Bus emissions measurement in operational conditions using PEMS: comparison between different Euro technologies

ERMES plenary – May 17th, 2021

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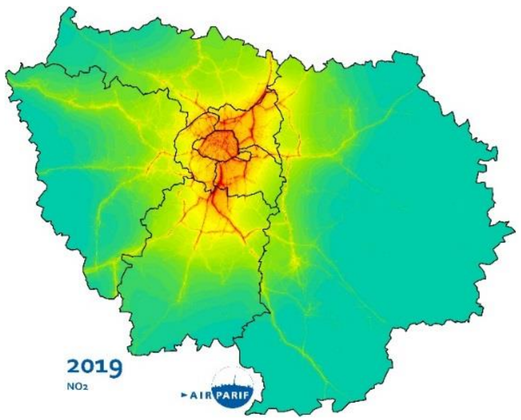
1. Introduction and objectives

Introduction to Airparif and Île-de-France Mobilités

- **Airparif, Regional Observatory of Air Quality in Île-de-France (Paris Region) since 1979**
  - Accredited by the French Ministry of Environment
  - Missions: monitoring, understanding and analysing, assessing and supporting, informing
  - Complementary tools: fixed stations, inventory, modelling, field campaigns

L'Observatoire de l'air en Île-de-France



- **Île-de-France Mobilités, local public authority organizing public transportation**
  - Imagines, organizes, finances public transportation for the whole region
  - Manages transportation modernisation programs

Objectives of the study

- **For Airparif**

Quantifying the uncertainties of emission factors used in the emissions inventory and in pollutant concentrations modelling

- **For Île-de-France Mobilités**

Committed to ecological transition, will to improve air quality and reduce greenhouse gas emissions, interest in ensuring that bus technological choices actually meet the expected improvement

- **More generally, for the scientific community**

Real-world emissions for buses not widely documented

Setting standards beyond Euro VI requires a good knowldege on current real-world emissions

Objectives of the study

More specifically:

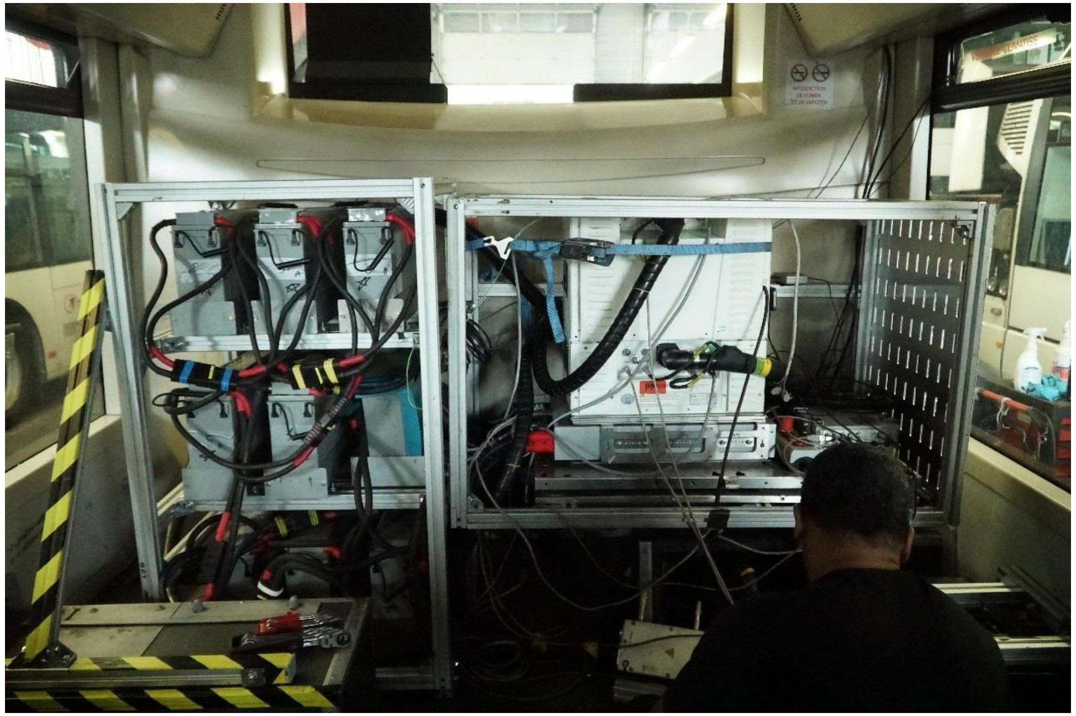
- **Characterize emissions ranges encountered in Île-de-France for the selected bus technologies, for real operating conditions with passengers:**
  - Euro IV diesel, Euro VI diesel, Euro VI hybrid, Euro VI CNG
  - For the atmospheric pollutants NO_x, CO, Particle Number (PN), and the GHG CO_2
- **Analyze how certain parameters influence emissions**
- **Compare with emissions factors used for modelling**
- **Contribute to point out some operational levers to reduce pollutant emissions**

Relevance of our work to current EU policy

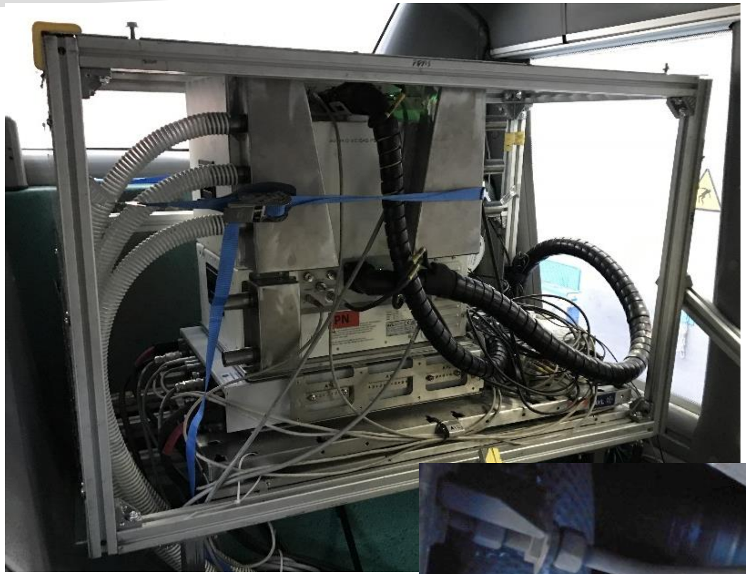
- **For AIRPARIF, it is important to have as much precise EF as possible in our models to provide qualitative information on:**
  - Hourly air quality concentrations at every point throughout the region, thus assess whether the national air quality standards are met
  - Air quality concentrations forecasts regarding different policy scenarios aiming at reducing air pollution

- **For public transport and manufacturers, this work provides information on the engine performance in real bus service conditions:**
  - Allows for investment decisions on the best available bus technologies, to reduce air pollution
  - Gives the opportunity to manufacturers to improve their technology on certain operating conditions, to reduce air pollution

2. Methodology

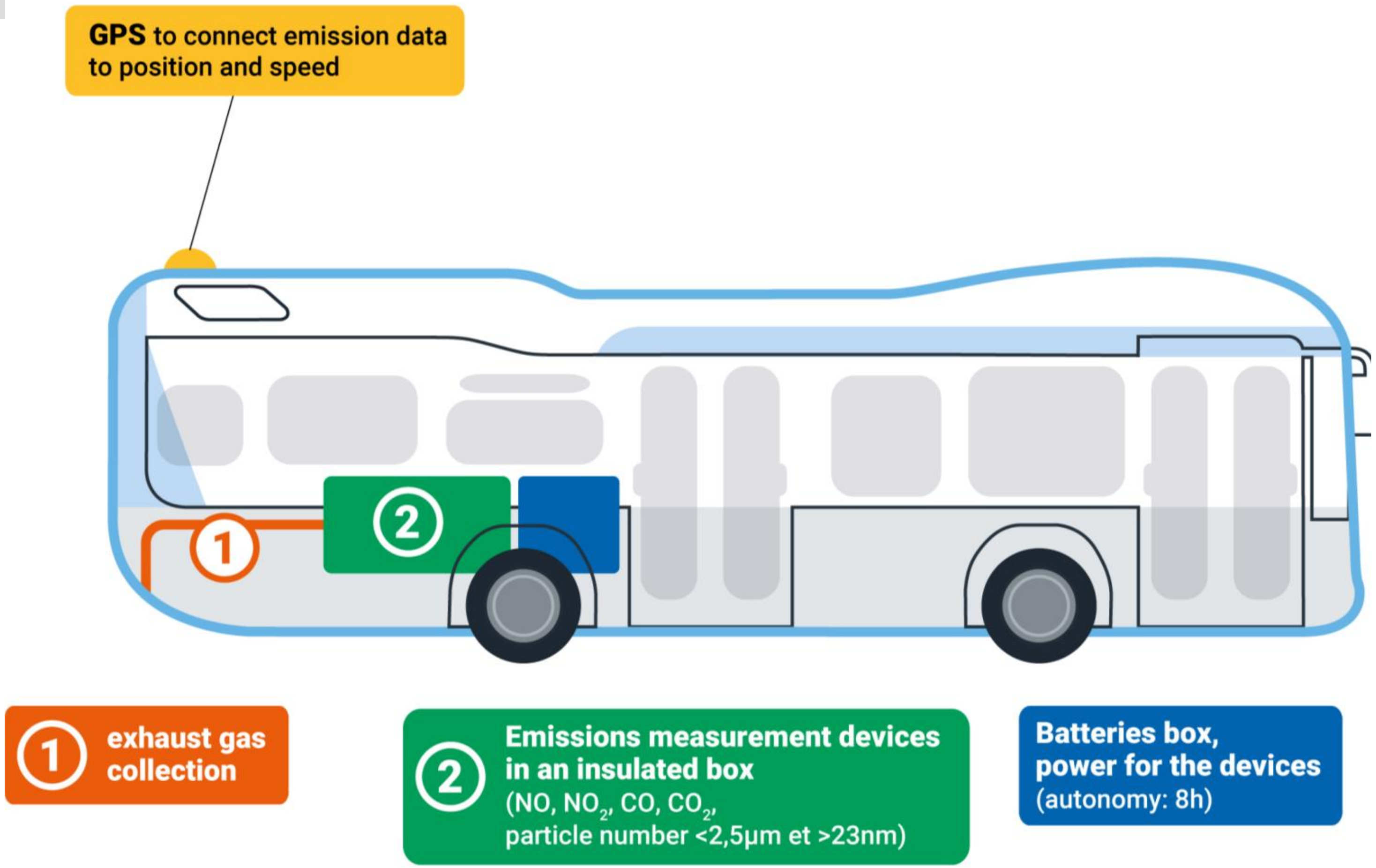


Instrumentation



- **AVL M.O.V.E GAS PEMS 492 iS: NO_x, CO, CO_2**
- **AVL M.O.V.E PN PEMS 496 iS: PN > 23 nm**
  - Measure frequency: 1 Hz
  - Sampling lines: 5m, 6 and 4 mm
  - PN PEMS dilution ratio: 6:1
  - Maintenance frequency: 1 to 2/week
  - Sampling probe: 20 cm from exhaust
- **Exhaust Flow Meter (EFM)**
  - 31 cm from sampling probe
- **Vehicles and engine parameters with CAN connection (OBD or FMS)**
  - Vehicle and engine speeds, coolant temperature, fuel rate if available
- **GPS and meterorological data**

Instrumentation



Passengers security ensured by specific technical choices approved by the manufacturers and the local public authority:

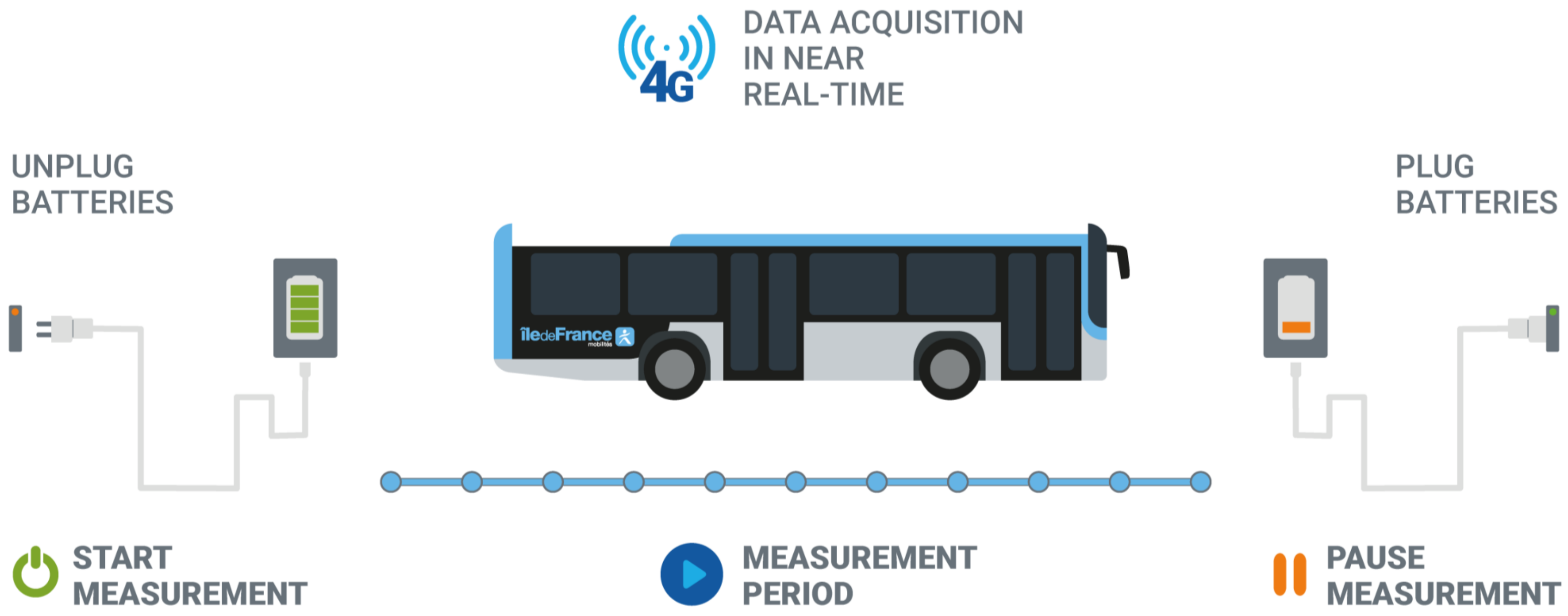
- **load distribution, fixations, insulation against exhaust gas leaks, electrical conformity, fire safety**

Automation

Automation required because:

- **Intensive measurement over multiple weeks at various locations and schedules**
- **Not possible to keep the devices measuring continuously (potential damage)**

→ Automatic software routine to switch between measurement and standby states

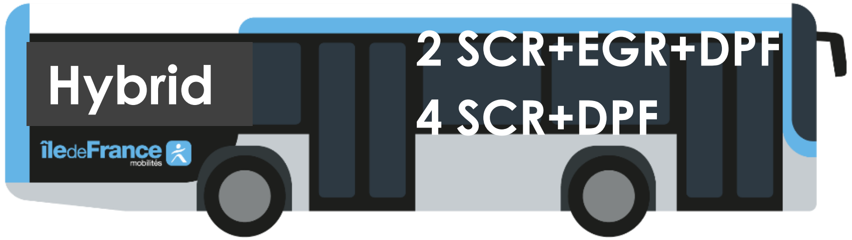


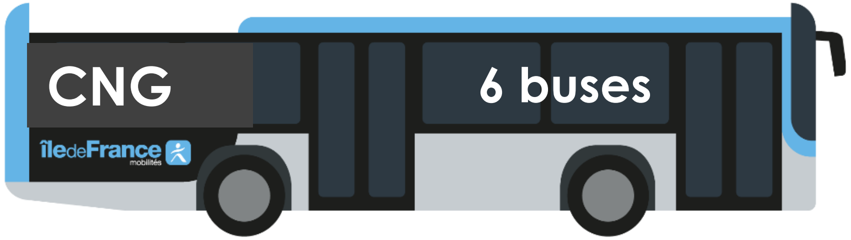
→ measurement of cold start at the beginning of the service

Tested buses

Euro IV

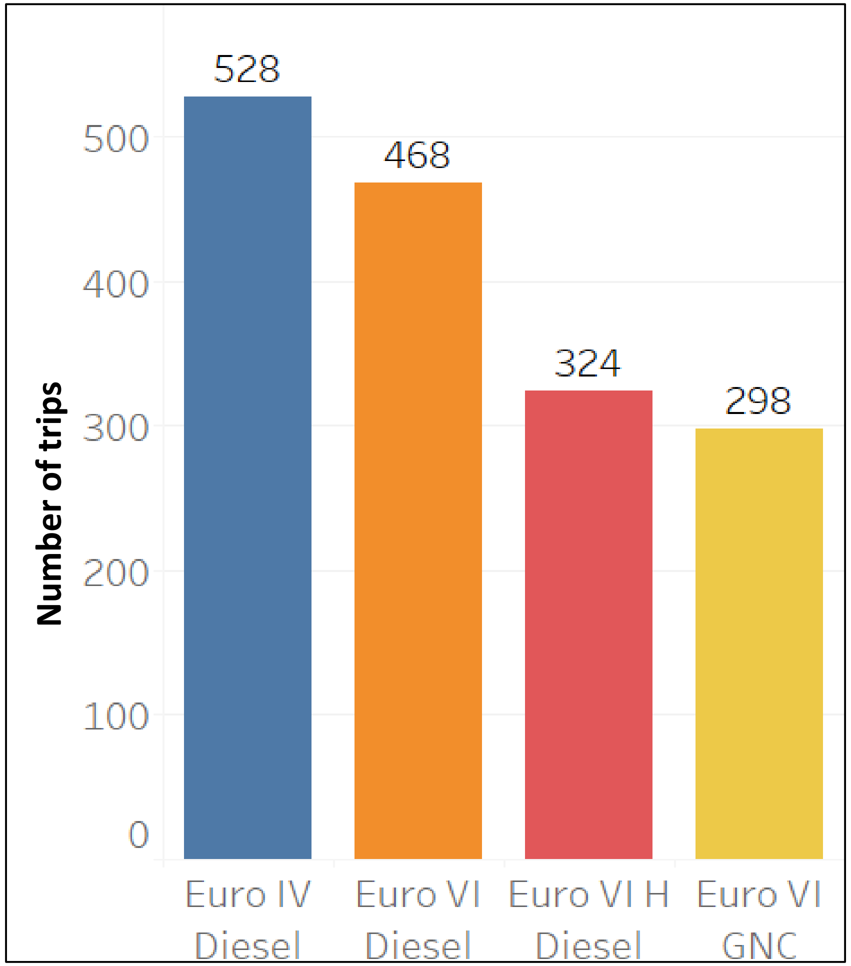
Euro VI





- **28 different buses**
  - 2 buses for each bus type (Euro standard+manufacturer)
- **16 measurement campaigns**
  - 2 buses/campaign
  - 5 days installation
  - State authority check
  - 2 week campaigns (10 days)
  - 3 days uninstallation

Operating conditions: bus lines



Data composed of:

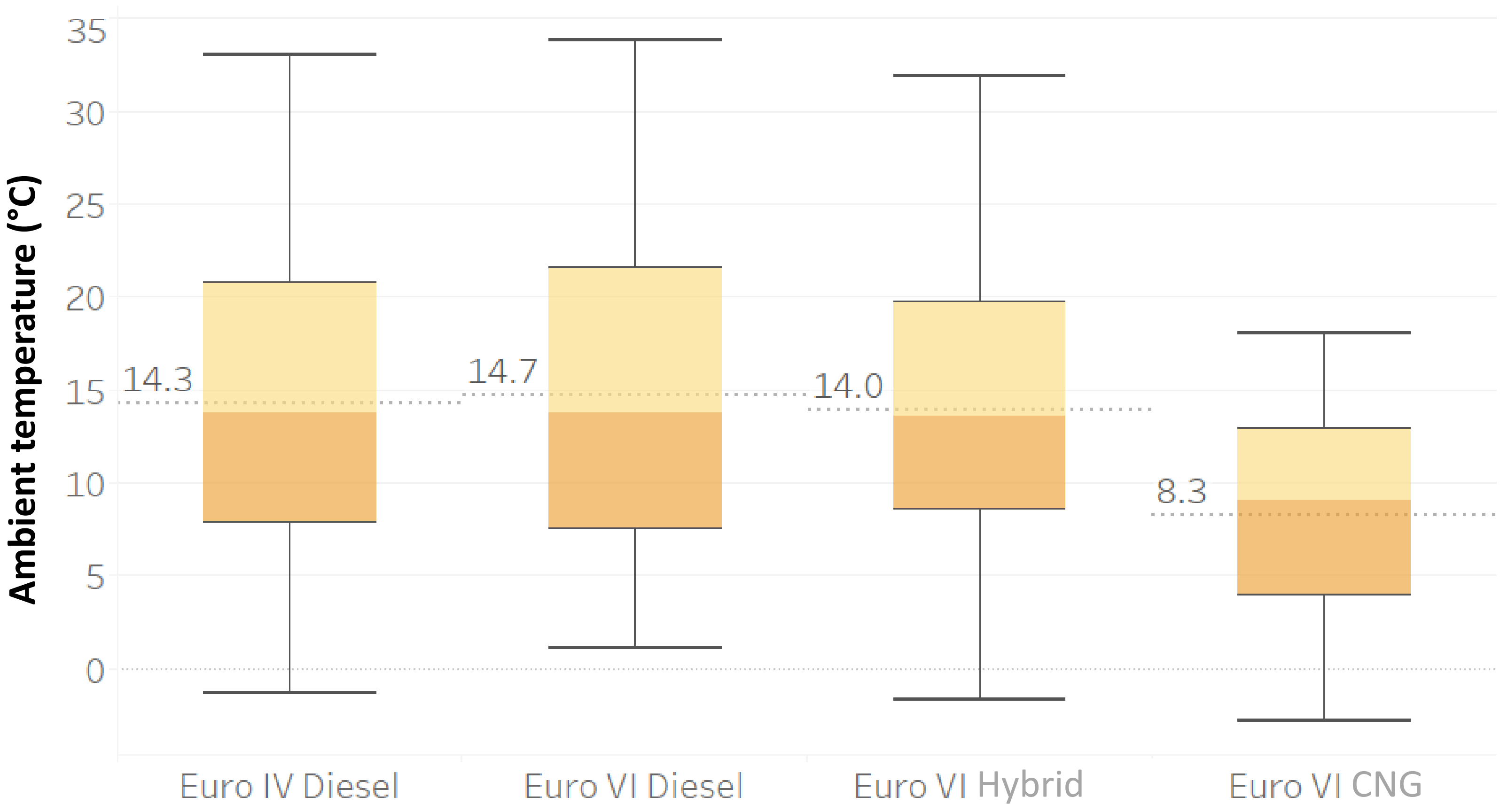
- Deadheading (including cold start)
- « Trips » : from start to end of a single bus line
- Idle times

11 bus lines

- **5 within Paris, <13 km/h**
- **3 in the inner suburbs (PC), ~14-22 km/h**
- **3 in the outer suburbs (GC), ~14-22 km/h**

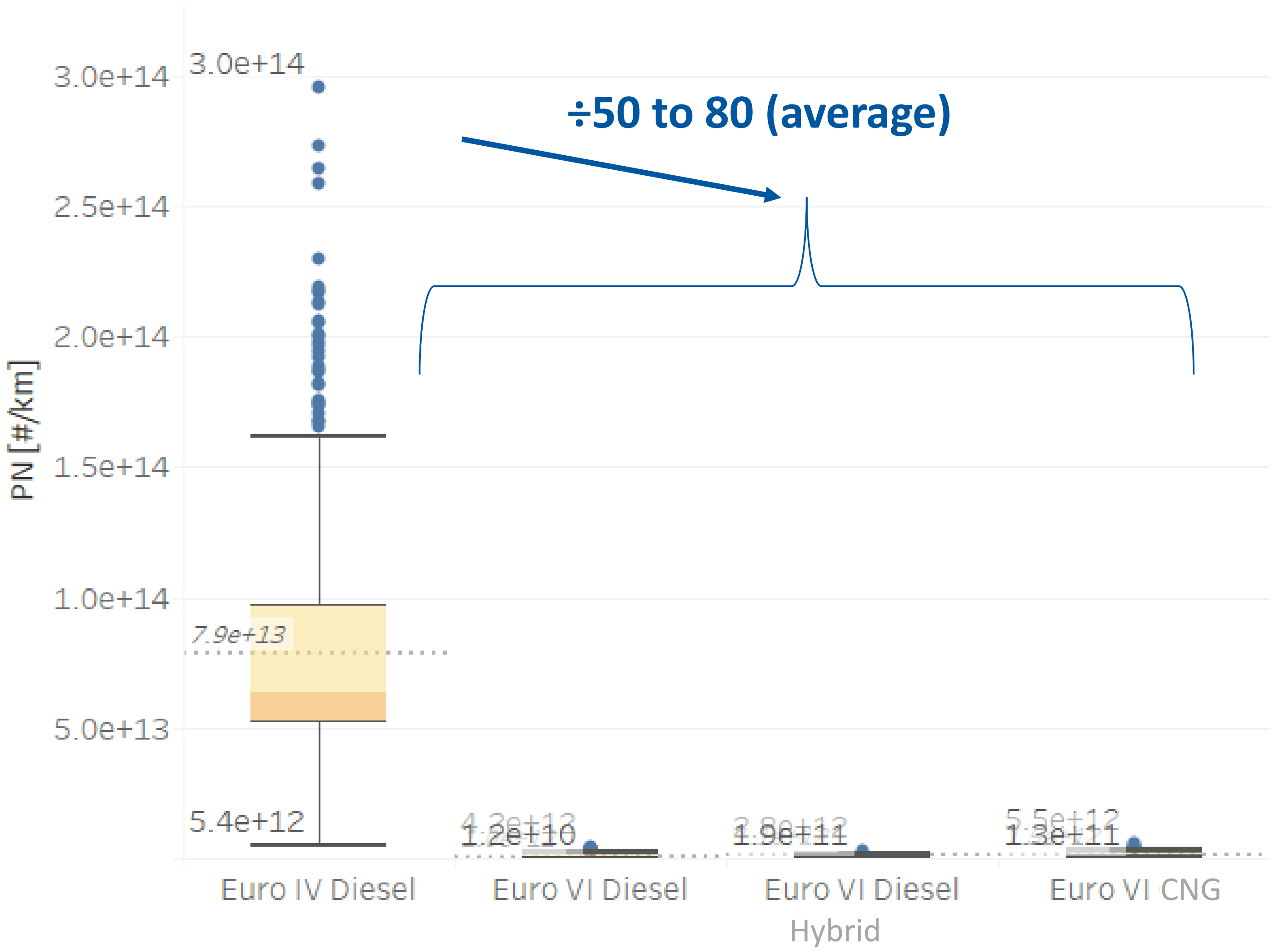
Operating conditions: temperature

Tests throughout the year, with very variable meteorological conditions, and globally colder for CNG buses



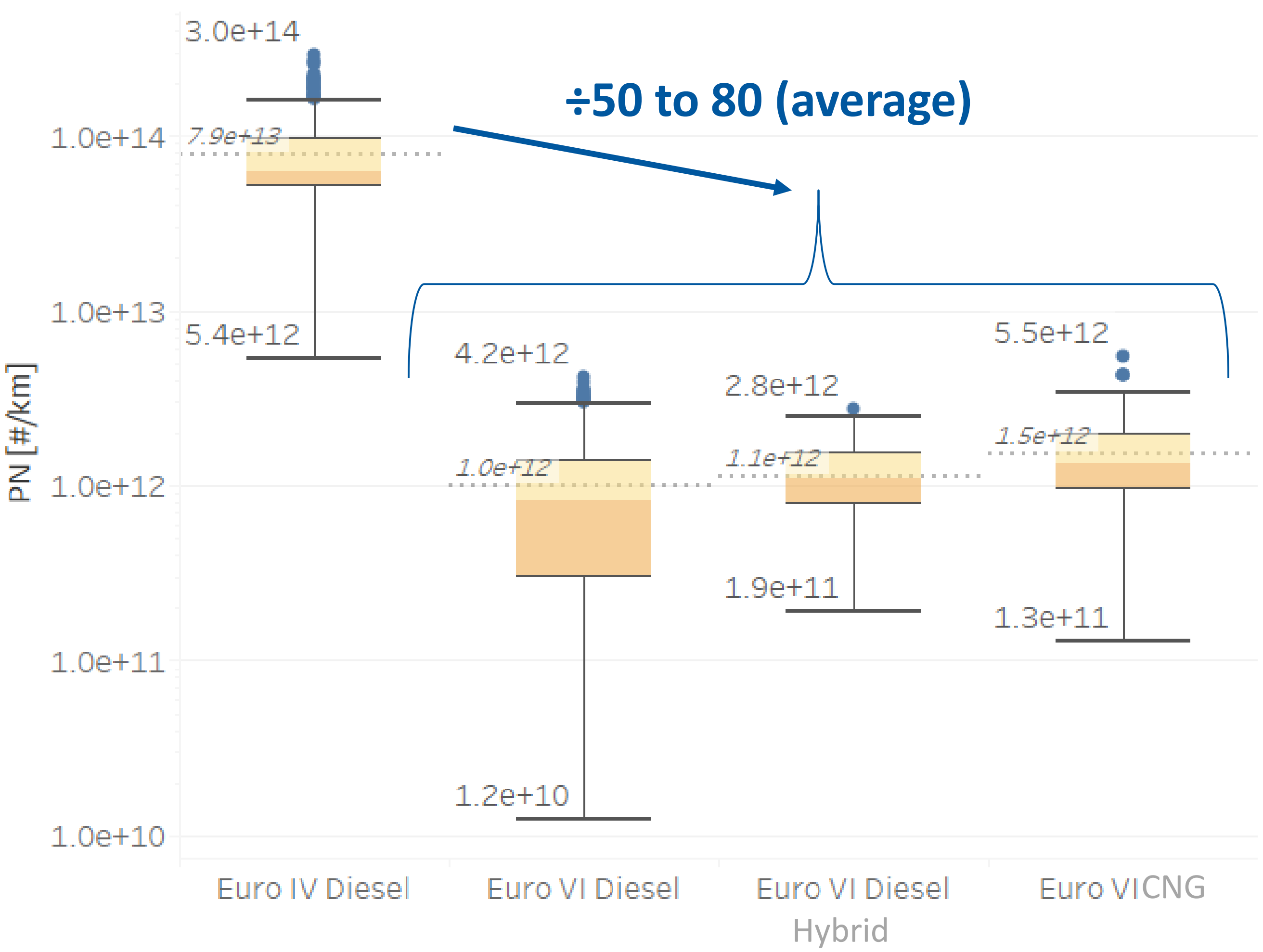
3. Emissions by bus technology

Emissions by bus technology: PN



- **Significant gap between Euro IV and Euro VI buses**
- **Great variability within Euro VI categories**
- **Statistically significant differences between Euro VI diesel and hybrid, diesel and CNG, but similar ranges**
- ***Results for PN>23nm***

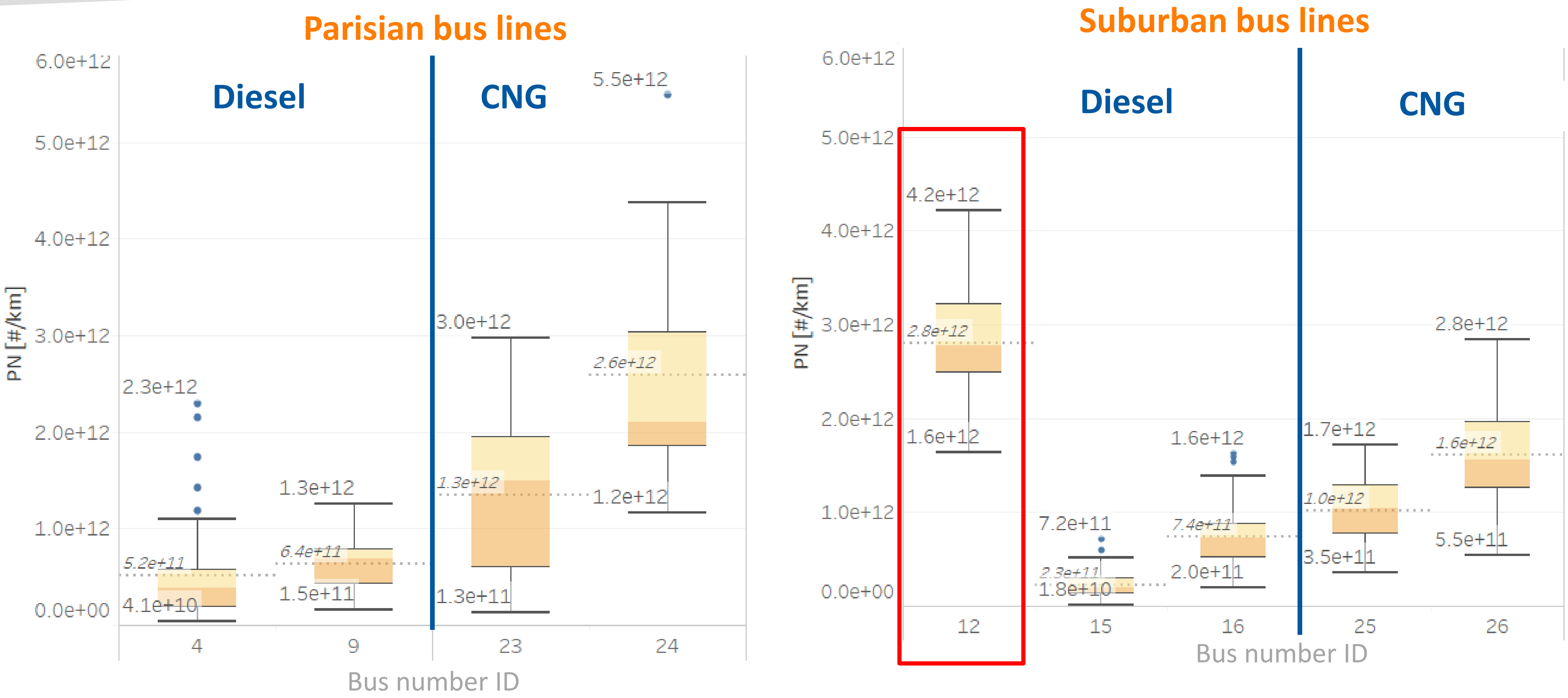
Emissions by bus technology: PN



Logarithmic scale

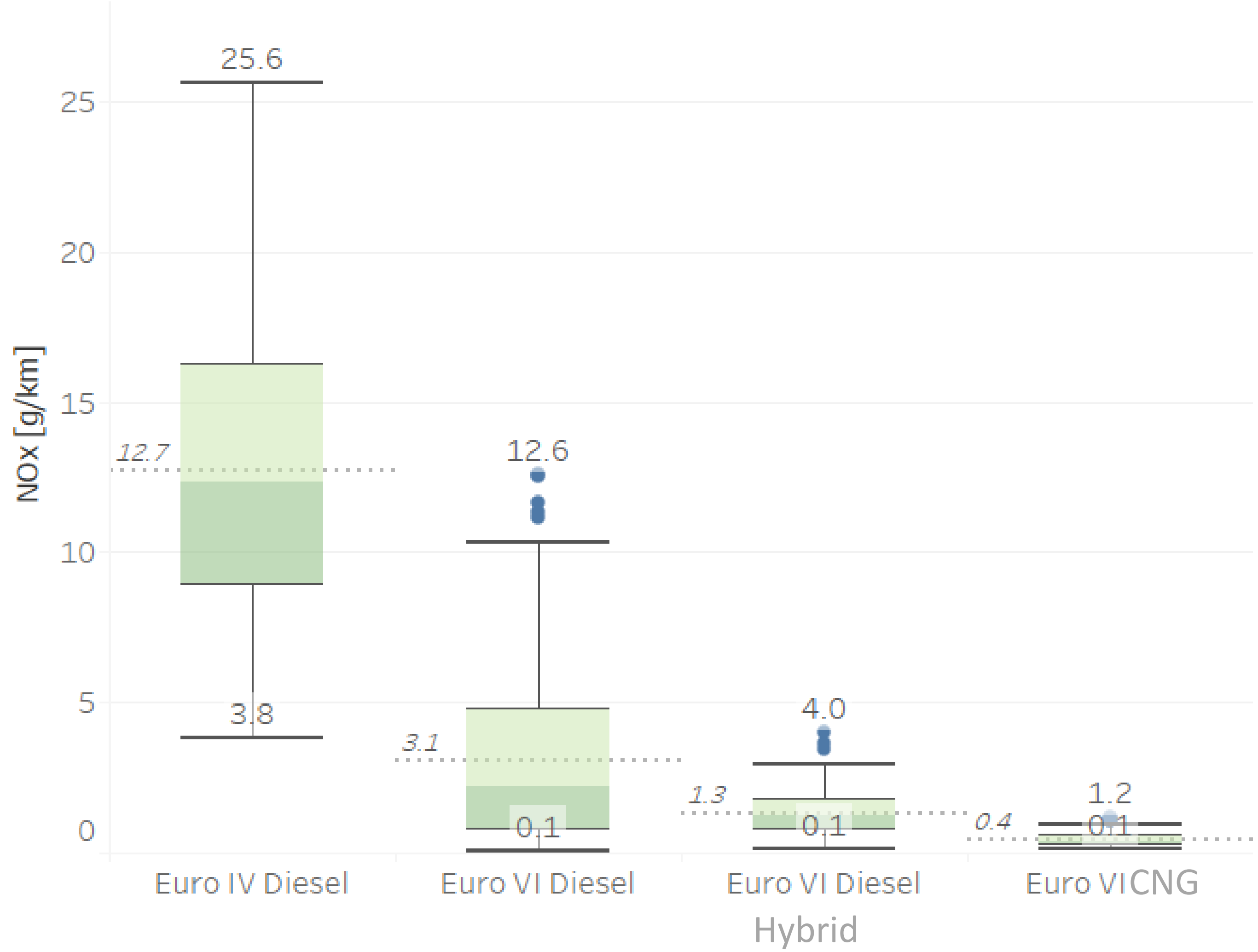
- **Significant gap between Euro IV and Euro VI buses**
- **Great variability within Euro VI categories**
- **Statistically significant differences between Euro VI diesel and hybrid, diesel and CNG, but similar ranges**
- ***Results for PN>23nm***

Emissions by bus technology: PN



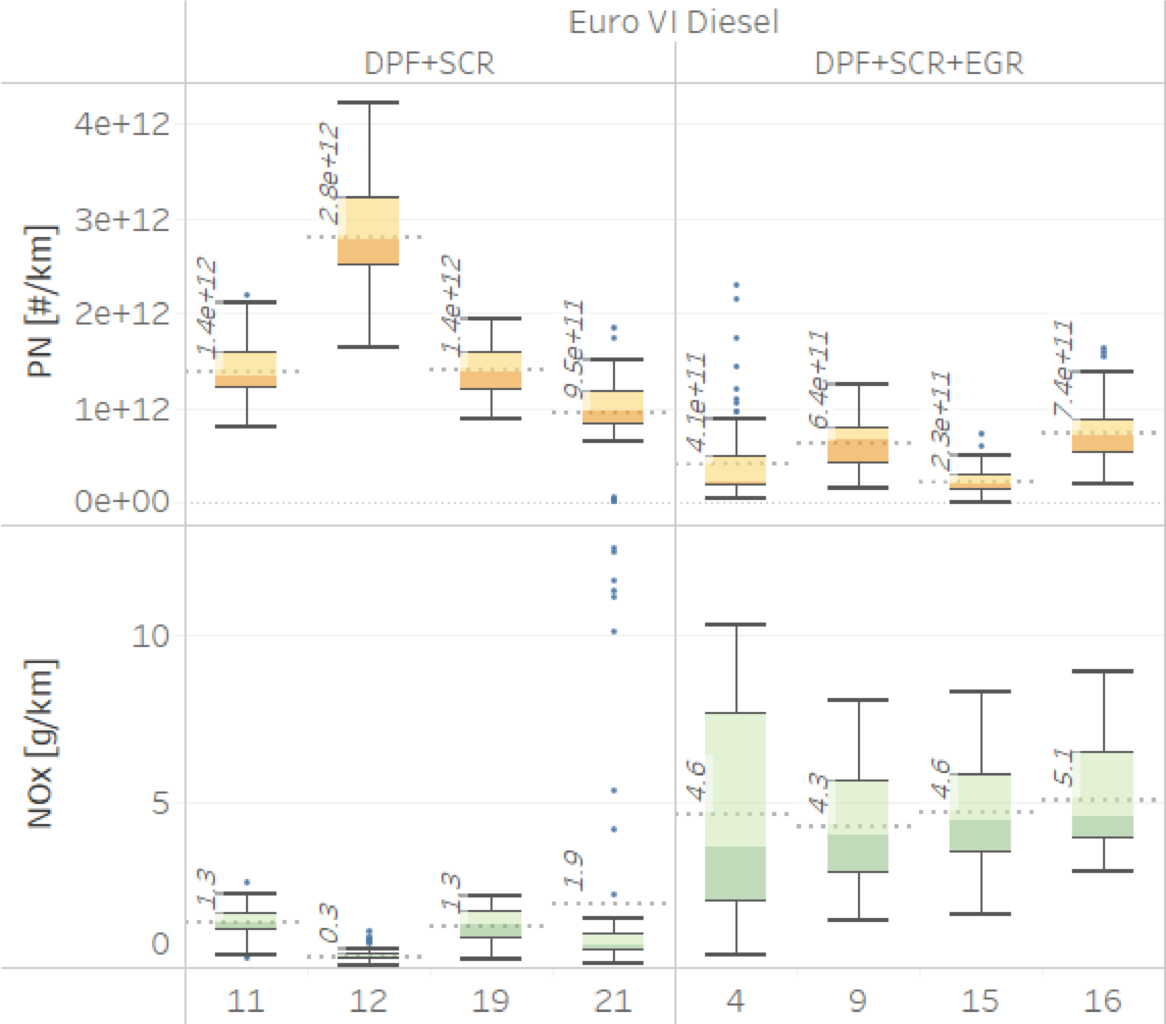
- ► **For similar operating conditions: mostly higher PN emissions for the tested CNG buses (1.5 to 7 times on average)**
- ► **But very different Euro VI diesel buses → can have higher PN emissions than CNG (at least twice higher on average)**

Emissions by bus technology: NO_x



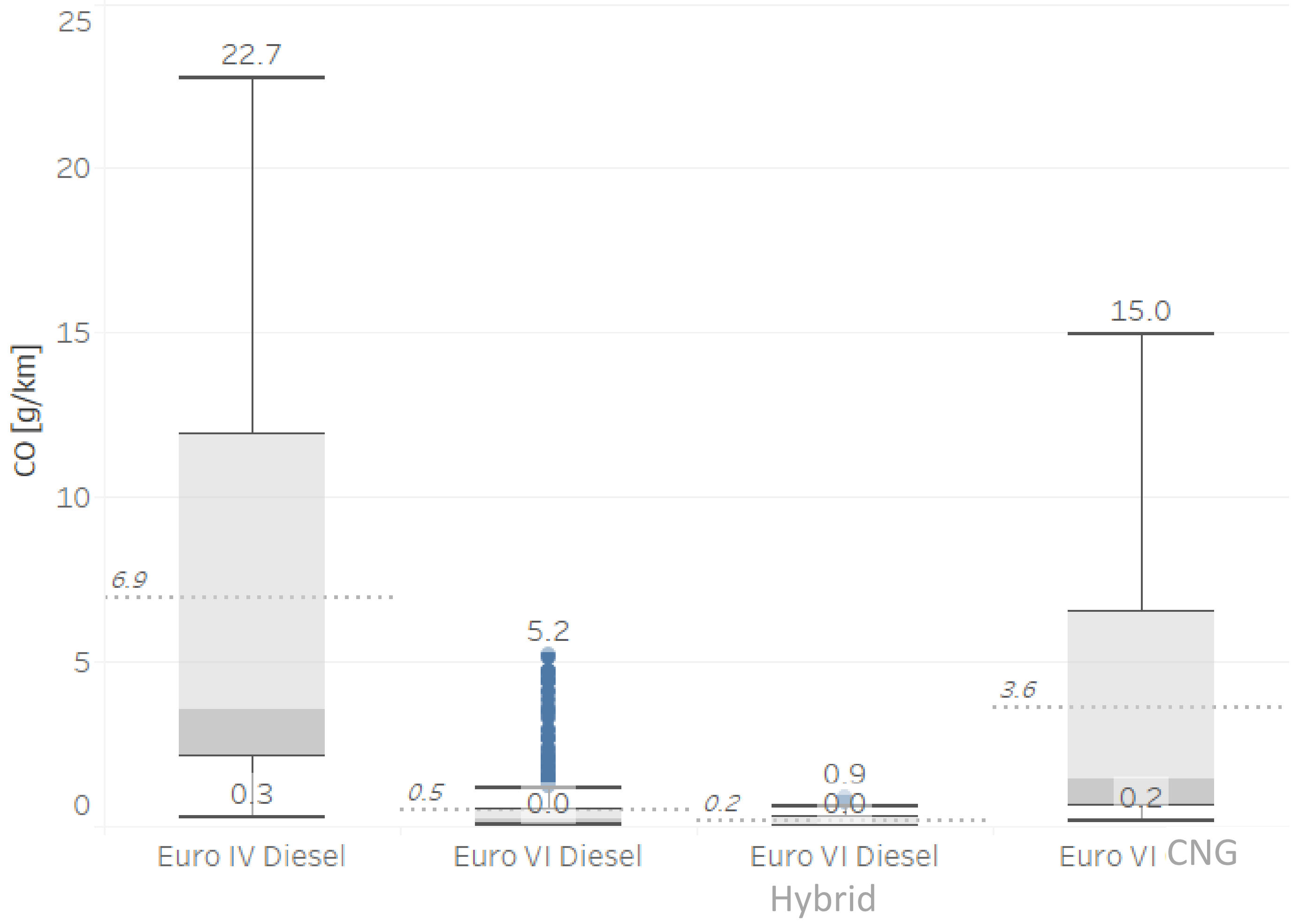
- Significant decrease in emissions from Euro IV to Euro VI diesel buses
- Even better performances for hybrid buses
- Very low variability for CNG buses

Emissions by bus technology: NO_x/PN trade-off



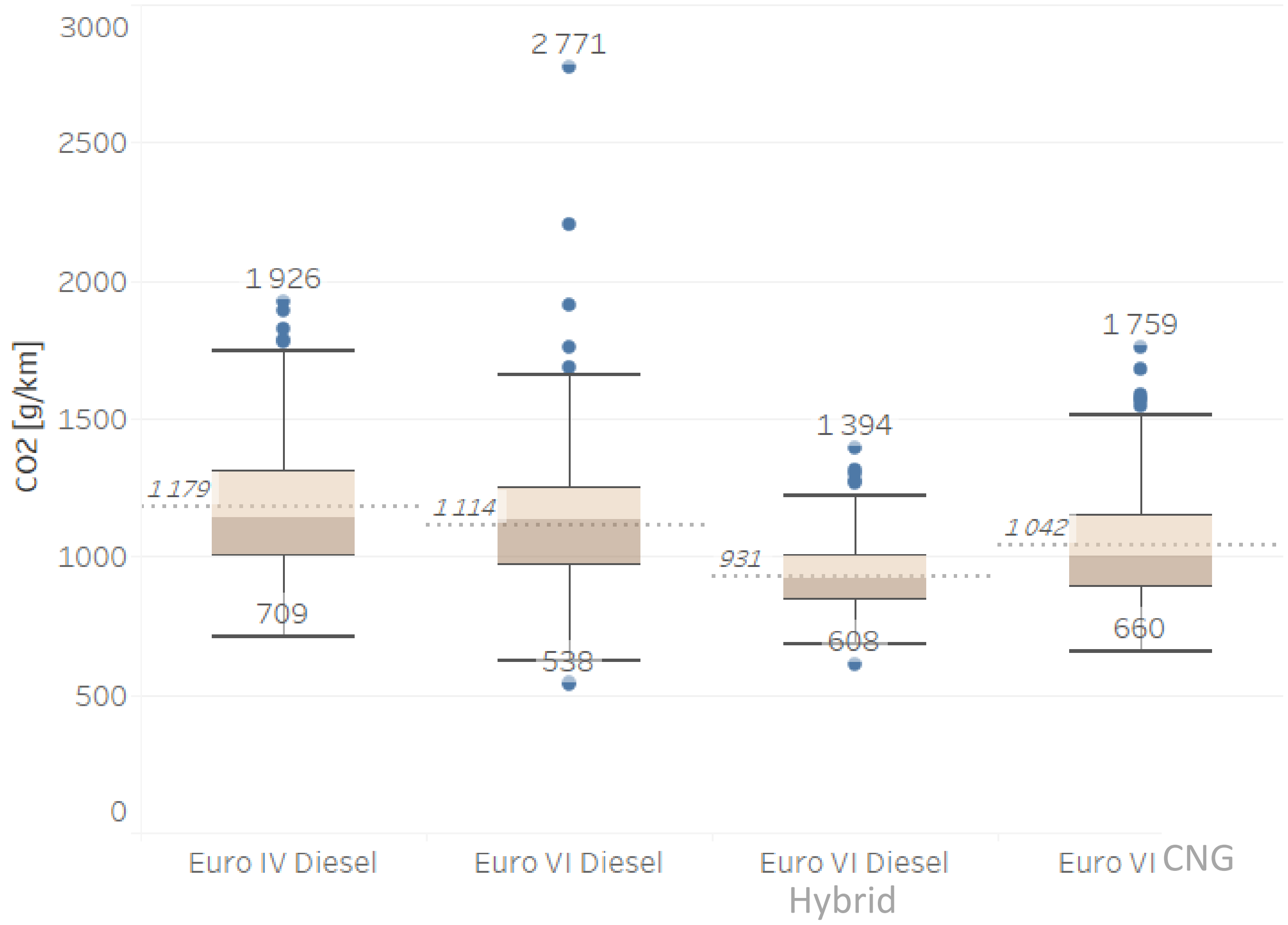
- **Difference in NO_x emissions between Euro VI diesel buses**
- **Opposite behaviour for PN emissions: NO_x/PN trade-off**
- **One hypothesis not tested in this study: different after-treatment systems**

Emissions by bus technology: CO



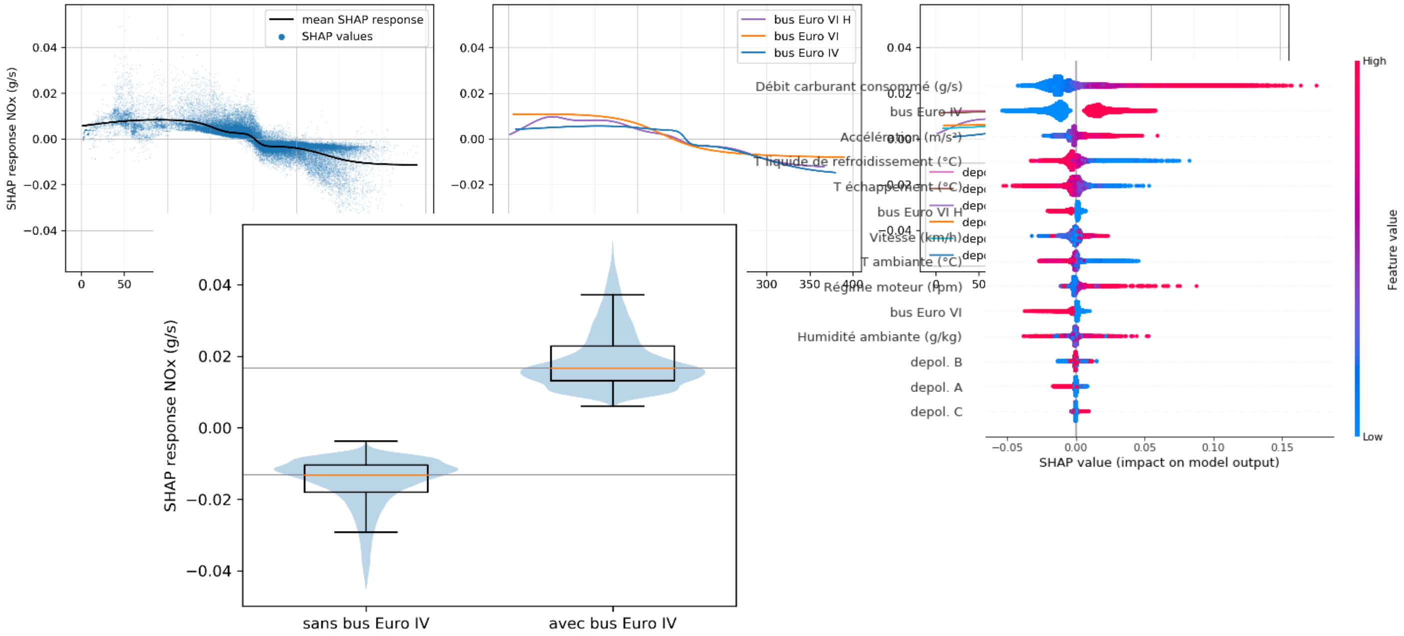
- **Very variable CO emissions within Euro IV buses**
- **Lower CO emissions for Euro VI diesel and hybrid buses**
- **2 CNG buses emitted high CO emissions**

Emissions by bus technology: CO_2



- -17% from Euro VI diesel to hybrid
- Slight decrease from Euro IV to Euro VI buses
- Similar ranges between Euro VI diesel and CNG

4. Influence of certain parameters



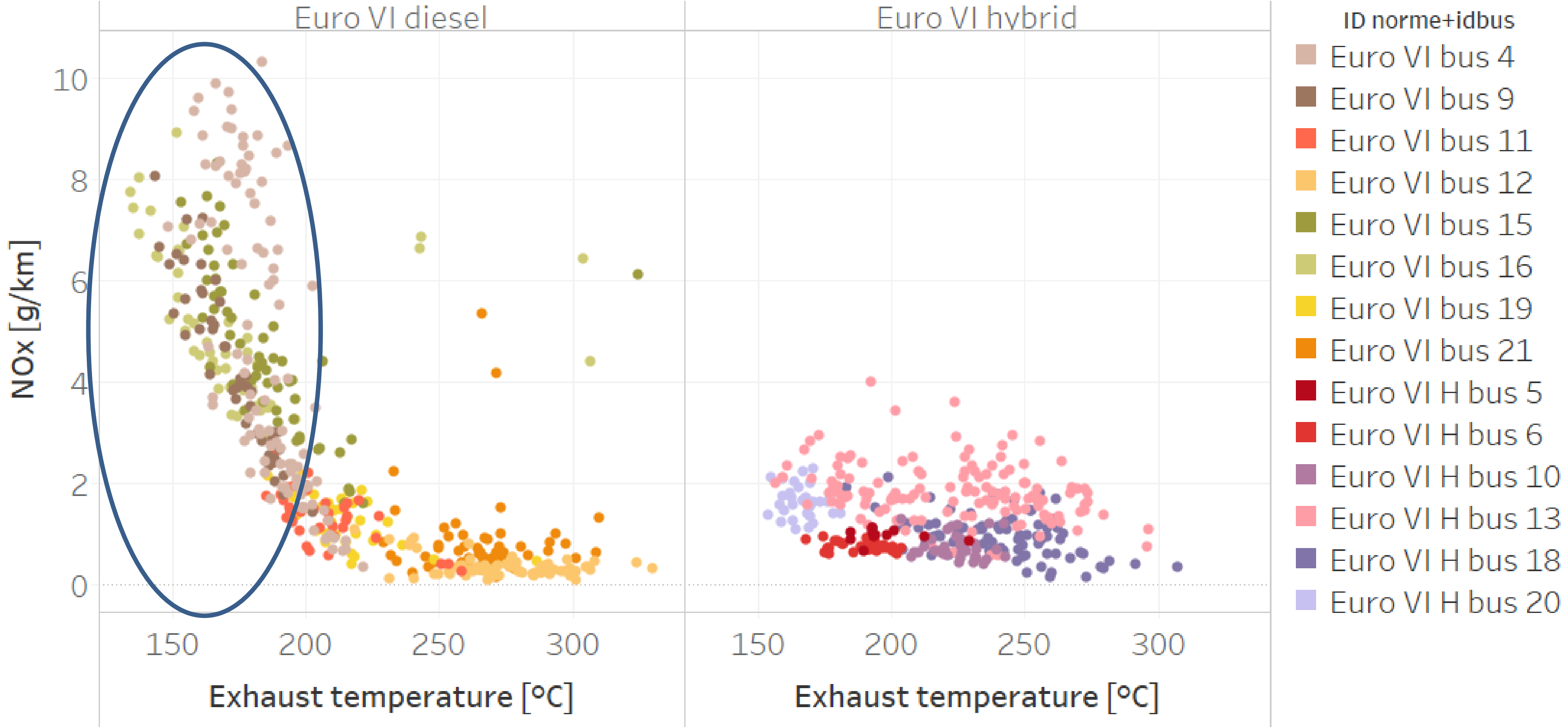
Methodology and significant parameters

- **Gradient-boosting model and explanatory analysis with a SHAP approach (for Euro IV diesel, Euro VI diesel, Euro VI hybrid buses), in addition to specific analysis (average speed, atypical events…)**

- **Most influential parameters on pollutants emissions:**
  - Euro standard
  - After-treatment systems failures
  - Exhaust temperature
  - Ambient temperature
  - Cold start
  - Driving style
  - Average velocity

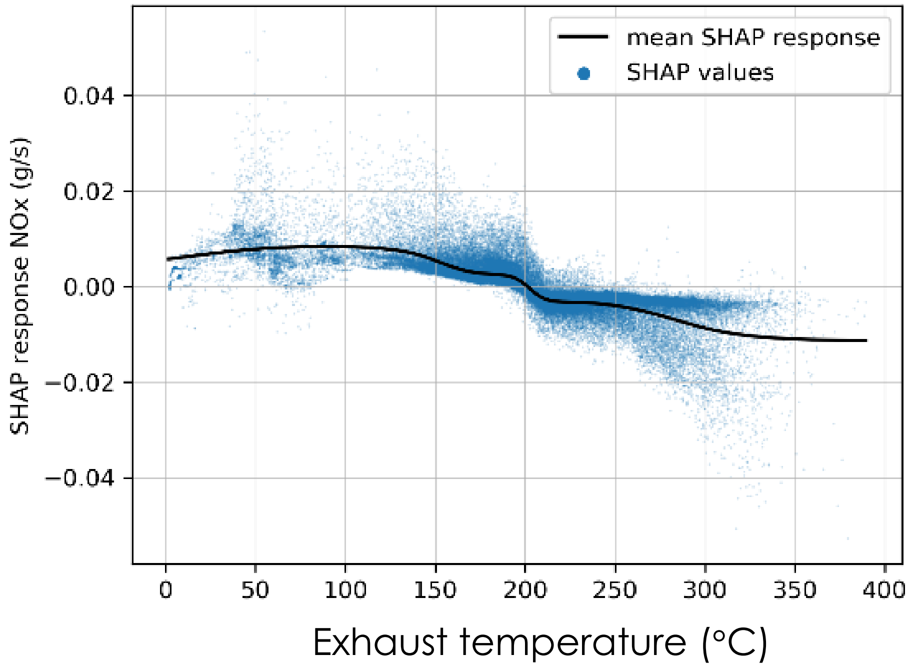
Example: exhaust temperature

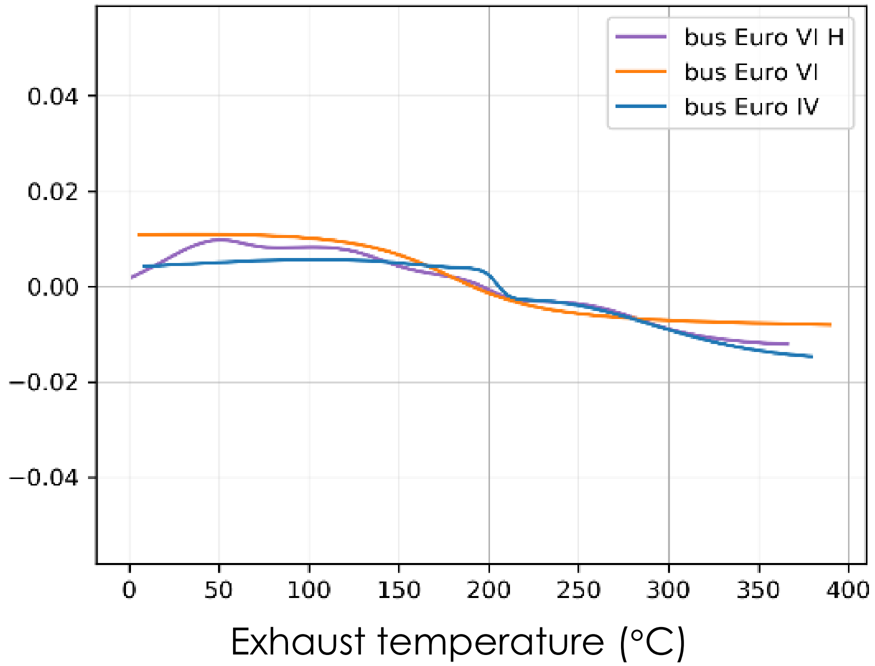
- Indicator of the operating conditions of the SCR and DPF (optimal if >200°C)
- High NO_x emissions if exhaust temp<200°C for Euro VI diesel buses



Example: exhaust temperature

- **Indicator of the operating conditions of the SCR and DPF (optimal if >200°C)**
- **High NO_x emissions if exhaust temp<200°C for Euro VI diesel buses**
- **+0.01 g/s of NO_x emissions if exhaust temp<200°C (about 3 g/km for an average velocity of 12 km/h)**

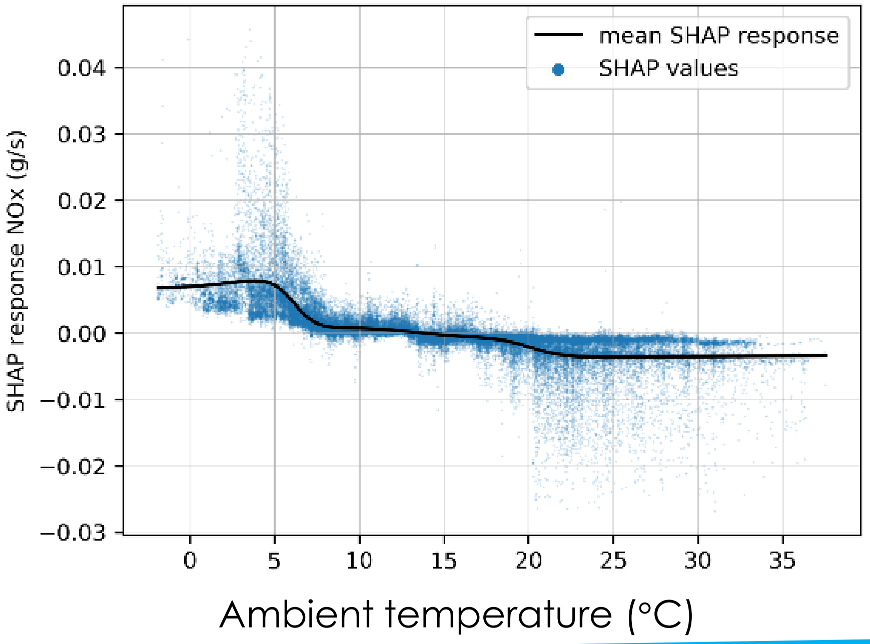


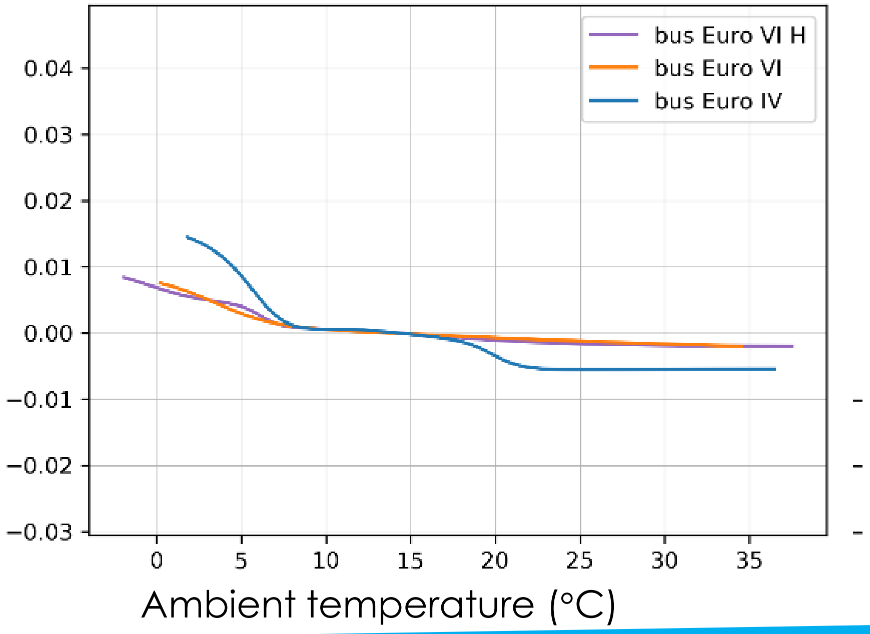


Example: ambient temperature

- **Low ambient temperature → suboptimal combustion conditions, or after-treatment systems functioning conditions (at hot engine and cold start)**

- **NO_x emissions for T<10°C :**
  - +40% for Euro IV diesel buses
  - +80% for Euro VI diesel buses (remained lower than Euro IV)
  - +13% for Euro VI hybrid buses
  - No significant effect on CNG buses





Example: cold start

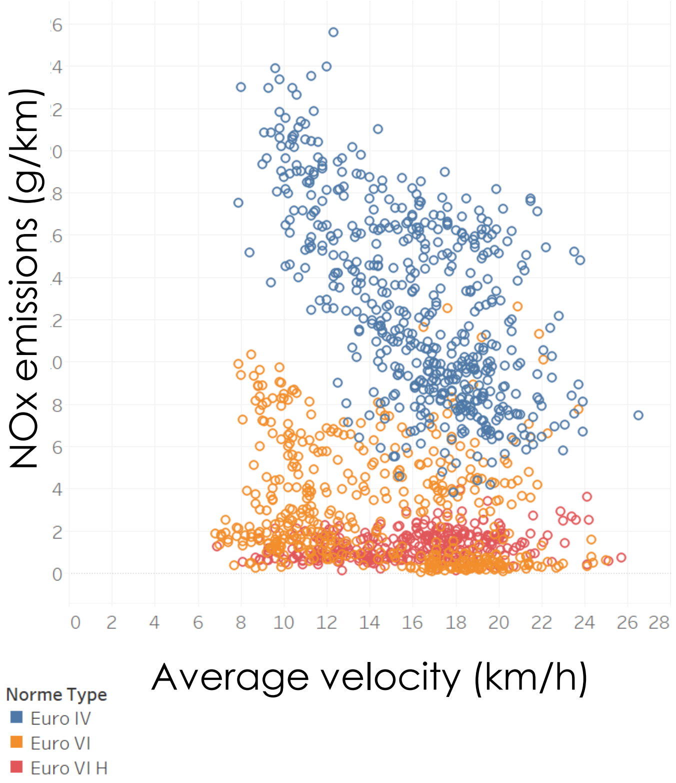
- Indicator : coolant temperature <70°C
- For all buses: duration 14 to 35 minutes (3 to 10 km), median 20 min (6 km)
- NO_x emissions 3 times higher on average at cold start for diesel and hybrid buses
- CNG buses: NO_x spikes if start at T_{amb}<8°C, otherwise no spikes measured

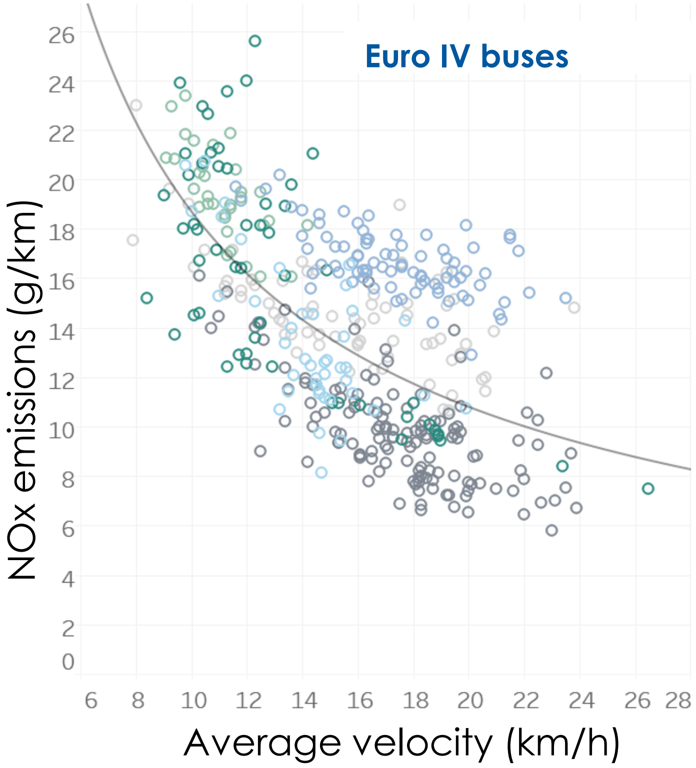
Example: average velocity

- **Moslty influent for Euro IV buses : faster trip → lower emissions**

- **From 8 to 20km/h, Euro IV**
  - NO_x : -42%
  - PN : -38%
  - CO_2 : -27%

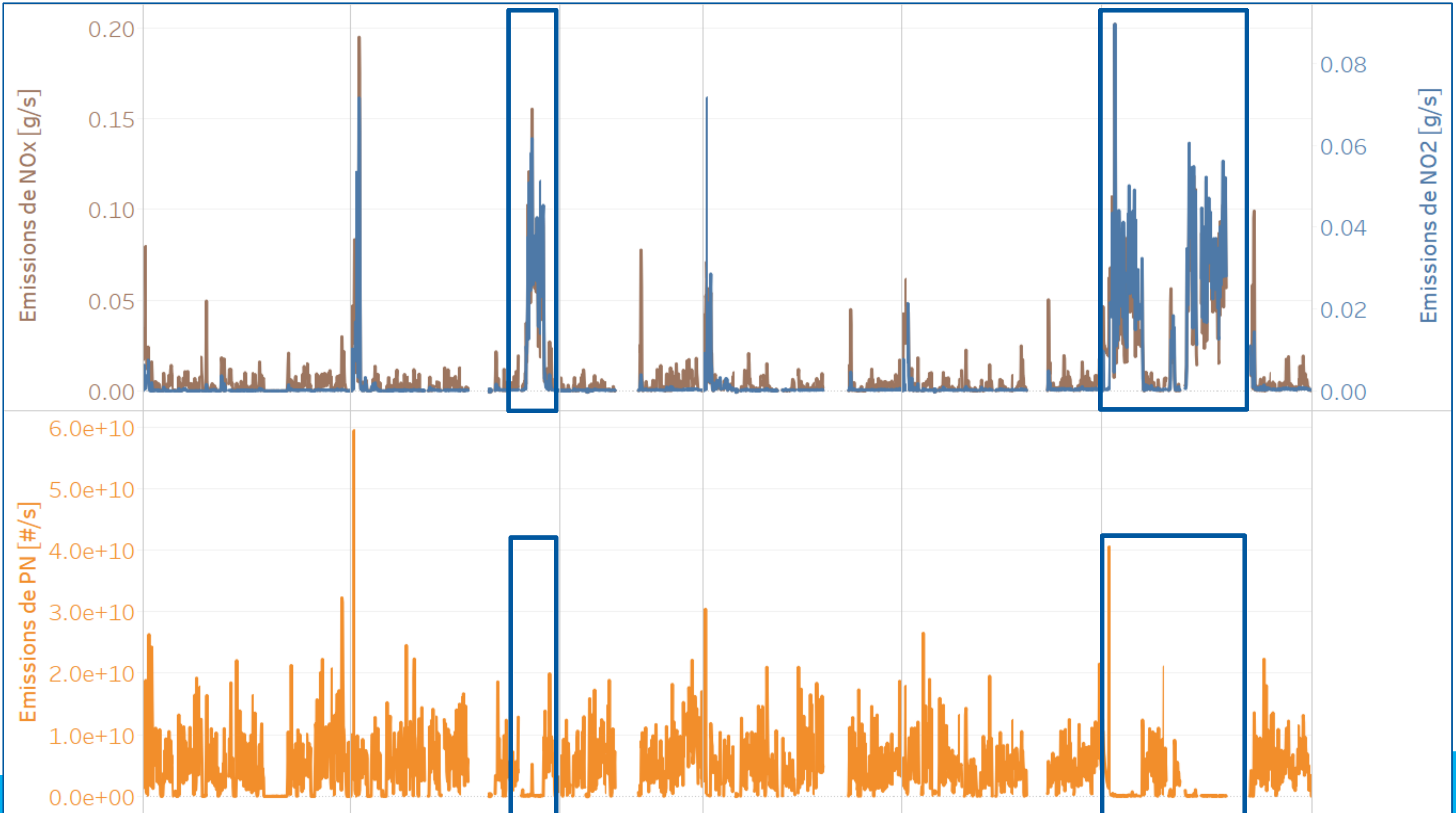
- **Hybrid buses emissions less sensitive to variation in average velocity (CO_2 and NO_x)**





Example: after-treatment systems failures

- **Urea injection system failure or lack of urea for SCR:**
  - 20 to 100 times more NO_x emissions
  - Reduced PN emissions
- **Very rare events (happened on two Euro VI diesel buses)**

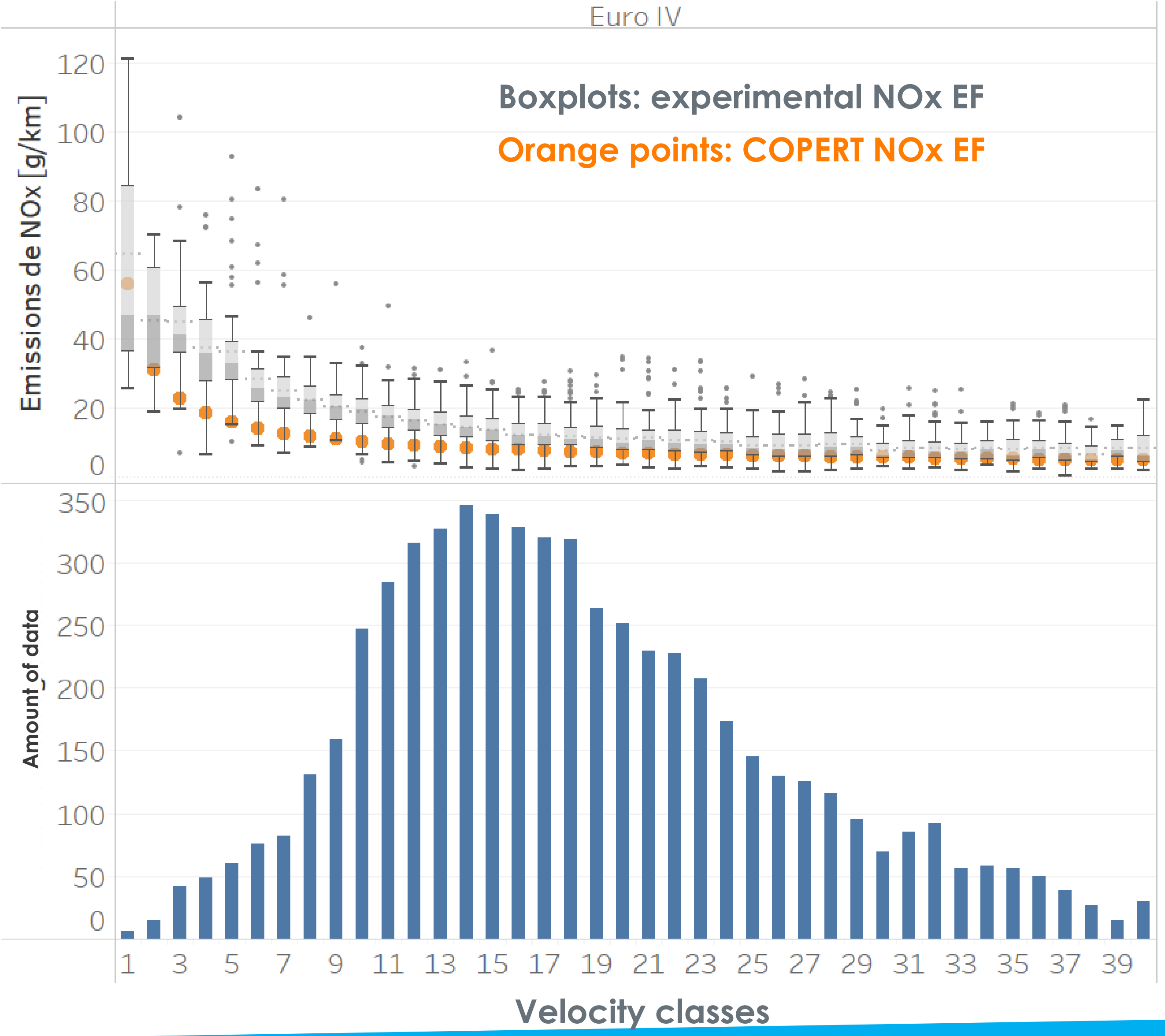


Urea injection system failure

5. Parallel with COPERT emission factors

Parallel with COPERT 5.2

- **In the specific experimental conditions of this study, COPERT underestimates NO_x emissions of the Euro IV and VI diesel buses tested, while remaining in the encountered ranges (first quartile)**
  - Euro IV diesel buses : median 1.6 times higher than COPERT 5.2
  - Euro VI diesel buses : median 2.8 times higher than COPERT 5.2



6. Conclusions

- Globally, lower emissions from Euro IV to Euro VI, with a great variability depending on various factors within Euro VI standard

- Proposal to share emission data to ERMES

- More pollutants to investigate: PN<23nm, NH_3, CH_4…

Thank you for your attention
Any questions?