Analysis Emission Data Pilot Phase vs. ERMES
排放数据分析：试点阶段 vs ERMES

International Workshop "Mobile Source Emission Modelling and Emission Reduction Strategy"

Beijing, March 4th 2016

M. Rexeis, S. Hausberger, P. Wüthrich, M. Keller

Sino-German Cooperation on Low Carbon Transport in China: Support in the Implementation

INFRAS MK Consulting

CONTENT 内容提要

- **Scope of pilot phase measurements** 试点阶段测试概览
- **Comparison of “matching” vehicles** 匹配车辆比较
  - Golf 1.4 GDI China 4 (DCT) vs. Euro 4 (MT)
  - Honda Accord 2.0 MT China 3 vs. Euro 3
- **Comparison of “most relevant” vehicles** 最相关车型比较
  - China 4 (2 vehicles (+Golf)) vs. Euro 4 average
  - China 5 (2 vehicles) vs. Euro 5 average
- **Conclusions** 总结

Scope of pilot phase measurements
试点阶段测试概览

- **Comparison of emission behaviour of Chinese cars with European data from ERMES Group(*) 中国车辆排放行为和欧洲ERMES数据比较**

  Approach 1: Measure identical vehicles and compare specific emission test results

  方法1： 对比特定车型污染物测试结果

  Approach 2: Measure most relevant makes and models and compare average emission levels

  方法2：测试相关车型对比平均排放水平

- **Exchange of methods for measurement of real world emissions** (e.g. test setup, quantities to be measured, test procedures NEDC + CADC, test evaluations) 交流实际排放测试方法
- **Collection of emission data for later re-calibration of CRTEM to specific Chinese conditions 为CRTEM校准中国排放数据**

(*) **ERMES Group: European Research on Mobile Emission Sources**
www.ermes-group.eu

Comparison Golf 1.4 TSI 高尔夫1.4 TSI比较

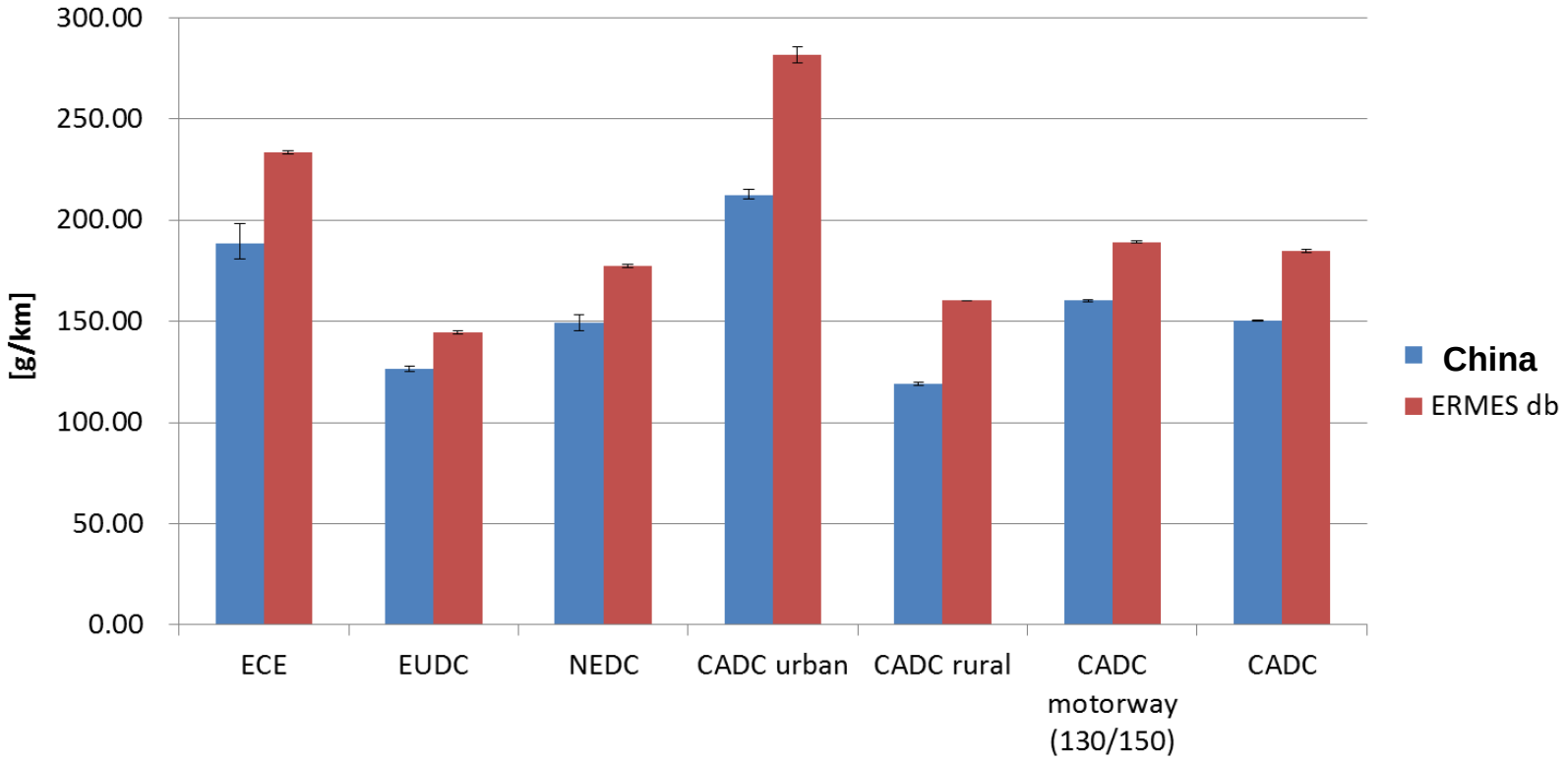
- **“China 4” vehicle measured at VETC in Nov. 2015 VETC 2015.11 测试国4车辆**
  - Year of construction 出厂年: 2012
  - Mileage 行驶里程: 48 700 km
- **“Euro 4” vehicle measured at TUG in 2006 TUG 2006年测试欧4车辆**
  - Year of construction 出厂年: 2006
  - Mileage 行驶里程: 4 000 km
- **Similar engine technology (capacity, injection system, emission standard)相同的发动机技术（能力，喷射技术，排放标准）**
- **Different full-load characteristics 不同的满载特征**
  China 4: 95kW@5000rpm vs. Euro 4: 125kW@6000rpm
- **Different transmission technology不同的变速器**
  China 4: Double Clutch Transmission (DCT) vs. Euro 4 Manual Transmission (MT)
- **Chassis dyno settings (inertia weight, road load) and test execution identical太假测试的参数和测试过程完全相同**

Comparison Honda Accord 2.0 VTEC
丰田Accord对比

- **“China 3” vehicle measured at VETC in Dez. 2015 VETC2015.12测试国3车辆**
  - Year of construction 出厂年: 2007
  - Mileage 行驶里程: 130 000 km
- **“Euro 3” vehicle measured at EMPA in 2002 EMPA2002年测试的欧3车辆**
  - Year of construction 出厂年: 2000
  - Mileage 行驶里程: 28 300 km
- **Vehicle specifications identical (engine + MT transmission) 车辆规格完全相同**
- **Chassis dyno settings (inertia weight, road load) and test execution identical台架测试参数设定和测试过程完全相同**

Comparison test results CO_2

Golf 1.4 TSI China 4



→ **On average China results 19% lower (min: -13% in EUDC; max: -26% in CADC rural)**

中国的平均结果比ERMES结果低19%

→ **Differences in CO_2 can be explained very well by transmission technology (DCT vs. MT, see next slides) CO_2结果的不同可以很好的解释为变速器技术不同(后续幻灯片介绍)**

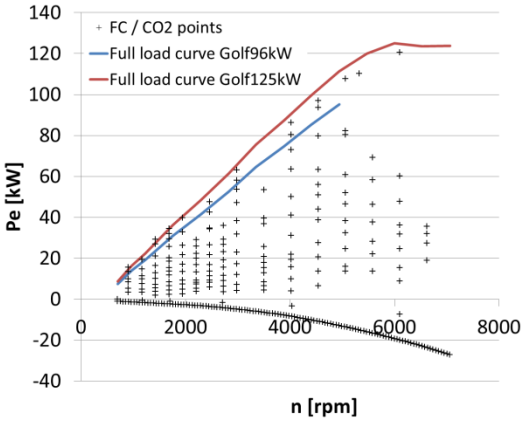
Comparison test results CO_2

Golf 1.4 TSI China 4

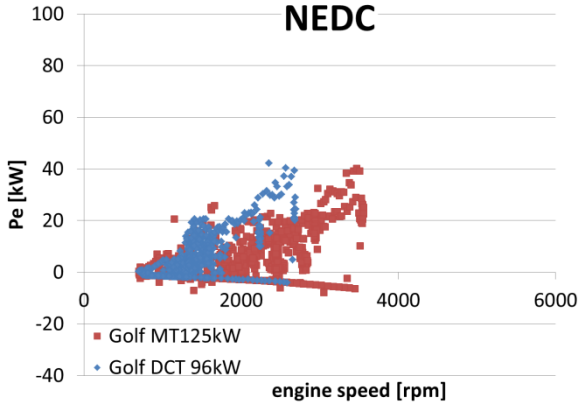
Difference in CO_2 between measurements in China (with DCT transmission) and at TUG (MT transmission) was further analysed by simulations with the PHEM model
利用PHEM模型进一步研究中欧测试车辆二氧化碳排放差异

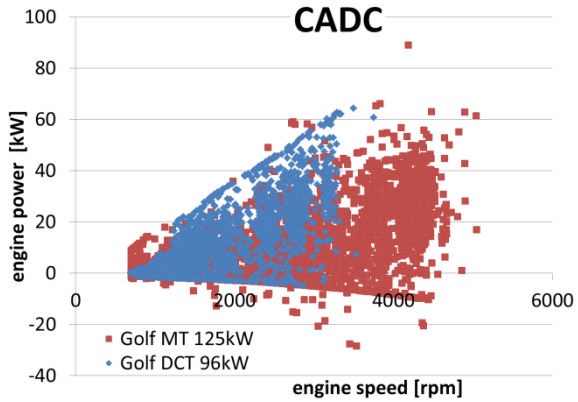
- Assumption: similar values for FC and CO_2 at given engine load point (engine speed and torque) for both vehicle variants 假定二者在加载点具有同样的油耗和CO_2值
- Engine map for FC / CO_2 and values for auxiliary power consumption taken from data available at FVT (small size turbocharged gasoline engine, data from particular 1.4 TSI engine not available) FC / CO_2 的发动机地图和额外功率消耗值可由FVT获取
- Settings for vehicle mass and road load as on chassis dyno 车重和道路负载与台架测试相同
- Actual vehicle speeds and engine speeds as measured on the chassis dyno (for DCT and MT) 与台架测试相同的车辆速度和发动机转速

Engine fuel map



Engine operation points

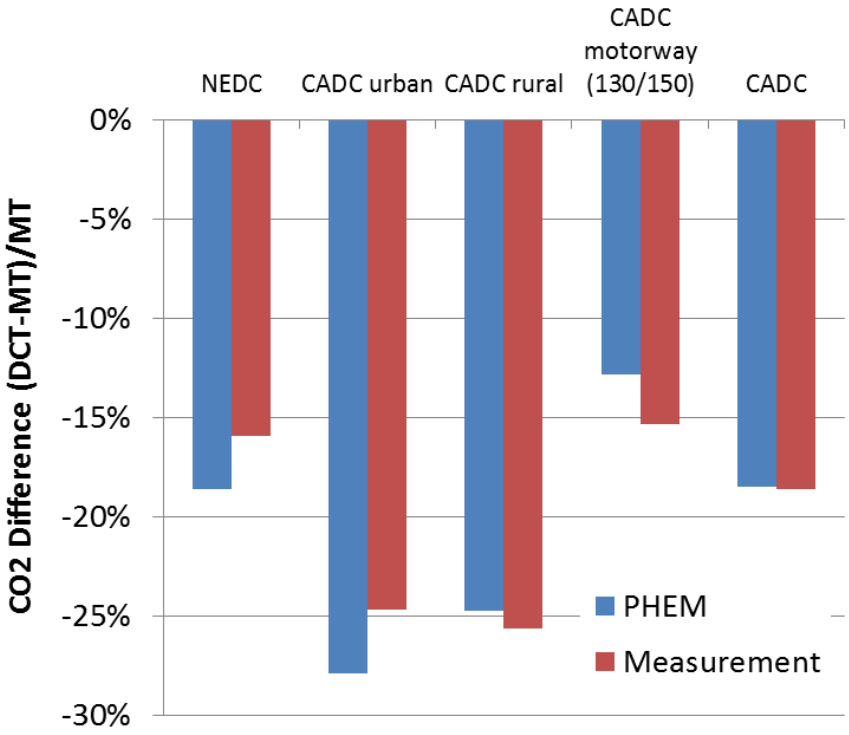




Comparison test results CO_2

Golf 1.4 TSI China 4

Difference in CO_2 between measurements in China (with DCT transmission) and at TUG (MT transmission) was further analysed by simulations with the PHEM model利用PHEM模型进一步研究中欧测试车辆二氧化碳排放差异



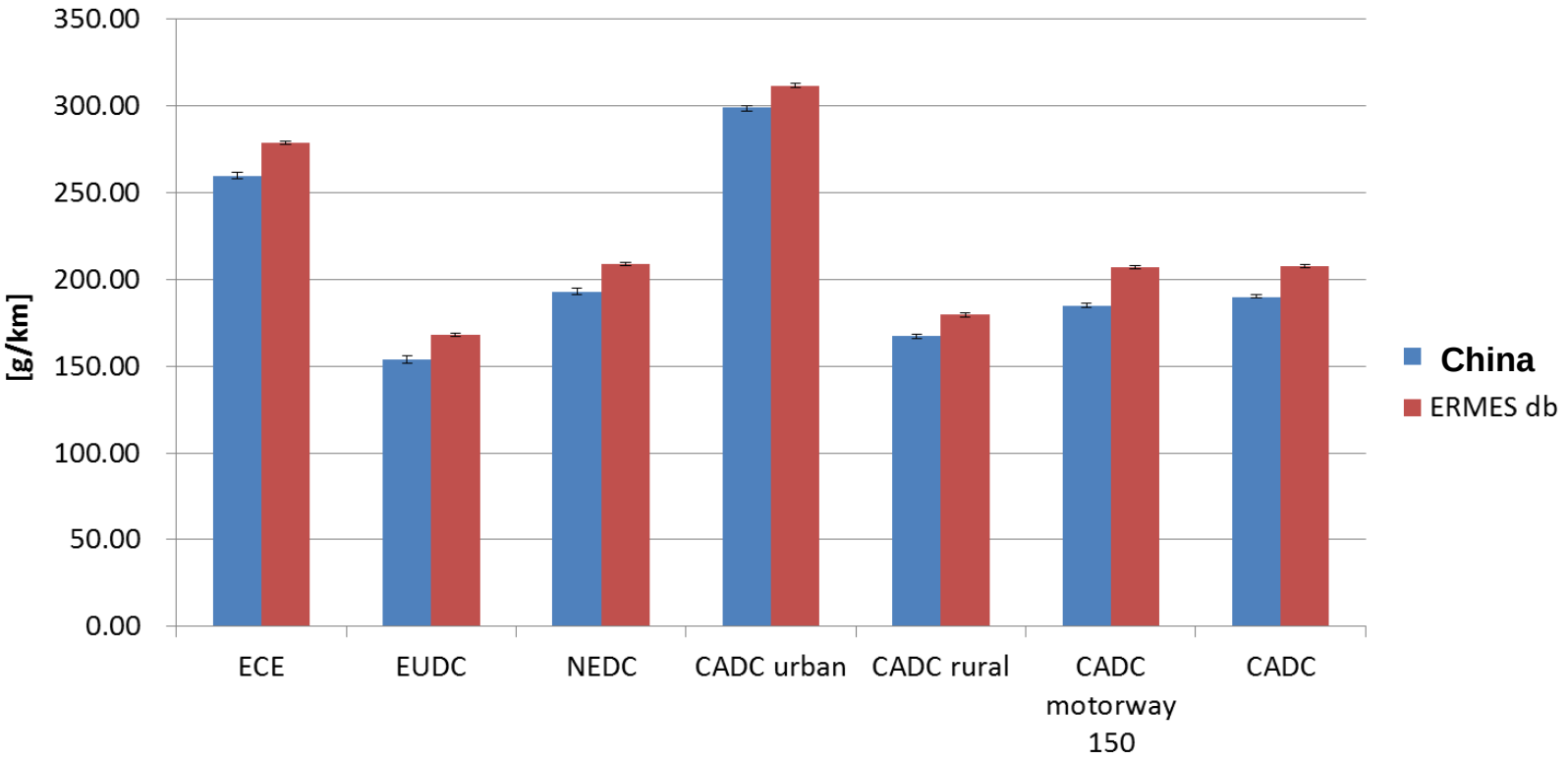
Conclusion结论:

Difference in CO_2 emissions from measurements can be very well explained by different gear shift behaviour in combination with similar engine CO_2 emission behavior

二氧化碳差异和相似的排放规律可以很好的解释为换挡方式的不同

Comparison test results CO_2

Accord 2.0 VETC China 3

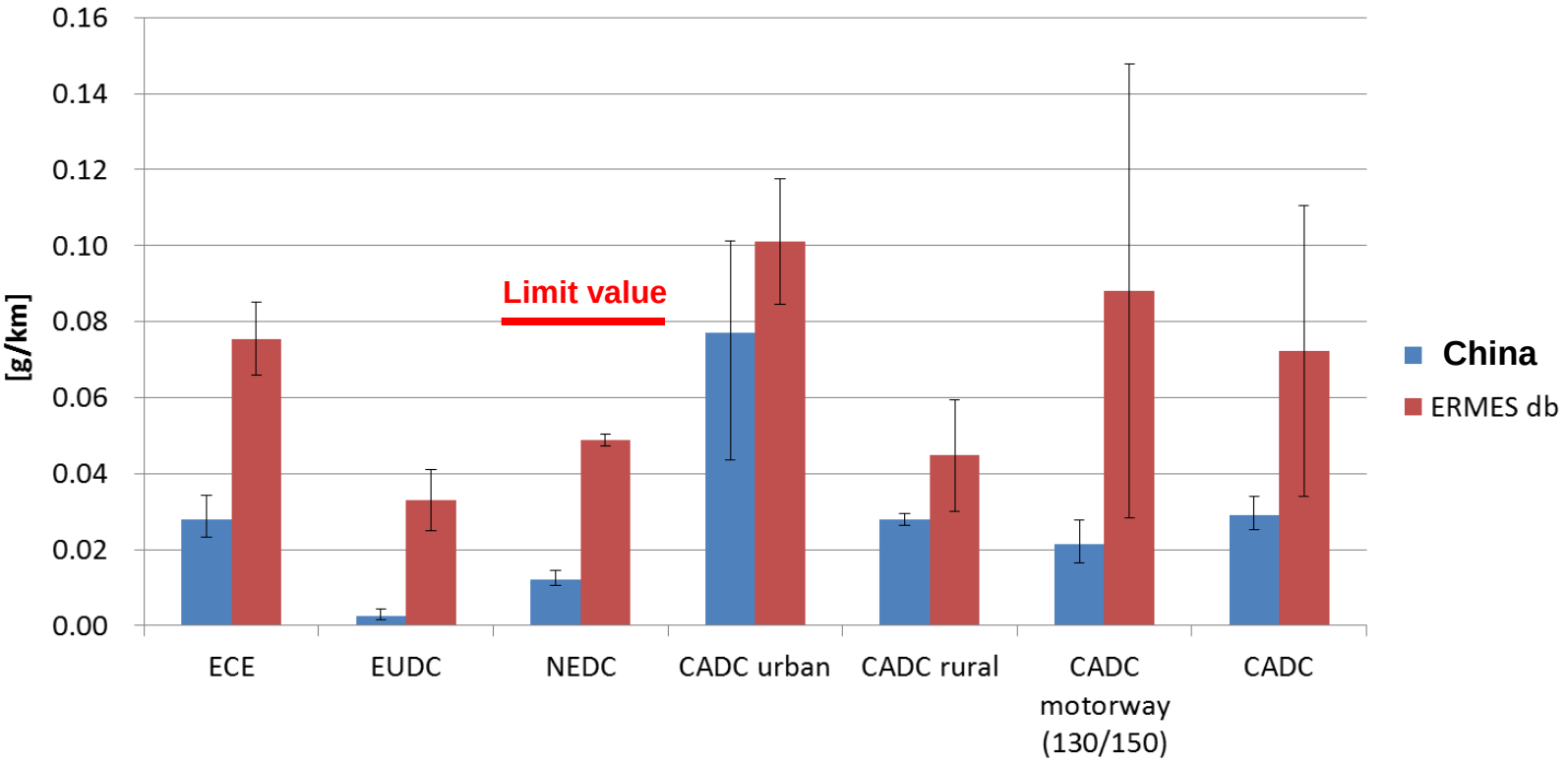


→ **On average China results 8% lower (min: -4% in CADC urban; max: -11% in CADC motorway)**
中国平均测试结果较ERMES低8%

→ **Possible reasons: Differences in engine and vehicles efficiencies (vehicle measured at ERMES built 7 years earlier) and/or chassis dyno forces (reproducibility of CO_2 approx. 5%)阻力可能由于不同的发动机和车辆效率(ERMES测试车辆早7年)，或不同的台架测试阻力**

Comparison test results NO_x

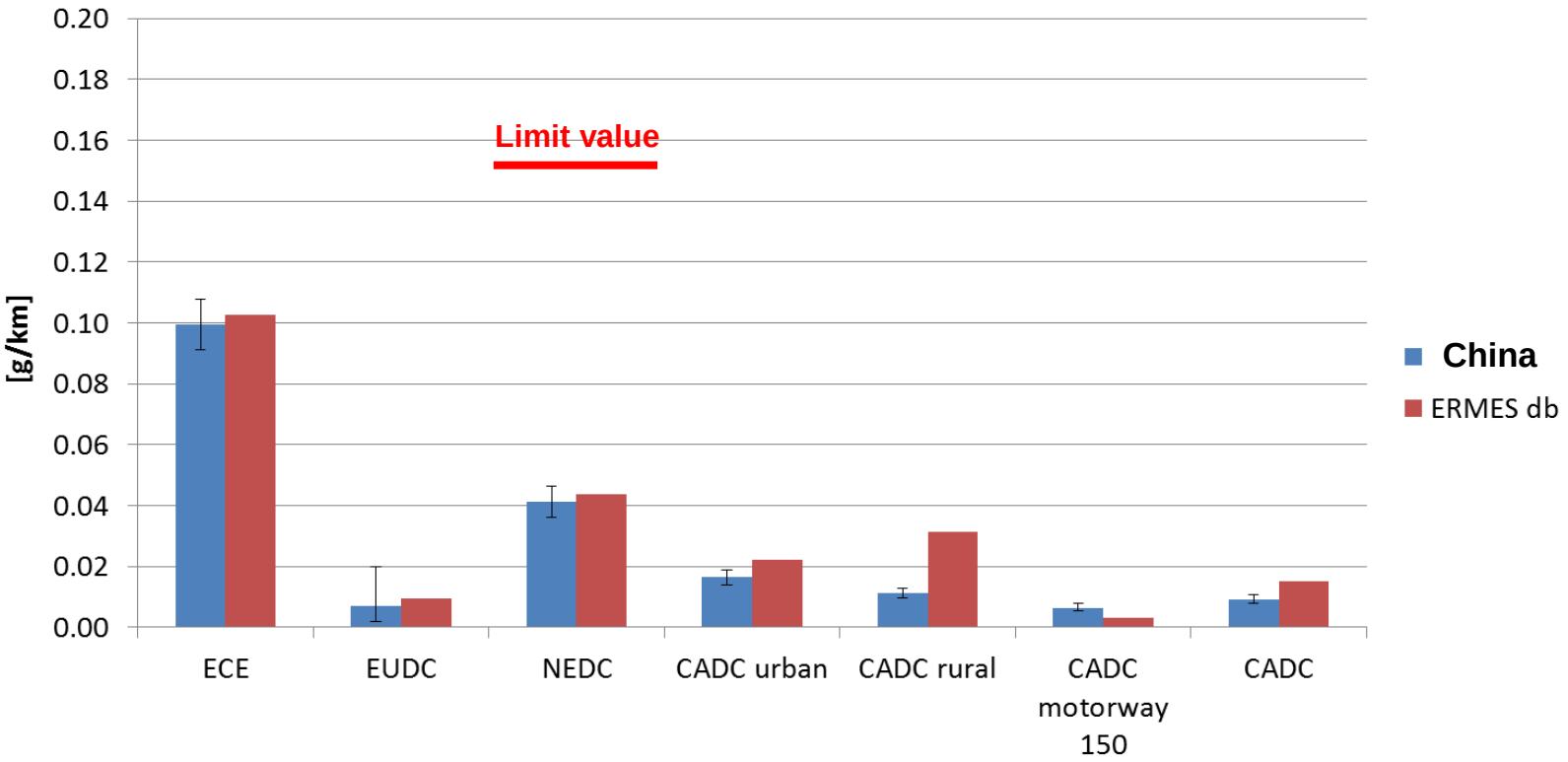
Golf 1.4 TSI China 4



- **Emissions on a low absolute level, differences in the range of reproducibility** 排放水平相对较低 数据区间范围不同
- **Emission limits in NEDC clearly met** 达到NEDC排放限值

Comparison test results NO_x

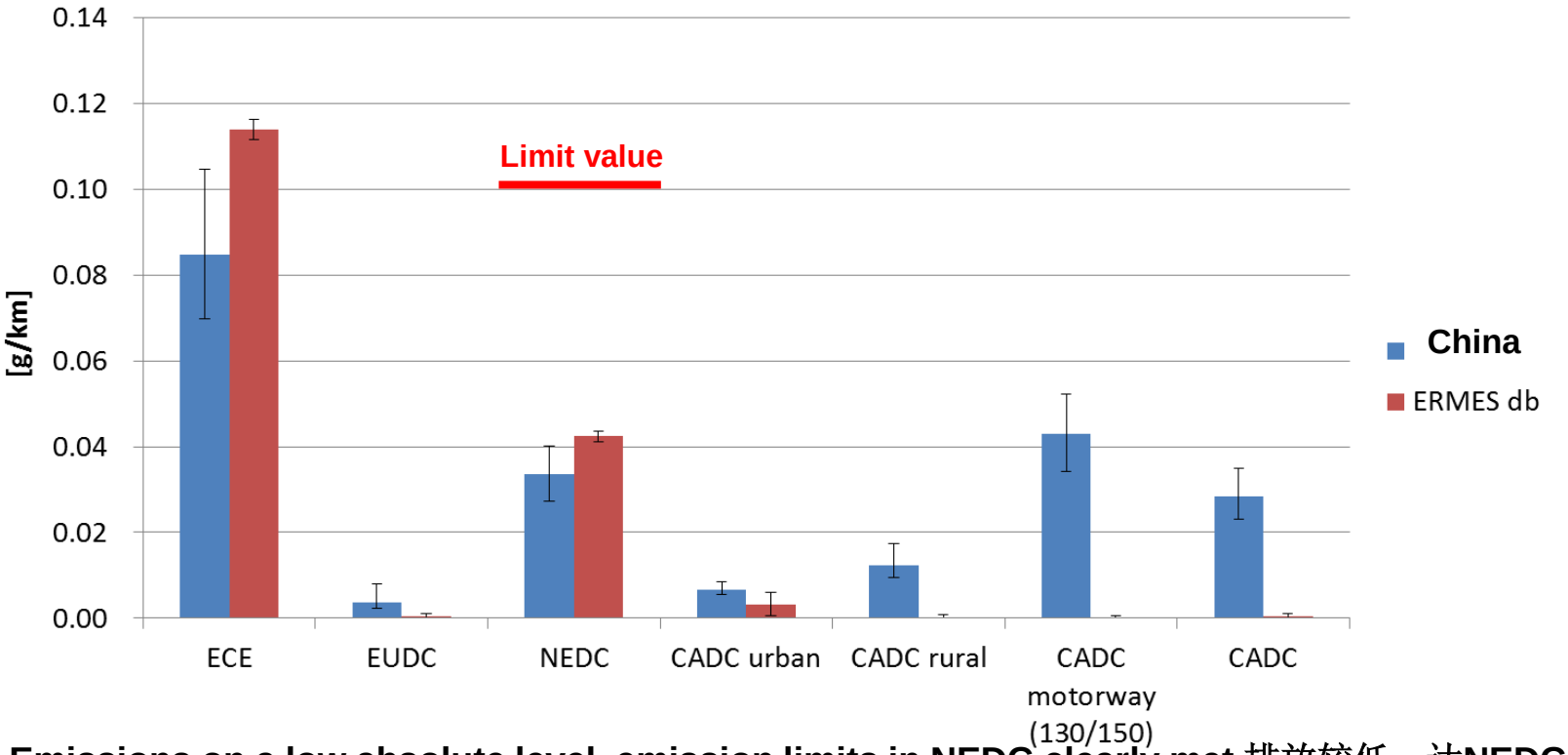
Accord 2.0 VETC China 3



- **Emissions on a low absolute level, differences in the range of reproducibility** 排放水平相对较低 数据区间范围不同
- **Emission limits in NEDC clearly met** 达到NEDC排放限值

Comparison test results THC

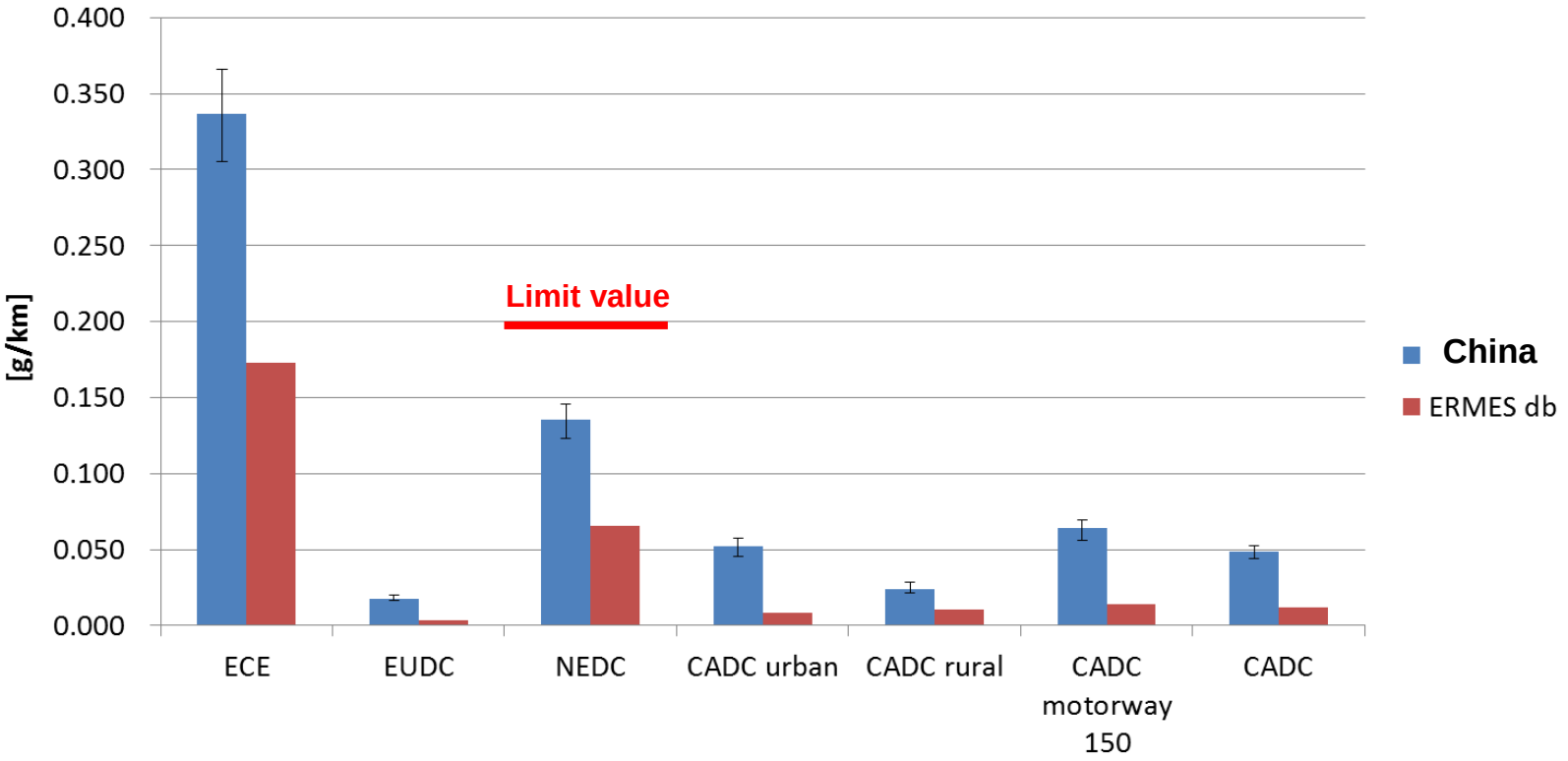
Golf 1.4 TSI China 4



- **Emissions on a low absolute level, emission limits in NEDC clearly met 排放较低，达NEDC限值**
- **DCT vehicle measured in China shows slightly higher HC levels in CADC (probably effect of different engine torque and speed pattern due to DCT, see also results for CO) 中国测试的DCT变速车辆在CADC工况上的HC排放水平较高(可能受DCT发动机扭矩和速度模式影响，CO的结果相似)**

Comparison test results THC

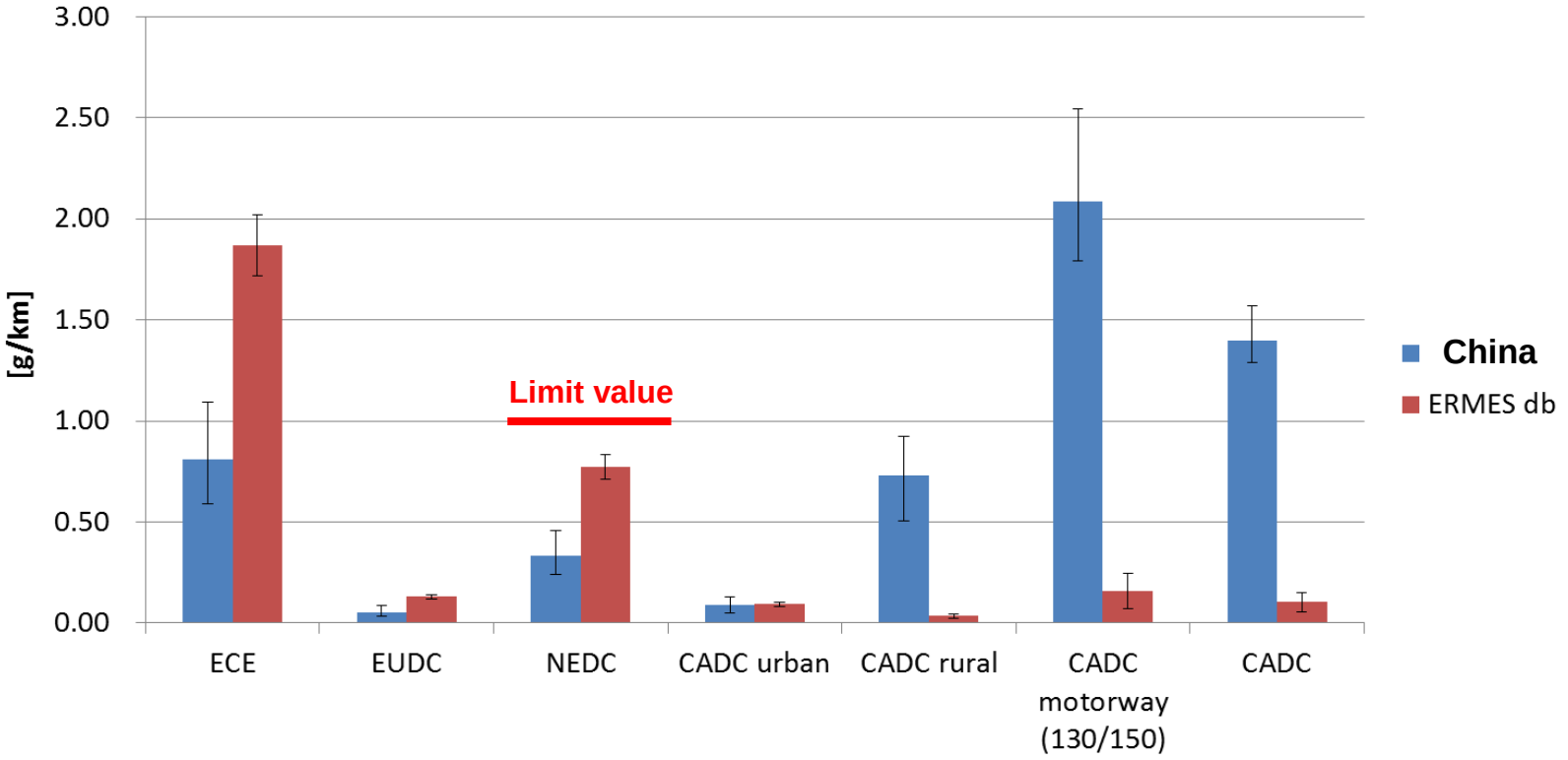
Accord 2.0 VETC China 3



- **Emissions on a low absolute level, emission limits in NEDC clearly met排放较低，达NEDC限值**
- **Vehicle measured in China somewhat higher emission values 中国测试车辆相对较高**

Comparison test results CO

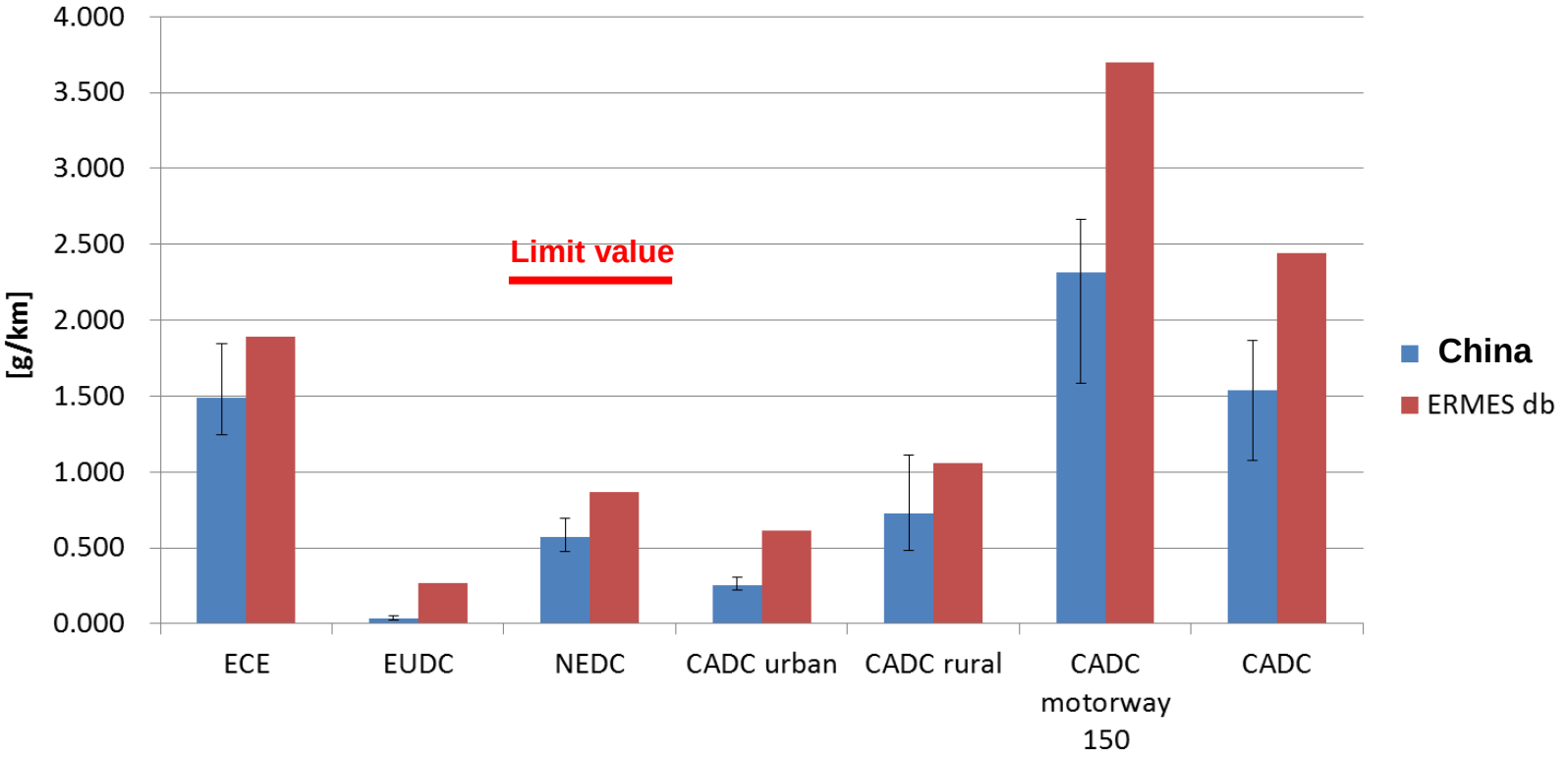
Golf 1.4 TSI China 4



- **Emissions on a low absolute level, emission limits in NEDC clearly met排放较低，达NEDC限值**
- **DCT vehicle measured in China shows slightly higher CO levels in CADC (probably effect lower engine speeds and higher engine torques for DCT vehicle)中国测试的DCT变速车辆在CADC工况上的CO排放水平较高(可能受DCT高发动机扭矩和低转速影响)**

Comparison test results CO

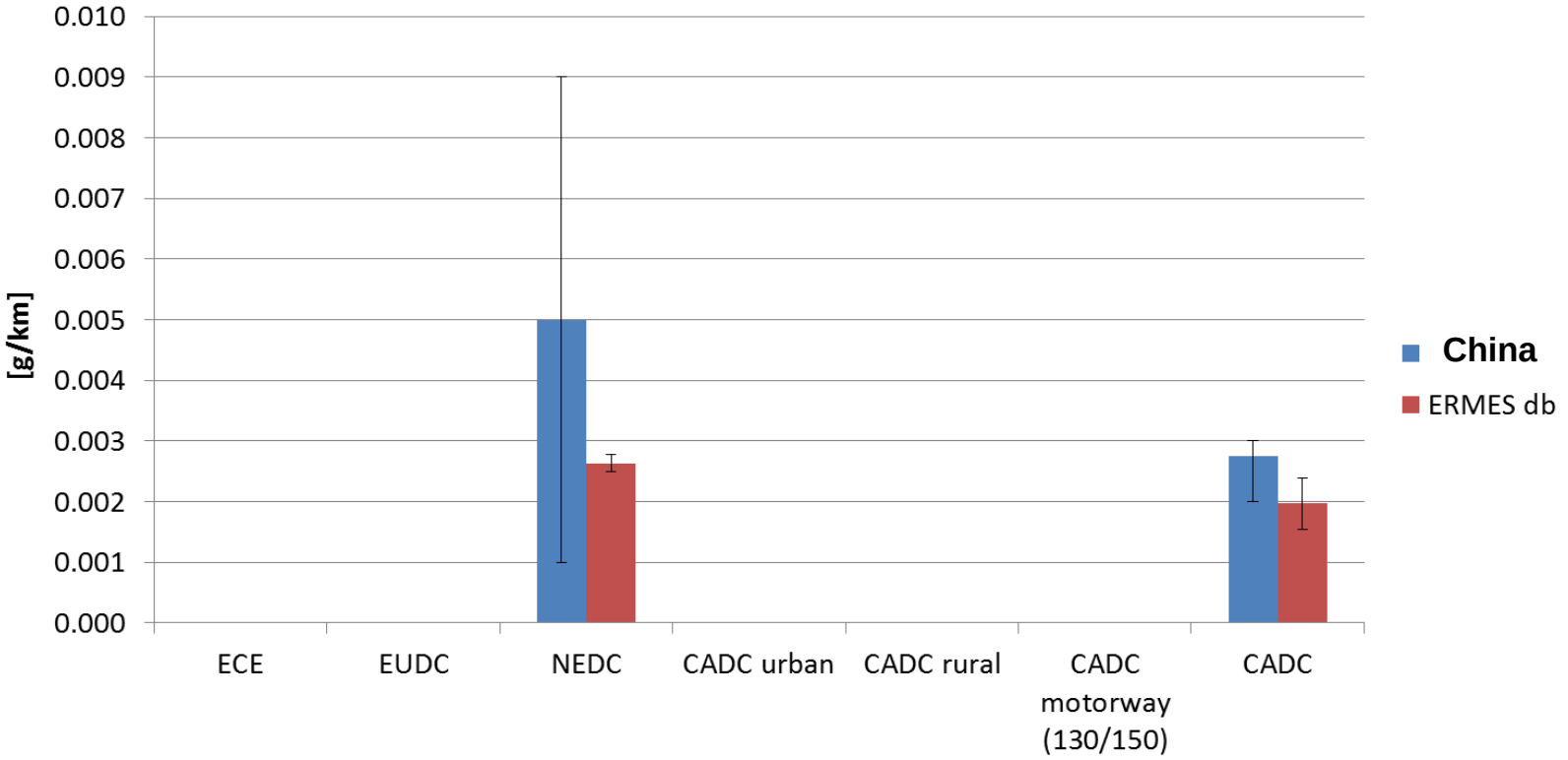
Accord 2.0 VETC China 3



- **Similar emission behaviour at both vehicles** 二者排放特征相似
- **NEDC limits clearly met** 达NEDC限值

Comparison test results PM

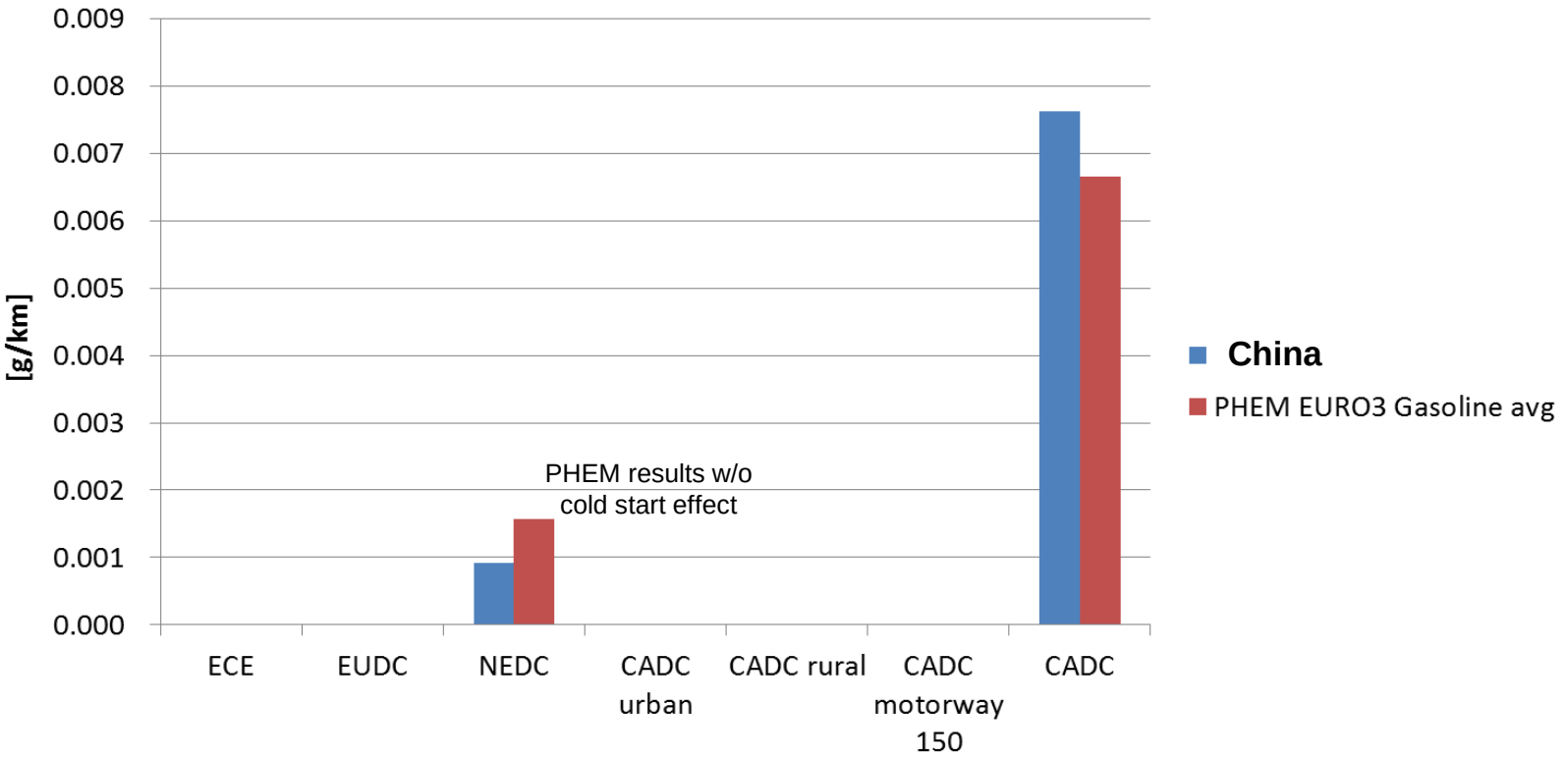
Golf 1.4 TSI China 4



- **Low absolute PM levels as typical for gasoline engines, no PM limit applicable 典型汽油车低PM排放，没有适用的PM限值**
- **Differences between vehicles in the range of reproducibility 数据变化范围不同**

Comparison test results PM

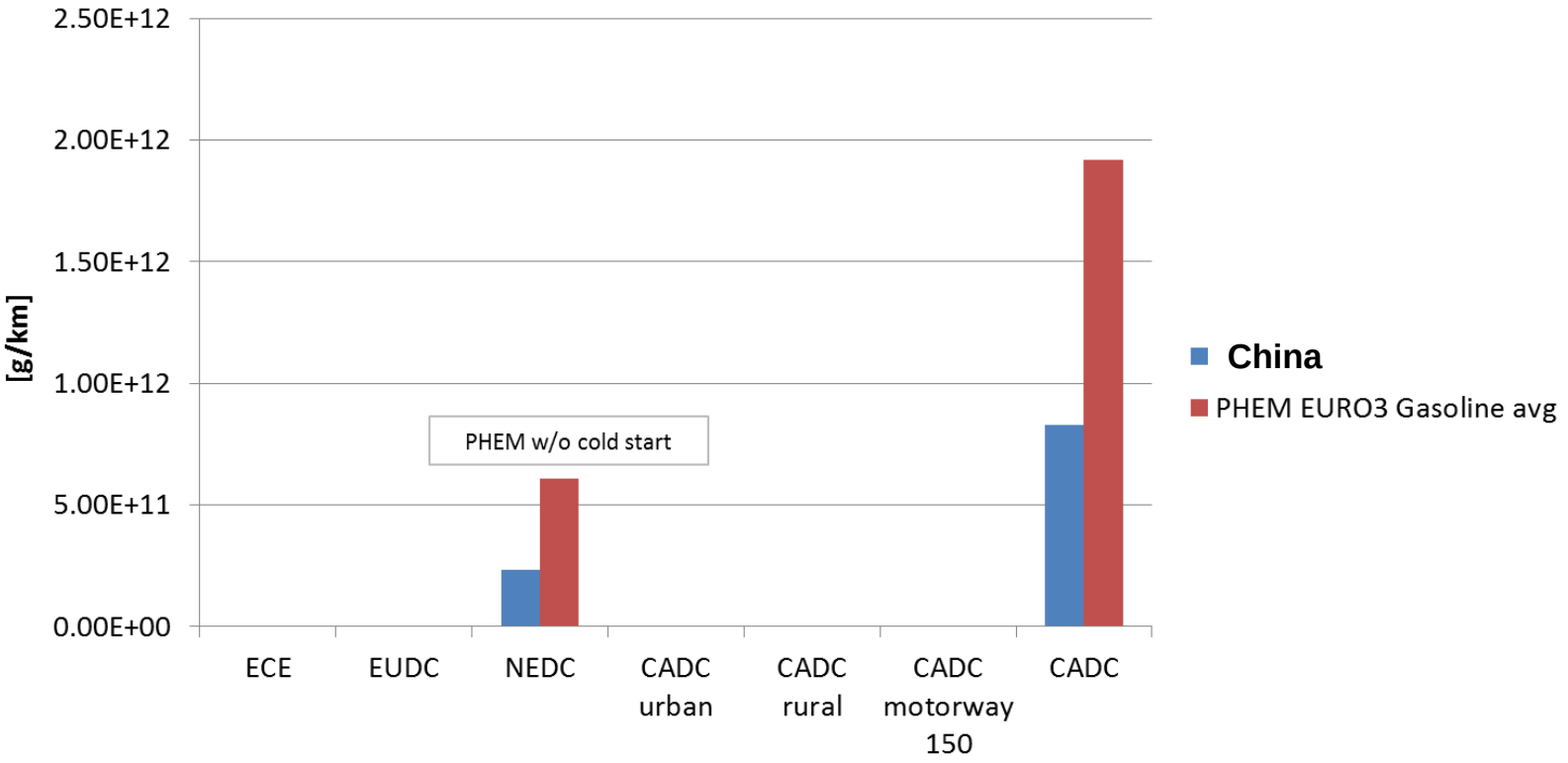
Accord 2.0 VETC China 3



- **No PM results available from ERMES (not standard for gasoline in 2002) ERMS没有PM结果**
- **PM measured at VETC match with average PM levels in PHEM model for gasoline Euro 3 VETC测试的PM结果达到PHEM模型中欧3汽油车PM平均排放水平**

Comparison test results PN

Accord 2.0 VETC China 3



- **No PN results available from ERMES (not standard in 2002) ERMS没有PN结果**
- **PN measured at VETC matches order of magnitude of average PN levels in PHEM model for gasoline Euro 3 VETC测试的PN结果与PHEM模型中欧3汽油车PN平均排放量级相似**

Conclusions from analysis of „matching“ vehicles
匹配车辆分析总结

- **Measurement techniques and data evaluation methods as applied by VETC are comparable with top standards as applied in ERMES group. VETC的排放和数据评估方法达到了ERMES提供的顶级标准**
- **Similar emission behaviour of found at “matching” vehicles at VETC, both for (engine) CO_2 emissions as well as for pollutant emissions.**
  However, sample size of 2 measured vehicles is too small to make general conclusions.双方测试车辆排放行为相似，但仅仅两组测试不足以说明整体请客
- **Analysis of vehicle stock in China indicates that other makes and models are relevant than in EU. 中国车队分析表明对其他厂商和车型的分析十分重要**

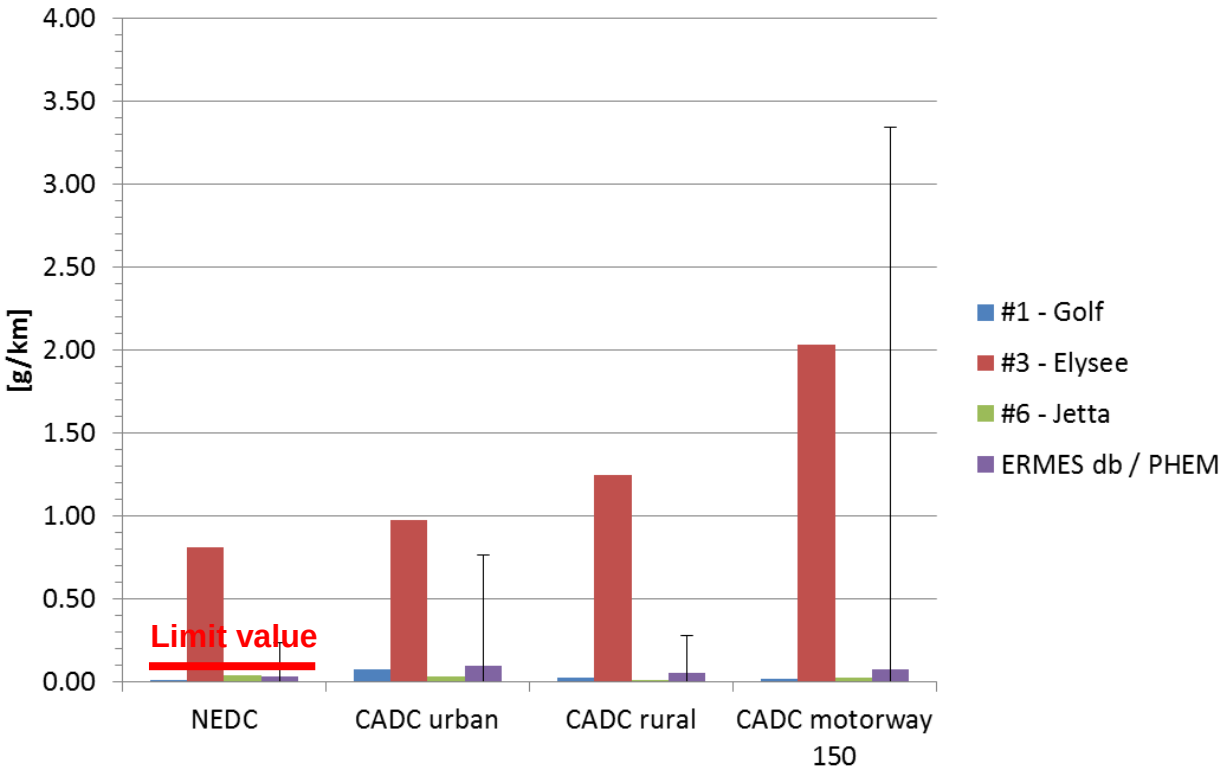
Comparison of „most relevant“ vehicles
相关车型对比

China 4 vs. Euro 4 国4 vs 欧4

- **Three vehicles measured at VETC (2 top sellers + Golf from „matching vehicles“)**
  3辆VETC测试车辆(2个销量最多车型，和匹配车型中的Golf)
  - Citroen Elysee 1.6 MT
  - VW Jetta 1.6 MT
  - Golf 1.4 TSI AT (data also shown in analysis)
- **Comparison of test results for pollutant emissions with data from ERMES database (average, min., max.)** 与**ERMES**数据库对比污染物排放数据
- **Direct comparison of test results for CO_2 not meaningful due to differences in vehicle size and engine and drivetrain technology** 直接对比CO_2排放没有意义，因为车辆的型号(排量)和发动机及动力技术不同

Comparison of „most relevant“ vehicles

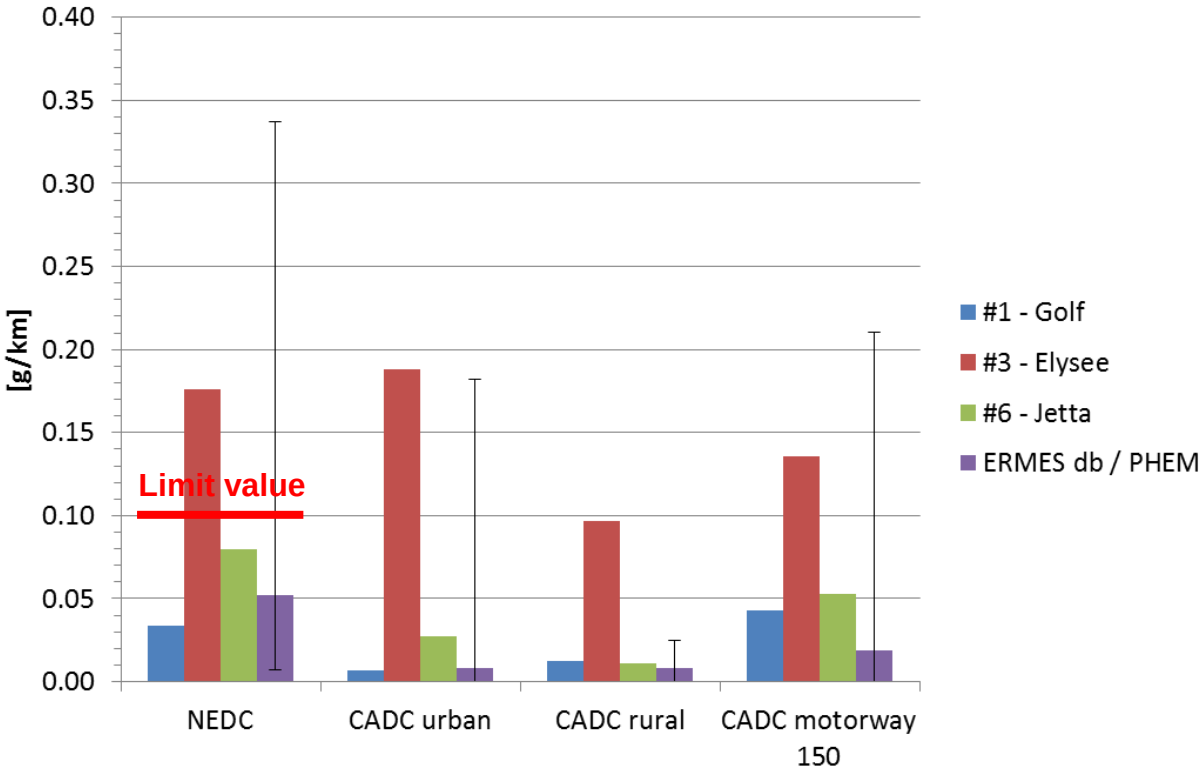
China 4 vs. Euro 4 - NOx



- **Jetta and Golf show typical low NOx emissions and meet NEDC limit Jetta和Golf 的NOx排放很低，达标**
- **Elysee „high emitting vehicle“ probably with malfuction in emission control system (NOx emissions meet order of magnitude of engine raw emissions) 高排放车Elysee可能是因为排放控制系统出现故障。(达到了未处理排放的量级)**

Comparison of „most relevant“ vehicles

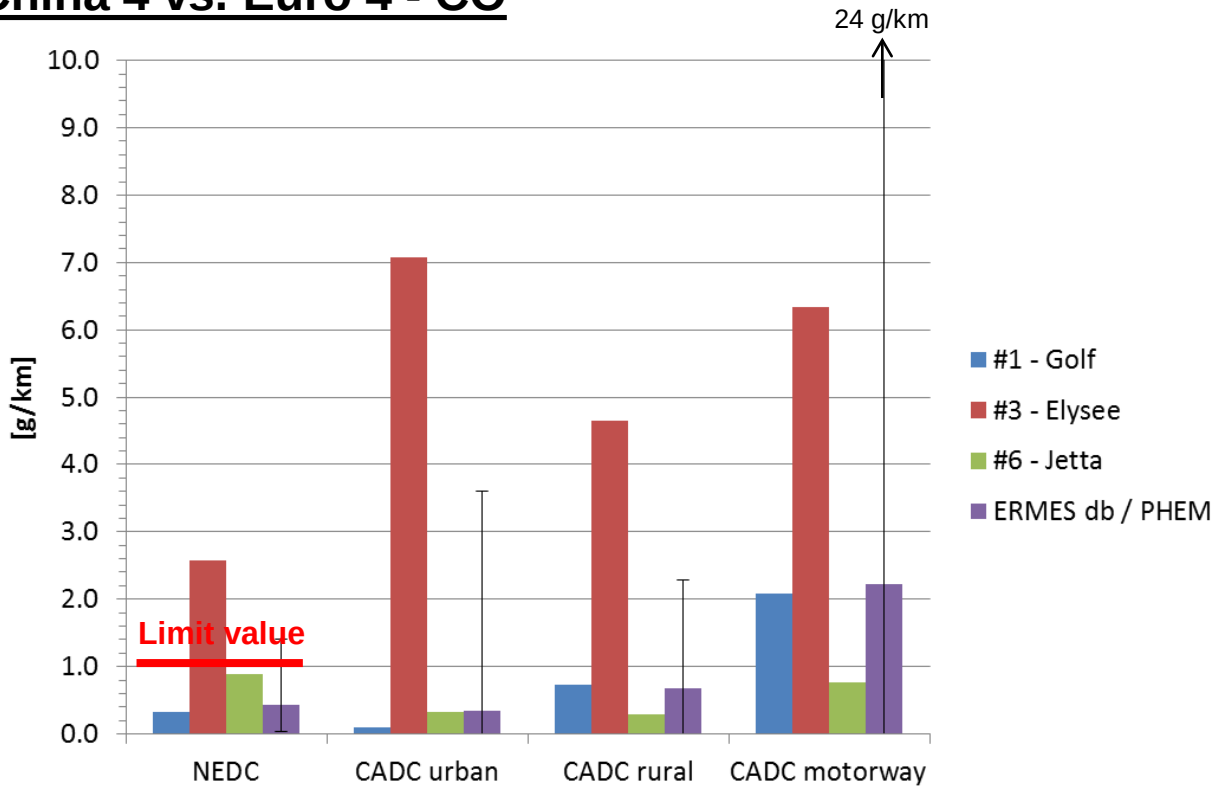
China 4 vs. Euro 4 - THC



- **Jetta and Golf show low THC emissions (approx. ERMES average) and meet NEDC limit**
  Jetta和Golf 的THC排放很低，达标
- **Elysee „high emitting vehicle“ probably with malfuction in emission control system**
  排放车Elysee可能是因为排放控制系统出现故障。

Comparison of „most relevant“ vehicles

China 4 vs. Euro 4 - CO

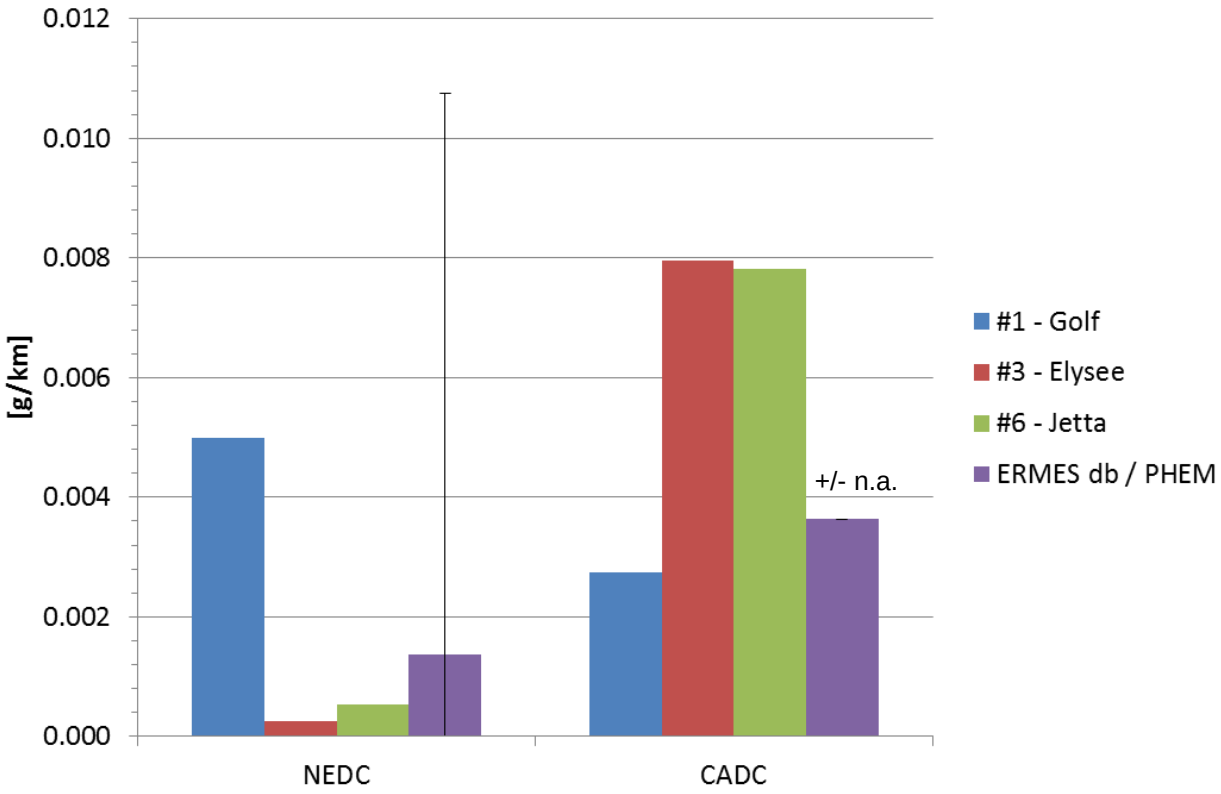


150

- **Jetta and Golf show low CO emissions (approx. ERMES average) and meet NEDC limit**
  Jetta和Golf 的CO排放很低，达标
- **Elysee „high emitting vehicle“ probably with malfuction in emission control system**
  排放车Elysee可能是因为排放控制系统出现故障。

Comparison of „most relevant“ vehicles

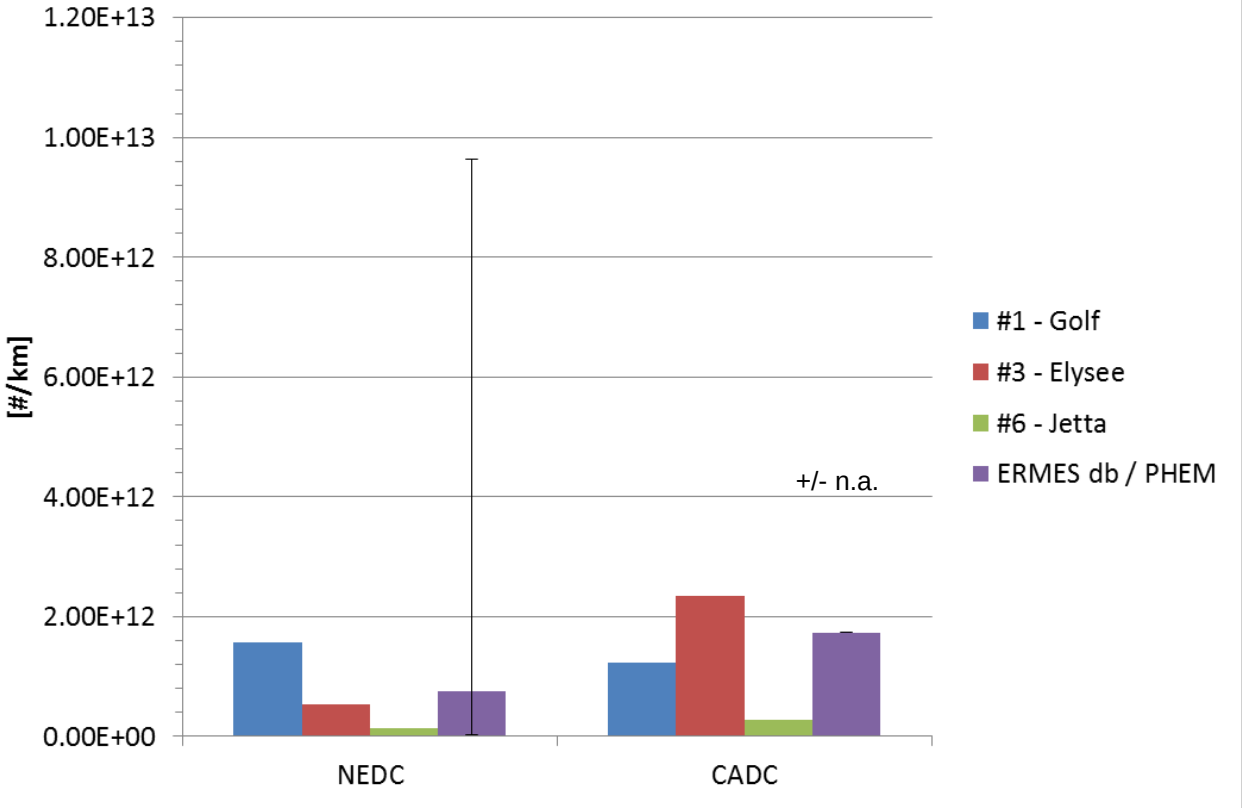
China 4 vs. Euro 4 - PM



- **Measured vehicles show typical low PM levels of gasoline engines 测试汽油车辆PM排放都很低**
- **Reproducibility of PM results on relative level known to be low PM数据数据范围相关水平较低**

Comparison of „most relevant“ vehicles

China 4 vs. Euro 4 - PN



- **Measured vehicles show typical PN levels of gasoline engines 测试车辆具有汽油车很低的PN排放**

Comparison of representative vehicles

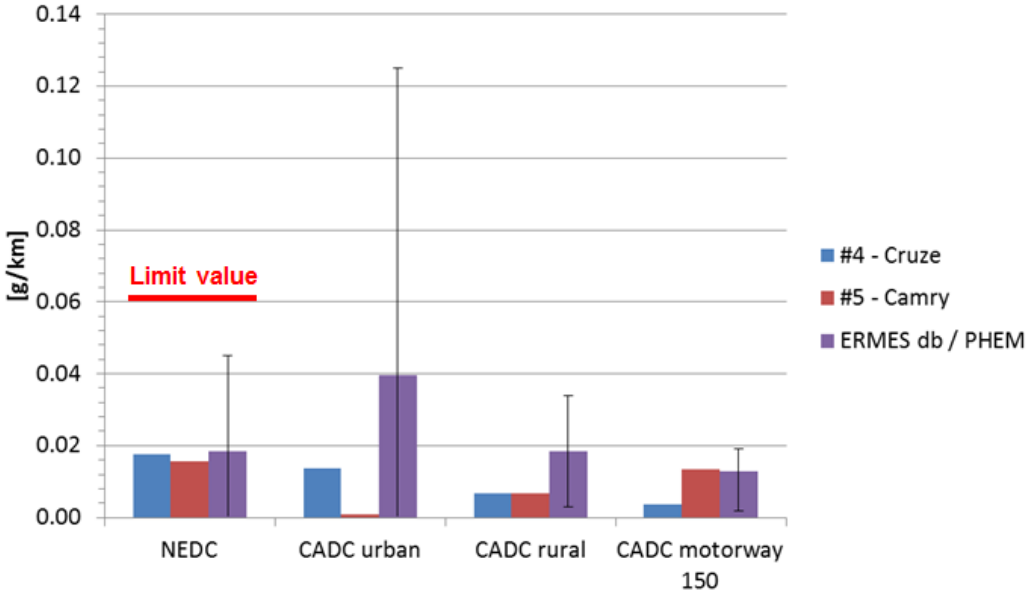
China 4 vs. Euro 4 – Conclusions 国4 vs 欧4

- **VW Jetta 1.6 and VW Golf 1.4 show typical low levels for pollutant emissions as predicted for Euro 4 gasoline by ERMES db and PHEM model** 大众捷达和高尔夫排放水平都远低于**ERMES**数据库与**PHEM**模型对欧**4**车的预测
- **Citroën Elysee identified as „high emitting vehicle“ probably with malfuction in emission control system ELYSEE**可能由于排放控制系统故障被认为是高排放车
- **For emission standards earlier than Euro 5 high emitting vehicles were usually excluded from ERMES in-use testing** 欧**5**千，高排放车通常不包含与**ERMES**测试
  → ERMES db is rather biased for effect of high emitting vehicles ERMES数据库可能忽略了高排放车的影响
- **Especially for gasoline vehicles the fleet average emission level is significally influenced by the share of high emitting vehicles. Due to the limitation of sample size this share can hardly be determined by in-use test programs on chassis dynos or with PEMS systems.** 汽油车排放水平很受高排放车影响，但很难被测试
- **Planned approach to consider “high emitters” in ERMES for next HBEFA version: Use emission data from “Remote Sensing” technique to determine average emission levels (g pollutant / g CO2) per vehicle segment and calibrate emission model and/or ageing functions (“ageing” would also include effect of increasing shares of high emitters with increasing mileage in the fleet)** 下个**HBEFA**版本将引入高排放车影响，利用遥感确定排放水平，并验证排放模型和裂化方程。

Comparison of representative vehicles

China 5 vs. Euro 5 国5 vs 欧5

- **Two vehicles measured at VETC (2 top sellers) 两量销量最多的车型**
  - Chevrolet Cruze 1.5 AT
  - Toyota Camry 2.0 AT
- **Comparison of test results for pollutant emissions with data from ERMES database (average, min., max.). Example NOx:与ERMES数据库对比，例如氮氧化物**



- **Main conclusion: Emission behaviour of China 5 vehicles matches „Euro 5 average“**
  主要结论，国5车排放特征与欧5平均水平相同

Summary and Outlook 总结与展望

- **In general emission behaviour was found to be similar for vehicles measured in China compared to ERMES data.** 综合来讲，中国测试车辆排放特征与**ERMES**数据相似
  - Similar CO_2 emission behaviour (on engine level) 相同的CO_2排放特征
  - Low emission levels for pollutant emissions 较低的污染物排放水平
- **One of 6 measured vehicles was identified as “high emitter”. Pollutant emission levels for gasoline vehicle fleet is mainly determined by share of “high emitters”. “High emitters” until now not systematically investigated in EU.** 6个测试车辆中有一辆为高排放车量。汽油车队排放水平主要取决于这一类车辆的比例，在欧洲此类高排放车并没有被系统研究过
- **Sample size of vehicles measures in pilot phase (n=6) is too small to make general conclusions** 试点阶段(6辆车)的样本仍然太小，不能对整体情况作出结论。

Thank you for your attention!

Contact & Information

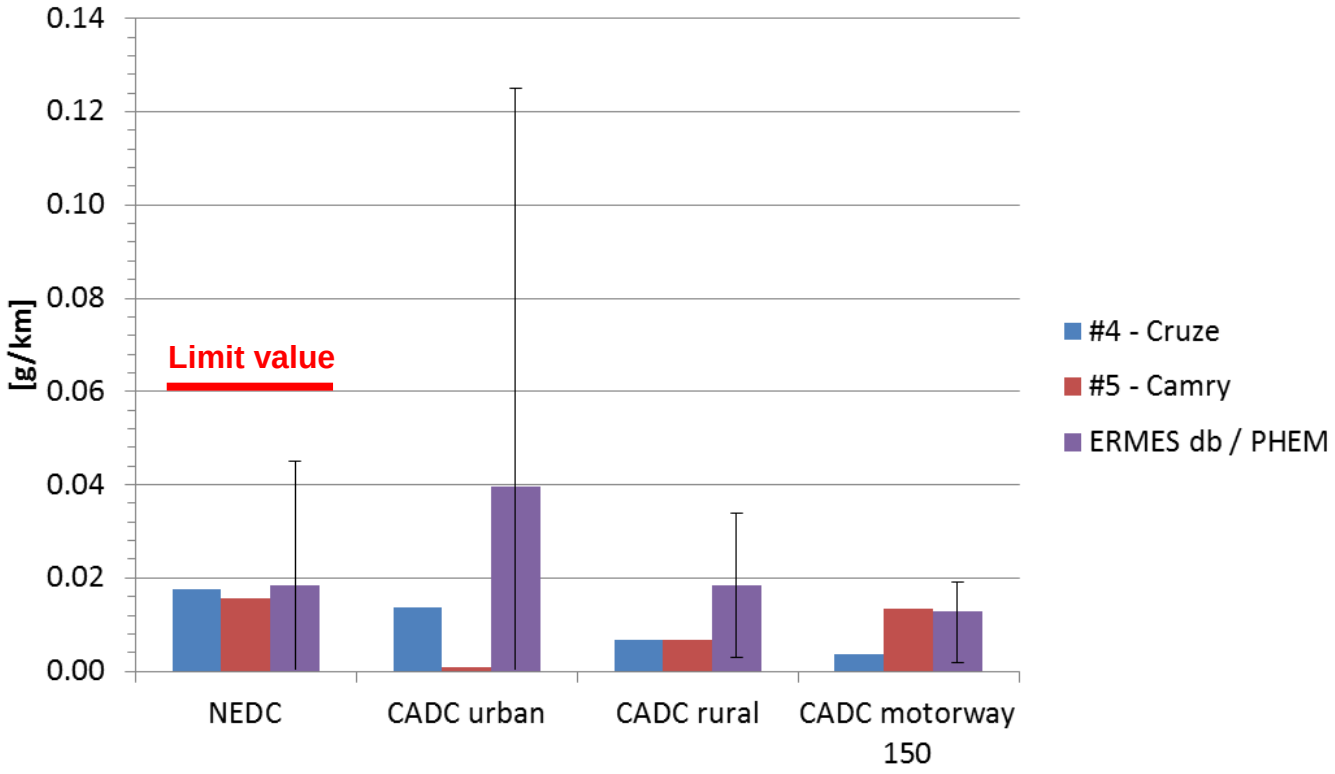
Dr. Martin Rexeis
Tel: +43 316 873 30270
Email: rexeis@ivt.tugraz.at

Graz University of Technology
Institute of Internal Combustion Engines and Thermodynamics
http://www.ivt.tugraz.at/

Backup slides

Comparison of representative vehicles

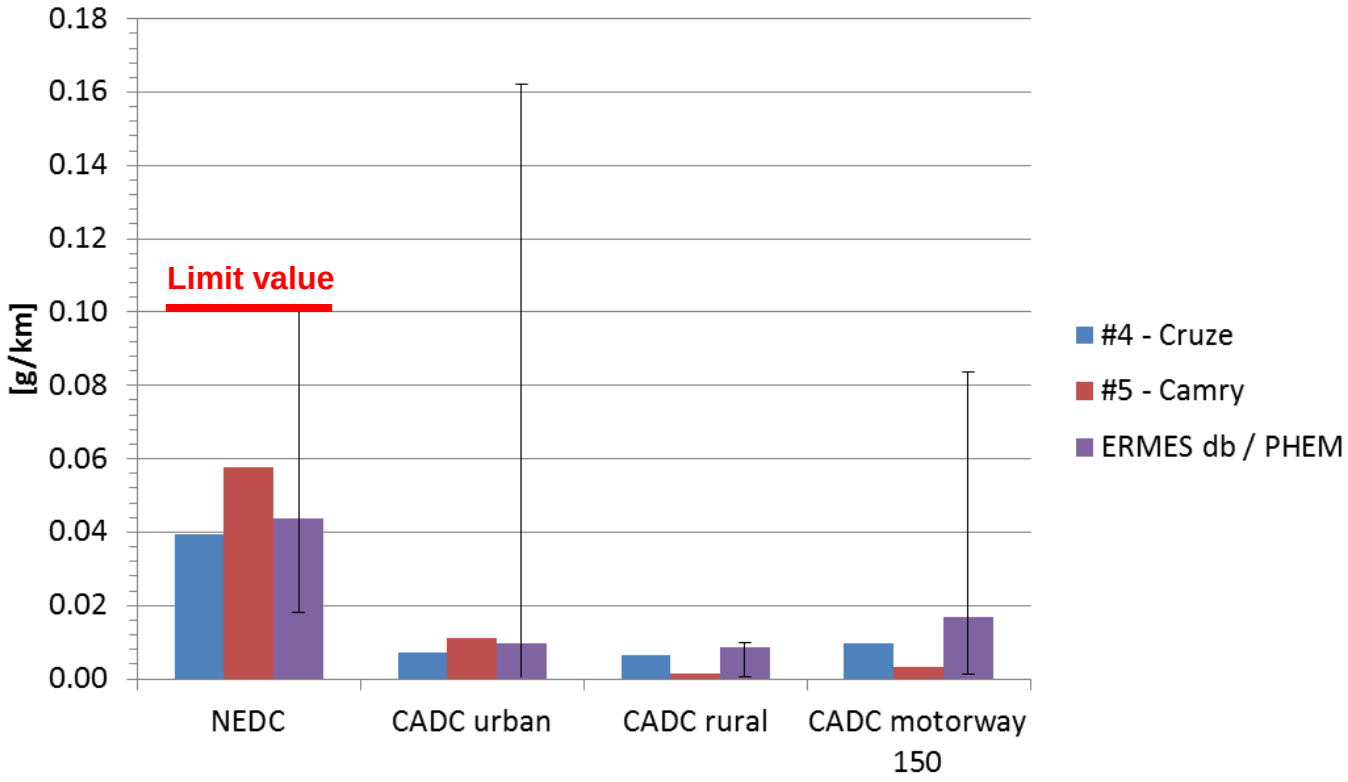
China 5 vs. Euro 5 - NOx



- **Emission behaviour of China 5 vehicles matches „Euro 5 average“**

Comparison of representative vehicles

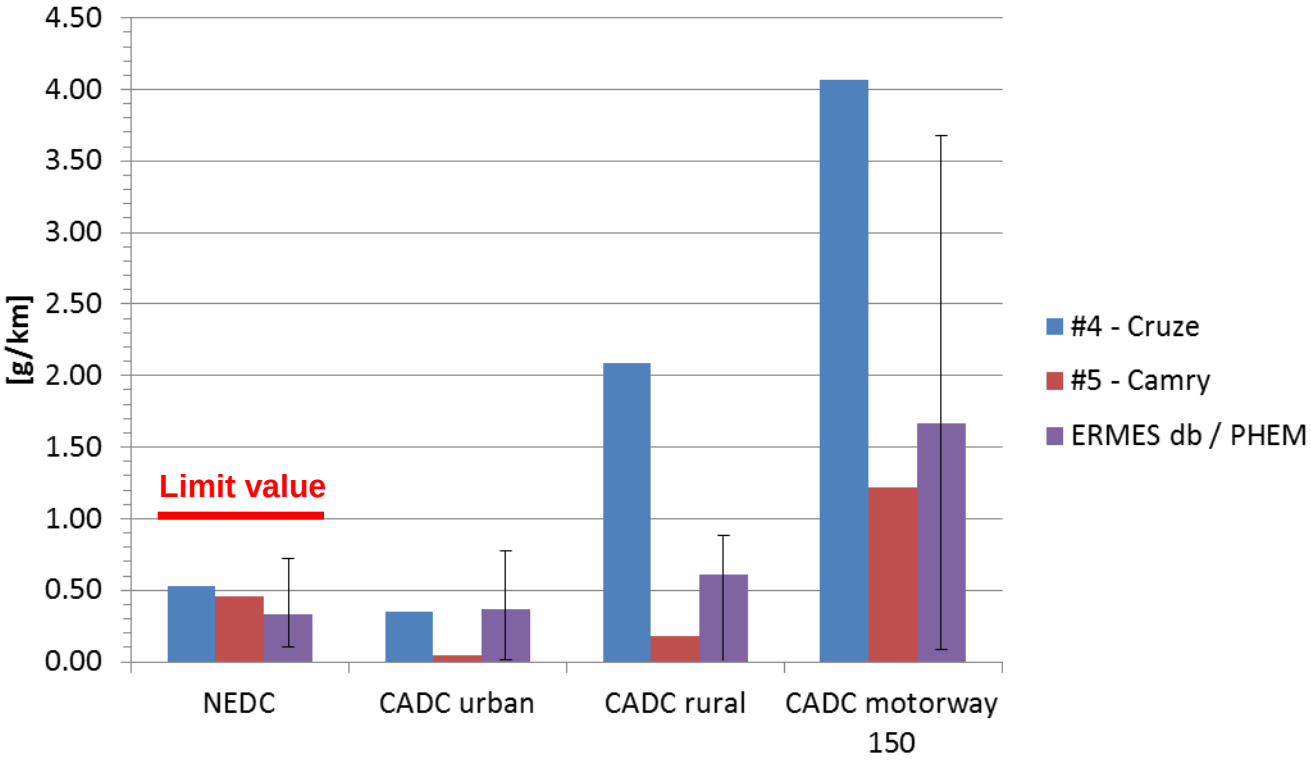
China 5 vs. Euro 5 - THC



- **Emission behaviour of China 5 vehicles matches „Euro 5 average“**

Comparison of representative vehicles

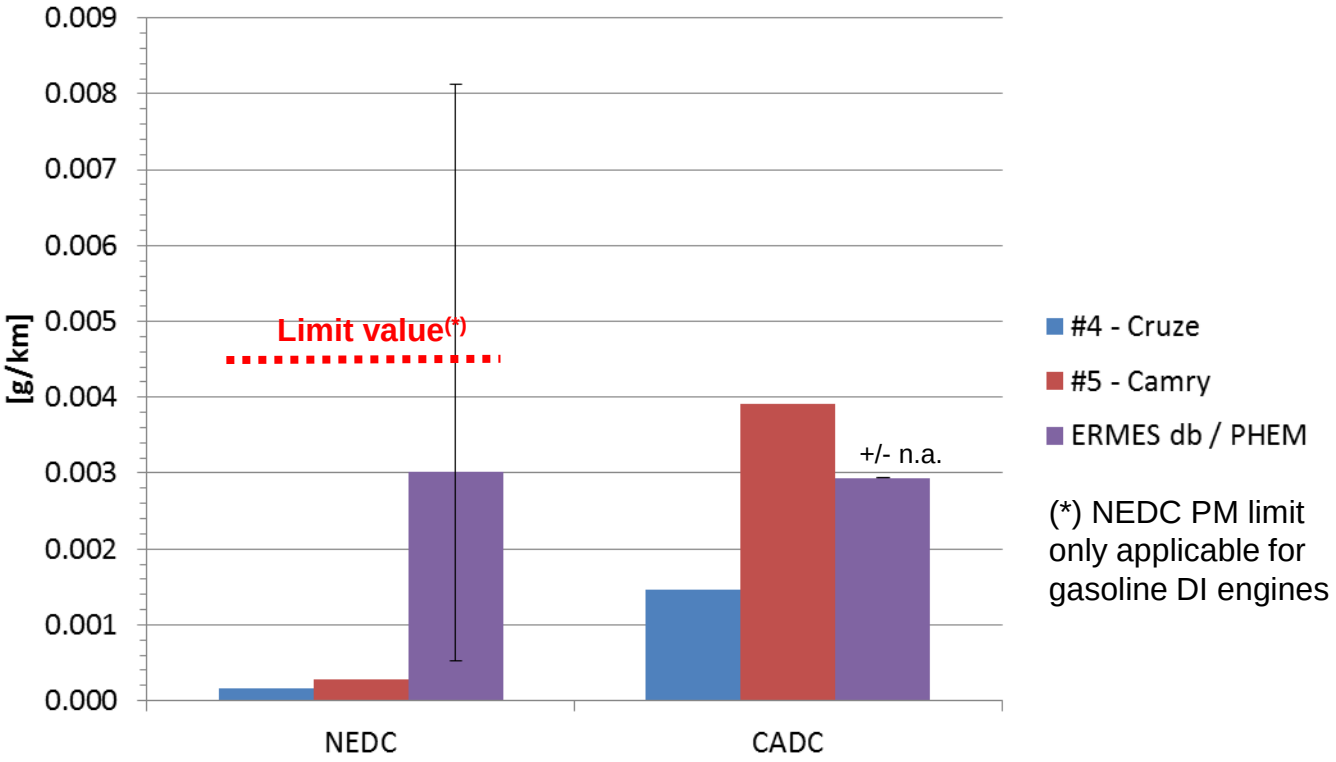
China 5 vs. Euro 5 - CO



- **Camry meets „Euro 5 average“**
- **Cruze shows higher CO levels in CADC**

Comparison of representative vehicles

China 5 vs. Euro 5 - PM

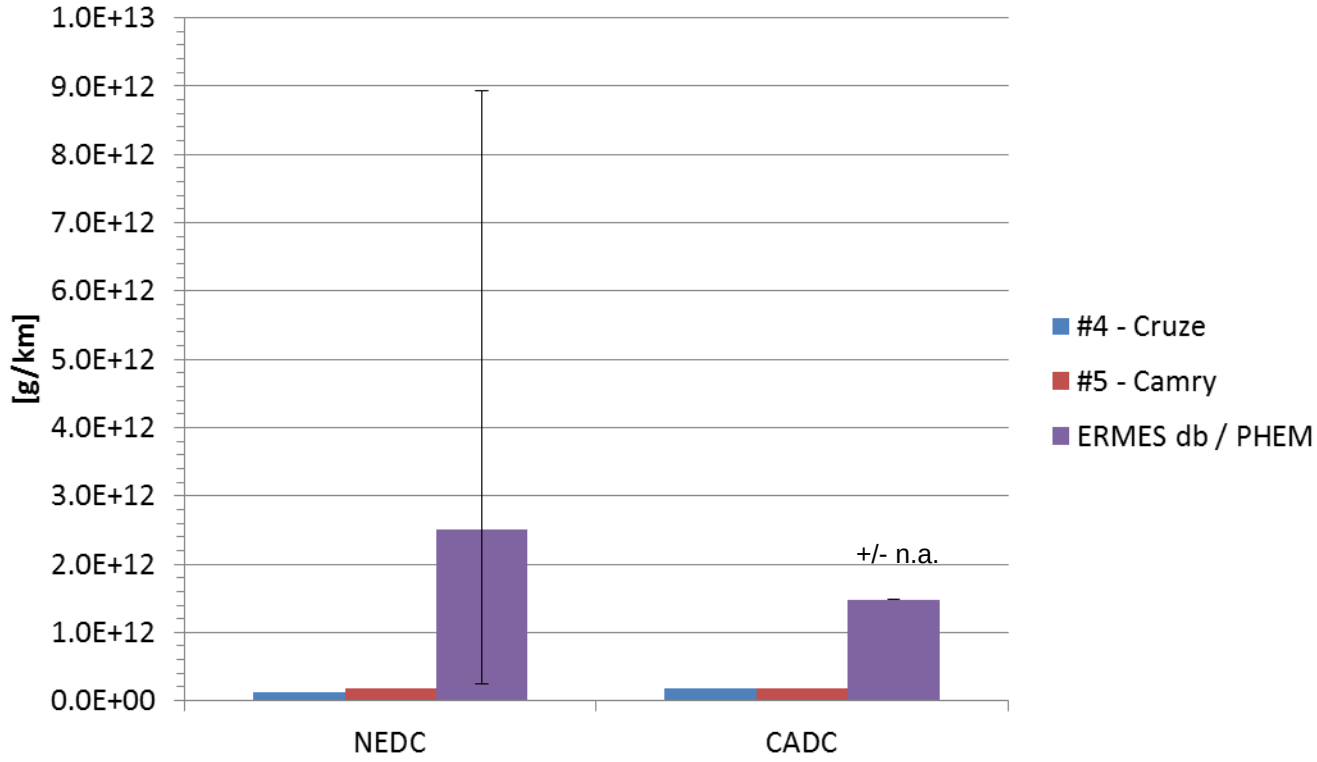


(*) NEDC PM limit only applicable for gasoline DI engines

- **Measured vehicles show typical low PM levels of gasoline engines**

Comparison of representative vehicles

China 5 vs. Euro 5 - PN



- **Measured vehicles show lower PN one order of magnitude lower than Euro 5 average**

Comparison of representative vehicles

China 5 vs. Euro 5 - Conclusions

- **Both tested China 5 vehicles show typical very low levels for pollutant emissions as predicted for Euro 5 average by ERMES db and PHEM model**

Modelling of CO_2 emissions

Method as applied in HBEFA 3.2 / CRTEM

Combined bottom-up & top-down approach

- **Bottom-up modelling of influence of drive cycle / traffic situation with emission model PHEM**
  - Engine FC maps (engine speed, engine power) per engine technology parameterised based on instantaneous FC data from transient chassis dyno in-use measurements
  - Baseline vehicle model (manual transmission, average gear shift behaviour, simple auxiliary model)
  - Fleet average vehicle specifications (masses, driving resistances, gear ratios) from vehicle statistics and in-use data

⇩

Baseline emission factors [g/km] for FC and CO_2 per traffic situation

⇩

- **Top-down calibration of overall FC / CO_2 level**
  - Calibration of FC, CO2 [g/km] per each “first registrations year” an “capacity class” to meet average official CO2-value NEDC test + real world correction factor

⇩

Final emission factors [g/km] for FC and CO_2 per traffic situation

Known short-comings of approach:

- FC maps inaccurate due to limitations of transient chassis dyno tests (determination of engine power + instantaneous signal quality)
- Actual PHEM models do not consider advanced vehicle technologies e.g. DCT, AT, ??
- Effect of cold start modelled by separate functions (not in PHEM)
- HEV; PHEVs, EV not covered by PHEM
- Real world correction factor uncertain

Modelling of CO_2 emissions

Until HBEFA3, focus of modelling was set to pollutant emissions. Due to increasing interest on FC / GHG emissions related modelling approaches are actually being further developed

Improvements planned for HBEFA4

- PHEM model
  - Engine FC maps (engine speed, engine power) per engine technology parametrised from engine dyno tests and from literature
  - Possibly higher disaggregation of vehicle categories into segments (e.g. compact car, van etc.). Details to be elaborated
  - Update of simulation data for driving resistances, transmissions and auxiliaries
  - Explicit modelling of electrified vehicles (HEV; PHEV, BEV)
- Possible China specific improvements
  - Adapation of driving cycles
  - Specific parameteristaion of vehicle parameters
  - High shares of AT transmissions with torque converter in China (not relevant for EU) → option to parameterise transmission loss model in PHEM for AT conditions (?)

Timeline CRTEM vs. HBEFA4?

Calibration of CRTEM

Pollutant emissions

1. Accomplishment of further in-use tests in China
    - Chassis dyno
    - PEMS
2. Analysis of measurement data
    - Case 1) Trends CADC urban / road / motorway predicted by existing PHEM data well → only need to adjust overall emission level
    - Case 2) Different emission behaviour detected at Chinese vehicles → processing of instantaneous data into PHEM parameters necessary
3. Analysis of Remote Sensing Data for final calibration of PHEM and /or CRTEM milage functions
4. Special case: “China 6” legislation follows US procedures. Spearate analysis of measurement data necessary anyway!