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Update of Emission Factors for EURO 5 and EURO 6 vehicles for the HBEFA Version 3.2

Final Report

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Final Report

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Content

Abbreviations

CADC..........Common ARTEMIS Driving Cycle (Urban, Rural, MW = Motorway)

CI95 ....95% confidence interval

DOC............Diesel Oxidation Catalyst

DPF.............Diesel Particle Filter

EGR ....Exhaust Gas Recirculation

ERMES ....European Research group on Mobile Emission Sources

FC ....Fuel consumption

HBEFA ....Handbook Emission Factors for Road Transport

JRC.............Joint Research Centre

LCV.............Light Commercial Vehicle (N I-1, N I-II, N I-III)

RD...............Real Driving

RDE ....Real Driving Emissions

PEMS..........Portable Emission Measurement System

PHEM..........Passenger car and Heavy duty Emission Model

SCR ....Selective Catalytic Reduction

TUG ....University of Technology Graz

TWC............Three Way Catalyst

Executive Summary

In January 2010 the current version 3.1 of the Handbook Emission Factors for Road Transport (HBEFA) was released. It includes emission factors for all relevant road vehicle types. As the measurements for this HBEFA version were carried out before mid-2009 the currently effective emission standard for passenger cars, EURO 5, as well as EURO 6 was not parameterised with measurement data. Also for heavy duty vehicles (HDV) no emission data on EURO V technology with exhaust gas recirculation (EGR) and for the upcoming EURO VI standard was available. Instead, those vehicle categories had been modelled based on data for earlier emission standards and on expert judgement on the future technologies.

Now comprehensive measurement data on EURO 5 LDVs and some first data on EURO 6 cars are available. The required measurements have been performed on roller test beds using the new ERMES driving cycle beside the well-established CADC. For HDV additional emission tests on EURO V vehicles have been collected comprising three measured vehicles with EURO V EGR technology. Furthermore emission tests on five EURO VI vehicles have been executed comprising both engine dyno tests as well in-use tests on HDV roller test beds. Scope of the work was to create a new set of emission data for the version 3.2 of the HBEFA.

The emission factors in the HBEFA are created by means of simulation as the huge number of driving situations and vehicle categories are impossible to be covered by measurements within reasonable time and financial constraints. The simulations are done using the simulation tool PHEM (Passenger car and Heavy duty vehicle Emission Model) developed by TUG since the late 1990's. In this project PHEM was updated to handle EURO 6 vehicle technologies, by adding e.g. improved models for exhaust gas after treatment simulation (DOC, DPF, SCR) and by simulation of start/stop function. Also models enabling detailed simulation of hybrid electric and electric vehicles have been developed, but the introduction of a separate set of emission factors for hybrid vehicles into the HBEFA has been postponed to the follow up major update (HBEFA Version 4). In addition the driver gear shift model for passenger cars and LCV was slightly adapted to actually available RD tests.

Emission factors for passenger cars and light commercial vehicles

The available emission data from the in-use tests comprise about 80 measured EURO 5 vehicles covering this emission standard relatively well. For EURO 6 vehicles so far emission measurements on only 20 vehicles are available (covering 13 different vehicle models) and the representativeness of the sample for the fleet is assumed to be questionable as mainly premium class vehicles are currently available on the market. In the HBEFA3.2 the emission standard EURO 6 is differentiated between first generation of EURO 6 vehicles (referring to stage EURO 6b, hereafter labelled as “EURO 6”) and vehicles which will enter the market based on a more stringent emission regulation in 2017/18 (hereafter labelled as “EURO 6c”). For EURO 6c it was assumed that RDE emissions will be tested in type approval mandatory by PEMS equipment and that PN limits are introduced for SI engines with direct injection. Emission measurements were only available for first generation of EURO 6 diesel vehicles. Hence the parameterisation for EURO 6c Diesel and both EURO 6 and EURO 6c petrol cars had to be generated based on a technology prognosis.

With the PHEM parameterisation for emission behaviour of EURO 5, 6 and 6c vehicles emission factors for the full set of HBEFA driving cycles in combination with all road gradients (-6%, -4%, -2%, +/-0%, +2%, +4%, +6%) have been calculated. For this purpose additionally vehicle related parameters (like mass, air resistance, rolling resistance etc) for representative fleet average conditions have been investigated. Below the main findings for hot start emission behaviour of EURO5 and EURO6/6c passenger cars are discussed. (Cold starts are not included in this report since the data for cold start extra emissions in the HBEFA are elaborated by EMPA and are described in separate reports). The results are shown on example of the simulated emissions in the CADC since this is a well-known test cycle where many test data is available and on which also the model calibration was performed. The emission factors for HBEFA have been computed for the driving cycles representative for the single HBEFA traffic situations.

NO_x emissions from diesel cars increased from EURO 4 to EURO 5 despite a limit tightening in the NEDC (from 250mg/km to 180mg/km). While in urban driving the differences between EURO 4 and EURO 5 diesel cars are small, the increase is more pronounced at road and highway driving. In general the ratio of NOx between EURO 5 to EURO 4 diesel cars increases slightly with increasing velocity and engine power.

For EURO 6 LDVs NO_x after-treatment systems are currently foreseen by most of the manufacturers to reach the 80 mg/km NEDC threshold and show clear positive effects also in real world driving resulting in more than 50% lower NOx levels compared to EURO 5. However, this finding of EURO 6 is based on a small sample of measured vehicles. Further improvements in NO_x emissions are expected with the introduction of the EURO 6c step due to the testing and limit values for RDE from 2017 onwards (Figure 1). NO_2 shares in total NO_x have fallen from EURO 4 to EURO 5 being quantified in the range of approx. 35% for EURO 5. CO and HC emissions remain on a very low level indicating that the DOC (Diesel Oxidation Catalyst) technology is well established and technically matured. This is also the case for the DPF which are effectively reducing PM and PN emissions in all driving situations. Fuel consumption and CO_2 emissions were found to be lower for EURO 5 than for EURO4. However, since the vehicle sample are not representative concerning mass, power, vehicle classes and other FC relevant properties no general trend from EURO 4 to EURO 5 and EURO 6 can be gained from the base emission factors. FC and CO2 are thus corrected in the HBEFA based on national CO_2 monitoring data.

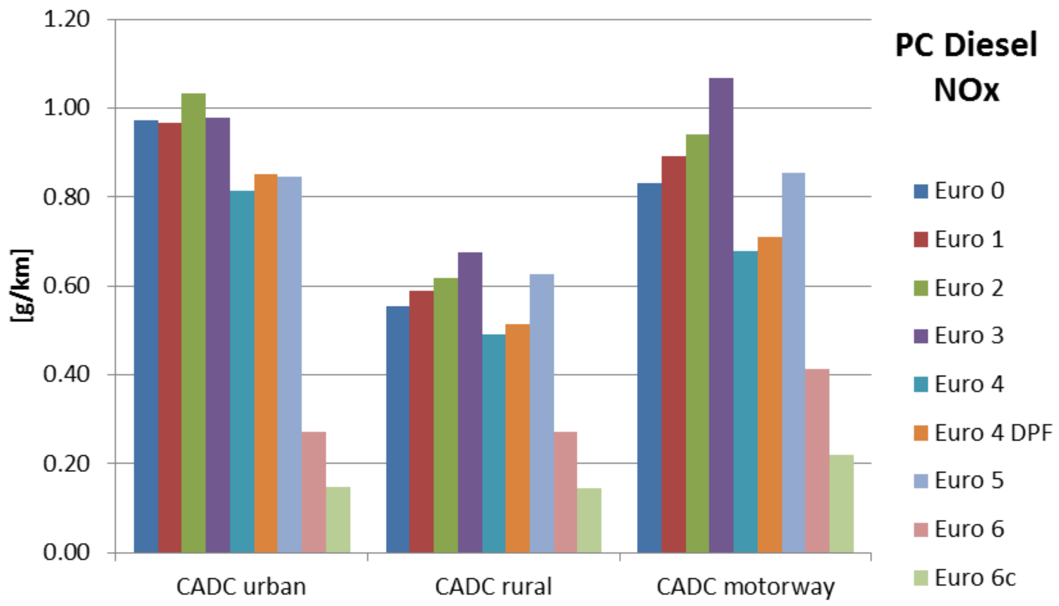

Figure 1: NO_x emissions simulated with PHEM for the HBEFA3.2 average diesel cars in the CADC (1/3-mix urban, rural, motorway)

For petrol cars further reductions of NO_x, CO and HC emissions can be observed in comparison to EURO 4 technology. Driving situations above the light-off temperature of the TWC cause only very low emissions of these pollutants. Malfunctions of the exhaust after-treatment systems have not been observed. The NO_2/NOx ratio remains on a low level around 5%. PM emissions of petrol direct injection technologies are slightly higher than of previous port injection generations for the urban CADC part, but show the opposite trend during motorway driving. In any case the absolute PM values are clear below the thresholds and on a comparable level of current diesel vehicles with DPF technology. PN has an increasing trend because of the rising share of direct injection engines. The projection for EURO 6c shows a PN level reduction since the tightening of PN limits will come into force on 1st Sept 2017 (Type approval) resp. 1st Sept 2018 (1st registration).

Emission factors for heavy duty vehicles

For HDV certified to EURO V using SCR aftertreatment data on two additional measured vehicles have been incorporated into the PHEM model. Now in total eight models are coved for this HDV emission concept. The new data does not result in major changes in emission factors compared to the HBEFA3.1. EURO V SCR vehicles are found to have low NO_x in motorway and rural driving situations but NO_x levels close to EURO III conditions in urban and stop and go driving. This emission behaviour can be explained by the low activity of the SCR system in the low exhaust gas temperature range which is not covered by the EURO V type approval cycles ESC and ETC. PM emissions of EURO V with SCR in real world driving approximately correspond with the EURO V type approval limits.

For EURO V technology using exhaust gas recirculation (EGR) in-use tests on three vehicles were available for the HBEFA3.2. In motorway driving the NO_x emissions meet the prognosis made in the HBEFA3.1 based on the type approval limits quite well. For urban driving situations the NO_x output is clearly higher than forecasted and in the range of EURO IV with EGR.

Real world particle emissions of EURO V with EGR are approximately similar to EURO V with SCR and correspond with the type approval limits

The main finding of the current study related to HDV emissions is the confirmation of the effectiveness of the EURO VI legislation based on the WHTC and additional provisions on real world emissions tested with PEMS as a part of the type approval. All tested EURO VI vehicles and engines were found to have very low NOx levels in all real world cycles. At medium and high engine loads the NOx levels are in the range of the limits in the WHTC which confirms the HBEFA3.1 prognosis. In cycles with low average engine loads the test results for NO_x showed a certain scattering: whereas some models met the WHTC NO_x limits even in this disadvantageous operation conditions some other models showed a clear sensitivity of NO_x levels to low engine loads. However, based on the data available so far, it is assessed that the NO_x reduction of EURO VI compared to EURO V for fleet average conditions is at least reflecting the reduction in type approval limits (EURO VI: 0.46g/kWh in the WHTC; EURO V: 2.0g/kWh in the ETC). All tested EURO VI products were equipped with a closed diesel particulate filter system (DPF). The type approval limits for PM and PN were found to be clearly met by all systems. Emissions of HC and CO were found to be low for all HDV emission standards.

Figure 2 gives a comparison of NO_x emission factors of different emission concepts for a section of typical driving cycles. Shown values refer to a typical 40t truck operated in half loaded conditions.

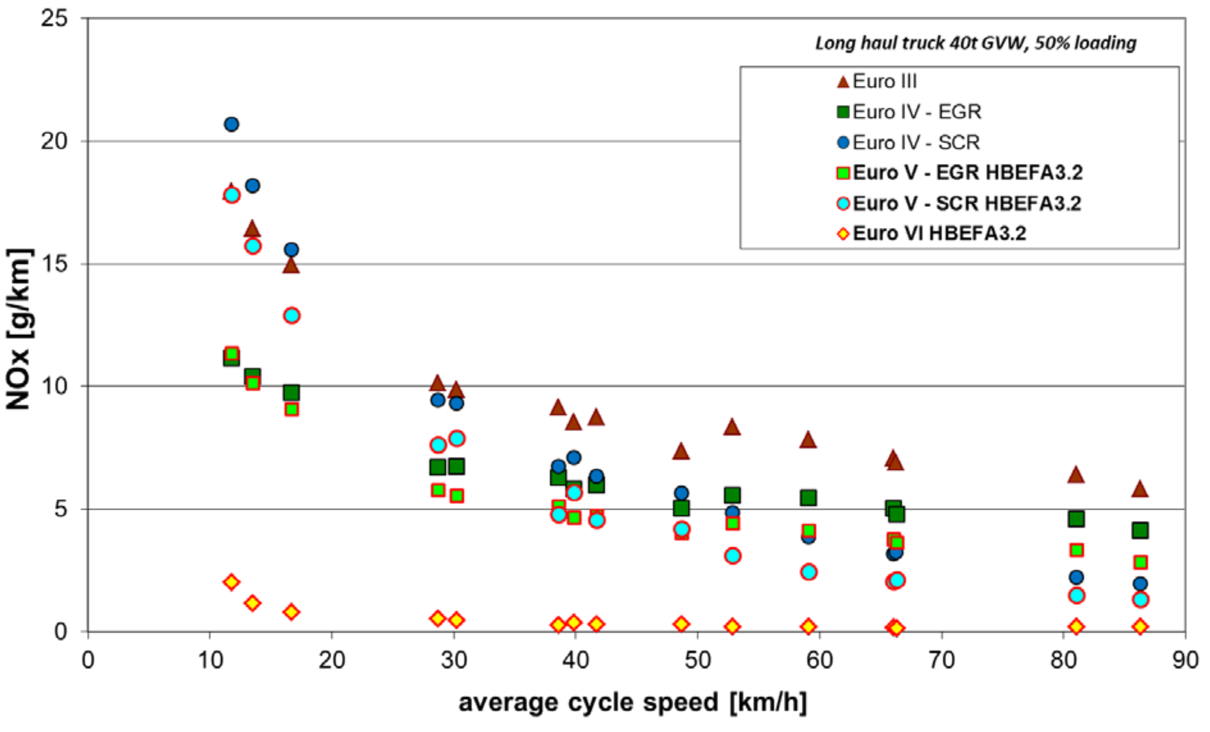

Figure 2: Examples HBEFA3.2 NOx emission factors for 0% road gradient; truck & trailer combination 40t gross vehicle weight, 50% loading

1. Background and scope of work

In January 2010 the current version 3.1 of the Handbook Emission Factors for Road Transport (HBEFA) was released. It includes emission factors for all relevant road vehicle types. As the measurements for this HBEFA version were carried out before mid-2009 the currently effective emission standard for passenger cars, EURO 5, as well as EURO 6 was not parameterised with measurement data. Also for heavy duty vehicles (HDV) no emission data on EURO V[1] technology with exhaust gas recirculation (EGR) and for the upcoming EURO VI standard was available. Instead, those vehicle categories had been modelled based on data for earlier emission standards and on expert judgement on the future technologies.

Now comprehensive measurement data on EURO 5 LDVs and some first data on EURO 6 cars are available. The required measurements have been performed on roller test beds using the new ERMES driving cycle beside the well-established CADC. Also for HDV additional emission tests on EURO V vehicles have been collected, comprising three measured vehicles with EURO V EGR technology. Furthermore emission tests on five EURO VI vehicles have been executed comprising both engine dyno tests as well in-use tests on HDV roller test beds. Scope of the work was to create a new set of emission data for the version 3.2 of the HBEFA. Only emissions in hot operation conditions are treated in this study.

The related efforts performed by TUG covering emission measurements and work on emission factors were sponsored by (in alphabetical order):

Department of the Environment, Transport, Energy and Communications, Switzerland

Environment Agency, Austria

European Commission DG JRC

Federal Environment Agency, Germany

Federal Ministry for Transport, Innovation and Technology, Austria

Federal Ministry of Agriculture, Forestry, Environment and Water Management, Austria

Federal State Government of Tirol, Austria

and by budget from the ERMES group.

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[1] Emission standards referring to light duty vehicle “LDV” legislation (comprising the vehicle categories passenger cars “PC” and light commercial vehicles “LCV”) are written in Arabic numbers, emission standards for heavy duty vehicles are numbered in Roman numbers.

As the HDV emission legislation for the stages EURO V and EEV (“enhanced environmentally friendly vehicle”) is very close (EEV has slightly tighter PM limits), no further differentiation between these standards is done in the HBEFA.

2. Methodology

The emission factors in the HBEFA are created by means of simulation as the huge number of driving situations and vehicle categories are impossible to be covered by measurements within reasonable time and financial effort. The simulations are done using the simulation tool PHEM (Passenger car and Heavy duty vehicle Emission Model). PHEM is an emission map based instantaneous emission model, which has been developed by TUG since the late 1990's. It calculates fuel consumption and emissions of road vehicles in 1Hz time resolution for a given driving cycle based on the vehicle longitudinal dynamics and emission maps (Figure 3). The model has already been presented in several publications, e.g. (Hausberger et al. 2009), (Zallinger, 2010), (Rexeis, 2009). PHEM simulates the engine power necessary to overcome the driving resistances, losses in the drive train and to run basic auxiliaries in 1 Hz over each driving cycle. The engine speed is simulated by the transmission ratios and a driver gear shift model. Then basic emissions are interpolated from the engine maps. Depending on the vehicle category, EURO class and exhaust gas component correction functions considering the transient engine loads and their influence on the engine out emission behaviour are applied and after treatment efficiencies are simulated based on the catalyst temperature and exhaust gas mass flow. With this approach realistic and consistent emission factors can be simulated for any driving condition since the main physical relations are taken into consideration. E.g. variations in road gradients and in vehicle loading influence the engine power demand and the gear shift behaviour and thus lead to different engine loads over the cycle.

The engine emission maps are gained by emission measurements on engine test stands and more frequently by chassis dyno tests or by PEMS measurements. To obtain representative emission factors for the vehicle fleet, vehicle and engine measurements are collected within the testing labs of the ERMES group. So far emission tests on more than 1000 vehicles are available.

For HBEFA 3.2, the model PHEM was updated to handle EURO 6 vehicle technologies, by adding e.g. improved models for exhaust gas after treatment simulation (DOC, DPF, SCR) and by simulation of the engine start/stop function. Also models for RESS (Rechargeable Electric Energy Storage System), for electric motors and for a controller of hybrid vehicles were installed. These models can be parameterised for a realistic simulation of hybrid powertrains and for battery electric vehicles. Furthermore advanced tools for the simulation of the energy consumption of auxiliaries were added, such as air conditioning, alternator, air compressor and steering pump. These auxiliaries are typically not running at all or are running on a lower power demand level (alternator) during the chassis tests. Thus these additions especially support the increasing importance of accurate simulation of fuel consumption and CO_2 emissions.

For the HBEFA 3.2 it was decided however, that the basic methods shall not be updated but only the new test data on EURO 5/V and 6/VI shall be implemented. This was based on the wish not to make new calculations of emission inventories necessary from 1990 on due to rather small adaptations which then would also influence emission factors for EURO 0 to EURO 4. An extensive update of the HBEFA has been postponed to the HBEFA (Version 4), where also the traffic situation scheme may be adapted.

Beside the additional functionalities also a clearly improved user interface was established in PHEM version 11.

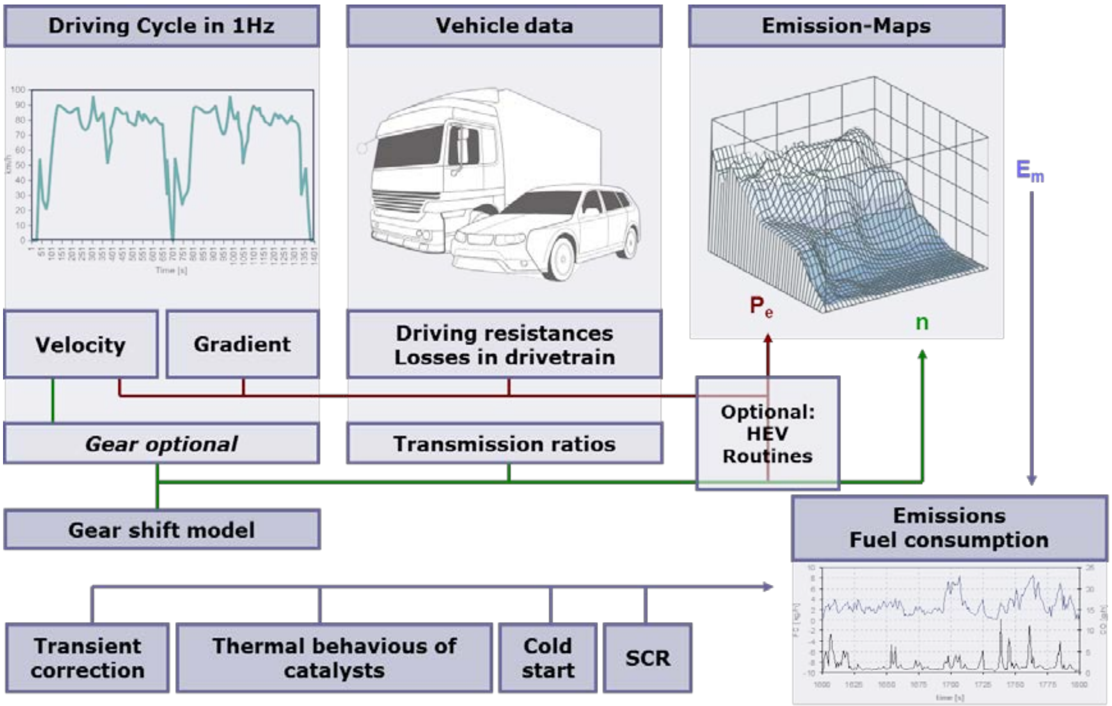

Figure 3: Scheme of the PHEM model

The actual version of PHEM certainly still offers the predefined data base for PC, LCV and HDV from EURO 0 to EURO 6 and for diesel and gasoline cars to allow a user friendly calculation of average emission values from the vehicle fleet. A first data set for 2-wheelers simulation in PHEM is under preparation but certainly will not be used in HBEFA before Version 4.

3. Emission factors for passenger cars

This chapter gives a documentation of the updated emission factors for EURO 5 and EURO 6 passenger cars.

3.1. Available emission data

3.1.1. Test cycles

In principle all test cycles are eligible to convert modal emission data into an emission map described by engine power (or torque) and engine speed. An important criterion for a reliable application of such engine maps is a good coverage of the entire engine map, i.e. that all relevant engine load and engine speed situations are included. Therefore vehicles being tested only in low engine load cycles like the NEDC are not sufficient to simulate emission factors in RD. In addition, NEDC results have not been used for the derivation of engine emission maps since vehicles have to be optimised for low emission levels in the type approval cycle which leads to discrepancies concerning emission results in type approval tests with real-world emissions.

In the ERMES in-use testing program usually the real world cycle CADC, (Andrè, 2001), was tested under hot start conditions. The CADC proved to be a very useful test cycle over the last decade. However, demands for an alternative cycle arise, due to the fact that the CADC is a rather long test (3x20 minutes), that the CADC does not include any of the actual traffic situations from the HBEFA and that the CADC does not cover high and full load engine operation for cars with higher power to mass ratio. The latter problem increases over time with increasing average engine rated power values since the CADC velocity pattern is independent from the engine power.

Therefore in 2011 the ERMES test cycle was developed (Knörr, 2011). The ERMES cycle adopted several ideas from the CADC, such as internal preconditioning phases and the division of each bag phase into sub-cycles. The novelties of the ERMES cycle are that the cycles from the most important traffic situations from the HBEFA were used as basis and that full load acceleration phases in different gears were added to fill the entire engine emission maps for all tested vehicles. The total ERMES cycle has a duration of 1308 seconds and can thus be added as a quick real world cycle to most vehicle chassis tests to enlarge the data base on tested vehicles. This approach proved to be successful since from the 50 newly measured cars described below 10 were measured in NEDC and ERMES only. Without the short alternative to the CADC from these vehicles the NEDC would have been the only result. Figure 4 shows the vehicle speed profile of the ERMES cycle and the gear position exemplarily for a diesel car with 6 gears.

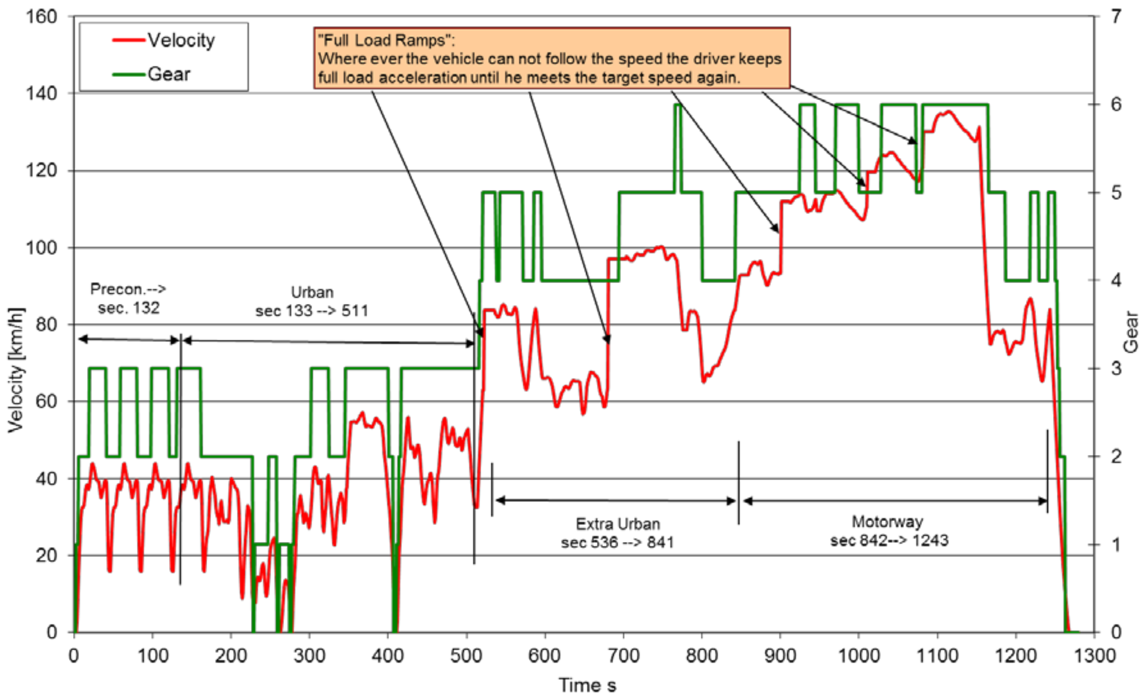

Figure 4: The ERMES test cycle with gear shift rules for a diesel car with 6 gears

Figure 5 shows the CADC test cycle.

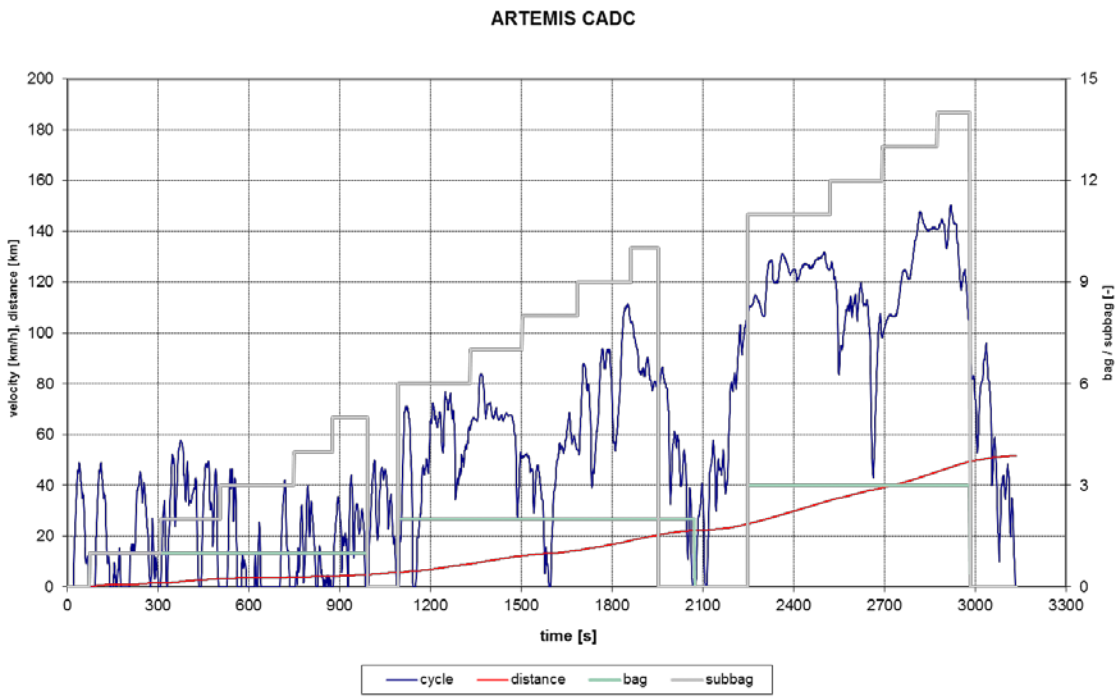

Figure 5: The CADC test cycle

3.1.2. Overview on the sample of measured vehicles

Table 1 gives an overview on the number of measured EURO 5 and 6 vehicles. Columns "bag data" refer to the total number of vehicles in the ERMES LDV database and include also the vehicles for which both, bag values and modal test results have been available (column “modal data”). For all vehicles in the data base bag data is available, since this is the standard test method for LDV chassis dynamometer tests. The vehicles for which a high quality modal data recording is available are thus a sub-sample from the total bag data set. Modal test data is necessary for setting up engine emission maps while bag values can be used for calibration and validation of the emission factors gained from the engine maps.

With about 80 measured vehicles the emission standard EURO 5 is covered with measurements relatively well. For EURO 6 vehicles so far emission tests on only 20 vehicles are available (covering only 13 different vehicle models) and the representativeness of the sample for the fleet is assumed to be questionable (see detailed discussion below).

Table 1: Number of measured cars available

Laboratory	EURO 5 petrol		EURO 5 diesel		EURO 6 petrol		EURO 6 diesel	
	bag data	modal data	bag data	modal data	bag data	modal data	bag data	modal data
ADAC	1		3				1	
TUG	8	8	15	15	1		5	5
EMPA	11	10	12	12				
TNO			16				13(*)	
JRC	11		4					
LAT	4		2					
Total	**31**	**18**	**50**	**27**	**1**	**0**	**19**	**5**

(*) only 9 different vehicle models

3.1.3. Available modal emission data

Altogether measurement data from 50 LDVs has been collected for the purpose of derivation of engine maps. The emission maps used by the model PHEM are characterised by engine power and engine speed. Therefore, an essential criterion for data selection was the availability of engine speed data in 1 Hz temporal resolution (or the availability of transmission ratios, vehicle speed and tyre size in case of manual gear boxes).

Table 2 gives the main specifications of the measured EURO 5 petrol cars for which modal data have been available. In the table also the weighting factors applied in the compilation of the fleet average emission factor is shown. These weighting factors refer to the number of new registrations of the particular model in 2012 according to the EU-27 CO_2 monitoring database. I

In the analysis of petrol vehicles it was differentiated between direct (DI) and port injection (PI) systems. Data from 8 DI and 10 PI vehicles has been evaluated. Because of the different emission behaviour between these technologies mean emission maps for EURO 5 and 6 petrol passenger cars have been calculated by applying weighting factors for DI and PI vehicles. These weighting factors have been derived also from the EU-27 CO_2 monitoring database. The mean shares of DI in the total number of petrol-driven PC have been estimated by 33% for EURO 5 and 65% for the future EURO 6 fleet.

Table 2: Available modal test data for EURO 5 petrol cars

Vehicle ID	Vehicle type	Rated power [kW]	Lab	Sales No 2012*
P5_v01	Mazda 3 2.0 DI	111	TUG	5
P5_v02	Fiat Punto 1.4 PI	77	TUG	4174
P5_v03	Honda Civic 1.4 PI	73	TUG	9853
P5_v04	Audi A5 2.0 DI	155	TUG	8853
P5_v05	Audi A1 1.2 DI	63	TUG	33103
P5_v06	VW Golf 1.4 PI	59	TUG	7914
P5_v07	BMW 528i 2.0 DI	180	TUG	2830
P5_v08	Opel Meriva 1.4 PI	88	TUG	13011
P5_v09	Opel Astra 1.6 PI	132	EMPA	3662
P5_v10	VW Polo 1.4 PI	63	EMPA	34353
P5_v11	Fiat 500 1.3 PI	51	EMPA	180921
P5_v12	Renault Grand Scenic 1.4 PI	96	EMPA	5940
P5_v13	Smart fortwo 1.0 PI	62	EMPA	2652
P5_v14	VW Golf 1.4 DI	90	EMPA	38550
P5_v15	Peugeot 207 1.6 PI	88	EMPA	39282
P5_v16	Skoda Octavia 1.8 DI	118	EMPA	6746
P5_v17	BMW 125i 3.0 DI	160	EMPA	569
P5_v18	Mazda 3 2.0 DI	111	EMPA	5

* Weighting factors per model I = (sales-number I) / (total sales numbers in sample)

For derivation of EURO 5 diesel emission maps modal data for 24 passenger cars and for 3 light commercial vehicles has been provided (Table 3). This implies market coverage of 35% of all new diesel vehicles being registered in 2012 in EU-27 characterised by engine displacement and rated power.

Table 3: Available modal test data for EURO 5 diesel cars (incl. LCVs)

Vehicle ID	Vehicle type	Rated power [kW]	Lab	Sales No 2012*
D5_v01	VW Golf 2.0	81	TUG	19137
D5_v02	VW Passat BM 2.0	81	TUG	19137
D5_v03	BMW 318d ED 2.0	105	TUG	39052
D5_v04	Peugeot 407 SW 2.0	103	TUG	91798
D5_v05	Opel Astra 1.7	92	TUG	16303
D5_v06	Fiat Doblo 1.6	77	TUG	23759
D5_v07	Audi A3 1.6	66	TUG	91434
D5_v08	Mitsubishi ASX 1.8	110	TUG	17011
D5_v09	Skoda Fabia 1.6	55	TUG	12248
D5_v10	Kia Optima 1.7	100	TUG	14778
D5_v11	Chevrolet Cruze 1.7	96	TUG	16054
D5_v12	Opel Vivaro 2.0	84	TUG	22243
D5_v13	BMW 320d 2.0	120	TUG	17113
D5_v14	VW T5 2.0	103	TUG	185922
D5_v15	Peugeot Boxer 2.2	81	TUG	746
D5_v16	Toyota Avensis 2.2	110	EMPA	23234
D5_v17	Renault Megane 1.5	81	EMPA	256710
D5_v18	Citroen C5 3.0	177	EMPA	2541
D5_v19	VW Passat 2.0	125	EMPA	107946
D5_v20	BMW 118d 2.0	105	EMPA	39052
D5_v21	Skoda Octavia 1.6	77	EMPA	160723

Vehicle ID	Vehicle type	Rated power [kW]	Lab	Sales No 2012*
D5_v22	VW Touran 2.0	103	EMPA	185922
D5_v23	Fiat Punto 1.3	70	EMPA	67514
D5_v24	Toyota Yaris 1.4	66	EMPA	33414
D5_v25	Opel Astra 1.7	92	EMPA	16303
D5_v26	MB C220 2.2	125	EMPA	69180
D5_v27	Skoda Fabia 1.6	77	EMPA	160723

* Weighting factors per model I = (sales-number I) / (total sales numbers in sample)

In contrast to EURO 5 the number of available modal measurement data for EURO 6 diesel cars is still on a low level (Table 4). In addition, EURO 6 cars already in the market belong to premium classes of vehicle segments which add a certain uncertainty to the resulting fleet emission factors.

In addition uncertainties are related to:

- Shares of NO_x control technologies in the future EURO 6 fleet.
- Level of exploitation of NO_x reduction potential of these technologies in the future fleet (e.g. AdBlue may not be dosed at high engine loads by a yet unknown share of vehicle models if not relevant in the type approval test)

Table 4: Available modal test data for EURO 6 diesel cars

Vehicle ID	Rated power [kW]	Lab
D6_v01	180	TUG
D6_v02	180	TUG
D6_v03	180	TUG
D6_v04	110	TUG
D6_v05	130	TUG

Further measurement data will be necessary to evaluate the functionality of NO_x after-treatment devices also for mid- and low-size cars and to provide more reliable EURO 6 emission factors for the HBEFA Version 4.

During the project period no EURO 6 petrol vehicles have been available on the market for emission testing. Hence the assessment of EURO 6 petrol emission behaviour was done based on EURO 5 petrol data. The resulting PHEM parameterisation was then checked based on the integral test results for the first EURO 6 petrol car, which was tested short before calculation of final HBEFA3.2 emission factors.

3.1.4. Available bag measurement data (“ERMES LDV data base”)

In addition to the vehicles listed above, further measurement results for EURO 5 and 6 LDV were collected in the ERMES group. These data comprise only integral results of complete cycles or sub-cycles (‘bag results’) and could therefore not be used directly for the calculation of engine maps. All reported bag results (including the vehicles were also modal emission test data is available) have been integrated into a common data base (called “ERMES LDV data base’) by INFRAS. The collected data in this data base related to the three CADC phases (urban, rural, motorway) has been used in this study for calibration purposes of the engine maps compiled based on the modal data.

The complete list of measured passenger cars included in the ERMES data base is given in Annex A of this report.

3.2. Elaboration of the PHEM engine emission maps

This chapter gives a description on the incorporation of the emission data collected in the ERMES group into the PHEM emission model. The generation of the HBEFA3.2 emission factors is documented in chapter 3.3. The emission behaviour of EURO 5 and 6 passenger cars and LCV is discussed in chapter 3.4.

Step 1: Compilation of available modal measurement data

In a first step the available instantaneous measurement data (1Hz data for CADC, ERMES and other transient driving cycles, see columns "modal data" in Table 1) had to be pre-processed to be applicable as input for the PHEM model. The pre-processing includes the following steps:

- Time alignment of modal data for vehicle operation (vehicle and engine speed) and recorded emissions
- Calculation of modal data for PM emissions based on gravimetric results for the total bag phases and on the modal data for PN emissions
- Generation of PHEM input files for modal measurement data, vehicle specifications and engine specifications

For these tasks the software tool "ERMES-Tool" was developed at the TUG. This tool allows for complete analysis of emission measurement data based on raw testbed recordings generating emission test results according to the actual legislation, standard test protocols and input data for the PHEM model. Additionally an emission test can be exported to the ERMES LDV database by one click. In this project the ERMES-Tool was used for pre-processing of emission measurements from the TUG testbed only. In future the ERMES-Tool is planned to be distributed to more labs within the ERMES group to achieve a common standard for emission test evaluation and to be more efficient in future updates of the HBEFA.

Step 2: Generation of engine maps with PHEM for each vehicle

Then for each vehicle engine maps for emissions and fuel consumption have been generated by application of the PHEM model. These engine maps have the following normalised formats:

Engine speed:	idle = 0%,	rated speed = 100%	
Engine power:	0 kW = 0%,	rated power = 100%	
Fuel consumption:	normalised to "(g/h) / $kW_{rated\ power}$"		
Emission values:	normalised either to	"(g/h) / $kW_{rated\ power}$" (HDV application)	
		or	"(g/h)" (PC and LCV application)

<u>Step 3: Calculation of weighted averaged engine maps for EURO 5 (petrol and diesel) and EURO 6 diesel cars</u>

The engine maps from the individual vehicles have been compiled applying weighting factors related to the number of new registrations in 2012 in the EU-27 countries. The current version of the CO_2 monitoring data base has been used for this purpose (EEA, 2013b). The EEA data contains characteristic engine data from most of the reporting countries.[2] The parameters ‘fuel’, ‘engine capacity’ and ‘rated engine power’ have been used for the differentiation of registration numbers. The vehicle chassis has not been taken into account since it is assumed as simplification that the emission behaviour of a vehicle is only determined by the kind of engine and not by make or model of the total vehicle. If the same engine has been measured several times (e.g. at different labs) the weighting factor has been applied only once, i.e. first the arithmetic mean of all measurements has been calculated and then, second, the weighting factor has been assigned to this average.

Table 5 gives the identified registration numbers in EU-27 for the 10 most popular petrol and diesel engines in 2012.

Table 5: Identified registration numbers of the most popular car engines in the EU-27 (2012)

Petrol				Diesel			
Manu-facturer	Engine capacity [ccm]	Rated en-gine power [kW]	Identified registrations 2012	Manu-facturer	Engine capacity [ccm]	Rated engine power [kW]	Identified registrations 2012
Fiat	1242	51	235460	VW	1968	103	372076
VW	1197	77	179332	VW	1598	77	321568
Renault	1149	55	176165	PSA	1560	82	237381
VW	1390	90	116897	PSA	1560	68	203826
VW	1197	63	100380	Renault	1461	81	181382
PSA	998	50	97065	BMW	1995	135	129648
VW	999	44	79632	PSA	1398	50	117423
VW	1198	51	61129	VW	1968	125	107983
Toyota	1329	73	60779	VW	1598	66	91450
Ford	1242	60	60612	Ford	1560	85	86606

For petrol-fuelled vehicles there is currently a technology changeover on-going from ‘port injection’ (PI) or ‘multipoint injection’ (MPI) to ‘direct injection’ (DI) systems. DI engines are characterised by higher fuel efficiencies and higher power output, but might feature worse emission behaviour. Especially for particle number (PN) emissions significant differences between DI and conventional engines have been revealed by the baseline measurements for the Handbook update. Therefore measurements and the derivation of the basic engine maps have been done by separating data from PI and DI vehicles. The compilation of one average

[2] Some countries still do not provide complete engine data sets. Therefore the total number of identified registrations assigned to certain engines is lower than in reality. But it can be assumed that these data lacks are equally spread over all engines and do not shift the relation of numbers between the different engines.

emission map from the two engine maps has been done afterwards by applying weighting factors reflecting the market penetrations for both technologies for the different EURO stages.

The 100 most popular petrol engines have been identified from the CO_2 monitoring data bases 2011 and 2012 (EEA, 2013b). The summing up of the reported numbers of registrations gave DI shares of 20.4% for 2011 and 27.0% for 2012. The projection to the future was done assuming a constant growth rate of 6.6% per year which is the difference between the two analysed years. The predicted DI shares for the EURO classes 5, 6 and 6c are given in Table 6.

Table 6: Projected shares of petrol passenger cars with direct injection technology engines

	Euro 5	Euro 6	Euro 6c
DI share	35%	58%	75%

<u>Step 4: Calibration of engine maps generated in step 3 using the ERMES LDV database.</u>

As described before. a quite large number of available vehicle measurements could not be taken into account for the derivation of the engine maps. Even if instantaneous data in high temporal resolution was available, for some vehicles engine speed or gear position data was missing. Therefore the number of measurements only with usable bag data (but not instantaneous data) for dynamic test cycles like the CADC or the ERMES cycle is much higher than those to be included in the basic engine maps as generated in step 3. The sample size is crucial for the representatives of the absolute levels of the emission factors. Therefore from all available CADC bag data (ERMES LDV database) mean values have been calculated to calibrate the engine maps which are basing on a smaller sample size. The CADC-1/3-mix has been used for the calculations of these calibration factors, i.e. the results from the three phases of the CADC 'urban', 'rural' and 'motorway' have been weighted each by 1/3. The calibration factors have been calculated from the quotients (measured value / simulated value) and applied consistently over the whole area of the engine maps as a constant correction factor. The calibration factors are shown in Annex C.

<u>Step 5: Correction of emission maps for diesel vehicles by including type approval Ki-factors which consider the influence of the regeneration of the DPF on the average emission behaviour</u>

To observe PM, PN emission limits for LDV, the introduction of closed-loop particle filters became obligatory at least with the transition from EURO 4 to EURO 5 standard. The particulate filter as part of the exhaust after-treatment system has to be cleaned when a certain level of loading with particles is reached. The deposited soot is burned at forced DPF regeneration phases by artificially increased exhaust temperatures exceeding the inflammation point. The temperature increase can be reached e.g. by modified engine control measures or by fuel post-injection. The regeneration phase normally lasts approximately 5 to 10 minutes. During filter regeneration pollutant emissions and fuel consumption are considerably higher than during normal driving conditions. This changed emission behaviour is normally not covered by regular dynamometer measurements. From time to time filter regeneration occurs during vehicle testing in an irregular manner. But these tests are recognized as outliers and are not taken into account for the derivation of regular pollutant and fuel consumption engine maps.

The higher emissions at filter regenerations during real-world driving are be taken into account here by correction factors applied to the initially derived emission maps. For that purpose official type-approval correction factors (‘Ki-factors’) have been requested for the ten most popular LDV diesel engines in Europe which have been identified from the CO_2 monitoring data base 2012 (EEA, 2013). Data has been provided for five engines from French manufacturers (UTAC, 2013) and for five engines from German manufacturers (KBA, 2013). The arithmetic mean for each pollutant has been calculated from these data sets. Since the Ki-factors base on experimental filter loading during the NEDC only, a shorter interval between consecutive regeneration phases has to be assumed during real-world driving. Based on higher PM and PN emissions (twice as high than NEDC) the averaged Ki-factors have been raised to reflect RD conditions. The final correction factors to be applied directly to the uncorrected test results are given in Table 7. Since no official Ki-factors for PN exist so far, PM correction factors have been also applied to the PN measurement data.

Table 7: Correction factors for regenerating particulate filters (Ki factors)

Pollutant	CO_2 (FC)	CO	HC	NO_x	PM (PN)
Ki factor	1.009	1.005	1.024	1.047	1.419

<u>Step 6: Correction of emission maps by considering engine start/stop-systems (zero emissions instead of idling phases)</u>

Start-stop systems switch off the engine automatically during vehicle standstill phases. Hence, emissions occurring during engine idling are avoided. The total positive effect depends on the share of idling in a driving cycle. Available data contain measurements of vehicles without or with activated or with deactivated start-stop systems. A special methodology has been developed and applied to handle these heterogeneous data sets.

Market penetrations for start-stop systems are available from battery manufacturers since the performance of batteries has to be adapted to the electrical requirements of start-stop designing, e.g. increased cycling and deeper discharge (Bosch, 2012), (Johnson, 2013). The activation of the start-stop system also depends on external parameters, i.e. the engine is not switched off if engine or external temperatures are below a certain threshold, if the A/C-system is activated or the current state-of-charge of the battery is not sufficient to do so. A unique average start-stop activation factor of 0.7 has been assumed for the performed calculations of emission factors. The start-stop activation factor describes the share of idling time in which the engine is switched off at vehicles equipped with start/stop systems. Table 8 gives market penetrations, activation factors and total start-stop factors. Petrol and diesel vehicles have not been differentiated. The total effect of start/stop systems in the fleet results then from the multiplication of the share of vehicles equipped with such systems with the activation factors.

Table 8: Market penetrations and activation factors of start-stop systems

	EURO 5	EURO 6	EURO 6c
Market penetration	50%	75%	90%
Activation factor	0.7	0.7	0.7
Total start-stop factor	0.35	0.525	0.63

To reflect the effects of start-stop technologies in the derived emission factors the following method has been applied: Engine switch-off phases during emission tests are cut off from the modal measurement protocols. Thus, engine emission maps with engine normal idle phases are produced. When PHEM simulates a driving cycle, then the emissions interpolated during idling phases are corrected by applying the total start-stop factors from Table 8 as weighting factors, i.e. idle emission get multiplied by (1 – total start-stop factor). In addition in PHEM a threshold of 5 seconds minimum engine on before stop-function can be activated again is set.

<u>Step 7: Prognosis for emission behaviour of emissions standards for which no measurements were available</u>

In the HBEFA3.2 the emission standard EURO 6 is differentiated between first generation of EURO 6 vehicles (referring to stage EURO 6b, hereafter labelled as "EURO 6") and vehicles which will enter the market based on a more stringent emission regulation in 2017/18 (hereafter labelled as "EURO 6c"). Emission measurements were only available for first generation of EURO 6 diesel vehicles. Hence the emission maps for EURO 6c Diesel and both EURO 6 and EURO 6c petrol cars had to be generated based on a technology prognosis. Below the underlying assumptions are summarised:

Diesel Vehicles

<u>EURO 6c</u>

For EURO 6c diesel technology the average NO_x real world emission level (in this context defined as 1/3 mix of CADC sub-cycles "urban", "road" and "motorway") has been defined with two times NEDC EURO 6 limits (2*80mg = 160mg) due to a mandatory PEMS test in real drive operation and a emission conformity factor lower than 2. The emission factors for all other regulated pollutants as well the NO_2/NO_x ratio is assumed as identical to EURO 6 (first generation) technology. The calibration of the map fuel consumption is in detail described further down below.

Petrol Vehicles

<u>EURO 6 and EURO 6c</u>

During the project period no EURO 6 petrol vehicles have been available on the market for emission testing. Hence the assessment of EURO 6 and EURO 6c petrol emission behaviour was done based on EURO 5 petrol data considering increasing shares of direct injection engines over the years (see Table 6 on page 20). The resulting PHEM parameterisation was then successfully checked for EURO 6 (first generation) based on the integral test results for the first EURO 6 petrol car, which was tested short before calculation of final HBEFA3.2 emission factors. In the prognosis for EURO 6c additionally the coming into force of the limit for PN emissions was considered.

Final calibration of fuel consumption and CO_2 emissions of EURO6 and EURO6c

The measured CO_2 and fuel consumption (FC) values from EURO 5 vehicles had to be projected to the EURO 6 respectively the EURO 6c levels. Statistical analyses from the EU CO_2 monitoring data base for passenger cars show average annual decreases until 2012 of 2.1% for petrol vehicles and 1.8% for diesel vehicles (EEA, 2013a). Table 9 gives the officially reported annual averages from 2000 till 2012, whiles Table 10 summarizes the absolute and relative changes over the whole reported period as annual averages.

Table 9: Official average CO_2 emissions from new passenger cars in the EU (EEA, 2013a)

gCO2/ km	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
All fuels	172.2	169.7	167.2	165.5	163.4	162.4	161.3	158.7	153.6	145.7	140.3	135.7	132.2
Petrol	177.4	175.3	173.5	171.7	170	168.1	164.9	161.6	156.6	147.6	142.5	137.6	133.7
Diesel	160.3	159.7	158.1	157.7	156.2	156.5	157.9	156.3	151.2	145.3	139.3	134.5	131.6

Latest studies reveal the discrepancy between official type approval (TA) and real values occurring during normal on-road driving. It is also reported that the efforts of the manufacturers to state CO_2 and FC on the lowest possible level have accumulated during the last years, i.e. a positive trend of the deviations between TA and on-road can be seen over time. It is assumed that roughly one half of the officially reported decline reflects the real technical developments while the second half of the reduction is caused by measures that are only effective under the very special conditions of the current type-approval process (ICCT, 2013).

Taking into account the available information it is concluded that the actual trend is a decline of approximately 1% per year for both petrol and diesel fuelled passenger cars. This is in good agreement with latest technical papers from manufacturers and suppliers about the future saving potential of petrol (Hadler, 2012) and diesel technologies (Gerhardt 2013).

For the projection of the fuel consumption from EURO 6 and EURO 6c vehicles the sample of measured cares was not representative since mainly upper class cars with high engine power and cylinder capacity have been tested. Thus the fuel consumption maps for EURO 6 and 6c have been gained from the EURO 5 maps by implementing the reduction rates shown in Table 10. A detailed technology assessment of EURO 6c engines was not performed but a constant reduction rate was applied in all engine map points.

Table 10: Average annual reduction of official CO_2 emissions

	Reduction per year 2000 → 2012 in type approval	
	absolute	**relative**
All fuels	- 3.3 g/km	- 1.9%
Petrol	- 3.6 g/km	- 2.1%
Diesel	- 2.4 g/km	- 1.8%
	Reduction per year in RD applied in PHEM for 2012 to 2017	
EU6b / EU5	Cycle dependent	-3%
EU 6c/ EU6b		-3%

In the HBEFA software the emission factors for FC and CO_2 as calculated by PHEM are further calibrated by country specific functions based on national CO2 monitoring data. So the final numbers obtained by the user might differ from the averaged numbers discussed in this report.

3.3. Calculation of HBEFA3.2 emission factors

With the PHEM parameterisation for emission behaviour of EURO 5, EURO 6 and EURO 6c vehicles as described in the previous chapter, emission factors for the full set of HBEFA driving cycles in combination with all road gradients (-6%, -4%, -2%, +/-0%, +2%, +4%, +6%) have been calculated. For this purpose additionally vehicle related parameters for representative fleet average conditions had to be provided to the PHEM model. The main vehicle specifications dominating the actual driving condition are: mass, air resistance, rolling resistance and inertias of engine and wheels. Furthermore for the determination of engine speed information about transmission ratios and tyre sizes are necessary. Various data sources have been analysed to derive the averaged technical parameters for EURO 5 and 6 petrol and diesel vehicles. The main vehicle parameters applied in the HBEFA3.2 calculations are summarised in Annex B.

For the HBEFA 3.2 no further emission measurements on earlier emission standards from “pre EURO 1” to EURO 4 have been analysed as these vehicles technologies were already well covered in the data available for the HBEFA3.1. So the related emission maps in PHEM have not been changed for the HBEFA 3.2 with exemption of the application of Ki factors to the Euro 4 DPF diesel map. Also the vehicle data files for EURO 0 to EURO 4 have not been changed against HBEFA 3.1. since no need for any adaptation was found.

Nevertheless also for these vehicle generations before EURO 5 a new set of emission factors has been calculated with the PHEM model. Reasons for this update compared to the HBEFA3.1 are:

- updated tire rolling resistance parameters for actual tire technologies (virtual replacement of tires at all EURO classes) in the definition of the ‘average vehicles’ of each technology class. The values are given in the annex.
- the fact that new driving cycles have been added in the HBEFA 3.2 compared to the 3.1 version
- and improved accuracy in the PHEM model compared to the version used for the HBEFA3.1 (e.g. improved gear shift algorithms, modified interpolation methods etc.)

Emission factors have been calculated for the following quantities: fuel consumption, emissions of CO_2, NO_x, NO_2, HC, CO, particle mass (PM) and particle number (PN). Figure 6 to Figure 8 exemplarily show emission factors calculated for the HBEFA cycles and flat conditions. In each figure the left picture shows the results for diesel cars, the right picture the results for petrol cars.

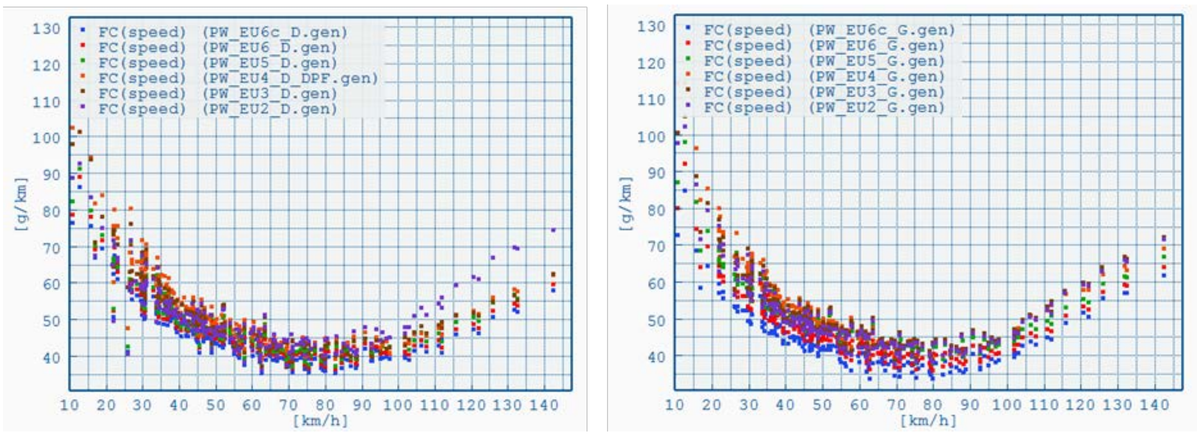

Figure 6: Example of HBEFA3.2 emission factors (fuel consumption)

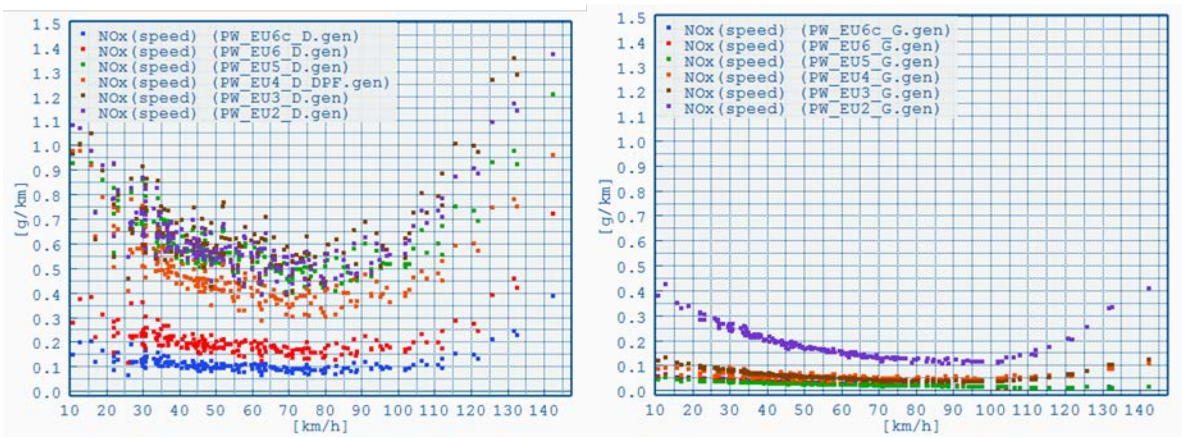

Figure 7: Example of HBEFA3.2 emission factors (NO_x emissions)

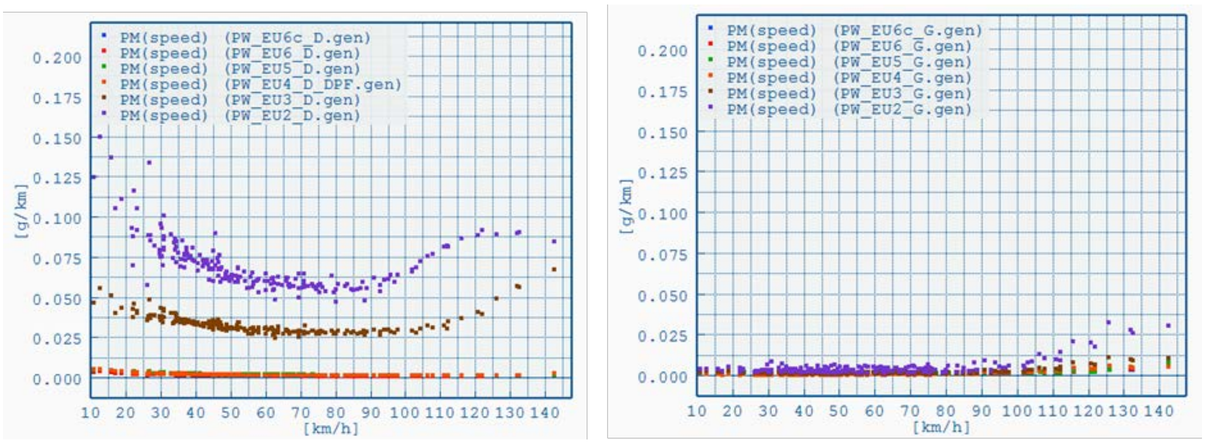

Figure 8: Example of HBEFA3.2 emission factors (particle mass emissions)

3.4. Discussion of emission behaviour of EURO 5 and EURO 6 passenger cars

Additionally for each combination of emission standard and diesel/petrol technology the three phases of the 'Common Artemis Driving Cycle' CADC (urban, rural, motorway) have been simulated with PHEM. These results are the basis for the comparison of the emission behaviour of the EURO classes as discussed in this chapter. Only hot start emission behaviour is treated in this study.

3.4.1. Diesel fuelled vehicles

The 130 km/h maximum speed version of the CADC with gear shift strategy No. 4 is used for discussion of emission factors for diesel fuelled passenger cars. Figure 9 to Figure 15 show the results for emission factors and the NO_2/NO_x ratio.

NO_x emissions are slightly increasing from EURO 4 to EURO 5 despite a limit tightening in the NEDC (from 250 mg/km to 180 mg/km). The difference between EURO 4 and EURO 5 is increasing with higher speed and engine loads.[3]

For EURO 6 LDVs NO_x after-treatment systems are currently foreseen by most of the manufacturers to reach the 80 mg/km NEDC threshold and show clear positive effects also in real world driving resulting in more than 50% lower NOx levels compared to EURO 5. However, this finding of EURO 6 is based on a small sample of measured vehicles. Further improvements in NO_x emissions are expected with the introduction of the EURO 6c step including a test procedure and limit values for RDE from 2017 onwards. NO_2 shares in total NO_x have fallen a bit from EURO 4 to EURO 5. EURO 5 shares are found to be in most cycles in the range between 30 to 40%. CO and HC emissions remain on a very low level indicating that the DOC (Diesel Oxidation Catalyst) technology is well established and technically matured. This is also the case for the DPF effectively reducing PM and PN emissions in all driving situations.

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[3] This statement is based on the data on EURO 4 vehicles as available from the HBEFA3.1. According to newer data and analysis results the NO_x emission levels of EURO 4 diesels cars are somewhat higher compared to the HBEFA3.1 especially in motorway conditions and approximately level with the actual EURO 5 data. Whether this finding shall be incorporated into the HBEFA3.2 (resulting also in an update of EURO 4, which was originally not foreseen) is actually being discussed in the ERMES group. At the latest for the HBEFA4 release the data on EURO 4 shall be updated.

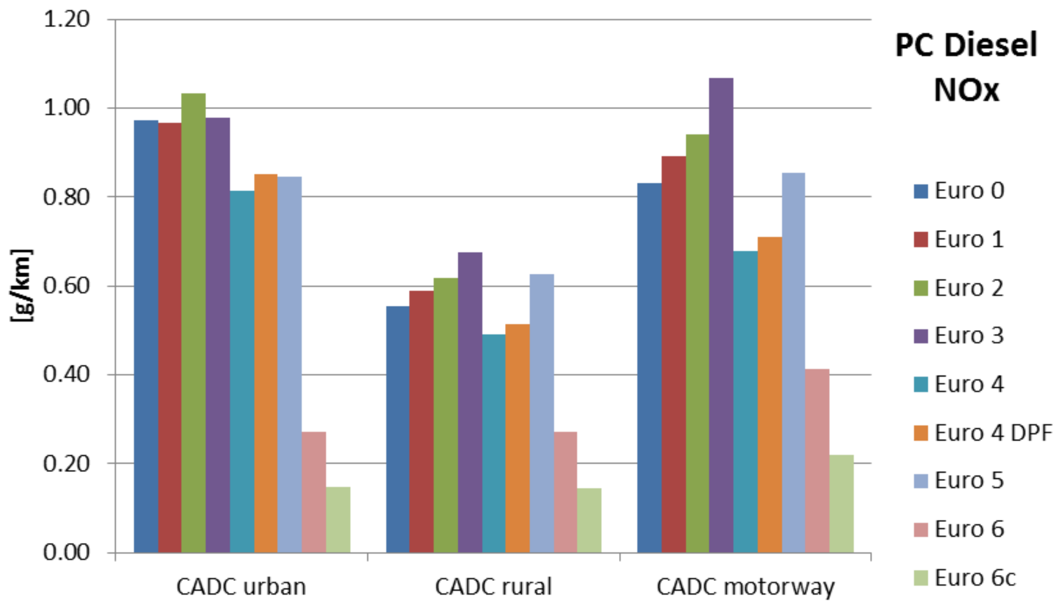

Figure 9: NO_x emission factors of the HBEFA3.2 average diesel cars in the CADC

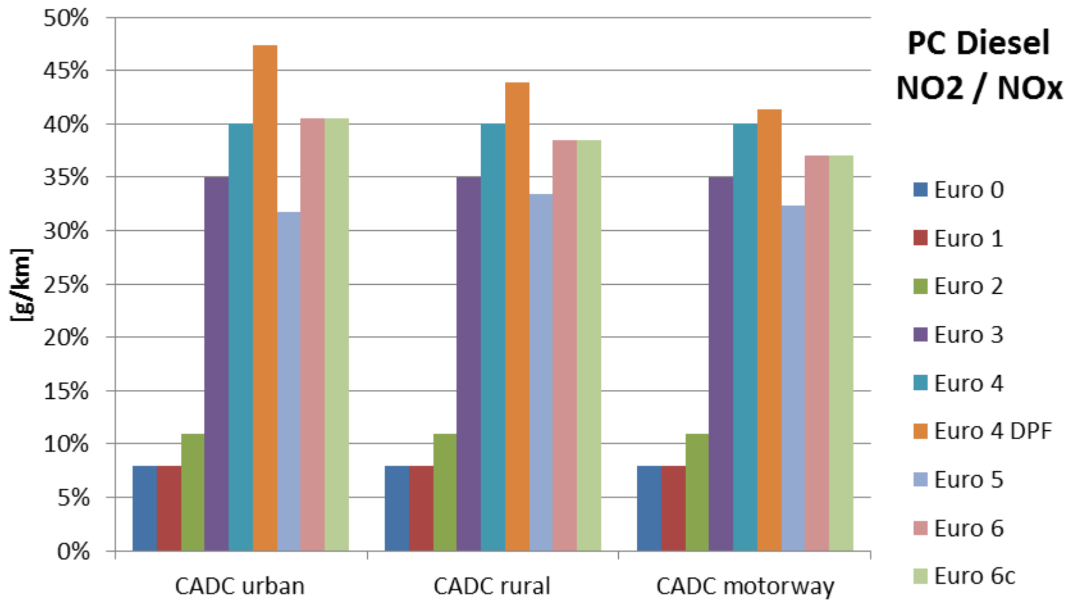

Figure 10: NO_2/NO_x ratios of the HBEFA3.2 average diesel cars in the CADC

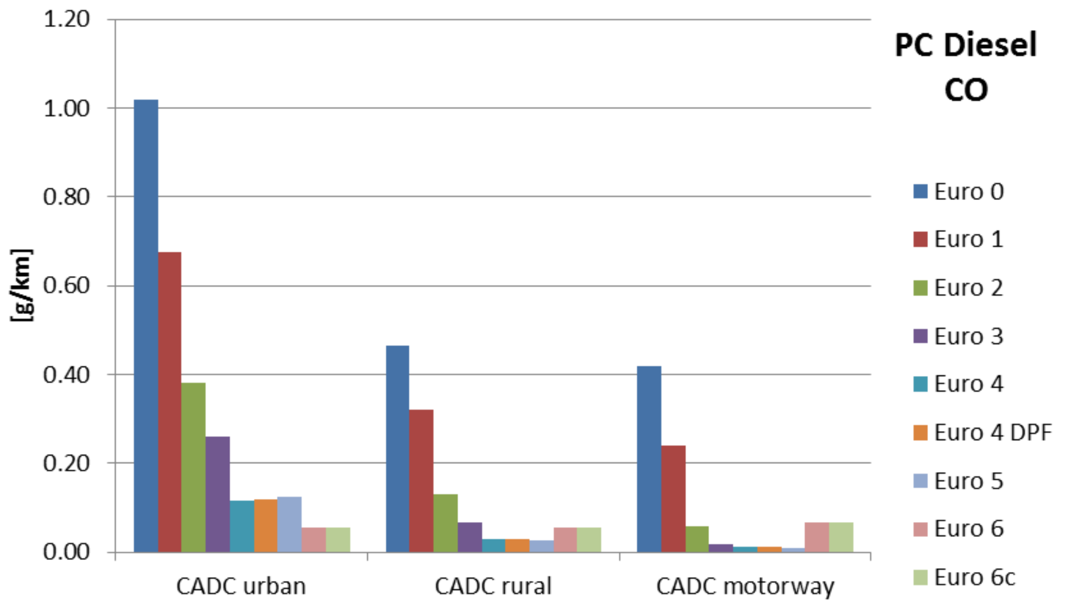

Figure 11: CO emission factors of the HBEFA3.2 average diesel cars in the CADC

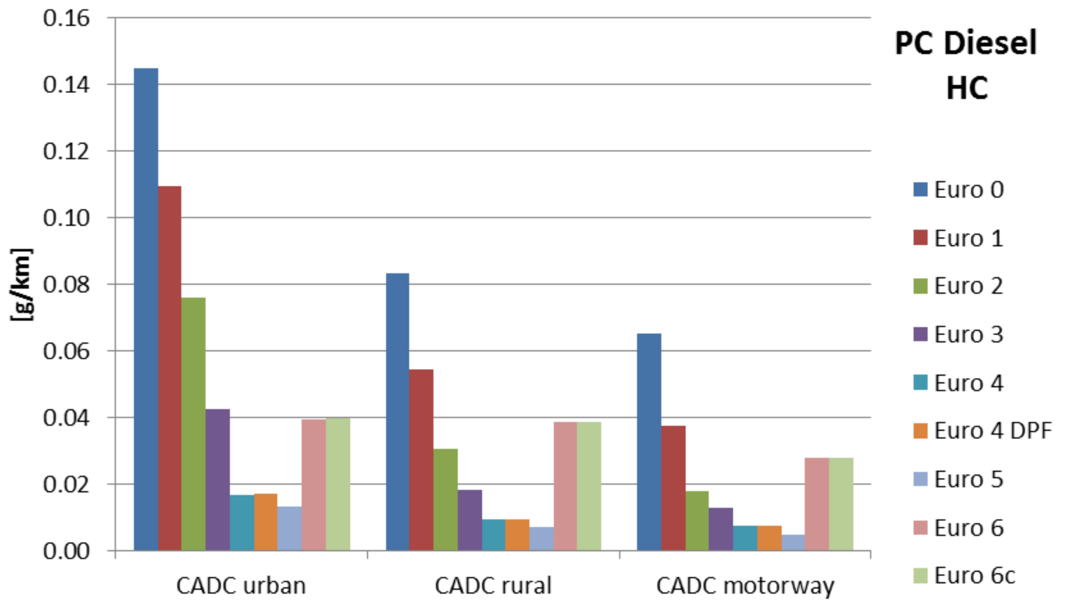

Figure 12: HC emission factors of the HBEFA3.2 average diesel cars in the CADC

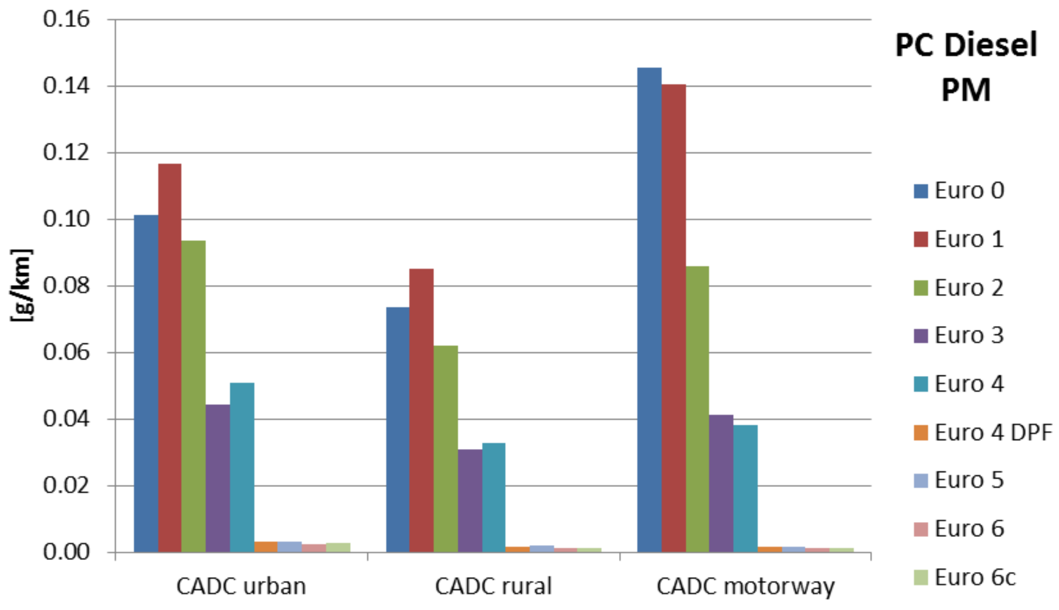

Figure 13: PM emission factors of the HBEFA3.2 average diesel cars in the CADC

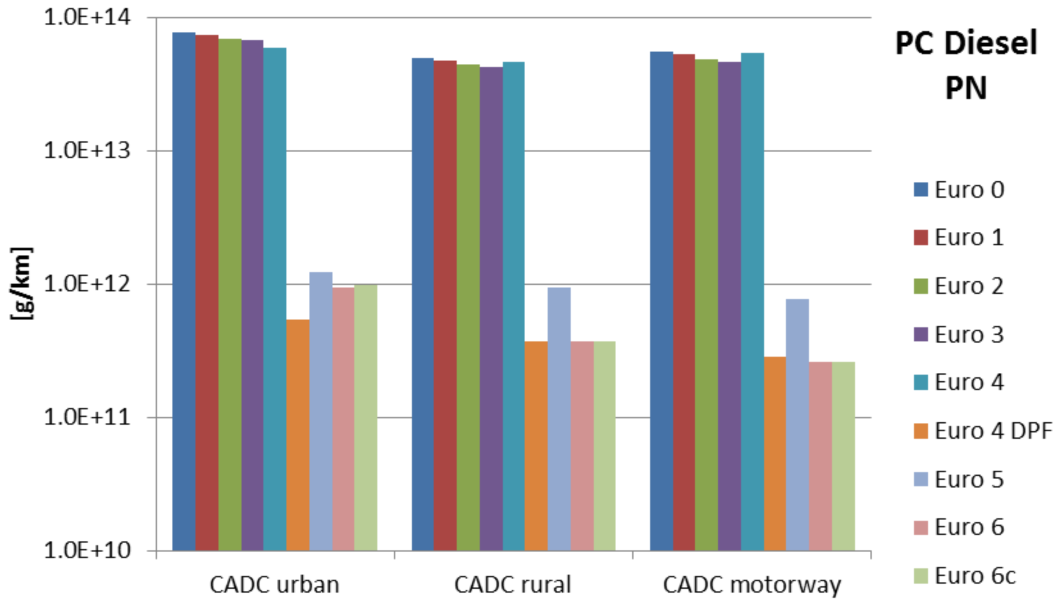

Figure 14: PN emission factors of the HBEFA3.2 average diesel cars in the CADC (logarithmic scale)

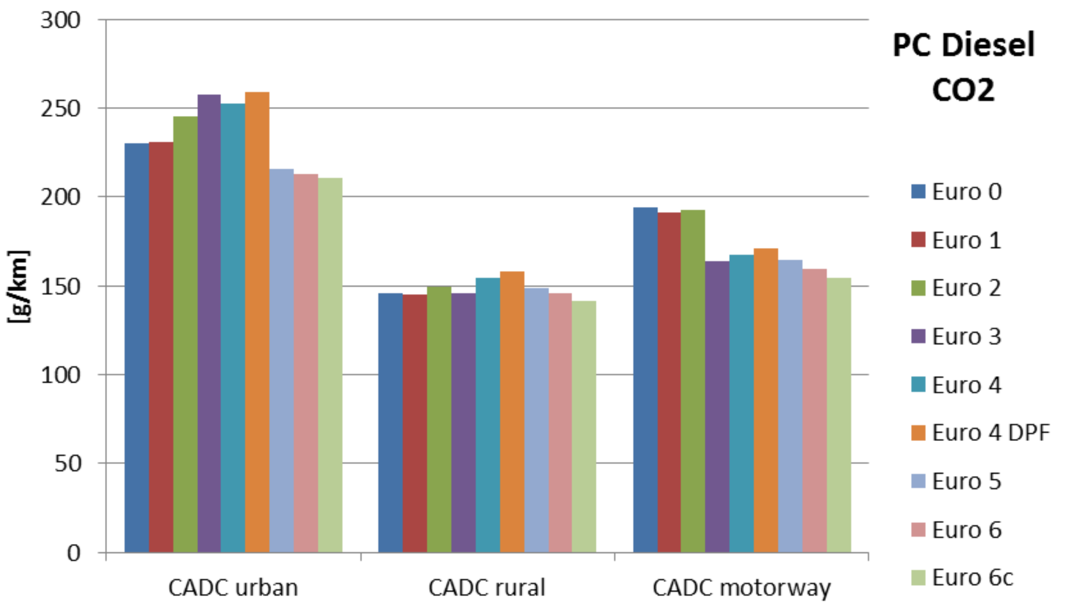

Figure 15: CO_2 emission factors of the HBEFA3.2 average diesel cars in the CADC

3.4.2. Petrol fuelled vehicles

The 130 km/h maximum speed version of the CADC with gear shift strategy No. 2 (EURO 1 to EURO 3) and gear shift strategy No. 3 respectively (all other emission standards) is used for discussion of emission factors for petrol-fuelled passenger cars. The results are shown in Figure 16 to Figure 22.[4]

In comparison to EURO 4 technology further reductions of NO_x, CO and HC emissions can be observed. Driving situations above the light-off temperature of the TWC cause only very low emissions of these pollutants. Malfunctions of the exhaust after-treatment systems have not been observed. The NO_2/NOx ratio remains on a low level around 5%. PM emissions of current petrol direct injection engines are higher than of port injection engines. In any case the absolute PM values are clear below the thresholds and on a comparable level of current diesel vehicles with DPF technology. PN for the average EURO 6 gasoline car was projected to be slightly higher than for EURO 5 because of the rising share of direct injection engines. Anyway, the projection for EURO 6c is downwards since the tightening of PN limits will come into force on 1st Sept 2017 (Type approval) resp. 1st Sept 2018 (1st registration). Also CO_2 emissions show a clear descending trend. Efforts of both improvements of engine efficiencies and vehicle body measures (air resistance, rolling resistance etc.) have clear positive effects.

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[4] The emission factors modelled with PHEM refer to an emission behaviour at a mileage of 50 000km. The influence of mileage (e.g. cause by catalyst aging) is added in a post-processing to the PHEM results in the HBEFA software as a function of selected base year. For the first generations of petrol cars equipped with Three-Way Catalysts (EURO 0 to EURO 2) this mileage influence significantly increases the emission factors, e.g. by a factor of 2 for NOx of EURO 0 vehicles in a base year after 2005.

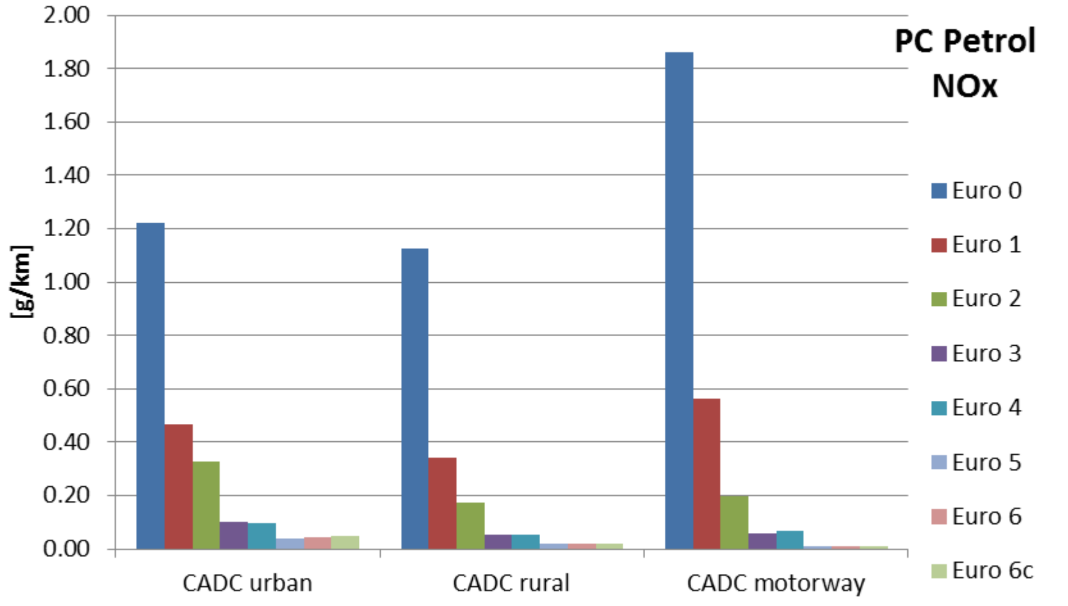

Figure 16: NO_x emission factors of the HBEFA3.2 average petrol cars in the CADC

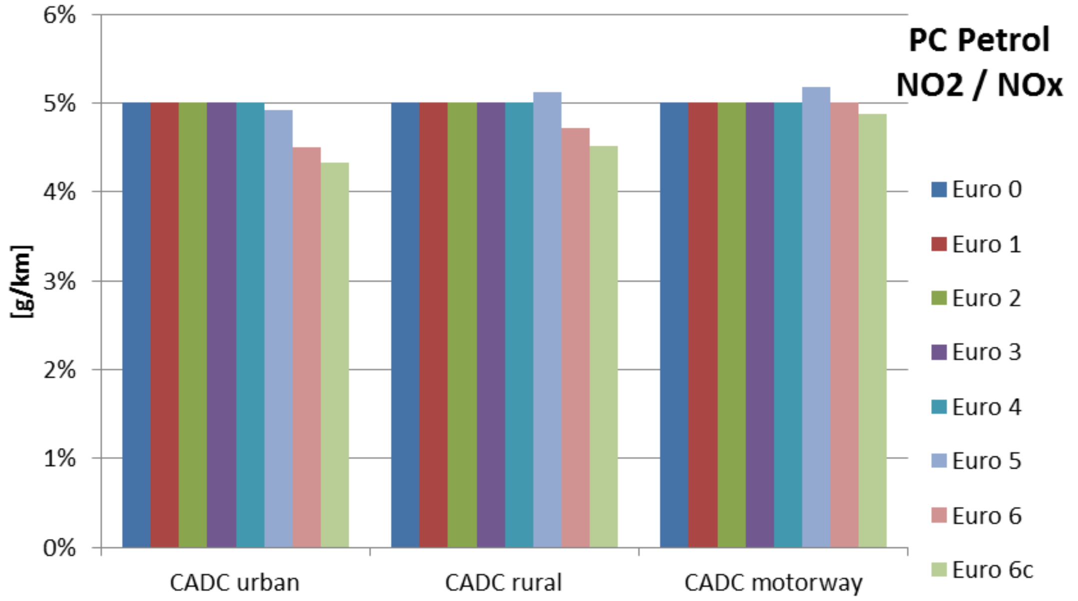

Figure 17: NO_2/NO_x ratios of the HBEFA3.2 average petrol cars in the CADC

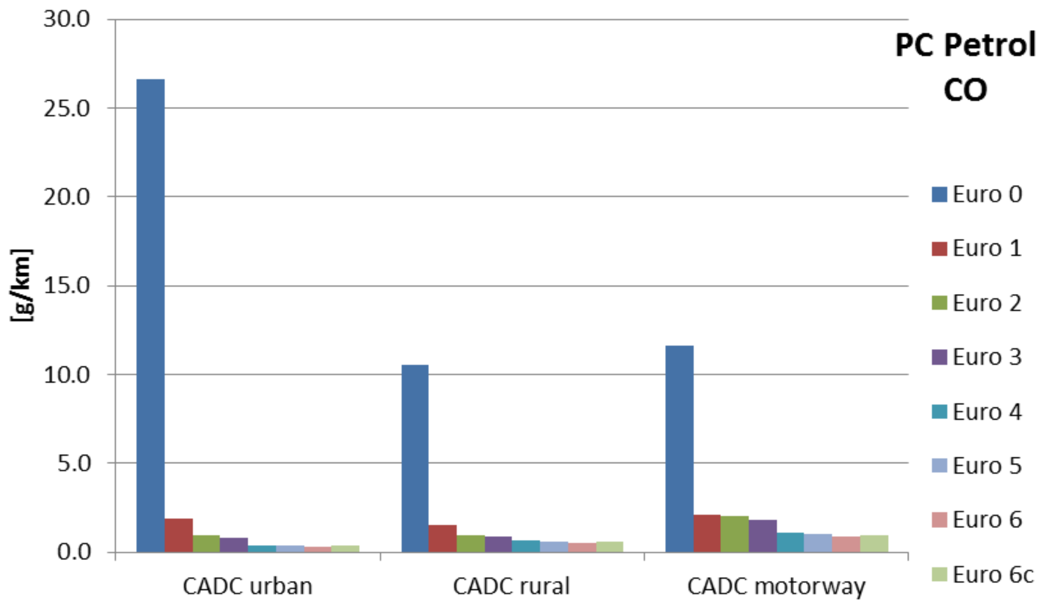

Figure 18: CO emission factors of the HBEFA3.2 average petrol cars in the CADC

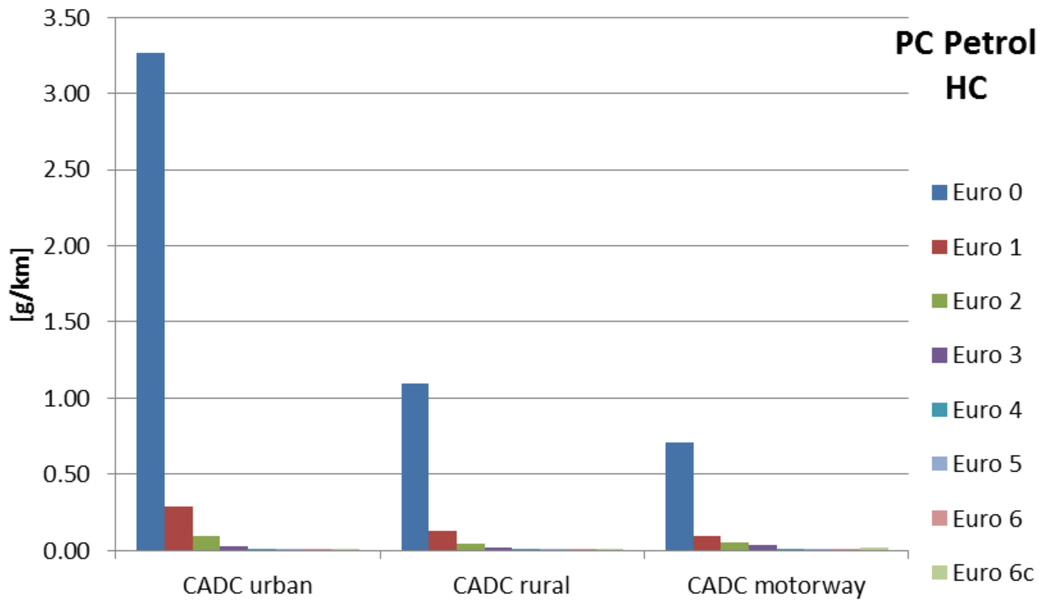

Figure 19: HC emission factors of the HBEFA3.2 average petrol cars in the CADC

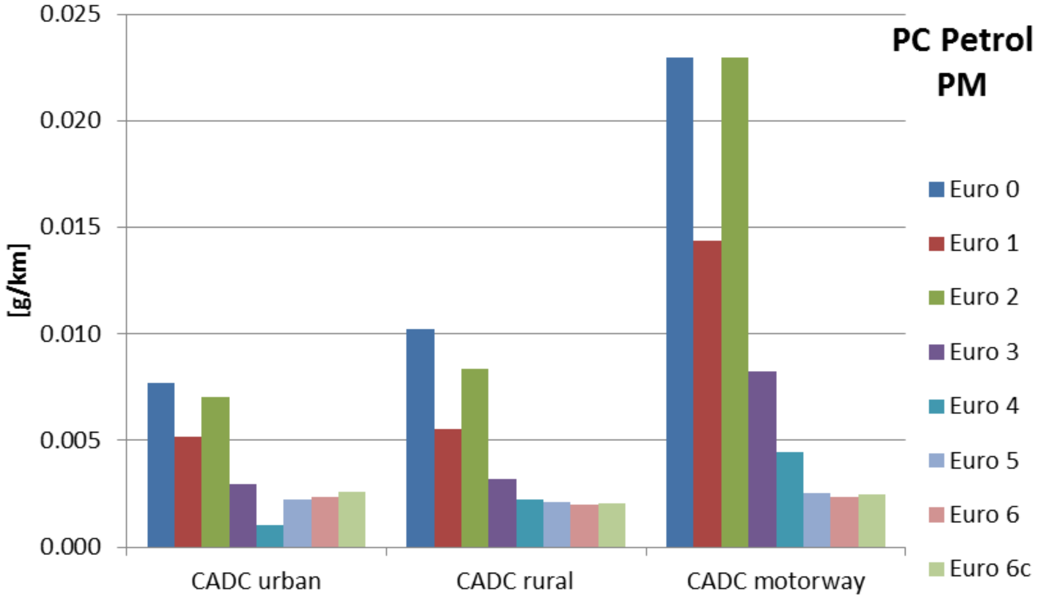

Figure 20: PM emission factors of the HBEFA3.2 average petrol cars in the CADC

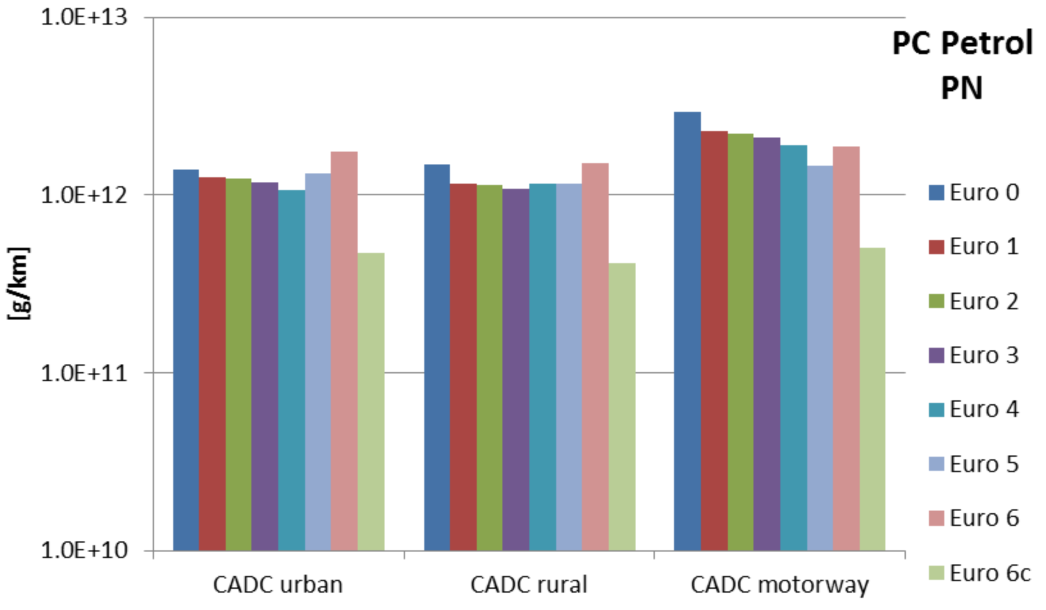

Figure 21: PN emission factors of the HBEFA3.2 average petrol cars in the CADC (logarithmic scale)

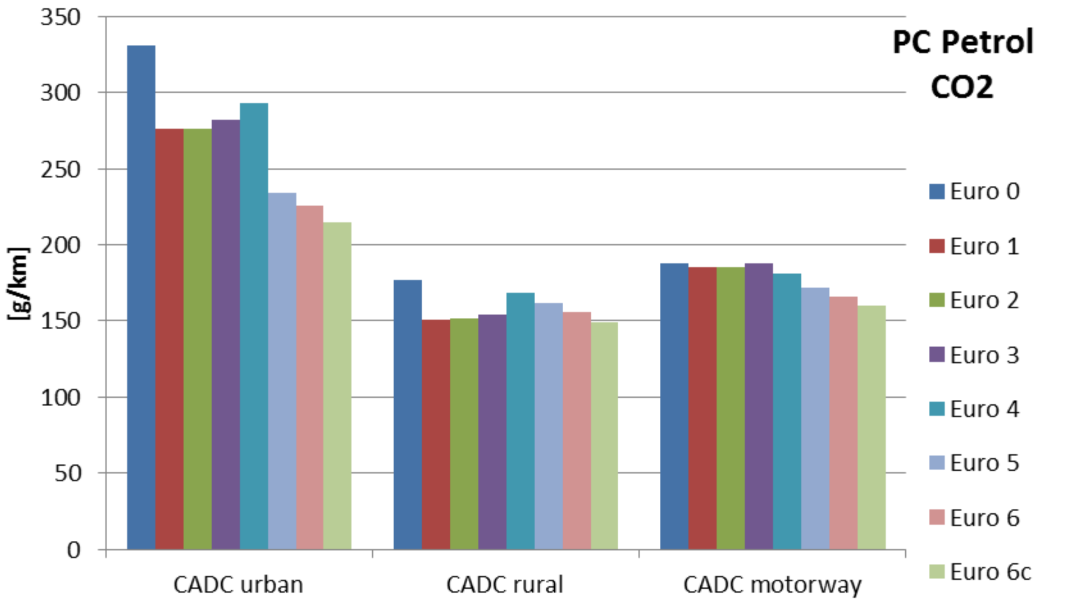

Figure 22: CO_2 emission factors of the HBEFA3.2 average petrol cars in the CADC

3.4.3. European activities on EURO 5 and 6 emission factors

Activities on updating emission factors for cars, LCV and HDV are coordinated in the ERMES group (http://ermes-group.eu/). Beside the update for cars and LCV presented here, TUG also updated the emission factors for HDV based on ERMES measurement data.

TNO made updates on EURO 6 passenger cars emission factors for NL, based mainly on similar test data than shown here. The results have been discussed between TNO and TUG but due to tight time schedules not a complete alignment was possible. However, results are quite similar and the summary on the TNO work is given below.

3.4.3.1. TNO activities on NOx emission of Euro-6 diesel passenger cars

Text provided by Norbert E. Ligterink & Gerrit Kadijk, TNO

At TNO the NO_x emission of diesel passenger cars are of continuing interest, due to the significant contribution of the total NO_x emission and the urban NO_2 concentrations. From Euro-3 onwards the restriction of the emission limits has not led to the similar decrease in real-world NO_x emission. Both in Euro-4 and Euro-5 the initial measurements, prior to the introduction of the new legislation, and a follow-up with vehicles tested with the large sales shares, has led to initial optimism, tempered by the performance of the eventual fleet on the road.

Also for Euro-6, the initial measurements in 2010 showed a decrease in the gap between type-approval emission values and real world emission values, down from a factor of three. These vehicles were sold and used in The Netherlands, but probably meant for the USA market. More recent testing of the few available Euro-6 vehicles, some obtained from the importer, some from private owners, led to a less optimistic forecast for Euro-6 diesel NO_x emission factors. However, the spread in the test results is large. Some vehicle perform less that Euro-5, some substantially better.

Given the fact that the largest sales in The Netherlands is in compact cars and the lower medium market segment, and that the current available cars are upper medium and luxury, the expectation is that the after-treatment technology will be as limited as possible, and the average values from the test program are not fully representative of the diesel passenger car fleet sold in 2014 and 2015. The emission factors from the test results are therefore upped with a risk, based on the spread in the data.

The VERSIT+ emission model is used to determine the 11 common Dutch emission factors, representing different service and congestion levels. The VERSIT+ model is a stylized emission map for vehicle velocity and acceleration. The maps are directly fitted to the emission data, yielding and exact post-diction of the data itself. The different emission factors each correspond to a different weighing of the derived emission map. In this approach 40 minutes of data is sufficient to fill the map of an individual vehicle. The remaining variations between different vehicles is covered as well as possible by a careful analysis of the vehicles sales data, recovering the most important engines, used in many cars.

Two different measurement programs exist at TNO. The chassis dynamometer testing and the on-road PEMS testing. Currently, 11 Euro-6 diesel vehicles, from which 3 are identical makes and models, are tested by TNO on the chassis dynamometer. Of these vehicles 2 are tested with PEMS as well. Typically PEMS emission results is in the same order of the chassis dynamometer. However, the result is partly coincidental, as the driving behavior on the road is less dynamic, but circumstances (wind, road surface, weight, steering, etc.) require more power for the same velocity and distance.

Eventually, the chassis dynamometer tests are the basis for the emission factors, the CADC and the WLTP tests are used to generate the emission maps, which are weighed to the Dutch emission factors. The NEDC tests and the TNO Dynacycle test are not used, both have both deviating driving behavior and emissions, which lead to emission factors which are inconsistent with the results from the CADC and WLTP. The CADC and WLTP driving cycles produce emission maps in the same line.

Table 1 yields the final result for the emission factors for Euro-6 diesel passenger cars to be used in the air-quality model. SRM1 refers to the urban model, SRM2 is the air-quaility model for motorways, where due to larger range, the effect of wind is included. Due to the importance of NO_2 *emissions for* NO_2 *concentrations in urban areas, TNO have been measuring and modeling* NO_2 *systematically since 2009. Euro-5 and Euro-6 show and increase in the* NO_2 *fraction with respect to Euro-4. The* NO_2 *fraction varies with driving behavior, cold-start, turbo, etc.. Eventually, the variation of the direct* NO_2 *fraction between the different emission factors is limited.*

Table 11 The emission factors for the air-quality model (SRM1 and SRM2, update 2014)

[mg/km]	emission estimate	NOx	NO_2
Urban	Congested	379	119
	Normal	237	71
	free-flow	252	69
Rural	Normal	202	53
motorway	Average	425	129
	Congested	377	132
	80 km/h	260	76
	100 km/h control	387	122
	100 km/h	394	123
	120 km/h	437	131
	130 km/h	468	138

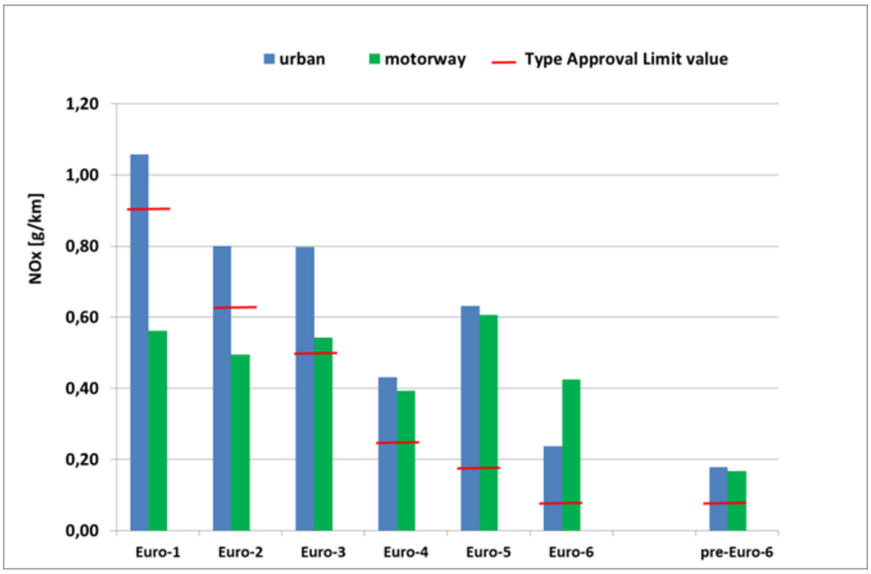

Figure 23: graphical representation of the urban and motorway NOx emission factors gained by TNO for VERSIT+.

3.5. Validation of the emission factors

The validation of the emission factors was based on two steps:

1) Simulation of the measured cycles with PHEM and comparison of test results with simulation
2) A structured comparison of emission factors with data gained by Remote Sensing (RS) measurements

The validation of the PHEM data simulated with the first set of engine maps, based on the sub sample of cars where modal data was available for the creation of engine maps, by comparison with the average bad values from the entire vehicle sample in the ERMES data base showed reasonable accuracy[5]. Since in this validation different vehicle samples are compared, no conclusion on model accuracies is possible. The ratio of bag data to PHEM simulation was finally used to calibrate the first set of engine maps to the total sample of measured vehicles. Thus the results from the calibrated engine maps meet the measured results exactly. Certainly this again cannot be interpreted as model accuracy but no further independent set of test cycles for the entire vehicle sample was available.

Figure 24 shows the comparison of the PHEM results for the first set of engine maps with the measured bag data for NOx from EURO 5 and EURO 6 cars together with the calibration factors applied then to the engine map values. The figures for the other exhaust gas components are shown in ANNEX C.

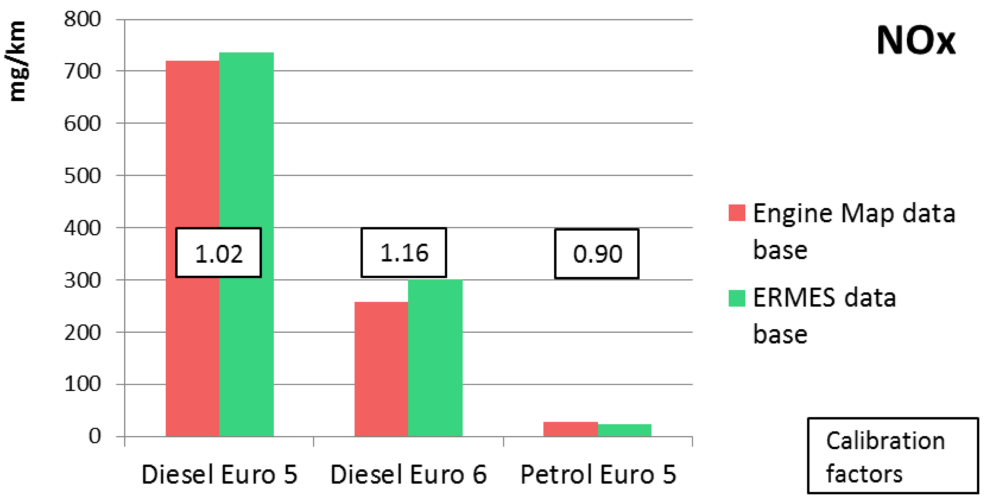

Figure 24: NOx emission factors for the CADC-1/3-mix simulated with PHEM based on the sub sample of cars where modal data was available for engine maps (red) and as averaged values from all available ERMES bag data (green)

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[5] The CADC was not measured for all vehicles in the ERMES data base, so also the sample behind the CADC bag data is not for the complete ERMES vehicle sample. Since on the other hand also vehicles tested in the ERMES cycle only were used to set up the engine emission maps if the ERMES test data was available in modal form, there are also vehicles which are in the first set of engine maps but not in the CADC bag data. However, the number of vehicles tested in the CADC was much higher than those tested in the ERMES cycle only, so the calibration method applied shall give a more representative emission level for the simulated vehicle fleet.

The attempt to use RS results for a structured validation of emission factors was born in an ERMES meeting. The structures will be further elaborated and it is foreseen to establish a data base for RS tests in ERMES too. In the past quite often emission factors have been compared to remote sensing data. Some comparisons showed very good agreement, others not. So the reliability of the information gained by RS for emission value development was seen to be limited.

The actual structure for the comparison foresees following main steps:

- Calculation of the ratio of emission of a pollutant to CO_2 emissions by dividing the concentrations measured in the plume of each vehicle
- Classification of the vehicles from the RS tests according to vehicle type, diesel or gasoline engine and EURO class
- Averaging the ratios of pollutant to CO2 emissions from RS per vehicle class
- Simulation of the emission factors for the speed + acceleration distributions measured at the RS site. Certainly the simulation has to include also the road gradient at the test site.
- Calculation of the pollutant to CO2 ratio of the simulated emission factors
- Comparison of the results from RS and from emission factor simulation (compared can be average values and also the spread of the emissions from single vehicles, which in the simulation result from the variations in speed and acceleration of the vehicles passing the RS site)

Further work and analysis is planned in the ERMES group during 2014. Since RS data is based on a very large vehicle sample, it seems to be helpful to validate if the emission models depicture the fleet average emission levels. On the other hand RS data always gives only a few seconds of driving per passing vehicle and thus is assumed to deliver less reliable data for “average driving behaviour” for different combinations of road categories and traffic situations. Thus RS has clear advantages in the vehicle sample size while emission models have clear advantage in the representatives of the simulated driving situations.

Figure 25 shows the actual status for NOx emissions from passenger cars. In this case just the CADC results from the PHEM simulation are shown, since the single driving situations at the tests sites where quite different and not all sites have been yet simulated with PHEM[6].

The trends between RS and PHEM correspond but some findings are made: for old vehicles PHEM seems to underestimate the RDE. This is logical since PHEM has not included aging effects of catalysts and of engines but uses the engine maps just from the underlying measurement campaigns. Aging functions are added later in the HBEFA software. These aging functions will be compared to the results found from RS. NOx emissions from diesel cars are higher from the RS data than from PHEM. Since some RS analysers measure NO only and NOx is computed by assumptions on the NO2/NOx ratio and since also the road gradients (most of them uphill) and the actual acceleration levels of the vehicles influence NOx levels significantly (but may not be measured with accurate time alignment to the emission plume test value) it cannot be concluded if the emission factors are too low or if RS shows too high

[6] No budget is available yet for a structured comparison of all sites. It is foreseen to do more RS validation work for HBEFA V4 (or earlier in the ERMES group if funding is found.

values. Nevertheless, RS data confirms the rather constant NOx levels from EURO 1 to EURO 5 found in the emission factors.

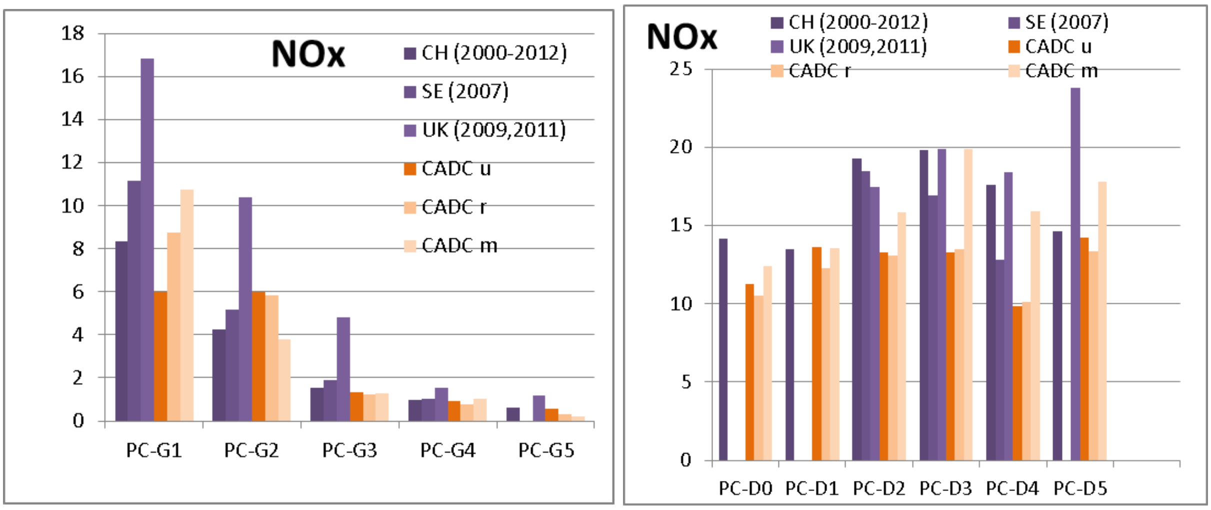

Figure 25: Comparison of the g NOx/kg CO_2 from Remote Sensing from different locations and from the CADC sub cycles simulated with PHEM (left picture for gasoline, right picture for diesel)

Comparisons for CO and HC show larger discrepancies between RS and PHEM yet and need further clarifications before publication.

3.6. Uncertainties in emission factors for passenger cars

Emissions factors resulting from measurements of limited samples sizes are faced to uncertainties. From former emission factor data bases it is known that the main sources of uncertainty are caused by the high variations between different vehicle variants and the sample sizes of measured vehicles which are rather small compared to the basic population of the total vehicle stock (Kühlwein, 2004). Uncertainties of mean emission factors become smaller with increasing sample size. Practically, the number of available emission measurements is restricted by cost aspects. Taking into account weighting factors from registration numbers allows for reducing uncertainties of final mean emission factors by selecting vehicles with high market shares for measurements.

Following the statistical literature (Sachs, 1997) standard errors from samples can be calculated to estimate the uncertainties of the derived means. If a symmetrical distribution of emission factors of single vehicles around the mean emission level in the fleet is assumed[7] the 95% confidence interval (CI95) for the mean emission factor is calculated according Equation 1 and Equation 2.

Equation 1: 95% confidence interval

$$\overline{x} - t \cdot S_{\overline{x}} \leq \mu \leq \overline{x} + t \cdot S_{\overline{x}}$$

[7] In reality the distribution is assumed to be asymmetric since lower emissions than zero are not possible while towards high emissions in RD much wider physical boundaries exist. For emission factors much higher than the related confidence interval, the assumption of normal distribution however shall approximate the real situation sufficiently well.

Equation 2: Weighted standard deviation of the mean value

$$S_{\bar{x}} = \sqrt{\frac{\sum w(x-\bar{x})^2}{(n-1)\sum w}}$$

with:

μ	mean emission factor in the fleet [g/km]
$\bar{x}$:	weighted arithmetic mean emission factor of the measured sample [g/km]
$S_{\bar{x}}$	weighted standard deviation of the mean value of the measured sample[g/km]
t	factor from students t-distribution calculated based on the number of measured vehicles (n-1) and the error probability (5%) [-]
x:	emission factor for a single measured vehicle [g/km]
n:	number of measured vehicles [-]
w:	weighting factor for particular measured vehicle (number of new registrations) [-]

The calculated CI95 for the mean emission levels are shown in Table 12 (EURO 5 petrol), Table 13 (EURO 5 diesel) and Table 14 (EURO 6 diesel). The relative variations clearly depend on the pollutant with CO_2 at the lower and PN at the upper end of the uncertainties.[8] It can also be seen that bigger sample sizes have a strong positive effect on the data quality, e.g. for CO_2 and NO_x diesel vehicles comparing the Euro 5 with the Euro 6 results. The main points emerging from the uncertainty analysis can be summarised as follows:

PN emissions:

Among all pollutants, highest uncertainties have been determined for PN emissions. Beside the effect of a large scatter of different vehicle and engine types, also large deviations between results from different labs can be observed, i.e. lab differences by a factor of 10 to 100 occur between measurements of the same engine type at the same driving cycle. Even the variability of test results within a single lab is high. One may conclude that calibration methodologies for PN measurement devices do still not fulfil the same standards as for other pollutants and/or that the vehicle PN emissions are very sensitive to the status of the DPF (empty, loaded, temperature) and to engine operation conditions. But further investigations on this topic are necessary to achieve PN data of more reliable quality.

NOx emissions of Diesel vehicles:

For EURO 5 diesel cars the CI95 for NOx is quite small (approx. +/-10% of the mean emission factor). So the conclusion that this vehicle segment has higher real world NOx emissions than its predecessor EURO 4 is statistically founded. Concerning NO_x emissions from EURO 6 diesel vehicles it is currently still very uncertain which NO_x reduction technologies (SCR, LNT, engine control) will dominate the market situation in the next years and how effective these techniques will be during real-world driving, e.g. in terms of urea dosing strategies. This factum additionally increases the uncertainty compared to the values shown in Table 14.

[8] For datasets where the weighted mean value is not significantly higher than the calculated margin for 95% confidence interval, the assumption of a symmetrical distribution of emission factors of single vehicles around the mean value is not valid. In these cases the calculated uncertainties are only indicative.

For all other criteria pollutants the relative uncertainties may appear high but are not important in absolute numbers as the mean emission levels are close to zero.

Table 12: 95% confidence intervals for mean emission levels **EURO 5 petrol** related to the limited sample size

CADC phase	pollutant	number of vehicles	weighted mean	95% confidence interval	
			[g/km]	± [g/km]	± [-]
urban	CO	22	0.185	0.062	34%
rural	CO	22	0.241	0.058	24%
motorway	CO	18	1.329	0.203	15%
urban	CO2	22	211.3	14.765	7%
rural	CO2	22	127.2	5.199	4%
motorway	CO2	18	156.2	5.064	3%
urban	HC	19	0.0163	0.010	62%
rural	HC	20	0.0045	0.002	37%
motorway	HC	19	0.0103	0.006	55%
urban	NOx	21	0.0477	0.014	29%
rural	NOx	21	0.0171	0.003	16%
motorway	NOx	18	0.0093	0.003	32%
urban	PM	9	0.0013	0.001	53%
rural	PM	9	0.0009	0.000	51%
motorway	PM	8	0.004	0.009	236%
urban	PN	12	1.22E+12	9.71E+11	80%
rural	PN	12	6.06E+11	5.15E+11	85%
motorway	PN	8	1.04E+12	2.22E+12	213%

Table 13: 95% confidence intervals for mean emission levels **EURO 5 diesel** related to the limited sample size

CADC phase	pollutant	number of vehicles	weighted mean	95% confidence interval	
			[g/km]	± [g/km]	± [-]
urban	CO	33	0.081	0.049	60%
rural	CO	32	0.048	0.069	144%
motorway	CO	23	0.01	0.004	41%
urban	CO2	35	214.2	14.835	7%
rural	CO2	35	119.6	6.097	5%
motorway	CO2	33	144.7	7.129	5%
urban	HC	36	0.0131	0.004	31%
rural	HC	36	0.0091	0.007	76%
motorway	HC	32	0.0026	0.001	39%
urban	NOx	35	0.9719	0.098	10%
rural	NOx	35	0.533	0.040	7%
motorway	NOx	33	0.793	0.102	13%

CADC phase	pollutant	number of vehicles	weighted mean	95% confidence interval	
			[g/km]	± [g/km]	± [-]
urban	PM	33	0.002	0.001	61%
rural	PM	25	0.0011	0.001	75%
motorway	PM	23	0.0022	0.002	85%
urban	PN	32	9.53E+11	1.42E+12	149%
rural	PN	32	6.22E+11	9.95E+11	160%
motorway	PN	29	7.41E+11	1.01E+12	136%

Table 14: 95% confidence intervals for mean emission levels **EURO 6 diesel** related to the limited sample size

CADC phase	pollutant	number of vehicles	weighted mean	95% confidence interval	
			[g/km]	± [g/km]	± [-]
urban	CO	10	0.018	0.011	63%
rural	CO	10	0.052	0.032	61%
motorway	CO	10	0.106	0.120	113%
urban	CO2	10	221.6	41.397	19%
rural	CO2	10	130.2	16.966	13%
motorway	CO2	10	164.4	23.753	14%
urban	HC	10	0.0354	0.031	87%
rural	HC	10	0.0355	0.023	64%
motorway	HC	9	0.0332	0.021	63%
urban	NOx	10	0.2553	0.166	65%
rural	NOx	10	0.1384	0.071	51%
motorway	NOx	10	0.2777	0.228	82%
urban	PM	5	0.0023	0.002	85%
rural	PM	5	0.0005	0.000	56%
motorway	PM	5	0.0011	0.001	50%
urban	PN	10	3.32E+11	4.84E+11	146%
rural	PN	10	4.69E+10	5.77E+10	123%
motorway	PN	10	7.97E+11	1.32E+12	165%

Additional sources of uncertainties like model inaccuracies or measurement errors further raise the total statistical errors of the final emission factors. Model uncertainties are relevant especially for emission factors related to driving conditions which are weakly covered by the vehicle tests used for model parameterisation. A quantification of these model related uncertainties was done in (Zallinger, 2010) for EURO 4 passenger cars. E.g. for fuel consumption and CO_2 emission factors a model accuracy related CI95 of approximately +/-6% was determined. For NOx emissions of diesel cars the CI95 arising from the model uncertainty was determined with +/-45% for urban traffic situations and +/-9% for motorway driving conditions. For EURO 5 and EURO 6 technology such analysis is not available as the available data hardly allow for such an analysis since almost all real world test cycles measured were used to set up and calibrate the model. Especially for the modelling of NOx emissions of first generation of EURO 6 diesel vehicles – which already apply advanced NOx reduction technologies but nevertheless show increased NOx levels in certain real world driving conditions – the model inaccuracy is assumed to significantly contribute to the overall uncertainty of HBEFA emission factors.

4. Emission factors for light commercial vehciles

The method used to produce the emission factors for LCV is basically similar to the one described for passenger cars before. The available test data for LCV however is much smaller than for passenger cars. Since the elaboration of emission factors for HBEFA 3.1 only 6 new LCV are made available, all tested at TUG (Table 15).

Table 15: Available new test data on LCV since the HBEFA 3.1

Vehicle	Fuel	EURO	Class	mass [kg]	R0 [N]	R1 [Ns/m]	R2 [N s²/m²]
Peugeot Boxer 2.2 HDI	Diesel	EU5	N1-III	2325	124.35	10.015	0.677
VW BUS T5 4Motion	Diesel	EU5	N1-III	2137	233.5	7.296	0.607
Opel Vivano 2.0	Diesel	EU5	N1-III	2154	228.03	7.125	0.593
Fiat Doblo 1.6l	Diesel	EU5	N1-II	1720	171.66	8.43	0.58
Fiat Ducato 3.0	Diesel	EU4	N1-III	2260	219.8	0	0.945
VW Crafter 35	Diesel	EU4	N1-III	2325	281.59	1.959	0.917

As no EURO 6 LCV were available for setting up the engine maps and for model calibration, the same relative changes between EURO 5 and EURO 6 have been assumed as found for passenger cars (Table 16).

Table 16: Ratios applied to generate emission factors for LCV EURO classes where no measurements are available yet

	FC	NOx	CO	HC	PM	PN
Diesel EU6 / EU5	0.97	0.37	1.22	4.65	0.75	0.50
Diesel EU6c / EU6	0.97	0.53	1.00	1.00	1.00	1.00
Petrol EU6 / EU5	0.95	1.11	0.87	1.05	0.99	1.30
Petrol EU6c / EU6	0.94	1.09	1.03	1.11	1.07	0.27

As for passenger cars vehicle data and engine maps for EURO 0 to EURO 4 was not changed against the HBEFA 3.1 version. The two newly available EURO 4 vehicle tests fitted very well to the former emission factors. Also the EURO 5 diesel LCV test data fit quite well the assessment made in HBEFA 3.1. For NO_x the measured values suggest an increase of 20% for N1-III vehicles and of more than 100% for the N1-II LCV compared to EURO 4. The high NOx emissions for the EURO 5 average are caused mainly by one vehicle in the N1-III class and in total only one N1-II vehicle was tested. It was decided not to change the emission factors based on these few measured LCV to such a large extend[9]. Thus the emission maps were calibrated towards the NOx values in HBEFA 3.1.

However, it has to be noted that further measurements on LCV with EURO 5 and – when available certainly also with EURO 6 – certification are urgently demanded if LCV emission factors shall become more reliable in HBEFA 4

For petrol driven LCV no new test data was available, thus the vehicle and engine data assessed for these vehicles in HBEFA 3.1 were used also for HBEFA 3.2. No major problems with the RD emission behaviour of gasoline LCV are expected. However, some tests of this vehicle category are also suggested.

The results of the PHEM simulation compared to measured results in the CADC are shown below.

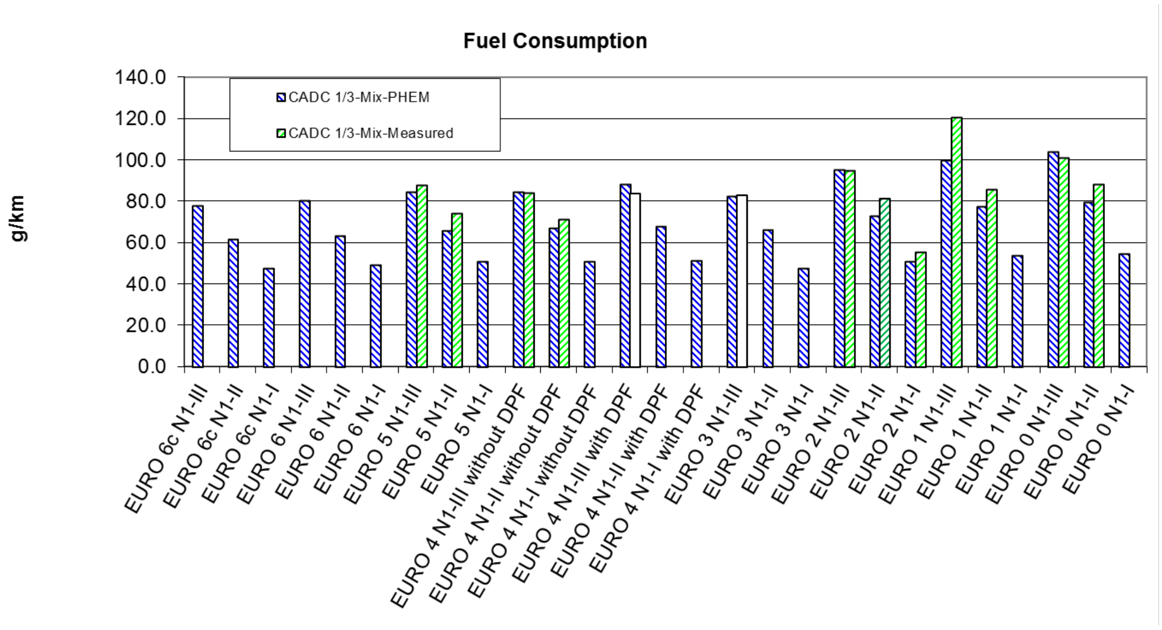

Figure 26: Fuel consumption of diesel LCV simulated and measured in the CADC 1/3 mix

9 Also the number of tested LCV in HBEFA 3.1 for EURO 0 to EURO 4 was very small (Hausberger, 2009), thus the relative changes between the EURO classes are very uncertain.

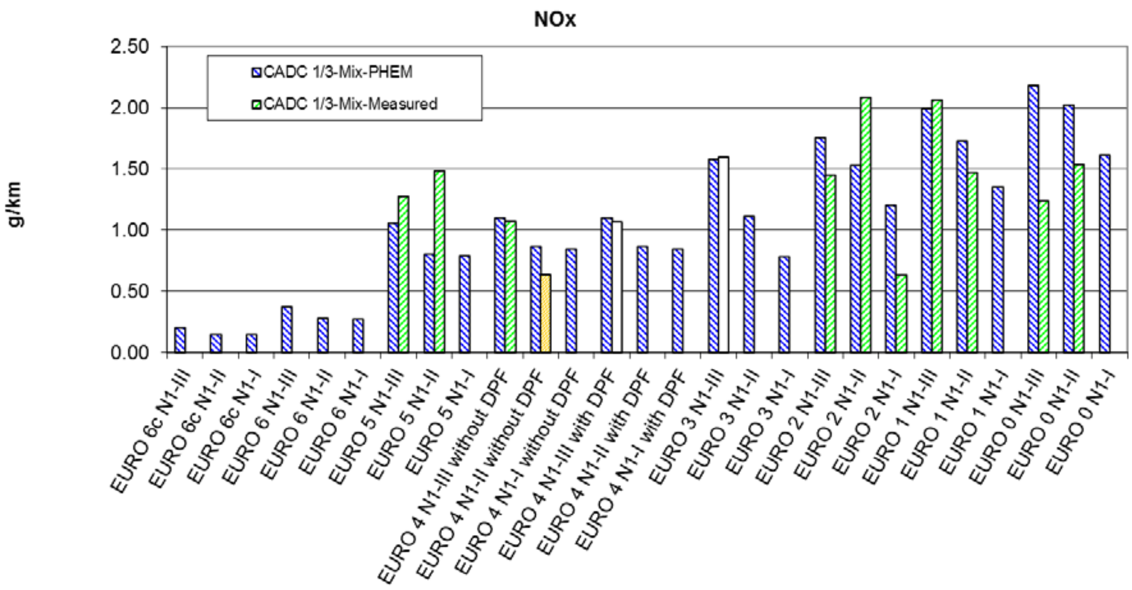

Figure 27: NOx emissions of diesel LCV simulated and measured in the CADC 1/3 mix

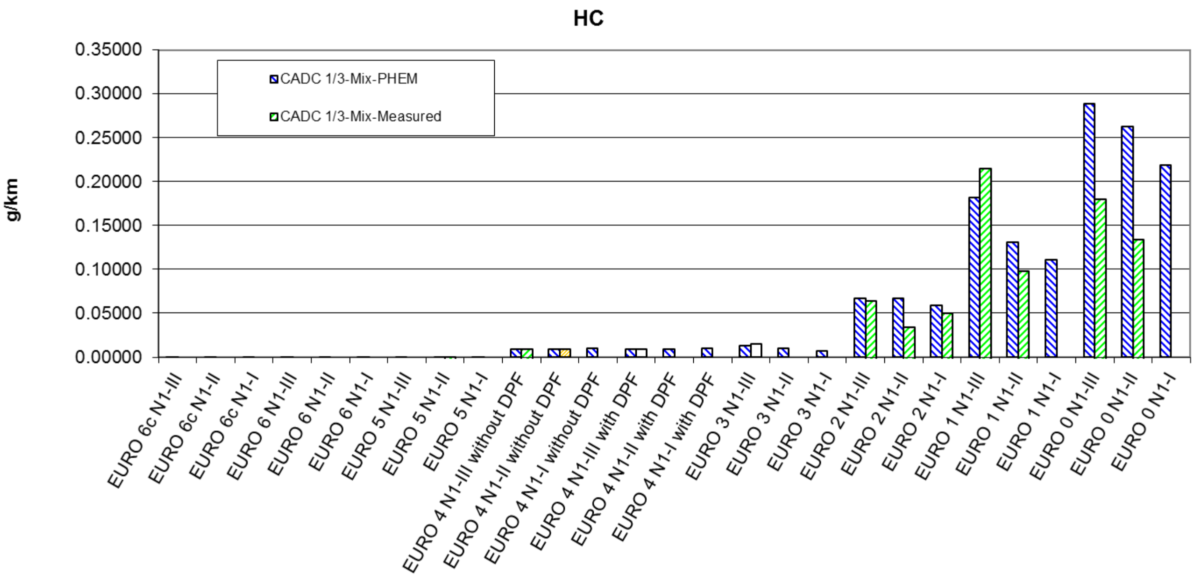

Figure 28: HC emissions of diesel LCV simulated and measured in the CADC 1/3 mix

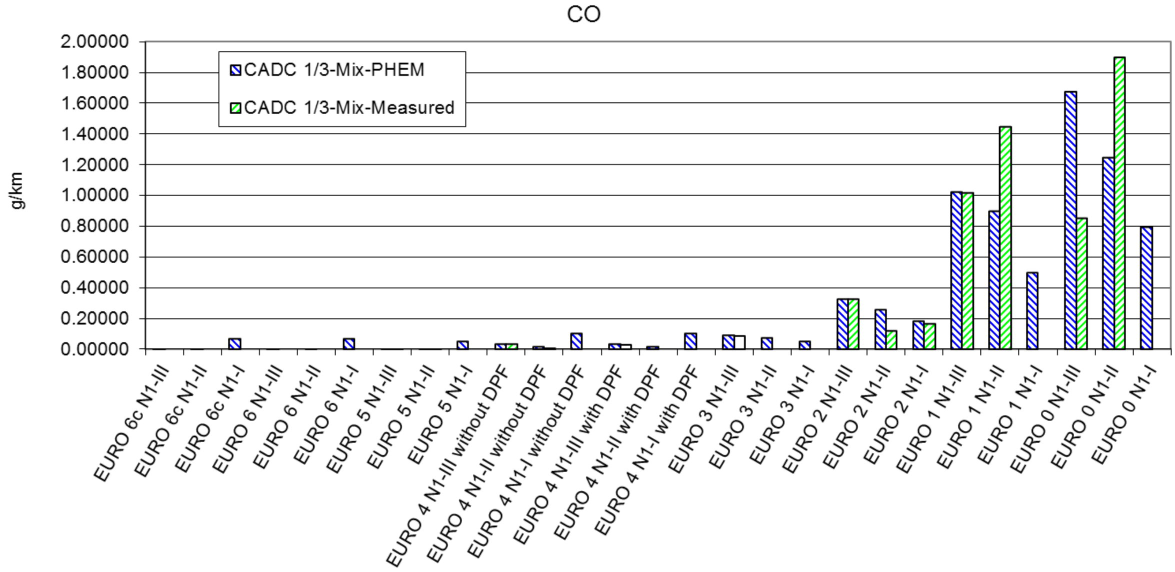

Figure 29: CO emissions of diesel LCV simulated and measured in the CADC 1/3 mix

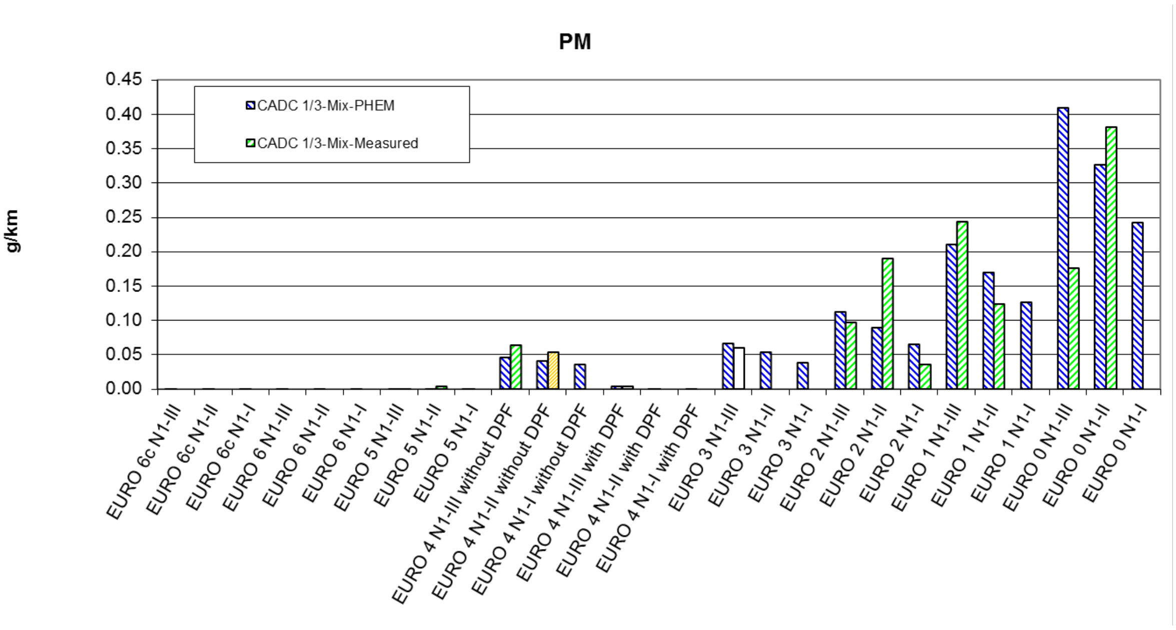

Figure 30: PM emissions of diesel LCV simulated and measured in the CADC 1/3 mix

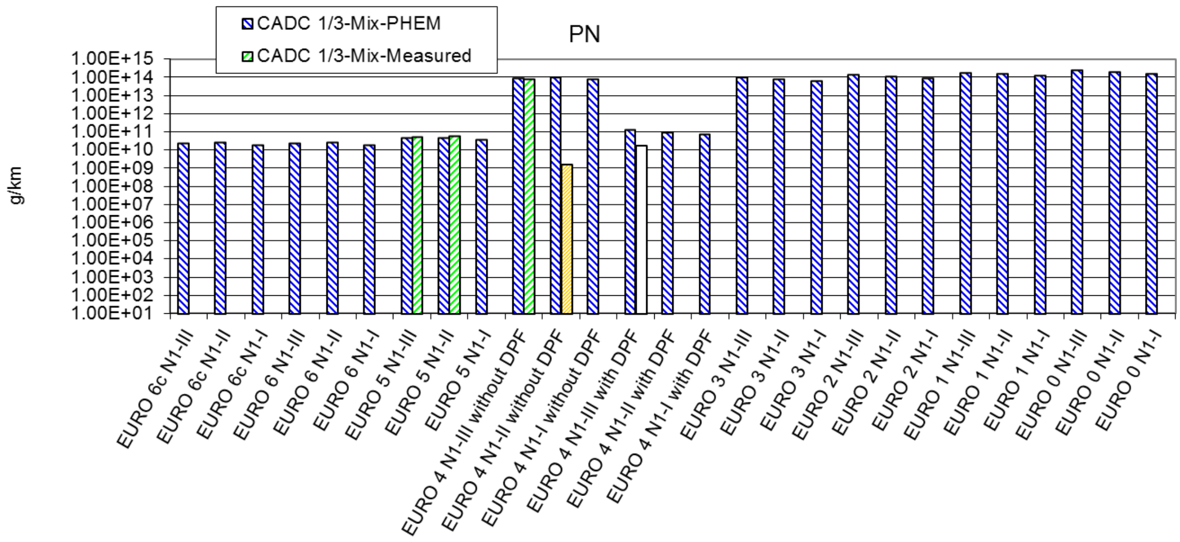

Figure 31: PN emissions of diesel LCV simulated and measured in the CADC 1/3 mix

5. Emission factors for heavy duty vehicles

Similar to PC and LDV in this study only emission factors for vehicle generations EURO V and EURO VI have been updated for the HBEFA3.2. In this chapter an overview on the available emission tests is given and the test results as well as the EURO V and EURO VI emission factors for the HBEFA3.2 are discussed.

5.1. Overview available emission tests

Table 17 gives an overview on the number of measured HDV available from the in-use tests. Bold numbers indicate the updated datasets for EURO V and EURO VI for the upcoming HBEFA3.2. Numbers in brackets refer to the number of measured EURO V and EURO VI HDV already included in the HBEFA 3.1 version. The dataset for EURO V with SCR is now supplemented by two additional vehicles and comprises in total eight HDV. For the technology EURO V with EGR now three and for EURO VI now five[10] different makes and models are available for the HBEFA3.2. The HBEFA3.1 emission factors for these emission concepts have based on a prognosis only.

Table 17: Overview available HDV emission test data (bold numbers: updated datasets for HBEFA3.2, numbers in brackets: measured HDV already included in the HBEFA3.1)

<table>
<tr><th colspan="2" rowspan="2">Emission concept</th><th colspan="3">number of vehicles/engines measured</th><th rowspan="2">remarks</th></tr>
<tr><th>engine test bed</th><th>chassis dynamometer</th><th>on board (PEMS)</th></tr>
<tr><td colspan="2">Pre Euro</td><td>40</td><td>---</td><td>---</td><td rowspan="2">only few data comprise transient test cycles</td></tr>
<tr><td colspan="2">Euro I</td><td>13</td><td>---</td><td>---</td></tr>
<tr><td colspan="2">Euro II</td><td>21</td><td>1</td><td>---</td><td></td></tr>
<tr><td colspan="2">Euro III</td><td>27</td><td>---</td><td>---</td><td></td></tr>
<tr><td rowspan="2">Euro IV</td><td>EGR</td><td>1</td><td>1</td><td>3</td><td>only in-use tests for one of three manufactures available</td></tr>
<tr><td>SCR</td><td>1</td><td>---</td><td>2</td><td></td></tr>
<tr><td rowspan="2">Euro V / EEV</td><td>EGR</td><td>---</td><td>2 (0)</td><td>1 (0)</td><td></td></tr>
<tr><td>SCR</td><td>---</td><td>5 (4)</td><td>3 (2)</td><td></td></tr>
<tr><td colspan="2">Euro VI</td><td>1 (0)</td><td>4 (0)</td><td>---</td><td>Since deadline for HBEFA3.2 data submission expired two additional measurements were made available (which confirm test results included in HBEFA3.2)</td></tr>
</table>

Makes and models of the measured EURO V and EURO VI HDV are listed in ANNEX D.

[10] After the deadline for HBEFA3.2 data submission had expired two additional datasets on EURO VI HDV (two vehicles of a single make measured on an engine test bed test and on the chassis dyno) were made available. The test additional results confirm the emission levels for this make as included in the HBEFA3.2.

5.2. Discussion of EURO V and EURO VI emission test results

Below the main findings for regulated pollutants from the analysis of the emission test data are discussed. Results for fuel consumption and CO_2 emissions are not included in the analysis as the restrictions in comparability of in-use test results measured with different methods (engine dyno chassis dyno or with PEMS) does not allow for direct comparison of emission concepts or makes and models.

5.2.1. EURO V with EGR

Only two manufacturers provide EURO V HDV with EGR NO_x abatement strategy. Products from both manufacturers have been measured for the HBEFA3.2 comprising two chassis dyno tests series and one PEMS measurement. For the vehicle measured by PEMS no data on particle mass and number were available. Due to several other data quality reasons the PEMS dataset was considered in the parameterisation of the PHEM emission model only with a weighting factor of 50% compared to the other measured vehicles.

Table 18 shows the weighted brake specific (BS) emission levels for the three measured HDV. These numbers have been determined based on the PHEM transient engine maps – which are generated by allocation of modal measured emissions to the engine speed and engine power grid – by applying weighting factors representing a typical HDV engine operation pattern. For the two HDV measured on the chassis dyno the average NO_x emission levels were somewhat higher than the EURO V emission limit in the ETC (2 g/kWh). The third vehicle – which was measured with PEMS – had significantly higher average NO_x levels. NO_2/NOx ratios from EURO V with EGR were found to be depended on the make. The vehicles which were equipped with aftertreatment systems (DOC or PM-catalyst) showed higher shares NO_2 on NO_x (15% to 25%) compared to the HDV without aftertreatment (3%). Real world PM output was measured in the range of the EURO V ETC limit (0.03g/kWh) or somewhat higher. CO and HC were found to be on a very low level.

Table 18: Weighted BS emission levels - EURO V EGR

[g/kWh]	**NO_x**	**CO**	**HC**	**PM**	**PN**	**NO2 / NOx**
veh 1	2.45	0.56	0.15	0.048	1.09E+14	15%
veh 2	2.78	0.40	0.08	0.030	6.58E+13	3%
veh 3	3.84	0.24	0.02	---	---	25%

Figure 32 gives the picture of the BS NO_x distribution of the average EURO V EGR engine as generated by PHEM from the in-use tests. The typical NO_x shape resulting from the ETC/ESC type approval can be observed: in the medium and high engine speed range – which is well covered in the EURO V type approval – the BS NO_x emissions meet the EURO V limit (2g/kWh) well. In the low engine speed range NO_x emissions are significantly higher.

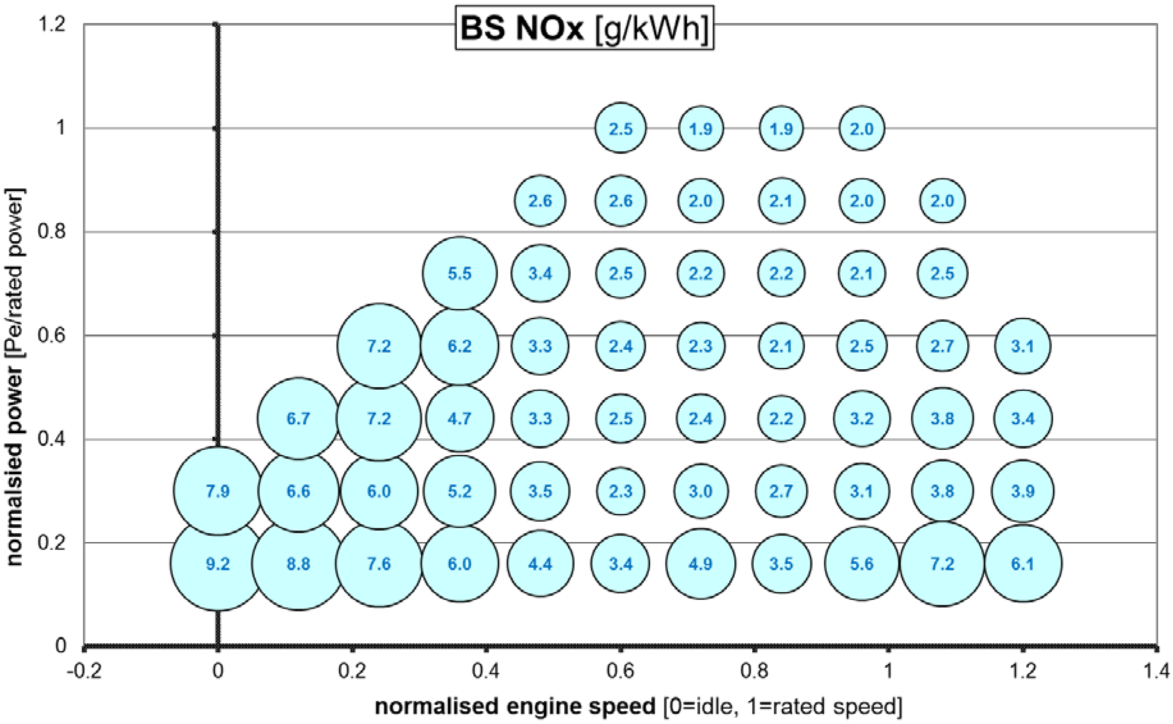

Figure 32: PHEM engine map- NO_x EURO V EGR

5.2.2. EURO V with SCR

For EURO V with SCR two additional measured HDV were available from the in-use tests (one HDV measured on the chassis dyno, one HDV measured with PEMS). Now for this emission concept in total data on eight different makes and models is included in the HBEFA3.2. The new emission data is basically in line with the behaviour as analysed from the previously measured vehicles. Average CO emission levels from EURO V with SCR were reduced by 8% compared to the HBEFA3.1. Regarding NO_x the new data indicate slightly lower emissions in the low engine load area and slightly higher NO_x levels at high engine loads.

Regarding modelling of PM emissions the PHEM parameterisation for EURO V SCR as used in the HBEFA3.1 lead to implausible emission factors in some cases. This bug was removed from the model for the HBEFA3.2. As a consequence compared to the HBEFA3.1 the new set of PM emission factors has a shift to higher emission levels in low dynamic driving conditions.

5.2.3. EURO VI

For the elaboration of the EURO VI emission factors data from five makes and models were available. Four EURO VI vehicles were tested on the chassis dynamometer, one EURO VI engine was measured on the engine testbed.

Figure 33 presents all test results for NO_x emissions in brake specific format (g/kWh). The results are plotted as a function of cycle average engine power (average power divided by rated engine power).[11] This format enables to compare test results of different engine sizes. For assessment reasons the picture also shows the EURO VI emission limits in the WHSC and WHTC (red crosses), typical emission behaviour of EURO V with SCR (grey dots) and the prognosis for EURO VI made in the HBEFA3.1. The presentation of measurement results furthermore differentiates between hot started emission tests (filled symbols) and test results for cold start (empty symbols).

All tested vehicles and engines were found to have very low NO_x levels in all operation conditions relevant for typical real world conditions. At medium and high engine loads the BS NOx levels are in the range of the limits in the WHSC/WHTC which confirms the HBEFA3.1 prognosis. In cycles with low average engine loads (normalised engine power around 10%) the test results for NO_x showed a certain scattering: whereas some models met the WHTC NOx limits even in this disadvantageous operation conditions some other models showed a clear sensitivity of NO_x levels to low engine loads. However, based on the data available so far, it is assessed that the NO_x reduction of EURO VI compared to EURO V for fleet average conditions is at least reflecting the reduction in type approval limits (EURO VI: 0.46g/kWh in the WHTC; EURO V: 2.0g/kWh in the ETC). Also the inclusion of a cold start into the EURO VI type approval procedure can be clearly seen in the fast warm-up behaviour of the aftertreatment systems and the comparably low sensitivity of test results to the preconditioning state (cold, hot).

Test results at average normalised engine power in a range of 3% to 5% as shown in Figure 33 and the following refer to the measurement results in the “HBEFA Stop-and-Go”-cycle. These measurement data are required to parameterise the emission model PHEM also in low engine load areas and the related low temperatures in the exhaust gas aftertreatment. This is of importance as for the HBEFA all combinations of driving situations with all gradients (e.g. Stop and Go driving in downhill conditions) have to be simulated. However, the shown specific emissions at normalised engine loads blow 5% are of minor importance for real world emission levels.

[11] For a typical 40ton truck operated on a flat motorway an average engine power of about 25% to 35% of rated power can be assumed. In urban driving these values are in a range of 10% to 20%.

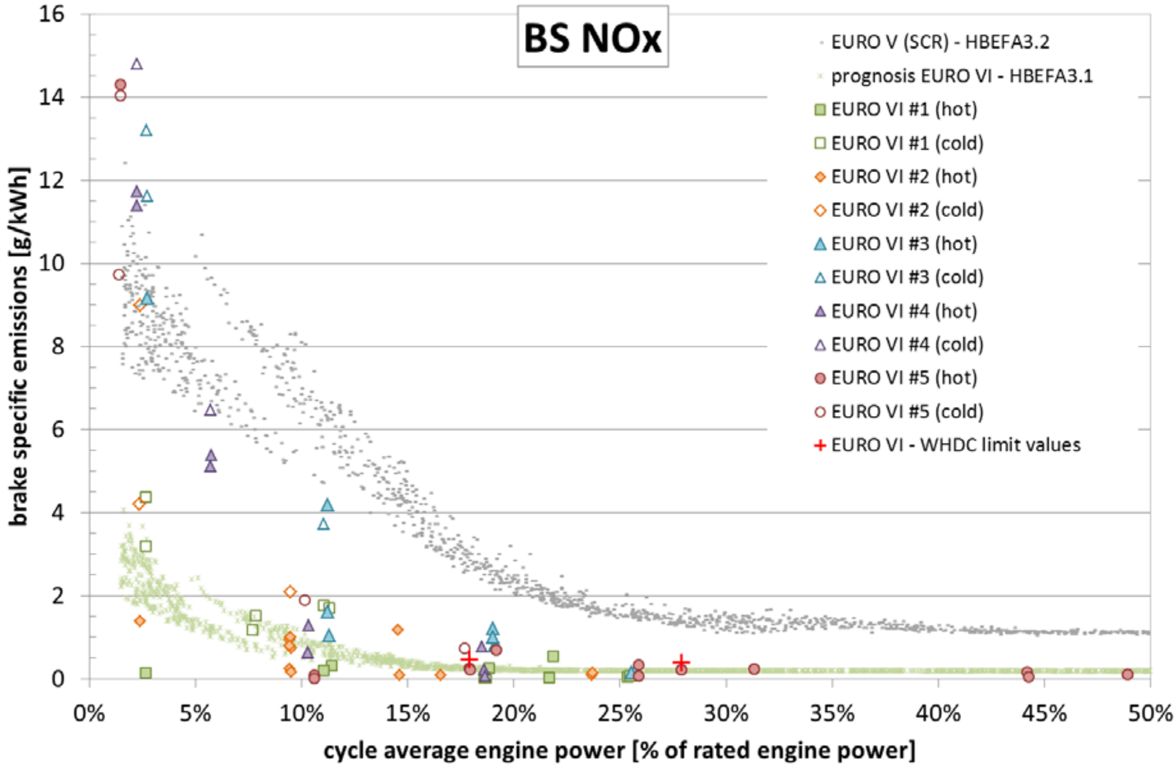

Figure 33: Measurement results EURO VI BS NO_x emissions –

Figure 34 plots the ratio of NO_2 to total NO_x emissions as a function of normalised engine power. A broad scattering of result for the different makes and models and also for single models in different test can be observed. Explanations for this effect are different layouts of the engine-aftertreatment systems as well measurement inaccuracies. The latter mainly arise due to the low absolute NO_x output of the measured vehicles. As a fleet average weighted value a NO_2/NO_x ratio of 36% was determined (compare EURO V with SCR: 7%). Relevant for roadside NO_2 concentrations is however not the NO_2/NO_x ratio as such but the absolute quantities of NO_2 emissions. For the measured EURO VI products this absolute NO_2 output is clearly below EURO V levels.

The test results for particle mass emissions (PM) are presented in Figure 35. All tested EU-RO VI products were equipped with a closed diesel particulate filter system (DPF). The EU-RO VI PM limits were found to be clearly met by all systems.

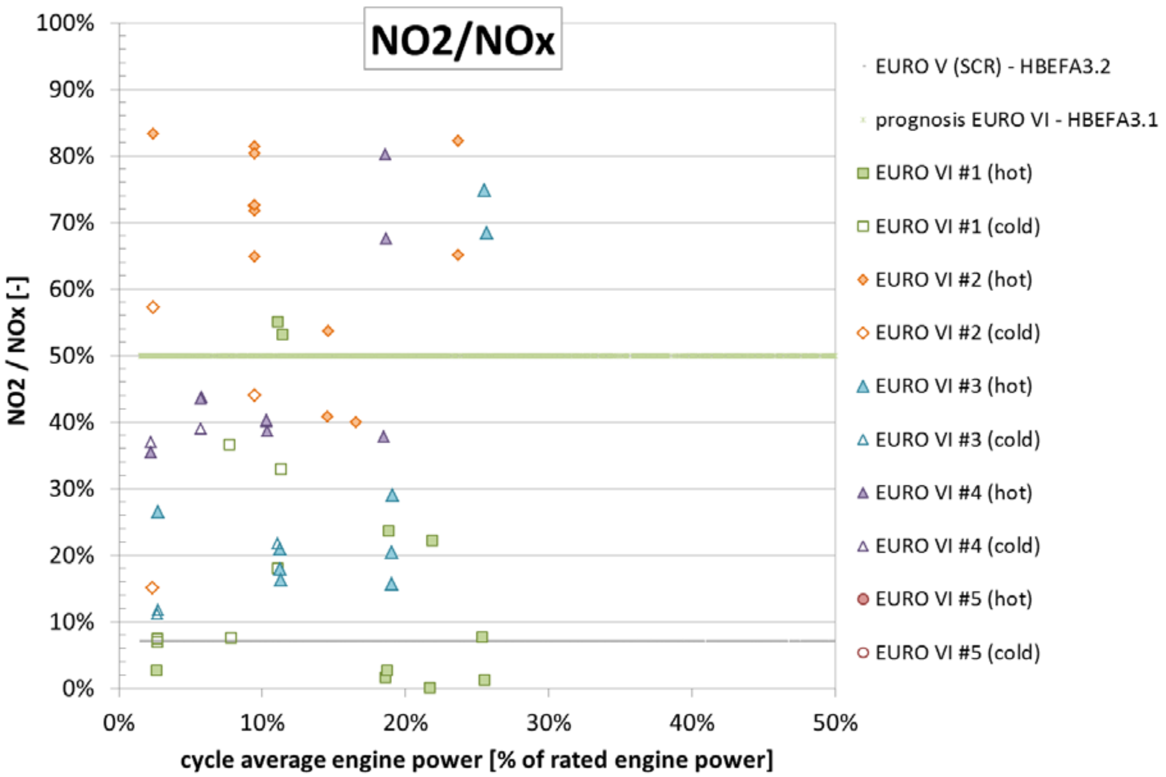

Figure 34: Measurement results share EURO VI NO2 on NOx

Figure 36 shows the results for particle number (PN) emissions. For this emission component emission limits have been introduced with EURO VI for the first time. Again all tested EURO VI models clearly underrun the PN limits in all relevant driving situations. Due to the introduction of EURO VI DPF technology in comparison to EURO V with SCR a reduction of PN levels by nearly three orders of magnitude is achieved by some of the tested models.

Figure 37 and Figure 38 present the test results for the exhaust components CO and HC. Emission levels were found to be very low. Especially for HC the standard equipment as used on emission test stands was hardly able to detect emission levels different from background concentrations.

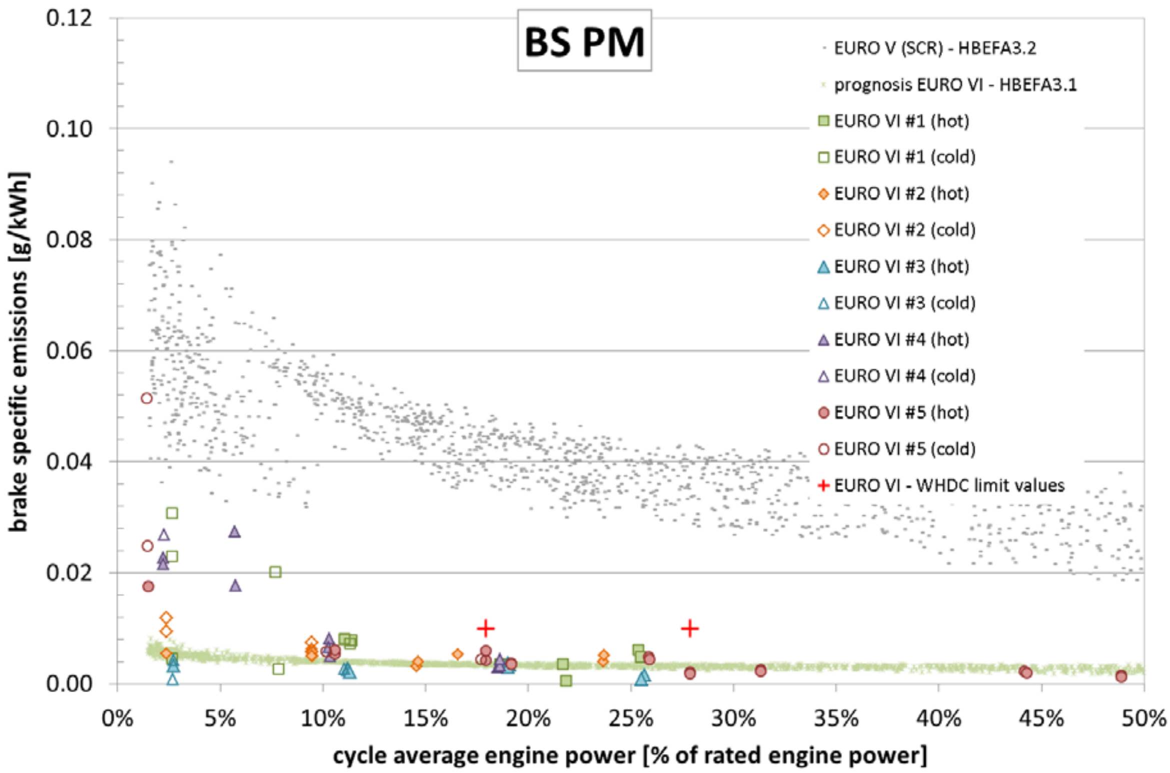

Figure 35: Measurement results EURO VI BS PM emissions

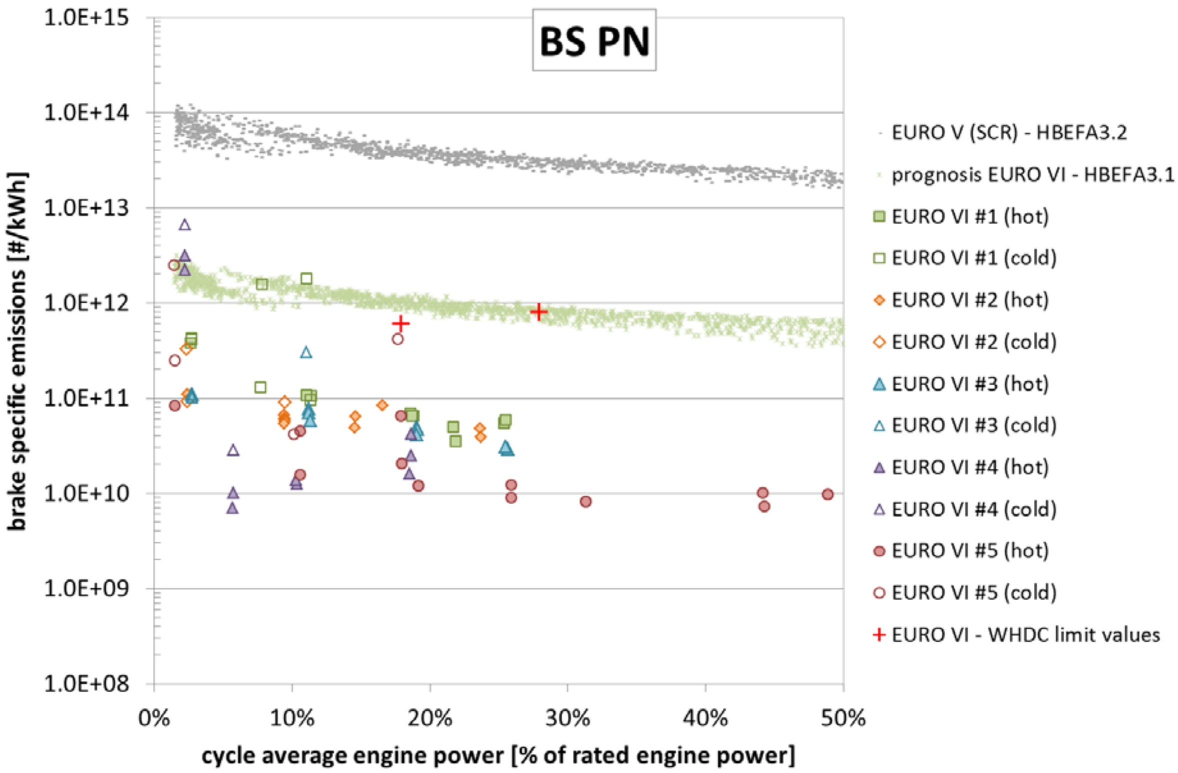

Figure 36: Measurement results EURO VI BS PN emissions

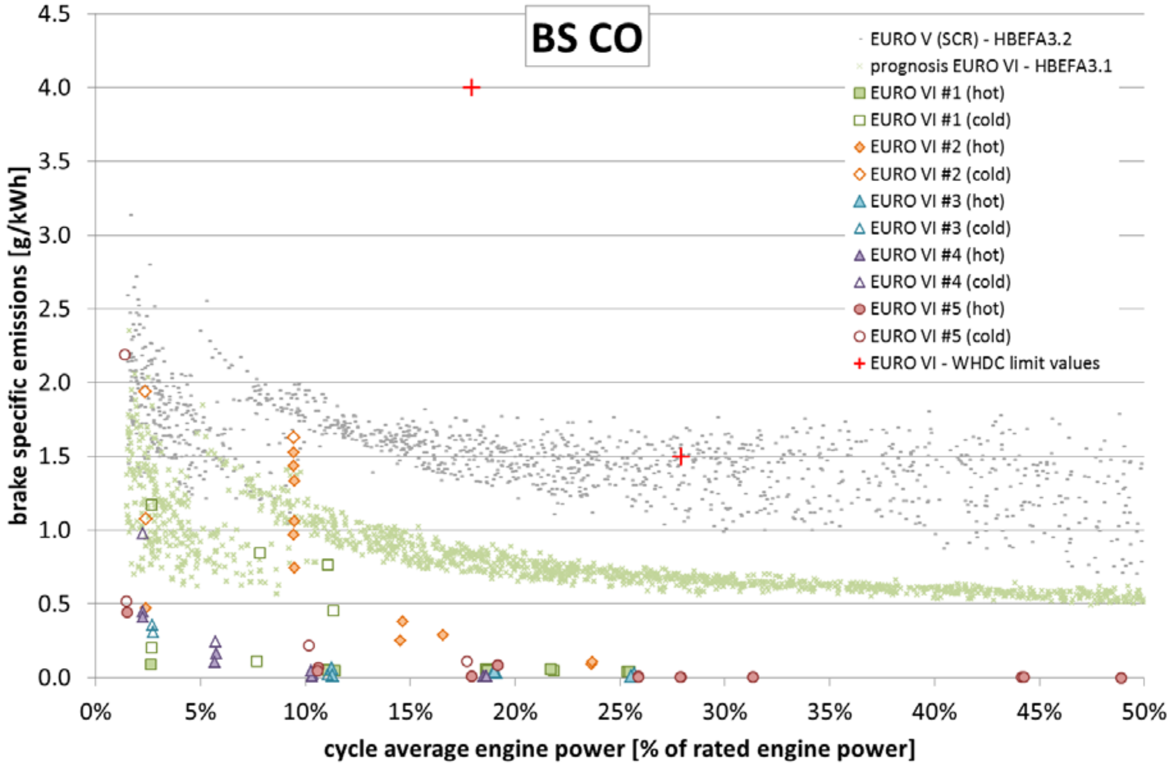

Figure 37: Measurement results EURO VI BS CO emissions

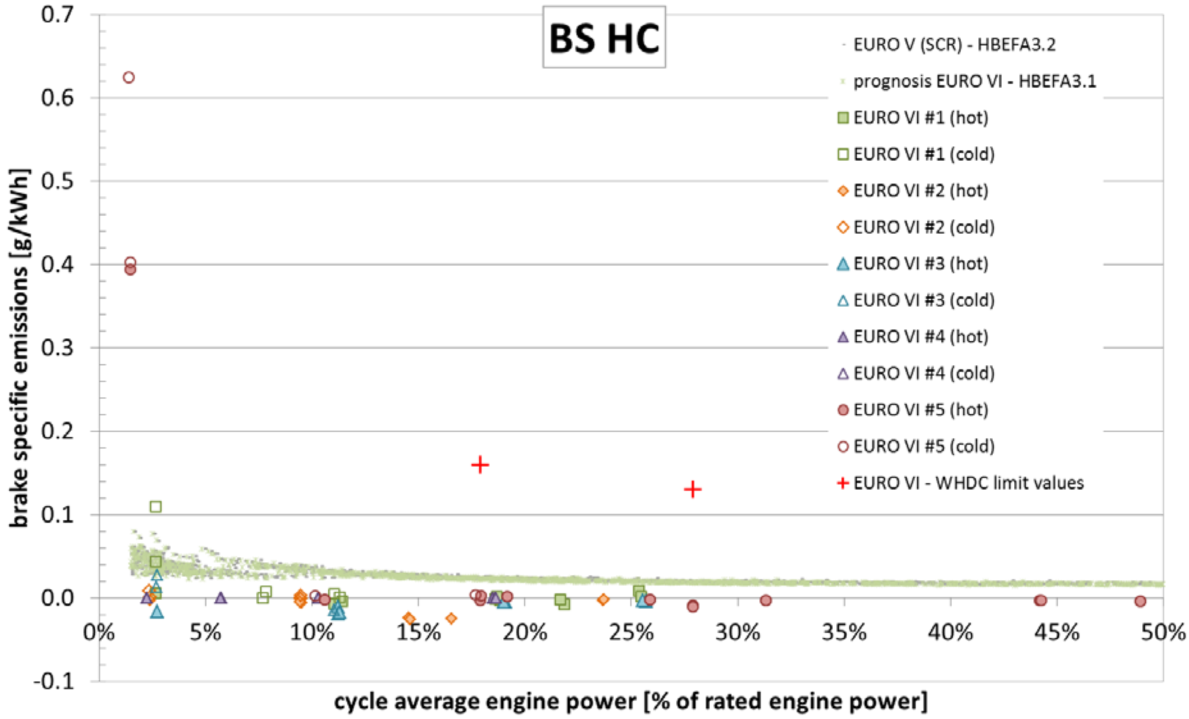

Figure 38: Measurement results EURO VI BS HC emissions

Based on the underlying modal data from the measurements shown in the pictures above the PHEM parameterisation for EURO VI HDV was elaborated. This was done applying weighting factors to the different tested makes related to their market shares in the EU-27 of the OEMs covered by the in-use tests (Table 19).

Table 19: Weighting factors based on EU-27 market shares from (Hill, N. 2011)

make	weighting factor
Daimler	36%
Iveco	25%
MAN	24%
Scania	15%

For modelling of EURO VI HDV for the HBEFA3.2 it was decided not to differentiate emission factors between the technologies “EGR+SCR” (4 vehicles measured) and “SCR only” (1 vehicle measured) as no increase in accuracy for prediction of fleet emission levels was appraised. This fact might change for the next update of the HBEFA based on additional tested vehicles and engines.

5.3. Calculation of emission factors for the HBEFA3.2

With the updated PHEM parameterisation for emission behaviour of EURO V (SCR), EURO V (EGR) and EURO VI emission factors for the full set of HBEFA driving cycles in combination with all road gradients (-6%, -4%, -2%, +/-0%, +2%, +4%, +6%) have been calculated. In the calculations the set of HDV vehicle parameters (masses, air resistances, rolling resistance etc.) was kept unchanged compared to the HBEFA3.1.

5.4. Discussion of updated emission factors for the HBEFA3.2

This section focuses on a discussion of updated emission factors for EURO V and EURO VI HDV. This is done based on results for a half loaded articulated truck with 40t gross vehicle weight operated at 0% road gradient. Exemplarily driving cycles for four fundamental road types and four levels of service have been selected. Table 20 shows the selection of driving cycles and also gives the average speeds. This dataset gives a quite good coverage of the whole range of vehicle speeds from highway to stop and go conditions.

Table 20: Selection of driving cycles for the discussion of HDV emission factor

traffic situation				**trucks / truck & trailer combinations**	
area type	**road type**	**Speed limit**	**level of service**	**HBEFA 3 driving cycle ID**	**average speed** (km/h)
rural	motorway-national	> 130 km/h	freeflow	6 469	86.3
			heavy	6 472	81.0
			saturated	6 475	66.3
			stop&go	6 006	16.6
	distributor / secondary road, sinuous	100 km/h	freeflow	6 257	66.0
			heavy	6 166	52.7
			saturated	6 086	41.6
			stop&go	6 003	13.5
urban	trunk-toad / primary-city road	70 km/h	freeflow	6 240	59.1
			heavy	6 147	48.6
			saturated	6 107	38.6
			stop&go	6 003	13.5
	distributor / secondary road	50 km/h	freeflow	6 074	39.8
			heavy	6 035	30.1
			saturated	6 026	28.7
			stop&go	6 422	11.8

The figures in this section show emission factors for HDV generations from EURO III to EURO VI. For the emission concepts updated for the HBEFA3.2 also the data from the previous HBEFA version are shown for comparison reasons.

NO_x-Emissions (Figure 39)

EURO V with SCR:
There is no significant change in NO_x emission factors for EURO V with SCR compared to the HBEFA3.1. The NO_x output in medium and high average engine loads (e.g. motorway and rural driving situations) is low. In contrast, NO_x emission factors are close to EURO III in urban driving and in stop-and-go conditions due to low $DeNO_x$-performance of EURO V SCR aftertreatment in the low exhaust gas temperature range.

EURO V with EGR:
In motorway driving the NO_x emission factors meet the prognosis made in the HBEFA3.1 based on the type approval limits quite well. For urban driving situations the NO_x output is clearly higher than forecasted and in the range of EURO IV with EGR. Nevertheless in urban driving EURO V with EGR is found to still have lower NO_x emissions than EURO V with SCR. In motorway condition it is the other way round.

EURO VI:
EURO VI NO_x emissions are modelled to be on a very low level in all analysed operation conditions. The related emission factors in the HBEFA3.2 are in the range or even lower than the forecast from the HBEFA3.1.

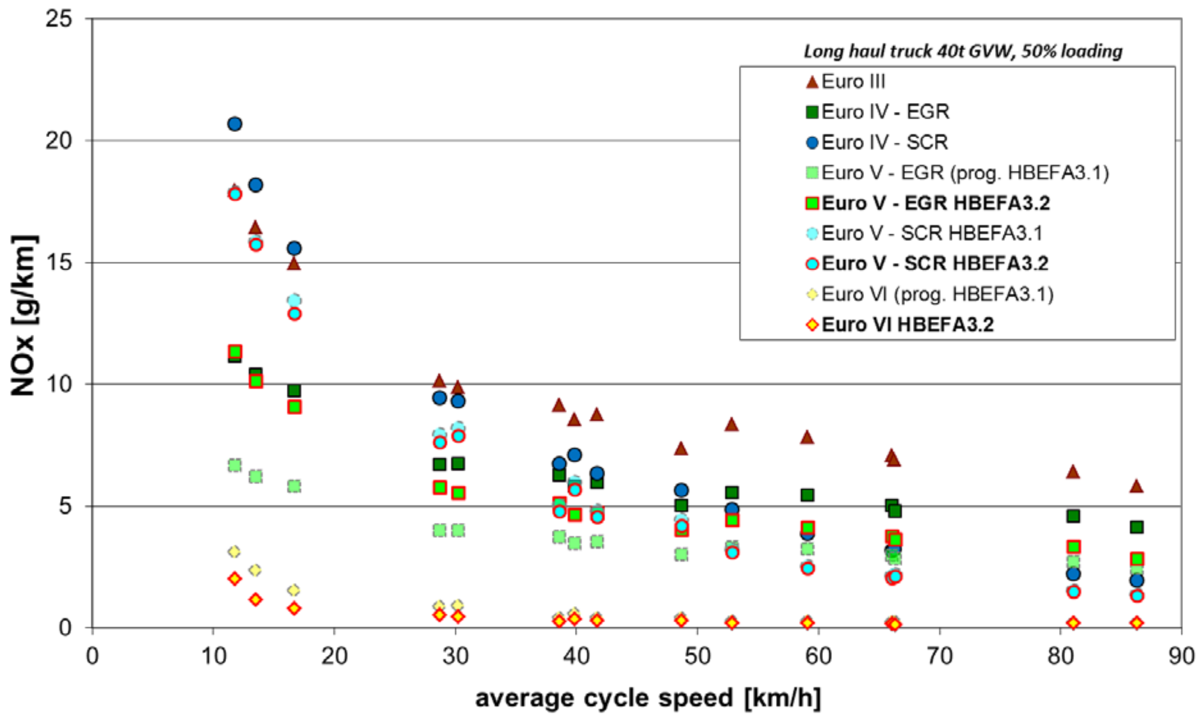

Figure 39: Examples HBEFA3.2 NOx emission factors for 0% road gradient; truck & trailer combination 34-40t GVW, 50% loading

Particle mass emissions ("PM"; Figure 40)

EURO V (SCR and EGR):
The PM emission factors in the HBEFA3.1 were confirmed. The PM emission levels are in the range of the EURO V type approval limits and about 3/4 lower than EURO III.

EURO VI:
Due to the application of DPF technology PM emission factors are close to zero as predicted in the HBEFA3.1.

Particle number emissions ("PN"; Figure 41)

EURO V (SCR and EGR):
Also for PN there is no relevant shift in emission factors from the HBEFA3.1 to the HBEFA3.2. The PN emission level of EURO V HDV is about one order of magnitude lower than of comparable EURO III vehicles rather independent which NOx abatement strategy is used (EGR or SCR).

EURO VI:
The PN emission factors for average EURO VI are about two orders of magnitude lower than for EURO V.

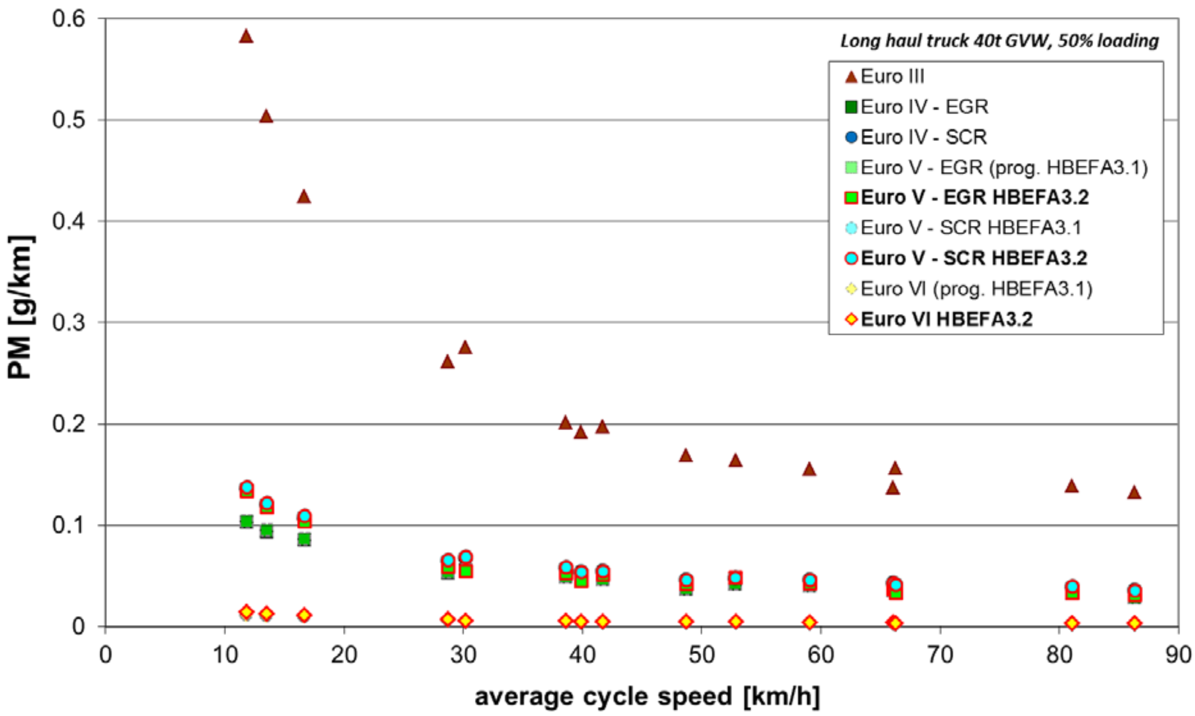

Figure 40: Examples HBEFA3.2 PM emission factors for 0% road gradient; truck & trailer combination 34-40t GVW, 50% loading

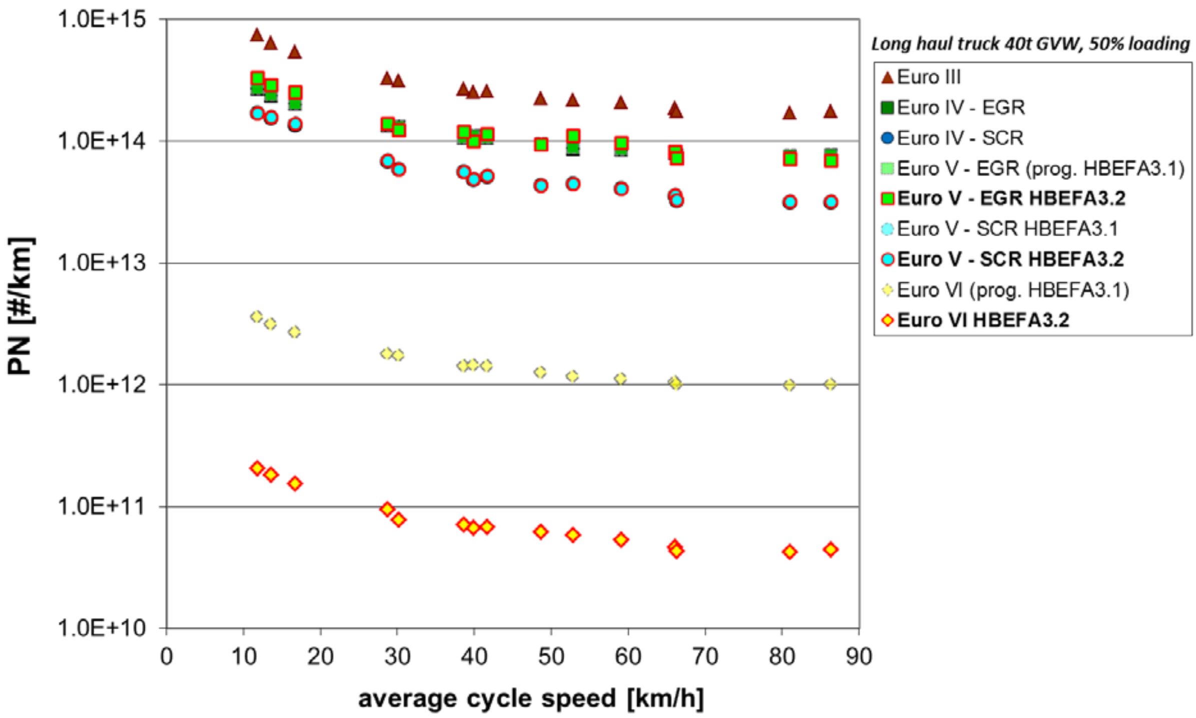

Figure 41: Examples HBEFA3.2 PN emission factors for 0% road gradient; truck & trailer combination 34-40t GVW, 50% loading; *logarithmic scale*

<u>CO- (Figure 42) and HC-emissions (Figure 43)</u>

EURO V (SCR and EGR):

CO and HC emissions were found to be clearly lower than demanded in type approval already for earlier EURO stages. For EURO V the related emission factors have remained nearly unchanged compared to the HBEFA3.1

EURO VI:

The CO output of EURO VI is even lower than of EURO V. For HC the emission levels were below the detection limits of the analyser in most of the in-use tests, so zero emissions are predicted are for this emission component.

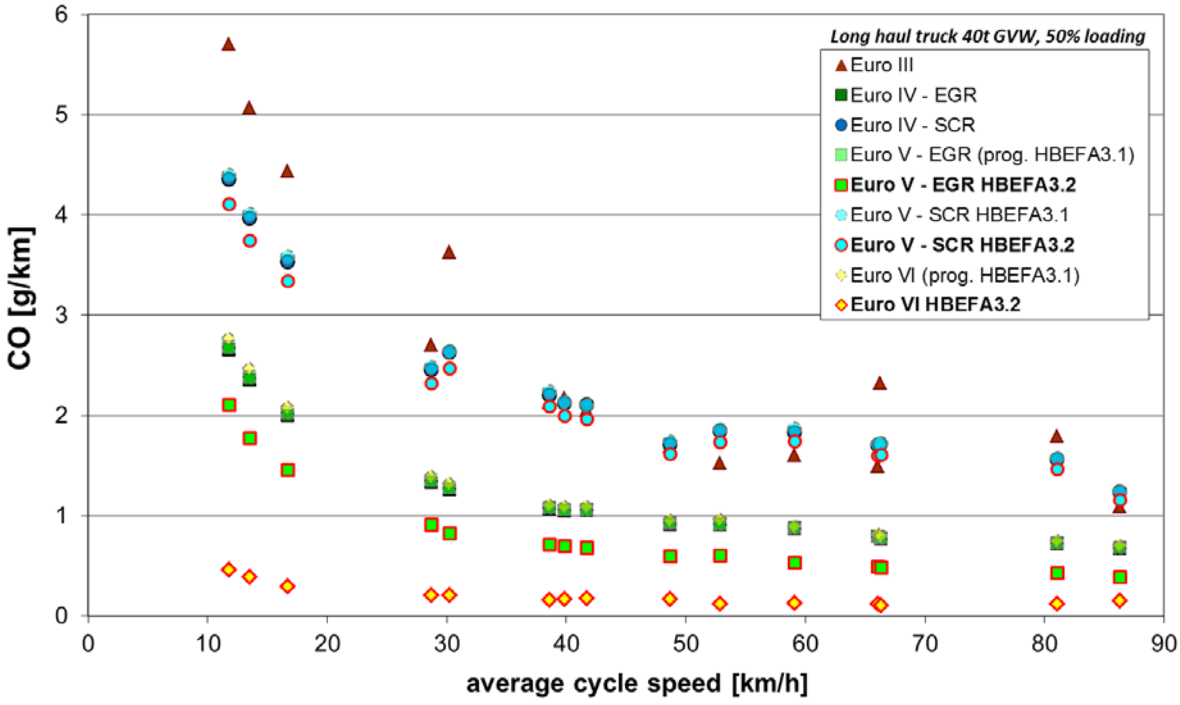

Figure 42: Examples HBEFA3.2 <u>CO</u> emission factors for 0% road gradient; truck & trailer combination 34-40t GVW, 50% loading

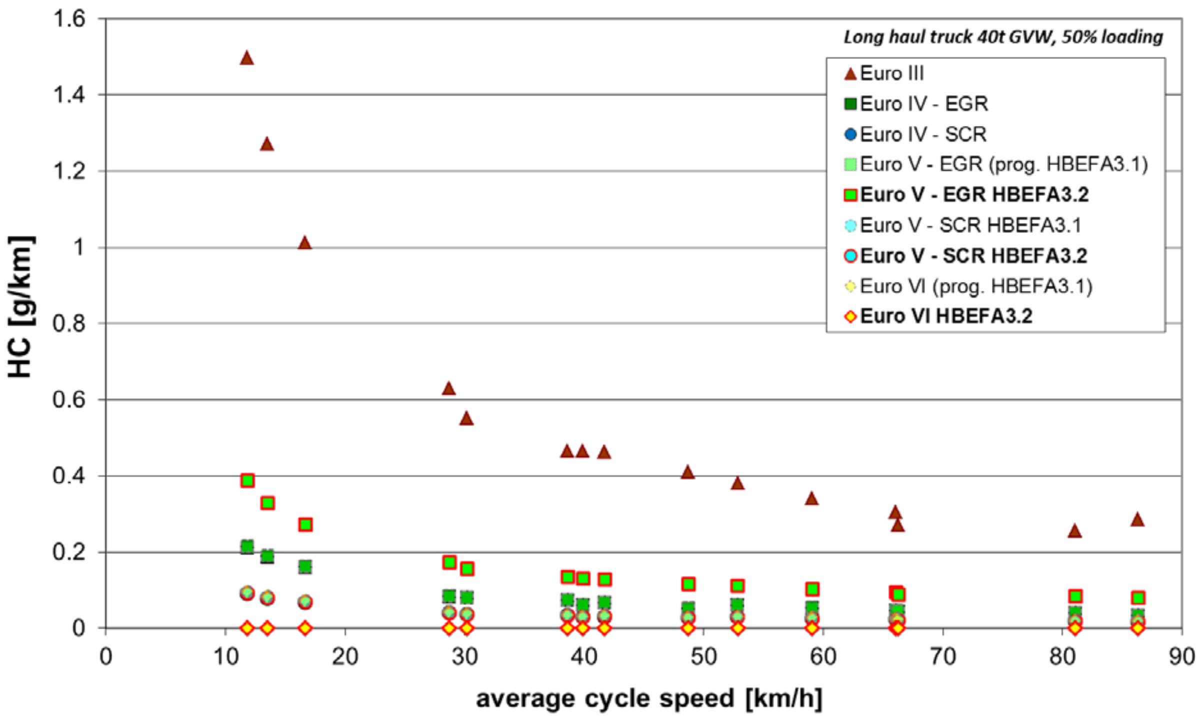

Figure 43: Examples HBEFA3.2 HC emission factors for 0% road gradient; truck & trailer combination 34-40t GVW, 50% loading

Figure 44 gives a comparison of HBEFA3.2 values for fuel consumption for half loaded 40t trucks from EURO III to EURO VI. As already discussed above for fuel consumption (and the related CO_2 emissions) the ranking between EURO IV, V and VI has been parameterised mainly on literature but no directly from the in-use data. HDV fuel consumption was not up-dated from the HBEFA3.1 to the version 3.2. Basically the lowest fuel consumption is achieved by the SCR technology for the emission standards EURO IV and EURO V. The considered half loaded long haul truck (with a total vehicle weight of 27.5t) can be operated at flat highway driving with approximately 25 litres per 100 kilometres. Fuel consumption of EURO V with EGR is modelled to be about 3% higher than EURO V SCR. EURO VI engines were parameterised to have brake specific fuel consumption which is in between EURO V with SCR and EURO V with EGR.

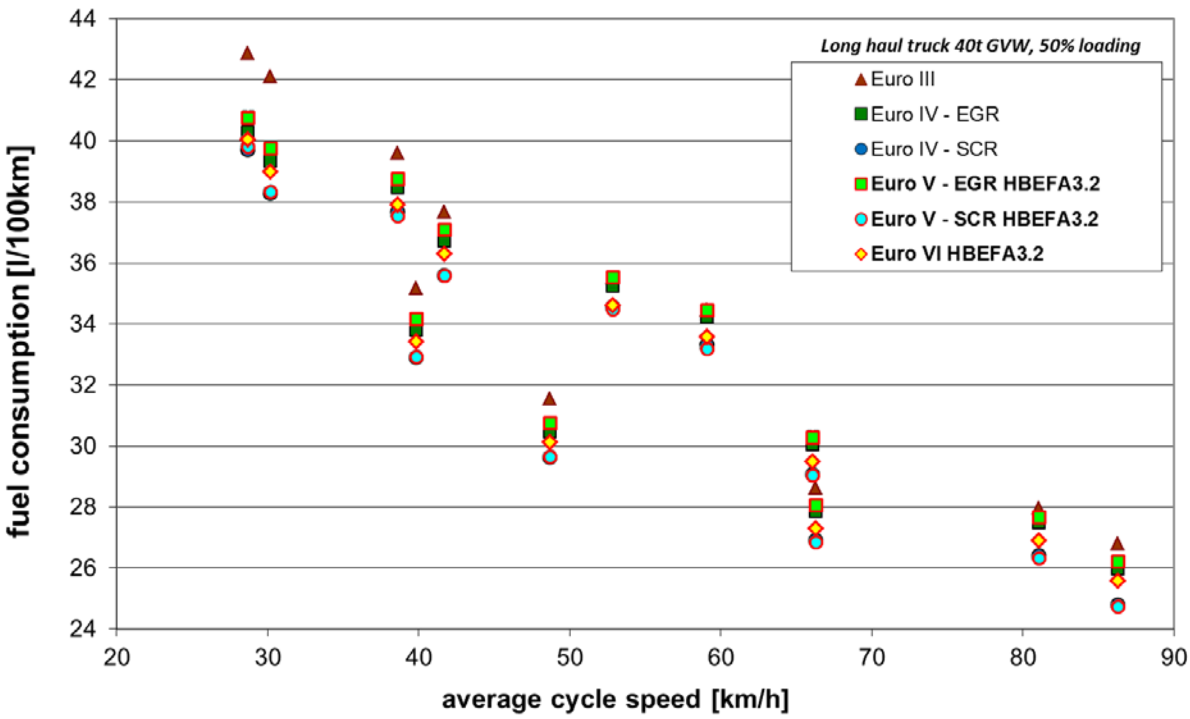

Figure 44: Examples HBEFA3.2 emission factors fuel consumption for 0% road gradient; truck & trailer combination 34-40t GVW, 50% loading

6. Conclusions and Outlook

The update on emission factors for EURO 5 and EURO 6 cars was based on a quite large number of tested EURO 5 cars (50 diesel and 31 gasoline) but on a limited number of EU-RO 6 cars (only one petrol and 19 diesel where only 13 different models are covered where some of them were US applications meeting EURO 6 limits). For LCV no EURO 6 tests are available yet.

Consequently the uncertainties in the emission factors for EURO 6 are quite high and it is recommended to go ahead with testing EURO 6 cars and LCV. The EURO 6 diesel cars tested showed different emission levels. Several of them had very low emissions in all tests, others were found not much below EURO 5 levels. Thus it is hard to predict which emission level will be found in the fleet, when EURO 6 becomes mandatory. Hence it is recommended to apply uncertainty scenarios for the EURO 6 emission factors produced here if important political conclusions shall be drawn from the results.

The NO_x emissions from the EURO 5 diesel vehicles were found to be even slightly higher than from EURO 4. Thus no NO_x reduction in real world driving of the diesel car fleet was achieved since the introduction of EURO 1. This demonstrates clearly that the test procedure and the test cycle (NEDC) are not at all adequate to control real world NO_x emissions. On board measurements (PEMS) for cars thus are urgently recommended and shall be introduced soon to prevent that also the EURO 6 fleet may have similar high NO_x levels than EURO 5.

For petrol cars the tests and simulation showed very low levels for CO, NO_x and HC but an increasing trend for PN emissions due to increasing shares of DI gasoline engines. However, the PN emission levels of these vehicles are much lower than those of diesel cars without DPF. In addition it was found that the test results on PN emissions show a high scattering between single tests and thus the PN emission factors seem to be quite uncertain values. The EURO 6c regulation will limit PN from SI engines. If still further actions shall be undertaken to improve the data base for PN emission factors needs to be discussed. Maybe the demand for such emission factors and their possible application should be surveyed in front to be able to judge the necessary accuracy.

The main finding of the current study related to HDV emissions is the confirmation of the effectiveness of the EURO VI legislation based on the WHTC and additional provisions on real world emissions tested with PEMS as a part of the type approval. All tested EURO VI vehicles and engines were found to have very low emissions levels for all regulated pollutants in all real world cycles. Nevertheless, available in-use data so far do not cover all makes and also do not contain emissions measured on-road with PEMS equipment. For further activities in the ERMES group it is recommended to close these gaps to confirm the low EURO VI emission factors as elaborated in this study.

We assume that accurate levels for CO_2 emissions and fuel consumption will become more important in future. Thus a realistic simulation of the energy demand from auxiliaries, mainly air conditioning, steering pump and alternator, should be included in a next major update of emission factors. These auxiliaries are not or not in the same way as in real world driving included in the chassis dyno tests. With these extensions PHEM would be in the position to produce even more accurately real world fuel consumption values and thus could support the assessments based on CO_2 monitoring data and analysis of real world fuel consumption data base substantially (the other sources cannot produce values for different traffic conditions and thus cannot provide emission factors but only average levels).

For the assessment of future transport scenarios the special consideration of electrified vehicle propulsion systems (e.g. hybrid electric vehicles, plug-in hybrids or battery electric vehicles) is of importance, especially if the total energy consumption including electric power from the national grid is of interest. Such vehicle technologies are so far not covered by the HBEFA. For the major revision of the HBEFA with version 4 it is envisaged to include the relevant vehicle segments into the HBEFA fleet segmentation and to provide the related values for energy consumptions [kWh/km] and - if applicable – emission factors. PHEM already offers the possibility to simulate electrified powertrain configurations. However, in order to generate realistic results still several methodical issues would have to be elaborated, e.g. an approach how to simulate the HBEFA cycles with plug-in hybrids, which can be driven either by the electric drive or by the internal combustions depending on various parameters like battery capacity, driving distance or availability of net power at the last stop.

7. Acknoledgements

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ANNEX A

Lists for measured EURO 5 and 6 passenger cars included in the ERMES LDV data base

Table A1: EURO 5 petrol passenger cars

Laboratory	Make	Model	Engine type	Capacity [ccm]	Rated power [kW]	New registrations 2012
ADAC	Skoda	Fabia Combi	petrol DI	1197	63	100380
EMPA	BMW	125i Coupe	petrol DI	2996	160	1731
EMPA	Fiat	500	petrol PI	1242	51	271823
EMPA	Mazda	3 2.0 DI	petrol DI	1999	111	32
EMPA	Opel	Astra J 16T	petrol PI	1598	132	5467
EMPA	Peugeot	207 SW	petrol PI	1598	88	59037
EMPA	Renault	Grand Scenic	petrol PI	1397	96	8870
EMPA	Skoda	Octavia C	petrol DI	1798	118	20468
EMPA	Smart	fortwo cabrio	petrol PI	999	62	3967
EMPA	VW	Polo 1.4	petrol PI	1390	63	51310
EMPA	VW	Golf 1.4 TSI	petrol DI	1390	90	116897
EMPA	Honda	Insight	Hybrid petrol/electric	1339	65	5263
JRC	Audi	A5	petrol DI	1984	132	8970
JRC	Audi	Audi B8	petrol DI	1984	132	8970
JRC	BMW	Series 1	petrol PI	1995	105	4932
JRC	Fiat	Punto	petrol PI	1248	55	51
JRC	Fiat	Punto	petrol PI	1248	55	51
JRC	Ford	Fiesta	petrol PI	1242	44	36223
JRC	Ford	Fiesta	petrol PI	1242	44	36223
JRC	Suzuki	SX4	petrol PI	1490	82	1646
JRC	Suzuki	SX4	petrol PI	1490	82	1646
JRC	Toyota	Lexus LS460	petrol PI	4608	280	6
JRC	Volvo	V50	petrol PI	1798	92	0
LAT	Alfa Romeo	MiTo	petrol DI	1368	99	3683
LAT	Alfa Romeo	MiTo	petrol DI	1368	99	3683
LAT	Toyota	Auris	petrol PI	1798	73	39755
LAT	Volkswagen	Golf	petrol DI	1390	90	116897
TUG	Audi	A5	petrol DI	1984	155	27033
TUG	Audi	A1	petrol DI	1197	63	100380
TUG	BMW	528i	petrol DI	1997	180	9028
TUG	Fiat	Punto	petrol PI	1368	77	6230
TUG	Honda	Civic	petrol PI	1339	73	14708
TUG	Mazda	3	petrol DI	1999	111	32
TUG	Opel	Meriva	petrol PI	1364	88	19420
TUG	VW	Golf VI	petrol PI	1390	59	11825

Table A1: EURO 5 diesel passenger cars

Lab	Make	Model	Capacity [ccm]	Rated power [kW]	New registra-tions 2012
ADAC	Citroen	C4 Picasso	1997	110	27773
ADAC	Opel	Insignia	1956	143	5275
ADAC	VW	Passat	1968	103	372076
EMPA	BMW	118d	1995	105	78208
EMPA	Citroen	C5 3.0 V6 Hdi	2992	177	2542
EMPA	FIAT	Punto Evo	1248	70	67515
EMPA	Mercedes Benz	C 220	2143	125	69414
EMPA	Opel	Astra J	1686	92	16303
EMPA	Renault	Megane	1461	81	256721
EMPA	Skoda	Octavia C greenline	1598	77	321568
EMPA	Skoda	Fabia Combi	1598	77	321568
EMPA	Toyota	Avensis	2231	110	23234
EMPA	Toyota	Yaris	1364	66	33415
EMPA	Volkswagen	Passat	1968	125	107983
EMPA	Volkswagen	Touran	1968	103	372076
JRC	Fiat	Bravo	1598	88	13179
JRC	Fiat	Punto	1248	55	77941
JRC	Volkswagen	Polo	1598	55	12250
JRC	VW	Polo	1598	55	12250
LAT	BMW	X1	1995	120	17136
LAT	Peugeot	308	1560	84	92067
TNO	BMW	320D	1995	120	17136
TNO	Fiat	Punto Evo	1248	62	18576
TNO	Ford	Mondeo	1997	103	91822
TNO	Mercedes	E220 CDI	2143	125	69414
TNO	Mercedes	E220 CDI	2143	125	69414
TNO	Mercedes	E220 CDI	2143	125	69414
TNO	Opel	Corsa	1248	70	67515
TNO	Peugeot	5008	1560	82	237381
TNO	Renault	Megane Grand Scenic	1461	81	256721
TNO	Renault	Megane Grand Scenic	1461	81	256721
TNO	Renault	Megane Grand Scenic	1461	81	256721
TNO	Renault	Twingo	1461	63	7910
TNO	VW	Passat	1598	77	321568
TNO	VW	Passat	1598	77	321568
TNO	VW	Polo	1199	55	62452
TNO	VW	Passat CC	1968	103	372076

Lab	Make	Model	Capacity [ccm]	Rated power [kW]	New registra-tions 2012
TUG	Audi	A3	1598	66	91450
TUG	BMW	318d ED	1995	105	78208
TUG	BMW	320d ED	1995	120	17136
TUG	Chevrolet	Cruze	1686	96	16059
TUG	Fiat	Doblo	1598	77	25821
TUG	Kia	Optima	1685	100	14781
TUG	Mitsubishi	ASX	1798	110	17014
TUG	Opel	Astra	1686	92	16303
TUG	Peugeot	407 SW	1997	103	91822
TUG	Skoda	Fabia	1598	55	12250
TUG	VW	Golf VI	1968	81	38313
TUG	VW	Passat	1968	81	38313

Table A3: EURO 6 diesel passenger cars

Lab	Make	Model	Capacity [ccm]	Rated power [kW]	New registra-tions 2012
ADAC	MAZDA	CX5	2191	110	5458
TNO	BMW	330d	2993	190	27215
TNO	BMW	330d	2993	190	27215
TNO	BMW	730d	2993	190	27215
TNO	BMW	320d	1995	135	129648
TNO	BMW	320d ED	1995	120	17136
TNO	Mazda	CX5	2191	110	5458
TNO	Mazda	CX5	2191	110	5458
TNO	Mercedes	E350	2987	185	64
TNO	VW	Passat	1968	103	372076
TNO	VW	Passat	1968	103	372076
TNO	VW	Passat	1968	103	372076
TNO	VW	Passat	1968	103	372076
TUG	Audi	Allroad	2967	180	60557
TUG	BMW	X5	2993	180	15485
TUG	BMW	530d	2993	180	15485
TUG	Mazda	CX5	2191	110	5458

ANNEX B

Main technical parameters for fleet average passenger cars used in PHEM for calculation of HBEFA3.2 emission factors:

Table 21: Passenger cars - petrol

parameter	unit	pre EURO 1	EURO 1	EURO 2	EURO 3	EURO 4	EURO 5	EURO 6
mass	[kg]	1180	1200	1230	1250	1235	1222	1200
Loading (*)	[kg]	50	50	50	50	50	50	50
Cd-value	[-]	0.3328	0.3253	0.3203	0.3163	0.3113	0.31	0.3
cross frontal area	[m²]	2	2.05	2.1	2.12	2.12	2.14	2.14
Inertia engine	[kg*m²]	0.5	0.5	0.5	0.5	0.5	0.4506	0.473
equivalent mass wheels	[kg]	40	40	40	40	40	40.06	40.06
Inertia gearbox	[kg*m²]	0.06	0.06	0.06	0.06	0.06	0.0576	0.0585
rated power	[kW]	60	66	68	70	72	80	84
rated speed	[1/min]	5400	5723	5723	5723	5565	5247	5247
idle speed	[1/min]	800	800	800	800	798	706	706
f_{R0}	[-]	0.009	0.009	0.009	0.009	0.009	0.009	0.009
f_{R1}	[s/m]	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005
f_{R4}	[s^4/m^4]	1.60E-09	1.60E-09	1.60E-09	1.60E-09	1.60E-09	1.60E-09	1.60E-09
axle ratio	[-]	3.925	3.9444	3.9444	3.9444	4.0826	3.876	3.876
wheel diameter	[m]	0.5491	0.5989	0.5989	0.5989	0.6064	0.607	0.607
transmission 1. gear	[-]	3.5	3.586	3.586	3.586	3.6298	3.672	3.672
transmission 2. gear	[-]	1.95	1.9902	1.9902	1.9902	2.0523	1.991	1.991
transmission 3. gear	[-]	1.295	1.3691	1.3691	1.3691	1.3801	1.334	1.334
transmission 4. gear	[-]	0.9	1.0447	1.0447	1.0447	1.0477	0.988	0.988
transmission 5. gear	[-]	0.73	0.8468	0.8468	0.8468	0.8423	0.789	0.789

* Since it is not clear which vehicle mass in the statistics is defined (empty mass or kerb mass for chassis dyno test), a compromise loading value of 50kg is chosen here. If the statistics from CO2 monitoring contain empty mass, then weight of fuel and approx. 1.5 persons would have to be added., if kerb mass is included, only the mass of 0.5 persons would have to be added. The meaning of “mass” in the statistical data was not clarified within the project but shall be updated for HBEFA V 4.

Table 22: Passenger cars - diesel

parameter	unit	pre EURO 1	EURO 1	EURO 2	EURO 3	EURO 4	EURO 5	EURO 6
mass	[kg]	1260	1300	1350	1420	1500	1547	1525
Loading (*)	[kg]	50	50	50	50	50	50	50
Cd-value	[-]	0.3328	0.3253	0.3203	0.3163	0.3113	0.31	0.3
cross frontal area	[m²]	2	2.05	2.1	2.16	2.16	2.27	2.27
Inertia engine	[kg*m²]	0.3727	0.3894	0.4525	0.4803	0.5234	0.5458	0.5682
equivalent mass wheels	[kg]	40.4976	40.4976	40.4976	41.3424	41.3424	42.4578	42.4578
Inertia gearbox	[kg*m²]	0.0521	0.0532	0.05606	0.05804	0.06046	0.06134	0.06222
rated power	[kW]	55	60	73	82	93	97	101
rated speed	[1/min]	4010	4010	4010	3930	4073	4014	4014
idle speed	[1/min]	800	800	800	800	816	798	798
f_{R0}	[-]	0.009	0.009	0.009	0.009	0.009	0.009	0.009
f_{R1}	[s/m]	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005
f_{R4}	[s^4/m^4]	1.60E-09	1.60E-09	1.60E-09	1.60E-09	1.60E-09	1.60E-09	1.60E-09
axle ratio	[-]	3.7914	3.7914	3.7914	3.6546	3.7284	3.678	3.678
wheel diameter	[m]	0.6136	0.6136	0.6136	0.6264	0.6264	0.6433	0.6433
transmission 1. gear	[-]	3.5867	3.5867	3.5867	3.6022	3.7079	3.798	3.798
transmission 2. gear	[-]	1.981	1.981	1.981	1.9719	2.0237	2.063	2.063
transmission 3. gear	[-]	1.2286	1.2286	1.2286	1.2334	1.2784	1.312	1.312
transmission 4. gear	[-]	0.8624	0.8624	0.8624	0.8751	0.9359	0.955	0.955
transmission 5. gear	[-]	0.6781	0.6781	0.6781	0.679	0.7414	0.743	0.743
transmission 6. gear	[-]	-	-	-	-	0.6162	0.61	0.61

* Since it is not clear which vehicle mass in the statistics is defined (empty mass or kerb mass for chassis dyno test), a compromise loading value of 50kg is chosen here. If the statistics from CO2 monitoring contain empty mass, then weight of fuel and approx. 1.5 persons would have to be added., if kerb mass is included, only the mass of 0.5 persons would have to be added. The meaning of “mass” in the statistical data was not clarified within the project but shall be updated for HBEFA V 4.

ANNEX C

Calibration factors applied to baseline PHEM engine maps generated from modal data to meet CADC tests results (1/3-mix) from entire ERMES LDV data base. For details see chapter 3.5.

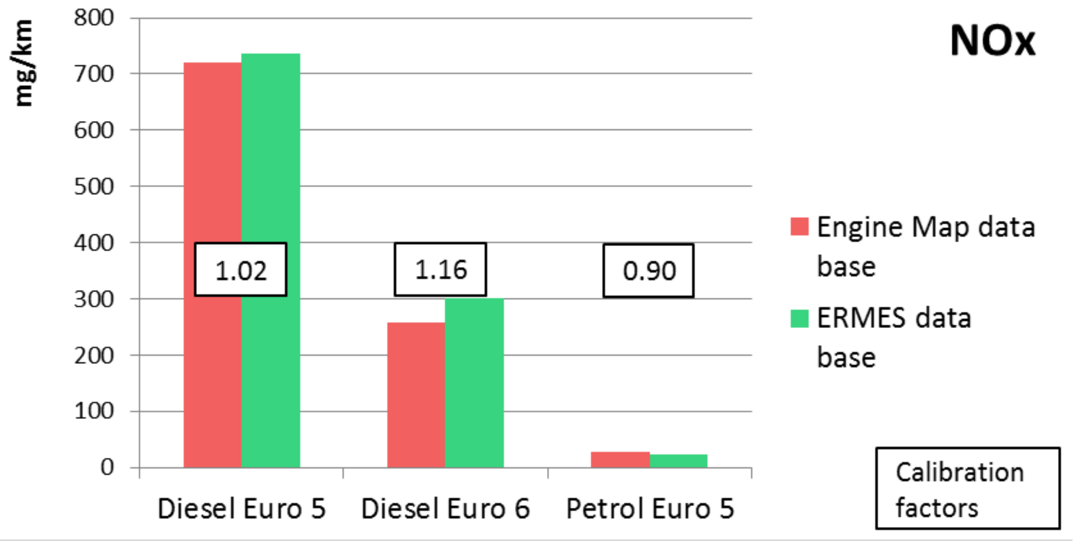

Figure 45: NOx emission factors for the CADC-1/3-mix from the engine map model results (red) and as averaged values from all available ERMES bag data (green)

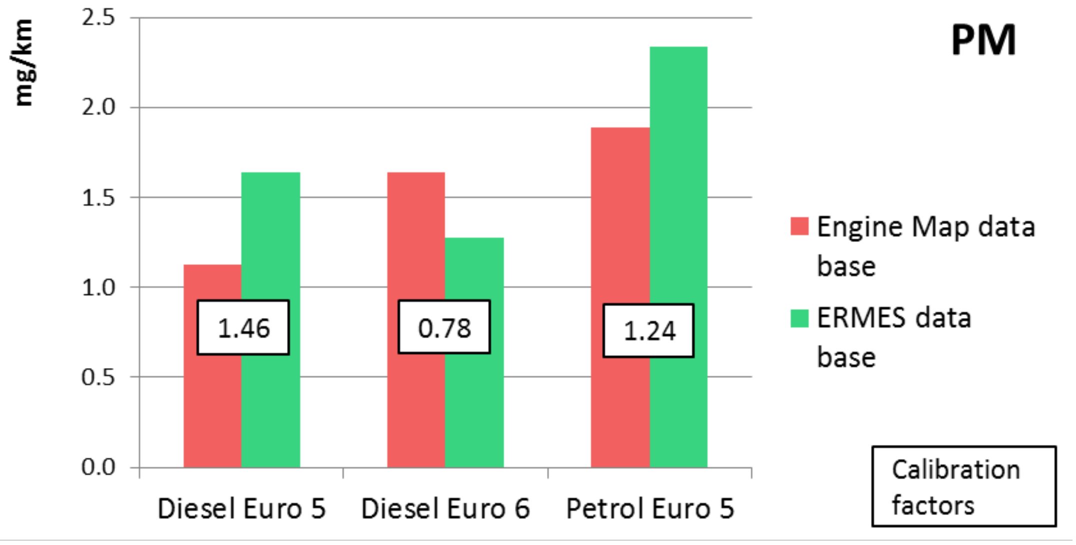

Figure 46: PM emission factors for the CADC-1/3-mix from the engine map model results (red) and as averaged values from all available ERMES bag data (green)

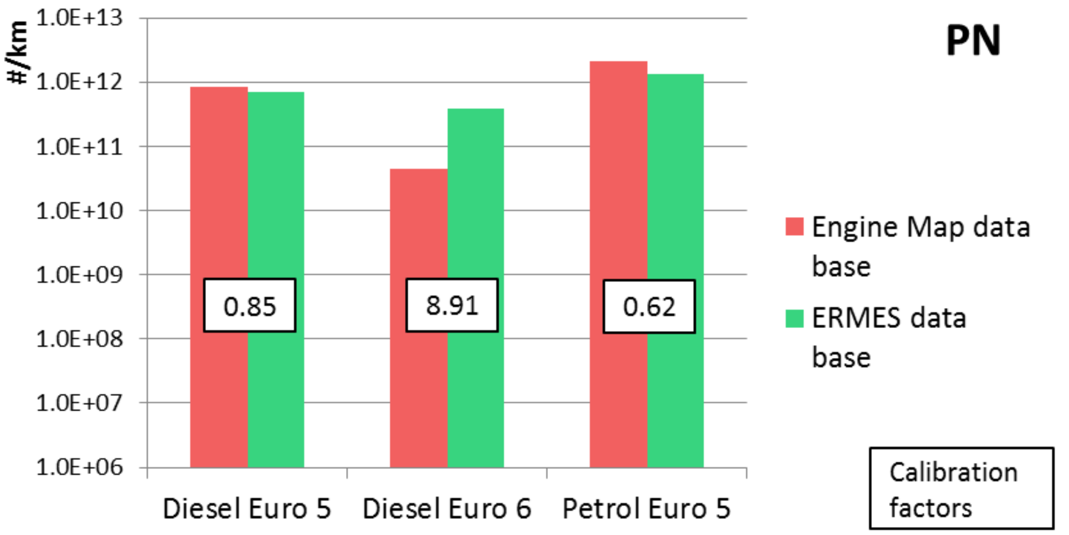

Figure 47: PN emission factors for the CADC-1/3-mix from the engine map model results (red) and as averaged values from all available ERMES bag data (green)

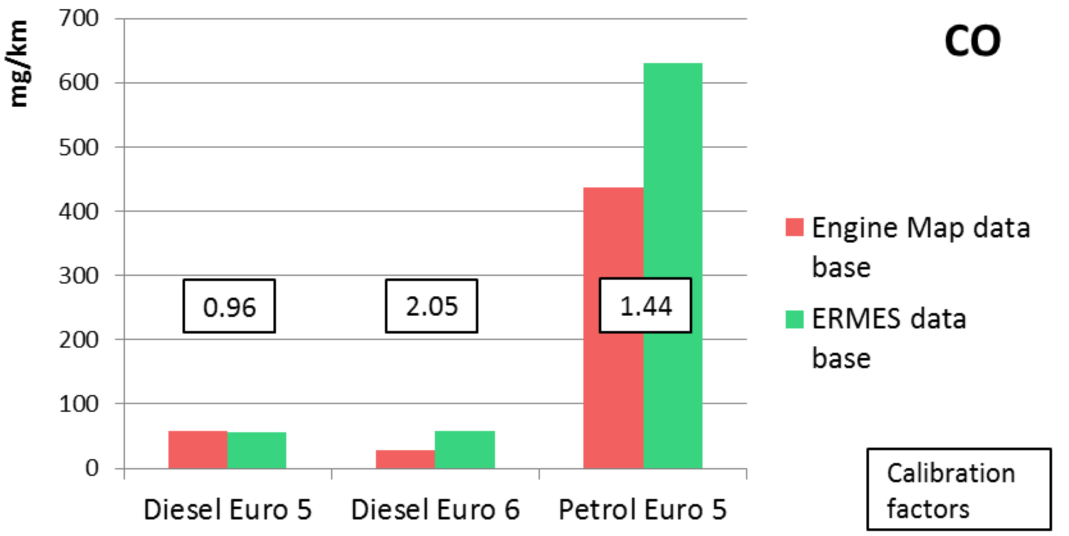

Figure 48: CO emission factors for the CADC-1/3-mix from the engine map model results (red) and as averaged values from all available ERMES bag data (green)

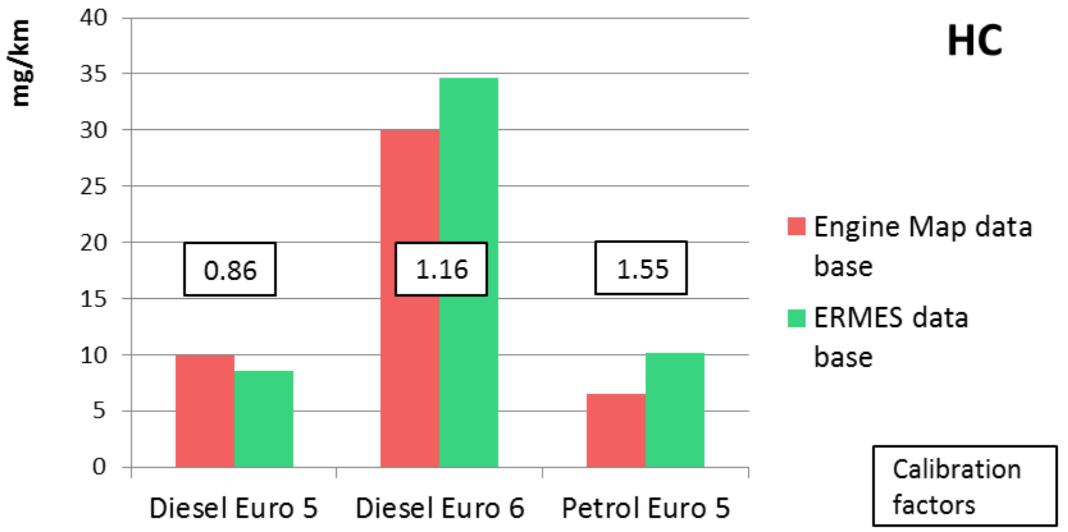

Figure 49: HC emission factors for the CADC-1/3-mix from the engine map model results (red) and as averaged values from all available ERMES bag data (green)

ANNEX D

Table 23: Overview measured HDV EURO V and EURO VI

laborоratory	engine and vehicle	vehicle typ / GVW (w/o trailer)	emission standard	technology (SCR, EGR, DPF,...)	rated power [kW]	capacity [l]	data new in HBEFA3.2
TUG	engine: OM501 LAV5 vehicle: Actros 1846 LS 4X2 BlueTec5	road tractor 18t	Euro V	SCR	335	12	
TUG	engine: Volvo D13A440 EC06B vehicle: VOLVO FH12 440	road tractor 18t	Euro V	SCR	325	12.8	
TUG	engine: D2066 LF23 vehicle: MAN TGA 18.440	road tractor 18t	Euro V	SCR	325	10.5	
AVL MTC	engine: D9B360 vehicle: Volvo 7700	city bus 18t	Euro V incentive	SCR + filter	265	9.4	
TÜV Nord	engine: D2066 LF31 vehicle: MAN TGA 18.440	road tractor 18t	Euro V	SCR	324	10.5	
TUG	engine: Iveco Cursor 8 vehicle: Irisbus Citelis S	city bus 18t	EEV	SCRT	213	7.8	
TUG	engine: D2066 LF23 vehicle: MAN TGA 18.440	delivery truck 18t	Euro V	SCR	325	10.5	yes
AVL MTC	engine: DAF 300kW Vehicle: DAF 105.410	tractor 18t & trailer	Euro V	SCR	300	12.9	yes
TUG	engine: Scania DC 13 05 vehicle: R400 LA4x2MNA	road tractor 18t	Euro V	EGR	324	12.7	yes
TUG	engine: MAN D036 LFL65 vehicle: MAN TGX 18.340 4x4	rigid truck 18t	Euro V	EGR	250	4.6	yes
AVL MTC	engine: MAN 353kW vehicle: MAN TGX 26.480	truck 26t & trailer	Euro V	EGR, PM-Kat	353	12.4	yes
TUG	engine: OM 471 LA 6-4 vehicle: MB Actros 1845 LS	road tractor 18t	EURO VI	AGR, DPF, SCR	330	12.8	yes
TUG	engine: DC 13 109 440 vehicle: Scania R LA 4x2	road tractor 18t	EURO VI	AGR, DPF, SCR	324	12.7	yes
TUG	engine: Cursor HI-eSCR vehicle: IVECO STRALIS Hi-Way	road tractor 18t	EURO VI	DPF, SCR	353	11.0	yes
TÜV Nord	engine: DC13 110 480 vehicle: Scania R LA 4x2	road tractor 18t	EURO VI	AGR, DPF, SCR	353	12.7	yes
TÜV Nord	engine: MAN D2676 L25 vehicle: - - - - -	---	EURO VI	AGR, DPF, SCR	353	12.4	yes