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ARISTOTLE UNIVERSITY THESSALONIKI
SCHOOL OF ENGINEERING
DEPT. OF MECHANICAL ENGINEERING

Evaluation of a miniaturized exhaust emission measuring system using an optoacoustic BC sensor and low-cost ambient sensors

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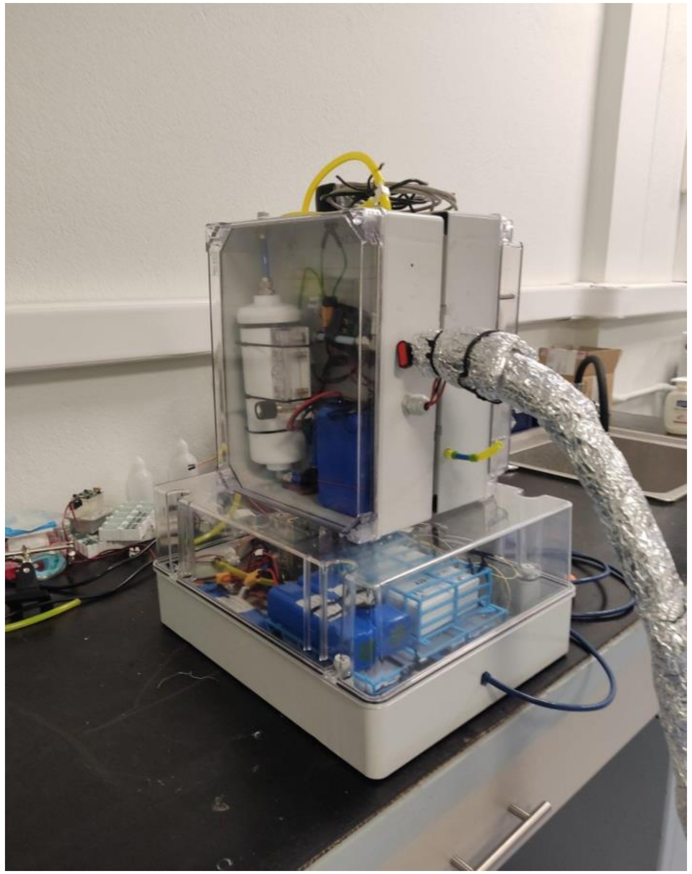
Objective

Evaluation of a miniaturized exhaust emission measuring system in real-world driving conditions using a PEMS device as reference



The new device

On-road measurement setup

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Background

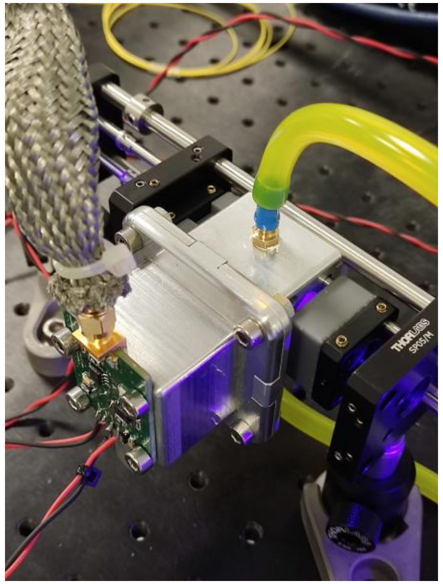
- PEMS were developed for type-approval of vehicles, as current regulations worldwide demand
- Assessing vehicle performance in on-road tests during their lifetime is also a main concern
- The major **limitations** regarding **PEMS** use beyond type approval are:
  - High **cost** of purchase (>150000 €) and use
  - High **energy consumption**
  - Long **installation time** needed
  - Can not be installed on small vehicles (heavy and bulky)
  - Only regulated pollutants can be measured
- There is a need to **develop low-cost emission measuring devices** for on board vehicle applications for large scale testing beyond type-approval!

PEMS system in use

BC optoacoustic sensor (1)

Design Parameters

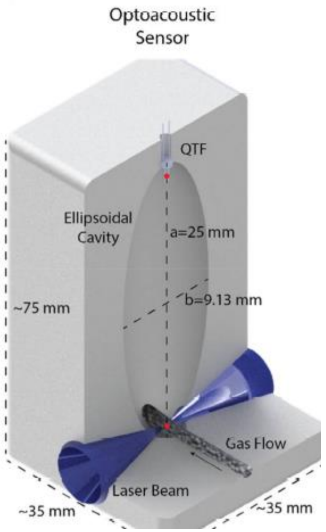
- Low-cost commercial Laser Diode (LD)
- Sensitive Quartz Tuning Fork (QTF) for sound detection
- Compact optical assembly

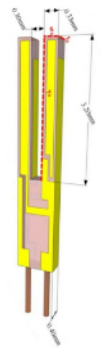


Key innovation

Innovative Ellipsoidal Sensor Chamber:

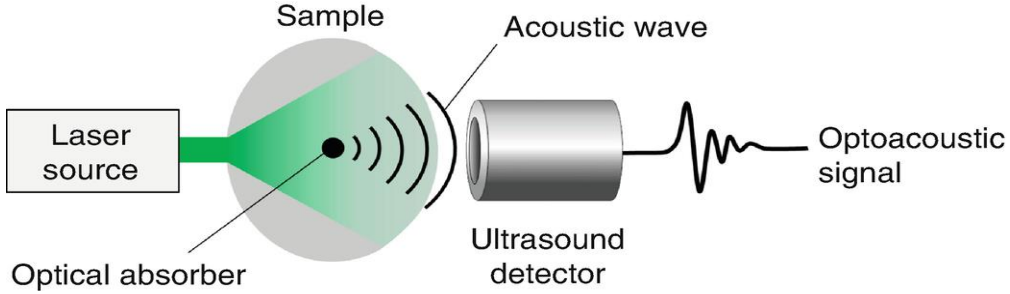
- No resonator
- High sensitivity
- No contamination





Basic Theory

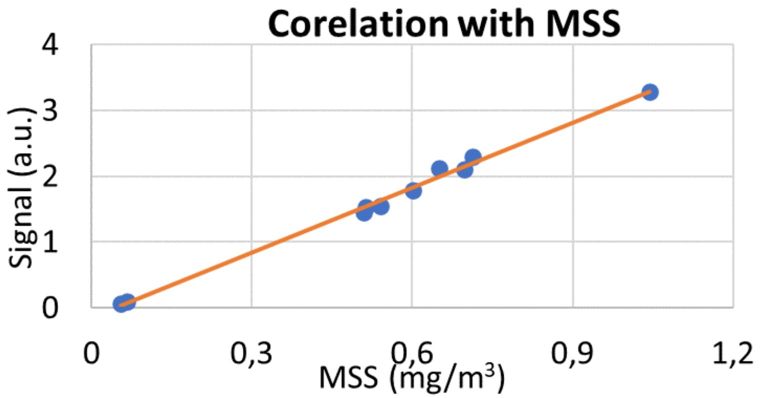
Optoacoustics (OA) is a reliable method for BC detection



Characterization

Very good correlation with a lab grade gold-standard instrument for BC (AVL MSS)

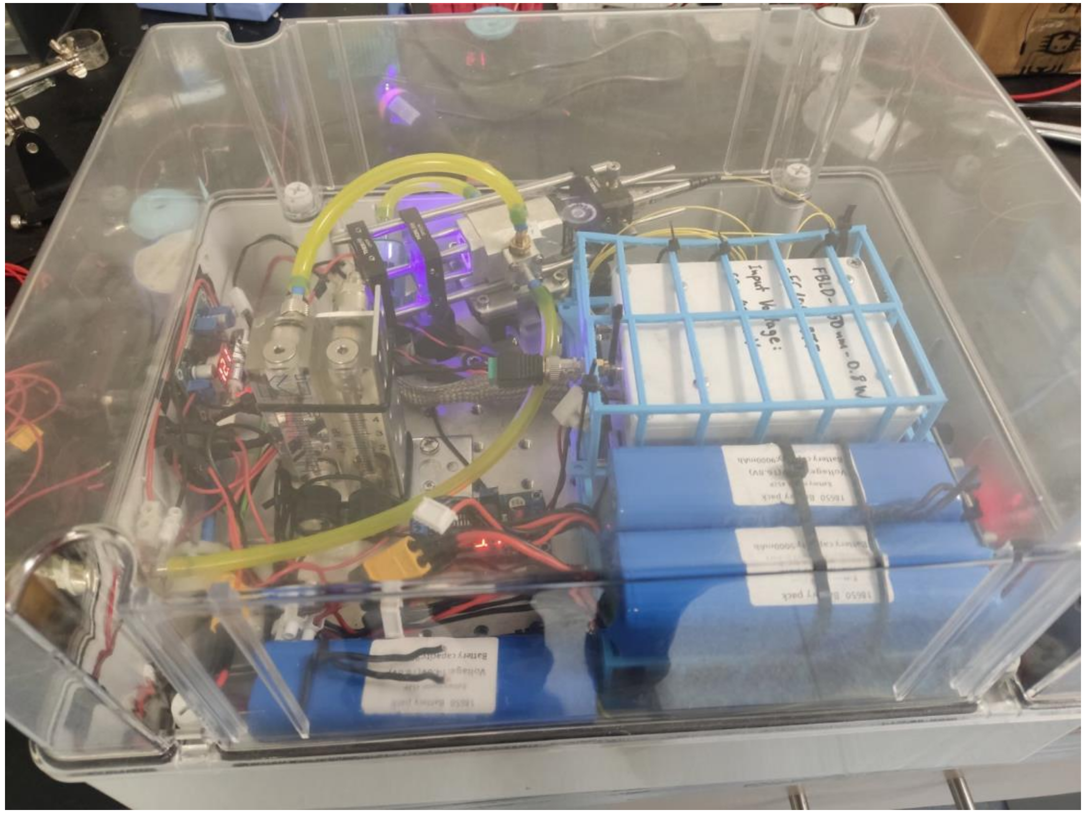
Sensitivity: 2 µg/m³



BC optoacoustic sensor (2)

- Based on laser-diodes, available in different wavelenghts, depending on application
- It has been successfully tested in the lab under ***various environmental conditions (T,RH)*** and on-board two ***ship-campaigns***
- This is the first ***portable battery-powered*** version

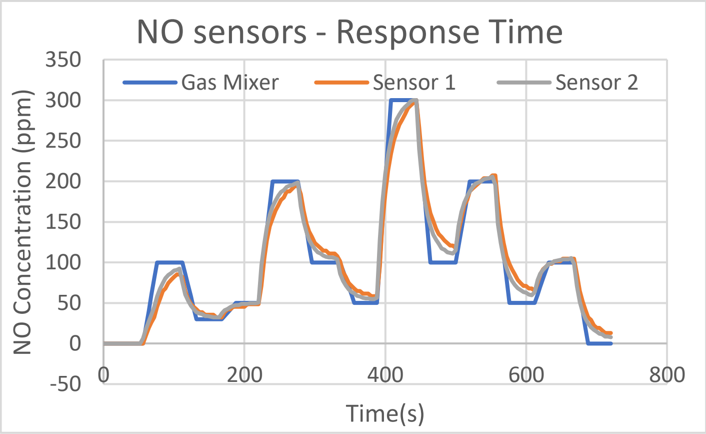
	Current version	Potential
Weight	5 kg	2 kg
Dimensions	38x30x18 cm^3	20x20x10 cm^3
Manufacturing Cost	5000 €	1500 €

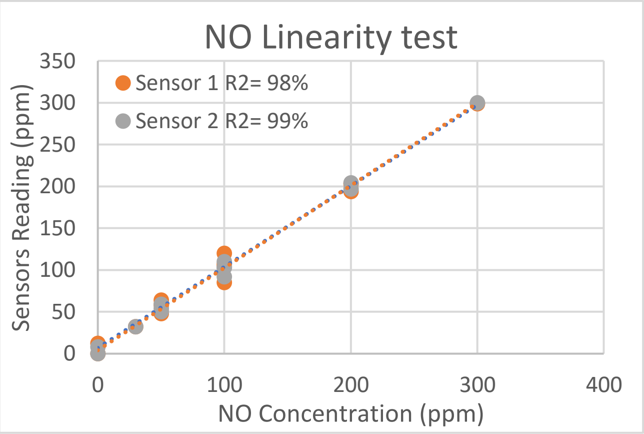


Portable BC Sensor configuration

Emiscout SEMS (1)

- Simple Emissions Measurement System (SEMS)
- Capable of measuring CO_2, CO and NO emissions using electrochemical and NDIR sensors
- The sensors were exposed to predetermined gas concentrations in the laboratory to evaluate their:
  - Sensitivity
  - Response time
  - Linearity
  - Repeatability
  - Cross sensitivity with other gases





Indicative results for sensor selection procedure

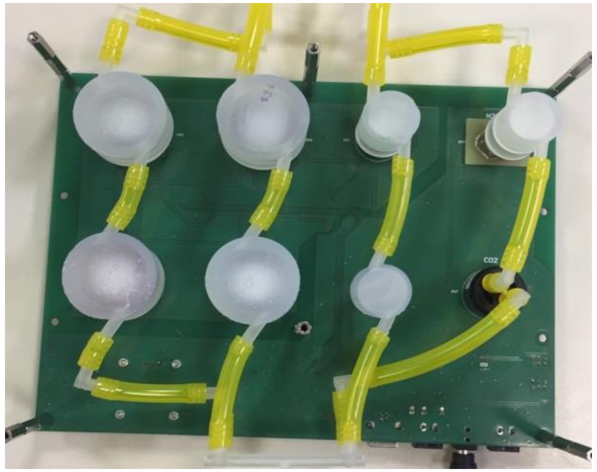
Detection Gas	Technology Used	Measurement Range	$T_{0\text{-}90}$ (s)	Resolution (ppm)
CO_2	NDIR	0-20 %	2-3	<70
CO	Electrochemical	0-5000 ppm	20-30	<0.5
NO	Electrochemical	0-500 ppm	5-10	<0.3

Gas sensors specifications

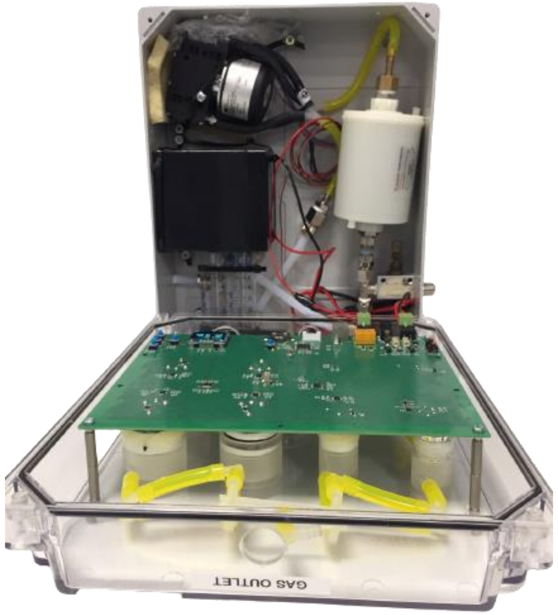
Emiscout SEMS (2)

Proprietary correction equations were formed to quantify the effects of:

- ❑ Temperature
- ❑ Relative Humidity
- ❑ Interference with other gases



Electronic sensor board



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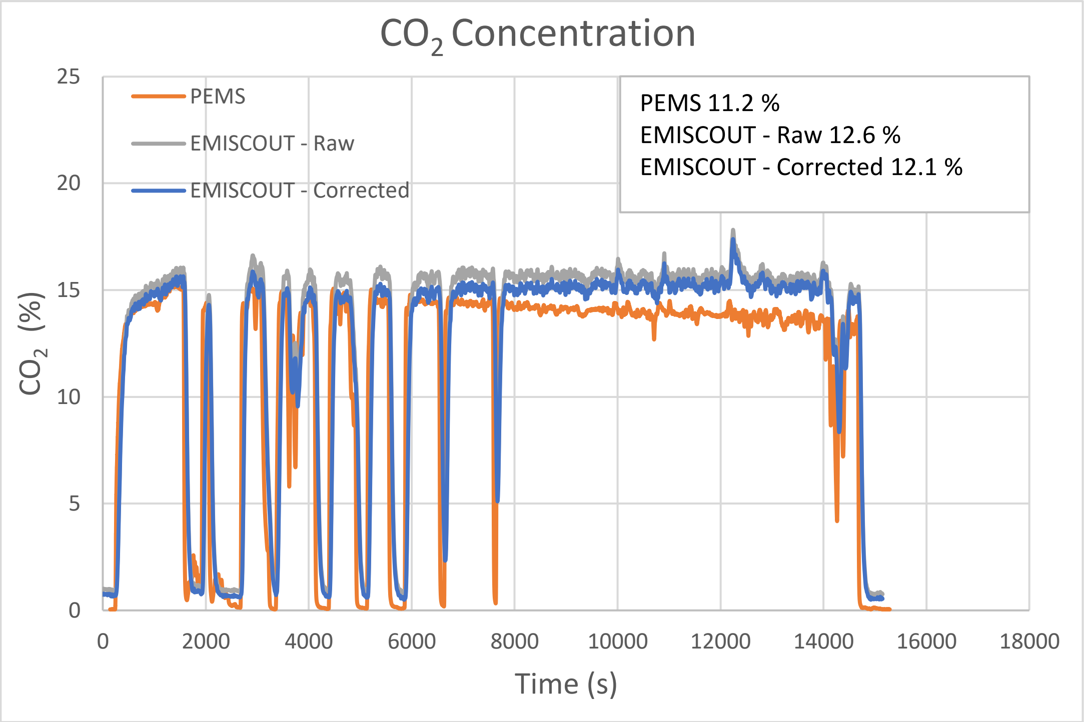


Comparison between raw and corrected CO_2 signal

Deviation decreased from 11.7 % to 7.4 %!

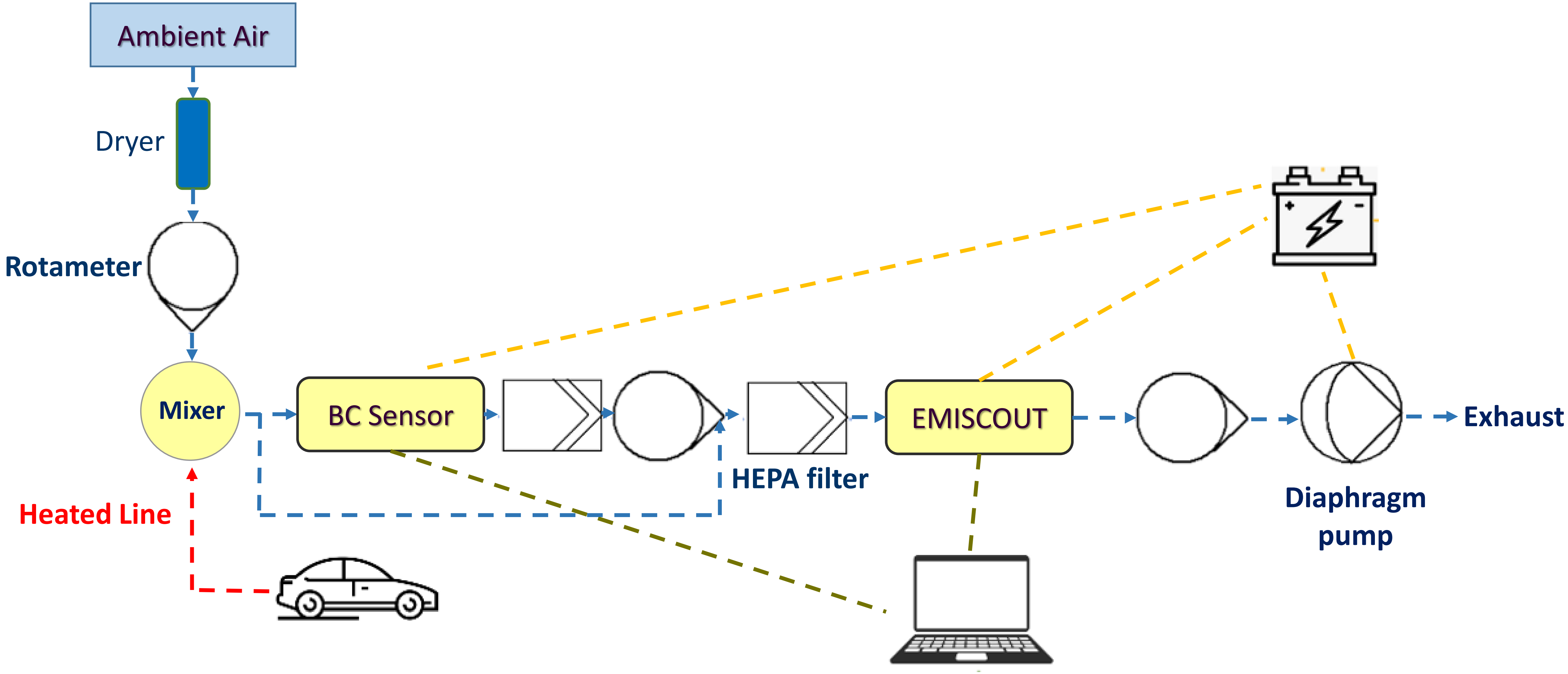
Sampling methodology

- A custom heated line was used to avoid water condensation (70° C)
- A battery was used exclusively for the heated line
- A dilution ratio of 3.5:1 was used after the heated line. The diluted sample was distributed to the two devices

Dilution Unit

Exhaust pipe and heated line

Experimental layout



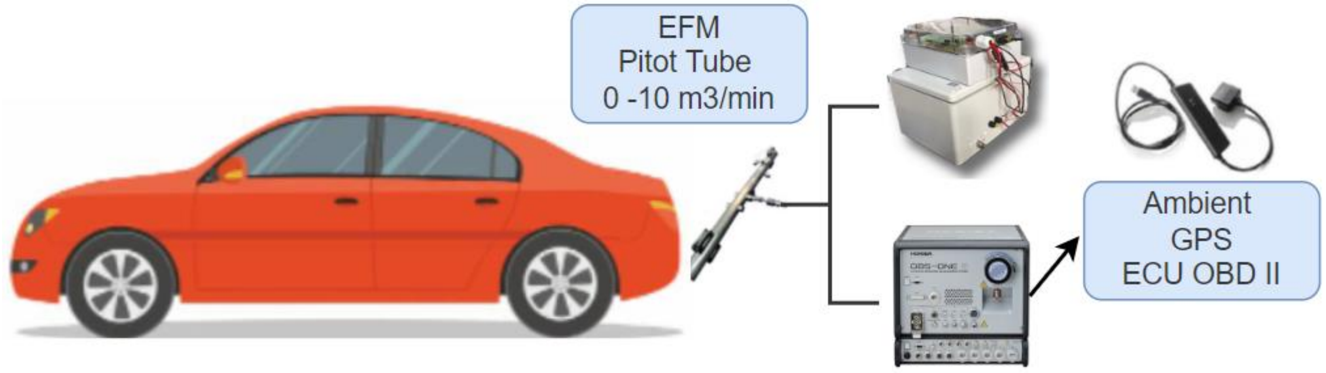
On road experiments - Overview

Objective: performance assessment under real-driving conditions

- Pollutants measured: (**BC, CO_2, CO, NO**)
- Various routes and driving styles were tested

Trip	Duration (Km)	Average Speed (Km/h)	Route	Driving style
Diavata	26.4	22.6	Urban-Rural-Motorway	Smooth
Thermi_1	31	39.5	Urban-Motorway	RDE Compliant
Hortiatis_1	30.8	36.7	Rural-Motorway	Smooth
Thermi_2	27.9	33.5	Urban-Motorway	RDE Compliant
Hortiatis_2	29.9	37.1	Rural-Motorway	Aggressive
Thermi_3	35.8	51.9	Urban-Motorway	RDE Compliant
Thermi_4	28	32.5	Urban-Motorway	RDE Compliant
Diavata_short	22.4	35.1	Urban-Rural-Motorway	RDE Compliant

On-road trips parameters

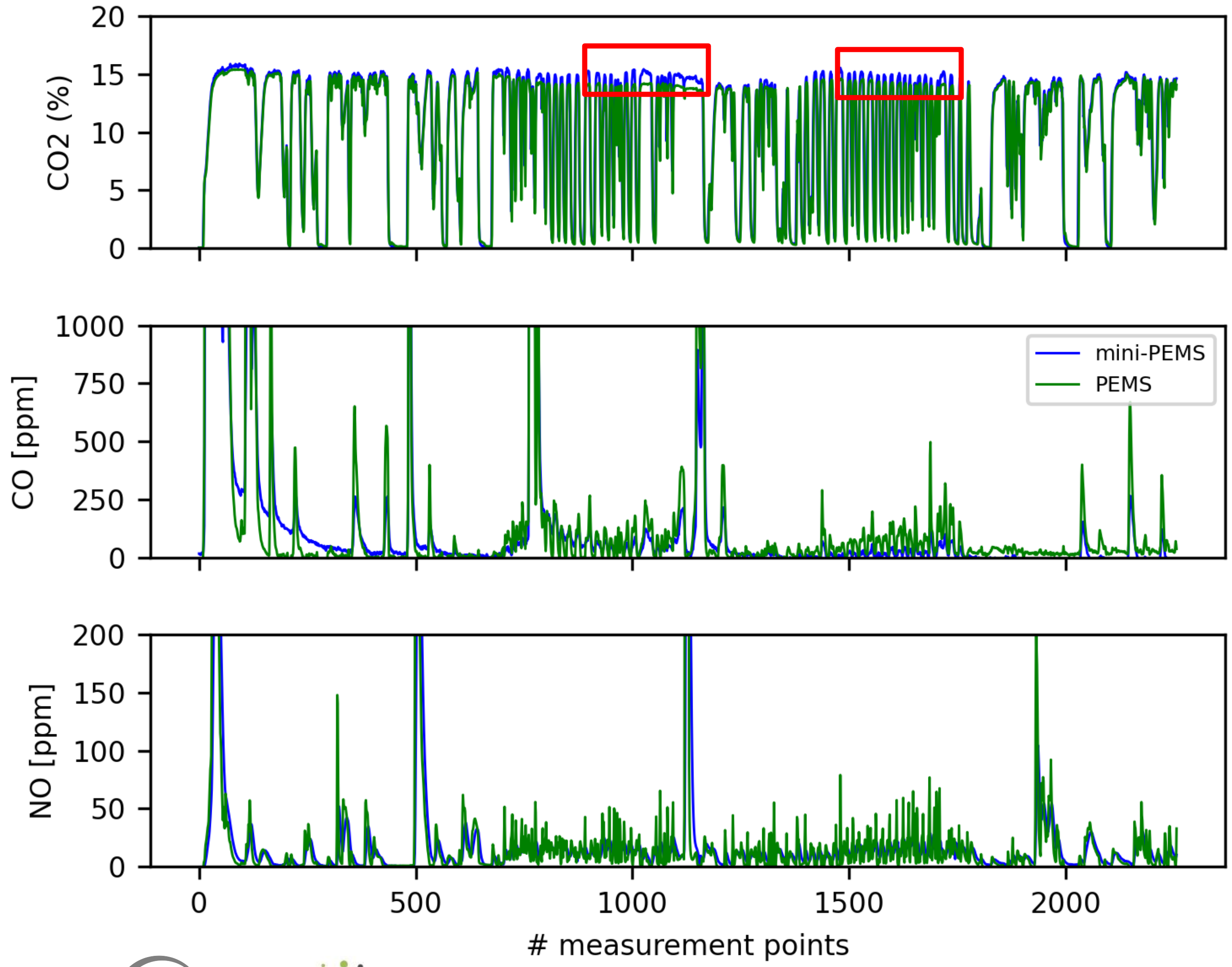


Experimental description

Parameter	Units	Value
Fuel		Gasoline
Capacity	cm^3	1498
Power	kW	81
Mileage		15000
Year		2022
Emissions		EURO6
Type approval		WLTP
Mass	kg	1750
Injection		Indirect injection

Vehicle specifications

Timeseries - Emiscout



- The CO_2 sensor has good responsivity
- In dynamic conditions when the exhaust is throttled some overshoot is observed, due to change in dilution conditions
- The NO sensor follows the trends adequately
- The CO sensor follows the trends but lags behind in second-by-second changes

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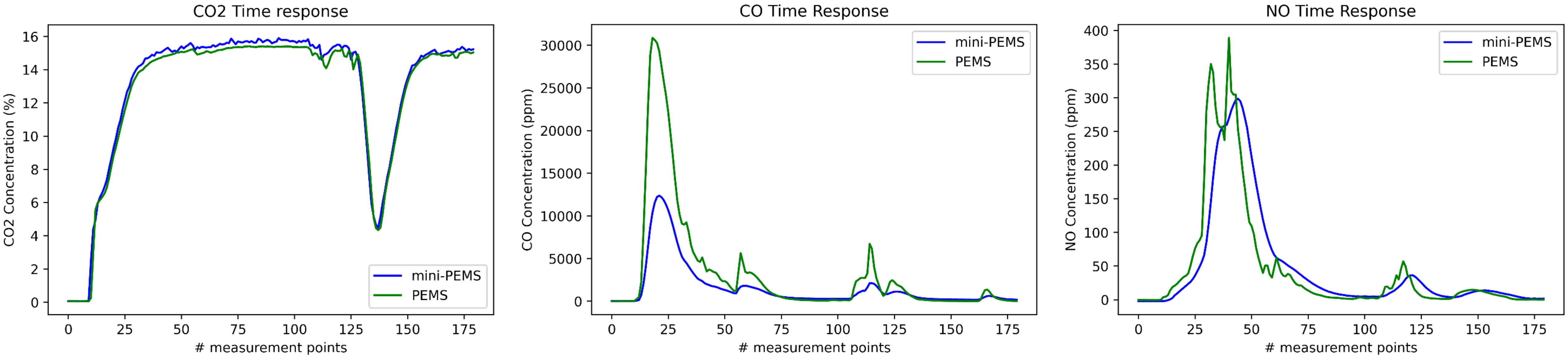
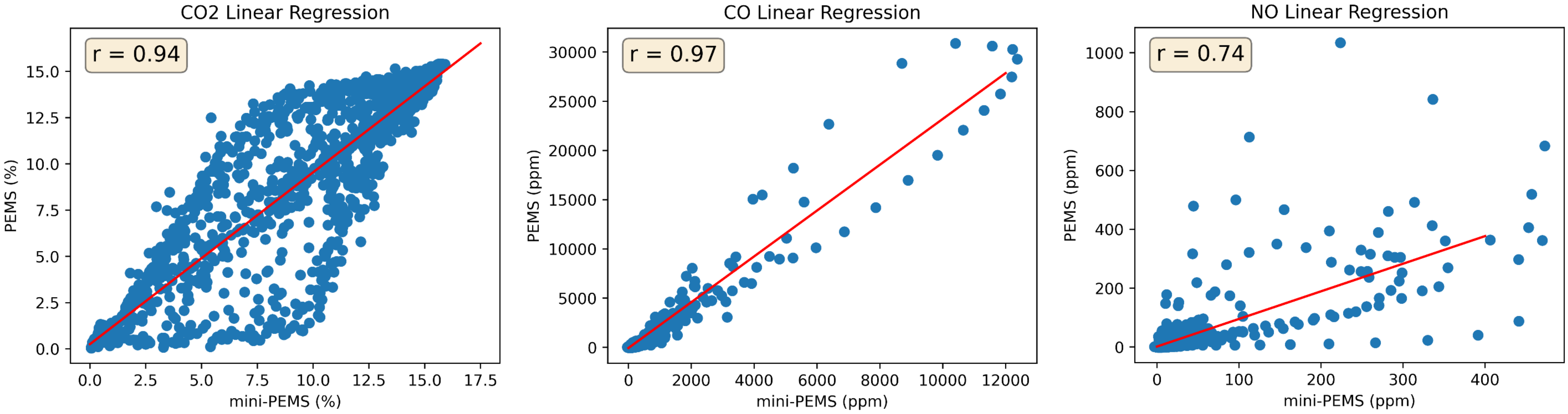
Time responses - Emiscout



- CO_2 : comparable time response and level with PEMS
- NO : follows the trend with a slight lag and overall deviation 10-15%
- CO : detect peaks, but underestimates them, mean deviation of ~40-50%

Correlation plots - Emiscout



- Typical 'hysterisis' loop for CO_2
- Strong indications of overall a linear relationship for all 3 sensors
- Especially CO, despite having a slow response has a perfectly linear response

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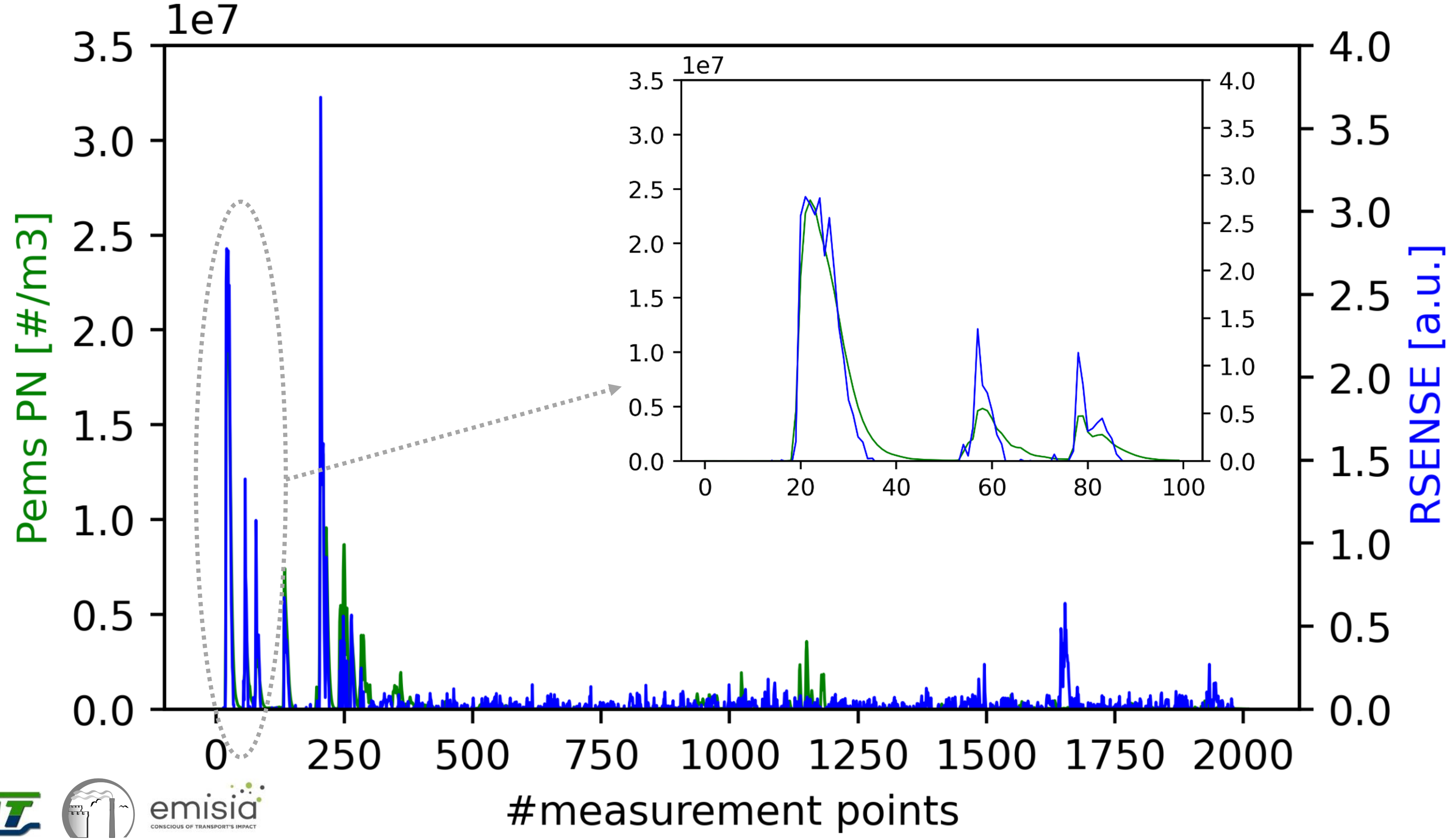
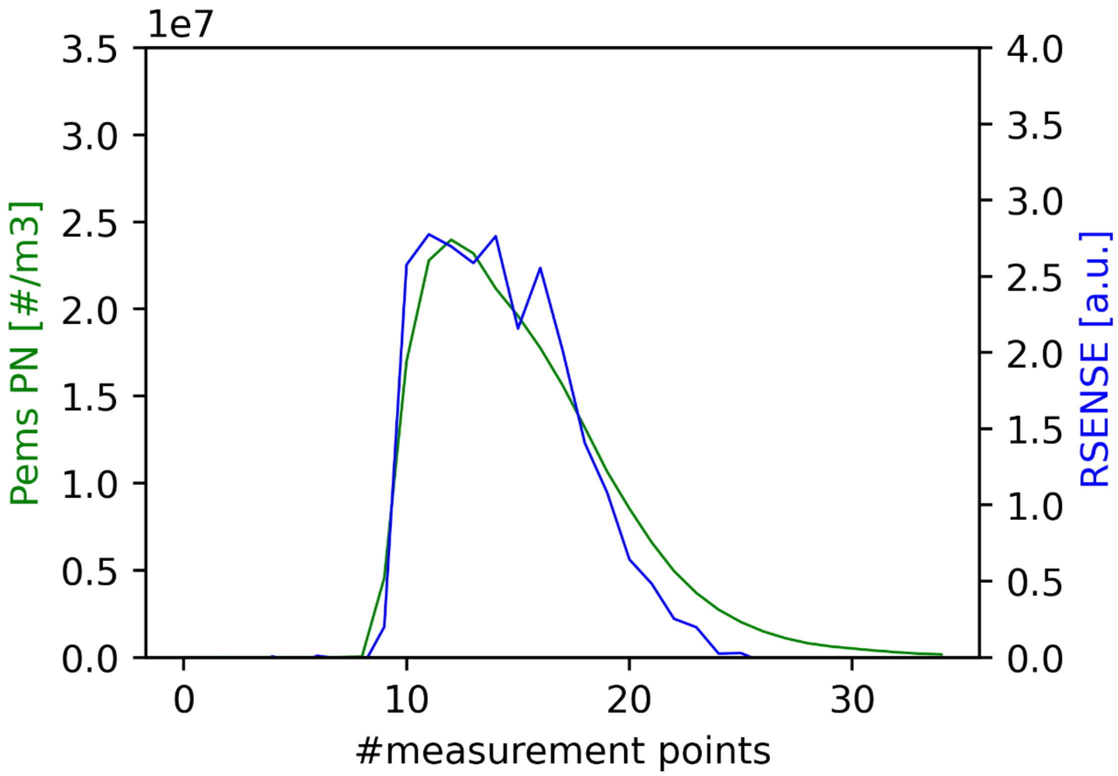
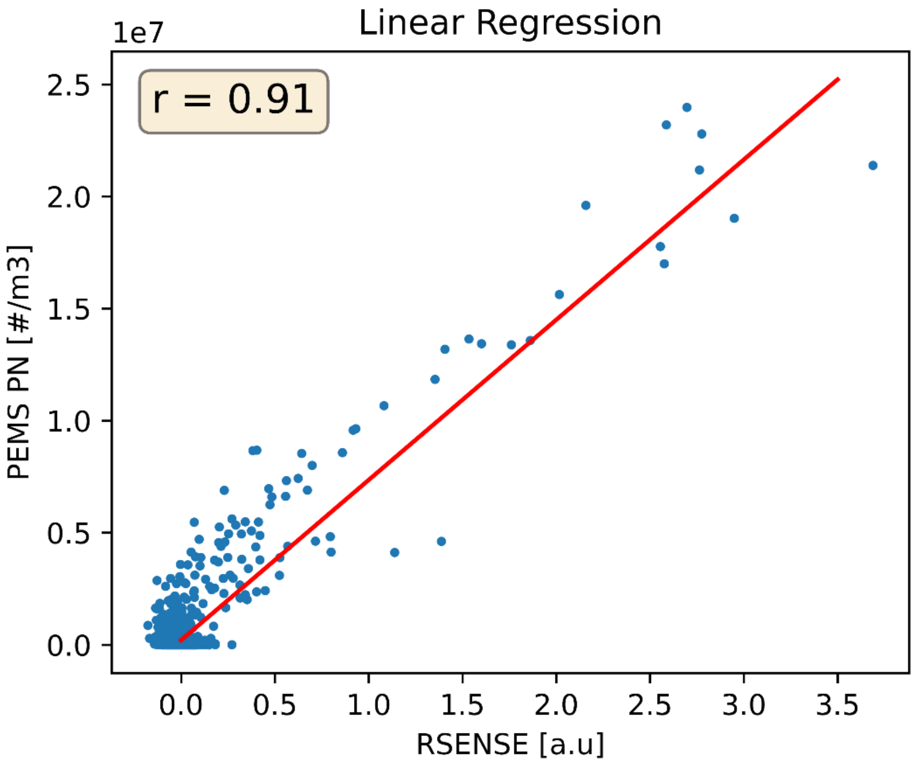
BC (OptA sensor) vs PN (PEMS)



Time response/Correlation optA sensor





Fast time response, comparable to the PEMS PN

Excellent correlation indicating that BC represents a constant contribution to PN

Conclusion and next steps

Key takeaways:

- SEMS of satisfactory operation for screening high emitting vehicles
- At least 30 minutes of continuous measurement on battery is successfully performed
- Humidity condensation occurred in some trips, further development of sampling system & optimisation of DR is needed
- For large on-board measuring campaigns, SEMS sensors need to be replaced in regular intervals (TBD)

Next steps:

- Further miniaturization
- Optimize sampling system
- L-vehicle measurements (LENS project)
- Integration of HC sensor

Thank you for your attention!

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Acknowledgments

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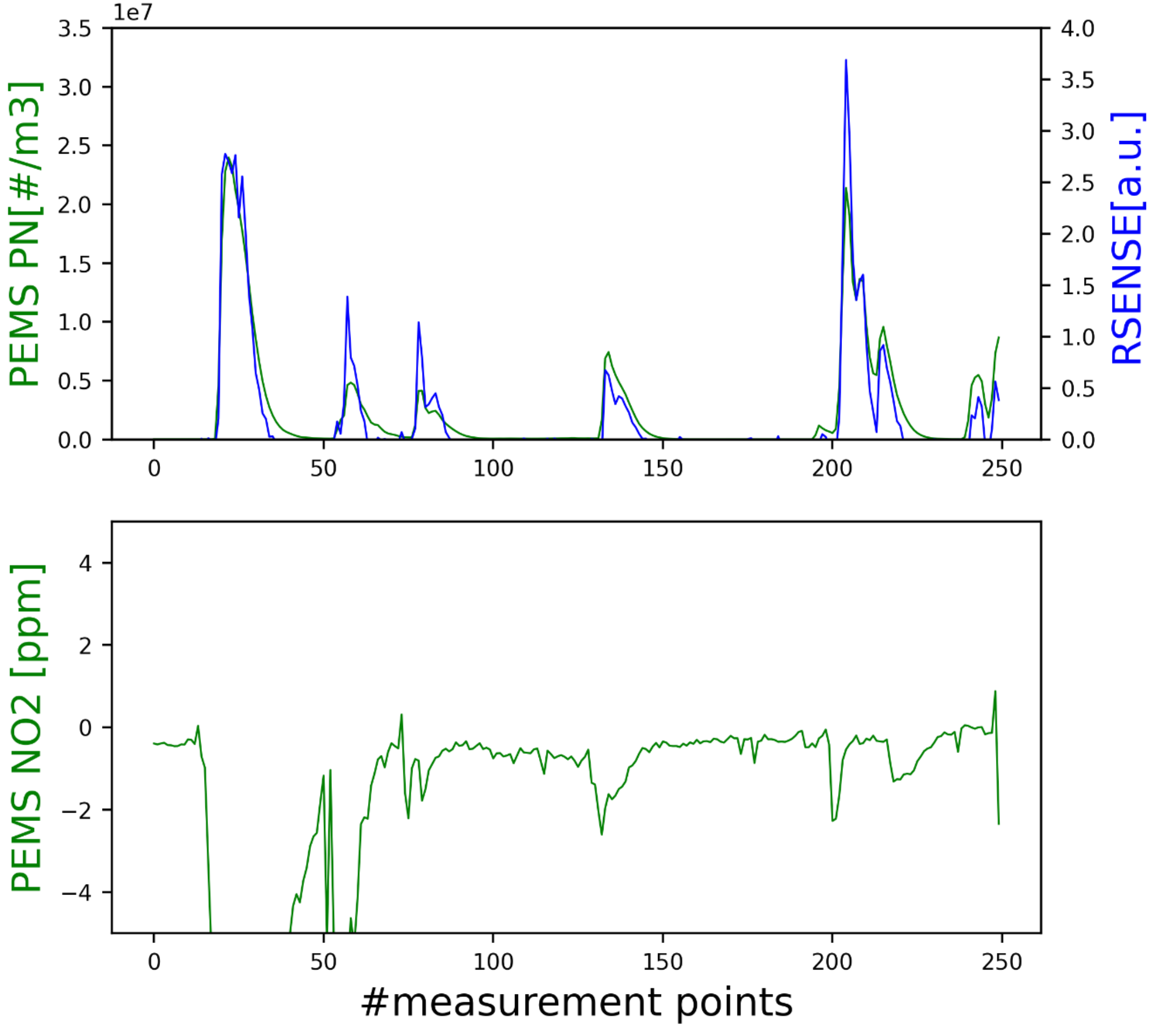
Back-up slides

Why only BC and no NO_2 measurement – optA sensor



- The 450 nm LD laser that the optA sensor uses is also capable of detecting NO_2
- Since the measurements were done with a gasoline vehicle we didn`t expect significant emissions of NO2
- PEMS measurement of NO_2 verifies that there was no contribution of NO2 and thus the correlation between PN and BC is confirmed