Airyx

Spin-off from

INSTITUTE OF ENVIRONMENTAL PHYSICS

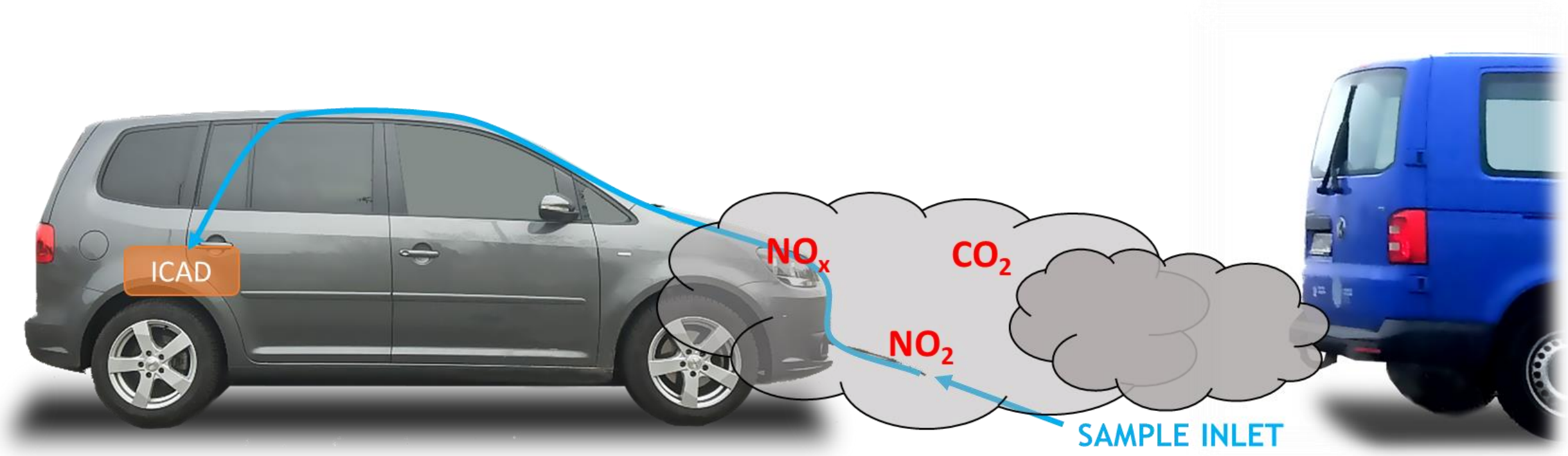
UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

CARES

Recent remote emission sensing measurements by means of the plume chase vehicle technique

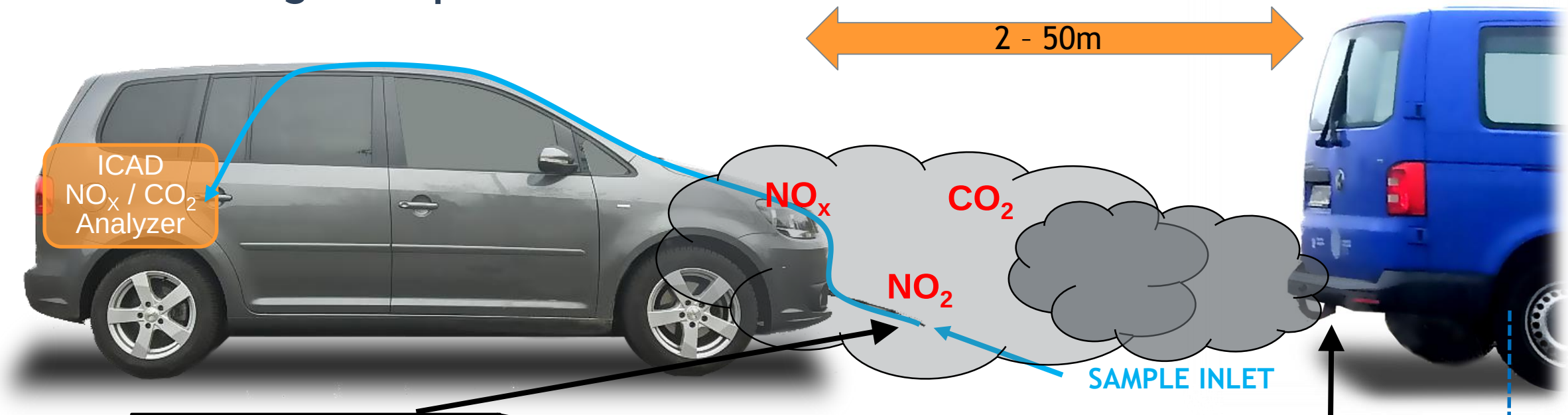
Denis Pöhler et al.

denis.poehler@airyx.de



Plume Chasing Principle

Lau et al. 2015



measured concentration

C^M_{NOx} & C^M_{CO2}

Correct background

$$E_R = \frac{C^M_{NOx} - C^{BG}_{NOx}}{C^M_{CO2} - C^{BG}_{CO2}}$$

dilution

Ratio E_R is constant
(background (BG) corrected)

concentration at exhaust

C^E_{NOx} & C^E_{CO2}

with

$$E_R = \frac{C^E_{NOx}}{C^E_{CO2}}$$

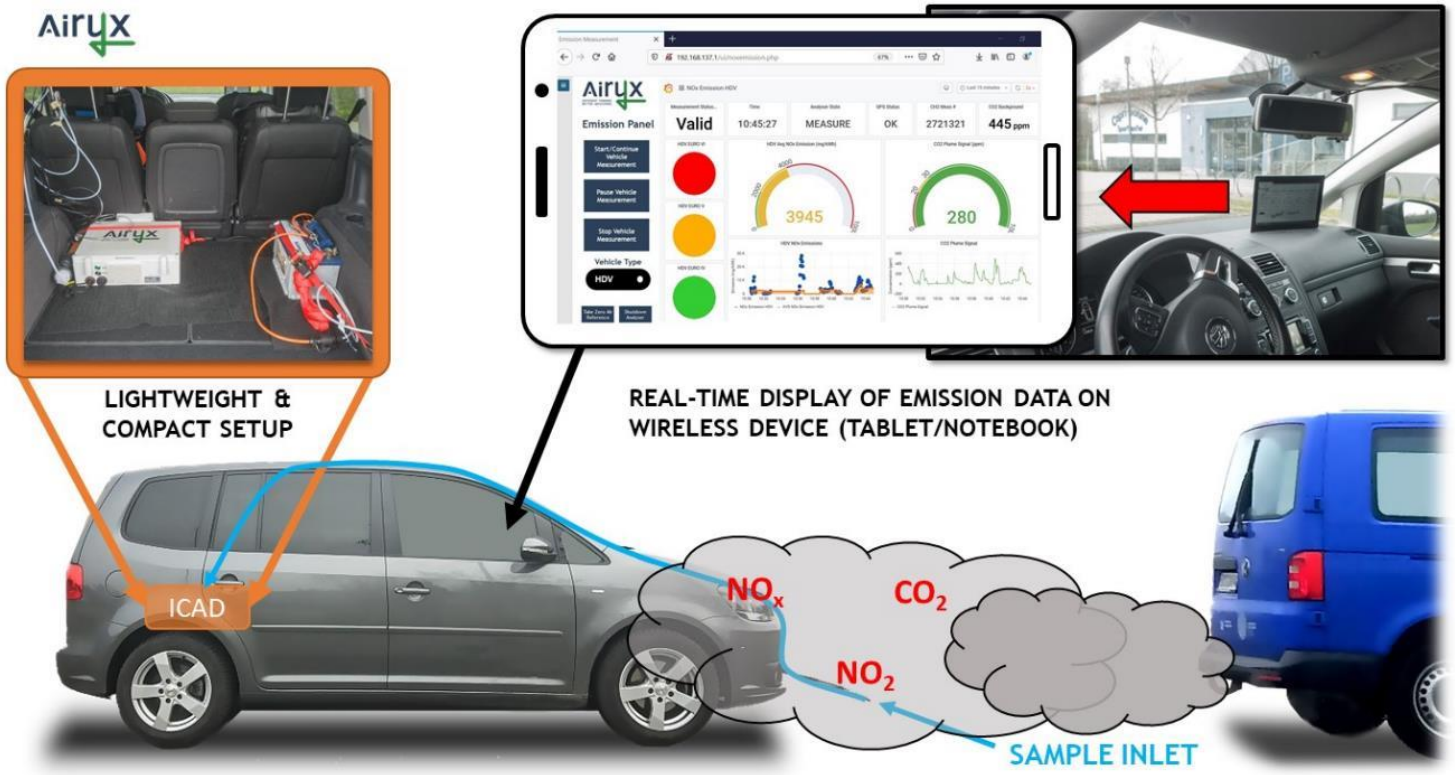
Calculate (average) NO_x Emission

Emission CO_2
(„known“, e.g. CO_2 per kWh)

Features & Simplified Plume Chasing System (NO_x)

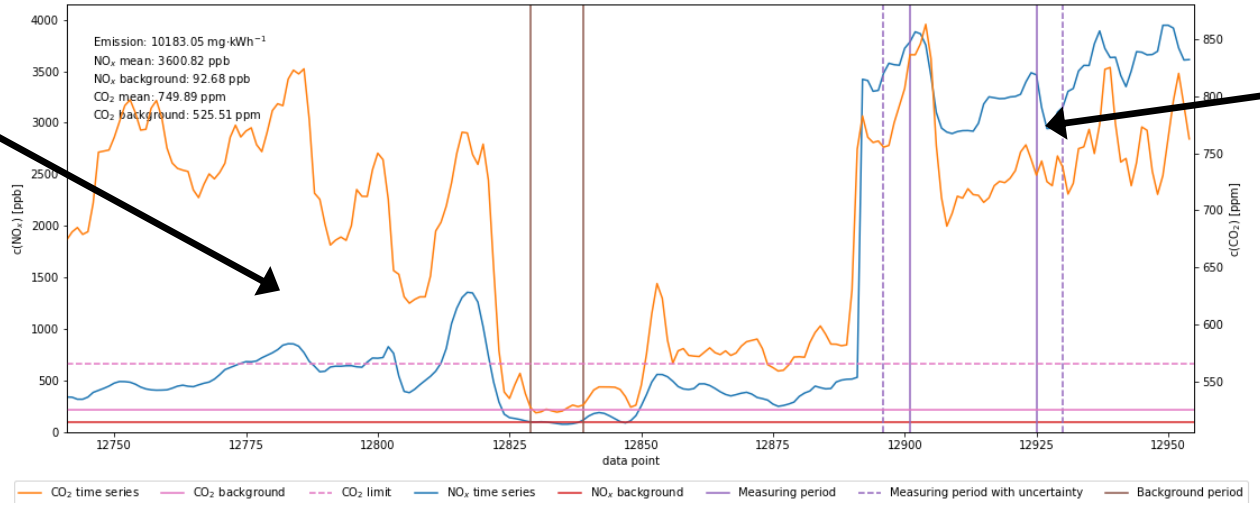
- Indirect emission measurement like for “classic” open path remote sensing
- No installation on the measured vehicle or stationary needed
- Measurements can be made over longer time periods (e.g. minutes) to derive a „representative“ emission value → ideal to identify high emitters
- Interferences from other emissions (other vehicles) can influence observed values
- Focus so far on NO_x

- New technologies (allow now much simpler plume chasing setups
- Automate measurements for users → direct emission results



Emission Calculation “Plume Chasing”

avg. 1.824 mg / kWh



Avg. 10.183 mg / kWh

- C_{NOx}^{M} & C_{CO2}^{M} in the emission plume (1 -10 min)
- C_{NOx}^{BG} & C_{CO2}^{BG} background (typ. before plume measurement)
- ΔCO_2 – threshold to identify plume: e.g. 30ppm
- Derive average $\overline{\Delta NO_X}$ & $\overline{\Delta CO_2}$ → average ratio

Calculate **average** emission factor:

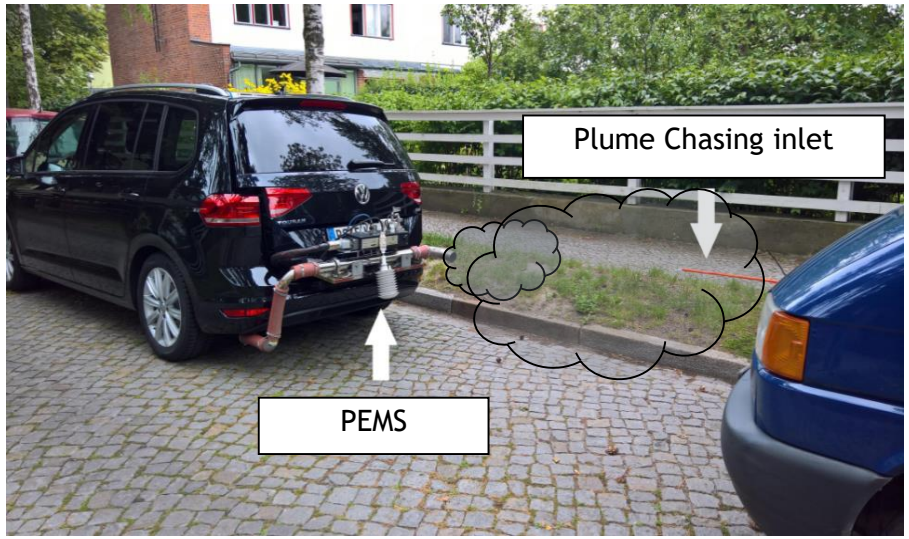
- HDV: NO_x (mg/kWh) with engine efficiency (μ) 40%
- LDV: NO_x (mg/km) with measured or estimated fuel consumption

$$E(NO_2) = E_R \cdot \frac{E(CO_2)}{k} = E_R \cdot \frac{E(CO_2)}{k} = E_R \cdot \frac{E(CO_2) \cdot V_{mol} \cdot 10^6 \cdot ppm}{M_{mol}(CO_2)}$$

$$E(NO_2) = E_R \cdot \frac{E_L(CO_2) \cdot V_{mol} \cdot 10^6 \cdot ppm}{M_{mol}(CO_2) \cdot \mu \cdot BW(Diesel) \cdot \rho(Diesel)}$$

Validation - LDV

A project with: Deutsche Umwelthilfe



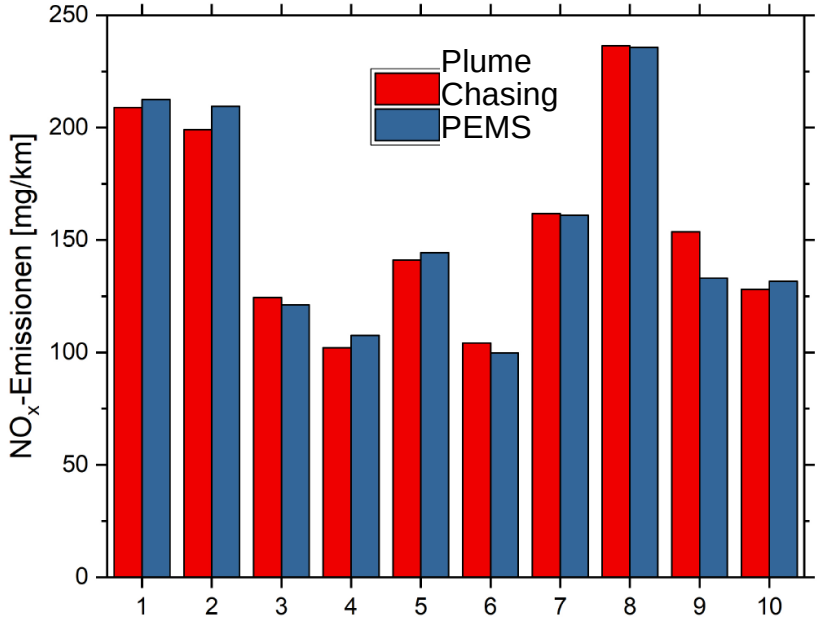
EURO 6: VW Touran TDI (& Skoda Octavia TDI)

- Compare PEMS with Plume Chasing EURO 6 Diesel
- Complete RDE test cycle in Berlin
- Mostly low traffic density

Very good agreement

~ 10mg/km

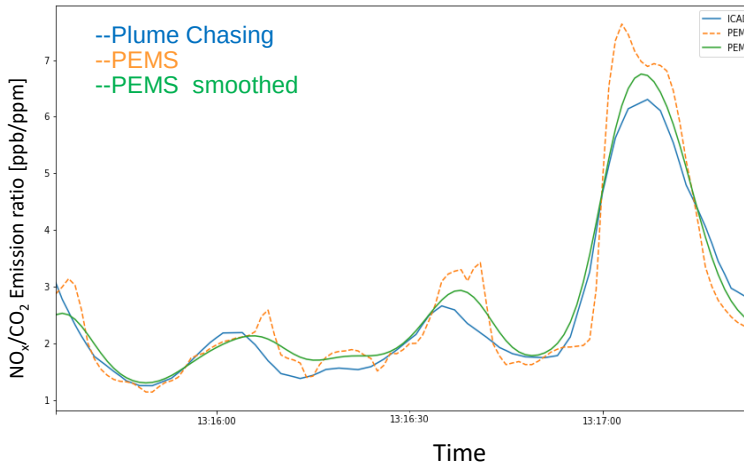
~ 5% (for EURO 6)

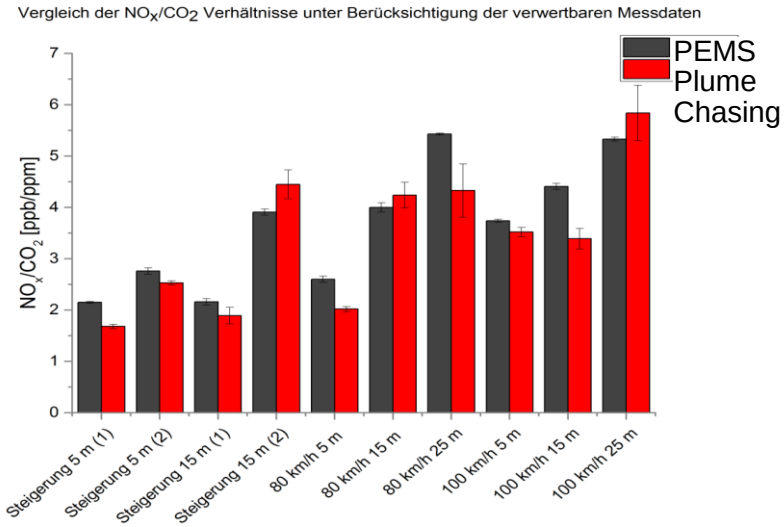


Short term measurements (1 - 2 min)

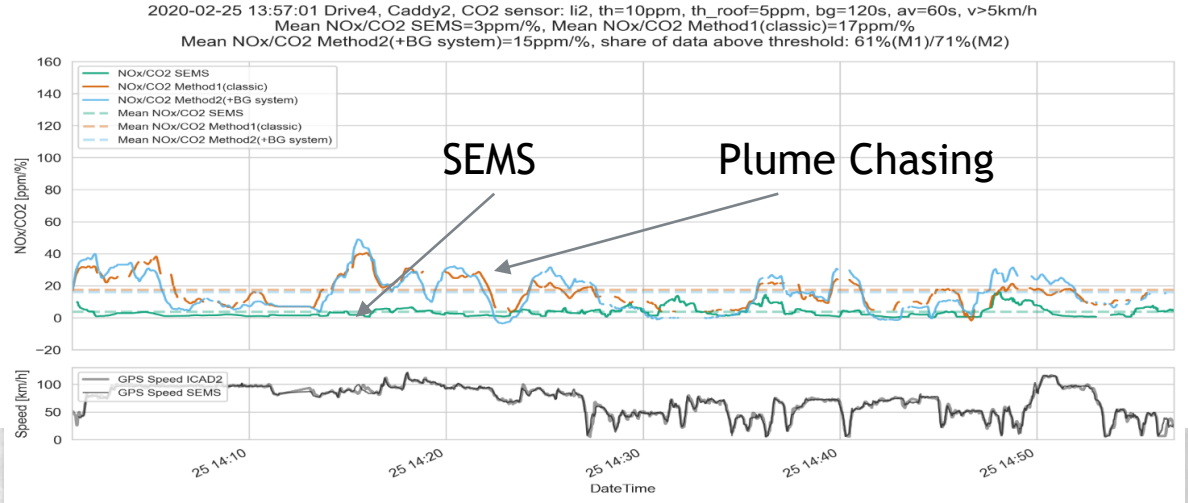
@ without other traffic

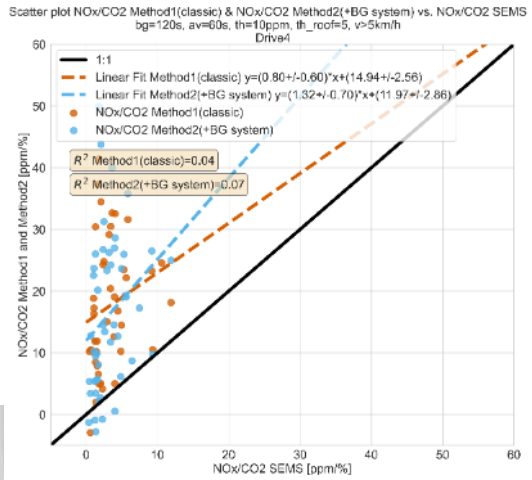
- Vary distance and speed
- Also good agreement





Low Emitter Measurements @ High Traffic Density



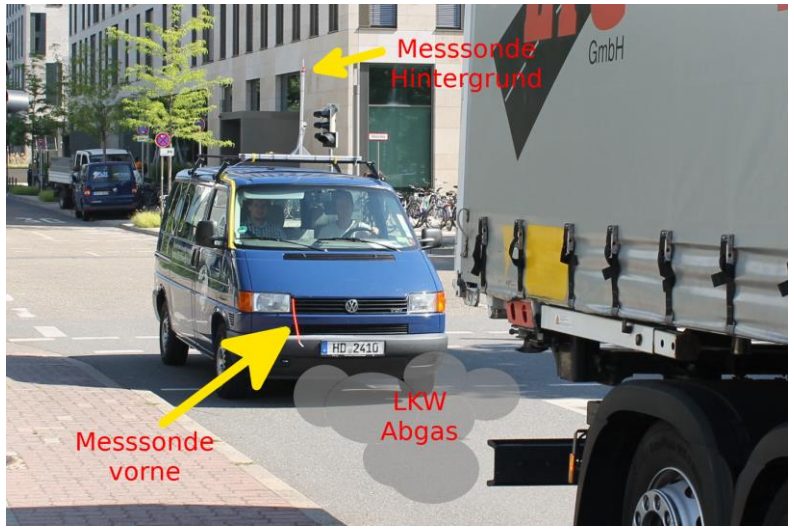


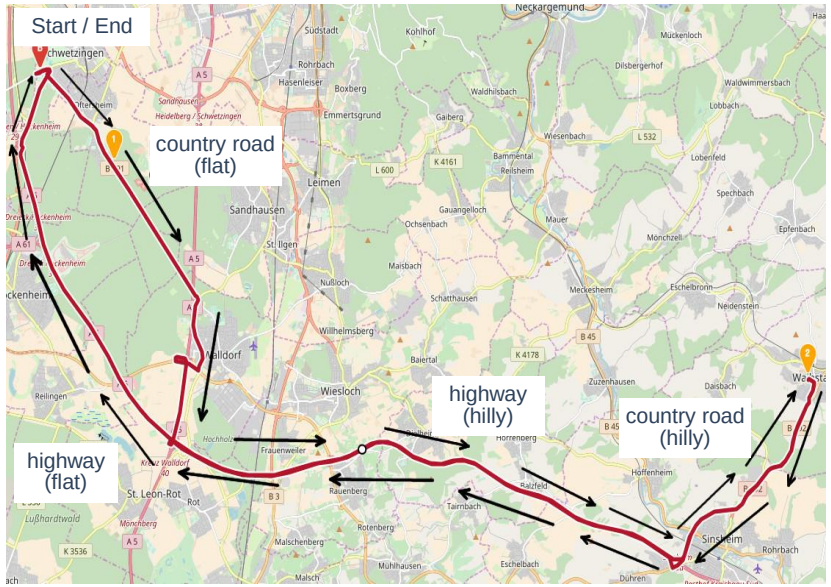
- Weak plume signal due to:
  - sub optimal sampling position
  - strong winds
- Weak signal requires low CO_2 threshold → large errors
- High traffic load cause large interference
- Other vehicles have higher emission ratios
  → cause overestimation

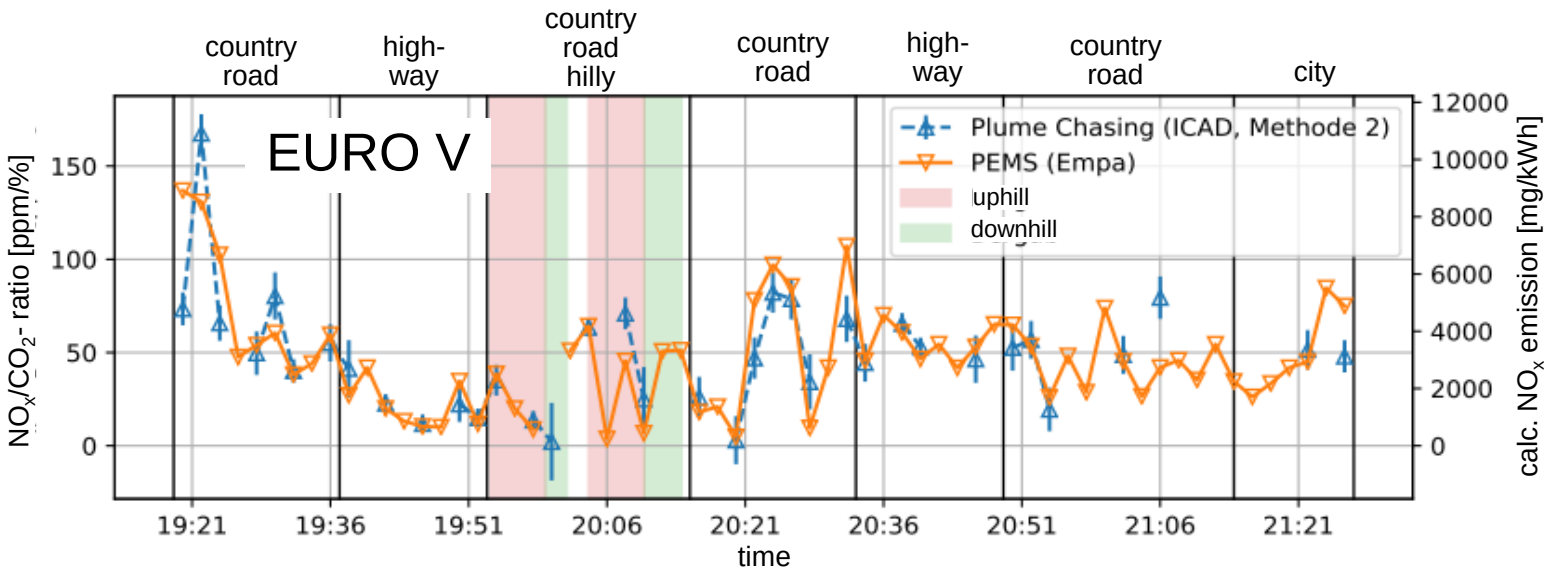
→ Optimization needed

Validation - HDV

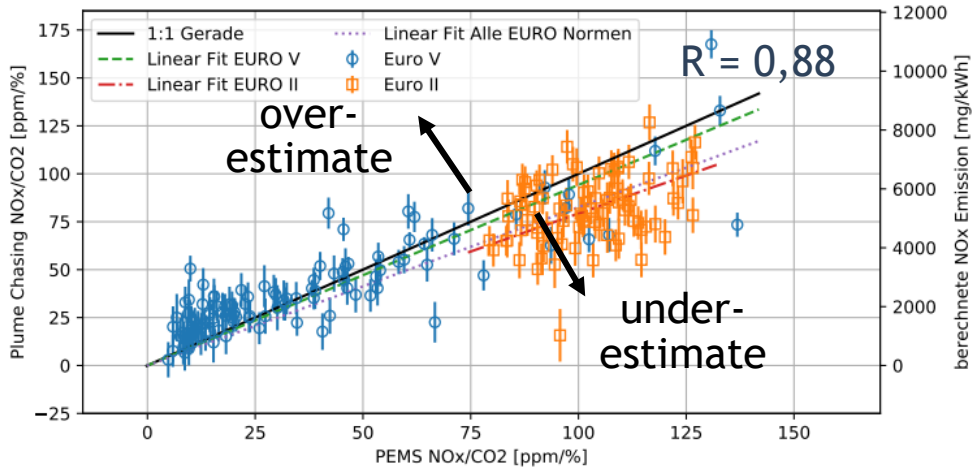
Project from: BAFU (CH) in cooperation with EMPA & Camion Pro e.V.







Correlation EURO V & II



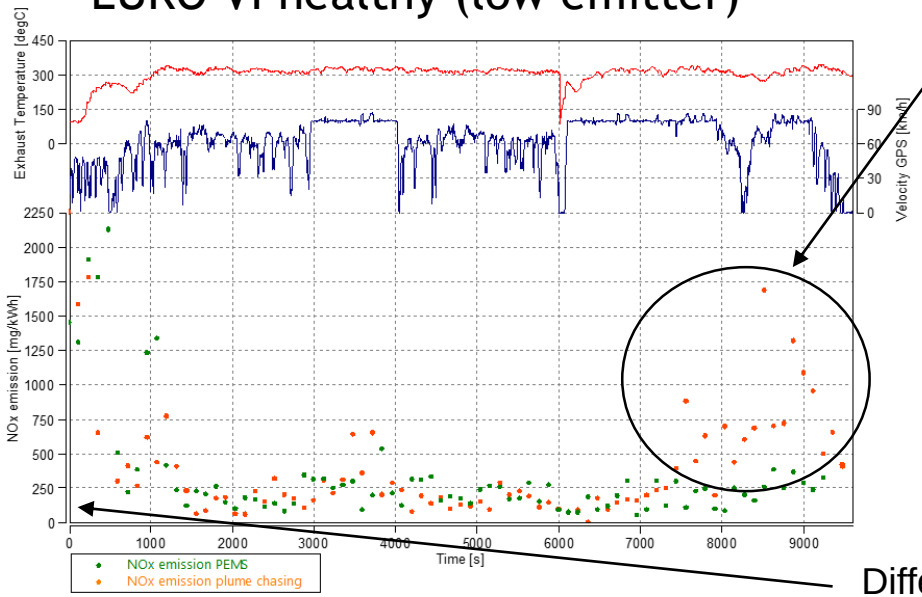
EURO V, II
Compare 2 min. data
NO_x / CO_2 ratios

Validation HDV by AVL Sweden (for FSTYR Denmark)

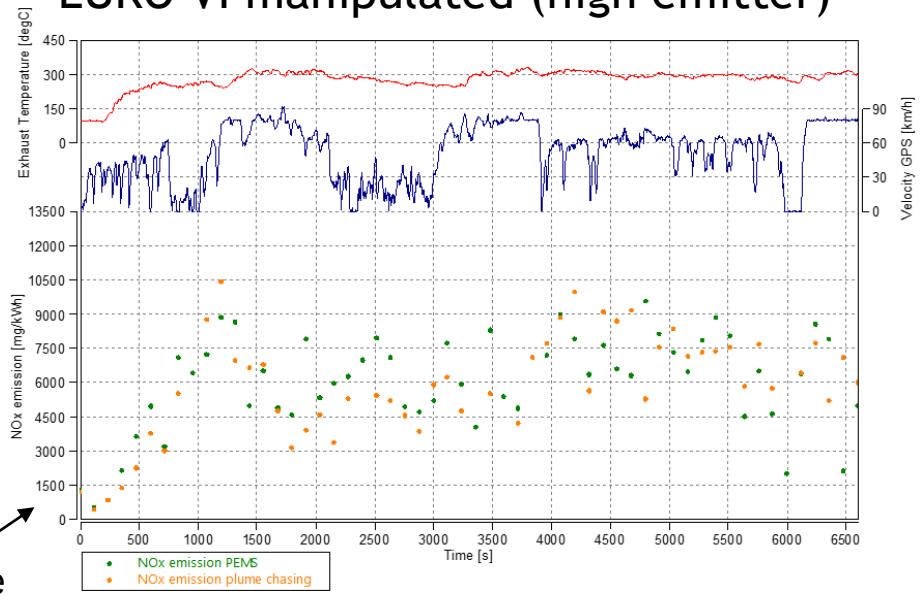
Janssen and Hagberg 2020

- Plume Chasing & PEMS agree well (especially rural & highway)
- No influence from rain, wet roads and fog observed
- Low and high emitter clearly separated for rural and highway
- Low emitter is overestimated in urban area with high traffic density (incl. traffic jam)

EURO VI healthy (low emitter)



EURO VI manipulated (high emitter)



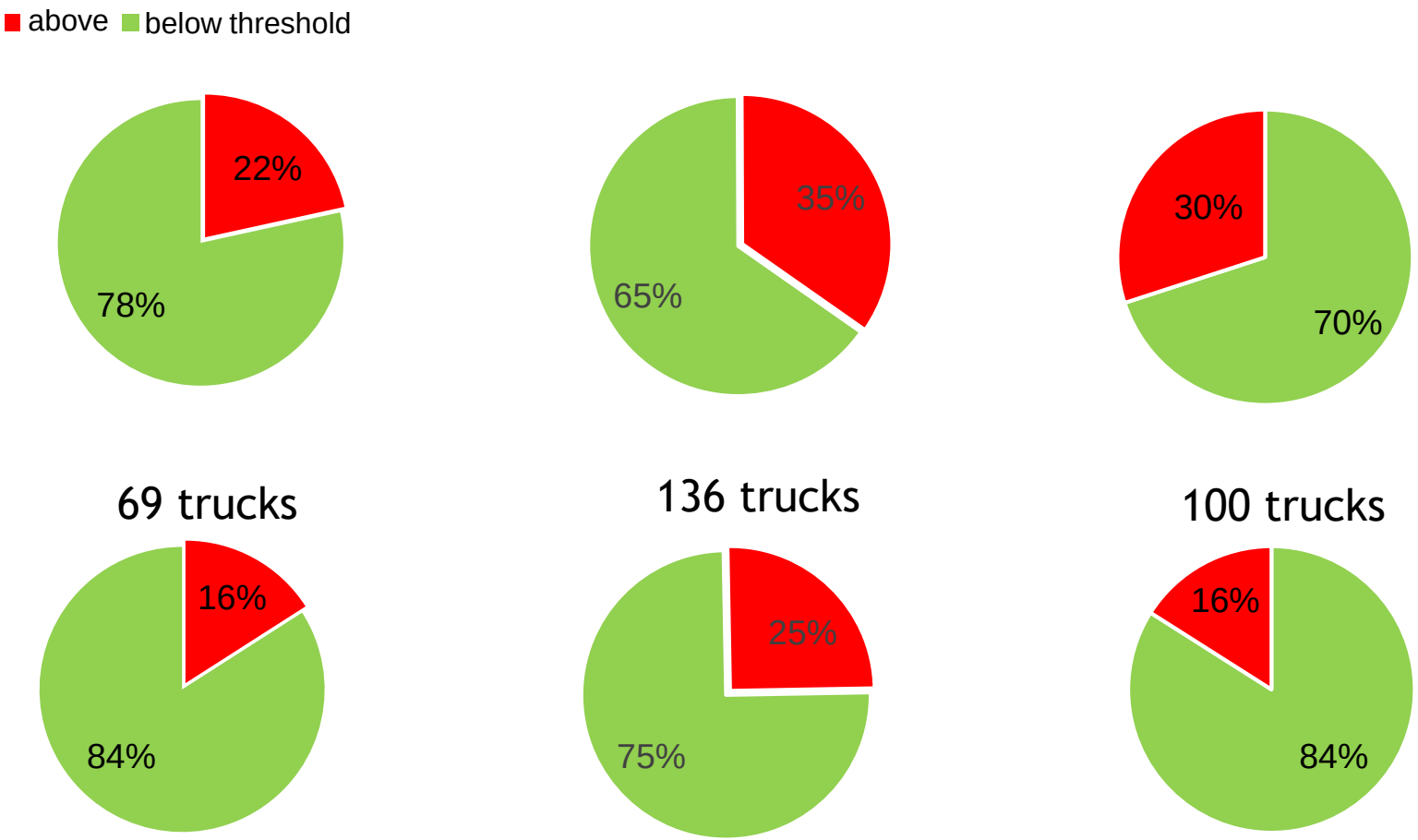
Different scale

HDV High Emitter Studies (on highways)

Quelle: Manfred Steinbach / Fotolia; Umweltbundesamt: https://www.umweltbundesamt.de/themen/verkehr-laerm/nachhaltige-mobilitaet/gueterverkehr

Overview High Emitter HDV Studies

	2016 - D	2018 - CH	2019 - D
EURO V threshold 3000mg/kWh	102 trucks	46 trucks	40 trucks
EURO VI threshold 1400mg/kWh	69 trucks	136 trucks	100 trucks



- Affected are EURO V & EURO VI all brands
- Mostly trucks from east and south Europe
- Correlation of high emitters with specific shipping companies observed

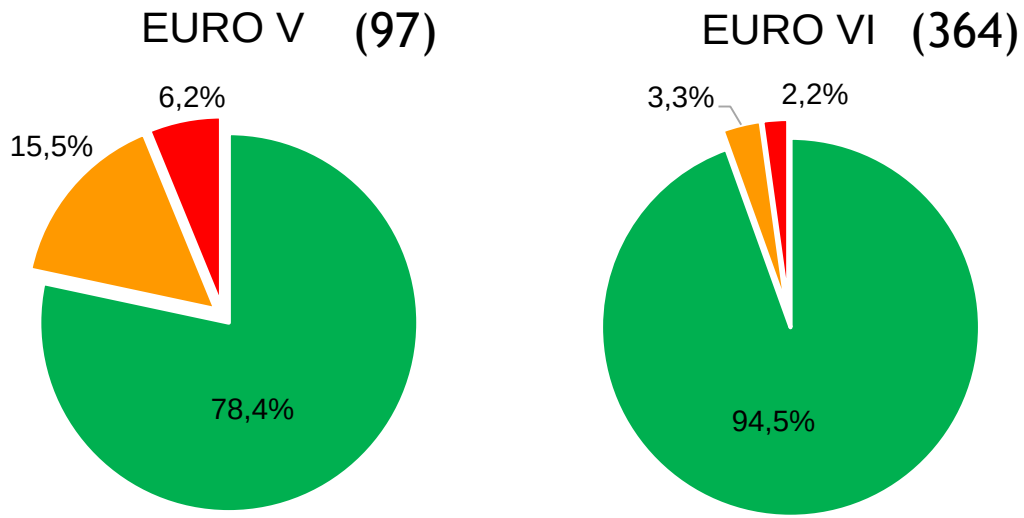
HDV High Emitter Study by Danish FSTYR & Police (09/10-2020)

- Measurement and operation by authority (instrument, training and support by Airyx)
- Emissions of 478 HDV studied (within 2 weeks)
- Suspicious & high emitters directly inspected by Police

https://www.fstyr.dk/da/-/media/FSTYR-lister/Publikationer/ReportDenmark2020v101.pdf

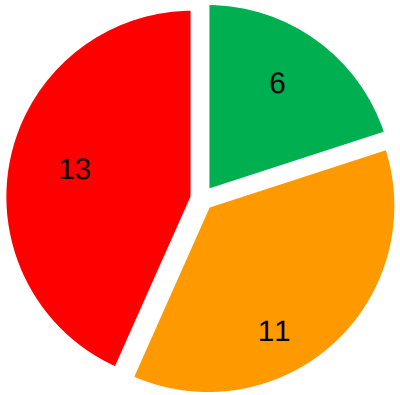
Plume Chasing in Danish authority car

	EURO III	EURO IV	EURO V	EURO VI
Classification	mg/kWh	mg/kWh	mg/kWh	mg/kWh
low (up to)	<6000	<4500	<3000	<1400
suspicious (up to)	<7000	<5500	<4000	<2400
high (above)	>7000	>5500	>4000	>2400
EURO emission limit	<5000	<3500	<2000	<460
RDE conformity factor				1,5



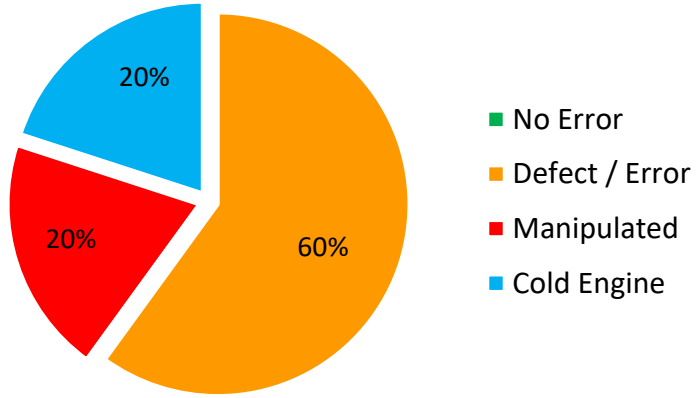
Inspection by Police

Emissions of inspected HDV - all



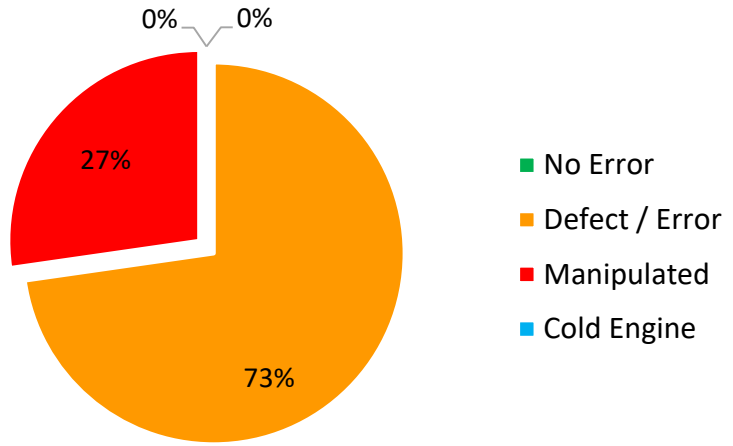
- For all inspected vehicles a reason for high emissions found (also ones slightly below threshold)
- 100% hit rate
  0% false positive (No Error)

Conclusion Inspection - EURO V

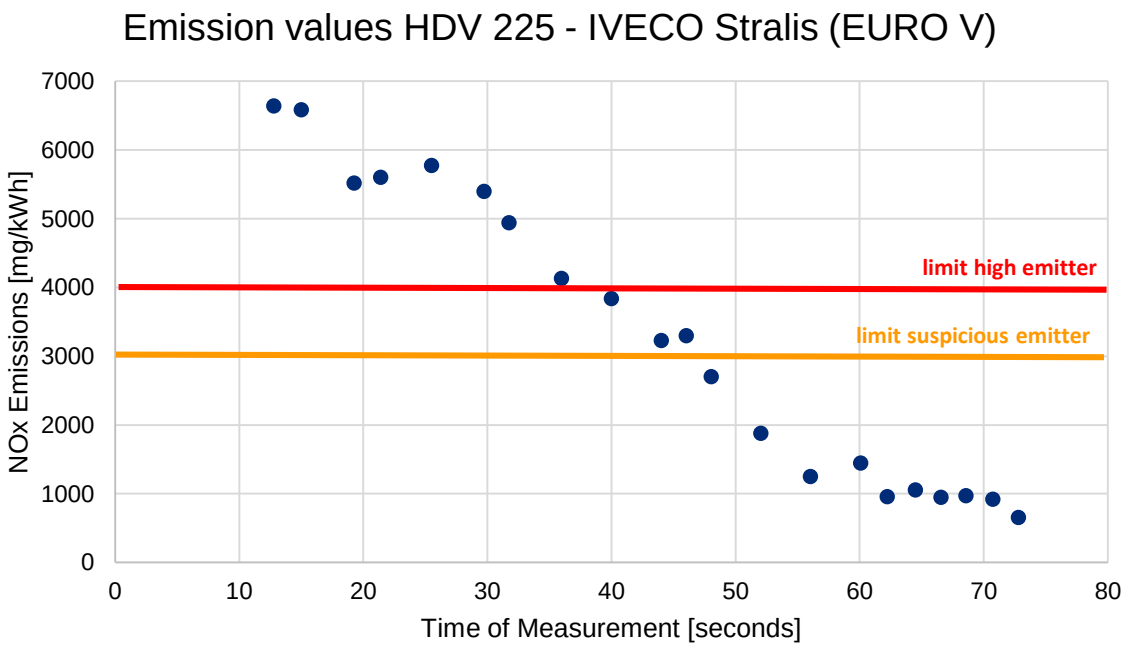


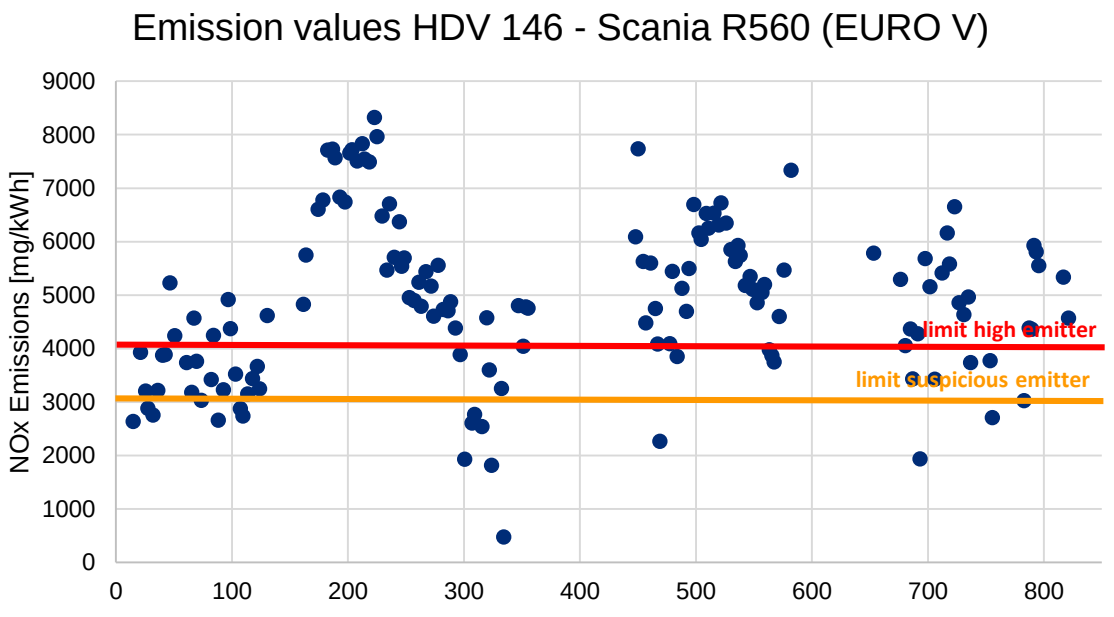
Excluding vehicles with expected cold engine

Conclusion Inspection - EURO VI



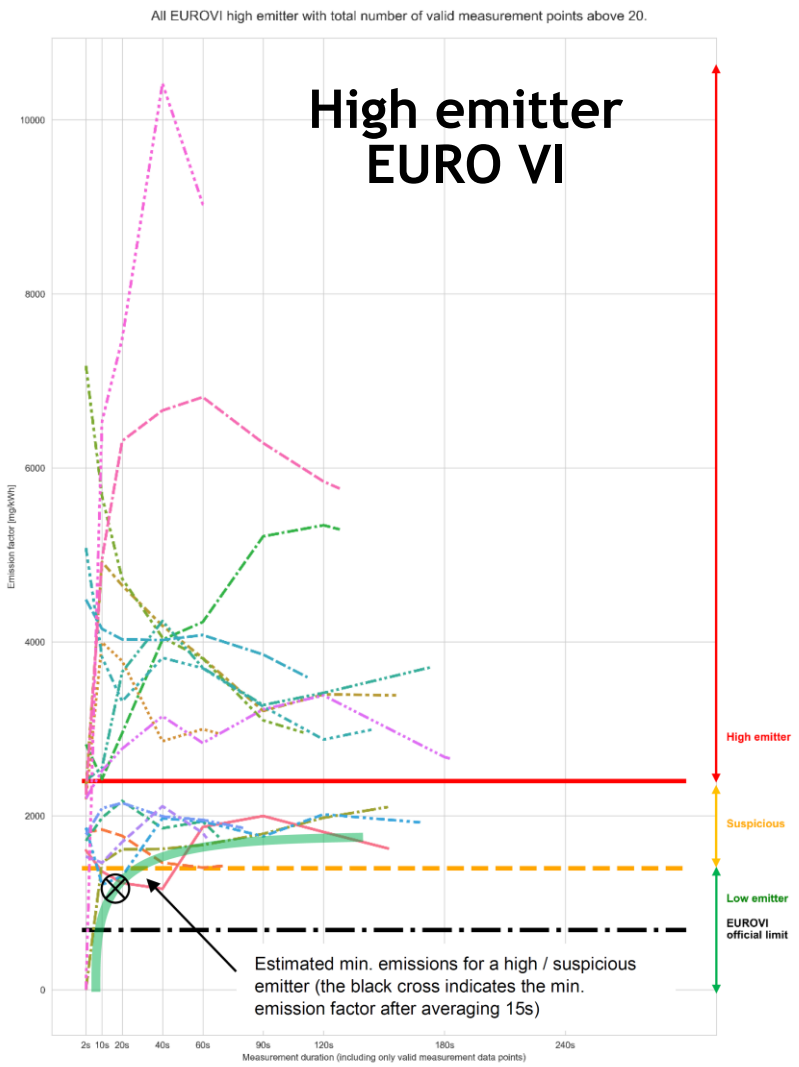
Engine Warmup & Long Term Cold Engines

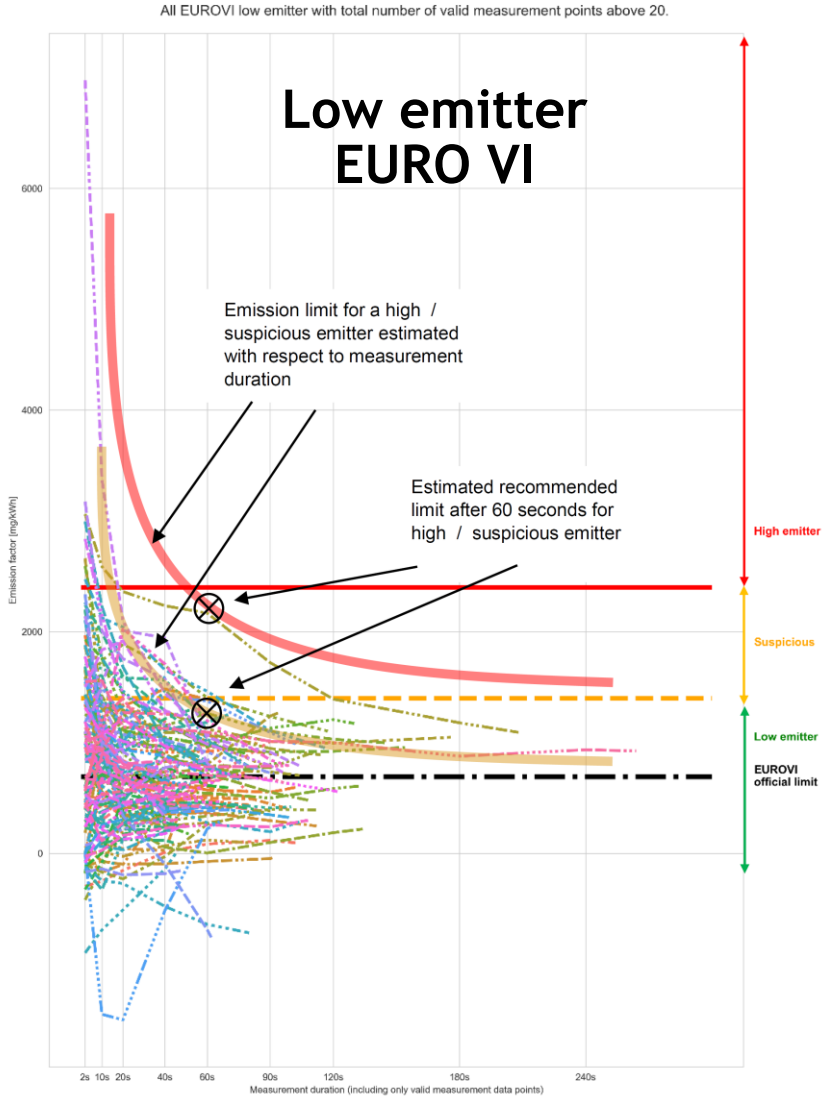




- Reducing emissions with engine warm up regularly observed
- Some EURO V never warm up
  → low load & large engine

Optimizing Measurement Time and Thresholds to Identify High Emitters





	EURO V recommended	EURO VI recommended
Classification	mg/kWh	mg/kWh
low	≤2.500	≤1.200
suspicious	>2.500	>1.200
high	>3.500	>2.200
Measurement duration for a valid emission classification of a high and suspicious emitter (equivalent to # data points)	**60** (30)	**60** (30)
Measurement duration for a preliminary emission classification to exclude a high emitter (equivalent to # data points)	**15** (7 -8)	**15** (7 -8)

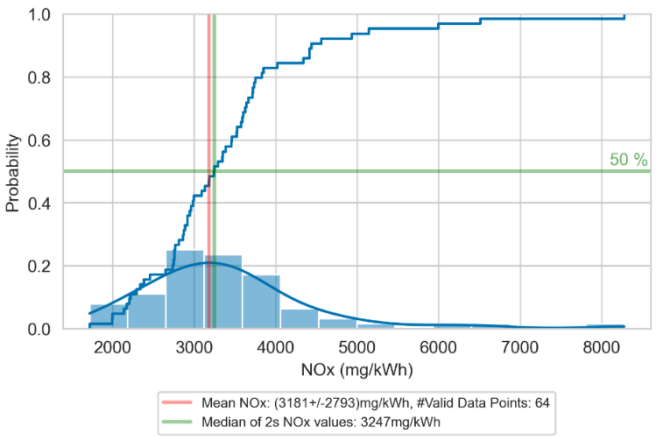
NOx Emissions City Busses Reutlingen, Germany

Conclusion

- Plume Chasing allow relatively simple NO_x emission investigations of individual vehicles (longer measurement time is essential for the individual RDE value)
- Good agreement to PEMS for most measurement conditions
- Study vehicle fleet is possible
- New developments allow direct application by authorities
- Detection of manipulated / defective NO_x emission systems work reliable for HDV
  - Rate of high HDV emitters : 5.5 - 35% (much higher than rate from inspections)
  - Affected are EURO V and EURO VI , all brands
- LDV measurements work, especially high emitter detection, but more influenced by interferences

Research Questions / Outlook

- **Extension for particles and other gases (NH_3, …)**
- Optimise setup and automated software, standard data product
- Compare different data analysis approaches
- **Reduce interferences, automated contamination flagging**
- **Derive statistical data on amount of high emitters in Europe**
- **Combine field measurements with inspections to validate high & suspicious emitters (risk false identification with low thresholds)**
- Under which circumstances plume chasing emission values can be used for emission inventory (HBEFA)?
- Model excess NOx emissions due to manipulations / defects
- More plume chasing statistical data of correct working vehicles (not focus only on high emitters)
- **Study applications to other sources: construction machinery, ships, …**



THANK YOU

Literature

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