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A New Approach for Systematic use of PEMS Data in Emission Simulation

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Abstract

Using on-board emission tests from portable emission measurement systems (PEMS) is becoming more and more a common approach for real world emission testing of passenger cars (PC), light commercial vehicles (LCV) and heavy duty vehicles (HDV). The advantages against chassis dyno tests are the high robustness to obtain unbiased emission levels and to cover a lot of real world driving situations. Disadvantages for the use in emission modelling are the high influence of the route, the driver, traffic conditions and ambient temperature on the resulting emissions. Consequently test results show a high variability for single vehicles and can hardly be used directly to obtain emission factors. Figure 1 shows as example test data from one EU 6 diesel car in 25 PEMS trips and in New European Drive Cycle (NEDC), Worldwide Harmonized Light-Duty Vehicles Test Procedure (WLTP) and European Research Group on Mobile Emission Sources cycle (ERMES) as chassis dyno tests. NO_x measured in the PEMS tests had a factor of 7 between lowest and highest test value. Obviously ambient temperature, engine load and cycle dynamics have high influence on the measured emissions and should be considered in a systematic way to elaborate reliable fleet emission values.

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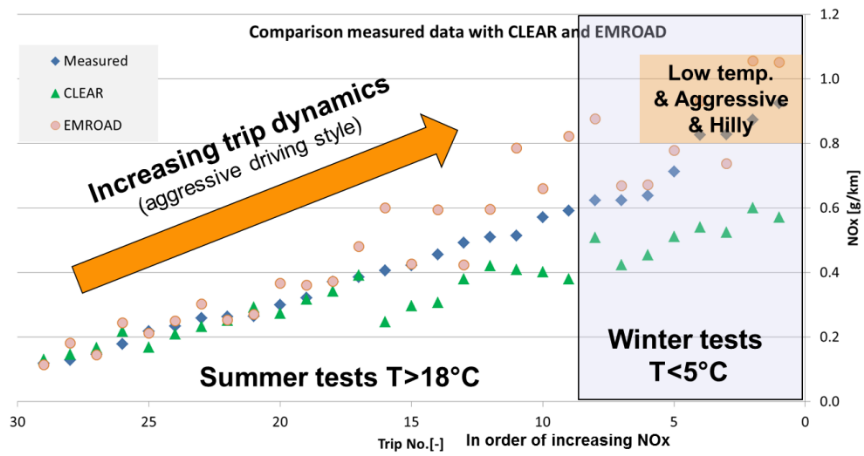

Figure 1: Example for NO_x emissions measured at a EU 6 diesel car in 28 trips (Hausberger S. et al. (2016)).

To solve the new issues in emission simulation the Institute for Internal Combustion Engines and Thermodynamics (IVT) at TU Graz has developed a novel approach to integrate PEMS tests into the Passenger car and Heavy duty Emission model (PHEM). The model PHEM is used to calculate real world emissions for PC, LCV and HDV, e.g. (Rexeis M. et al. (2013)). PHEM simulates engine power and engine speed based on longitudinal dynamics and interpolates base emission values then from engine emission maps. Depending on vehicle class and technologies also the influences of dynamic load changes and of the space velocity and temperature in the exhaust gas after treatment systems are considered for the tailpipe emissions.

To simulate representative fleet average emissions per vehicle class, from all vehicle emission measurements engine emission maps are calculated. The emission maps are produced by PHEM by sorting the instantaneously measured emissions into standardized maps according to the actual engine speed and torque. Average emission maps from all tests are obtained by averaging the single maps in normalized formats. To produce representative engine maps tests from many vehicles shall be included and realistic driving situations shall be used. Consequently the inclusion of PEMS data would be very beneficial for the PHEM simulation if done properly.

Since a reliable torque signal most often is missing in PEMS test data, PHEM offers now a new option to calculate the engine power from measured CO_2 mass flow (or fuel flow) and engine speed based on generic engine efficiency maps (Figure 2). Thus only engine speed needs to be measured beside the standard emission components to compile engine emission maps for the measured vehicle. To improve the accuracy of the allocation of emissions and engine speed the method to correct for variable transport times of the exhaust gas implemented in the ERMES Tool can be applied.

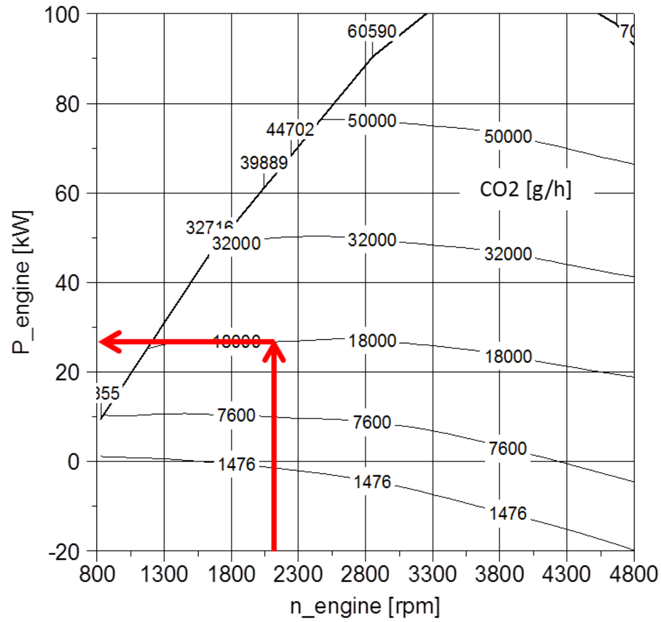

Figure 2: Example for interpolation of the engine power from a generic CO2 map.

With this method all new data from PEMS tests can be integrated into the existing data base from the model PHEM to have a broader number of vehicle tests as basis for future updates of emission factors. The paper describes the method and validation results.

Keywords: CO_2 interpolation method, engine map, emission, simulation, PEMS.

1 Introduction

The discussions on defeat device software together with the introduction of on-board emission tests in the vehicle type approval procedure for PC, LCV and HDV led to increasing number of vehicles tested in real traffic with PEMS (Table 1). For EU 5 cars 18% of the vehicles were tested with PEMS while for EU 6 cars already 60% of the vehicles are tested with on-board equipment.

Table 1: Vehicle tests available within the ERMES group.

Category	Test category	No. of vehicles
PC EU 5	Total: Chassis dyno + PEMS (1)	119
	Share PEMS, SEMS	18%
PC EU 6	Total: Chassis dyno + PEMS	93
	Share PEMS, SEMS	60%
LCV EU 5	Total: Chassis dyno + PEMS	24
	Share PEMS, SEMS	42%
HDV EU V	Total: Chassis dyno + PEMS	20
	Share PEMS, SEMS	50%
HDV EU VI	Total: Chassis dyno + PEMS	40
	Share PEMS, SEMS	65%

(1)…additional 190 EU 5 cars shall be available from the SE In-use Compliance test program

Actual emission models have to react on this trend and have to find proper ways to consider the PEMS test data for model parameterization. In the past the main problem was the rather unknown driving conditions during PEMS tests. Nearly none of the PEMS data included a reliable engine torque signal and a simulation of the engine torque with the uncertainties concerning real world air drag, rolling resistance, gradient and loading lead to quite inaccurate assessments of the engine power. Thus from the typically available PEMS data an assessment of the representativeness of the trip was hardly possible.

If the PEMS test data is used only to calculate average emission factors for urban, road and motorway driving, testing on well-defined routes and with "representative drivers" can reduce the uncertainties. However, this approach does rather not allow to elaborate more detailed emission information, e.g. for uphill, downhill driving at different gradients, driving with different loads etc. If the routes used for the measurement campaign prove not to produce representative emission levels in future, approaches based on simple averaging of emissions measured cannot adjust the results ex post. Also a fair comparison of PEMS results from different sources is hardly possible since typically different routes, drivers, loadings and weather conditions are different.

To use emission test data in a highly flexible way the model PHEM converts any emission test on a vehicle into engine emission maps with normalized engine speed and normalized power as parameters. PHEM needs for the map creation engine speed, engine power and emissions measured instantaneously as input.

With the engine emission maps emissions can be simulated for any driving condition. The engine power and speed are in this application computed instantaneously for the given velocity and road gradient cycle and for the user defined vehicle properties and loading situation. Emissions are then just interpolated from the emission map for the power and rpm values. By changing the gear shift model also adjustments in driver behavior and/or transmission systems can be made.

The main obstacle to convert data from PEMS tests into engine maps was so far the missing or unreliable engine power signal. The paper describes a novel method which can solve this problem for any measurement as long as signals for CO_2 and engine speed are available.

The approach was developed after an analysis of engine fuel maps in a PHEM application to assess future CO_2 reduction potentials of different technologies (Hill N. et al. (2015)). The maps measured steady state on engine test beds showed a much better quality than the maps produced from transient chassis dynamometer tests. Main reasons for the poorer quality of transient maps are the uncertainties in the time alignment between engine torque and fuel flow or CO_2 mass flow.

On the other hand pollutant emission maps are not very representative if measured steady state on an engine test bed. Since vehicle emission tests hardly take place on engine test beds but use typically the entire vehicle either on a chassis dynamometer or with PEMS, in the past the pollutant maps and the fuel consumption maps were calculated from transient vehicle tests as basis for the model PHEM.

The new approach combines now the advantages of both data sources:

- The fuel consumption and CO_2 engine maps are gained from existing engine steady state tests from representative engines. Since the engine efficiencies from engines with similar technology differ only by a few percent between makes and models, the uncertainty from the small engine sample is much lower than the uncertainty coming from inaccurate time alignment when the map was produced from transient tests. The accuracy of the CO_2 simulation thus is increased in PHEM by using generic fuel maps.
- Since the fuel consumption and CO_2 engine maps are defined now by generic maps, the engine power can easily be interpolated from the instantaneous engine speed and CO_2 mass flow or fuel flow as shown in the abstract. Since engine power is calculated from CO_2 errors in the time alignments between engine power and pollutant emissions can be excluded, as long as the time alignment between the different exhaust gas components is not wrong. Thus signal misalignments are restricted to engine speed and CO_2. Since engine speed usually changes less dynamically than the torque, the influence of misalignments is reduced compared to the former method. To reduce the remaining uncertainty also a new method for variable time alignment of exhaust emissions and engine torque and rpm was elaborated (Weller K. et al. (2016)).
- Since engine speed can be measured quite easily and accurately also in PEMS tests, the new method allows also to convert on-board emission test data into PHEM engine maps as long as CO_2, rpm and some pollutant emissions are recorded instantaneously.

The following chapters describe the new method and show the results of the validation work done so far.

2 Input data for CO2 interpolation method

To apply the new CO_2 interpolation method for power interpolation, the measured CO_2 and engine speed must be known for each trip. Also a generic CO_2 map is necessary for the interpolation method.

The CO_2 and other emissions are measured and recorded by PEMS in an adequate temporal resolution (1Hz or better). If possible the PEMS also records the engine speed. The signal could be obtained from the CAN-Bus in most of the cases. If not, an additional engine speed sensor could be installed for the tests. Due to a time shift between the measured CO_2 and load signal the CO_2 should be time aligned to the engine speed in an appropriate way. Following options for the time alignment have been investigated by TU

Graz (Weller K. et al. (2016)):

- Constant time shift: With a constant offset the CO_2 signal is shifted over the time axis according to a reference signal.
- Variable time shift: The instantaneous emission signals are time shifted for the transport time computed for each time step based on the exhaust gas mass flow rates.

The constant time shift was used for all validations described in the next chapter since the variable time shift was implemented in the software too late to be presented in this paper. In the next months possible improvements in the model accuracy due to the better time alignment shall be analyzed.

The vehicle speed and the altitude for gradient calculations in this paper were recorded by a global positioning system (GPS).

The generic CO_2 map describes the correlation between CO_2, engine speed and engine power. Since engine maps usually are not provided by the OEMs and measurements on the engine test bed from a third party are expensive due to the high effort such data are rarely available. Thus generic maps were elaborated which represent average engine technology for 2013 and 2015 diesel and petrol engines. The data are gained from a CO_2 study for the European Commission (EU), executed by Ricardo and TU Graz (Hill N. et al. (2015)). Also estimated engine maps for a 2020 engine technology are available.

The generic maps are normalized to allow their application for all power classes. The simplified approach is to scale the same CO_2 map for vehicles with similar engine technologies but different engine capacities. For a validation of the best method for normalization measured maps were normalized and then de-normalized according to the data from another measured engine. The criterion for "best normalization" was to get lowest differences in the de-normalized fuel maps from one engine compared to the original fuel map of other engines with different power. Following cases for investigation of the best normalization were done:

- Case 1: $FC = f(n, P_{engine})$

- n normalization with $(n-n_{idle})/(n_{rated}-n_{idle})$
- P_{engine} normalization with P_{engine}/P_{rated}
- FC normalization with FC/P_{rated}

n… engine speed in [rpm]
n_{idle}… idle speed in [rpm]
n_{rated}… engine speed @rated engine power in [rpm]
P_{engine}… engine power in [kW]
P_{rated}… rated engine power in [kW]
FC… fuel consumption in [g/h]

- Case 2: $FC = f(n, p_e)$

- n normalization with $(n-n_{idle})/(n_{rated}-n_{idle})$
- p_e normalization with p_e/p_{emax}
- FC normalization with FC/P_{rated}

p_e… mean effective pressure in [Pa]
p_{emax}… max. mean effective pressure in [Pa]

- Case 3: $FC = f(c_m, p_e)$

- c_m not normalized
- p_e normalization with p_e/p_{emax}
- FC/ normalization with FC/P_{rated}

c_m… mean piston speed in [m/s]

- Case 4: FC = f (c_m, p_e)

- c_m not normalized
- p_e normalization with p_e/p_{emax}
- FC normalization with FC/V_H

V_H… engine capacity in [l]

- Case 5: FC = f (c_m, p_e)

- c_m not normalized
- p_e normalization with p_e/p_{emax}
- FC normalization with FC/h

h… stroke in [mm]

To find out the best case 2 diesel and petrol engines with similar engine technology but different engine capacity were measured on the engine test bed. As an example, the diesel engine comparison is presented.

Table 2 shows the deviation between two maps, namely of the averaged measured FC from the steady state map of the original 2.0l engine and the averaged FC from the steady state map of the 3.0l engine de-normalized to a 2.0l engine according to the described cases. Similar exercise was done for upsizing the 2.0l engine to 3.0l. The corresponding deviations are also shown in Table 2.

Table 2. Average FC deviations.

	Case 1	Case 2	Case 3	Case 4	Case 5
Deviation between the averaged measured FC from the steady state map of the original 2.0l engine and the averaged FC from the steady state map of the 3.0l to 2.0l de-normalized engine	3.44%	1.87%	5.80%	-4.54%	43.19%
Deviation between the averaged measured FC from the steady state map of the original 3.0l engine and the averaged FC from the steady state map of the 2.0l to 3.0l de-normalized engine	3.22%	2.05%	5.37%	-4.88%	-30.08%

Additionally one significant load point at 1400rpm and 4.7kW was investigated.

Table **3** shows the results for the de-normalized engines.

Table 3. FC deviations for one significant load point.

	Case 1	Case 2	Case 3	Case 4	Case 5
Deviation between the averaged measured FC from the steady state map of the original 2.0l engine and the averaged FC from the steady state map of the 3.0l to 2.0l de-normalized engine	0.78%	-2.86%	4.30%	-5.90%	41.16%
Deviation between the averaged measured FC from the steady state map of the original 3.0l engine and the averaged FC from the steady state map of the 2.0l to 3.0l de-normalized engine	1.47%	3.85%	3.50%	6.95%	-28.70%

Case 1 and 2 show the lowest deviations for normalization of diesel and petrol engine maps. Since case 1 was already implemented in the simulation tool PHEM before, this option was chosen to normalize and de-normalize the engine maps according to the fuel map. CO_2 is treated like the fuel flow as separate column in the engine map or simply computed from the carbon content of the fuel as basis for the CO_2 interpolation method.
Furthermore, measurements from the diesel engine show, that the engine out temperature is similar between an engine with small and large cylinder displacement in an engine map with the normalized engine speed and power axis. The same is valid for petrol engines. Therefore the temperature value in the map points is not normalized for engines with different cylinder displacement but engine power and speed are normalized as for fuel consumption and for pollutants as described in case 1.

3 Validation of CO_2 interpolation method

To validate the previously described CO_2 interpolation method, four diesel vehicles with EU 5 and EU 6 exhaust emission standard were measured on the chassis dynamometer and on the road with PEMS. Table 4 shows main data of the investigated vehicles. The investigation of petrol and of further diesel vehicles will follow.

Table 4. Vehicles investigated in the validation.

Vehicle ID	Segment	Exhaust emission standard	After treatment	Transmission
1	D-segment, 2.0l, 120kW	EU 6	NSC and DPF	6-speed MT
2	D-segment, 1.6l, 77kW	EU 5	DOC and DPF	7-speed AT
3	SUV, 3.0l, 160kW	EU 6	DOC, DPF and SCR	8-speed AT
4	D-segment, 2.0l, 105kW	EU 5	DOC and DPF	6-speed MT

For the measurements on the chassis dynamometer the appropriate settings for Worldwide Harmonized Light-Duty Vehicles Test Cycle (WLTC), ERMES and Common Artemis Driving Cycles (CADC) were used. This means that the road load and test masses in WLTC settings are adjusted according to the WLTP draft, the ERMES and CADC settings according to real world standard. To validate the CO_2 interpolation method a benchmark was necessary. On the chassis dynamometer as reference signal the wheel power from the investigated vehicle provided by the chassis dynamometer in 1Hz was chosen. For the comparison with the power interpolated from the CO_2 map the measured power was recalculated to the clutch with an estimated constant transmission efficiency of 92%. The inertia of the rotational accelerated components was considered in the comparison since the CO_2 interpolation method delivers the "quasi-stationary engine power". As an example, the comparison for the WLTC with vehicle no. 4 is presented in detail. Since the CO_2 method cannot describe the breaking power (lowest value is the motoring power with zero CO_2 mass flow), only the positive power is compared. For the CO_2 interpolation method the measured CO_2, the measured engine speed and the generic CO_2 map from PHEM for 2013 EU 5 diesel engines was used. The measured CO_2 signal was time shifted according to the measured wheel power by a constant offset as explained before. In Figure 3 the measured positive power at the clutch is shown in grey. The dotted black line is the interpolated power at clutch. The interpolated power matches the measured power with an average deviation of -3%.

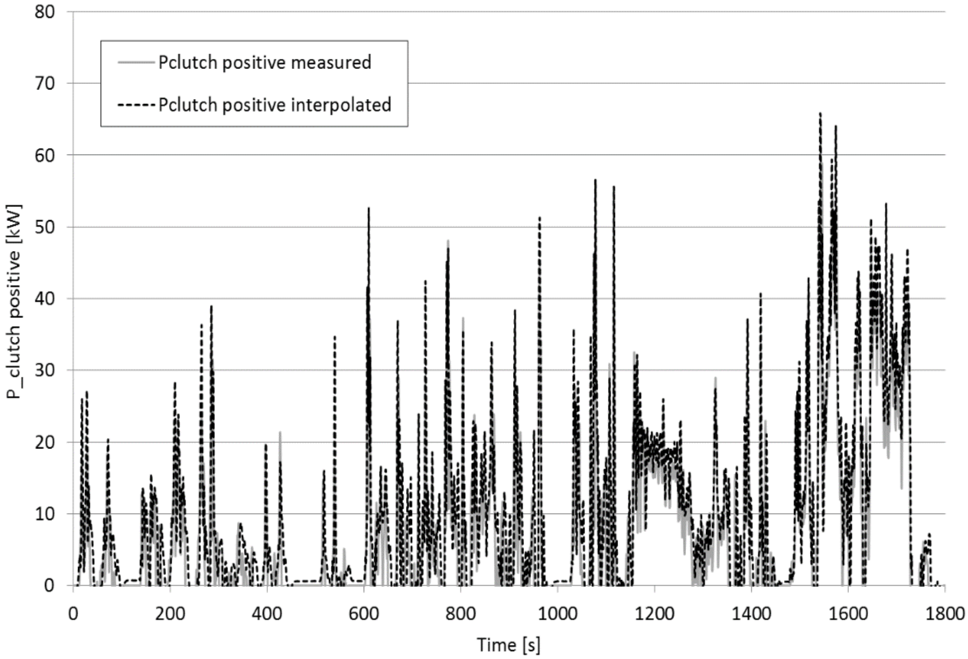

Figure 3: Positive power validation for a D-segment diesel vehicle in WLTC.

The same exercise was done for the CADC urban, CADC road, CADC motorway and ERMES. For the ERMES cycle the average deviation between measured and interpolated positive power was 6%, for CADC between -12% and 8%. In consideration of the generic CO_2 map used for the calculation and the uncertainties in measurement and transmission efficiencies the deviations are in an acceptable range.

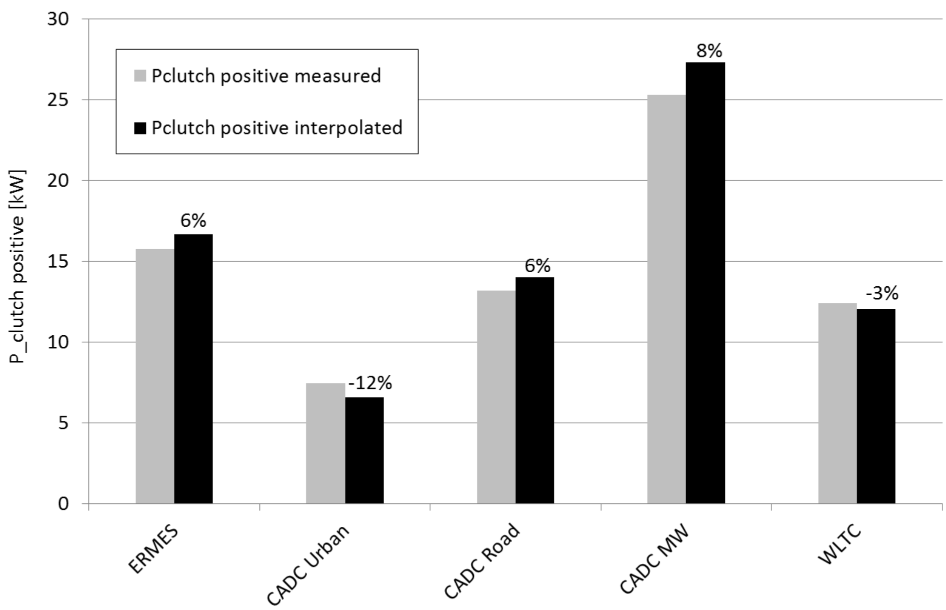

Figure 4: Power deviations between measured and simulated data from a D-segment diesel vehicle.

With improvements of the CO_2 map according to the engine technology of the vehicle investigated the deviations may be reduced (i. e. a higher efficiency in the part load area for this vehicle) but the effort seems not to be justified due many other and larger uncertainties in the emission factors (representative driving cycles and driver behavior, real world rolling and air resistance, average loading, etc.).
The measurements on the road were carried out in accordance with the actual real driving emissions (RDE) draft regulation. The analysis shown includes hot starts. The vehicles were driven by different drivers on different routes. For completeness it is mentioned that not all vehicles were measured on all routes and for testing the repeatability some routes were measured several times with the same vehicle.
The first route is called Ries-Route, which leads from Graz to Sinabelkirchen (east of Graz). The second route leads from Graz to Köflach (west of Graz) and is called Köflach-Route and the third one is from Graz to Arzberg (north of Graz), called Arzberg-Route. To investigate different driving and ambient conditions the measurements were done for one vehicle in winter and in summer. The average ambient temperature was between 1.5°C and 30°C.
A similar exercise was done for the RDE trips as described before for the chassis dynamometer tests. As an example, the following figure shows the load points interpolated with the CO_2 method for vehicle no. 4 driven on the Ries-Route. Each grey point describes one load point, calculated in 1Hz. The black points describe the stationary full load and drag curve for the generic diesel engine with 2013 technology standard. Resulting from the generic full load curve, transient measurement and measurement uncertainties some data points are above the full load curve.

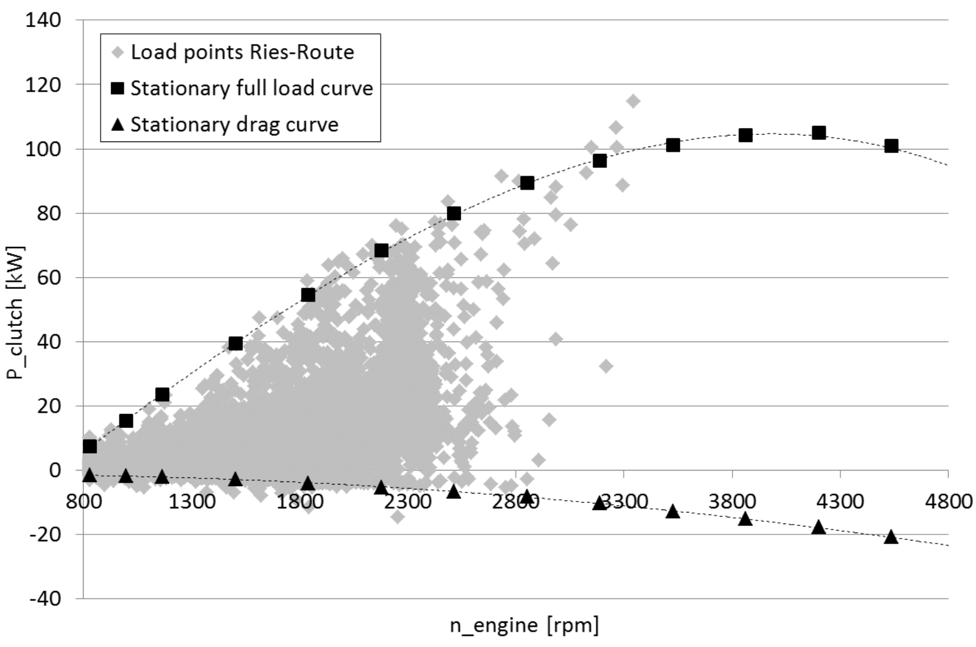

Figure 5: Interpolated load points from a RDE trip with a D-segment diesel vehicle.

Due to missing engine power data during the RDE trip from the CAN-Bus and in absence of torque measuring wheel hubs, no measured reference signal for the engine power for validation is available at the moment for PEMS tests. Thus the validation is based on the simulation of the engine power via longitudinal dynamics from the measured vehicle speed and road gradient data as shown later. All measured pollutant emissions i.e. NO_x, CO and others were matched in the engine map as described before, using the rpm signal as x-axis and the power interpolated from CO_2 as y-axis. The CO_2 and fuel map used for map production and for the vehicle simulation was always the generic map. The emission map was then used to simulate the pollutant emissions in the RDE trips. In Figure 6 the generic CO_2 basis map is shown as function of P_{engine} and rpm (both normalized according to the described case 1). Figure 7 and Figure 8 represent the NO_x and CO map gained from the measured data.

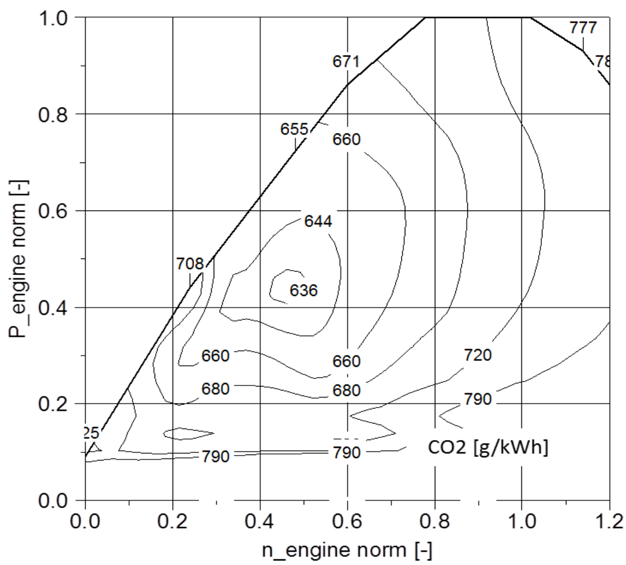

Figure 6. CO_2 in [g/kWh] as function of P_{engine} and n normalized.

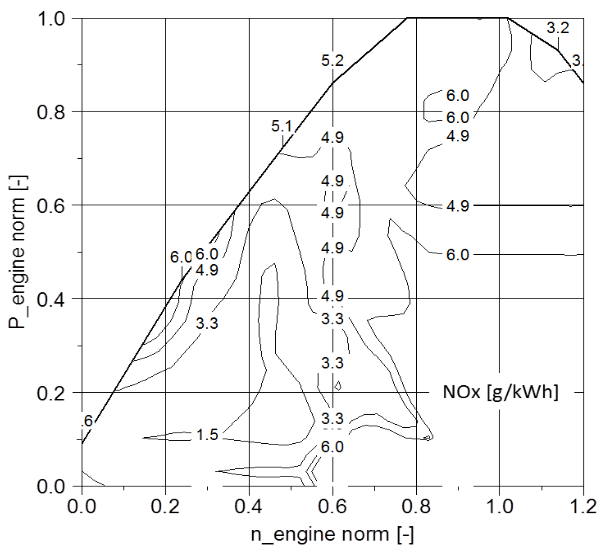

Figure 7. NO_x in [g/kWh] as function of P_{engine} and n normalized.

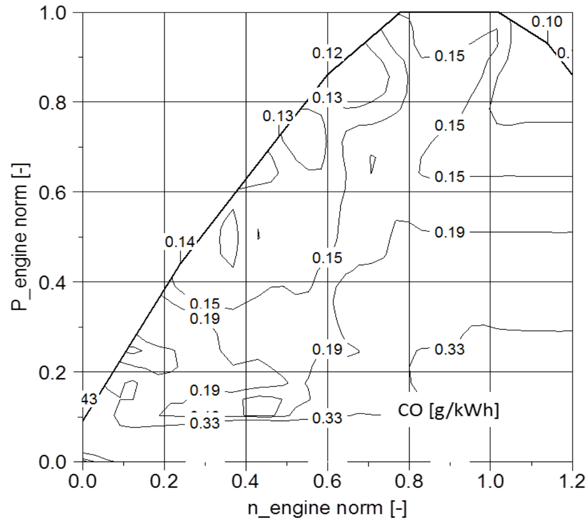

Figure 8. CO in [g/kWh] as function of P_{engine} and n normalized.

For the validation all driven routes were simulated using PHEM with the engine map elaborated from a PEMS test with following steps:

- Option 1: Simulation with measured engine speed and engine power as input (engine power interpolated from CO_2 and rpm) to check the quality of the interpolation method.
- Option 2: Simulation with measured engine speed, but vehicle velocity and road gradient input to check additional to option 1 the quality of power calculation based on the longitudinal dynamics model.
- Option 3: Simulation with velocity and gradient input to check additional to option 2 the quality of the gear shift model from the simulation tool.

With the deviation between the measured and the simulated data a qualitative assessment of the interpolation method can be done. It has to be noted that the uncertainties cover the entire chain from production of the emission map up to simulation of the trip for the vehicle. Following tables show in extracts the results of the comparison for vehicle no. 4 with validation option 1 and option 3. The Ries-Route was driven five times with the vehicle no. 4. One trip was invalid according to the RDE regulation draft, thus the trips Ries no. 2 to no. 5 were inputs for the simulation.

It shall be mentioned that the simulation is not optimized yet. The effect of the interpolation routines used for the interpolation from the engine map is quite large and seems to need further analysis. The deviations include also several other uncertainties such as:

- Default CO_2 map for the interpolation method
- Road gradients are based on the GPS data (relevant for option 2 and 3)
- Power calculations based on default road load resistances (relevant for option 2 and 3)
- Unknown power of auxiliary demand (relevant for option 2 and 3)
- Default gear shift model (relevant for option 3)

Figure 9 contains the CO_2 comparison between the measured and simulated data. As

mentioned before, option 1 gives an overview on the quality of the interpolation method. In this case the "bi-linear" interpolation method shows good results; the simulated CO_2 (grey bar) is equal to the measured one (black bar).
Simulation results with option 3 include a lot of uncertainties as mentioned before. Different gear shift behavior from driver compared to the simulated behavior can be one reason for the different deviations between -8% and 1%. One further reason could be the different auxiliary power demand and different state of charge (SOC) from the battery at the end of each measured trip. In the simulation the same average auxiliary power demand for all trips was estimated and the SOC was not corrected.

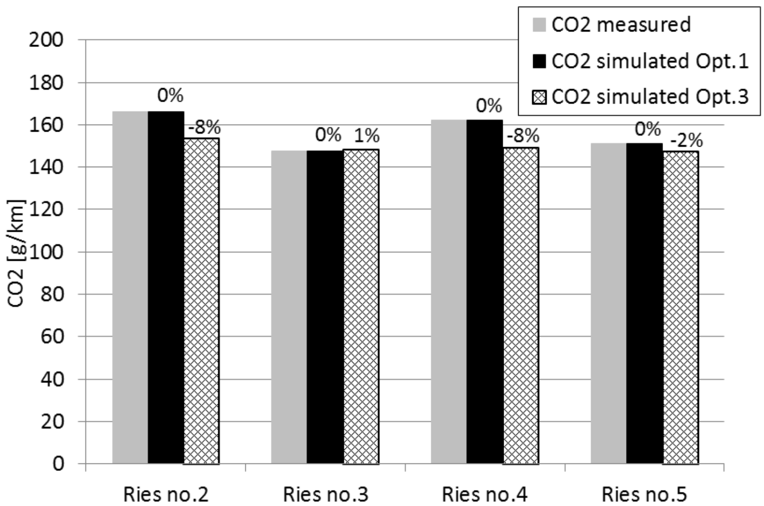

Figure 9. CO_2 deviations between measured and simulated data.

In Figure 10 the measured and simulated NO_x levels for four RDE trips are shown. The simulation overestimates the NO_x up to 25%. The bars in black represent the simulated data with option 1, the crosshatched bars show the simulation results with option 3. Possible reason for the high deviations with option 3 could be the steep gradient of NO_x in the engine map (Figure 7). Minor deviations in engine power calculations due to the uncertainties mentioned before, could be lead in a higher deviation of NO_x.

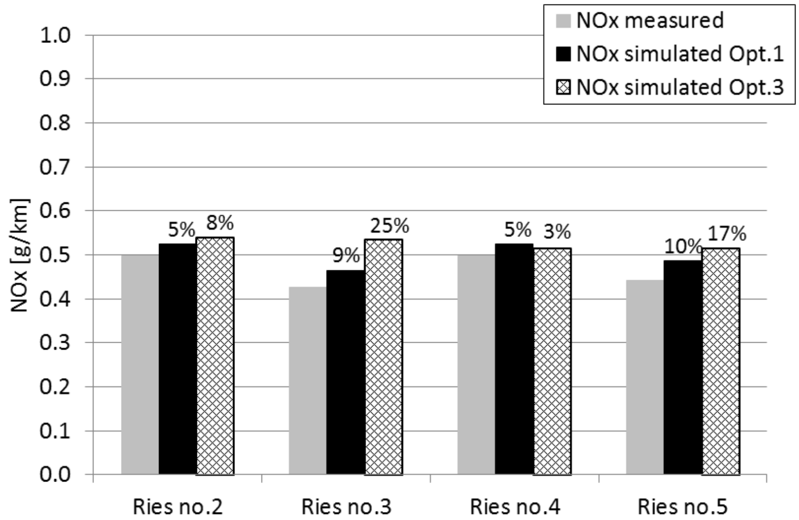

Figure 10. NO_x deviations between measured and simulated data.

Figure 11 contains the CO comparison. The grey bars show the measured CO values for the same trips mentioned before. The black bars represent the simulation results with option 1. In one case the CO value is underestimated. In all other cases the simulation overestimates the CO values. The crosshatched bars show the simulation results with option 3. The deviation trend is identical with option 1. The deviations up to 33% could also come from minor deviations in engine power calculation.

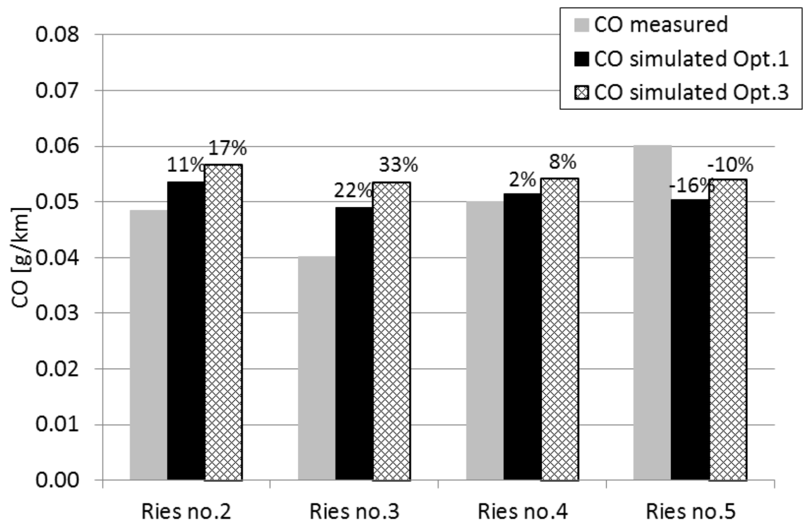

Figure 11. CO deviations between measured and simulated data.

First investigations of the simplified power determination approach show a good accordance with the measured data. With elimination of uncertainties mentioned before, the deviations could be further reduced. With this method it is possible to create engine maps from vehicles driven on RDE trips.

4 Effect of the ambient temperature

Since chassis dynamometer tests are typically measured between 20°C and 30°C while RDE tests can be done at any ambient condition, the effect of ambient temperature on emissions have to be considered when emission maps are produced in future. The influence of the temperature under hot start conditions on emissions, especially for NO_x, was investigated on a few vehicles so far. As mentioned before the RDE trips were performed in summer and winter. The average ambient temperature from the trips was between 1.5°C and 30°C. Due to the other influencing parameters (driving style, traffic conditions) the influence of the temperature is not directly visible from the PEMS data but a trend to higher NO_x at lower ambient temperatures is visible for several cars, e.g. Figure 1.
To assess temperature effects chassis dyno tests are preferable, because only temperature can be changed while all other parameters are kept constant over the tests. Four diesel vehicles with EU 5 and EU 6 exhaust emission standard were tested. As driving cycle the ERMES cycle with hot start was chosen. Each vehicle was measured under hot engine conditions at 0°C and at 23°C ambient temperature. All other settings were identical with the settings described before. The small test campaign shows that the NO_x level is higher for lower ambient temperatures for several vehicles, but not for all (Figure 12).

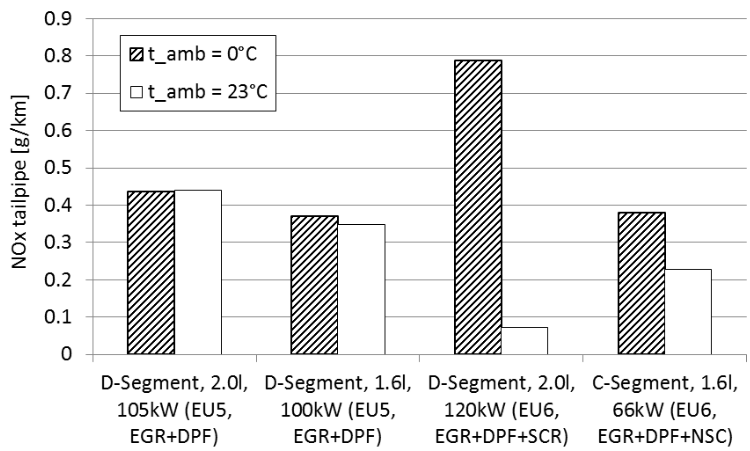

Figure 12: NO_x dependency on ambient temperature.

A recent publication (BMVI (2016)) measured a larger number of diesel cars and shows significant increases in NO_x emissions in NEDC after a hot start with 10°C compared to a hot start at 20°C to 24°C (on average 1.6 times higher for EU 5 and 2 times higher for EU 6).
Possible reasons are the reduction of exhaust gas recirculation (EGR) rates to prevent condensation effects in EGR cooler or/and intake system and lower temperature levels in the exhaust gas after treatment system which can lead to lower NO_x conversion efficiencies at low engine loads.
Especially for the D-segment vehicle with 120kW and selective catalytic reduction (SCR) the deviation is very high in Figure 12. This may be a result of the engine control unit (ECU) application as mentioned before and the operational range of the SCR, which has less than 200°C a poor efficiency (Hausberger S. et al. (2016)). The conclusion of this

investigation is that different NO_x engine maps for different ambient temperatures shall be used for accurate simulation. Most likely the core engine maps for PHEM will be produced from tests at 20°C and 30°C since all chassis dynamometer tests from EU 0 to EU 5 used this temperature range for hot start emission tests.
In addition the quite high number of PEMS tests for EU 5 and EU 6 cars shall cover also lower temperature levels (e.g. in ranges such as 0°C to 10°C and 10°C to 20°C). Possibly from this data a 4 dimensional map can be produced with power, rpm and temperature as axis. Effects from exhaust gas after treatment temperatures can be simulated by the existing catalyst models in PHEM. The analysis on this issue is ongoing.

5 Conclusion and outlook

The application of real world tests as basis for emission simulation for vehicles will become more important in future. The novel method calculating the actual engine power instantaneously from engine speed and CO_2 mass flow signals allows the use of PEMS test data to set up engine emission maps with good accuracy. For the interpolation of the power signal generic engine fuel maps are used which shall be representative for actual engine technologies. The error from using generic fuel maps due to variations in engine efficiencies from engines with similar technology but from different OEMs is much smaller than the uncertainty in the fuel maps gained from transient chassis dynamometer tests in the former method. Thus the quality of CO_2 simulation for different traffic situations is assumed to be clearly improved. The new method is also less sensitive against inaccurate time alignment between exhaust gas emission and engine speed and torque recording since the power is calculated from the CO_2 signal which shall have the same transport time as all other exhaust gas components.
Validations by simulation of measured RDE trips show a good accordance. In the simulation of the RDE trips the uncertainties due to the unknown auxiliary power demand, gear shifts, real world vehicle driving resistances and engine specific data are included. For overall high model accuracy beside emission maps also accurate vehicle input data are necessary (i.e. real world rolling resistance, air resistance, weight, etc.) for the simulation tool PHEM. A novel method to assess the driving resistances and auxiliary power demand from the data recorded usually in RDE tests is under development based also on the power interpolated from the CO_2 map. If this method is successful, also the data quality on real world vehicle data could be improved leading to a better overall model accuracy.

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