New Emission Factors for EURO 5 & 6 Vehicles

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Introduction

In January 2010 the current version 3.1 of the HBEFA was released. It includes emission factors for all relevant road vehicle types. Since the measurements for the last update of HBEFA 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. Instead, those categories had been modelled based on EURO 4 data and calibrated towards then-future technologies and emission limits.

For the next major update of HBEFA the measurement base is being expanded to adequately cover the passenger cars' EURO 5 segment and to give an outlook on EURO 6. The required measurements are determined on roller test beds using the newly developed ERMES driving cycle beside the well-established CADC. The measurements presented in this paper have been carried out by the ADAC, TÜV Nord and TUG and are funded by the Environment Agencies of Austria and Germany as well as by the German BAST. JRC is funding adaptations of the simulation tool PHEM to EURO 6 technologies and the calculation of emission factors. Additional tests are being performed by other test labs of the ERMES group but are not yet available for the integration into the model PHEM. Thus the update of the HBEFA was postponed to spring 2013. Main reason for the delay is the poor availability of EURO 6 vehicles for emission measurements. This situation will hopefully improve within the next months.

However, the actual paper is based on fifteen tested EURO 5 and five measured EURO 6 cars. Two EURO VI trucks have been measured as well as one EURO V truck which operates without SCR, a technology also not covered by test results in the actual HBEFA.

Abbreviations

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

DOC..... Diesel Oxidation Catalyst

DPF ..... Diesel Particle Filter

EGR..... Exhaust Gas Recirculation

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

HBEFA..... Handbook Emission Factors for road transport

JRC..... Joint Research Centre

PEMS ..... Portable Emission Measurement System

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

SCR ..... Selective Catalytic Reduction

TUG ..... University of Technology Graz

The Emission Model PHEM

The emission factors from HBEFA 3.1 were 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 were done using the simulation tool PHEM. PHEM is an emission map based instantaneous emission model, which has been developed by TUG since the late 1990's. It calculates the fuel consumption and emissions of road vehicles in 1Hz for a given driving cycle based on the vehicle longitudinal dynamics and emission maps (Figure 1). The model has already been presented in several papers, e.g. Hausberger, 2003 and Zallinger et. al., 2008. 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 useful tests on more than 1000 vehicles are available.

For the next version of the Handbook Emission Factors (HBEFA V3.2), 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 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 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 additions especially support the increasing importance of accurate simulation of fuel consumption and CO_2 emissions. Which of these options finally will be used for the update of the HBEFA depends if sufficient model input data for “average auxiliaries” will be available in time and on the availability of resources to implement and test the data. Beside the additional functionalities also a clearly improved user interface was established in PHEM version 11.2.

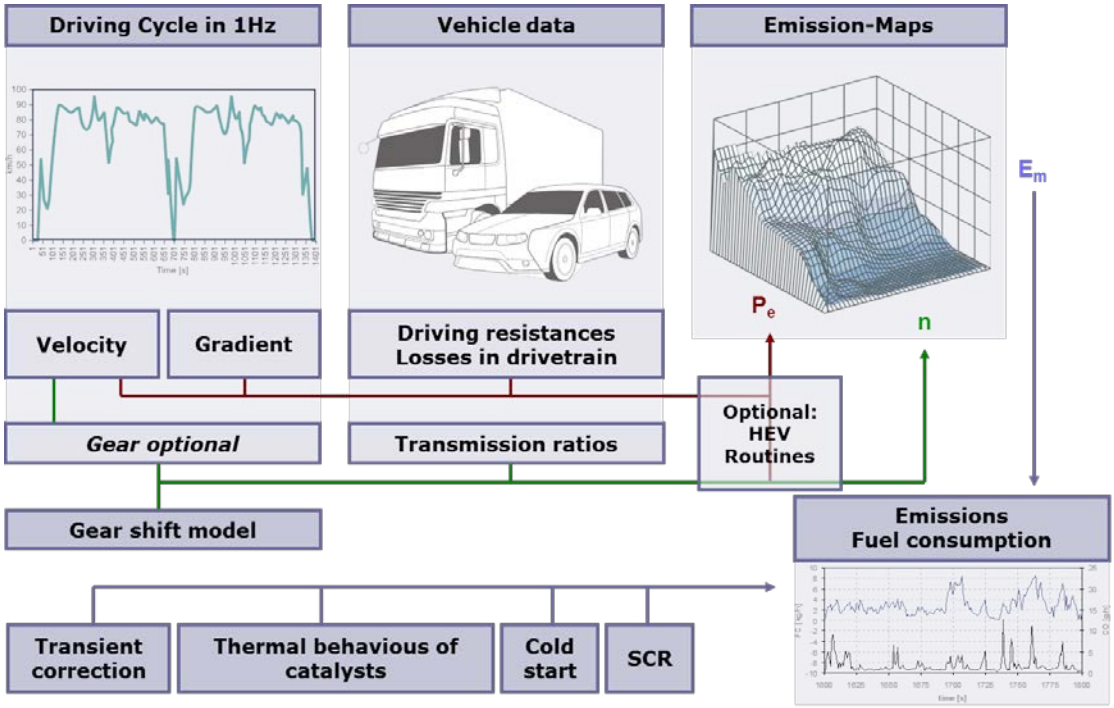

Figure 1: Scheme of the PHEM model

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 to allow user friendly calculation of average emission values from the vehicle fleet. A first data set for 2-wheelers simulation in PHEM is under preparation. The interface to micro scale traffic models as alternative source for providing vehicle speed patterns to the model PHEM allows purely simulation based analysis and optimisation of traffic control systems to minimise emissions and energy consumption. The standardised output files include also total emission quantities allocated to the single segments of the road network under consideration to directly feed air quality models.

ERMES Cycle and ERMES Tool for Evaluation of Modal Test Data

The measurement program for the HBEFA update for passenger cars typically starts with a NEDC to check if the vehicle fulfils the type approval limits. Due to the cold start and the quite low engine load levels the NEDC is not an appropriate cycle to set up the engine emission maps for the model PHEM. Therefore 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 1280 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 29 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.

Due to the short test duration the ERMES cycle certainly does not cover as many different engine load situations as the CADC. Similar to the CADC the share of the single sub-cycles on the total mileage of the test are not fully representative for their shares in real world driving. Otherwise the entire test would be much too long or some sub-cycles would be much too short to obtain meaningful emission results. The ERMES cycle is further divided into 17 sub-cycles (6 for urban, 5 for rural and 7 for motorway).

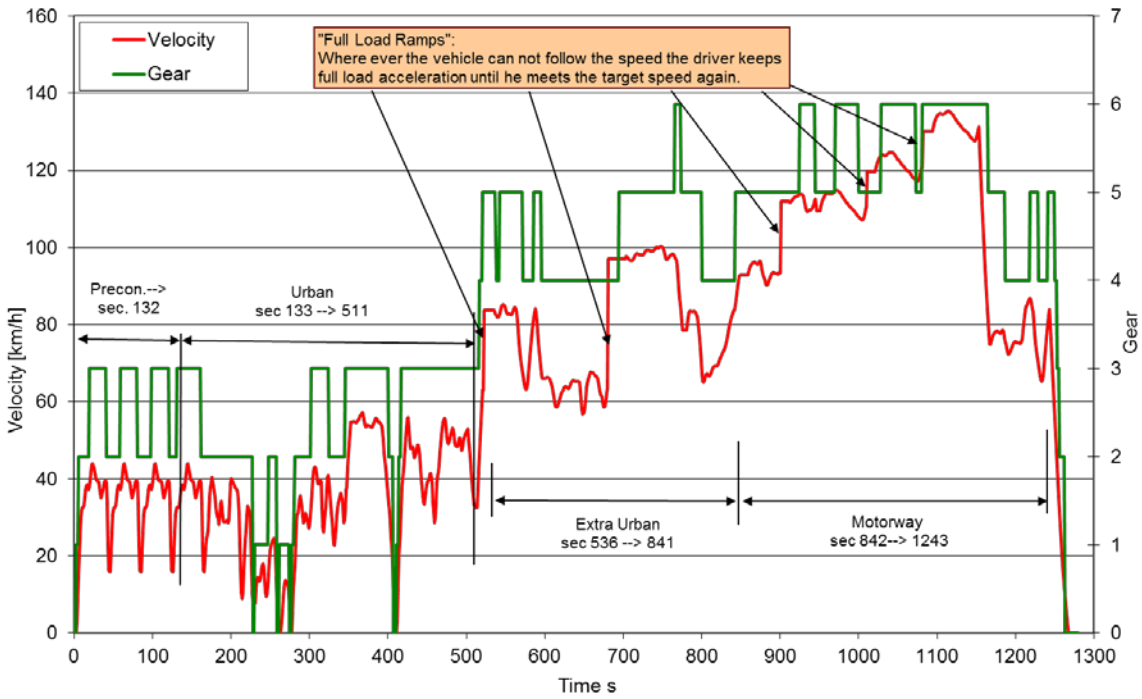

Figure 2: The ERMES test cycle with gear shift rules for a diesel car with 6 gears

To improve the data quality and the user friendliness for test bed personnel, especially for the evaluation of the modal test data, the “ERMES evaluation tool” was developed at TUG. The ERMES tool calculates the modal mass emissions over a test cycle applying all relevant corrections defined in the regulation just for bag measurements, such as for humidity, for dilution in the CVS tunnel etc. and correcting also for variable transport time of the exhaust gas from the engine to the analyser as well as for mixing effects during the exhaust gas transport and for analysers’ response time. These functions shall improve the time allocation of measured emissions to engine load conditions as important prerequisite to create engine emission maps from transient vehicle test cycles. Furthermore the ERMES tool provides standardised result formats which can directly be read by the model PHEM to create the engine maps and the vehicle data file.

Results for Passenger Cars

The data base from HBEFA 3.1 covers passenger cars from EURO 0 to EURO 4. In addition now test results from EURO 5 and EURO 6 cars are available (Table 1). The sample for EURO 5 is already large enough to give robust trends for the emission level. For EURO 6 diesel the sample consists of only 4 different models from three different manufacturers. Since these models are pioneers in applying emission control technology to fulfil the future EURO 6 limit values, this sample cannot be assumed to be representative for the future EURO 6 fleet.

Table 1: Number of measured cars available for the analysis here and additional data expected

Lab	EU 5 gasoline	EU 5 diesel	EU 6 gasoline	EU 6 diesel
ADAC	1	3	0	1
TUG	7	13	0	4
Total today	**8**	**16**	**0**	**5**
Additional data expected until 01/2013:				
EMPA	*10*	*4*	*0*	*0*
TNO	*5*	*7*	*0*	*3*
JRC	*8*	*4*	*0*	*0*
Total 01/2013	***31***	***31***	***0***	***8***

Figure 3 compares the NO_x-emissions measured for the EURO 5 and EURO 6 cars with the EURO 0 to EURO 4 data base from HBEFA 3.1. In all real world cycles NO_x from EURO 5 vehicles is on average above EURO 4. In the NEDC NO_x from EURO 5 was on a similar level than EURO 4. However, the variation of NO_x emissions measured within each EURO class is high. As a result the confidence intervals of the average emission levels are overlapping and the ranking shown in the figures may not exactly represent the real fleet averages. The EURO 6 vehicles tested so far showed clearly lower NO_x-levels than EURO 5. These tests show that the technology applied in these cars (high EGR rates with SCR) to meet the EURO 6 limits has the potential for low NO_x levels. To ensure that all future EURO 6 makes and models will have sufficient EGR and SCR dosing strategies to reach low NO_x in all relevant real world conditions it seems to be necessary to extend the actual type approval procedure. At the moment random cycle or PEMS tests are under discussion as potential solutions. Without such additions the trend from EURO 0 to EURO 5 may be extended for EURO 6, what would mean roughly constant NO_x levels for all EURO classes since 1990. The gasoline EURO 5 vehicles tested showed in general very low NO_x emissions. The NO_2/NO_x ratio was 35% on average for EURO 5 and 43% for the EURO 6 diesel cars. For the EURO 4 data set in the HBEFA 3.1 NO_2 accounts for approx. 40% of NO_x.

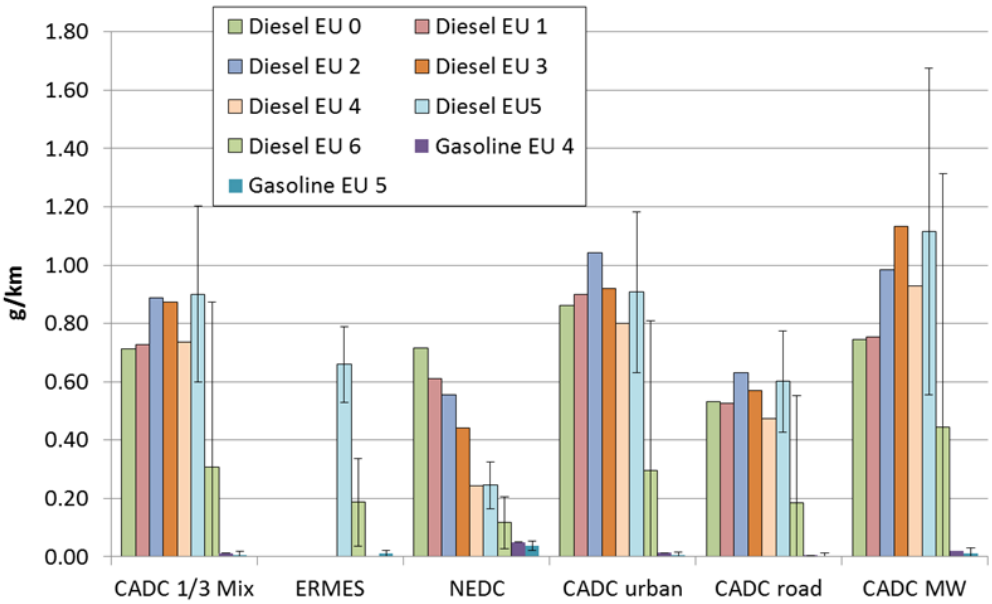

Figure 3: NO_x Emissions measured at passenger cars (error bars show 95% confidence interval)

Figure 4 shows the particle number (PN) emissions. For Diesel before EURO 3 no reliable measurement results are available. The reduction in diesel PN emissions against EURO 3 is impressive and can be attributed mainly to the introduction of the DPF. For gasoline cars from EURO 4 to EURO 5 a clear increase in PN is visible, however, the absolute levels are certainly much lower than for diesel without DPF. The increase may be attributed to the increasing share of direct injecting gasoline engines in the sample. PM emissions show similar trends as PN.

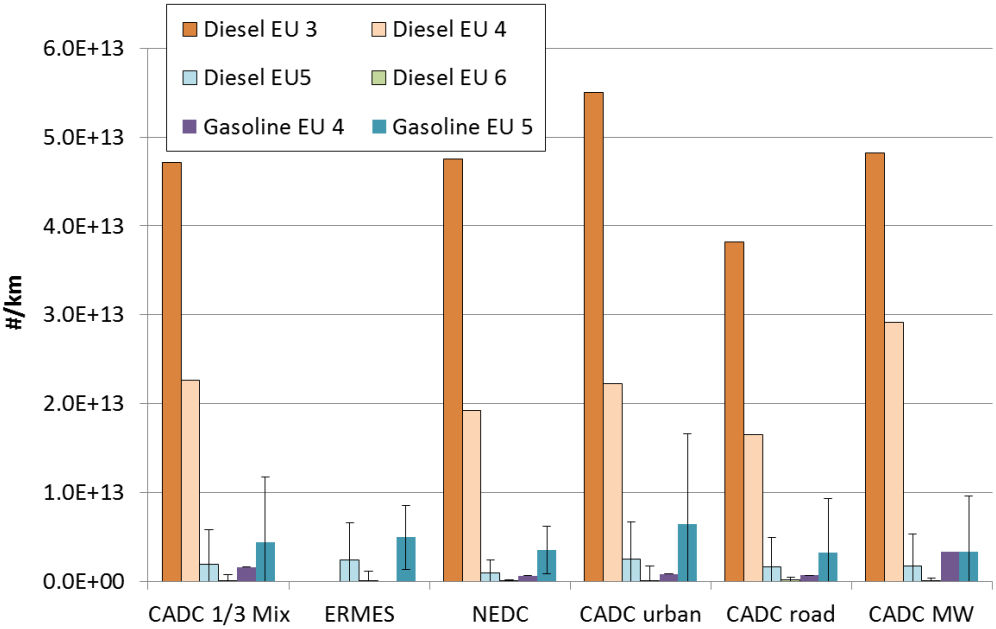

Figure 4: Particle number emissions measured at passenger cars

HC and CO emissions from EURO 6 diesel cars were found to be higher than from EURO 5 but on a rather low absolute level. This trend can be attributed to higher EGR rates and resulting lower exhaust gas temperature levels. Results for other exhaust gas components will be reported with the update of emission factors.

Emission Trends for HDV

For HDV also the update of NO_x emissions seems to be the most important topic for HBEFA 3.2. Since test cycles and also vehicle size and loading from the measured HDV are different, a comparison of measured emissions on a g/km basis cannot be done in a meaningful way. *Figure 5* shows such a comparison on the left side. The EURO VI truck measured had even lower NO_x under hot conditions than assumed for the EURO VI trucks in HBEFA 3.1. The second EURO VI truck was measured at Emitec without loading. Due to the different engine work and resulting differences in the SCR temperature levels the emissions can only be compared when plotted related to the engine work delivered over the test cycle. Here the second make and model (veh#2) showed clearly higher NO_x levels at lower engine loads than veh#1. The main reason is the reduced SCR conversion efficiency at lower temperatures which needs technical measures at the engine to increase exhaust gas temperatures at low loads. How efficient these measures will be implemented in the first generation of EURO VI trucks is open yet. In total the tests available until now support the NO_x levels estimated for EURO VI in the HBEFA 3.1.

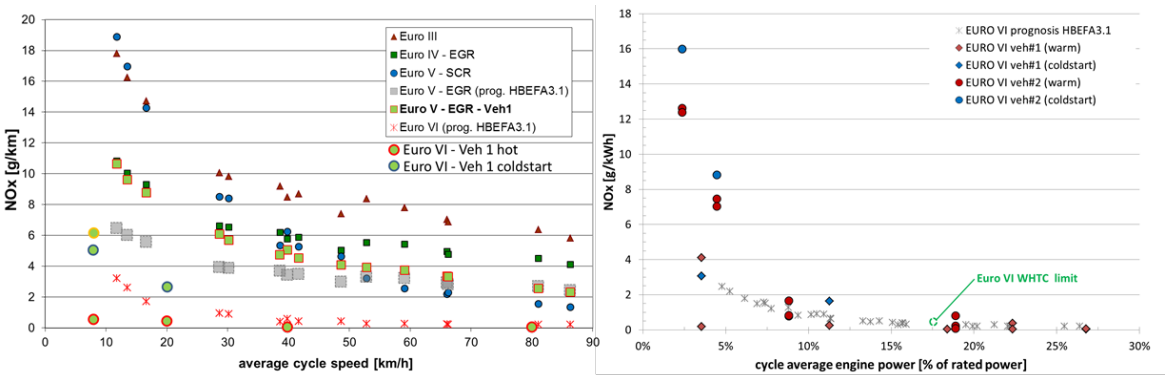

Figure 5: Emissions of half loaded articulated trucks in selected traffic situations according to HBEFA 3.1 in comparison to the first measured EURO VI truck (left picture) and engine work specific emissions of the two tested EURO VI trucks (right picture, with veh#2 tested unloaded)

Summary

Due to limited availability of EURO 6 vehicles for emission tests the update of the HBEFA 3.1 is postponed to spring 2013. The entire process from test data evaluation, set up of average engine emission maps, definition of average vehicle data sets and simulation of the emission factors for all traffic situations shall result mainly in updated emission values for EURO 5 and EURO 6 cars as well as for EURO VI HDV. For those vehicle categories the actual HBEFA 3.1 data is based on technology assessments only. The emission tests available yet indicate, that EURO 5 diesel cars may have even higher NO_x levels than assumed in HBEFA, where similar NO_x emissions in [g/kWh] than for EURO 4 were presumed. The few EURO 6 cars measured yet had clearly lower emissions than EURO 4. Since only two EURO VI HDV test results are available until now, no reliable conclusion for the fleet average can be drawn. But the test results so far are in line with the (low) NO_x emission values supposed in HBEFA. For PM and PN emission levels from diesel engines, clear reductions against EURO 4 were found. For gasoline the trend towards higher shares of direct fuel injection tends to increase PM and even more PN emissions. However, the levels are still rather low and the introduction of appropriate PN limit values in type approval shall solve this issue.

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