CARES

Deliverable D4.2

Final guidance document on how to apply remote emission sensing for policy relevant applications

June 2023

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 814966.

Summary

- This slide deck provides recommendations for an efficient deployment of different remote sensing measurement devices.
- The recommendations for most suitable use are specific according to the primary pollutant(s) under investigation and the vehicle category targeted. This leads to differentiated recommendations for each instrument.

CARES

Participating organizations

- **IIASA – International Institute for Applied Systems Analyses** (coordination)
- **Technische Universität Dresden (TUD)** for RES analysis
- **The ICCT – International Council on Clean Transportation** for RES analysis
- **Universität Heidelberg & Airyx GmbH** for plume chasing
- **Technische Universität Graz (TUG)** for point sampling

CARES

Attainment of the objectives and explanation of deviations (1/3)

Description of work related to deliverable as given in DoW

- The core deliverable is a guidance document, “written in a comprehensive yet easy-to-understand way.” That is presented by this slide deck. As promised the guidance addresses practical issues like the selection of suitable measurement sites, the choice of instrument(s), their set-up and most efficient deployment, questions of quality assurance and control, and data analysis.
- In addition, we provide recommendations for several use cases of remote sensing instruments, notably monitoring of the emissions from the vehicle fleet and the identification of individual high-emitting vehicles.

CARES

Attainment of the objectives and explanation of deviations (2/3)

Time deviation from original DoW

- The final deliverable was originally planned towards the end of the project (M33 according to the initial planning).
- However, the last measurement campaign took place only in September 2022; it offered crucial lessons as this was the only campaign conducted in close cooperation with police and vehicle inspection authorities. Therefore it was agreed to delay the finalisation of this deliverable to the end of this project.
- Importantly, a draft final version of recommendations was presented as scheduled at the final dissemination event.

CARES

Attainment of the objectives and explanation of deviations (3/3)

Content deviation from original DoW

- None.

Remote emission sensing: Useful applications

1. **Representative emission factors** of fleets, by emission standard, by vehicle class…
   Important for rational air quality planning and models

2. **Monitor emissions by vehicle classes** / families / model years & technologies…
   Important for effective monitoring (PTI/ISC)

3. **Evaluate policy effectiveness**: Emission standards, fuels, technologies,
   Low Emission Zones:

4. Identifying individual **high-emitting vehicles**
   For effective enforcement

5. Recommendations per RES technology

CARES

1) Representative emission factors

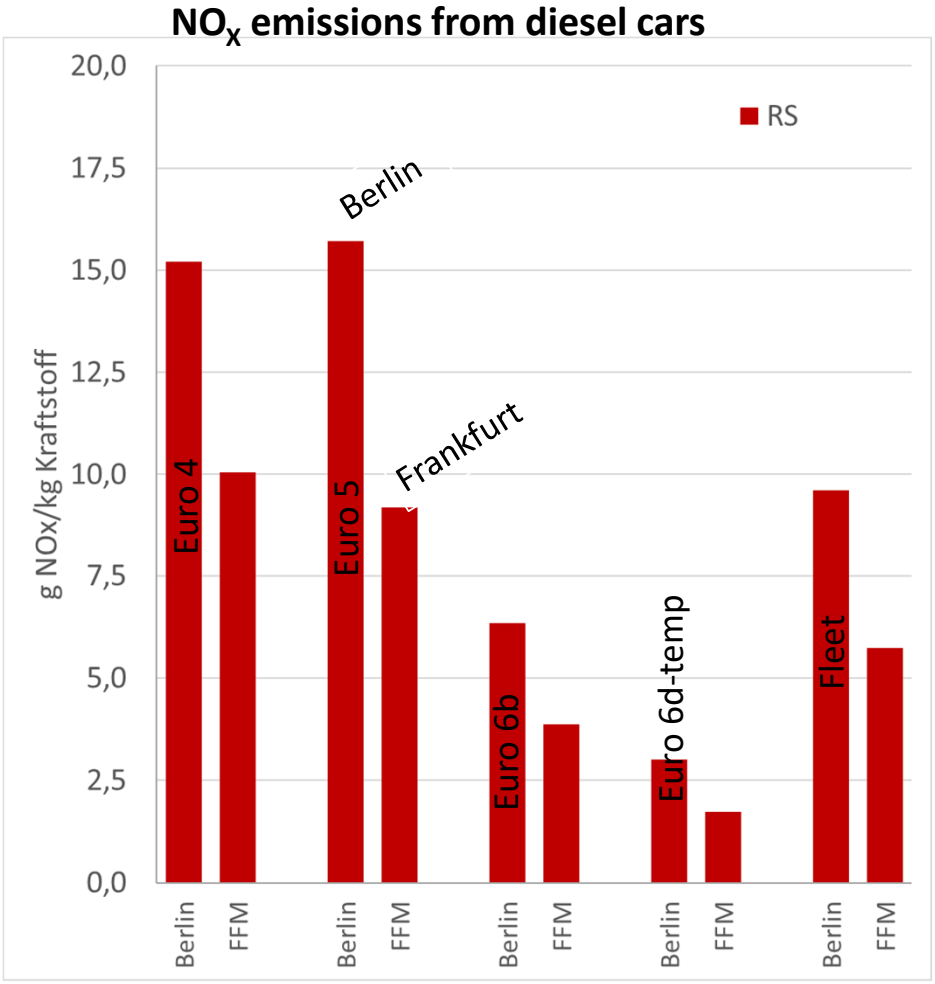
Remote sensing = Mass sampling without interference with vehicle, driver or traffic

- Measure emissions per Euro class / model year / manufacturer / engine family… under wide range of ambient and driving conditions
  Recommended:
  - **Monitor Euro 6d** long-term performance or deterioration
  - **Monitor trucks**
  - **Measure on highways**

Recommendation:
Coordinated low-intensity campaigns e.g. with 4 states participating every year, exchanging data, and rotating across Europe.

CARES

1) Representative emission factors, here different cities



The local situation – even in the same country – can be quite different:

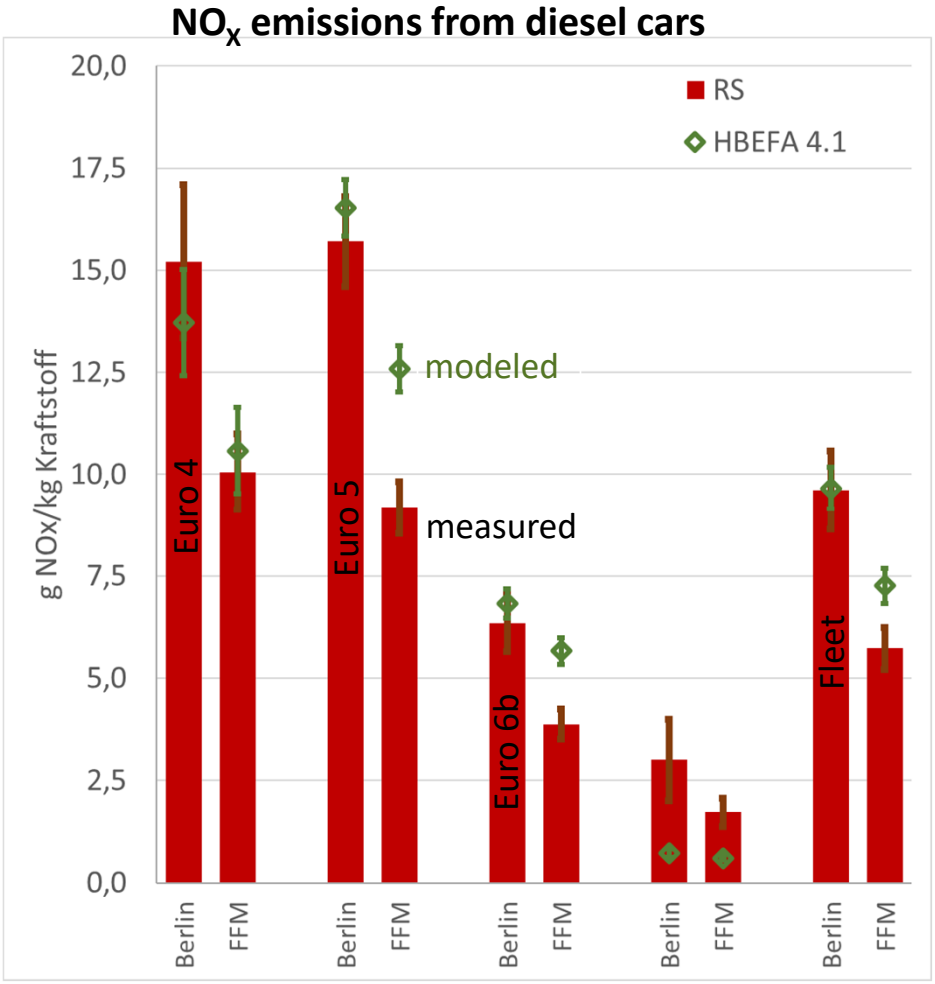
- Different ambient conditions
- Different driving conditions
- Different fleets

Useful to understand the local situation!

Data sources: RS measurements in Berlin & Frankfurt

CARES

1) Representative emission factors, here vs. HBEFA model



The local situation – even in the same country – can be diverse:

For good air quality planning good input data - from measurement & models - needed.

RES provides unique input to emission modeling!

Data sources: RS measurements in Berlin & Frankfurt

CARES

2) Monitoring in-use fleet

- Focus on compliance of in-use fleet and vehicle classes
- Identify worst performing vehicle families (or models, technologies, series, …) for dedicated confirmatory measurements

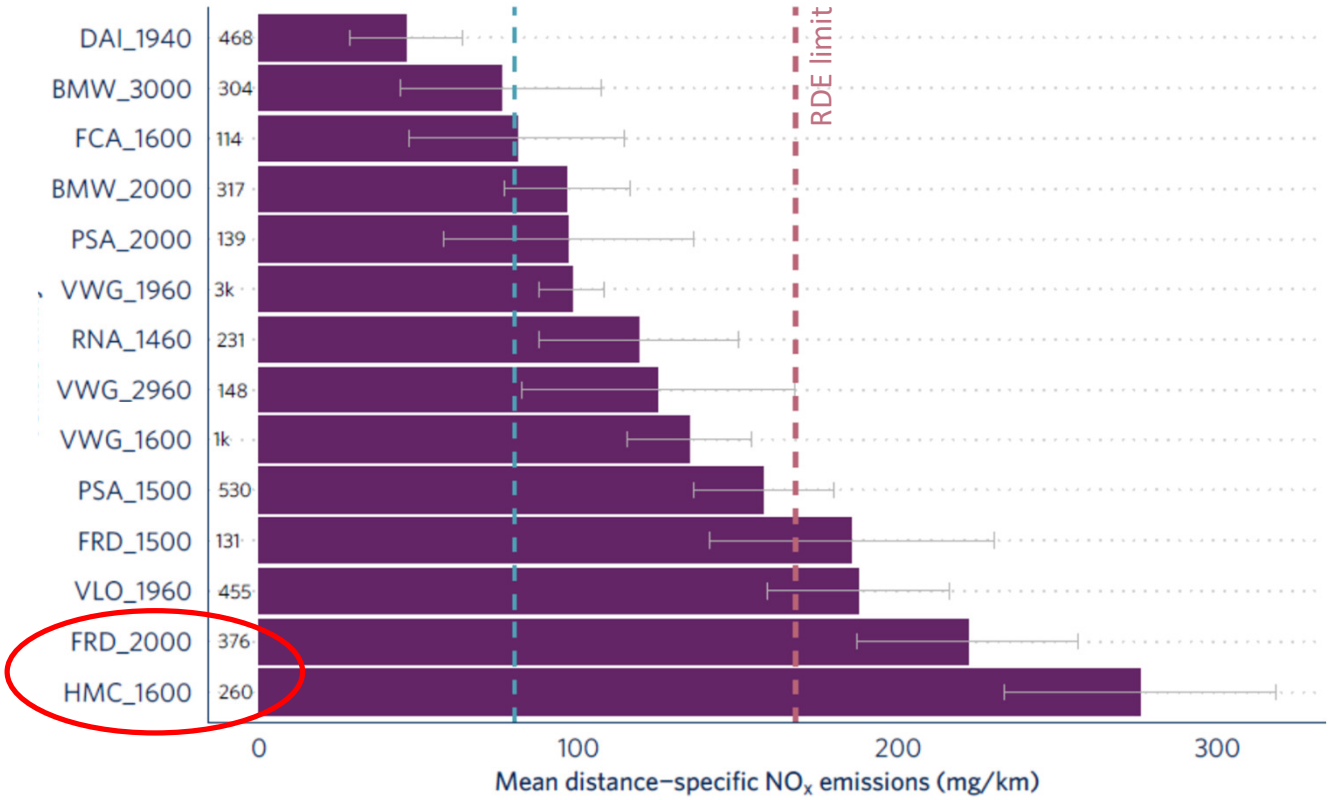
Recommendation: Coordinated low-intensity campaigns e.g. with 4 states participating every year, exchanging data, and rotating across Europe.

+ dedicated campaigns focusing on the pre-identified vehicle families, models, technologies…

CARES

2) Monitoring, here worst-in-class vehicle family

Euro 6d-TEMP diesel cars



Vehicle family := Vehicle manufacturer x engine displacement in ccm

Data sources: RS measurements in Krakow, Milan & Prague

CARES

3) Evaluating impact of measures

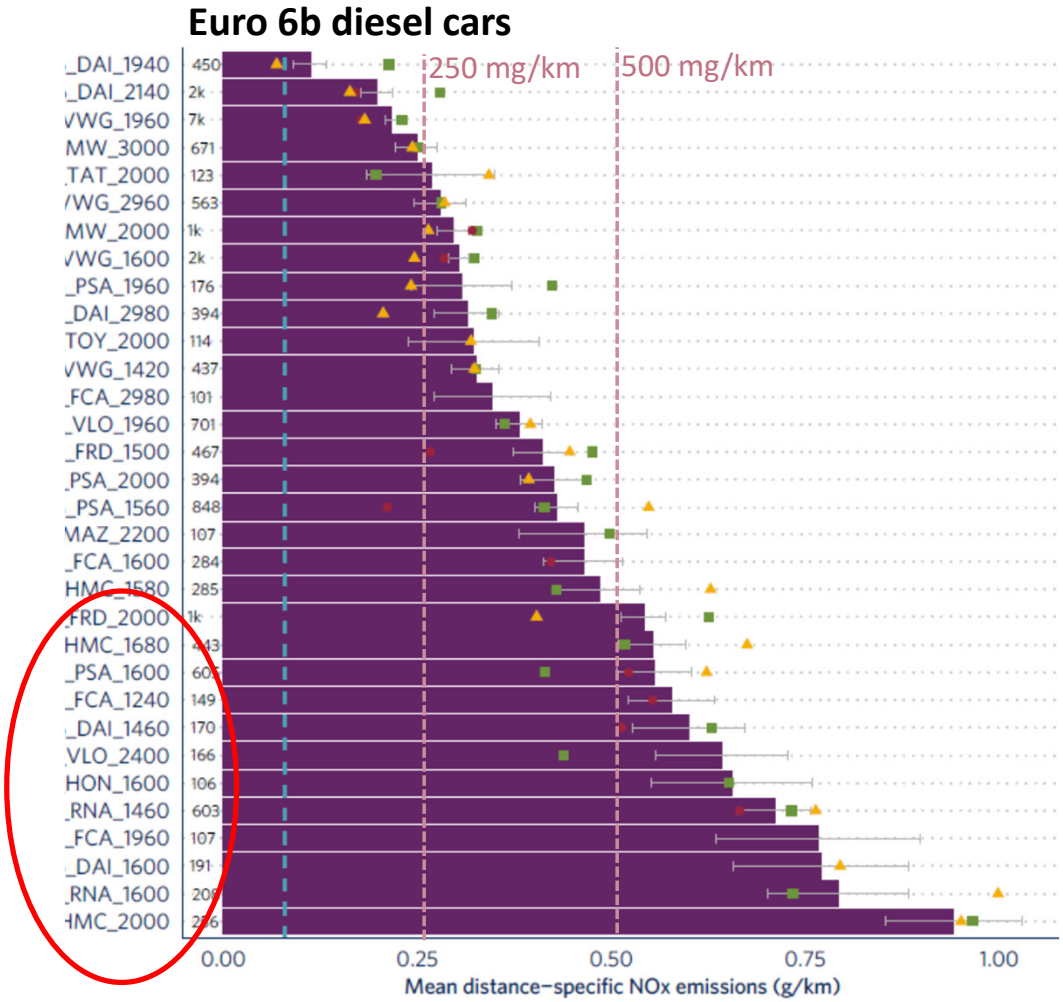
Some important real-world questions:

- Is the **software update** for cars/trucks (Euro 5/6) effective?
- How durable are Euro 6d emission controls for passenger cars and light-commercial vehicles?
- What is actual on-road performance of Euro 7 for light- and heavy-duty vehicles?
- Are emissions from CNG/LPG powered cars lower than from petrol?
- What is actual electric share of PHEVs?
- How much emissions can be reduced by different stages of a Low Emission Zone?

Recommendation: Dedicated campaigns + data mining.
Data mining requires accumulation of data in the first place!

CARES

3) Evaluating impact of measures, here software update?



Vehicle family := Vehicle manufacturer x engine displacement in ccm

Data sources: RS measurements in Krakow, Milan & Prague

CARES

4) Identifying individual high-emitting vehicles

Needs robust classification, i.e. several measurements per vehicle. **Recommended:**

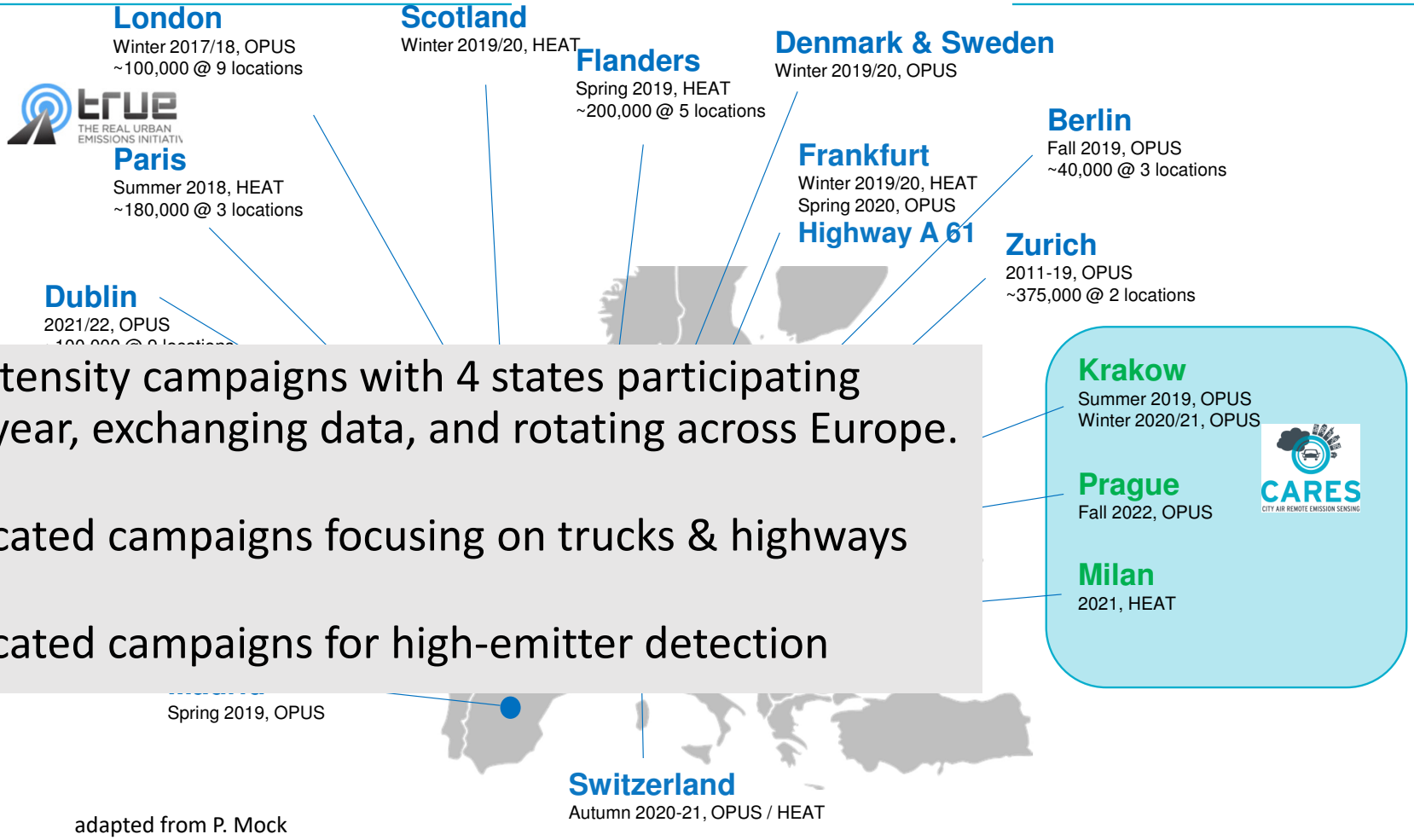
- For **trucks**: Plume chasing measurements on highways.
  Inspector should be in the chasing car for immediate inspection as in Denmark.
- For **light-duty vehicles**: Point samplers on both road sides in not too dense traffic.
  Inspectors to be on stand-by & vehicle data be quickly available.

- With **cross-road & top-down remote sensing** both light and heavy vehicles:
  Set-up several (3+) sensors in a row to have several valid emissions.
  For live enforcement: Inspectors on stand-by & vehicle data be quickly available.

- Under development: Profiling vehicle emissions to avoid number plate recording, i.e. relieve GDPR requirements.

CARES

RES campaigns so far & recommendations for more



Low-intensity campaigns with 4 states participating every year, exchanging data, and rotating across Europe.

+ dedicated campaigns focusing on trucks & highways

+ dedicated campaigns for high-emitter detection

adapted from P. Mock

5a) Recommendations for fleet monitoring

		Fleet monitoring	Comments
NO_X	**Trucks** on highways	Top-down RES Plume chasing	Top-down RES to be installed over each lane seperately. Plume chasing feasible in principle and acurate, but lower productivity.
NO_X	**Passenger cars** **Light-commercial vehicles** **Heavy-duty vehicles** on urban & extra-urban roads	Cross-road / top-down RES *Recommendations see right.* Point sampler *Recommendation see bottom right.*	Cross-road RES: Two sensors recommended for cross-calibration and to increase capture rate. Seperated lanes with vehicle acceleration required.
PN/ BC	**Passenger cars** **Light-commercial vehicles** **Heavy-duty vehicles** on urban & extra-urban roads	Point sampler	Traffic flow ≥ 3s between vehicles for plume separation, preferably single lanes, samplers at each road side to increase capture.

CARES

5b) Recommendations for individual high-emitter detection

		Individual high-emitters	Comments
NO_X	**Trucks** on highways	Plume chasing	Identification within 60 secs possible. Best to have inspector on board of chasing vehicle to perform immediate road-side control.
NO_X	**Passenger cars** **Light-commercial vehicles** **Heavy-duty vehicles** on urban & extra-urban roads	Cross-road & top-down RES *Recommendations see right.* Plume chasing *Recommendations see top right.* Point sampler *Recommendation see bottom right.*	Separated lanes with vehicle acceleration required. 3+ sensors in row; restrict analysis to 3< VSP <22/30 kW/t; Live identification needs live retrieval of number plate information/vehicle registration data
PN/ BC	**Passenger cars** **Light-commercial vehicles** **Heavy-duty vehicles** on urban & extra-urban roads	Point sampler	Traffic flow ≥ 3s between vehicles for plume separation, preferably single lanes, samplers at each road side to increase capture.

CARES

Recommended set-up & operation: Plume chasing

- Measure on highways or rural roads where vehicles are sufficiently warmed up; slight uphill can be an advantage to get a good plume signal;
- Avoid roads where the vehicles idle or where the SCR may cool down, e.g. on long downhill sections; avoid measurements on vehicles that have just began driving e.g. entering the highway from a parking space;
- Avoid strong accelerations or engine loads which are outside normal certification conditions, e.g., steep uphill;
- Drive in close but still safe distance behind the truck; the signal is stronger in closer distance; avoid very dense traffic, driving speeds below 30km/h, tunnels & street canyons
- Avoid very strong winds (>10 m/s) as exhaust plumes get too diluted

CARES

Recommended procedure for spot checks: Plume chasing

If high emissions are recorded the following procedure is recommended to avoid a false classification:

- overtake the vehicle with preliminary high emissions and measure the emissions at its front, i.e., from preceding vehicles;
- if the emissions are now even higher, then the measurement was likely interfered by plumes from preceding vehicles.

Inspection procedure:

- The inspecting officer(s) drive together with the plume chasing car;
- Whenever high emissions are determined the suspect vehicle is pulled over by the officers as soon as possible, e.g., at the next parking lot;
- The inspectors investigate the vehicle e.g., with advanced OBD tools to validate a manipulation or defect and to exclude a cold SCR.

CARES

Plume chasing: Thresholds for high-emitter detection

NOx emissions: Plume chasing thresholds and procedure tested with road-side spot checks

- Inspection vehicle follows truck on highway and measures emissions in the plume
- Automatic classification into clean within 15 secs, suspicious or high-emitter after 60 secs
- High-emitter stopped: Road-side inspection whether cold SCR, defect, manipulation, software issue,...

NO_X threshold values	Euro V [mg/kWh]	Euro VI [mg/kWh]	Measurement duration
Suspicious emitter	> 2.500	> 1.200	≥ 60 sec
High emitter	> 3.500	> 2.200	≥ 60 sec

CARES

Recommended set-up & threshold: Point sampling

Point sampling is a passive measurement technique which samples the diluted exhaust from passing vehicles.

- Medium/light traffic (vehicle spacing ≥3 s) allows for robust separation between vehicles and plumes
- Sampling inlet preferable in middle of road
- Single lanes with positive VSP to measure engines under moderate load
- Avoid strong wind conditions as they negatively influence the sample extraction

PTI inspection limit PN: 250‘000 - 1‘000‘000 # per cm^3 (Euro 5, 6 Diesel)
RDE limit: 250‘000 # per cm^3 ⇔ PN 1,5 * $6*10^{11}$ # per km ⇔ $1,8*10^{13}$ # per kg fuel
PS threshold (tentative) PN: > $1*10^{14}$ # per kg fuel , incl. safety margin

CARES

Recommended set-up for X-road/top-down RES

The preferable conditions for RES measurements are:

- Single lanes with moderate acceleration to have clearly separated vehicles/plumes
- Avoid stop-and-go or traffic jams;
- Minimize influence from cold-started vehicles, feasible e.g. at extra-urban roads
- Deploy at several locations in the area of investigation; measurements at different seasons would be an advantage
- Deploy two instruments in a row (>30 m distance) for inter-calibration and higher capture rate;

For high-emitter detection:

- 2+ valid records **required**, therefore 2+ instruments in a row;
- normal VSP, e.g., 3…30 kW/t
- Threshold values depend on the number of valid records per vehicle.

CARES