S C I E N C E ▪ P A S S I O N ▪ T E C H N O L O G Y

WG Emission Factors, Measurements and Models

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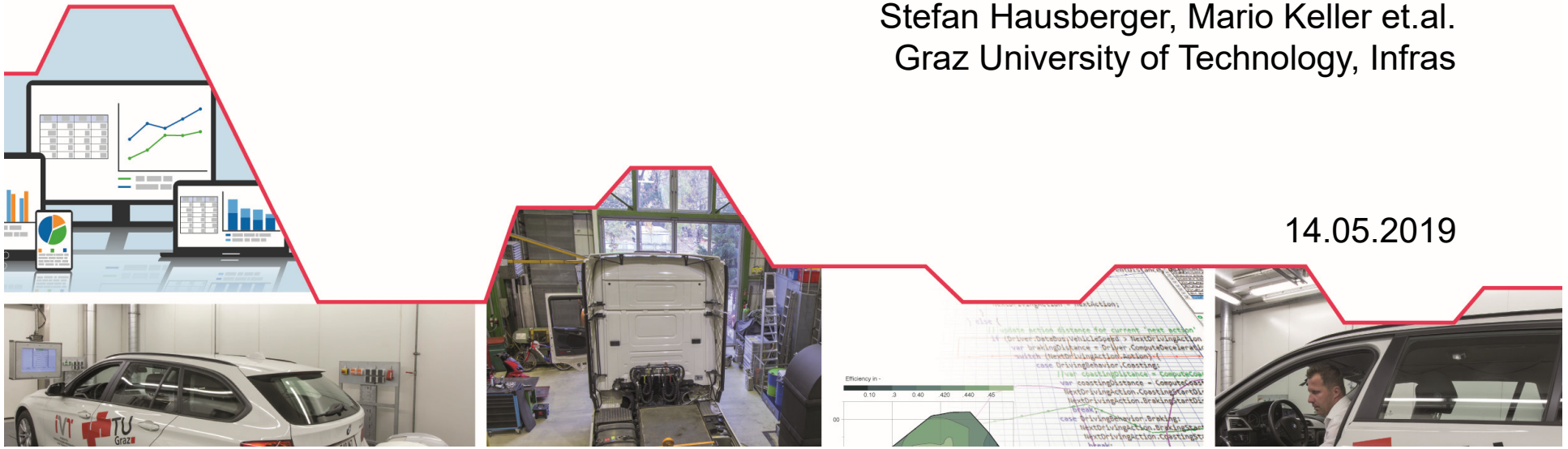


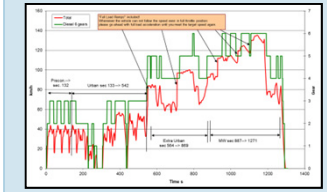
Content

- HBEFA / ERMES data base
- Available vehicle test data
- Simulation of Emission Factors for HBEFA
- Discussions and other input for the WG

Method for Hot Emission factors in HBEFA

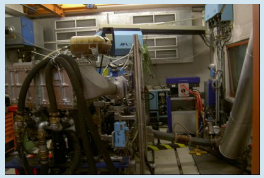
ermes

Coordination of test activities,
data collection, model development

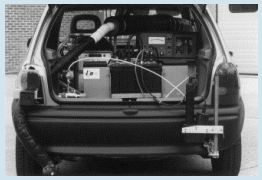


(Real world)
driving cycles

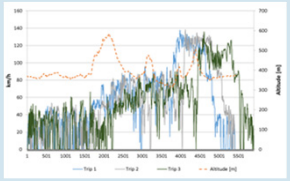
Roller
test bench



Engine
test bed



PEMS
tests

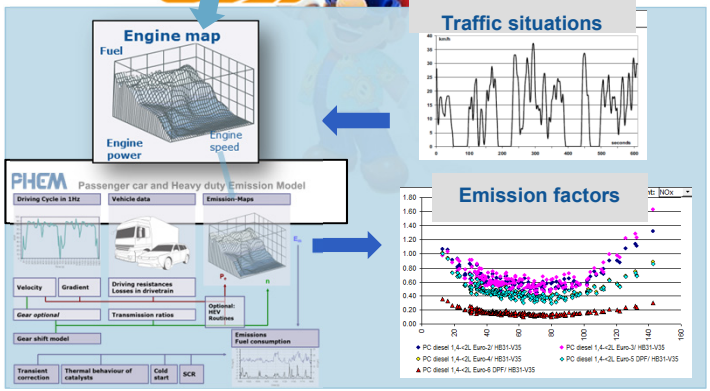


RDE tests with
various profiles

ermes Data Base

Super, Mario!

PHEM

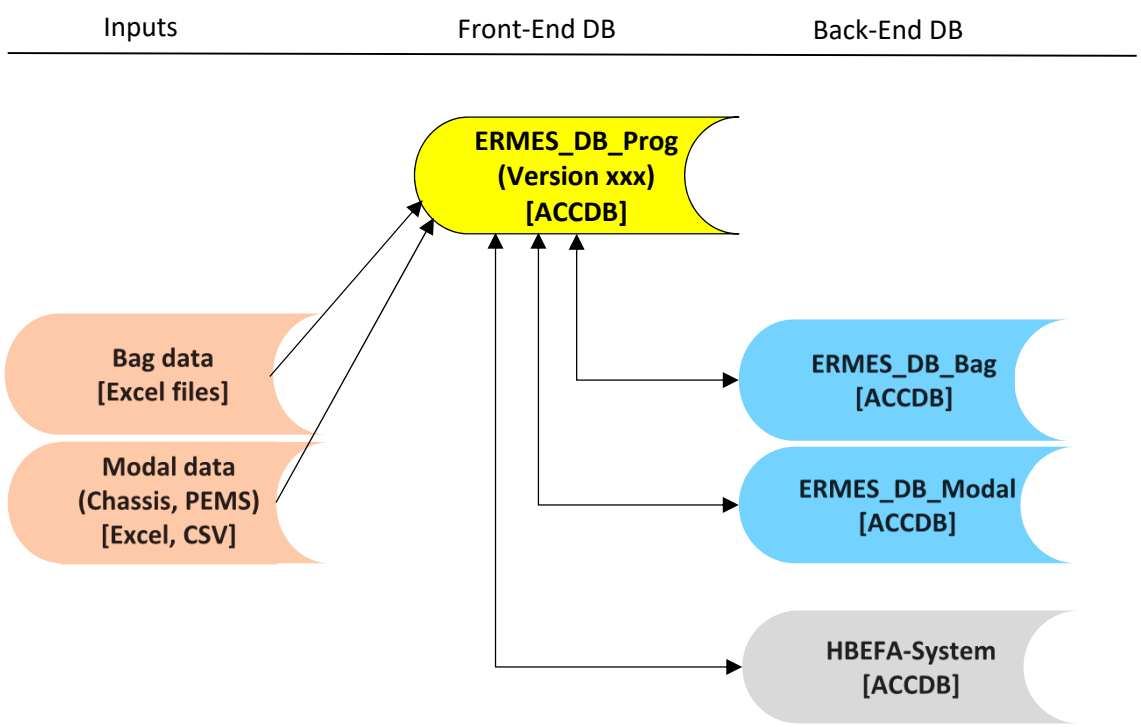


HBEFA

Data collection of emission measurements

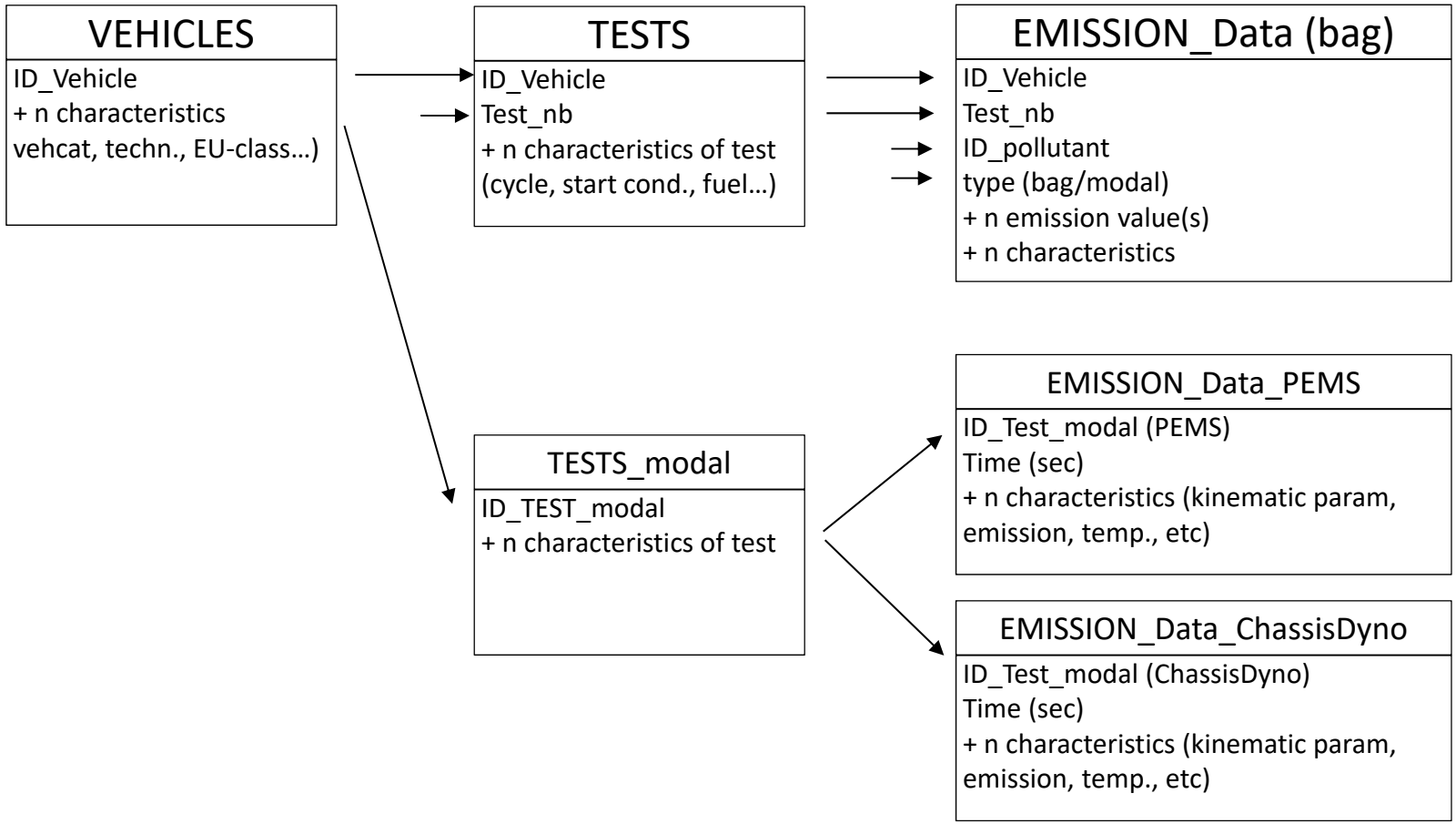
- ERMES db used to collect data on passenger cars, LCVs and 2-wheelers
- HDV data collected separately (merge data base in future version?)
- Huge amount of test data collected
  - As a result of diesel gate
  - And due to the efforts from labs providing data to the ERMES db
  - And due to the efforts to collect all the data

ERMES DB structure: based on MS Access



← With HBEFA 4.1

DB structure



Content of the ERMES DB (May 2019)

Nr of vehicles

Total	Total	E0	E1	E2	E3	E4	E5	E6
pass. car	4'684	1'085	1'246	221	302	590	668	572
LCV	215	47	56	35	7	7	34	29
moped	69	15	18	30	4	2	-	-
motorcycle	139	28	39	24	29	19	-	-
ATV	4	-	-	4	-	-	-	-
MiniCar	2	-	-	2	-	-	-	-
All Veh Cat	5'113	1'175	1'359	316	342	618	702	601

Nr of modal measurements (sec-per-sec):

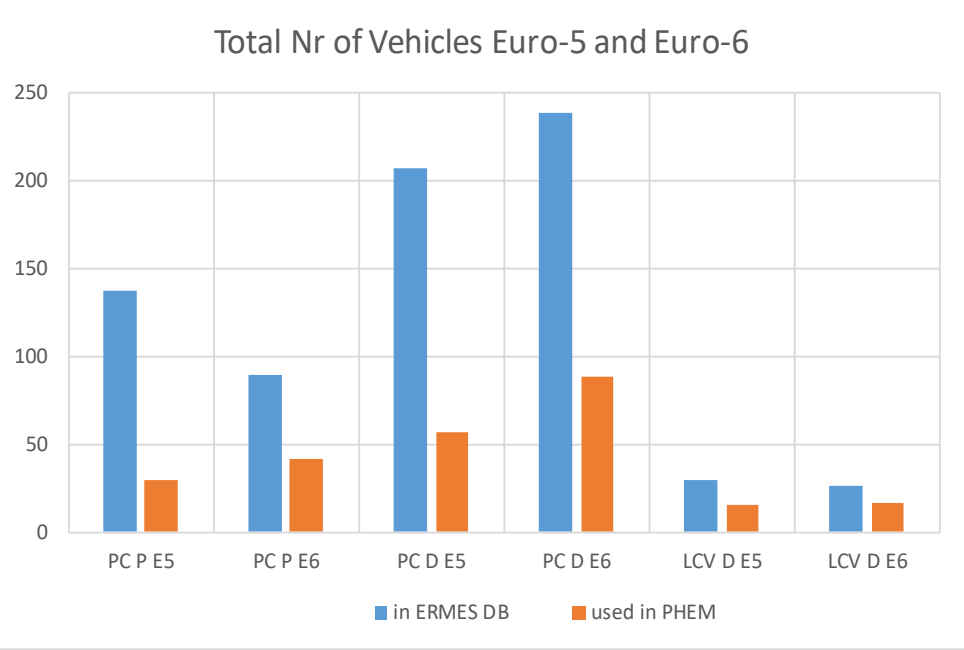
Ca. 7 Mio records (3 mio ChassisDyno, 4 mio PEMS)

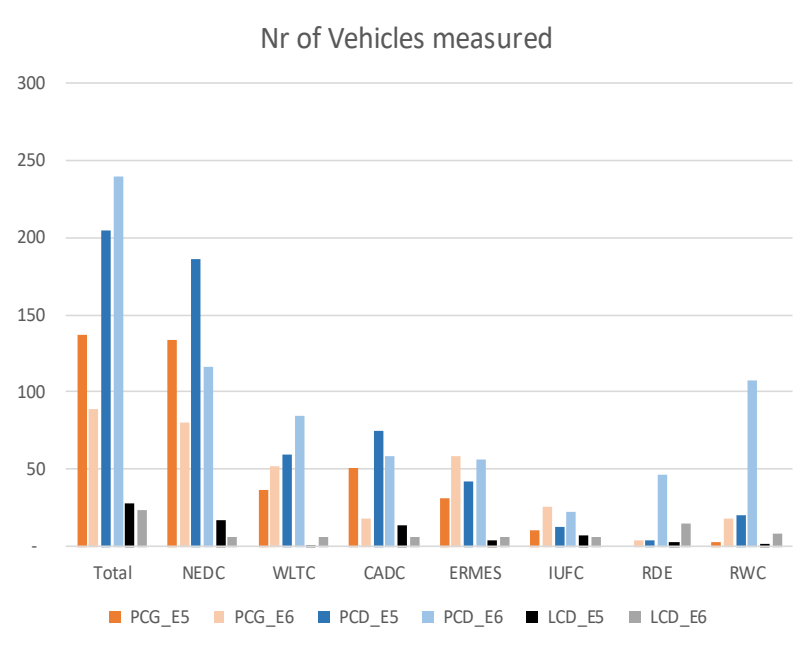
This amount brings the „ERMES_Modal_DB“ now to the limit of MS Access (2 GB)

New EU 5 and 6 cars and LCVs in the ERMES db

Nr of veh per veh'cat, technology and EU-class
- usable for PHEM = real world cycle, instantaneous records for rpm, CO_2 and pollutant(s) available

Nr of veh per veh'cat, technology and EU-class
- per cycle (Euro-5/-6)





HDV data collected

New data since HBEFA 3.2
All HDV data available as instantaneous records

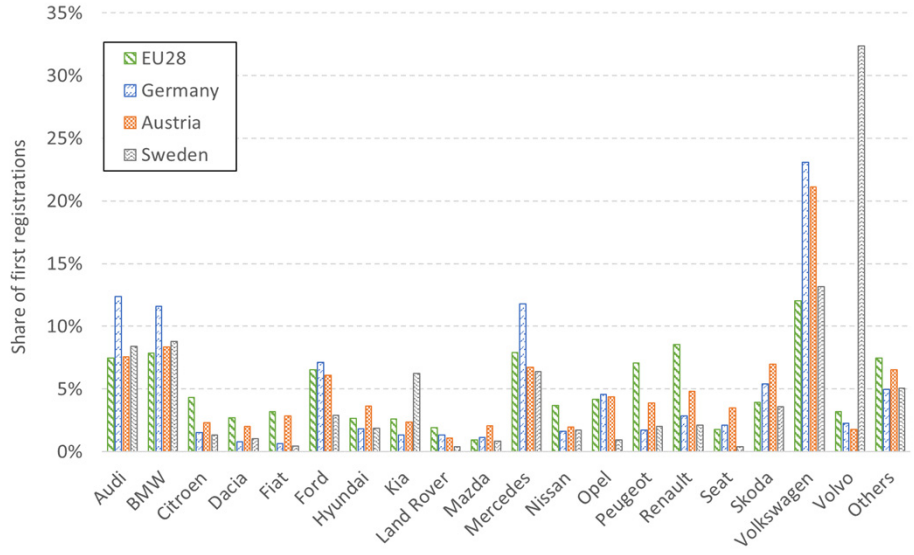
vehicle	category	EURO class	Technology	vehicles			cycles
				total	test bench	PEMS	total
HDV	N2	EURO 5	Diesel	1	-	1	4
		EURO 6	Diesel	1	-	1	5
		EURO VI	Diesel	8	2	8	31
	N3	EURO V	Diesel	1	1	1	7
		EURO VI	Diesel	25	9	22	70
		EURO VI	CNG	1	-	1	4
Bus	M3	EURO VI	CNG	2	-	2	4
∑				39	12	36	125

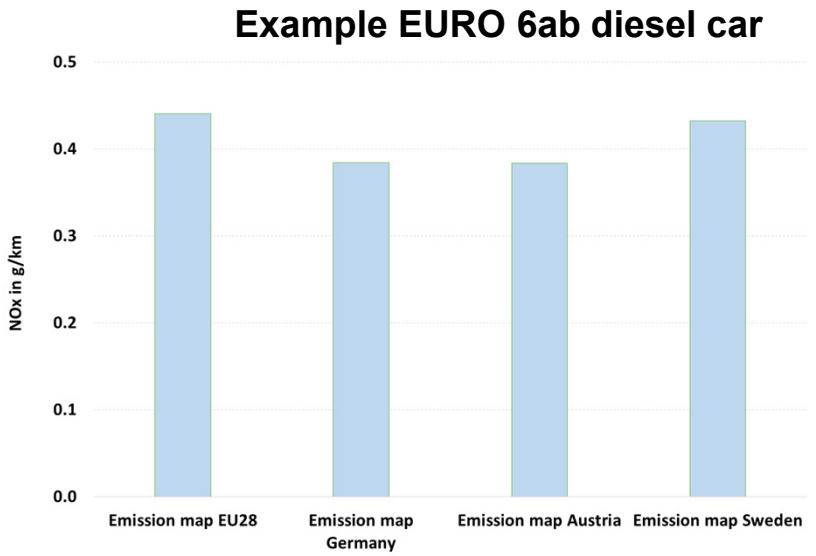
Simulation of Emission Factors for HBEFA

- For each vehicle with suitable emission tests one engine map was produced.
- Single maps weighted to average engine emission map per segment according to shares in EU28 new registrations of each model and/or brand
- Vehicle input data for PHEM calibrated to meet real world fuel consumption per segment
- Model PHEM produced the hot emission factors for all traffic situations and vehicle segments with this input data
- Cold start model updated by EMPA (simulation of extra emissions)
- Correction for deterioration effects
- Correction for influence of ambient temperature on hot NOx emissions from diesel cars

Emission maps weighted for EU 28

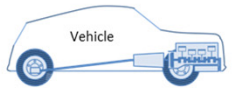
- Different weighting of brands gives different engine maps and different emission factors (e.g. NOx for diesel cars)





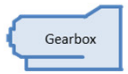
Calibration of vehicle data

Model Input

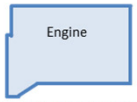


C_d x a, Mass,
rot. Inertias

r_{dyn}, RRC



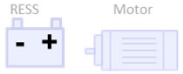
loss map, i_{gears}



P_{rated}, full load curve
Emission map
Transient parameters

Avg. Power demand
per auxiliary

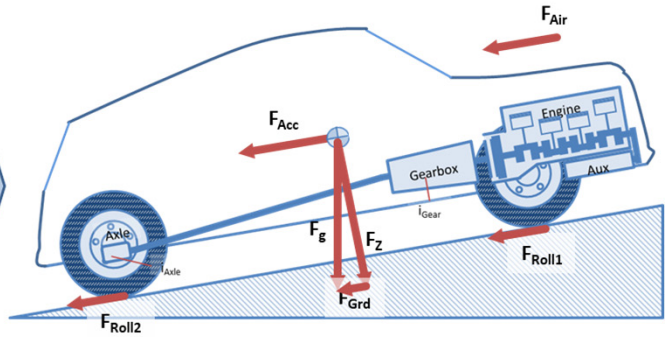
Thermal capacities
Functions for
conversion efficiencies



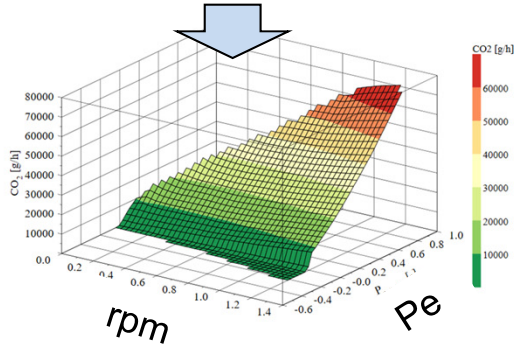
Electric system
motor, battery

PHEM

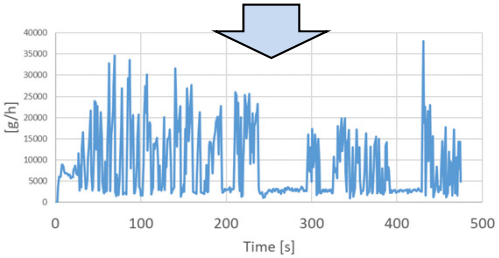
Passenger car and Heavy duty Emission Model



$P_e = P_{Air} + P_{Roll} + P_{Acc} + P_{Grd} + P_{Loss} + P_{Aux}$



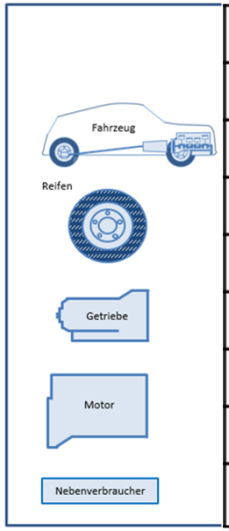
Transient correction,
model for exhaust
after treatment



Calibration of vehicle input data for PHEM

Targets:

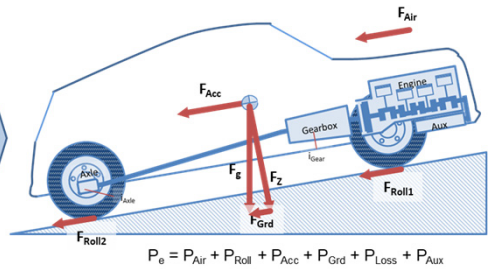
- Analyse typical real world settings (loading, tire pressure, auxiliary power demand, share mileage with winter tires, roof boxes etc.)
- Define generic data sets and transfer functions for these real world settings
- Use the data as input for PHEM to calculate representative fuel consumption and emission values



	NEDC	WLTP	RDE	Real
Air drag				
Vehicle mass				
Loading				
Rolling resistance				
Transmission ratios				
Rated power, etc.				
Engine fuel map				
Aux. power demand				

PHEM

Passenger car and Heavy duty Emission Model



$P_e = P_{Air} + P_{Roll} + P_{Acc} + P_{Grd} + P_{Loss} + P_{Aux}$

Defined	Generic functions	To be calibrated

Some of the calibration functions

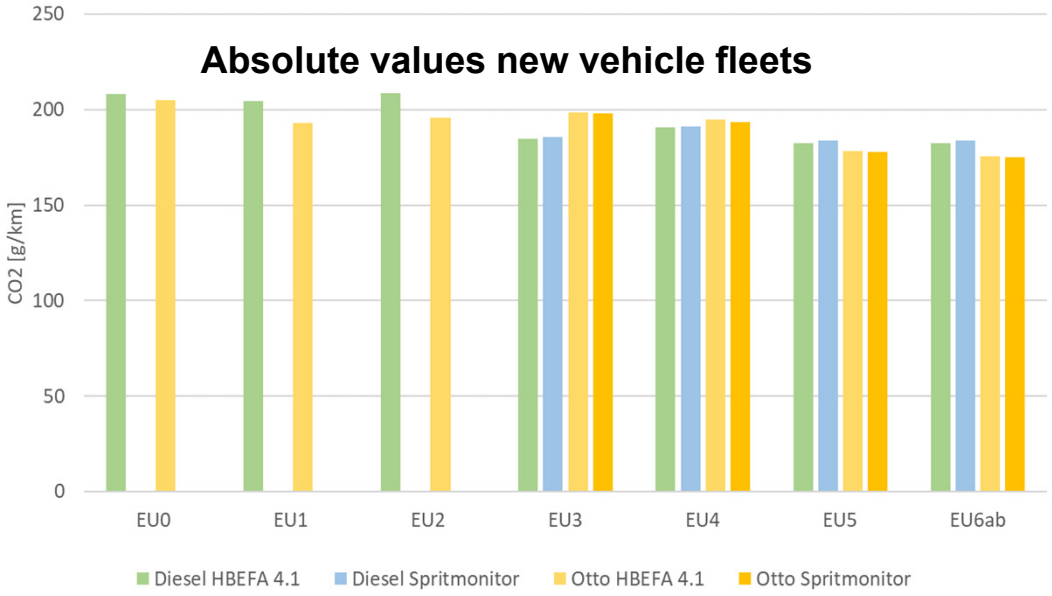
Physical explanations:

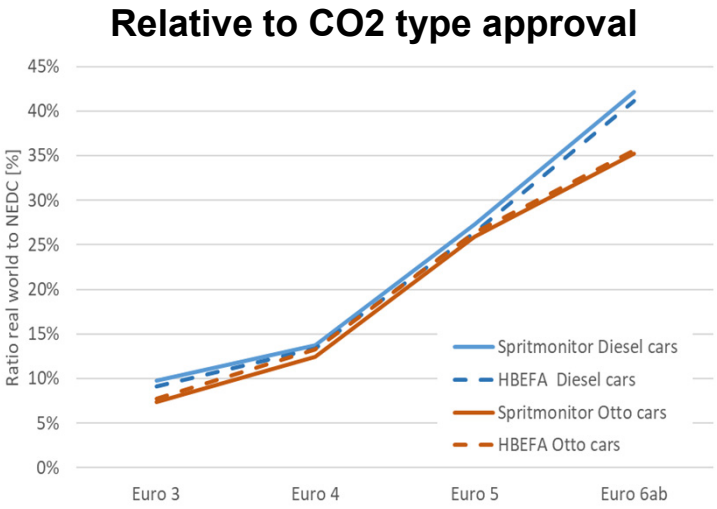
- NEDC: Tolerances allowed in regulation lead to underestimation of RDE road load,..
- WLTP: here = base values with real vehicle mass, Cd*A, RRC from coast down
- RDE: Higher loading and air drag (PEMS system), air density depends on temperature during test, higher auxiliary power demand (HVAC activated etc.)
- Real World vs. WLTP: Higher loading due to shares in vacation trips, etc.;
  higher air drag due to cross-wind, share roof box and trailers and air density;
  higher RRC due to share winter tires, snow, wet road). Diesel additional +5.7% (SUV-tires?)

Test	Empty Mass [kg]	C_d x A [m²]	Fr_0 [-]	P_{Aux} [W]
NEDC	DIN + 100	0.83*$WLTP_{low}$	0.80*$WLTP_{low}$	100
WLTC	WLTC value	WLTC value	WLTC value	600
RDE-PEMS	Test mass	$WLTC_{high}$	Tire specific	1500
Real world CI	DIN*1.05 +215	0.5*($WLTC_{high}$ + $WLTC_{low}$) * 1.085	1.12*WLTC	1500
Real world SI	DIN*1.05 +120		1.063*WLTC	

WP 8: Fuel consumption and CO2-emission factors

Relative ratio compared to type approval values in NEDC and absolute values fit with spritmonitor.de
Since EURO 0 German new cars reduced CO_2 by -0.14% p.a. for diesel and -0.9% for gasoline (diesel car shares increased in large segments)



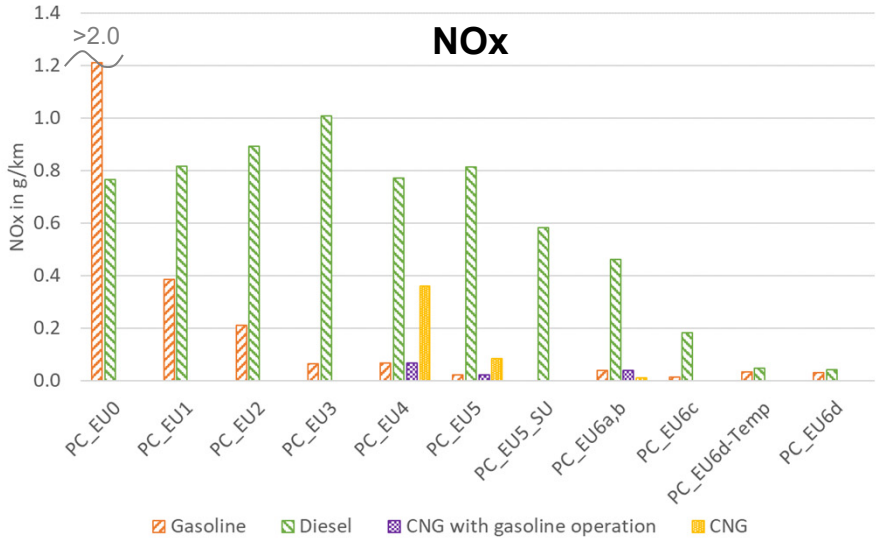


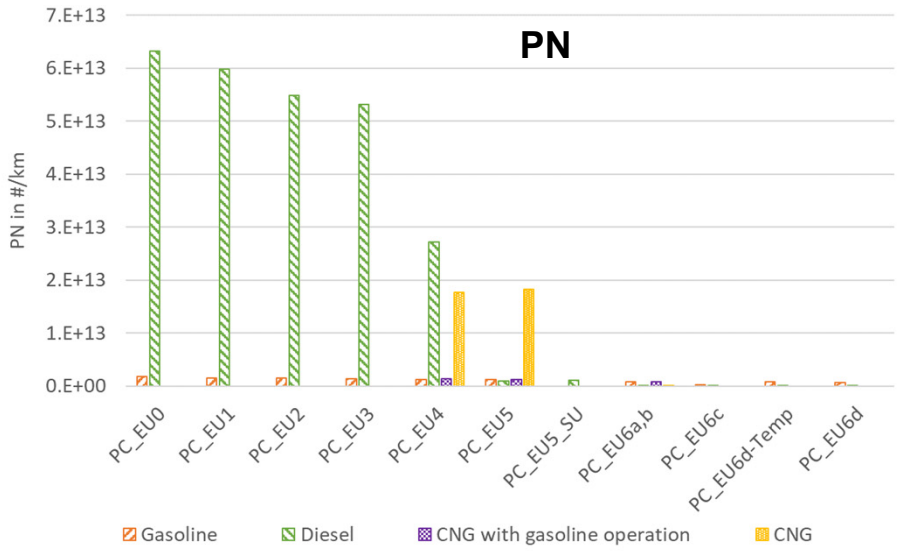
Similar for LCVs but spritmonitor.de due to low number of entries inaccurate and not met exactly by PHEM

Preliminary HBEFA 4.1 results for EU 28

Passenger cars

- Hot emission factors for cars - German mix of traffic situations:





Passenger cars

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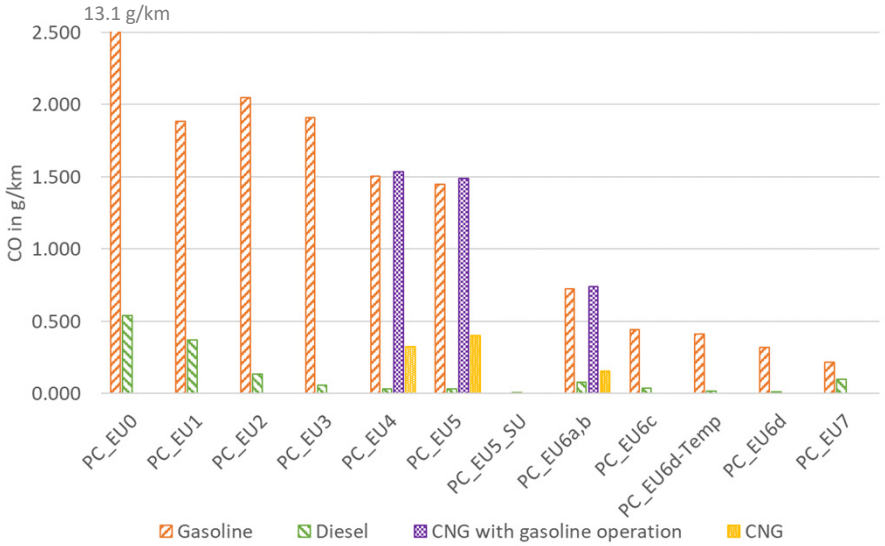
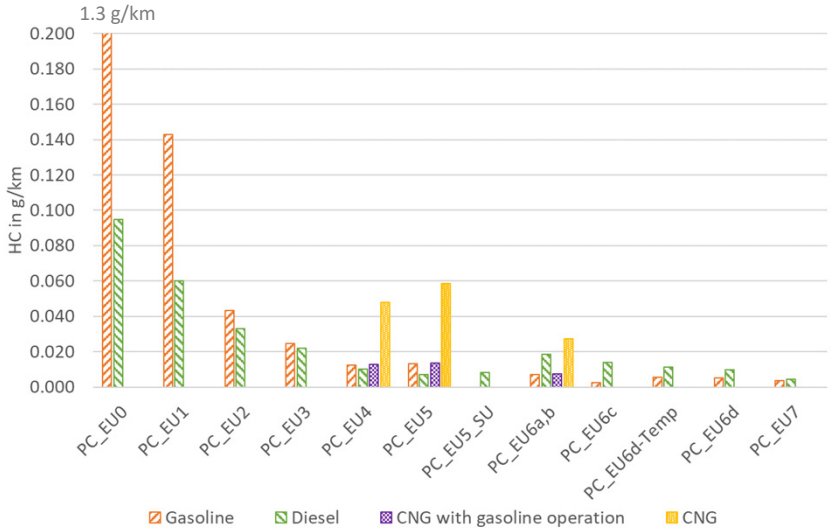
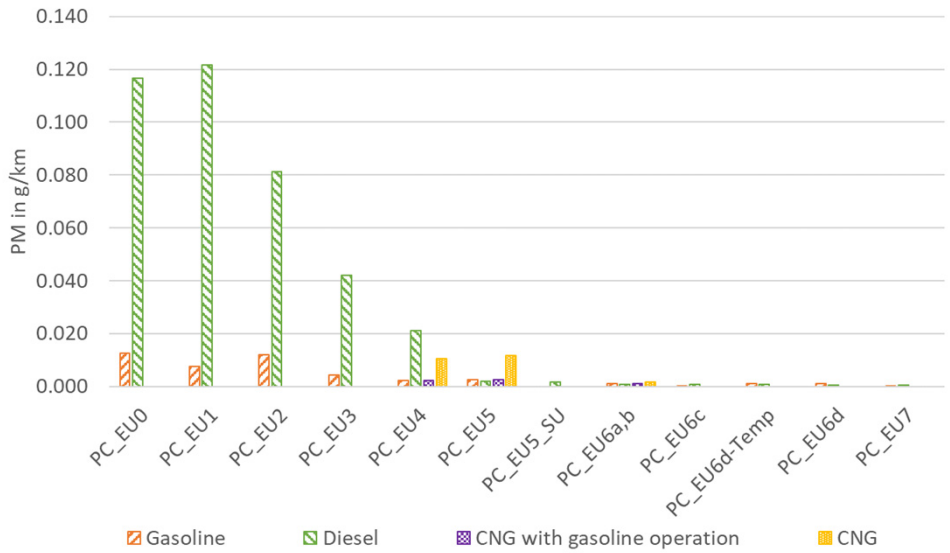




Passenger cars

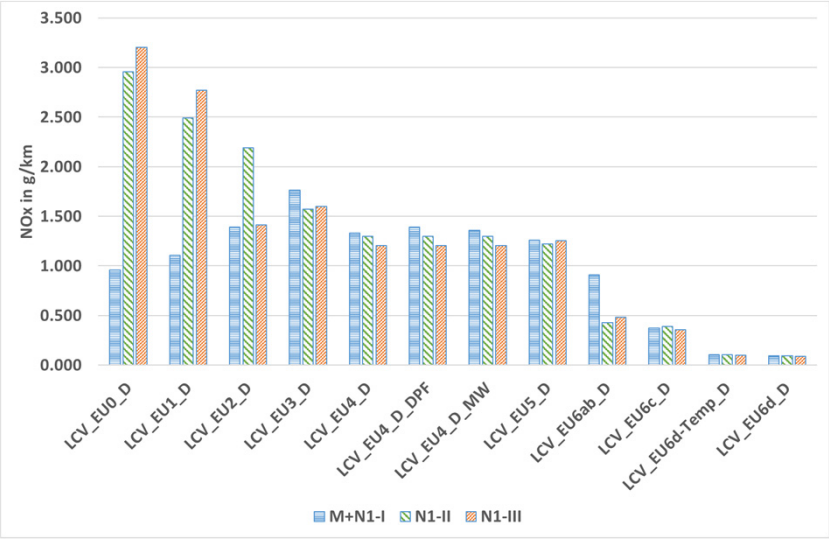
- Hot emission factors for cars - German mix of traffic situations:



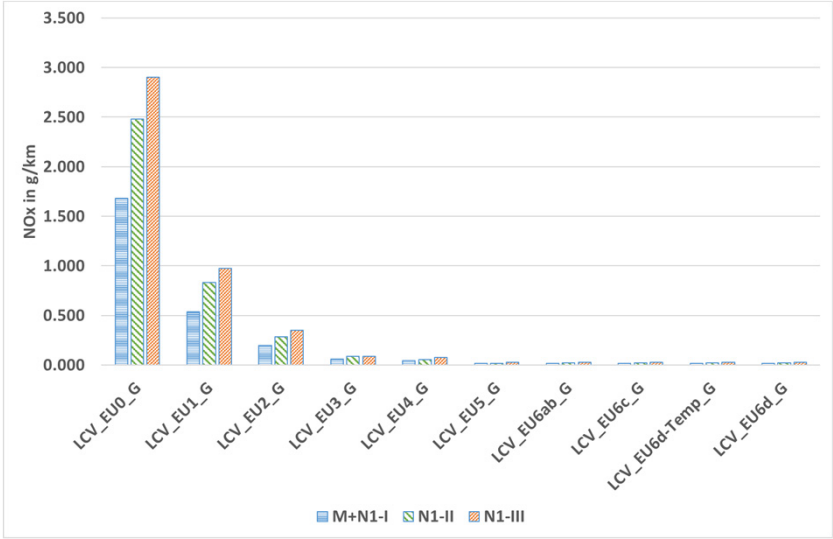
Hot emission factors for regul. pollutants

- Hot emission factors for **LCV** - German mix of traffic situations:

LCV Diesel:



LCV Gasoline:

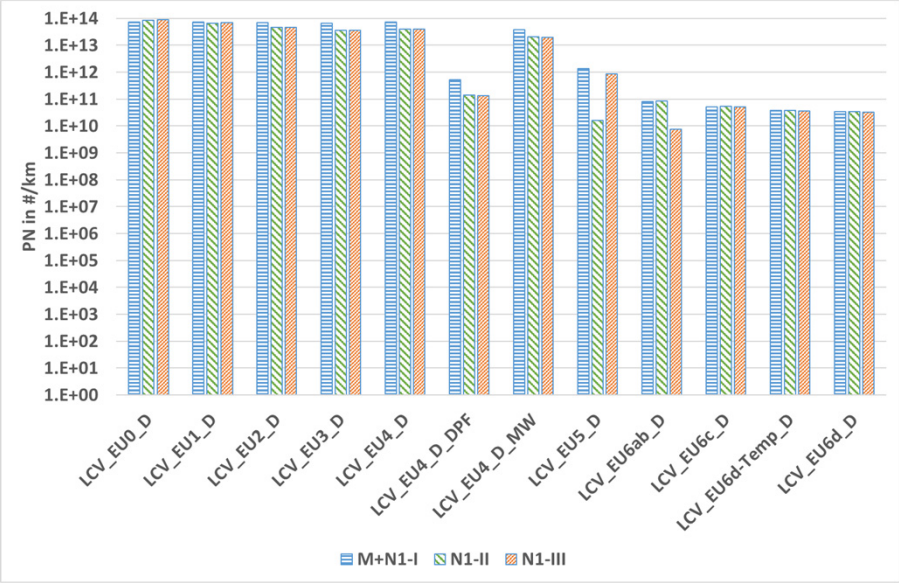


NOx from EU0 to EU4 to be checked

WP 3: Hot emission factors for regul. pollutants

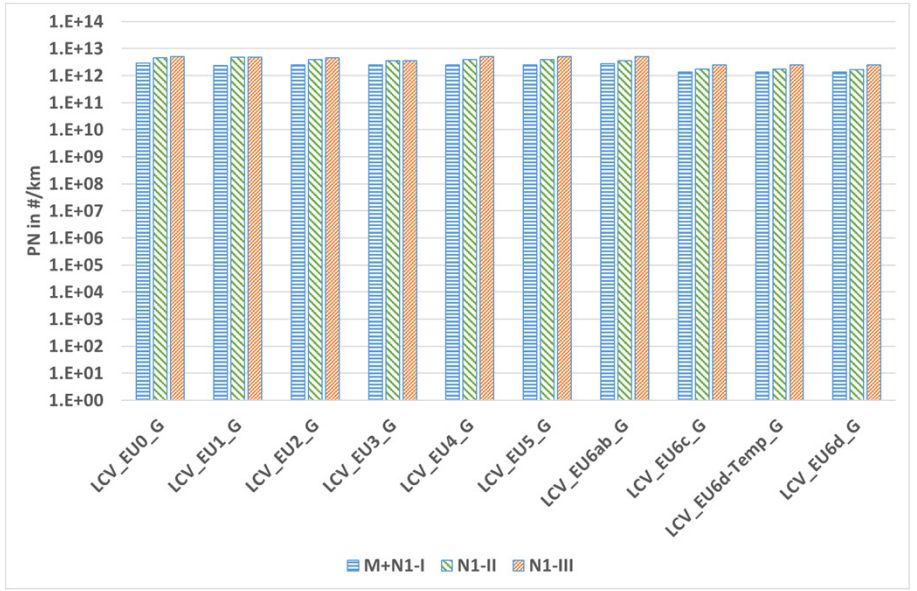
- Hot emission factors for LCV - German mix of traffic situations:

LCV Diesel:



PN from EU0 to EU4 to be checked

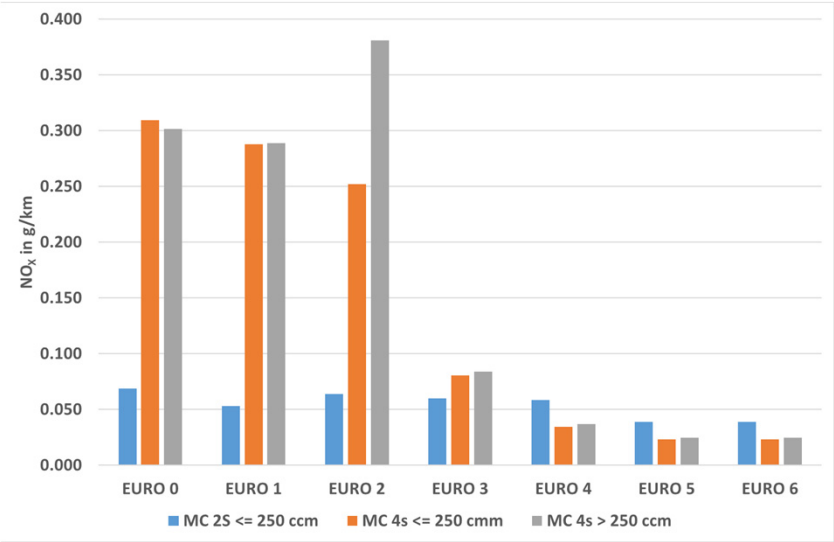
LCV Gasoline:

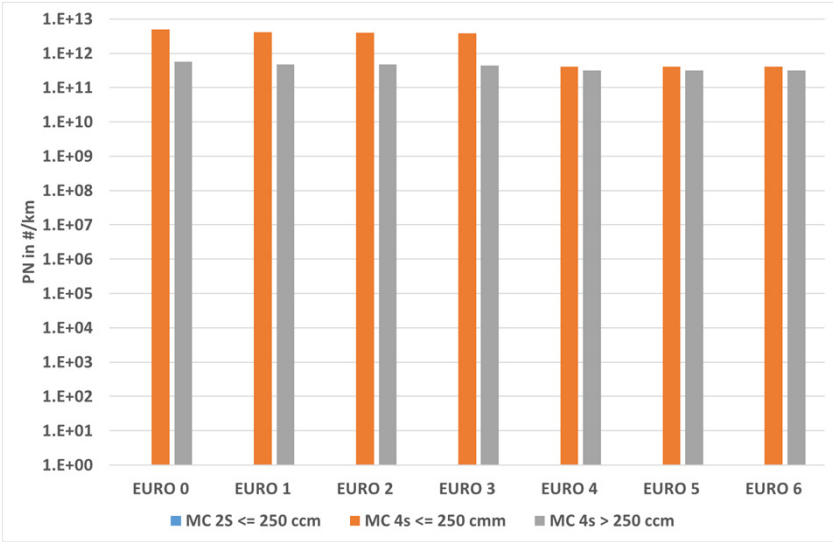


PN from on EU6c to be checked (used engine maps from cars)

Hot emission factors for regul. pollutants

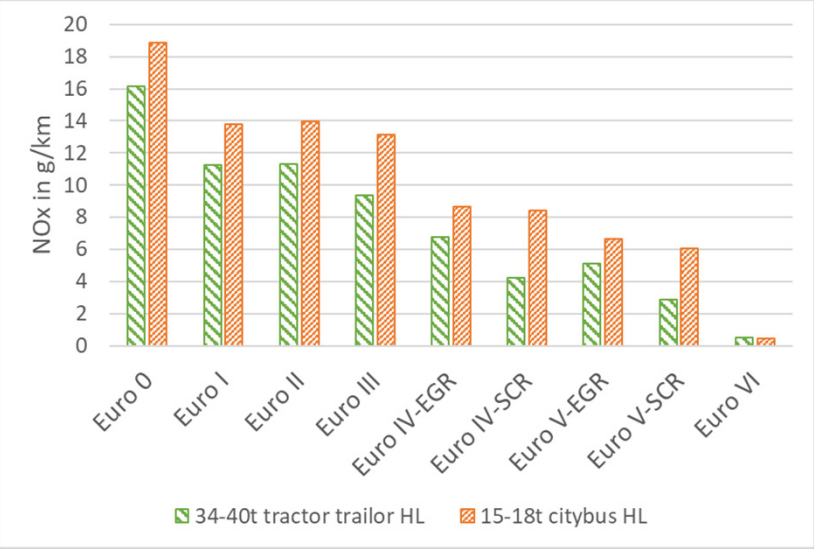
- Hot emission factors for **2-wheelers** - German mix of traffic situations

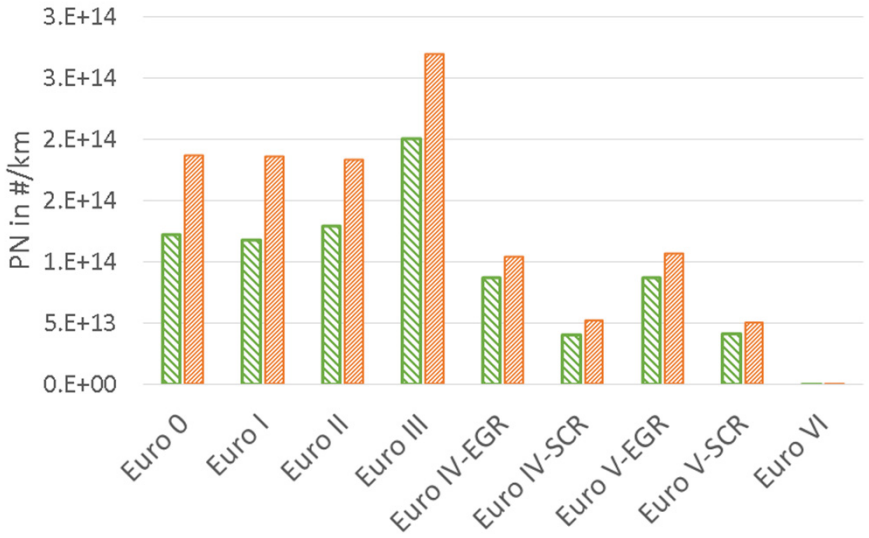




Hot emission factors for regul. pollutants

- Hot emission factors for **HDV TT 34-40t** HL - German mix of traffic situations
- Hot emission factors for **CB 15-18t HL** - German urban mix of traffic situations



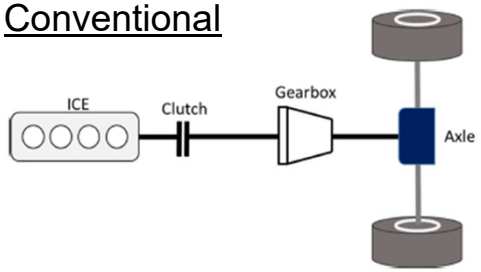


WP 7: Electric vehicles

Emission Factors simulated with PHEM for:

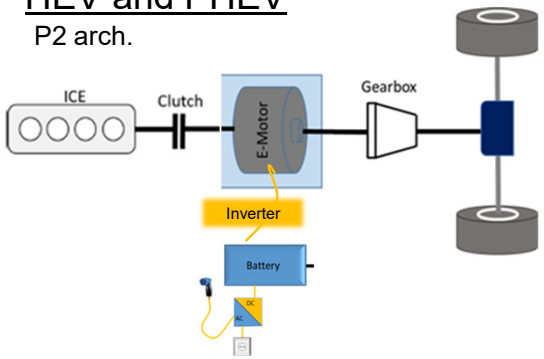
- Hybrids: Pass cars and city buses
- Plug-In-Hybrids (PHEVs): Pass cars and LCVs; for HDVs by combination of BEV and HEV emission factors
- BEVs: for all vehicles (HDV only the most relevant segments)

Conventional

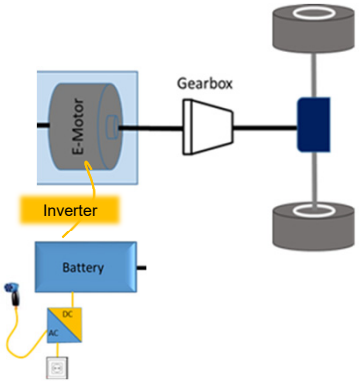


HEV and PHEV

P2 arch.

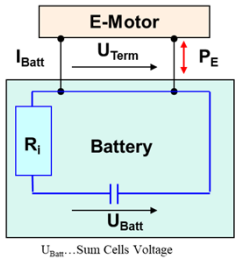


BEV



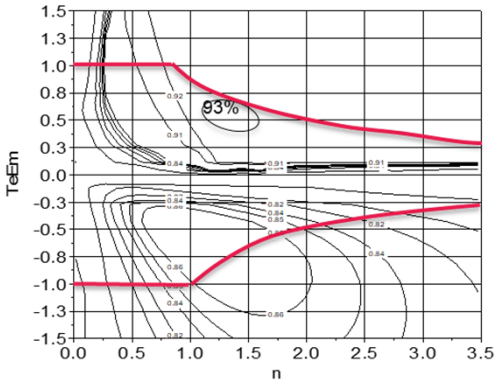
WP 7: Method for Simulation of Electric vehicles

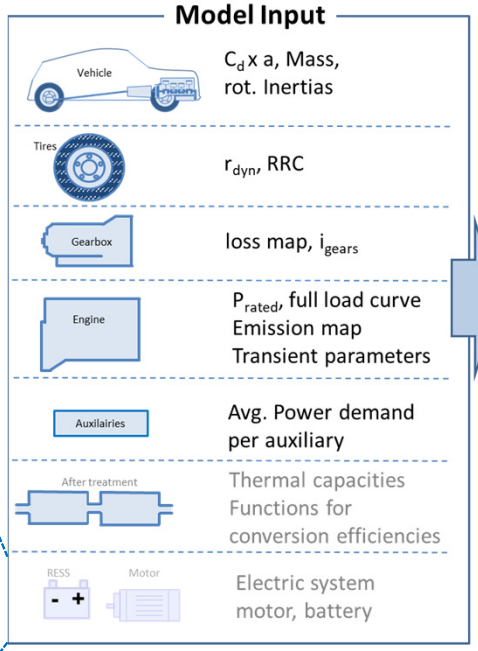
Generic **Battery** model



$P_{Batt} = P_E + I_{Batt}^2 \times R_i$

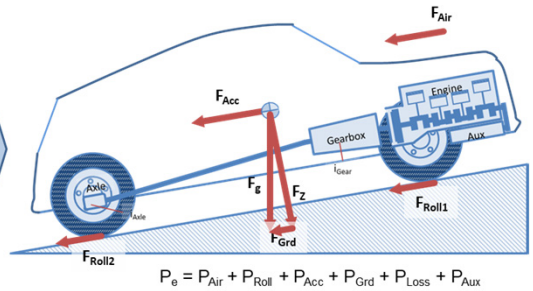
Electric **motor & power electronics**: generic map





PHEM

Passenger car and Heavy duty Emission Model



$P_e = P_{Air} + P_{Roll} + P_{Acc} + P_{Grd} + P_{Loss} + P_{Aux}$

Simulation in 1 Hz for:
power demand, engine speed, fuel consumption, emissions, etc.

Combustion engine: same map as for conventional vehicles but different power

WP 7: Vehicle Data for BEVs

Basis is HBEFA 4.1 conventional vehicle
- Mass of fuel tank and combustion engine and catalysts etc. subtracted
+ Mass of battery and electric motor added. Example for pass car below

Mass [kg]	EU 6a,b gasoline	BEV
Total vehicle mass	**1237**	-
ICE	-165	-
After treatment	-15	-
Tank capacity	-34	-
E-Motor	-	+76
Voltage transformer	-	+5
Inverter	-	+10
Battery	-15	+409
Charger	-	+12
Additional wiring	-	+56
Total vehicle mass		**1562**

= gasoline car +325kg

BEV car based on gasoline car chassis (diesel car chassis would lead to ~300kg higher weight)
Similar for LCVs weight is computed with weight difference to gasoline chassis.

HD BEVs: basis = diesel vehicle

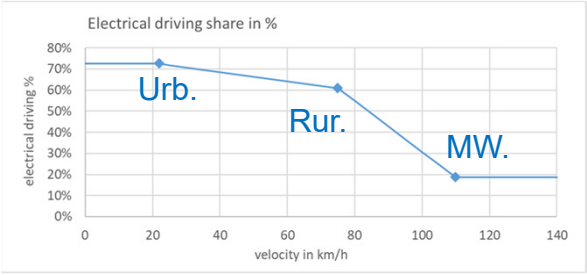
PHEVs: weight difference to diesel and to gasoline

WP 7: Vehicle Data for PHEVs

PHEVs: weight difference to diesel and to gasoline calculated similar to BEVs
Loading, driving resistances, auxiliary power etc. as for conventional vehicles

Parameter	Unit	PHEV EU6a,b D	PHEV EU6a,b G
Vehicle mass	[kg]	1885	1483
Difference to conv. Veh.	[kg]	+245	+236
System power	[kW]	121	99
ICE power	[kW]	94	77
E-motor power	[kW]	80	66
Battery	[kWh]	9.9	
El. Range in HBEFA TS mix Germany	[km]	25	31

Share electric driving calculated from electric range, trip distance distribution and SOC-start distribution

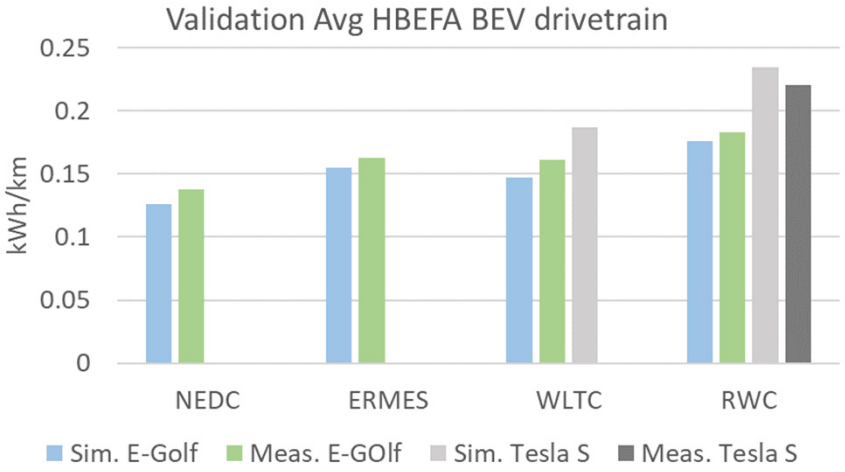


WP 7: Validation Electric vehicles

Validation for passenger cars based on TUG measurements:

- Generic electric motor and battery simulated with vehicle data from E-Golf
- Compared to measured energy consumption at chassis dyno TU Graz

VW e-Golf		
Power	kW	100
Empty weight (EU)	kg	1615
Battery size	kWh	35.8
Electric range	km	231

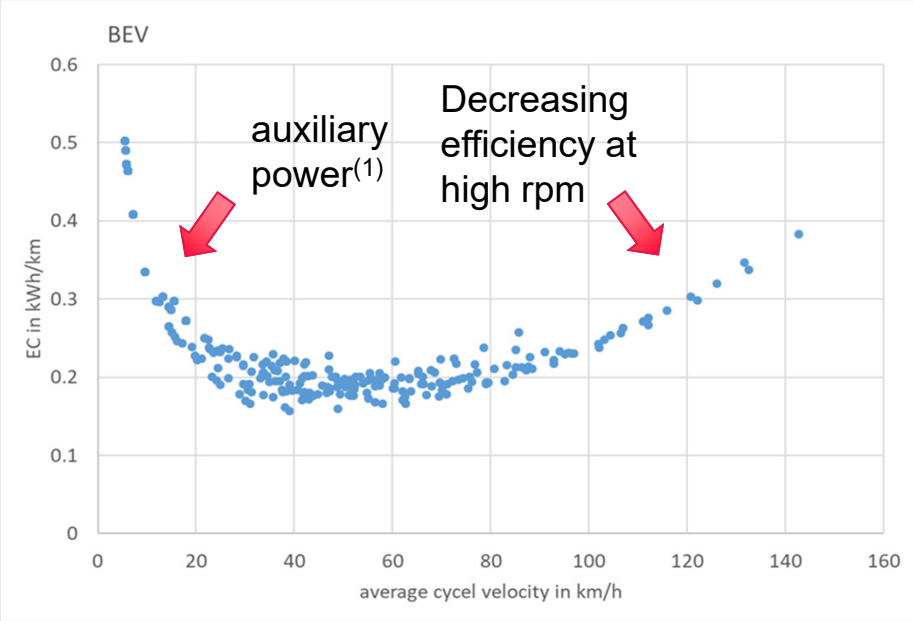


→ Plausible results
reliable Validation needs
more tested vehicles!

Measurements Real World Cycle (RWC) had
no extra load or power consumers

WP 7: Electric vehicles

Results for BEV cars for traffic situations at 0% gradient



Tbd:
Simulated as replacement of gas. cars.

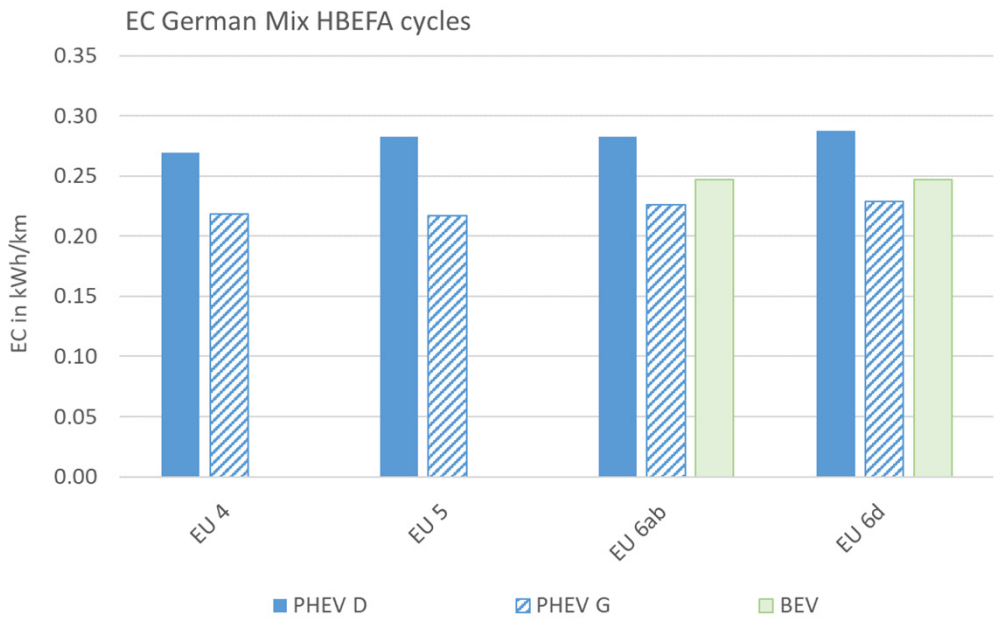
- Same cycles
- Same driving style (e.g. higher speed on highway)
- Same comfort demands
- Shares of roof boxes, trailers, winter tires,…

Realistic or pessimistic results for BEVs with high share in fleet?

(1) auxiliary power as for conventional cars (ECUs, AC,…) + 300 W for heating = 1800W avg. power (heating calculated for annual temperature trajectory area Frankfurt)

WP 7: Electric vehicles

Results for passenger cars for weighted German traffic situations



PHEV: results for charge depleting mode

→ Rather high results.
Today's BEV users seem to drive much more energy efficient than average car driver (range anxiety?).
Also true if we have >10% BEVs?

For HBEFA 4.1 the BEV results will be adjusted to 1.2 driver, ideal tires,..
→ 200Wh/km
Similar adjustments for PHEVs

WP 7: Electric HDVs

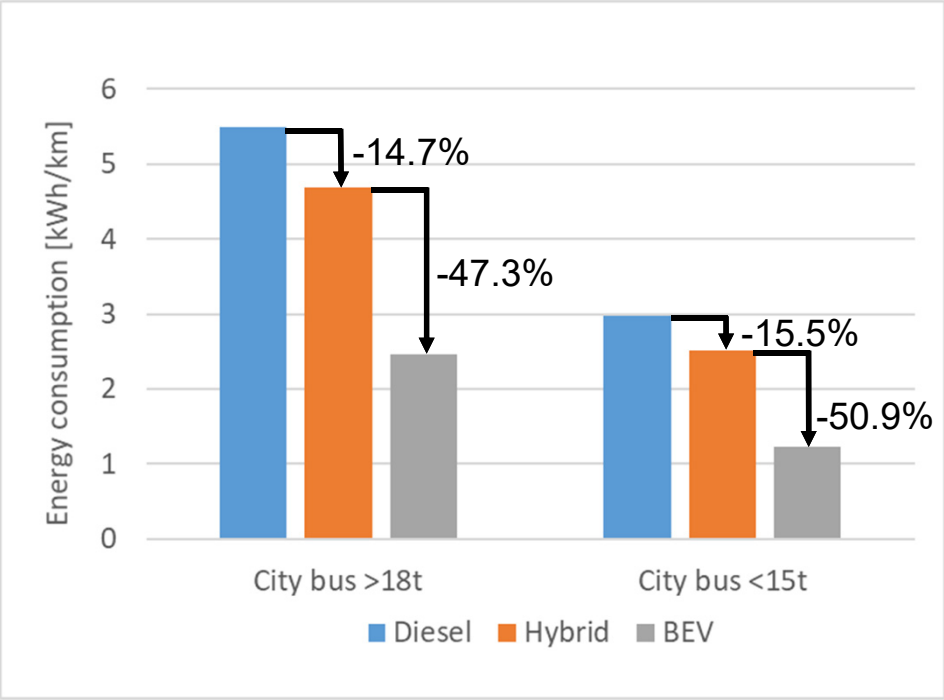
Comparison of vehicle specifications for a Citybus >18t

Specifications	Diesel (EUVI)	HEV (EUVI)	BEV
Vehicle weight empty [t]	15.750	18.160	18.629
P_ICE [kW]	265	177	---
P_E-Motor	---	150	265
Battery capacity[1] [kWh]	---	9.6	532
SoC operating window		0.3-0.7	0.2-0.8
Electric range[2] [km]	---	not relevant	150
Add. heating power [kW]	---	---	12.45

1: Installed battery capacities
2: On average German mission profiles for City busses

WP 7: Electric vehicles

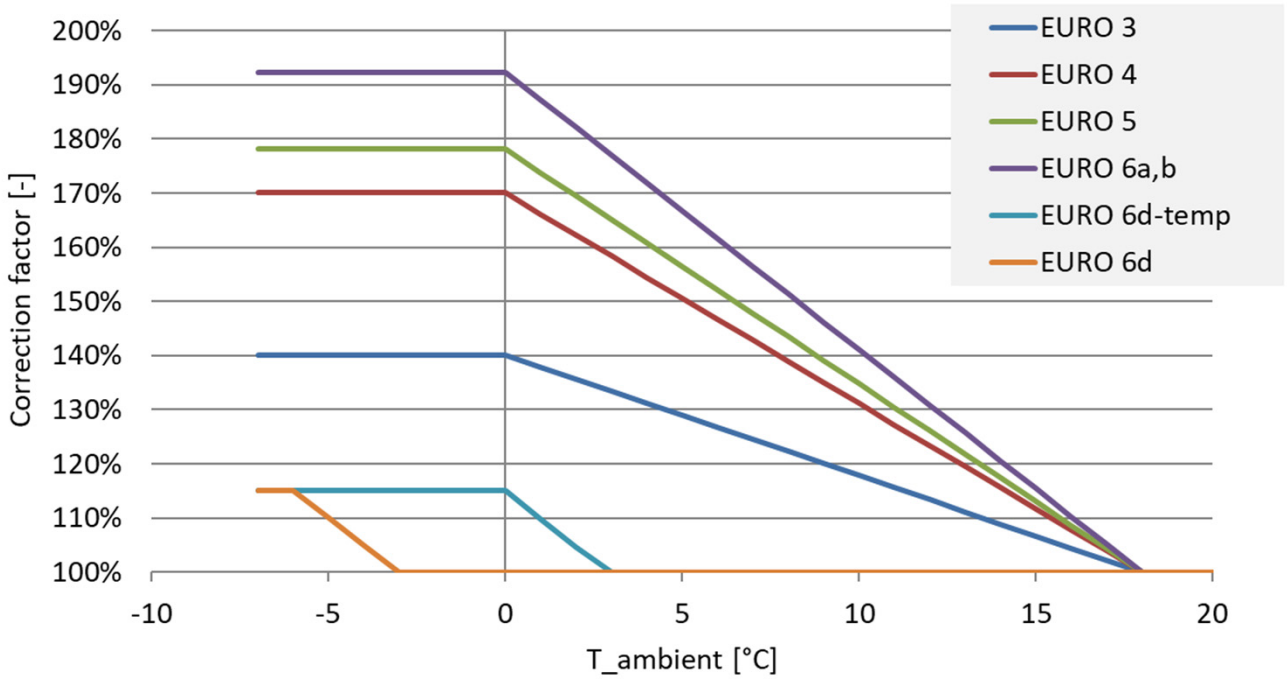
Results for half loaded City busses for weighted German traffic situations



Correction factors

Ambient temperature effects on hot Nox emissions from diesel cars ("thermal window"): results from remote sensing

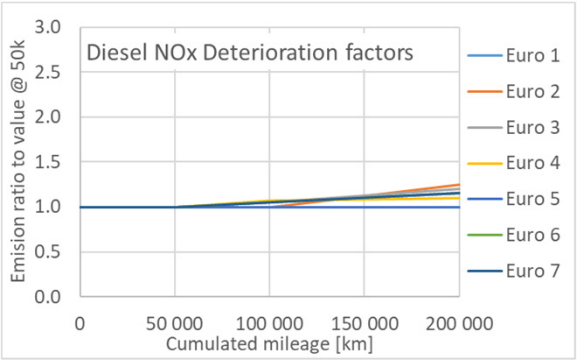
(many thanks to David Carslaw, Jens Borken-Kleefeld)

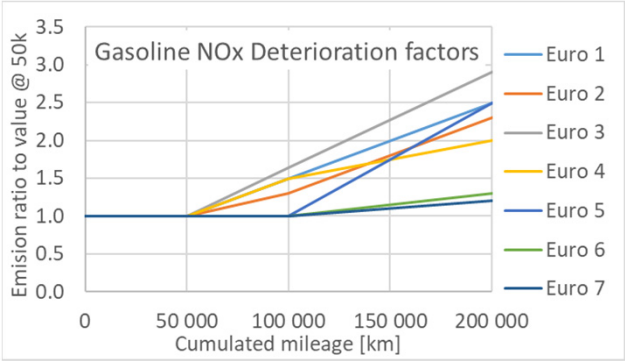


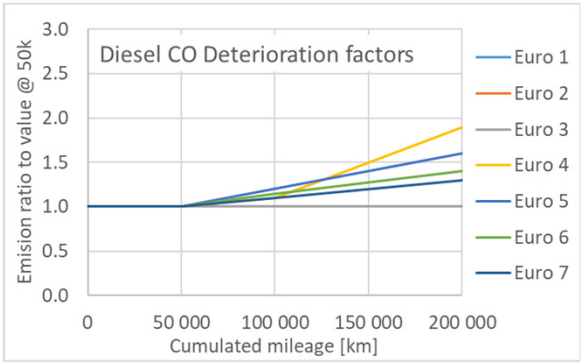
Correction factors

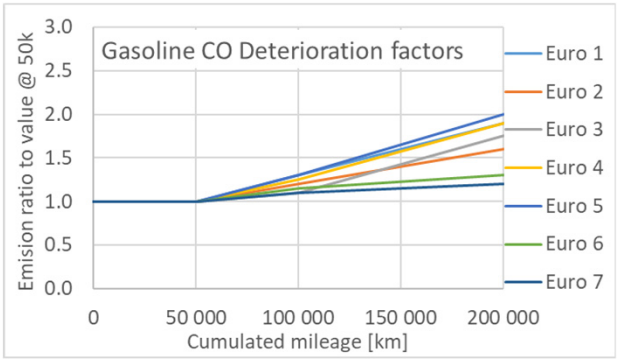
Deterioration passenger cars, results from remote sensing

(many thanks to David Carslaw, Jens Borken-Kleefeld, Ake Sjödin)









Correction factors

Deterioration for NOx from EU VI HDVs, results from vehicle tests at TUG