.5950	0.217
Average E85/E5 for speed 17.5 km/h			**1.037**
Geometric mean E85/E5 for speed 17.5 km/h			**0.701**
57.5	0.3500	0.6300	0.556
	0.0500	0.2100	0.238
	0.2450	0.2850	0.860
	0.1430	0.4580	0.312
	0.1600	0.3010	0.532
	0.0510	0.3640	0.140
	0.0780	0.1160	0.672
	0.0430	0.4620	0.093

	0.0280	0.3990	0.070
	0.0540	0.0700	0.771
	0.0660	0.5920	0.111
Average E85/E5 for speed 57.5 km/h			**0.396**
Geometric mean E85/E5 for speed 57.5 km/h			**0.285**
99.7	0.9000	10.0100	0.090
	0.4000	1.4800	0.270
	0.2620	0.4840	0.541
	0.2590	0.5340	0.485
	0.2730	0.8800	0.310
	0.2240	0.4620	0.485
	0.1810	0.4360	0.415
	0.2750	0.4390	0.626
	0.1750	0.6690	0.262
	0.2850	0.8110	0.351
	0.2440	0.5720	0.427
Average E85/E5 for speed 99.7 km/h			**0.388**
Geometric mean E85/E5 for speed 99.7 km/h			**0.350**
60.2	0.3170	0.4180	0.758
	0.2270	0.6410	0.354
	0.1420	0.3850	0.369
	0.1270	0.2790	0.455
	0.1670	0.4060	0.411
Average E85/E5 for speed 60.2 km/h			**0.470**
Geometric mean E85/E5 for speed 60.2 km/h			**0.450**

The following table shows the CO emission rates in g/km for E85 and E0, as well the quotients of E85/E0.

Table 20: CO emission rates (g/km) for E85 and E0 and their ratio (-)

Average cycle speed (km/h)	E85	E0	E85/E0
17.5	1.0792	1.0757	1.003
	1.0306	0.6673	1.544
	0.6210	1.2569	0.494
	0.0264	0.1171	0.225
	0.0233	0.0501	0.466

Average E85/E0 for speed 17.5 km/h			**0.747**
Geometric mean E85/E0 for speed 17.5 km/h			**0.604**
57.5	0.5034	0.5495	0.916
	0.4204	0.4227	0.995
	0.6534	0.5159	1.267
	0.0509	0.0848	0.599
	0.0837	0.0684	1.223
Average E85/E0 for speed 57.5 km/h			**1.000**
Geometric mean E85/E0 for speed 57.5 km/h			**0.967**
99.7	2.0254	2.7003	0.750
	1.0774	1.5894	0.678
	2.3003	2.1226	1.084
	0.0775	0.3496	0.222
	0.1745	0.2724	0.641
Average E85/E0 for speed 99.7 km/h			**0.675**
Geometric mean E85/E0 for speed 99.7 km/h			**0.601**
60.2	1.3838	1.7601	0.786
	0.8354	1.0784	0.775
	1.5420	1.4586	1.057
Average E85/E0 for speed 60.2 km/h			**0.873**
Geometric mean E85/E0 for speed 60.2 km/h			**0.864**

The following figure shows the graphs that correspond to the above numerical results.

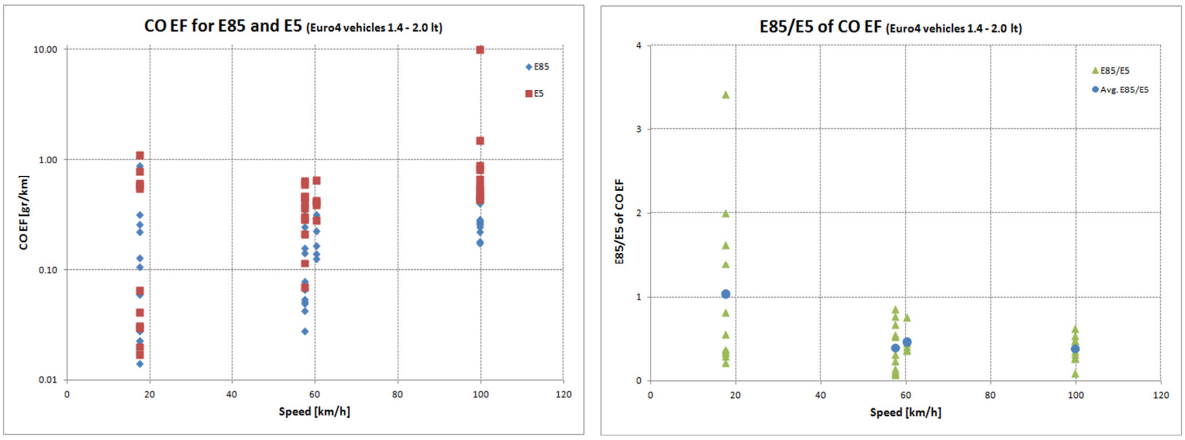


Figure 9: CO emission rates for E85/E5

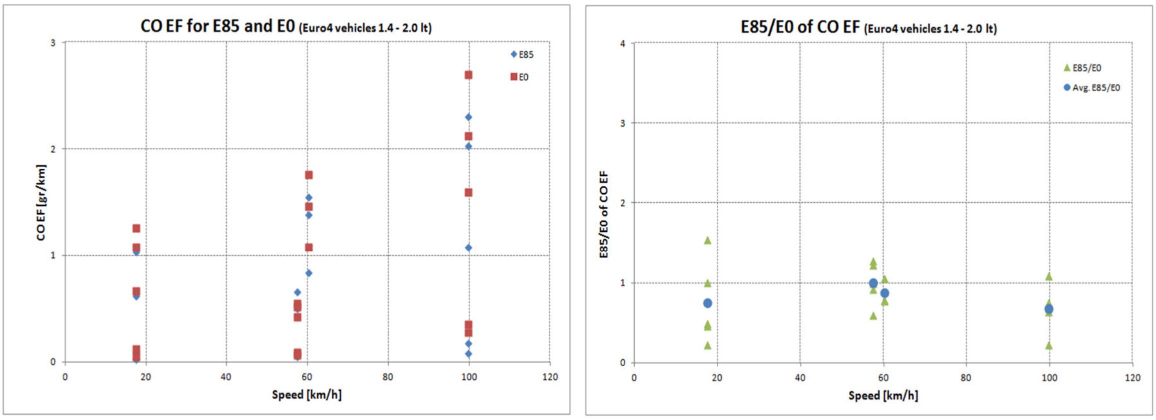


Figure 10: CO emission rates for E85/E0

HC emission rates for E85/E5 and E85/E0 comparison

The following table shows the HC emission rates in g/km for E85 and E5, as well the quotients of E85/E5.

Table 21: HC emission rates (g/km) for E85 and E5 and their ratio (-)

Average cycle speed (km/h)	E85	E5	E85/E5
17.5	0.0100	0.0100	1.000
	0.0100	0.0100	1.000
	0.0010	0.0000	#DIV/0
	0.0020	0.0000	#DIV/0
	0.0010	0.0000	#DIV/0
	0.0060	0.0040	1.500
	0.0020	0.0030	0.667
	0.0060	0.0040	1.500
	0.0080	0.0040	2.000
	0.0070	0.0030	2.333
	0.0160	0.0190	0.842
Average E85/E5 for speed 17.5 km/h			**1.355**
Geometric mean E85/E5 for speed 17.5 km/h			**1.248**
57.5	0.0100	0.0100	1.000
	0.0100	0.0100	1.000
	0.0000	0.0040	0.000
	0.0000	0.0000	#DIV/0
	0.0000	0.0000	#DIV/0
	0.0030	0.0110	0.273
	0.0020	0.0080	0.250
	0.0040	0.0120	0.333

	0.0020	0.0060	0.333
	0.0020	0.0030	0.667
	0.0070	0.0130	0.538
Average E85/E5 for speed 57.5 km/h			**0.488**
Geometric mean E85/E5 for speed 57.5 km/h			**0.478**
99.7	0.0100	0.0200	0.500
	0.0100	0.0200	0.500
	0.0060	0.0140	0.429
	0.0030	0.0080	0.375
	0.0020	0.0080	0.250
	0.0070	0.0110	0.636
	0.0050	0.0110	0.455
	0.0060	0.0120	0.500
	0.0150	0.0340	0.441
	0.0250	0.0440	0.568
	0.0380	0.0560	0.679
Average E85/E5 for speed 99.7 km/h			**0.485**
Geometric mean E85/E5 for speed 99.7 km/h			**0.470**
60.2	0.0030	0.0090	0.333
	0.0010	0.0040	0.250
	0.0050	0.0110	0.455
	0.0040	0.0090	0.444
	0.0050	0.0110	0.455
Average E85/E5 for speed 60.2 km/h			**0.387**
Geometric mean E85/E5 for speed 60.2 km/h			**0.377**

The following table shows the HC emission rates in g/km for E85 and E0, as well the quotients of E85/E0.

Table 22: HC emission rates (g/km) for E85 and E0 and their ratio (-)

Average cycle speed (km/h)	E85	E0	E85/E0
17.5	0.0218	0.0358	0.608
	0.0117	0.0109	1.075
	0.0093	0.0123	0.757
	0.0280	0.0172	1.623
	0.0153	0.0068	2.238

Average E85/E0 for speed 17.5 km/h			**1.260**
Geometric mean E85/E0 for speed 17.5 km/h			**1.124**
57.5	0.0169	0.0239	0.706
	0.0066	0.0100	0.660
	0.0094	0.0139	0.676
	0.0020	0.0016	1.250
	0.0014	0.0008	1.855
Average E85/E0 for speed 57.5 km/h			**1.029**
Geometric mean E85/E0 for speed 57.5 km/h			**0.939**
99.7	0.0468	0.0656	0.714
	0.0199	0.0182	1.089
	0.0301	0.0296	1.017
	0.0046	0.0194	0.236
	0.0066	0.0158	0.420
Average E85/E0 for speed 99.7 km/h			**0.695**
Geometric mean E85/E0 for speed 99.7 km/h			**0.601**
60.2	0.0336	0.0476	0.706
	0.0143	0.0146	0.981
	0.0206	0.0223	0.927
Average E85/E0 for speed 60.2 km/h			**0.871**
Geometric mean E85/E0 for speed 60.2 km/h			**0.863**

The following figure shows the graphs that correspond to the above numerical results.

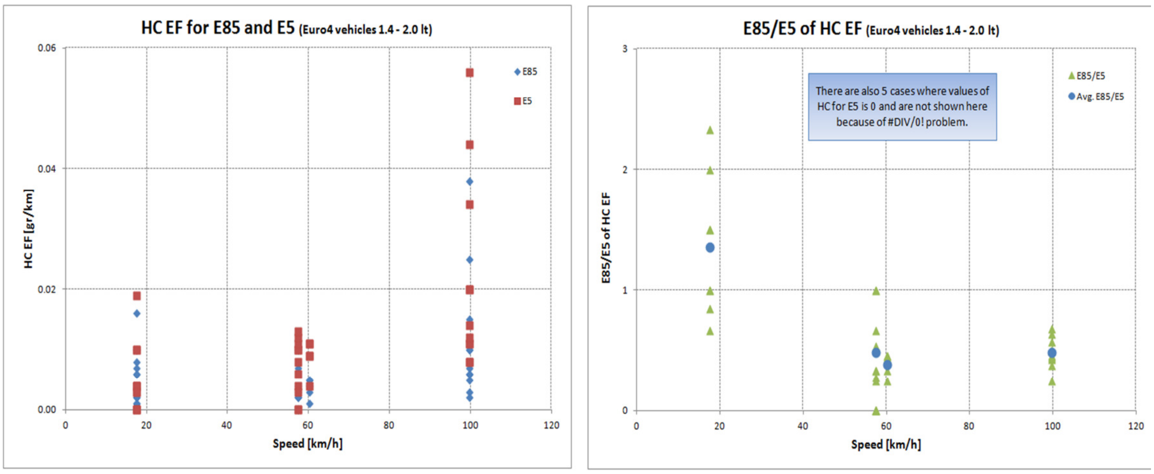


Figure 11: HC emission rates for E85/E5

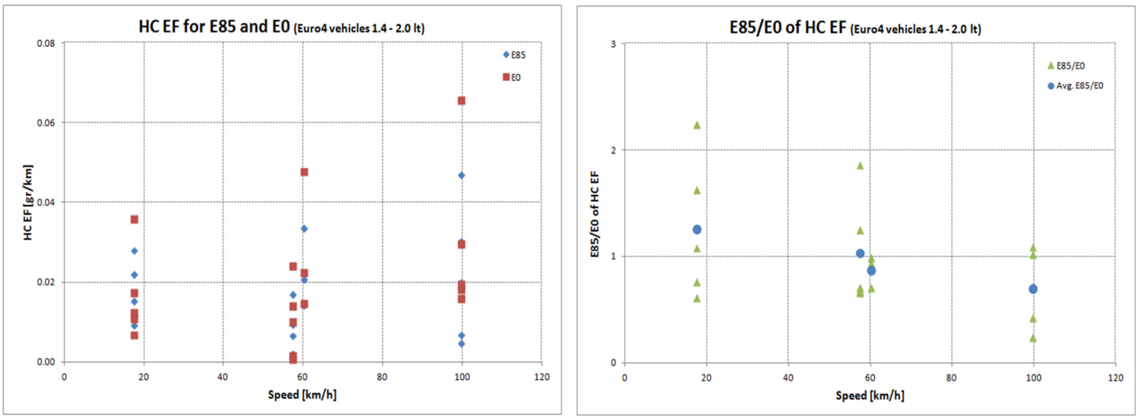


Figure 12: HC emission rates for E85/E0

NOx emission rates for E85/E5 and E85/E0 comparison

The following table shows the NOx emission rates in g/km for E85 and E5, as well the quotients of E85/E5.

Table 23: NOx emission rates (g/km) for E85 and E5 and their ratio (-)

Average cycle speed (km/h)	E85	E5	E85/E5
17.5	0.1000	0.1300	0.769
	0.1000	0.2000	0.500
	0.0310	0.1170	0.265
	0.2340	0.0420	5.571
	0.0250	0.0340	0.735
	0.0300	0.0100	3.000
	0.0260	0.0120	2.167
	0.0390	0.0920	0.424
	0.0310	0.0240	1.292
	0.0040	0.0020	2.000
	0.0050	0.0010	5.000
Average E85/E5 for speed 17.5 km/h			**1.975**
Geometric mean E85/E5 for speed 17.5 km/h			**1.278**
57.5	0.0200	0.0300	0.667
	0.0200	0.0100	2.000
	0.0080	0.0130	0.615
	0.0360	0.0120	3.000
	0.0350	0.0100	3.500
	0.0140	0.0420	0.333
	0.0070	0.0060	1.167
	0.0070	0.0640	0.109
	0.0150	0.0050	3.000

	0.0020	0.0010	2.000
	0.0020	0.0040	0.500
Average E85/E5 for speed 57.5 km/h			**1.536**
Geometric mean E85/E5 for speed 57.5 km/h			**1.009**
99.7	0.0200	0.0200	1.000
	0.0400	0.0100	4.000
	0.0040	0.0100	0.400
	0.0220	0.0110	2.000
	0.0290	0.0060	4.833
	0.0080	0.0080	1.000
	0.0070	0.0090	0.778
	0.0130	0.0110	1.182
	0.0020	0.0070	0.286
	0.0030	0.0080	0.375
	0.0060	0.0080	0.750
Average E85/E5 for speed 99.7 km/h			**1.509**
Geometric mean E85/E5 for speed 99.7 km/h			**1.012**
60.2	0.0080	0.0220	0.364
	0.0310	0.0100	3.100
	0.0120	0.0210	0.571
	0.0090	0.0080	1.125
	0.0130	0.0380	0.342
Average E85/E5 for speed 60.2 km/h			**1.100**
Geometric mean E85/E5 for speed 60.2 km/h			**0.757**

The following table shows the NOx emission rates in g/km for E85 and E0, as well the quotients of E85/E0.

Table 24: NOx emission rates (g/km) for E85 and E0 and their ratio (-)

Average cycle speed (km/h)	E85	E0	E85/E0
17.5	0.0798	0.0583	1.369
	0.0659	0.0615	1.071
	0.0426	0.0260	1.638
	0.0507	0.2605	0.195
	0.0558	0.1702	0.328
Average E85/E0 for speed 17.5 km/h			**0.920**

Geometric mean E85/E0 for speed 17.5 km/h			**0.687**
57.5	0.0821	0.0652	1.260
	0.1331	0.2387	0.558
	0.0417	0.0098	4.237
	0.0540	0.0961	0.562
	0.0278	0.0744	0.374
Average E85/E0 for speed 17.5 km/h			**1.398**
Geometric mean E85/E0 for speed 57.5 km/h			**0.910**
99.7	0.2273	0.1673	1.359
	0.2199	0.3591	0.612
	0.0920	0.0213	4.313
	0.0317	0.0165	1.927
	0.0575	0.0623	0.923
Average E85/E0 for speed 17.5 km/h			**1.827**
Geometric mean E85/E0 for speed 99.7 km/h			**1.449**
60.2	0.1605	0.1195	1.343
	0.1735	0.2866	0.605
	0.0690	0.0176	3.909
Average E85/E0 for speed 17.5 km/h			**1.952**
Geometric mean E85/E0 for speed 60.2 km/h			**1.470**

The following figure shows the graphs that correspond to the above numerical results.

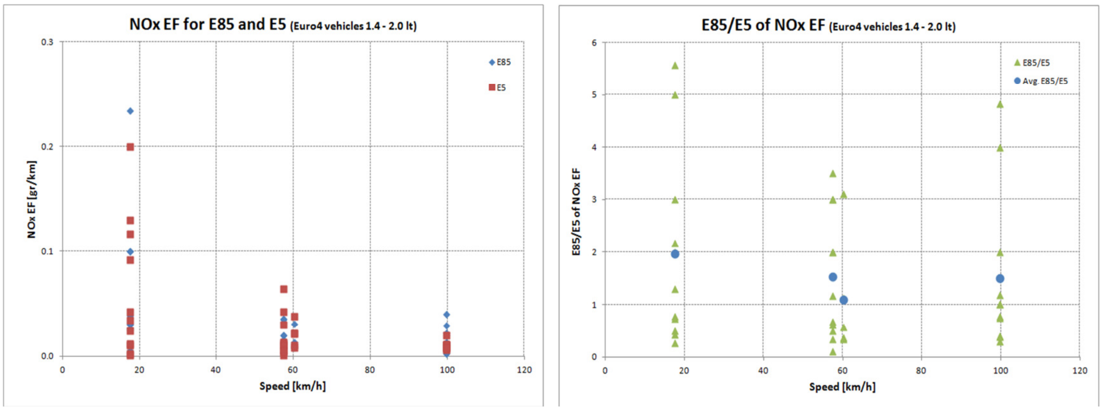


Figure 13: NOx emission rates for E85/E5

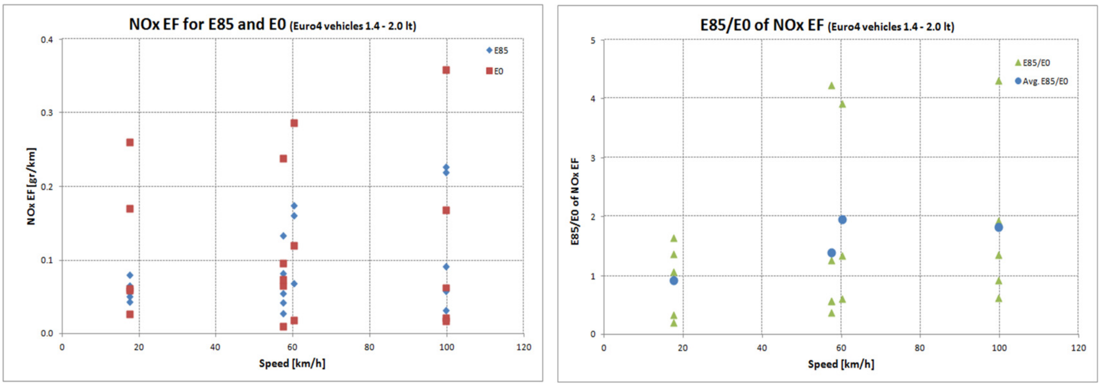


Figure 14: NOx emission rates for E85/E0

CO_2 emission rates for E85/E5 and E85/E0 comparison

The following table shows the CO_2 emission rates in g/km for E85 and E5, as well the quotients of E85/E5.

Table 25: CO_2 emission rates (g/km) for E85 and E5 and their ratio (-)

Average cycle speed (km/h)	E85	E5	E85/E5
17.5	263.1	281.9	0.933
	266.5	279.4	0.954
	262.8	281.7	0.933
	245.0	267.0	0.918
	246.0	258.0	0.953
	245.0	255.0	0.961
	344.0	355.0	0.969
	344.0	370.0	0.930
	351.0	373.0	0.941
Average E85/E5 for speed 17.5 km/h			**0.944**
Geometric mean E85/E5 for speed 17.5 km/h			**0.943**
57.5	138.5	146.4	0.946
	134.7	145.5	0.926
	140.3	146.1	0.960
	133.0	140.0	0.950
	131.0	137.0	0.956
	132.0	140.0	0.943
	173.0	186.0	0.930
	178.0	183.0	0.973
	173.0	183.0	0.945
Average E85/E5 for speed 57.5 km/h			**0.948**

Geometric mean E85/E5 for speed 57.5 km/h			**0.948**
99.7	164.2	175.5	0.936
	161.6	175.0	0.924
	165.8	176.0	0.942
	167.0	175.0	0.954
	165.0	174.0	0.948
	169.0	176.0	0.960
	184.0	194.0	0.948
	185.0	193.0	0.959
	187.0	194.0	0.964
Average E85/E5 for speed 99.7 km/h			**0.948**
Geometric mean E85/E5 for speed 99.7 km/h			**0.948**
60.2	165.0	176.0	0.938
	166.0	176.0	0.943
	162.0	171.0	0.947
	161.0	169.0	0.953
	163.0	171.0	0.953
Average E85/E5 for speed 60.2 km/h			**0.947**
Geometric mean E85/E5 for speed 60.2 km/h			**0.947**

The following table shows the CO_2 emission rates in g/km for E85 and E0, as well the quotients of E85/E0.

Table 26: CO_2 emission rates (g/km) for E85 and E0 and their ratio (-)

Average cycle speed (km/h)	E85	E0	E85/E0
17.5	264.8	267.7	0.989
	277.5	289.6	0.958
	272.8	279.2	0.977
	245.5	254.2	0.966
	232.8	247.0	0.943
Average E85/E0 for speed 17.5 km/h			**0.967**
Geometric mean E85/E0 for speed 17.5 km/h			**0.966**
57.5	154.2	159.3	0.968
	157.3	163.2	0.963
	161.8	159.1	1.017

	143.1	153.8	0.930
	144.2	150.4	0.958
Average E85/E0 for speed 57.5 km/h			**0.967**
Geometric mean E85/E0 for speed 57.5 km/h			**0.967**
99.7	183.7	189.4	0.970
	186.9	193.6	0.965
	188.7	190.5	0.990
	172.0	182.3	0.944
	173.9	182.5	0.953
Average E85/E0 for speed 99.7 km/h			**0.964**
Geometric mean E85/E0 for speed 99.7 km/h			**0.964**
60.2	181.0	186.3	0.972
	185.0	192.0	0.964
	187.1	188.0	0.995
Average E85/E0 for speed 60.2 km/h			**0.977**
Geometric mean E85/E0 for speed 60.2 km/h			**0.977**

The following figure shows the graphs that correspond to the above numerical results.

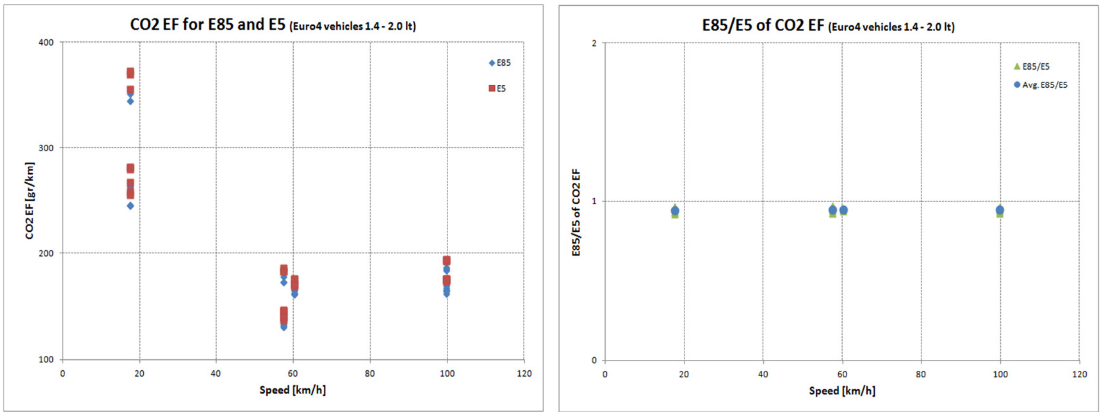


Figure 15: CO_2 emission rates for E85/E5

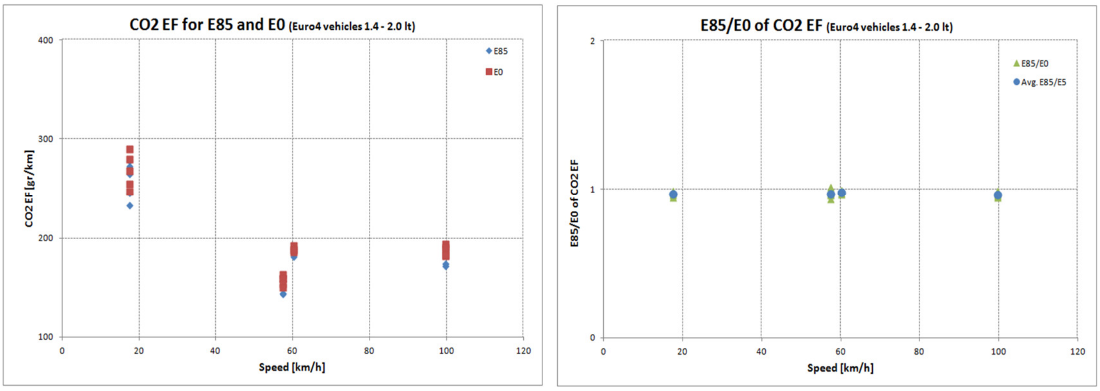


Figure 16: CO_2 emission rates for E85/E5 and E85/E0

Fuel consumption for E85/E5 and E85/E0 comparison

The following table shows the fuel consumption in lt/100km for E85 and E5, as well the quotients of E85/E5.

Table 27: Fuel consumption (l/100 km) for E85 and E5 and their ratio (-)

Average cycle speed (km/h)	E85	E5	E85/E5
17.5	16.00	12.40	1.290
	19.50	15.20	1.283
	16.37	11.83	1.384
	16.53	11.76	1.406
	16.29	11.82	1.378
	15.19	11.15	1.362
	15.24	10.78	1.414
	15.16	10.66	1.422
	21.31	14.87	1.433
	21.31	15.50	1.375
	21.74	15.67	1.387
Average E85/E5 for speed 17.5 km/h			**1.376**
Geometric mean E85/E5 for speed 17.5 km/h			**1.375**
57.5	9.30	7.70	1.208
	11.00	8.30	1.325
	8.60	6.14	1.401
	8.35	6.12	1.364
	8.70	6.13	1.419
	8.21	5.90	1.392
	8.12	5.73	1.417
	8.16	5.91	1.381
	10.68	7.80	1.369

	11.05	7.68	1.439
	10.69	7.68	1.392
Average E85/E5 for speed 57.5 km/h			**1.373**
Geometric mean E85/E5 for speed 57.5 km/h			**1.372**
99.7	13.00	11.20	1.161
	15.11	11.00	1.374
	10.19	7.38	1.381
	10.03	7.36	1.363
	10.29	7.42	1.387
	10.33	7.36	1.404
	10.23	7.33	1.396
	10.50	7.41	1.417
	11.42	8.18	1.396
	11.46	8.12	1.411
	11.59	8.15	1.422
Average E85/E5 for speed 99.7 km/h			**1.374**
Geometric mean E85/E5 for speed 99.7 km/h			**1.372**
60.2	10.23	7.37	1.388
	10.31	7.40	1.393
	10.03	7.20	1.393
	9.95	7.09	1.403
	10.11	7.18	1.408
Average E85/E5 for speed 60.2 km/h			**1.397**
Geometric mean E85/E5 for speed 60.2 km/h			**1.397**

The following table shows the fuel consumption in lt/100km for E85 and E0, as well the quotients of E85/E0.

Table 28: Fuel consumption (l/100km) for E85 and E0 and their ratio (-)

Average cycle speed (km/h)	E85	E0	E85/E0
17.5	16.50	11.28	1.463
	17.28	12.16	1.420
	16.95	11.77	1.440
	15.20	10.65	1.427
	14.41	10.34	1.394
Average E85/E0 for speed 17.5 km/h			**1.429**

Geometric mean E85/E0 for speed 17.5 km/h			**1.429**
57.5	9.59	6.71	1.431
	9.77	6.86	1.425
	10.08	6.69	1.505
	8.86	6.44	1.375
	8.93	6.30	1.417
Average E85/E0 for speed 57.5 km/h			**1.431**
Geometric mean E85/E0 for speed 57.5 km/h			**1.430**
99.7	11.58	8.11	1.427
	11.68	8.21	1.422
	11.90	8.11	1.467
	10.65	7.65	1.392
	10.78	7.66	1.408
Average E85/E0 for speed 99.7 km/h			**1.423**
Geometric mean E85/E0 for speed 99.7 km/h			**1.423**
60.2	11.34	7.92	1.432
	11.53	8.11	1.423
	11.73	7.96	1.473
Average E85/E0 for speed 60.2 km/h			**1.443**
Geometric mean E85/E0 for speed 60.2 km/h			**1.442**

The following figure shows the graphs that correspond to the above numerical results.

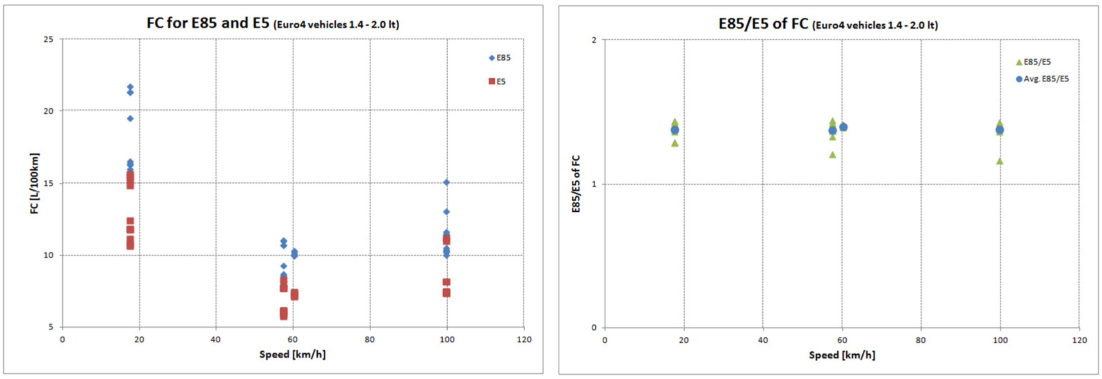


Figure 17: Fuel consumption for E85/E5

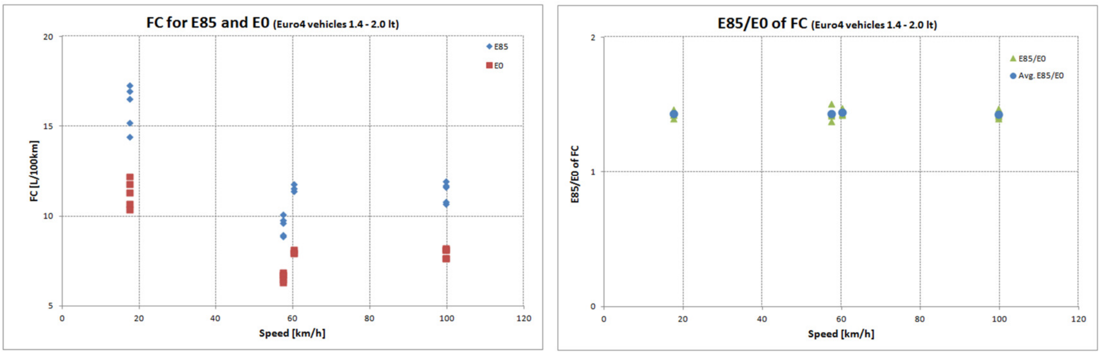


Figure 18: Fuel consumption for E85/E0

4.3.2 Euro 5 vehicles

CO emission rates for E85/E5 and E85/E10 comparison

The following table shows the CO emission rates in g/km for E85 and E5, as well the quotients of E85/E5 for tested speeds.

Table 29: CO emission rates (g/km) for E85 and E5 and their ratio (-)

Average cycle speed (km/h)	E85	E5	E85/E5
17.5	0.1231	0.2549	
	0.1021	0.2487	
	0.0904	0.1730	
		0.2007	
Average for speed 17.5 km/h	**0.105**	**0.219**	**0.480**
Geometric mean for speed 17.5 km/h	**0.104**	**0.217**	**0.482**
57.5	0.3253	0.4043	
	0.3999	0.4319	
	0.2453	0.5304	
		0.5877	
Average for speed 57.5 km/h	**0.324**	**0.489**	**0.662**
Geometric mean for speed 57.5 km/h	**0.317**	**0.483**	**0.657**
99.7	0.4210	0.8058	
	0.3780	0.5282	
	0.2621	0.5086	
		0.5736	
Average for speed 99.7 km/h	**0.354**	**0.604**	**0.586**
Geometric mean for speed 99.7 km/h	**0.347**	**0.594**	**0.584**

The following table shows the CO emission rates in g/km for E85 and E10, as well the quotients of E85/E10.

Table 30: CO emission rates (g/km) for E85 and E10 and their ratio (-)

Average cycle speed (km/h)	E85	E10	E85/E10
17.5	1.142	0.713541	1.601
17.5	0.064	0.178822	0.361
57.5	0.036	0.335367	0.109
57.5	0.083	0.185	0.453
99.7	0.055	0.126	0.441
99.7	0.124	0.106	1.16
65.5	0.054	0.292	0.186
65.5	0.434	1.506	0.288
Average E85/E10			**0.575**
Geometric mean E85/E10			**0.409**

The following figure shows the graphs that correspond to the above numerical results for E85 and E5.

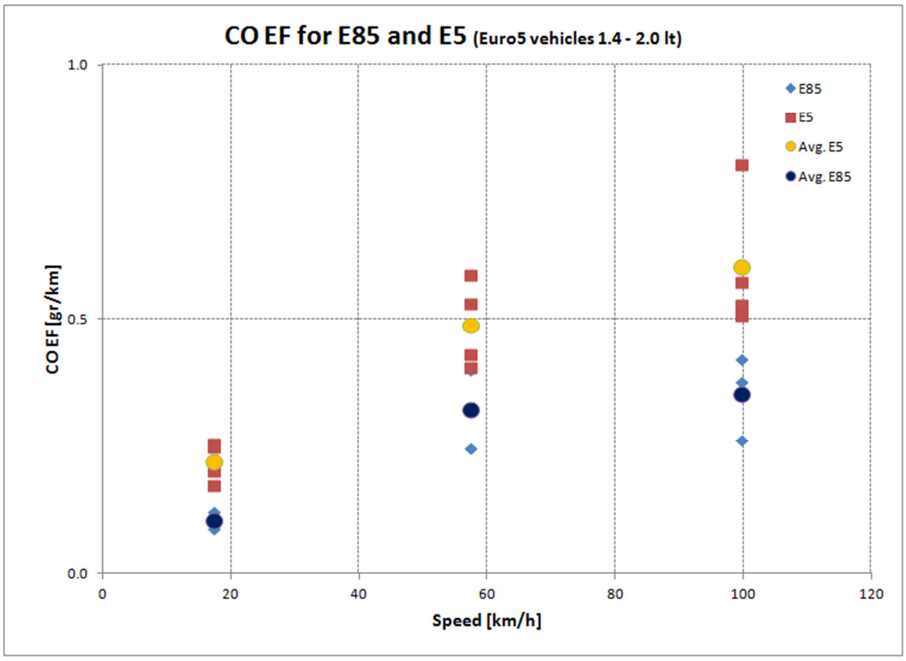


Figure 19: CO emission rates for E85/E5

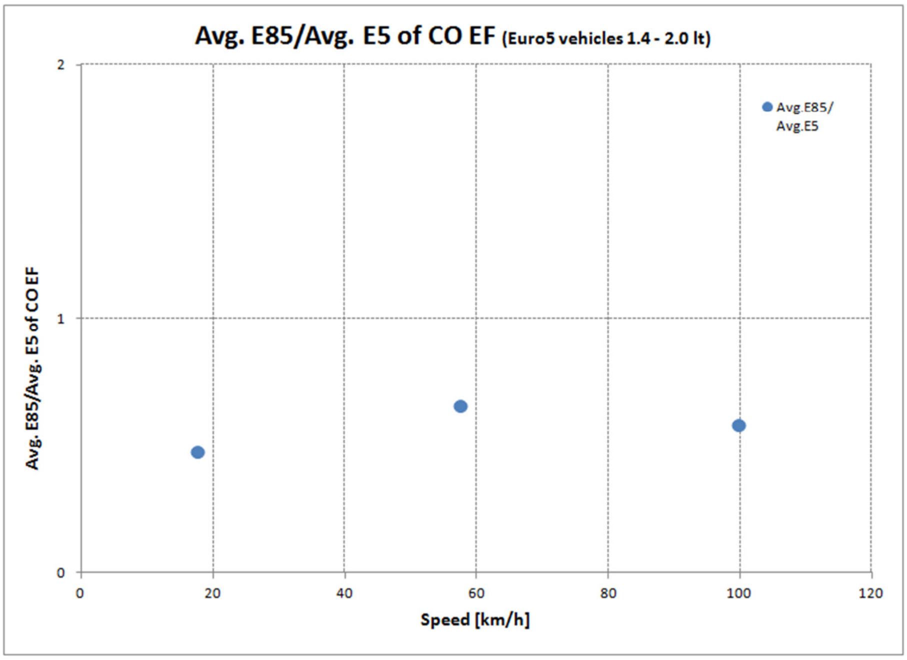


Figure 20: CO emission rates for E85/E5

HC emission rates for E85/E5 and E85/E10 comparison

The following table shows the HC emission rates in g/km for E85 and E5, as well the quotients of E85/E5 for tested speeds.

Table 31: HC emission rates (g/km) for E85 and E5 and their ratio (-)

Average cycle speed (km/h)	E85	E5	E85/E5
17.5	0.0092	0.0148	
	0.0121	0.0081	
	0.0064	0.0079	
		0.0075	
Average for speed 17.5 km/h	**0.009**	**0.010**	**0.965**
Geometric mean for speed 17.5 km/h	**0.009**	**0.009**	**0.973**
57.5	0.0075	0.0106	
	0.0077	0.0087	
	0.0057	0.0095	
		0.0087	
Average for speed 57.5 km/h	**0.007**	**0.009**	**0.748**
Geometric mean for speed 57.5 km/h	**0.007**	**0.009**	**0.744**
99.7	0.0222	0.0279	
	0.0194	0.0221	

	0.0189	0.0199	
		0.0206	
Average for speed 99.7 km/h	**0.020**	**0.023**	**0.891**
Geometric mean for speed 99.7 km/h	**0.020**	**0.022**	**0.897**

The following table shows the HC emission rates in g/km for E85 and E10, as well the quotients of E85/E10.

Table 32: HC emission rates (g/km) for E85 and E10 and their ratio (-)

Average cycle speed (km/h)	E85	E10	E85/E10
17.5	0.032	0.0101	3.24
17.5	0.0081	0.0052	1.53
57.5	0.0046	0.0027	1.69
57.5	0.0020	0.0024	0.857
99.7	0.0060	0.0031	1.88
99.7	0.0038	0.0028	1.32
65.5	0.0046	0.0033	1.39
65.5	0.0043	0.0144	0.30
Average E85/E10			**1.53**
Geometric mean E85/E10			**1.29**

The following figure shows the graphs that correspond to the above numerical results for E85 and E5.

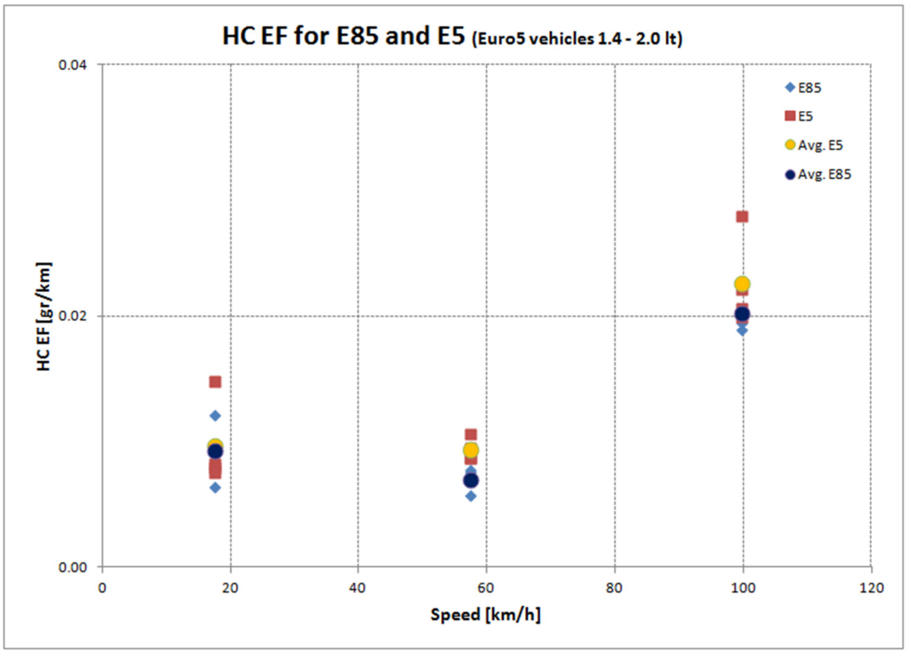


Figure 21: HC emission rates for E85/E5

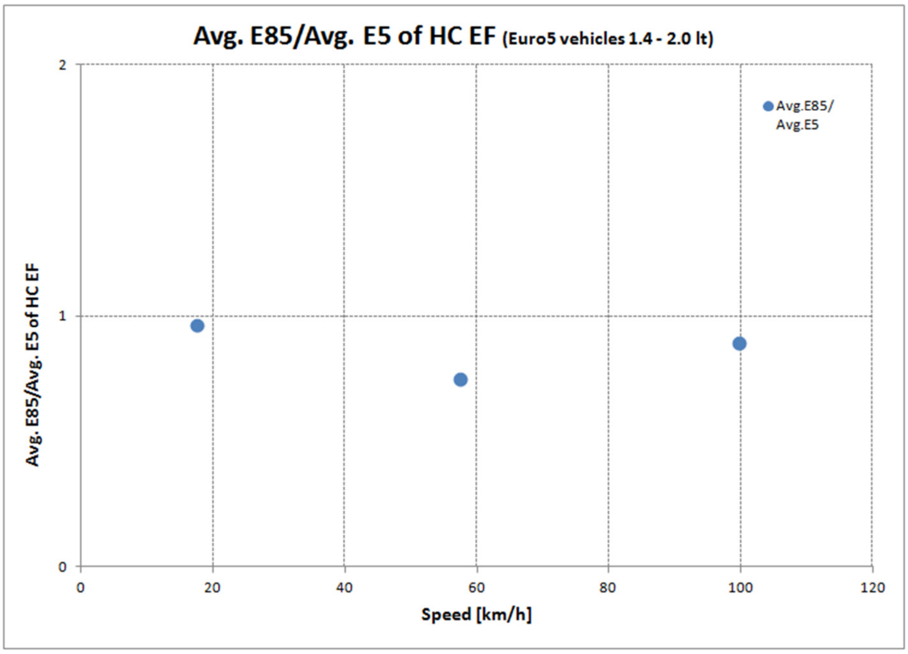


Figure 22: HC emission rates for E85/E5

NOx emission rates for E85/E5 and E85/E10 comparison

The following table shows the NOx emission rates in g/km for E85 and E5, as well the quotients of E85/E5 for tested speeds.

Table 33: NO_x emission rates (g/km) for E85 and E5 and their ratio (-)

Average cycle speed (km/h)	E85	E5	E85/E5
17.5	0.0139	0.0088	
	0.0209	0.0179	
	0.0054	0.0112	
		0.0133	
Average for speed 17.5 km/h	**0.013**	**0.013**	**1.047**
Geometric mean for speed 17.5 km/h	**0.012**	**0.012**	**0.939**
57.5	0.0070	0.0158	
	0.0080	0.0130	
	0.0053	0.0129	
		0.0138	
Average for speed 57.5 km/h	**0.007**	**0.014**	**0.488**
Geometric mean for speed 57.5 km/h	**0.007**	**0.014**	**0.483**
99.7	0.0296	0.0480	

	0.0240	0.0566	
	0.0192	0.0571	
		0.0423	
Average for speed 99.7 km/h	**0.024**	**0.051**	**0.476**
Geometric mean for speed 99.7 km/h	**0.024**	**0.051**	**0.472**

The following table shows the NOx emission rates in g/km for E85 and E10, as well the quotients of E85/E10.

Table 34: NO_x emission rates (g/km) for E85 and E10 and their ratio (-)

Average cycle speed (km/h)	E85	E10	E85/E10
17.5	0.038	0.052	0.748
17.5	0.284	0.157	1.81
57.5	0.009	0.022	0.413
57.5	0.022	0.022	1.02
99.7	0.009	0.015	0.581
99.7	0.025	0.025	0.979
65.5	0.019	0.021	0.916
65.5	0.013	0.028	0.483
Average E85/E10			**0.870**
Geometric mean E85/E10			**0.785**

The following figure shows the graphs that correspond to the above numerical results for E85 and E5.

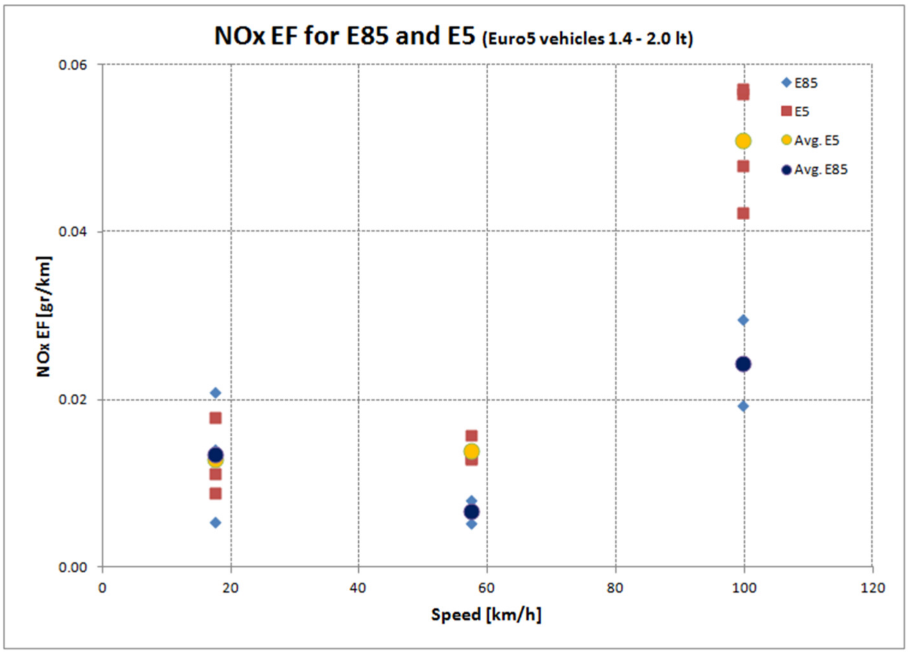


Figure 23: NOx emission rates for E85/E5

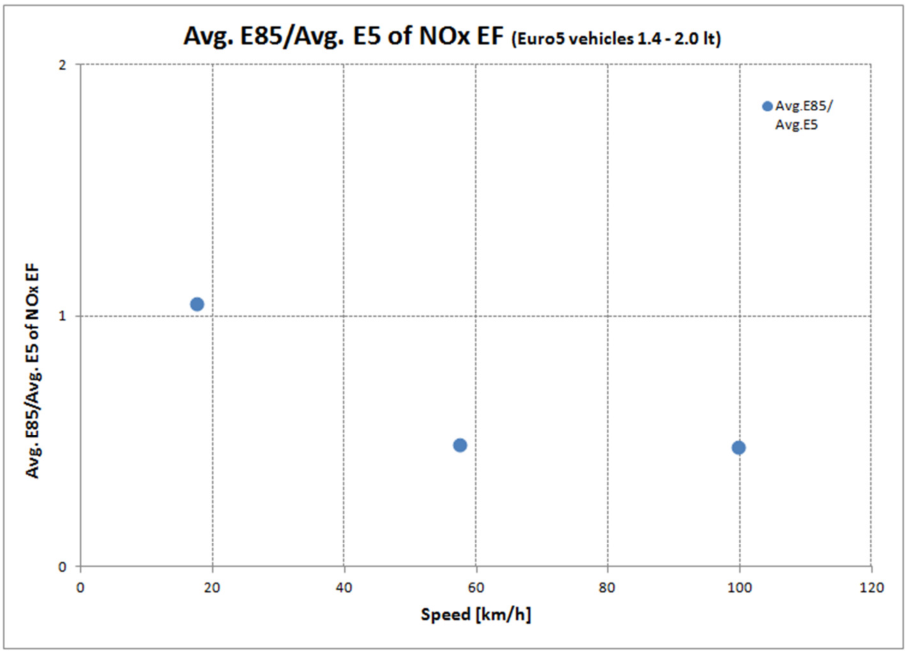


Figure 24: NOx emission rates for E85/E5

CO_2 emission rates for E85/E5 and E85/E10 comparison

The following table shows the CO_2 emission rates in g/km for E85 and E5, as well the quotients of E85/E5 for tested speeds.

Table 35: CO_2 emission rates (g/km) for E85 and E5 and their ratio (-)

Average cycle speed (km/h)	E85	E5	E85/E5
17.5	275.1	289.8	
	266.3	288.4	
	262.0	285.7	
		289.2	
Average for speed 17.5 km/h	**267.8**	**288.3**	**0.929**
Geometric mean for speed 17.5 km/h	**267.7**	**288.3**	**0.929**
57.5	147.5	159.9	
	145.0	158.1	
	142.6	153.4	
		156.5	
Average for speed 57.5 km/h	**145.0**	**157.0**	**0.924**
Geometric mean for speed 57.5 km/h	**145.0**	**156.9**	**0.924**
99.7	198.3	210.3	

	196.7	209.6	
	194.8	207.2	
		207.6	
Average for speed 99.7 km/h	**196.6**	**208.6**	**0.942**
Geometric mean for speed 99.7 km/h	**196.6**	**208.6**	**0.942**

The following table shows the CO_2 emission rates in g/km for E85 and E10, as well the quotients of E85/E10.

Table 36: CO_2 emission rates for E85 and E10

Average cycle speed (km/h)	E85	E10	E85/E10
17.5	291.5	354.2	0.822
17.5	266.5	285.2	0.934
57.5	154.7	171.4	0.902
57.5	137.5	148.5	0.925
99.7	166.8	220.7	0.755
99.7	163.2	174.3	0.936
65.5	154.4	171.3	0.901
65.5	151.9	164.1	0.925
Average E85/E10			**0.888**
Geometric mean E85/E10			**0.885**

The following figure shows the graphs that correspond to the above numerical results for E85 and E5.

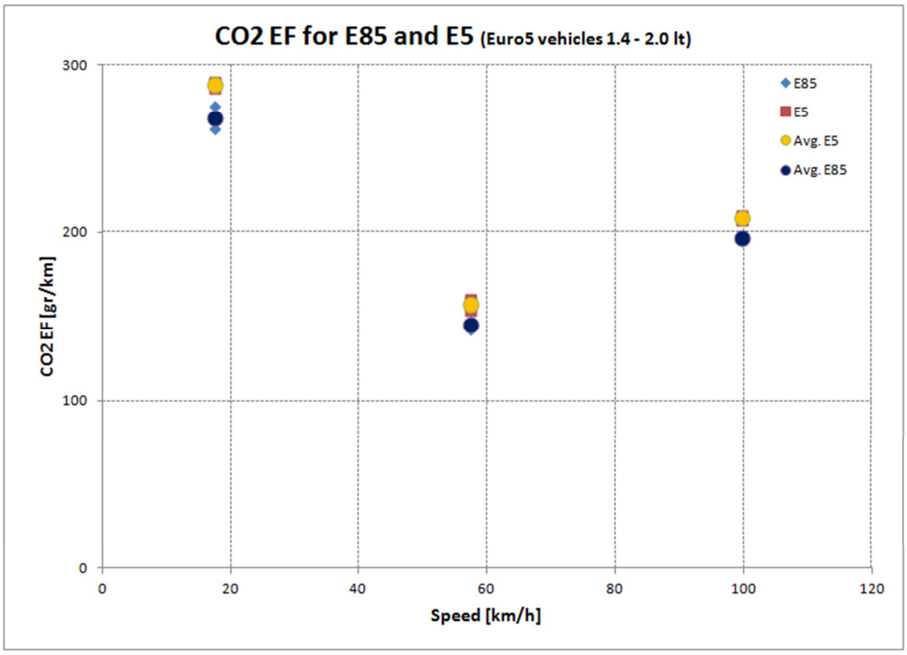


Figure 25: CO_2 emission rates for E85/E5

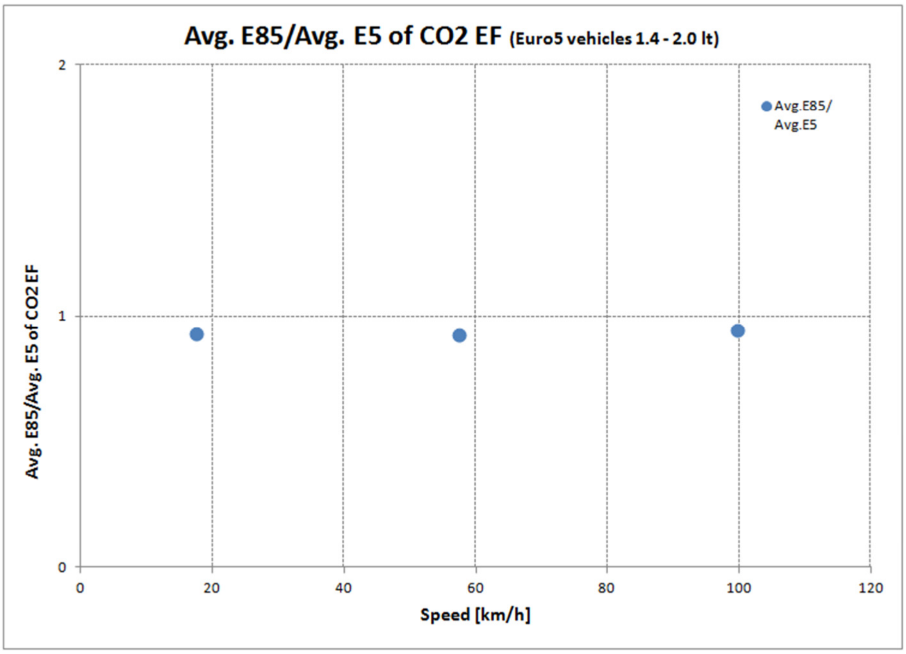


Figure 26: CO$_2$ emission rates for E85/E5

Fuel consumption for E85/E5 and E85/E10 comparison

The following table shows the fuel consumption in lt/100km for E85 and E5, as well the quotients of E85/E5 for tested speeds.

Table 37: Fuel consumption (l/100 km) for E85 and E5 and their ratio (-)

Average cycle speed (km/h)	E85	E5	E85/E5
17.5	16.6	12.4	1.33
	16.1	12.4	1.30
	15.8	12.2	1.29
		12.4	
Average for speed 17.5 km/h	**16.2**	**12.4**	**1.31**
Geometric mean for speed 17.5 km/h	**16.2**	**12.408**	**1.31**
57.5	8.95	6.90	1.30
	8.81	6.82	1.29
	8.64	6.63	1.30
		6.76	
Average for speed 57.5 km/h	**8.80**	**6.78**	**1.30**
Geometric mean for speed 57.5 km/h	**8.80**	**6.78**	**1.30**
99.7	12.0	9.09	1.32

	11.9	9.04	1.32
	11.8	8.94	1.32
		8.96	
Average for speed 99.7 km/h	**11.9**	**9.01**	**1.32**
Geometric mean for speed 99.7 km/h	**11.9**	**9.01**	**1.32**

The following figure shows the graphs that correspond to the above numerical results for E85 and E5.

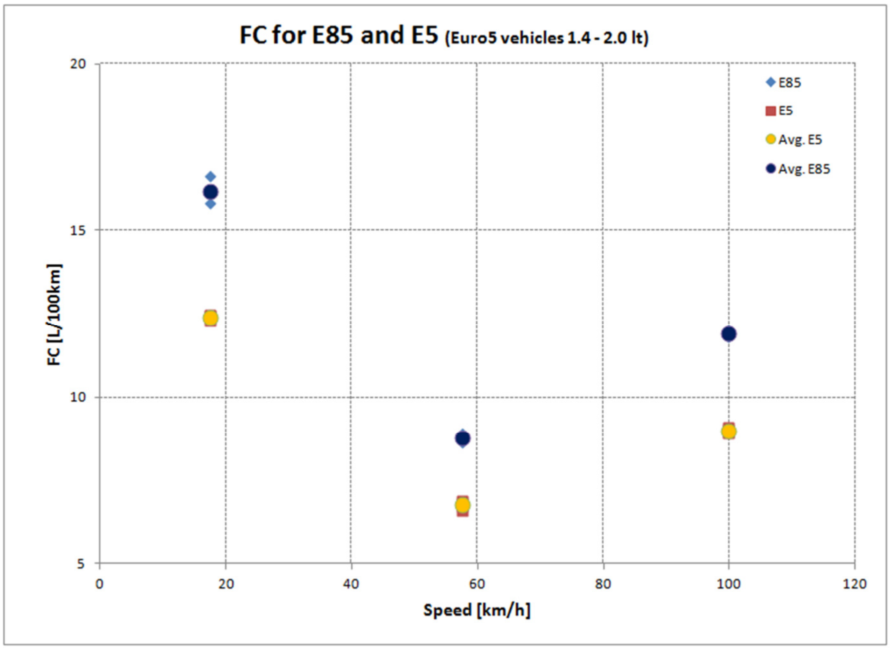


Figure 27: Fuel consumption (l/100 km) for E85/E5

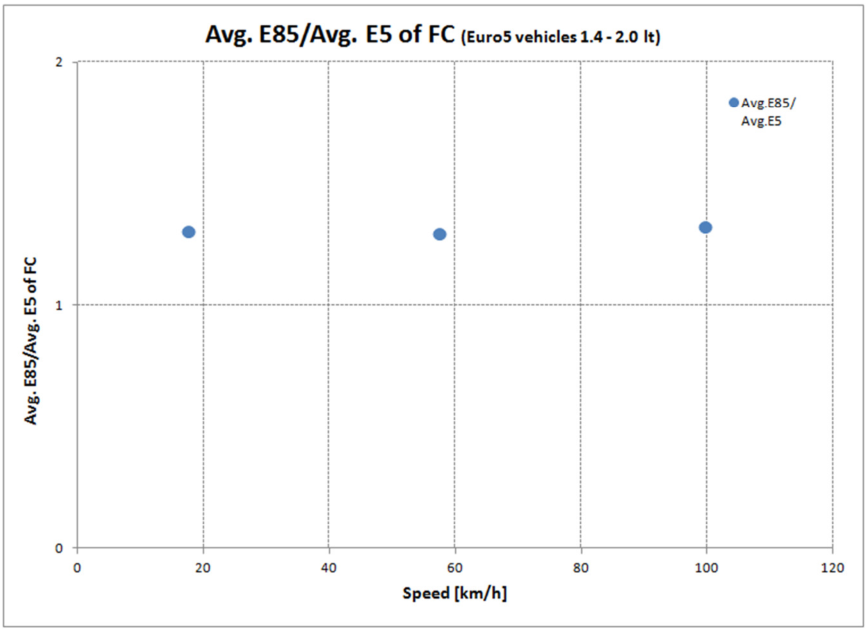


Figure 28: Fuel consumption (l/100 km) for E85/E5

4.4 Discussion and conclusions

4.4.1 Euro 4 vehicles

The results of this dataset show what has generally been observed in several similar studies in the past, i.e. that the impact of high ethanol blends on emissions from gasoline vehicles is vehicle specific (e.g. Yanowitz and McCormick, 2009; Winther et al., 2012). Hence, on an individual vehicle basis both an increase and a decrease over gasoline emission levels can be observed. Interestingly, these emission differences can be quite wide reaching or exceeding three-fold or four-fold differences. These differences generally apply to very low emission levels, hence, with a few exceptions, vehicles continue to comply with their emission limits.

Use of E85 may affect the stoichiometry of combustion as well as flame characteristics in cylinder. Therefore it is expected that engine out emissions between gasoline and E85 will differ. Moreover, E85 results in a completely different chemistry of the exhaust gas, consisting of a large fraction of oxygenated species compared to the aromatic and long chain species of neat gasoline exhaust. This affects the catalyst operation and performance. Therefore, both engine calibration, and catalyst specifications will affect the relative impact of E85 on emissions. In this short report we only addressed hot emissions, i.e. taking into account both the impacts on engine out emissions and catalyst performance.

Having this wide range of emission differences in mind and the complex nature of ethanol impact on emissions, the following general conclusions can be reached:

CO

Significant decreases in CO are observed when using E85 over E5 or E0 fuel. The overall geometric mean decrease is in the order of 50% collectively for the E85/E5 and E85/E0 ratios. In fact, the reductions are 59% for the E85/E5 ratio and 27% for the E85/E0 ratio. These inconsistent results between the two data sample imply that the average values are specific to the sample. However, a reduction of CO is also consistent with the much higher content of oxygenated species in the exhaust that should assist in CO oxidation and hence to an overall CO reduction. Moreover, both samples showed that the reduction is more significant as vehicle speed (and hence catalyst temperature) increases. Hence, while the reduction is approximately only 30% at urban conditions, this becomes 65% at highway conditions. These values are in general higher than reductions considered in US, which is of the order of 20% for (111 tests) Tier 2 FFV vehicles (Yanowitz and McCormick, 2009).

HC

Comparison of HC between neat gasoline and E85 misses the oxygenated part, which is included in the definition of NMOG. Hence, comparing only hydrocarbon emissions may not be the most relevant from an environmental perspective. However, current emission estimation models include HC only (distinguished into CH4 and NMHC), hence impact of E85 on HC is relevant for current emission inventories. The overall mean when using E85 over E5 or E0 is 33% less than using gasoline alone. However, this value differs again substantially for the two ratios (42% reduction for the E85/E5 ratio, compared to 14% for the E85/E0 ratio). The reduction is in general more significant at high speeds. In urban speeds, use of E85 over E5 actually leads to an increase in emissions by 25% while emissions over highway conditions drop by 53% when using E85. Tier 2 FFV values in US exhibited a reduction of 12% when using E85 (Yanowitz and McCormick, 2009).

NOx

Impacts on NOx overall are negligible, with an overall increase when using E85 of 4%. The increase is limited to 1% when comparing E85 vs. E5 and 4% when comparing E85 vs. E0. No evidence of impact on emissions with speed can be found in this case. Evidence from US indicates a reduction of 19% (114 tests) for Tier 2 FFV cars.

Fuel Consumption

Neat gasoline has an energy density of approximately 33 MJ/l compared to approximately 25 MJ/l for E85. Hence, E85 has an approximately 25-30% lower energy density than neat gasoline (exact value will depend on specs of gasoline and E85), which should lead to an approximately equivalent increase in fuel consumption. In fact, some reports argue that the actual fuel consumption increase is lower due to the higher octane number and enthalpy of volatilization of ethanol, that can increase combustion efficiency. Actually, in our case, fuel consumption increases by 39% when using E85 in our sample, with limited impact of the driving cycle. The actual increase ranges from 37% for the E85 over E5 ratio compared to 43% for the E85 over the E0 ratio. More fuel specifications are needed to understand this difference, which appears much higher than what energy density differences would call for.

CO2 Emissions

Despite the higher fuel consumption, tailpipe CO_2 emissions actually are lower when using E85 compared to lower blends. Use of E85 results to 5% lower CO_2 than E5 and 3% less CO_2 than E0. More details on the fuels used are needed to estimate whether fuel consumption increase and carbon dioxide decrease are internally consistent.

4.4.2 Euro 5 vehicles

The Euro 5 vehicle sample is much smaller than the Euro 4 one. While Euro 5 and Euro 4 gasoline vehicles should not substantially differ in their technology, we have decided to keep the two samples separate and see whether the same trends are observed between the two vehicle technologies.

CO

E85 use over E5 or E10 overall leads to 51% lower CO emissions, in direct comparison with the Euro 4 value established. The change in the ratio with speed is not evident here, however these Euro 5 cars appears as very low emitters at urban speeds.

HC

In terms of HC, use of E85 on average over E5 and E10 leads to a slight increase of 2% in HC emissions. This differs between the two Euro 5 datasets. The E85 over E5 leads to a 17% reduction in emissions and the E85 over E10 leads to a 29% increase in emissions. The Euro 4 dataset exhibited 33% decrease in emissions. These lead to very inconsistent findings

NOx

The average NOx when using E85 was 32.5% lower than E5 and E10 for the Euro 5 cars. This again varied between 41% reduction for the E85 over E5 and 21.5% reduction for the E85 over E10. This is in contrast to the Euro 4 negligible impact.

Fuel Consumption

No fuel consumption values are given for the E85/E10 ratio as these were in g/km while all other values in the report are in l/100 km. The E85 over E5 fuel consumption appears 30%

higher, this time in consistency with the expected difference in the energy density between the two fuels.

CO2

CO2 emissions appear overall 9% lower with E85 over E5 and E10. In fact there is significant difference between the two fuel ratios with the E85 vs E5 appearing 6% lower and E85 over E10 appearing 11.5% lower. This last figure, taking into account that the base fuel is already E10 appears as a very high difference that has to be justified.

4.4.3 Final proposed values

The previous analysis has shown that technology level, impact of driving cycle, and ratio of fuel considered (E85/E0, E85/E5, E85/E10) are rather of secondary importance compared to the vehicle specificity of the impact of E85 on emissions. Also, trying to analyze the impacts per technology leaves a very small dataset in the end. In such a case, obtaining a lump sum of all values available may seem as the only option. This is shown in Table 38 together with some descriptive statistics. The notes under the table have to be considered with the potential to obtain better estimates in a second version of this report.

Table 38: Impact of E85 blends on post Euro 4 FFVs hot emissions and consumption compared to gasoline (gasoline is considered any blend up to maximum E10)

Pollutant/ Consumption	Geom. Mean Difference (%)	Geom. 95% -CI (%)	Geom. 95% +CI (%)	Sample Size
CO (g/km)	-50	-58	-41	73
HC (g/km)	-25	-36	-14	67
NO_x (g/km)	-6	-23	+15	73
FC (l/100 km)	+38	36	40	60
CO_2 (g/km)	-6	-7	-5	68

Notes

1. FC difference appears very high and a check of its calculation in the AVL measurements has to be conducted
2. HC emissions do not contain the complete range of non methane organic gases (NMOG) which is a better descriptor for E85 emissions.
3. If E85 fuel specifications are known for the tests used in this report, then these can be used to improve the estimates of the ranges in the table.

4.4 References

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5 Mopeds: Emissions update

The goal of this short chapter was the development of a mopeds emissions database for regulated and unregulated pollutants based on published reports on the internet. Euro 1 and Euro 2 CO and HC emissions do not present significant differences with the given COPERT emission factor in contrast with the NOx emissions. In addition, a comparison of Euro 2 two-stroke and four-strokes mopeds is presented.

5.1 Introduction

Mopeds (or scooters) are small two wheel vehicles with a maximum capacity of 50 cc that are used for road transport. Despite the small size of their engine, they can emit significant levels of air pollutants as a result of their primitive emission control systems. Moreover, a significant number of vehicles are still powered by 2-stroke engines. Such engines are known of being high hydrocarbon emitters as the result of scavenging losses and direct in-cylinder lube oil addition. As a result, two-stroke and four-stroke vehicles may have different performance, despite fulfilling the same emission limits. In COPERT 4 v10.0, separate emission factors have been introduced for these two vehicle configurations while the database was based on literature data and some (Italian) unpublished values.

5.2 Data collection

A short description of the database built based on available measurements [1-24] is conducted in this section. Most of the vehicles had displacement of 50 cc except two vehicles with a displacement of 100 cc (Kymco Easy 1000 M, Yamaha Jog XC 100 [1]).

Both two-stroke and four-stroke vehicles have been included in the database, with maximum power up to 4 kW, and air or water cooling system. The mixture preparation and emission control system varied. The fuel systems varied from electronic fuel injection, carburettor (both mechanical and electronically controlled), low pressure direct injection, air supported direct injection, direct injection with auto oil pump, carburettor with auto oil pump. The exhaust system consisted either of 3-way catalysts, oxidation catalyst, oxidation catalyst with secondary air system, or even no catalyst at all.

The vehicles satisfied up to Euro 3 emission standards and were tested under one of the following driving cycles or steady state tests: ECE40, ECE47, WMTC, WMTC v7, WMTV v11, Artemis Urban, ZUS 98, NEDC, 30 km/h, and 40 km/h. In fact, Euro 3 mopeds are not ‘officially’ available as the result of the fact that Euro 3 moped emission standards have not been regulated yet (2012). However, preparatory discussions in the framework of the MCWG have already suggested that the Euro 3 testing procedure will be similar to Euro 2 (ECE47) with a cold start and a weighing factor of 30% for cold-start emissions. Hence, the two vehicles included as Euro 3 in this database were specifically designed to demonstrate the capabilities of advanced emission control in such small vehicles [6]. Therefore, they should not be necessarily considered as representative of the upcoming Euro 3 regulation.

Information about the population number of vehicles and individual measurements included in the database per emission standard and combustion system are shown in Table 39. No details on the vehicles specifications are given in some studies. These are included in the database for reference but have not been included when calculating average values.

5.3 Results

5.3.1 All mopeds results

COPERT 4 included an averaged emission factor for moped, independent of the combustion system (2S or 4S). This emission factor was derived from a very limited number of measurements (~10). In this section we compare how this averaged emission factor of COPERT compares to the mean emission rate of the vehicles in the current database (Table 40-Table 42, Figure 29-Figure 31). The tables present results over the hot ECE 47 test, the cold ECE47 test (where available) and all tests, as separate columns. These are compared to COPERT 4 v9.0 emission factors.

Table 39: Number of vehicles and individual measurements in the database.

-	Euro – Conv.	Euro 1	Euro 2	Euro 3*	Unknown/not specified
2-S mopeds	13	19	17	2	7
2-S measurements	26	33	59	6	18
4-S mopeds	0	2	10	0	0
4-S measurements	0	4	15	0	0

* Demo vehicles only

Table 40: Average CO values of mopeds in the database (corresp. Figure Figure **29**) [g/km].

	ECE 47 (hot)	ECE 47 (cold)	All driving cycles	COPERT
Conventional	18.1	-	14.7	13.8
Euro 1	5.5	3.8	4.9	5.6
Euro 2	1.8	2.5	3.1	1.3
Euro 3	2.3	0.72	0.64	1.0

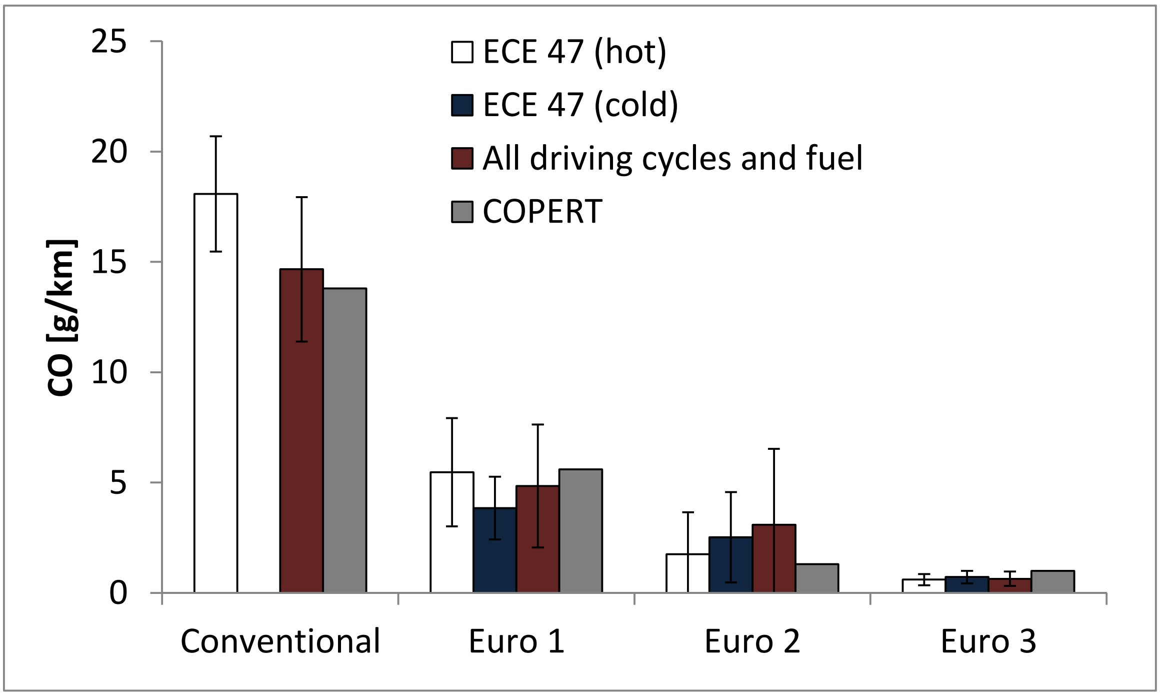

Figure 29: CO emission rate per emission standard and COPERT emission factor.

In general, COPERT 4 emission reductions have been consistent with the values in the database, in terms of CO. However, it seems that the reductions assumed at Euro 2 level are not achievable in reality, especially when cold-start cycles are included in the database. On the other hand, reductions at Euro 3 level are higher than what assumed in COPERT, but it is again repeated that the two vehicles included in the database at Euro 3 level should be considered as demonstration vehicles only and not necessarily representative of the expected fleet average emission level at Euro 3.

Table 41: Average HC values of mopeds in the database (corresp. Figure Figure **30**) [g/km].

	ECE 47 (hot)	**ECE 47 (cold)**	**All driving cycles**	**COPERT**
Conventional	8.6	-	8.4	13.91
Euro 1	2.0	5.0	2.9	2.73
Euro 2	1.0	1.3	2.3	1.56
Euro 3	0.10	0.56	0.42	1.20

In terms of HC, COPERT included a higher emission factor than the emission rate of conventional vehicles in the database. Still HC emission factors are very substantial from this vehicle type. Emissions decrease for subsequent emission levels and COPERT and database values are rather consistent. In terms of Euro 3 and similar to CO, the emission rates from the demonstration vehicles included in the database appear quite low.

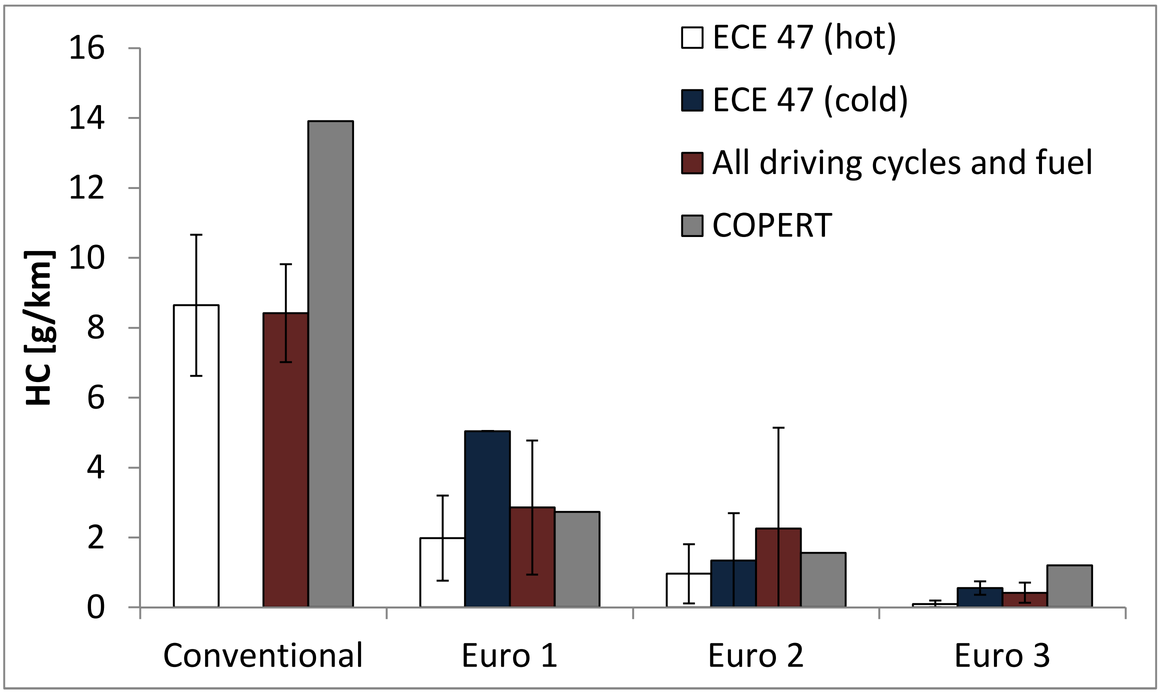

Figure 30: HC emission rate per emission standard and COPERT emission factor.

Table 42: Average NO$_x$ values of mopeds in the database (corresp. Figure Figure **31**) [g/km].

NO$_x$	**ECE 47 (hot)**	**ECE 47 (cold)**	**All driving cycles**	**COPERT**
Conventional	-	-	0.06	0.02
Euro 1	0.18	0.04	0.19	0.02
Euro 2	0.18	0.16	0.17	0.26
Euro 3	0.09	0.13	0.11	0.26

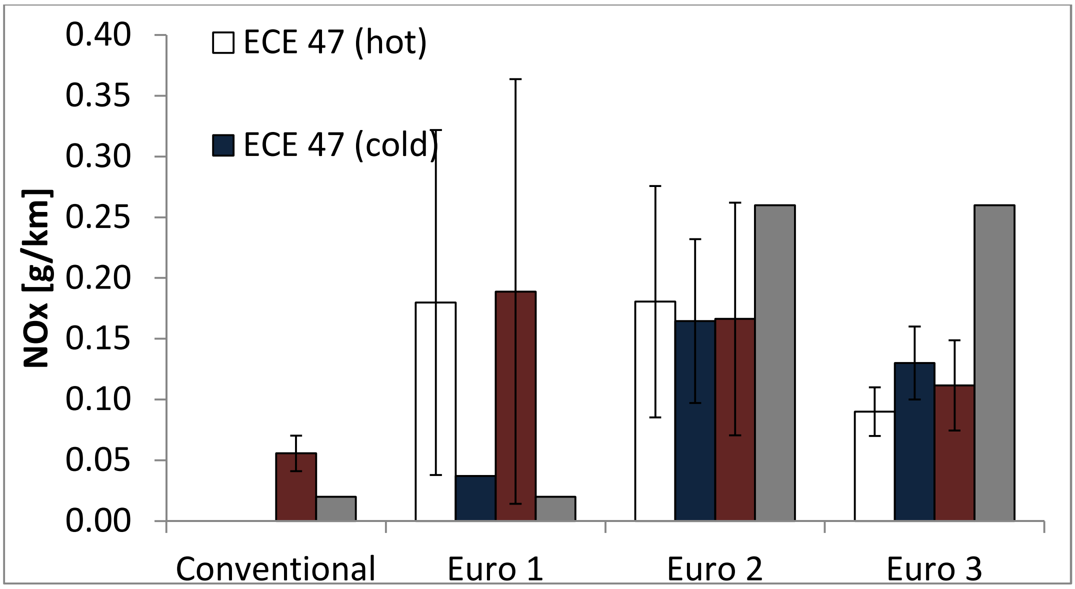

Figure 31: NO$_x$ emission rate per emission standard and COPERT emission factor.

NO_x emission measurements in the database show the increase from conventional vehicles to Euro standards. This has been the result of a shift from rich mixtures at a conventional level to leaner mixtures as the technology gradually improves. This has been in general consistent with what COPERT emission factors also predicted but the absolute levels between the database average rates and the COPERT levels differ. In this case, similar to the other pollutants, Euro 3 levels should be seen as a potential rather as a representative for the average of this vehicle technology.

5.3.2 Two-stroke, four-stroke comparison

In this chapter a comparison between two-stroke and four-stroke mopeds is presented (Figure 32-Figure 34) per emission standard. Differences in the emission performance are to be expected between the two combustion types, especially in off-cycle driving conditions. Unfortunately, there are several data missing in the database for four-stroke vehicles so a clear picture of the comparison cannot be obtained. However, it is clear that the emission levels in terms of HC are much higher for two stroke than four stroke vehicles, as it would be expected taking into account the scavenging losses of this combustion concept. No clear differences can be seen for other pollutants, especially given the high variability of the emission levels.

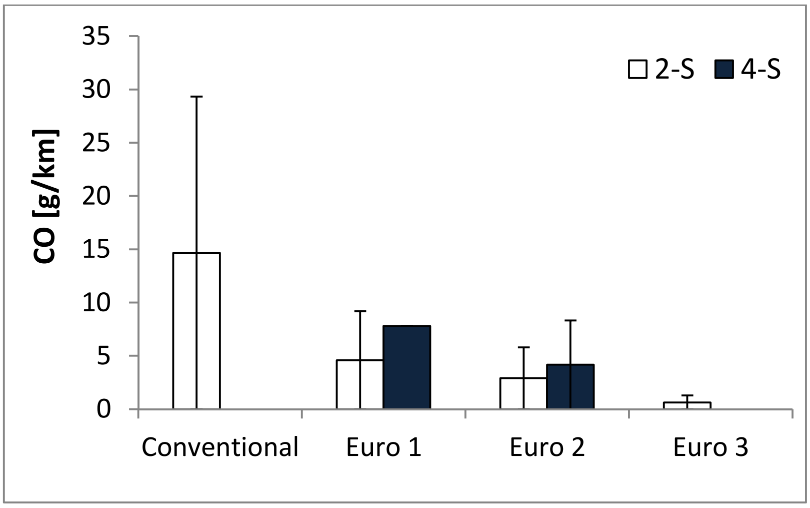

Figure 32: Comparison of CO emissions between two-stroke and four-stroke engines.

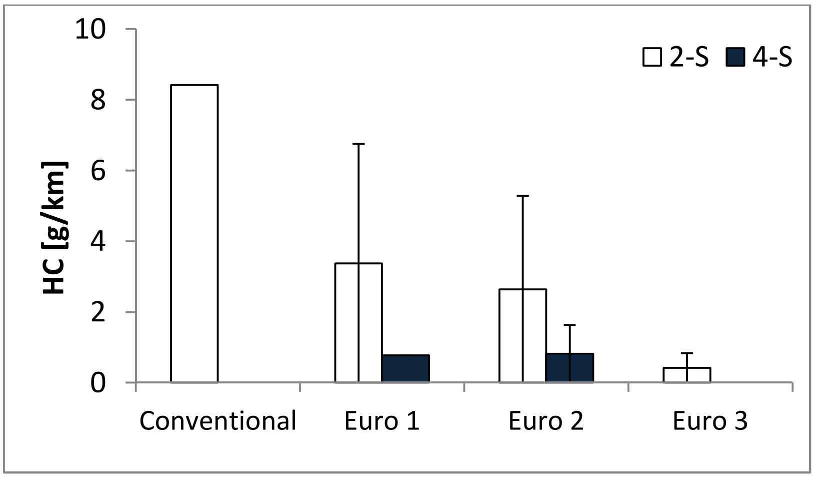

Figure 33: Comparison of HC emissions between two-stroke and four-stroke engines.

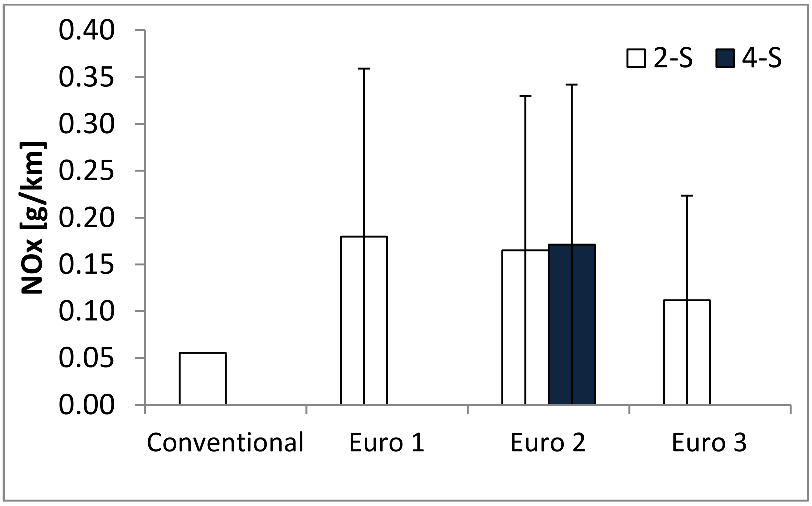

Figure 34: Comparison of NO_x emissions between two-stroke and four-stroke engines.

5.4 Proposed Values

Despite that a database has been compiled in this activity with moped emission measurements, there continues generally to be a limited number of available emission measurements for mopeds. Also measurements in the literature are conducted over a limited number of driving cycles and conditions (basically the type-approval ECE47 driving cycle), which means that understanding of emissions is limited to a narrow range of driving situations. This does not allow a significant analysis of emission factors in terms of speed effect or the effect of cold start. Therefore, in this report we have lumped all measurements together (transient, steady-state, cold-start and warm-start) on a single emission factor. We name such emission factors as 'bulk' ones in COPERT to designate that they correspond to averaged driving conditions. Of course, when developing such emission factors one always recognizes the need to develop better emission factors once new measurements become available.

Given these limitations of the current analysis, Table 43 presents the average emission levels per combustion concept (2S and 4S) that result from the database compiled. Where dashes appear, this means that no data are available.

Table 43: Proposed emission factors for two stroke and four stroke mopeds [g/km].

	Two stroke mopeds				**Four stroke mopeds**			
	CO	**HC**	**NOx**	**PM**	**CO**	**HC**	**NOx**	**PM**
Conventional	14.7	8.4	0.06	0.176	-	-	-	-
Euro 1	4.6	3.4	0.18	0.045	6.7	0.78	0.22	0.040
Euro 2	2.8	2.6	0.17	0.026	4.2	0.79	0.17	0.007
Euro 3	0.64	0.42	0.11	0.018	-	-	-	-

The following remarks can be made on the basis of this table:

1. The two stroke vehicle sample for Conventional, Euro 1, and Euro 2 vehicles is quite satisfactory in terms of number of measurements, so these values can be safely used as emission factors for the corresponding vehicle categories.

2. The Euro 3 motorcycles emission rates originate from a study [6] that wishes to show the potential for improvement, using state-of-the-art emission control systems. It is therefore not safe to assume that all Euro 3 mopeds will be able to perform as satisfactory as these demonstration vehicles. Instead of using these values, we suggest to use fabricated emission factors derived from the Euro 2 ones and the expected changes in the emission standards that will come into force with the new regulations. According to that, it is expected that the Euro 3 emission standards will have the same emission limit with Euro 2 but with the addition of a cold-start type approval procedure and a 30% weighing factor for the cold start part. In order to find the expected reduction of the Euro 3 emission factor (which includes a cold-start part), over the Euro 2 (which only refers to hot conditions), we estimated a Euro 2 equivalent emission standard. This hypothetical emission standard ($ES_{Euro2Cold}$) corresponds to the equivalent Euro 2 emission standard, in case the Euro 2 type approval was given on the basis of the Euro 3 cycle (cold start). Therefore, the Euro 3 emission factor would be calculated as:

$$EF_{Euro3} = EF_{Euro2} \cdot \frac{ES_{Euro3}}{ES_{Euro2Cold}}$$

The hypothetical cold Euro 2 emission standard was calculated according to:

$$ES_{Euro2Cold} = ES_{Euro2} \cdot \left[(1-WF) + WF \cdot \left(\frac{Cold}{Hot} \right)_{Euro2} \right]$$

Where, WF is the weighting factor for the cold part of the cycle (30%), and *Cold/Hot* is the assumed contribution of cold start emissions for Euro 2 mopeds. Since the Euro 2 and Euro 3 emission limits are numerical identical, the two last equations reduce the following one:

$$RF = \frac{1}{\left[(1-WF) + WF \cdot \left(\frac{Cold}{Hot} \right)_{Euro2} \right]}$$

RF stands for the reduction factor of Euro 2 over Euro2, i.e. Euro 3 = Euro 2* RF. In determining the Cold/Hot ratio, Table 44 shows data collected from 2-Stroke Euro 2 mopeds available in the database. For calculating the average ratio (last row on the table), we have excluded the last vehicle in the table which is a clear outlier.

Table 44: Calculation of reduction factors for estimating Euro 3 emission levels.

Source	**Cold**			**Hot**			**Ratio**		
(Reference)	**CO**	**HC**	**NOx**	**CO**	**HC**	**NOx**	**CO**	**HC**	**NOx**
[18]	2.3	1.9	0.35	0.60	1.15	0.39	3.9	1.6	0.9
[17]	1.0	0.9	0.17	0.41	0.54	0.125	2.5	1.7	0.9
[3]	1.8	5.5	0.05	0.88	1.05	0.056	2.0	5.3	0.9
[3]	1.9	1.3	0.16	0.60	0.70	0.20	3.2	1.8	0.8
[3]	0.9	2	0.075	0.15	0.10	0.092	*6.0*	*20.0*	0.8
Average (excl. outlier)							2.9	2.6	0.9

RF	**0.64**	**0.68**	**1.04**

The reduction factor for NOx appears more than 1, which means that Euro 3 emission factors should appear higher than Euro 2. This is an artifact of the method used, because cold start levels are higher than Euro 2 levels. We do not expect this to be occurring in reality so we assume that Euro 2 and Euro 3 levels will be identical.

3. The database for four-stroke vehicles is generally quite small, even for Euro 1 and Euro 2 vehicles (no measurements for conventional vehicles). Despite the small size, results are rather consistent with what one would expect in terms of the impact of emission limit to the emission values and with respect to the impact of combustion system (2S or 4S) to the emission rate. Hence, it is considered safe to retain these values as emission factors as well.

4. For the missing values of Euro 4 vehicles, one will have to device appropriate emission rates. We therefore use the 2-stroke ratios Euro 2 over Euro 3 also on 4-stroke ones. This is because we expect the introduction of cold-start to have the same impact on both combustion technologies. For conventional 4-stroke, we suggest using the same emission factors as Euro 2 ones. Although this is a rather abstract assumption, the relevance of four stroke conventional vehicles has always been too small. This is because the conventional vehicle technology was dominated by 2-stroke vehicles. Therefore, even making some error in appreciating the exact 4-stroke conventional emission factors is of little relevance to the final calculation. Also, the approach utilized for hydrocarbons has also been adopted for PM as PM basically is formed due to the condensation of hydrocarbons for such vehicle types.

5. Based on these considerations and assumptions, the final proposed emission factors for inclusion in COPERT are given in Table 45.

Table 45: Final proposed moped emission factors [g/km] for inclusion in COPERT 4 v10.0

	Two stroke mopeds				**Four stroke mopeds**			
	CO	**HC**	**NOx**	**PM**	**CO**	**HC**	**NOx**	**PM**
Conv.	14.7	8.4	0.056	0.176	14.7	8.4	0.056	0.176
Euro 1	4.6	3.4	0.18	0.045	6.7	0.78	0.22	0.040
Euro 2	2.8	2.6	0.17	0.026	4.2	0.79	0.17	0.007
Euro 3	1.8	1.8	0.17	0.018	2.7	0.54	0.17	0.004

6. In terms of fuel consumption, there is some limited information in the database collected. Based on that, a value of 25 g/km is proposed for conventional vehicles dropping to 20 g/km for all Euro stages, due to the better utilization of the fuel. No distinction is possible between two stroke and four stroke vehicles.

5.5 ANNEX

Reference number	Vehicle	Emissions standard	Start conditions
[1]	Kymco Easy 100 M (SG20AB)	Euro 2	Cold
	Yamaha Jog 50 (CE50)	Euro 2	Cold
	Yamaha Jog XC 100	Taiwan Reg.	Cold
[2]	Gillera Runner	Euro 2	Hot
	Piaggio Typhoon	Euro 2	Hot
[3]	2-stroke CA	Euro 2	Cold
	2-stroke CA	Euro 2	Hot
	2-stroke CA	Euro 2	Cold
	2-stroke CA	Euro 2	Hot
	2-stroke DI	Euro 2	Cold
	2-stroke DI	Euro 2	Hot
	2-stroke DI	Euro 2	Cold
	2-stroke DI	Euro 2	Hot
	2-stroke CAecl	Euro 2	Cold
	2-stroke CAecl	Euro 2	Hot
	2-stroke CAecl	Euro 2	Cold
	2-stroke CAecl	Euro 2	Hot
[4]	Peugeot Looxor TSDI	Euro 2	Hot
	Peugeot Looxor TSDI	Euro 2	Hot
	Peugeot Looxor Carb	Euro 2	Hot
	Peugeot Looxor Carb	Euro 2	Hot
[5], [19]	M1	Euro 0	Hot
	M2	Euro 0	Hot
	M3	Euro 0	Hot
	M4	Euro 0	Hot
	M5	Euro 1	Hot
	M6	Euro 1	Hot
	M7	Euro 1	Hot
	M8	Euro 1	Hot
	M9	Euro 2	Hot
	M10	Euro 2	Hot
[6]	4-stroke EFI	Euro 2	Hot
	4-stroke carburettor	Euro 2	Hot
	2-stroke LPDI	Demo Euro 3	Hot
	2-stroke carburettor	Demo Euro 3	Hot
	2-stroke ASDI	Euro 2	Hot
	4-stroke EFI	Euro 2	Cold
	4-stroke carburettor	Euro 2	Cold
	2-stroke LPDI	Euro 3	Cold
	2-stroke carburettor	Euro 3	Cold
	2-stroke ASDI	Euro 2	Cold
[7], [8]	BK08	Euro 1	Hot
	BK08	Euro 1	Cold
	BK08	Euro 1	Cold
	BK11	Euro 1	Hot
	BK11	Euro 1	Cold
	BK11	Euro 1	Cold
[10]	A	-	unknown
[11]	Moped 30	-	Hot
[12]	Vehicle 1	-	-
	Vehicle 2	-	-
[13]	Bench Engine	-	Hot
[14], [15]	Peugeot Looxor TSDI	Euro 2	-
[16]	Peugeot Looxor TSDI	Euro 2	Cold
	Yamaha EW50 Slider	Euro 1	Cold
	Piaggio Vespa ET4	Euro 2	Cold

[17]	Peugeot Looxor TSDI	Euro 2	Cold
	Peugeot Looxor TSDI	Euro 2	Hot
[18]	Euro 1 moped	Euro 1	Cold
	Euro 1 moped	Euro 1	Hot
	Euro 2 moped	Euro 2	Cold
	Euro 2 moped	Euro 2	Hot
[20]	Piaggio Typhoon	Euro 2	Hot
	Piaggio Typhoon	Euro 2	Hot
	Kreidler Florett RS K54/511	Euro 0	Hot
	Honda Zoomer NPS 50	Euro 2	Hot
[21]	Carburettor two-stroke moped	-	-
	Direct injection 2S moped	-	-
[22]	2S Pre 97/24	Euro 0	Hot
	2S 97/24 Stage 1	Euro 1	Hot
	2S 97/24 Stage 2	Euro 2	Hot
	4S 97/24 Stage 1	Euro 1	Hot
	4S 97/24 Stage 2	Euro 2	Hot
[23]	AirAssInj 50 ccm Scooter	Euro 1	Cold
	AirAssInj 50 ccm Scooter	Euro 2	Cold
	Liquid cooled carb, lean burn	Euro 1	Cold
	Liquid cooled carb, lean burn	Euro 2	Cold
	Liquid cooled carburated	Euro 1	Cold
	Liquid cooled carburated	Euro 2	Cold
[24]	Yamaha EW50 Slider	Euro 1	Cold
Unpublished results from ANPA, IM_CNR, LABECO, ANCMA, SSC, TNO, ENEA	ANPA moped	Euro 0	Hot
	IM_CNR moped	Euro 0	
	LABECO moped	Euro 0	
	ANCMA moped	Euro 0	
	SSC moped	Euro 0	
	ANPA moped	Euro 1	
	IM_CNR moped	Euro 1	
	LABECO moped	Euro 1	
	ANCMA moped	Euro 1	
	SSC moped	Euro 1	
	ANPA moped	Euro 2	
	IM_CNR moped	Euro 2	
	LABECO moped	Euro 2	
	ANCMA moped	Euro 2	
	SSC moped	Euro 2	
	TNO moped	Euro 0	
	ENEA moped	Euro 0	
	ENEA moped	Euro 1	
JRC Database used in the WMTC/ECE47 equivalence work	W62-C1-49	Euro 2	-

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23. Winkler F., et al., *Strategies to reduce scavenge losses of small capacity 2-stroke engines pressurized by the common market cost.* SAE Technical Paper 2005-32-0098, 2005.

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6 Gasoline PCs: Methane update

Current COPERT version includes the same Euro 4 methane emission factor for Euro 5 and Euro 6. Studies report that gasoline Euro 5 PCs may have decreased cold CH4 emissions compared to Euro 4 vehicles.

Hot methane emissions also differ; COPERT deems that there are no CH4 highway hot emissions while some studies show that highway methane emissions are in fact higher than urban and rural emissions.

The Biogasmax study includes two Euro 4 vehicles and one Euro 5 vehicle which can run either on CNG or gasoline.

6.1 CH_4 cold emissions comparison

In order to carry out a comparison between current COPERT methane cold emission factor and the ones from the study, the UDC cycle results were chosen to depict the cold phase performance.

According to the proposed methodology, three steps were followed:

- The bulk cold HC emission factor was calculated by using COPERT on the Germany 2010 database with an urban speed of 25km/h.
- The UDC CH_4/HCs ratio was calculated
- Then, the CH_4 corrected cold emission factor was set as the product of these parameters:

$$CH_{4,corrected}\Big|_{COLD} = Ratio\left(\frac{CH_4}{HC}\right)\Big|_{UDC} \cdot HC_{bulk,COPERT}\Big|_{COLD} \quad \text{(g/km)}$$

This ratio was then compared to the COPERT cold CH_4/HCs ratio:

$$\frac{E^{CH_4}_{COLD}}{E^{HC}_{COLD}} = \frac{e^{CH_4}_{COLD}}{b_c \cdot \left(\dfrac{e^{HC}_{COLD}}{e^{HC}_{HOT}} - 1\right) \cdot e^{HC}_{HOT} + b_c \cdot \beta \cdot e^{HC}_{HOT}}$$

The extra parameter is used to compensate the different methodology used to calculate CH_4 cold emissions compared to HC emissions. The results can be seen in the following tables:

Table 46: Cold CH4/HCs ratios based on the study and different vehicle samples

Report	Ratio(CH4 /HCs) %
Euro 4	21.4
Euro 5	9.8
Euro 4/5	14.1

Table 47: Cold CH4/HCs ratios based on COPERT (different subsectors)

COPERT	Ratio(CH4 /HCs) %
G<1.4	19.48
G1.4 -2l	15.67
G>2l	21.01

Table 48: Final results in g/km - Bulk cold HC emission factor was calculated by using Germany 2010 database with an urban speed of 25 km/h.

	HCs	**CH_4 based on COPERT**	**CH_4 based on Euro 4**	**CH_4 based on Euro 5**	**CH_4 based on Euro 4/5**
G<1.4	0.292	0.057	0.029	0.062	0.041
G1.4 -2l	0.363	0.057	0.035	0.078	0.051
G>2l	0.271	0.057	0.026	0.058	0.038

It is evident that the ratio of methane vs. HCs for cold emissions is similar to the existing COPERT values (~20%). Lower values are reported for Euro 5 vehicles, but the database is very limited to validate this trend. Consequently, the cold emission factor for methane will remain the same.

6.2 CH_4 hot emissions comparison

The CADC cycle was chosen for the hot emissions estimation (real-world conditions), while the previous approach was used for the calculation of hot CH_4 emissions:

$$CH_{4,corrected}\Big|_{HOT} = Ratio\left(\frac{CH_4}{HC}\right)\Bigg|_{HOT} \cdot HC_{bulk,COPERT}\Big|_{HOT} \quad \text{(g/km)}$$

This calculation is applied for urban, rural and highway emissions. Note that hot HC emissions use the same factor for all gasoline PCs in the current version of COPERT.

Table 49: Ratio (CH4/HCs)% depending on the database used in the study

Report	**Urban Ratio(CH_4 /HCs) %**	**Rural Ratio(CH4 /HCs) %**	**HW Ratio(CH4 /HCs) %**
Euro 4	25.0	25.0	33.3
Euro 5	0.0	0.0	20.0
Euro 4/5	25.0	25.0	20.0

Table 50: Final results for CH4 (g/km)

	HCs	**CH_4 based on COPERT**	**CH_4 based on Euro 4**	**CH_4 based on Euro 5**	**CH_4 based on Euro 4/5 (Biogasmax)**
Urban	0.01149	0.00196	0.00287	0.00000	**0.00287**
Rural	0.01344	0.00200	0.00448	0.00269	**0.00269**
Highway	0.01830	0.00000	0.00511	0.00457	**0.00508**

Comparing the current methane values in COPERT and the ones proposed by the combined Euro 4/5 sample vehicle database, it can be seen that the urban and rural emission values are increased by as much as 45%, while highway methane emissions are almost double than rural ones, instead of the assumed zero highway emissions.

6.3 Final Proposed Values

Based on the previous analysis Gasoline methane hot emissions will be updated as shown in the table below.

Table 51: Proposed values CH4 (g/km)

	CH_4 (urban)	**CH_4 (rural)**	**CH_4 (hw)**
COPERT v.9.0	0.00196	0.00200	0.00000
Proposed Euro 4/5/6 for COPERT v.10.0	**0.00287**	**0.00269**	**0.00508**

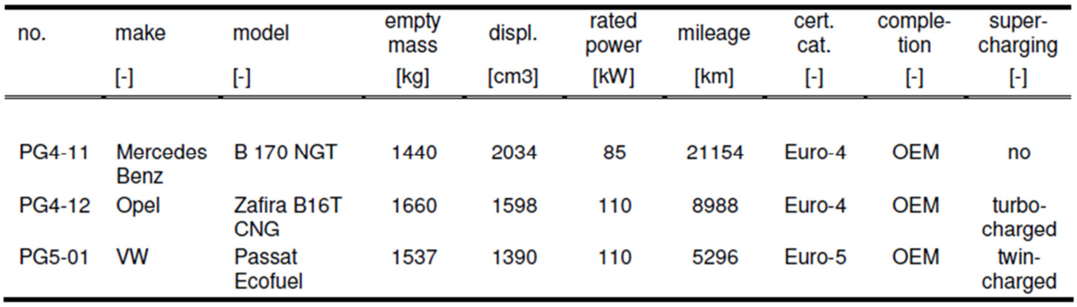
6.4 References

Christian Bach, Robert Alvarez and Dr. Alexander Winkler (2010), Exhaust gas aftertreatment and emissions of natural gas and biomethane driven vehicles, BIOGASMAX - Integrated Project

Efthimios Zervas and Eleni Panousi (2010), Exhaust Methane Emissions from Passenger Cars, SAE International

6.5 ANNEX

Table 52: Sample vehicle main characteristics



no.	make [-]	model [-]	empty mass [kg]	displ. [cm3]	rated power [kW]	mileage [km]	cert. cat. [-]	comple-tion [-]	super-charging [-]
PG4-11	Mercedes Benz	B 170 NGT	1440	2034	85	21154	Euro-4	OEM	no
PG4-12	Opel	Zafira B16T CNG	1660	1598	110	8988	Euro-4	OEM	turbo-charged
PG5-01	VW	Passat Ecofuel	1537	1390	110	5296	Euro-5	OEM	twin-charged

7 PCs: CNG subsector

Methane vehicles (Compressed Natural Gas – CNG) represent a mature technology which leads to the reduction of the emissions of NOx and PM as well as a moderate reduction in CO_2, compared to their gasoline counterparts Natural gas can be blended with bio-methane, generated from biomass, leading to a further reduction of CO2 emissions.

COPERT current version includes CNG busses, but no CNG passenger cars. This report will add a CNG medium passenger car.

The combustion process as well as the engine out emissions in natural gas operation are similar to those of gasoline operation (similar exhaust aftertreatment technology). For retrofitted natural gas vehicles (NGVs) and 1st generation of OEM NGVs, exhaust emissions were often significantly higher in natural gas operation compared to gasoline (imperfections in mixture preparation). Modern OEM-NGVs show similar emissions with gasoline vehicles with respect to conversion and durability.

Due to the huge difference between OEM NGV / non-OEM converted ones, NO_x, CO, PM emission factors remain identical to gasoline ones, until the situation clarifies.

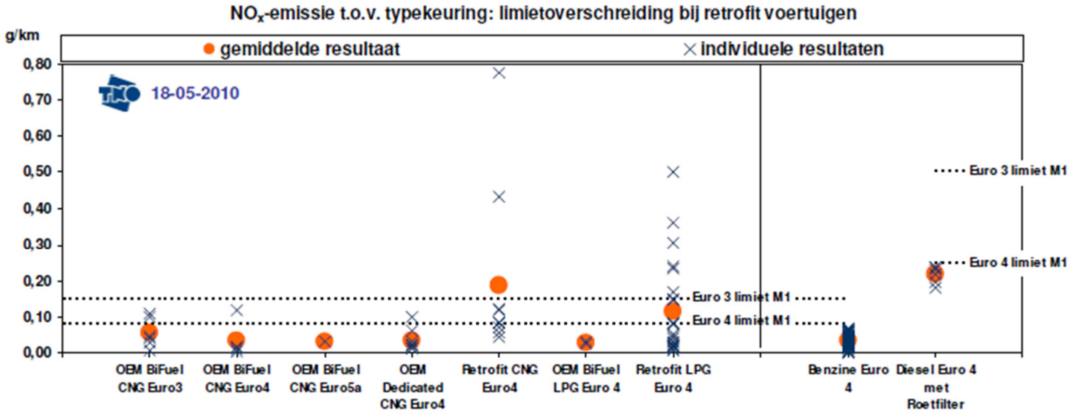


Figure 35: Evidence from TNO work on CNG/LPG [W.A. Vonk, R.P. Verbeek, H.J. Dekker (2010), Emissieprestaties van jonge Nederlandse personenwagens met LPG en CNG installaties, TNO-rapport, MON-RPT-2010-01330a]

This new subsector aims at estimating an average CNG medium passenger car, which would be a compromise between a retrofitted and an OEM vehicle.

7.1 Emissions

In order to develop a CNG PC model, emphasis was placed on fuel consumption (FC), CO_2, HC and CH_4 emissions. FC estimation will be based on a reduction factor applied upon the gasoline fuel consumption factor (difference in enthalpy of combustion). As a result, tailpipe CO2 estimation is then computed using the calculated FC. Apart from FC, HC and CH_4 calculation was considered important for the characterisation of CNG cars, for which consistent differences may be seen.

HC calculation is computed by correcting PCG emission factors based on experimental evidence, while CH_4 bulk emissions have been calculated based on experimental evidence.

The following figures present CNG vs. gasoline fuel performance in NEDC and CADC cycle runs.

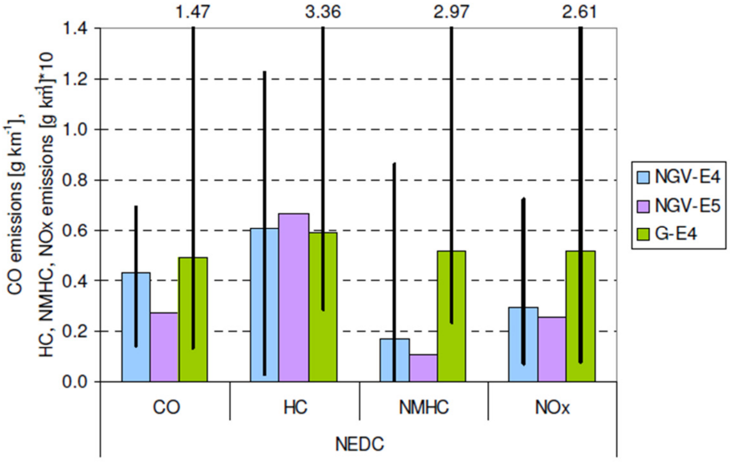


Figure 36: CNG vs. gasoline comparison in NEDC [Source: Christian Bach, Robert Alvarez and Dr. Alexander Winkler (2010), Exhaust gas aftertreatment and emissions of natural gas and biomethane driven vehicles, BIOGASMAX - Integrated Project]

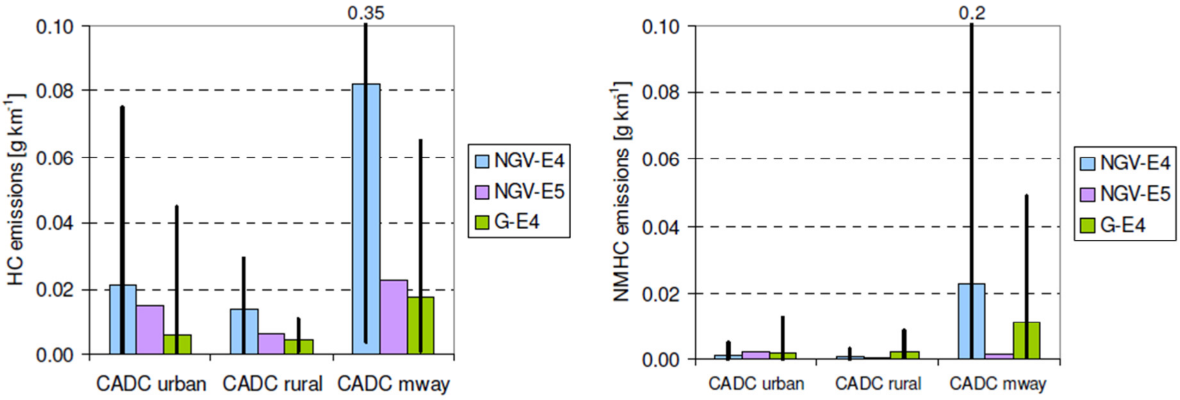


Figure 37: CNG vs. gasoline comparison in CADC [Source: Christian Bach, Robert Alvarez and Dr. Alexander Winkler (2010), Exhaust gas aftertreatment and emissions of natural gas and biomethane driven vehicles, BIOGASMAX - Integrated Project]

7.1.1 Fuel Consumption and CO_2

Fuel consumption is estimated on the assumption that average engine efficiency (if both retrofitted and OEM NGVs are considered) is similar to gasoline passenger cars. Neat gasoline has an energy density of approximately 43.8 MJ/tn compared to approximately 48 MJ/tn for natural gas. This yields a reduction factor:

RF=0.043774/0.048=0.088

Therefore CNG PCs are estimated to consume 8.8% less than gasoline PCs in terms of mass, which is less optimistic than the typically 20-25% advertised gain for OEM NGVs.

CO_2 calculation is then straightforward.

7.1.2 Hydrocarbons

HC emission calculation will be based on the HC emission for medium-sized gasoline (G1.4-2.0l) cars. The ratio of HC emissions between a CNG PC and a gasoline equivalent based on UDC measurements is calculated. This process is separately followed for cold emissions as well as hot emissions. HCs are then computed as the product of this ratio and the HC emissions of a gasoline car.

Hot emissions

The following equation is used:

$$HC\Big|_{CNG,HOT|COPERT} = \left(\frac{HC\big|_{CNG}}{HC\big|_{Gasoline}}\right)\Bigg|_{CADC} \cdot HC\Big|_{Gasoline,HOT|COPERT}$$

$$HC\Big|_{CNG,HOT|COPERT} = Ratio \cdot HC\Big|_{Gasoline,HOT|COPERT} \qquad \text{(g/km)}$$

The resulting modifying ratios are shown below:

Table 53: Proposed modifier for CNG over gasoline HC calculation. Bulk HC EF was calculated using Germany 2010 database.

CADC	HCs (CNG) (g/km)	HCs (gasoline) (g/km)	Ratio
Urban	0.021	0.004	5.25
Rural	0.013	0.005	2.60
Highway	0.078	0.018	4.33
Average			**4.06**

The average ratio is chosen for all hot HC emissions. Therefore, CNG hot HC emissions use the gasoline formula multiplied by the 4.06 modifier, in other words this ratio is used as a reduction factor (1-RF) over hot gasoline emissions (RF=-3.06).

Cold emissions

In a similar manner the cold emissions are:

$$HC\Big|_{CNG,COLD|COPERT} = \left(\frac{HC\big|_{CNG}}{HC\big|_{Gasoline}}\right)\Bigg|_{UDC} \cdot HC\Big|_{Gasoline,COLD|COPERT},$$

$$HC\Big|_{CNG,COLD|COPERT} = Ratio \cdot HC\Big|_{Gasoline,COLD|COPERT} \qquad \text{(g/km)}$$

Table 54: Proposed modifier for CNG over gasoline HC calculation. Bulk cold HC EF was calculated using Germany 2010 database with an urban speed of 25km/h.

UDC	HCs (gasoline)	HCs (CNG)	Ratio
CNG medium	0.192	0.145	**0.755**

Therefore, CNG cold HC emissions use the gasoline formula multiplied by the R=0.755 modifier, i.e. the cold/hot HC emission quotient of CNG will be:

$$\frac{e^{COLD}}{e^{HOT}}\bigg|_{CNG} = \left(\frac{e^{COLD}}{e^{HOT}}\bigg|_{Gasoline} \cdot -1\right) \cdot Ratio(cold) + 1 = \left(\frac{e^{COLD}}{e^{HOT}}\bigg|_{Gasoline} \cdot -1\right) \cdot 0.755 + 1$$

As a result, the CNG subsector (Euro 4-6) will use the same calculation process for cold HCs as gasoline vehicles of the same technology, i.e. based on gasoline Euro 1 vehicles, the only difference being the updated over-emission ratios e_{COLD} / e_{HOT} . The emission reduction during the warm-up phase of post-Euro 1 is used in the same manner as gasoline vehicles. The new values for the A, B, C coefficients can be seen below ($e_{COLD}/e_{HOT} = A \times V + B \times ta + C$).

Table 55: CNG A,B, C coefficients for the calculation of the over-emission ratio.

Speed range	A	B	C
1	0.118568	-0.15633	5.538047
2	0.212969	-0.25526	3.339635
3	0.035948	-0.36023	10.39479

7.1.3 CH_4

CH4 emission calculation will be based on the previously calculated CNG HC emissions (which is based on G1.4-2l cars). The ratio of CNG CH4/HC emissions using the UDC measurements of the study is calculated. This process is followed for cold emissions as well as hot emissions in urban, rural and highway conditions. CH4 are then computed as the product of this ratio and the previously calculated CNG HC emissions.

Cold emissions

The formula used to compute the cold emissions is

$$CH_4\Big|_{CNG,COLD|COPERT} = \left(\frac{CH_4|_{CNG}}{HC|_{CNG}} \right)\Bigg\|_{UDC} \cdot HC\Big|_{CNG,COLD|COPERT} \quad \text{(g/km)}$$

$$CH_4\Big|_{CNG,COLD|COPERT} = Ratio \cdot HC\Big|_{CNG,COLD|COPERT} \quad \text{(g/km)}$$

Table 56: CNG cold emission factor ratio for methane. Bulk cold HC EF was calculated using Germany 2010 database with an urban speed of 25km/h.

UDC	CH4 (CNG)	HCs (CNG)	Ratio
CNG medium	0.090	0.145	**0.620**

Using this equation the resulting ratio and corresponding CH4 emission factor is shown in Table 56. Then cold methane emissions are calculated based on the cold HC emissions (see the previous section).

Hot emissions

Similarly, hot emissions are calculated with a similar formula:

$$CH_4\Big|_{CNG,HOT|COPERT} = \left(\frac{CH_4\big|_{CNG}}{HC\big|_{CNG}}\right)\Bigg|_{UDC} \cdot HC\Big|_{CNG,HOT|COPERT} \quad \text{(g/km)}$$

$$CH_4\Big|_{CNG,HOT|COPERT} = Ratio \cdot HC\Big|_{CNG,HOT|COPERT} \quad \text{(g/km)}$$

Table 57: Methane hot emissions. Bulk HC EF was calculated using Germany 2010 database

CADC	CH4 (CNG) (g/km)	HCs (CNG) (g/km)	Ratio	CH4 (proposed) (g/km)
Urban	0.020	0.021	0.952	**0.05730**
Rural	0.012	0.013	0.923	**0.02773**
Highway	0.057	0.078	0.730	**0.04339**

Using these ratios and the minimum calculated HC bulk hot emissions (using Germany 2010 database) will yield the hot CH_4 emissions for CNG passenger cars for each share (urban, rural, highway) as shown on Table 57. These minimum values are chosen in order to avoid higher CH_4 than HCs hot emission calculations due to the different approach used.

7.1.4 Notes

It can be observed that CNG HC emissions are lower than gasoline for cold start and higher in the hot state, while CH_4 emissions dominate HC emissions for all types of hot emissions and most of the cold start as well.

7.1.5 References

Christian Bach, Robert Alvarez and Dr. Alexander Winkler (2010), Exhaust gas aftertreatment and emissions of natural gas and biomethane driven vehicles, BIOGASMAX - Integrated Project

Efthimios Zervas and Eleni Panousi (2010), Exhaust Methane Emissions from Passenger Cars, SAE International

Suzanne Timmons (2010) NG Fuel effects on vehicle exhaust emissions and fuel economy, SwRI Project, Fina Report

W.A. Vonk, R.P. Verbeek, H.J. Dekker (2010), Emissieprestaties van jonge Nederlandse personenwagens met LPG en CNG installaties, TNO-rapport, MON-RPT-2010-01330a

7.2 ANNEX

7.2.1 Sample vehicle main characteristics

Table 58: Sample vehicle main characteristics

no.	make [-]	model [-]	empty mass [kg]	displ. [cm3]	rated power [kW]	mileage [km]	cert. cat. [-]	comple-tion [-]	super-charging [-]
PG4-01	VW	Touran	1640	1984	80	2814	Euro-4	OEM	no
PG4-02	Opel	Zafira 1.6 CNG	1590	1598	69	4404	Euro-4	OEM	no
PG4-03	VW	Caddy	1642	1984	80	32429	Euro-4	OEM	no
PG4-04	Volvo	V70 CNG	1591	2435	103	47709	Euro-4	retrofit	no
PG4-05	Fiat	Punto 1.2 Bipower	1025	1242	44	23426	Euro-4	OEM	no
PG4-06	Opel	Combo C16CNG	1395	1598	71	39459	Euro-4	OEM	no
PG4-07	VW	Golf Variant Bifuel	1434	1984	85	93344	Euro-4	OEM	no
PG4-08	Citroěn	C3 1.4i	1014	1360	54	11300	Euro-4	OEM-retrofit	no
PG4-09	Mercedes Benz	E 200 NGT	1690	1796	120	44192	Euro-4	OEM	compr.
PG4-10	Fiat	Multipla 1.6Bipower	1470	1596	65	46401	Euro-4	OEM	no
PG4-11	Mercedes Benz	B 170 NGT	1440	2034	85	21154	Euro-4	OEM	no
PG4-12	Opel	Zafira B16T CNG	1660	1598	110	8988	Euro-4	OEM	turbo-charged
PG5-01	VW	Passat Ecofuel	1537	1390	110	5296	Euro-5	OEM	twin-charged