The CONOX project: Pooling, sharing and analyzing European remote sensing data

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CONOX

- **CO**mprehending **NOx** remote sensing measuring
- **CO**mbining **NOx** remote sensing measurements
- **CO**mparing **NOx** real driving emissions
- **CO**llaborating on **NOx** real driving emission measurements

Questions

- How reliable are remote sensing measurements, especially the measurement of NOx emissions?
- For what purposes can we use remote sensing (in use market surveillance, establishing of emission factors for emission calculations, detecting high-emitters, etc.)?
- How can we use remote sensing in an efficient way?
- How can remote sensing complement RDE testing?

Comparing remote sensing data with PEMS and other official tests data. Can we detect high emitting car models with the help of remote sensing?

Collaborating: how can remote sensing complement chassis dynamometers and PEMS measurements for in service surveillance and the measurement of real driving emissions?

Comprehending: Developing of a method that allows comparison of the emission rates from laboratory and PEMS studies with those derived from remote sensing

Combining: Establishing of a database and pooling and sharing data of remote sensing measurements

The CONOX/ERMES Remote Sensing Database

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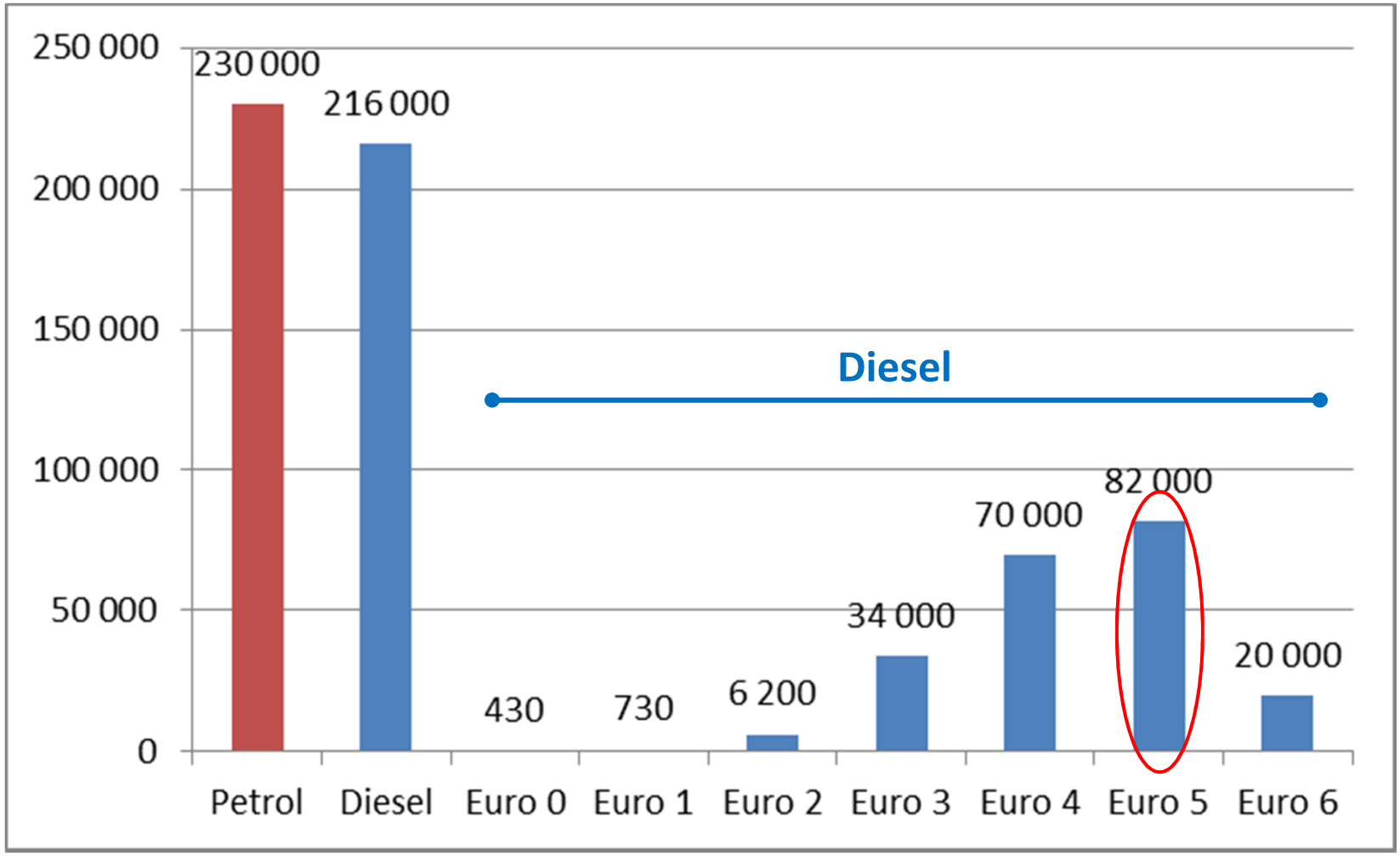
CONOX… or the power of big data

- ~750,000 remote sensing measurements from across Europe, and growing…
- Covering different fleets (makes & models), vehicle ages, Euro standards, etc….
- Covering a wide range of driving conditions and ambient conditions
- ***Keywords:*** pooling, sharing and collaborating – a great ground for *understanding and monitoring real driving emissions* in Europe (and elsewhere)

No. of database records for **passenger cars**



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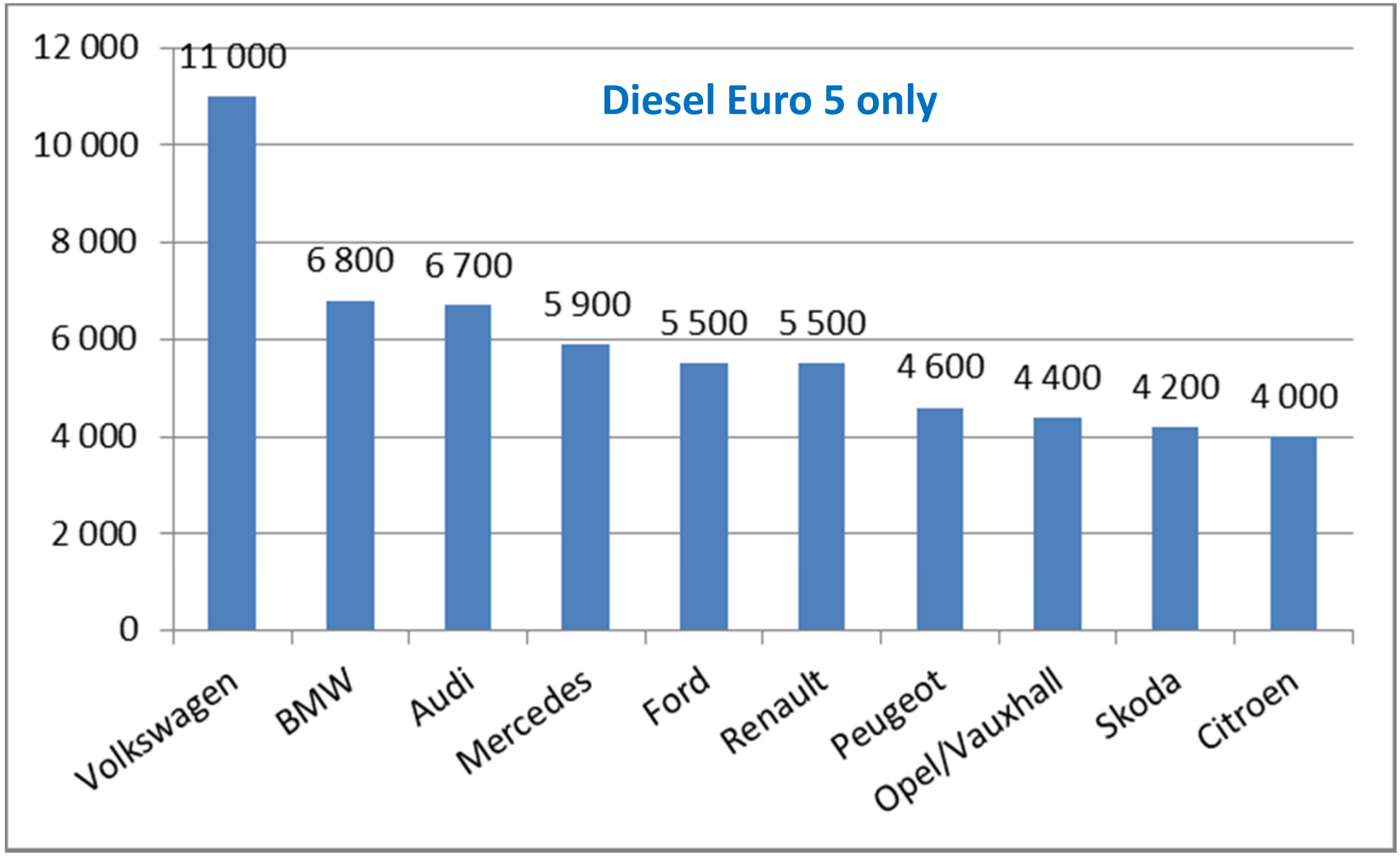
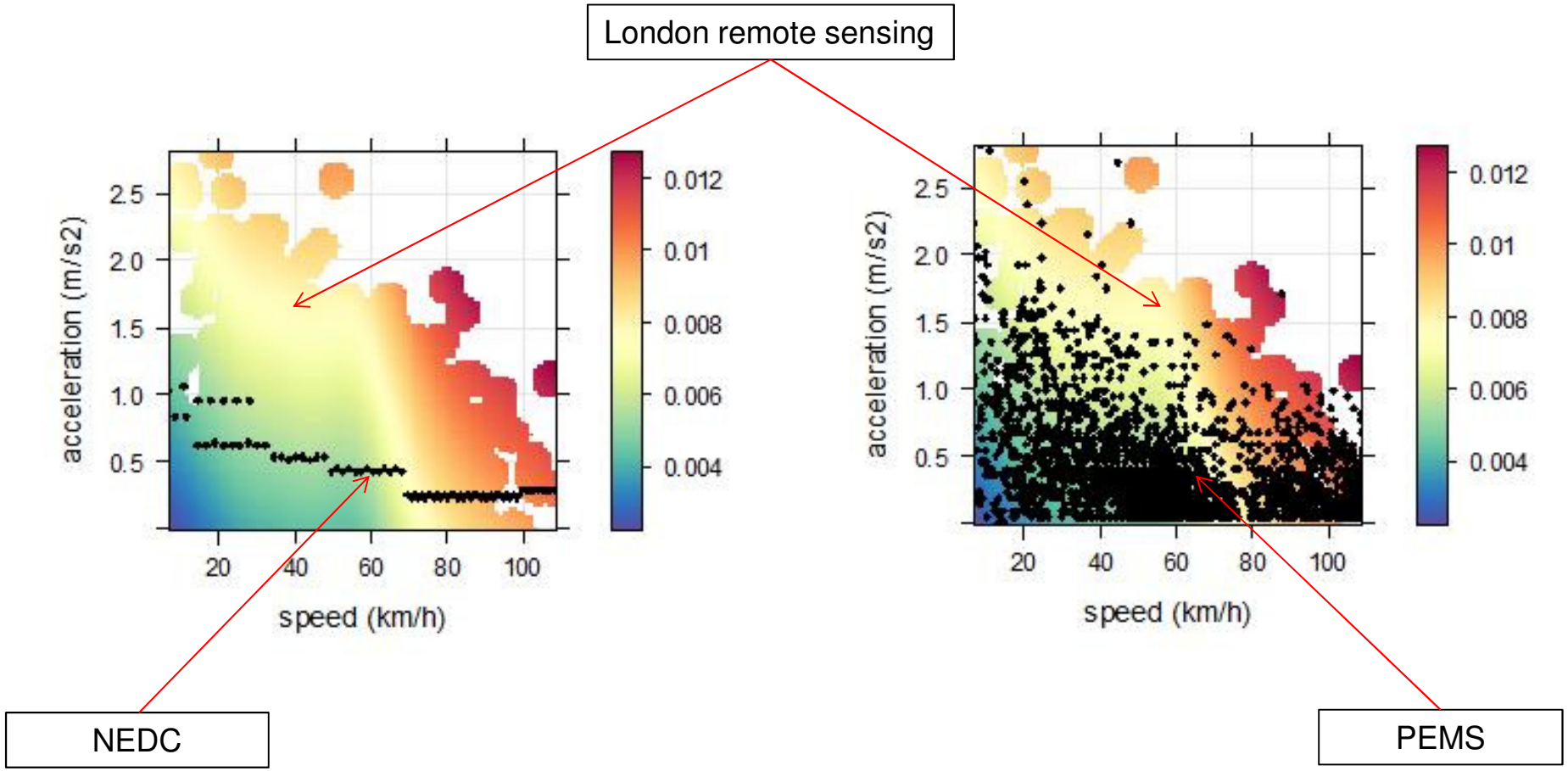


Covering lots of driving and ambient conditions



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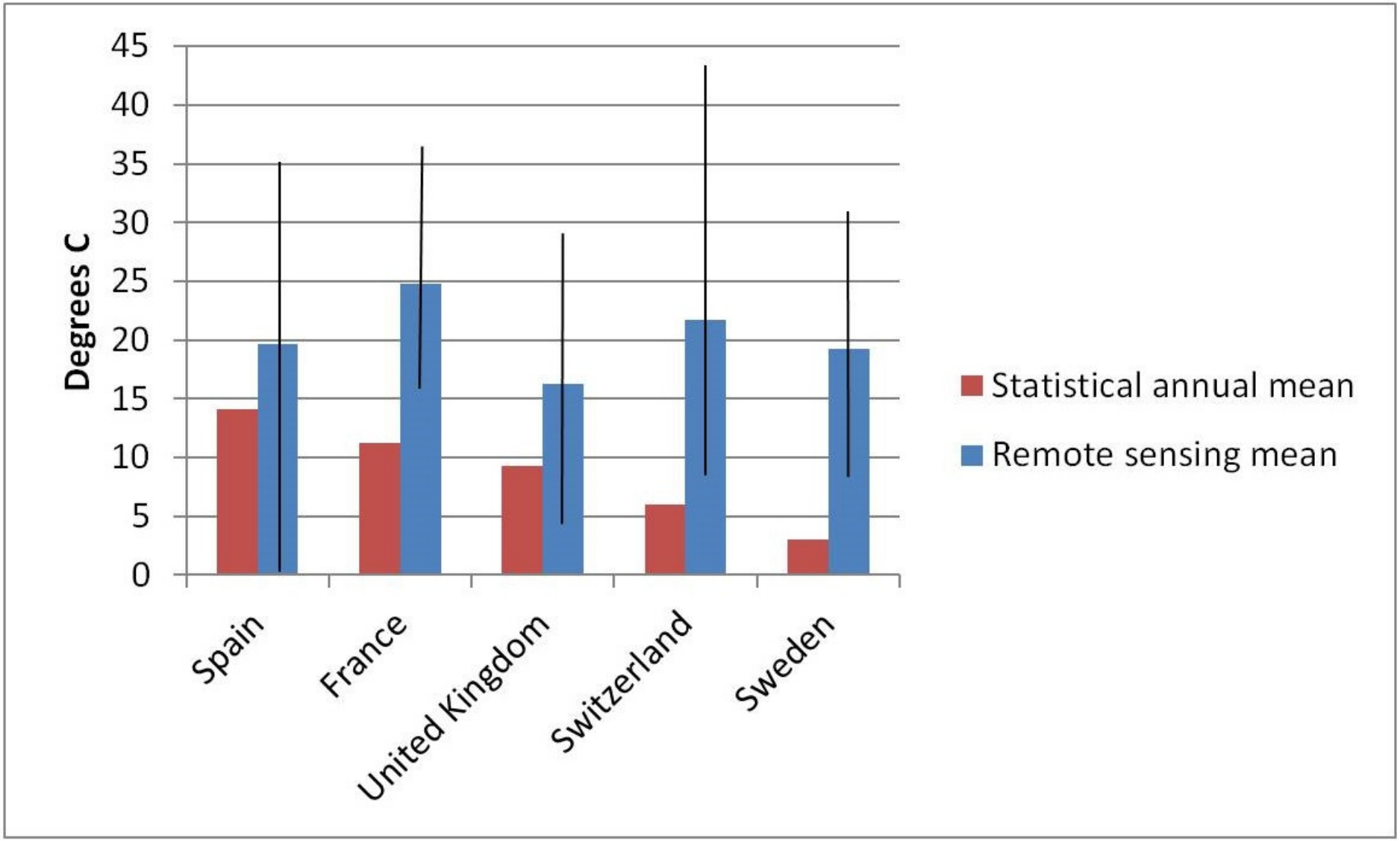

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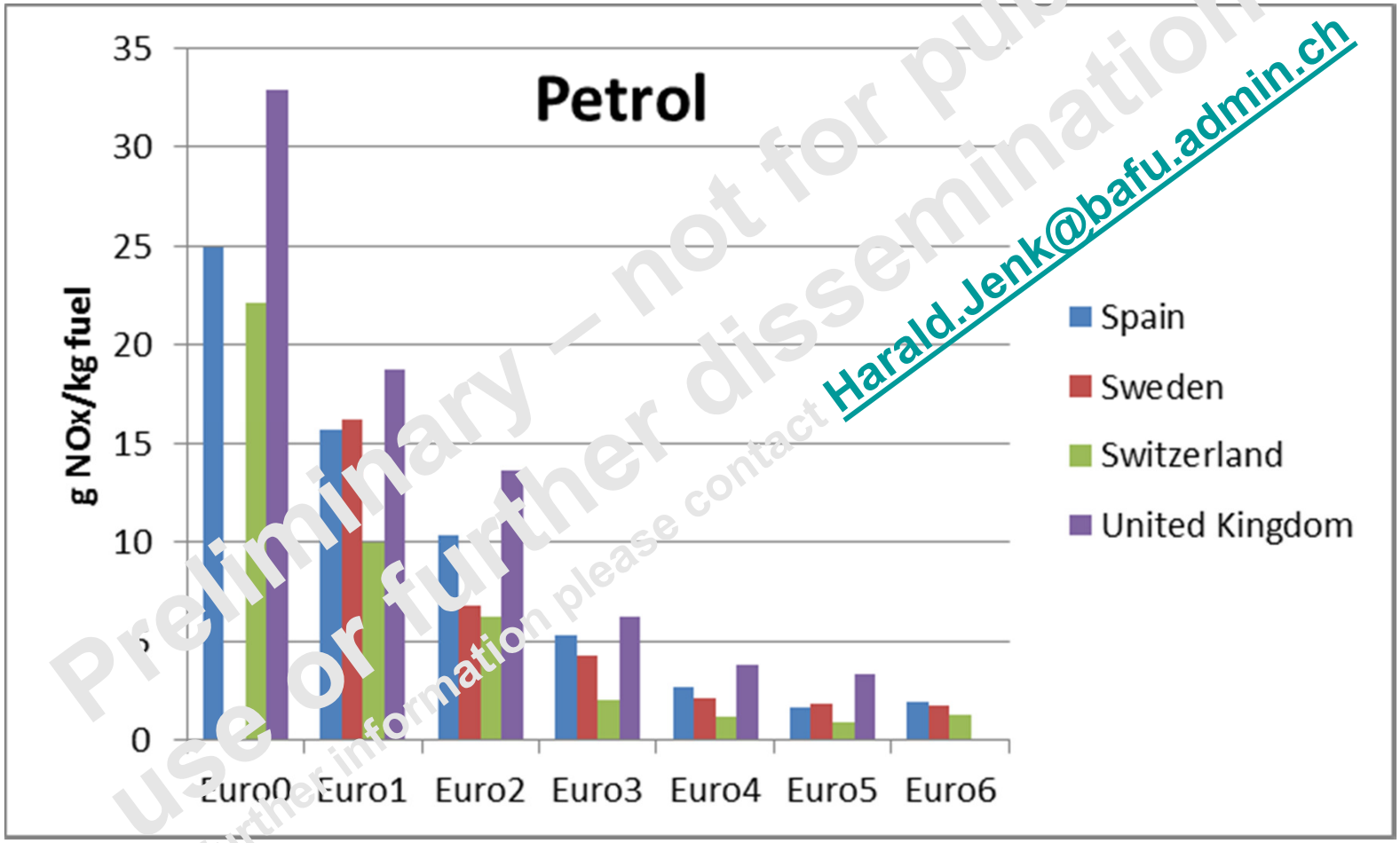
Cross-country comparison of NO_x emissions

~450,000 remote sensing records



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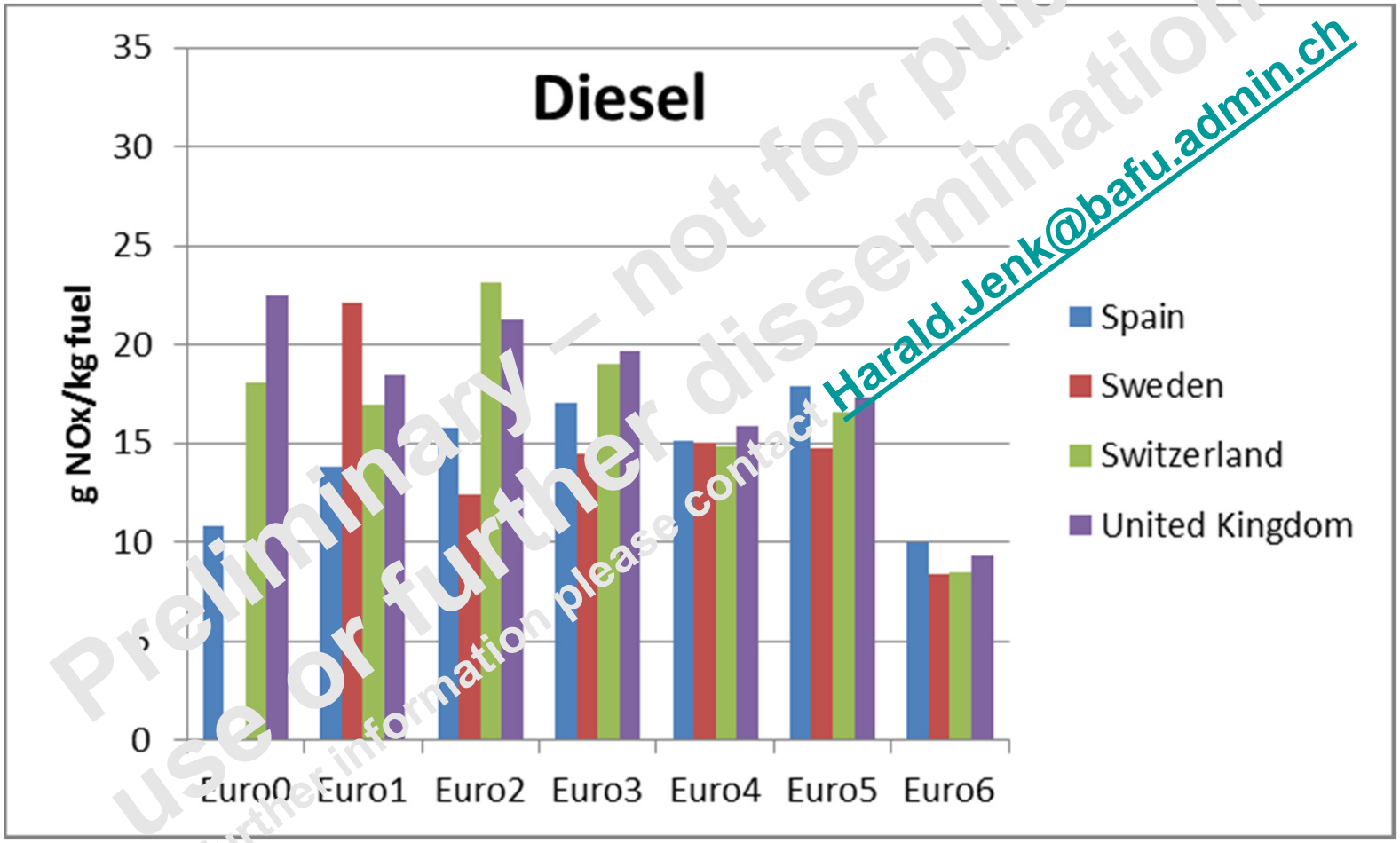

NO_x fleet estimation from remote sensing and comparison with on-board measurements from official tests

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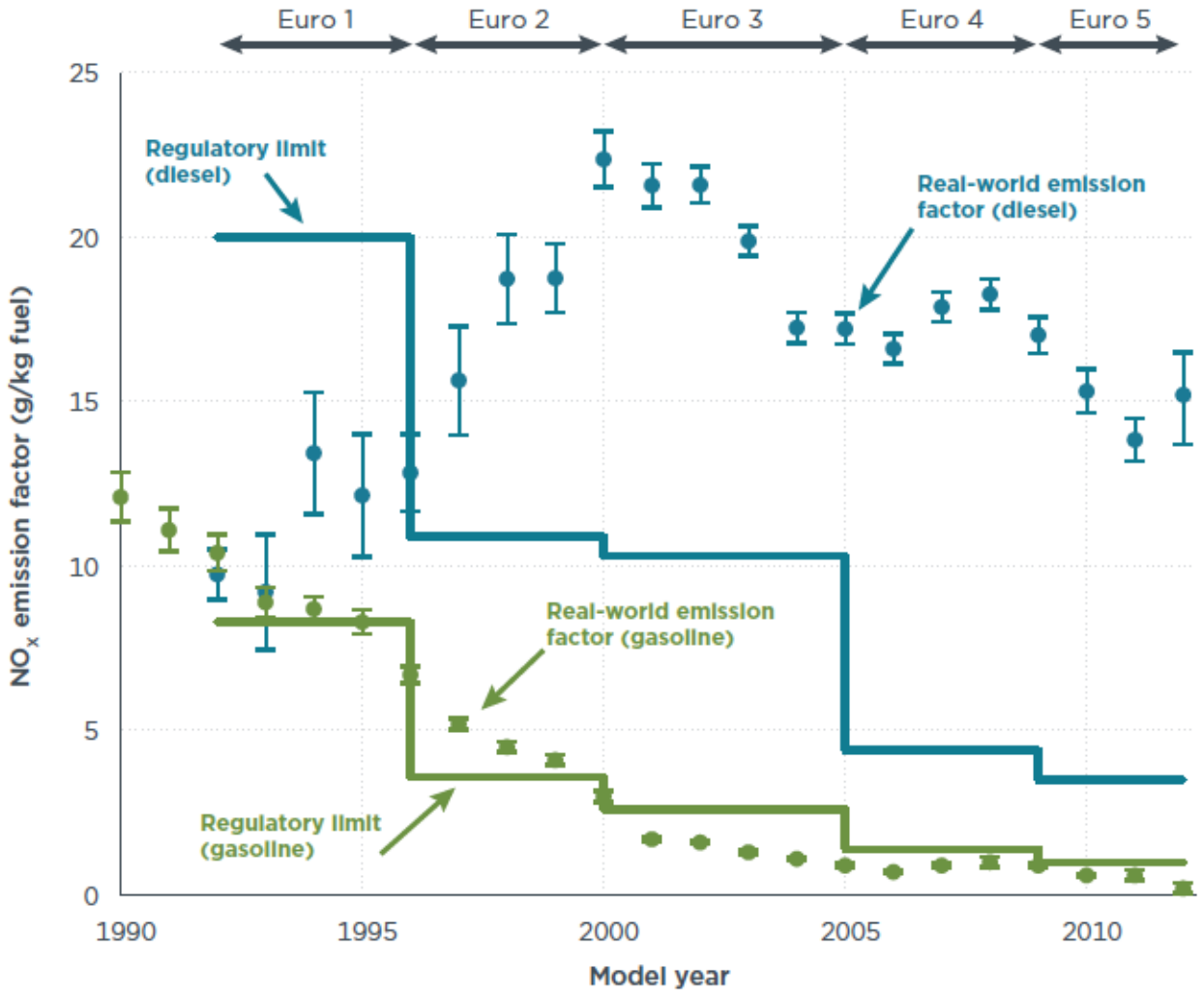
Remote sensing data had shown wide disparity in petrol v. diesel car NO_x emissions, and substantial non-compliance by diesel cars



Zurich data based on Chen and Borken-Kleefeld (2014)

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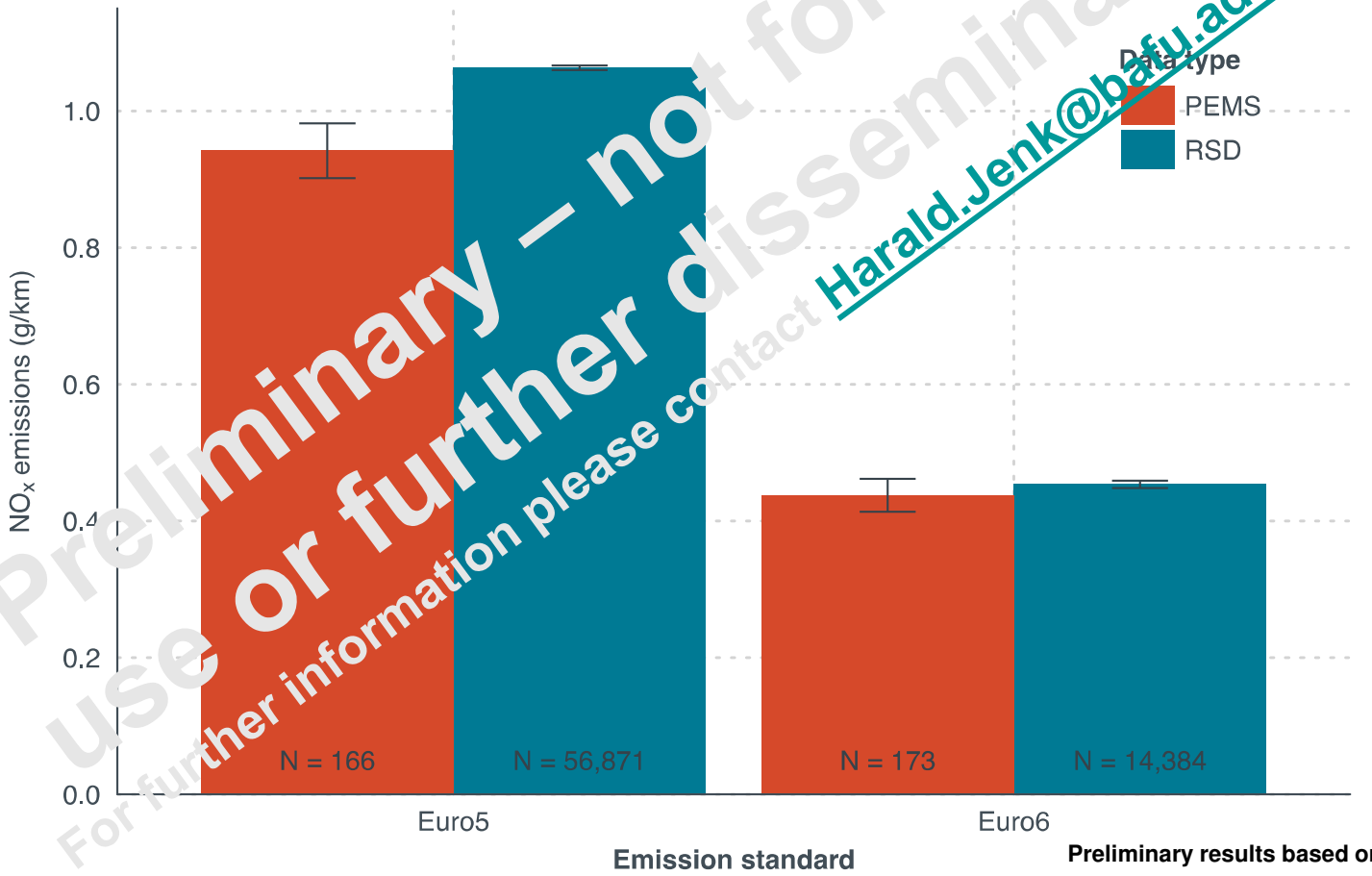
How RSD and on-board (i.e PEMS) results compare for NOx emissions ?

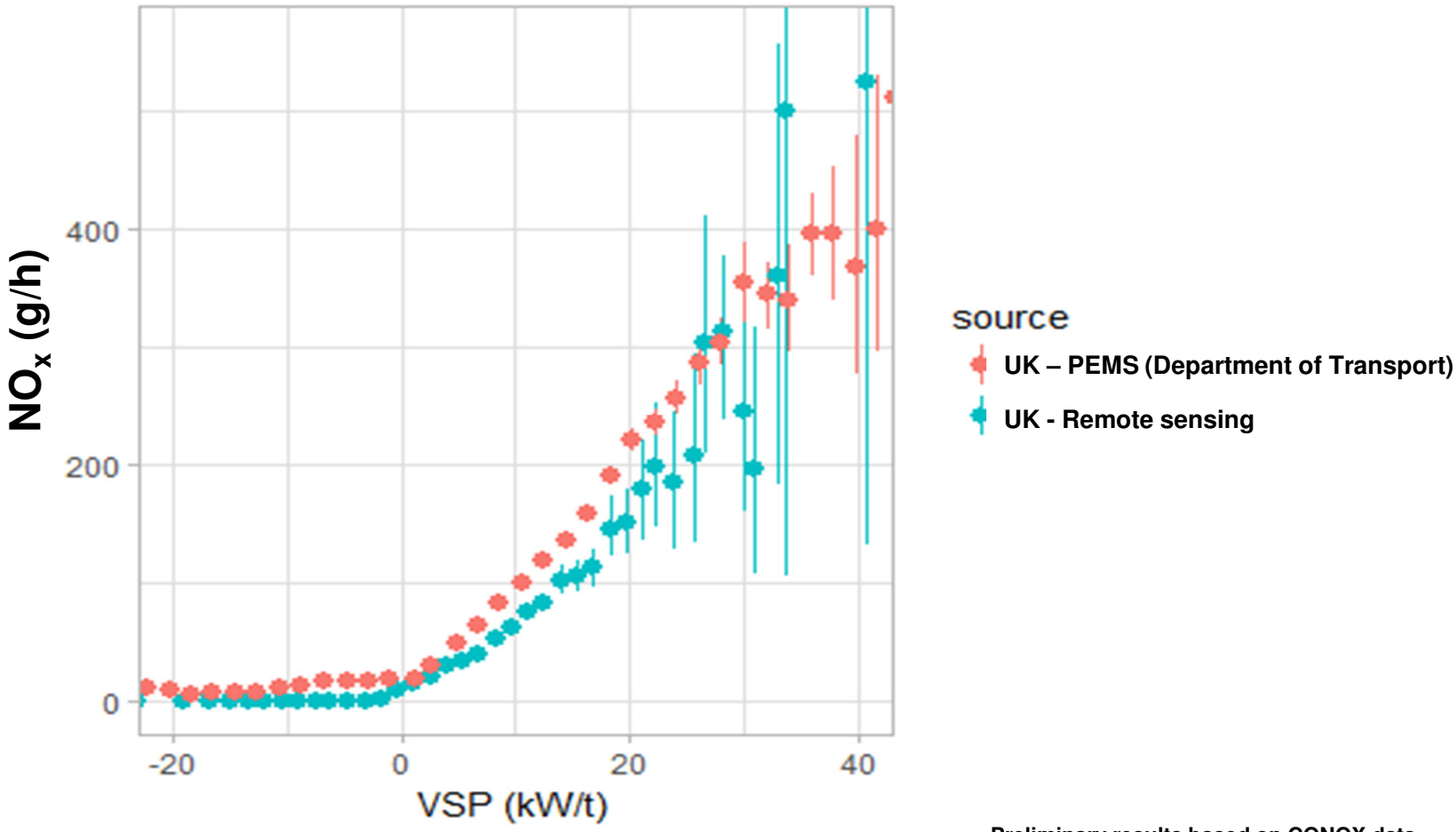
- **NO_x emissions from Euro 5/6 diesel passenger cars**
  - **Average comparison with all available tests from on-road campaigns (not the exact same vehicles)**
  - **Good overall correlation in g/km**



Preliminary results based on CONOX data

How RSD and on-board (i.e PEMS) results compare for NOx emissions ?

- **Instantaneous NO_x emissions for Euro 6 diesel passenger cars as a function of the vehicle specific power**



Preliminary results based on CONOX data

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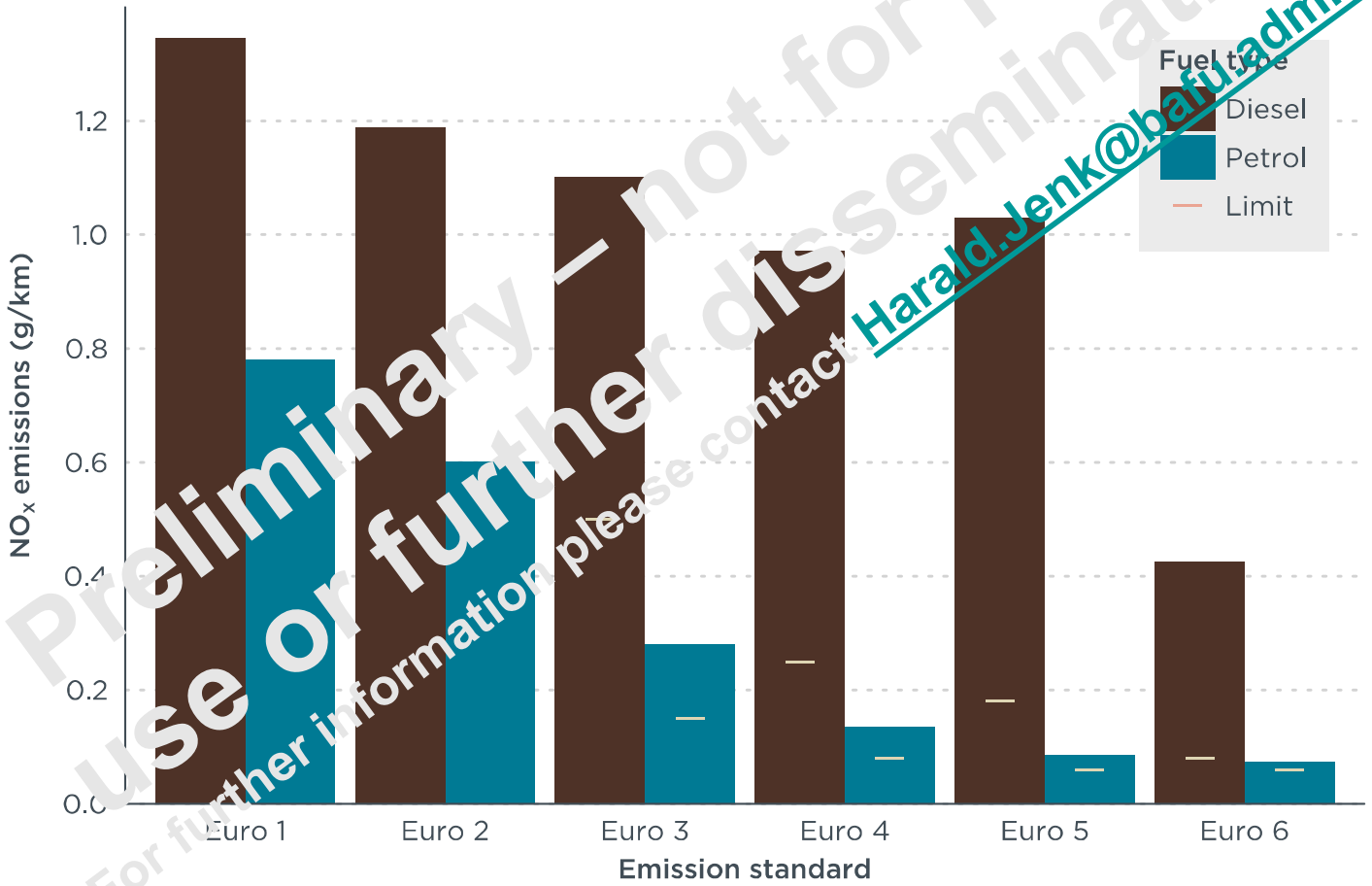
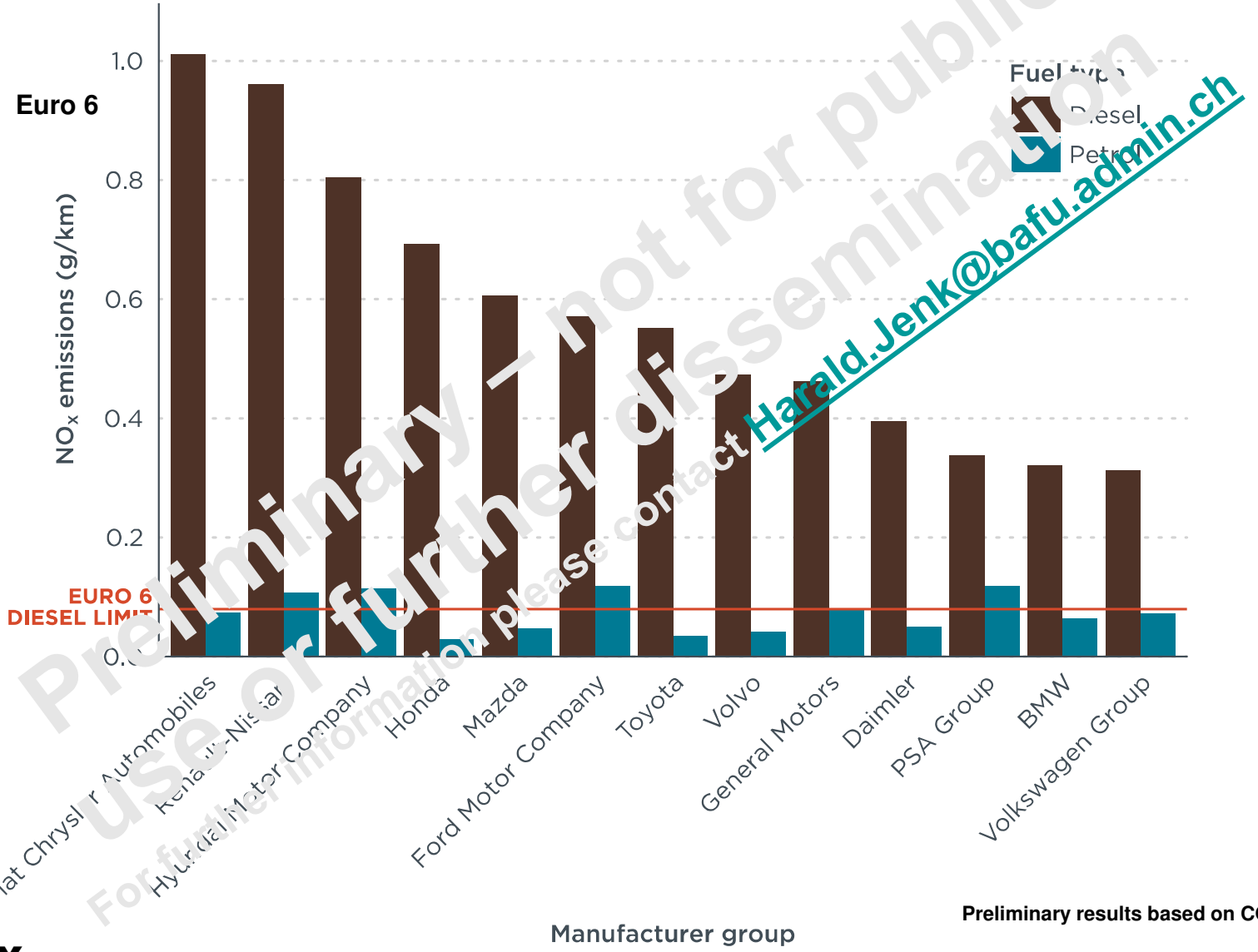
Remote sensing has the ability to quantify in-use emissions in a number of different ways - per fuel type and Euro standard

- **Overview of NOx emissions per km of the fleet as driven, from Euro 1 to Euro 6, gasoline and diesel**



Preliminary results based on CONOX data

Remote sensing has the ability to quantify in-use emissions in a number of different ways - per fuel type, Euro standard and group of manufacturer



Preliminary results based on CONOX data

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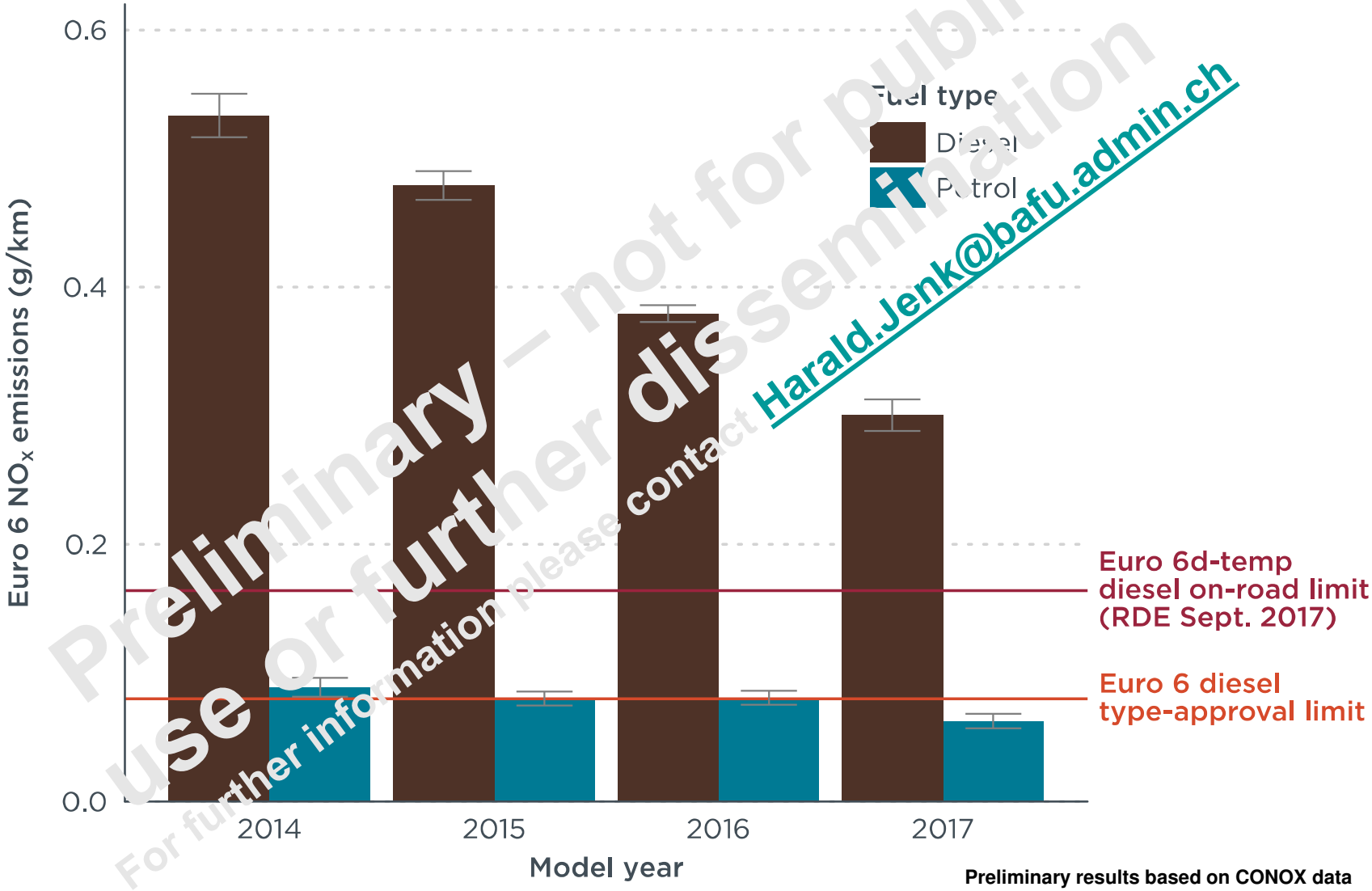
Remote sensing has the ability to track the development of in-use emissions over time - per fuel type, Euro standard and model year



Preliminary results based on CONOX data

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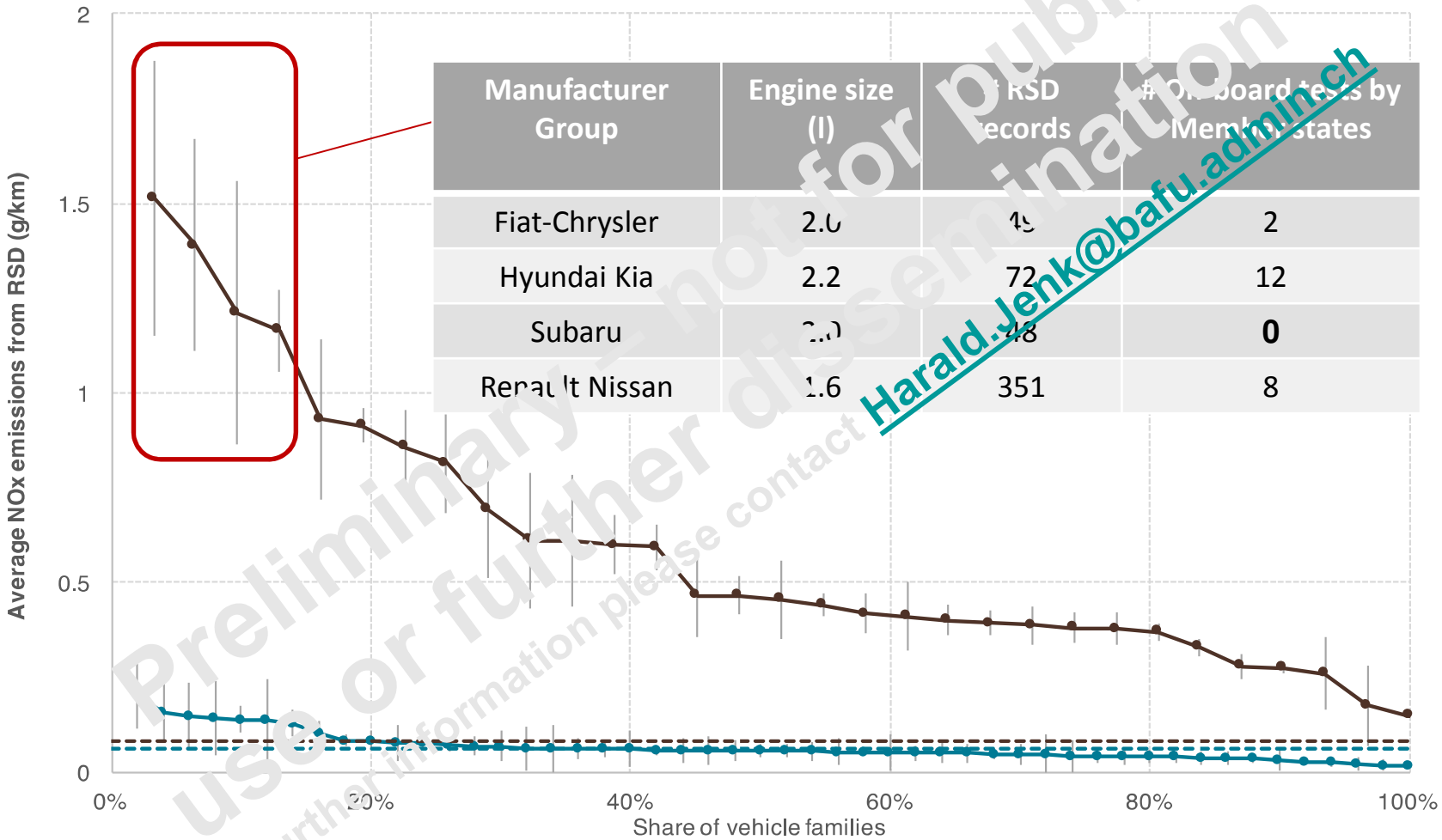
Highest to lowest emitting groups of engines by fuel type compared to their respective type-approval limit for Euro 6



Manufacturer Group	Engine size (l)	# RSD records	# On-board tests by Member States
Fiat-Chrysler	2.0	45	2
Hyundai Kia	2.2	72	12
Subaru	2.0	48	**0**
Renault Nissan	1.6	351	8

CONOX remote sensing data is covering > 90 % EU sales families

Preliminary results based on CONOX data

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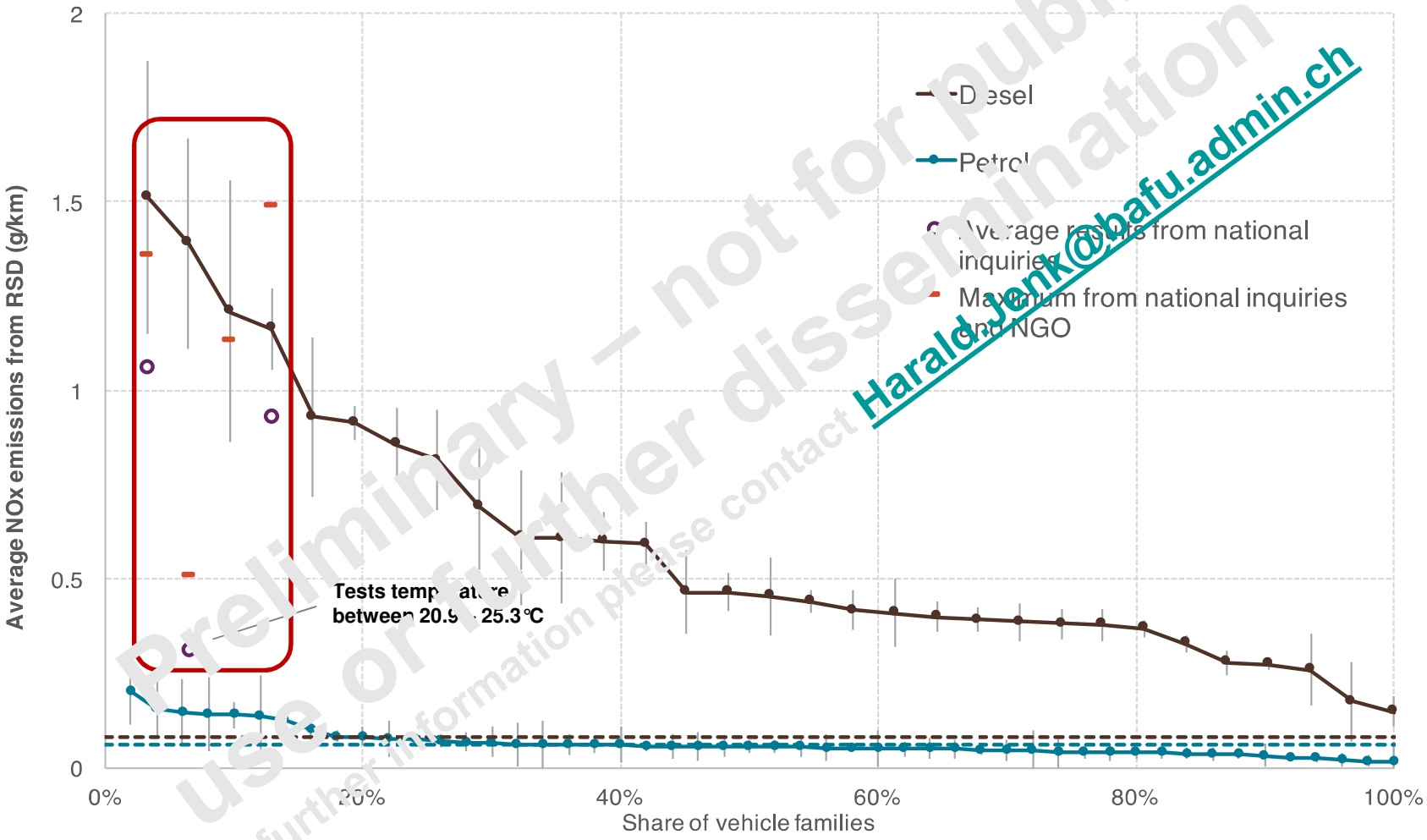

Preliminary results based on CONOX data

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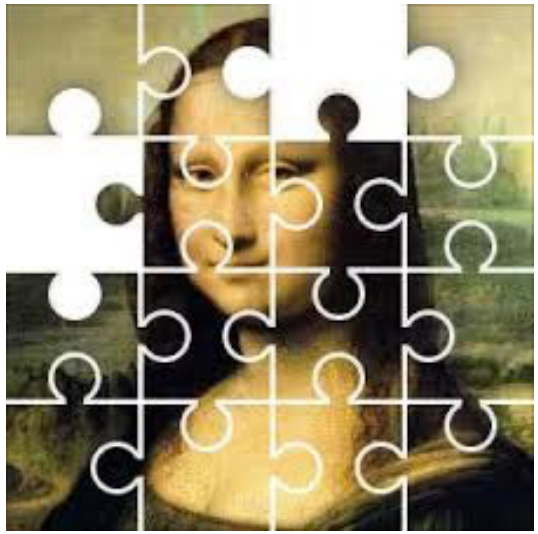
The use of remote sensing for market surveillance

- Allows to track emissions of vehicle in-use as they are being driven
- A complementary tool to PEMS testing: non-intrusive, mass surveillance, etc.
- Monitors older vehicles than the in-service conformity process (max 5 years), and includes effect of aging, deterioration and malfunctions
- Grouping remote sensing observations into relevant vehicle's family can identify worst emitters (i.e manufacturer, fuel type, engine type, etc.) for more in-depth investigations
- A cost-effective solution with an average cost of 1 euro per vehicle tested – a budget of 1 million euro every year for remote sensing campaigns across member states could provide a first step to an efficient market surveillance tool

The use of remote sensing for market surveillance

- **One remote-sensing observation is not enough to know**

- **But once there is enough information we can start drawing conclusions**



The use of remote sensing for a better understanding of air pollution

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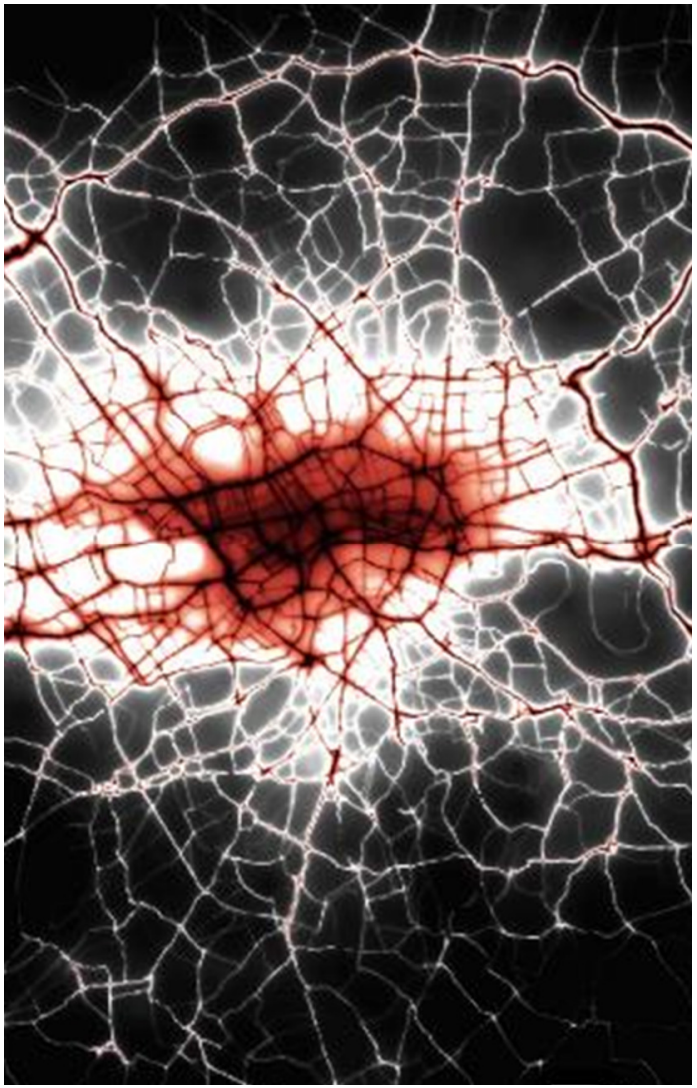
Understanding air pollution

- The impact of road vehicles on air pollution can be thought of as the aggregate effect of all emissions from all vehicles
- **Ideally we would like to know what all road vehicles emit at all times!**
  - With > 250 million passenger cars alone in the EU, that is an impossibility
- The factors are numerous:
  - Emissions vary in space and time
  - Effect of vehicle fuel, vehicle type and technology
  - Effect of driver behaviour and driving conditions
  - Emissions system degradation
  - Ambient temperature… and so on
- We can only ever have an approximate understanding of these issues



Acknowledgement: Dr Scott Hamilton, Ricardo

Vehicle emission remote sensing

- Remote sensing is very well aligned with the need to understand air pollution
  - ‘Real’ real world – no interference with the vehicle being measured
- The measurement of the whole fleet (and large sample sizes) is particularly important – air pollution is more than the contribution made by diesel cars!
- Data can be partitioned in the same way as emission factors used for local and national emission inventory development
- Data can be gathered for specific city fleets and to understand any differences between cities and countries
- ‘Big data’ discovery – it’s surprising what you can find out, but only if you can look

The measurement and impacts of NO_2

- From an **emissions** perspective, limits are set (Type Approval) for total **NO_x** (NO and NO_2)
- From an **ambient air quality** perspective, limits are set for **NO_2** – and that is where the health concern is
- There is a disjoint: almost all emission studies only report total NO_x and do not quantify the NO_2 part
- Recent remote sensing data tackles this issue by providing NO and NO_2 = NO_x
- The direct emission of NO_2 from vehicles is important for exceedances of NO_2 ambient limits across Europe – most important close to roads
- Allows a much better chance of understanding ambient NO_2 concentrations … and therefore developing focused action to mitigate impacts

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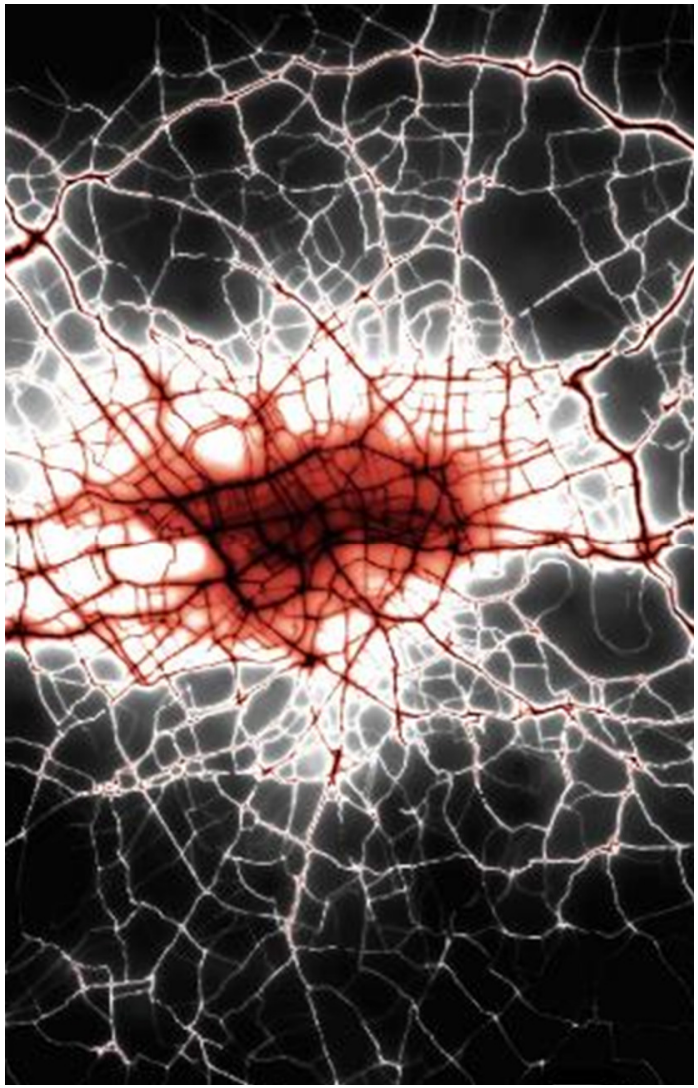

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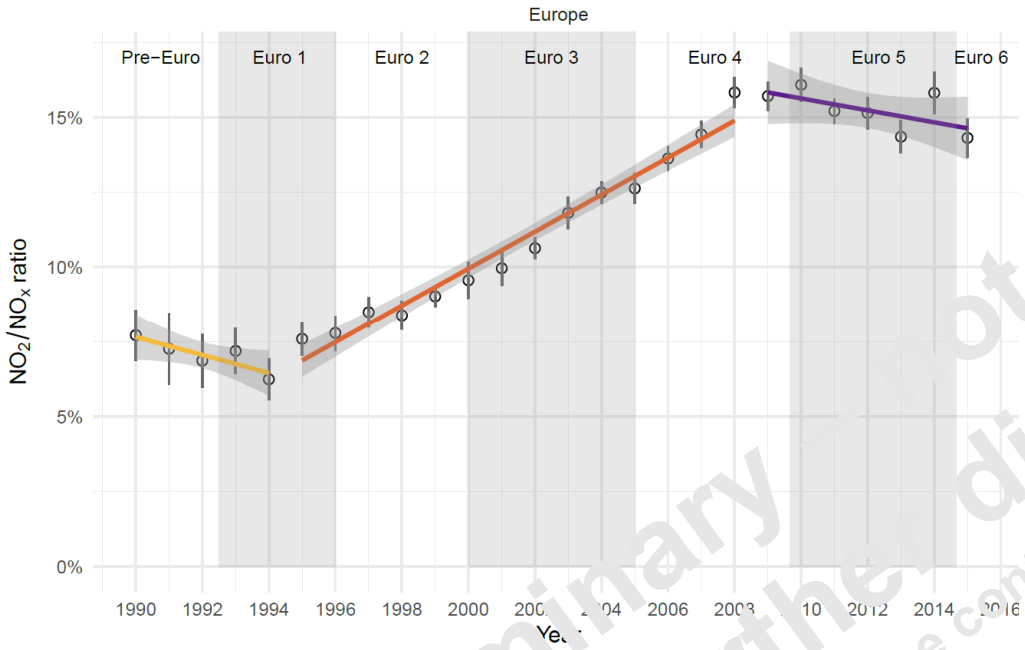
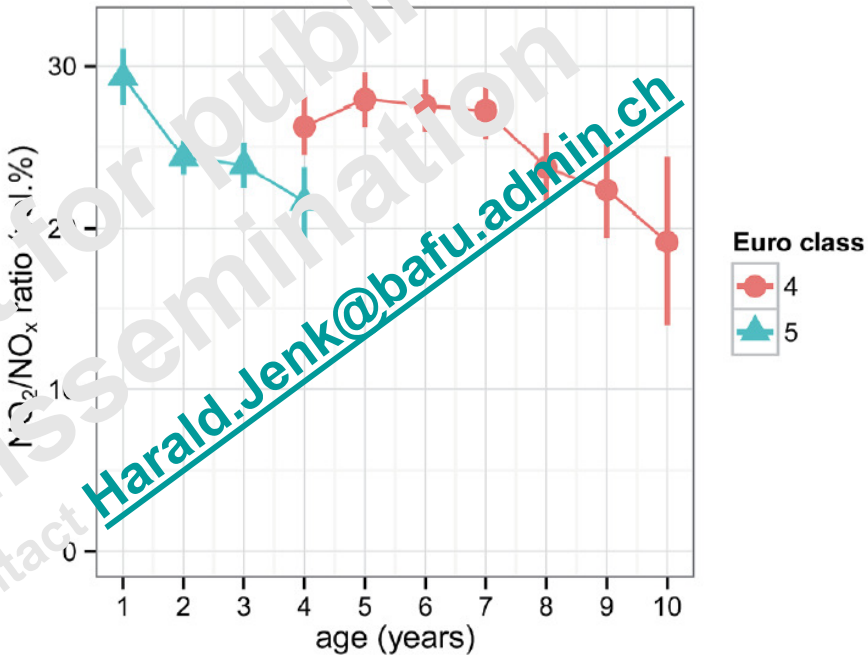
Linking ambient measurements and emissions





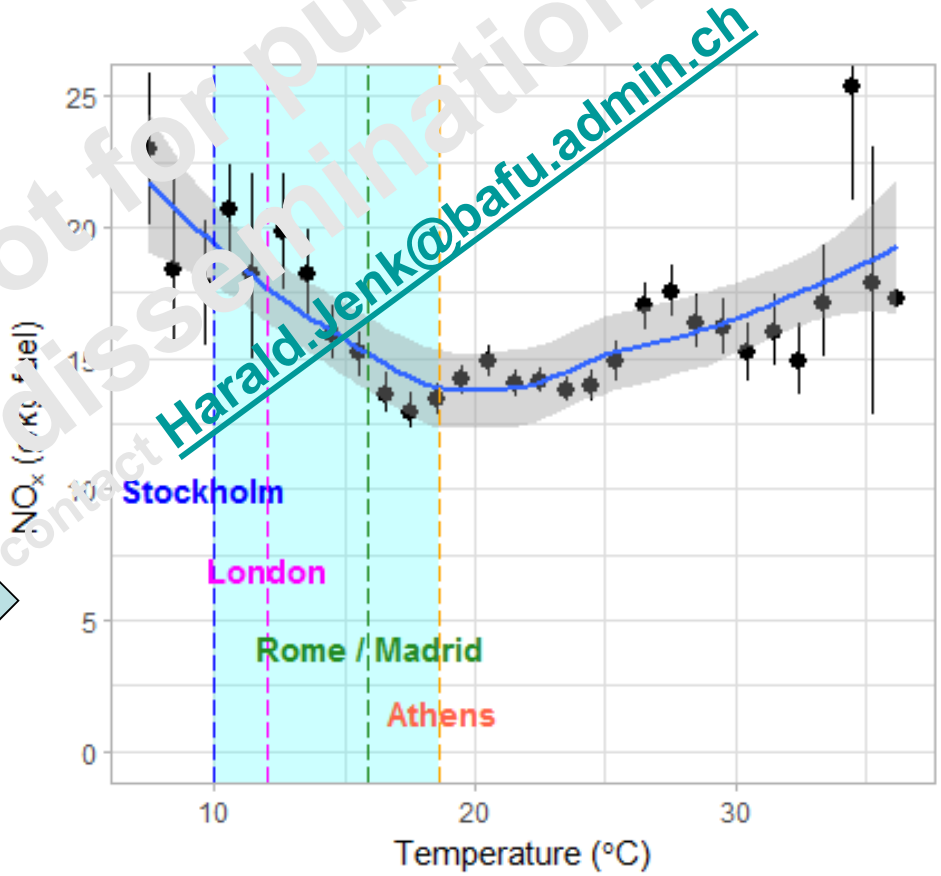
Analysis of ambient data in Europe (61 urban areas, 130 million hourly measurements) shows directly emitted NO_2 from vehicles is decreasing or has stabilised – why?*

- Remote sensing data shows that as diesel vehicles age, the amount of NO_2 emitted decreases
- Future NO_2 air quality projections pessimistic?

*Grange, S. K., Lewis, A. C., Moller, S. J. and D. C. Carslaw (2017). Evidence for a recent decline in European vehicular primary NO_2. *Nature Geoscience.* Accepted.

Effect of ambient temperature on NO_x

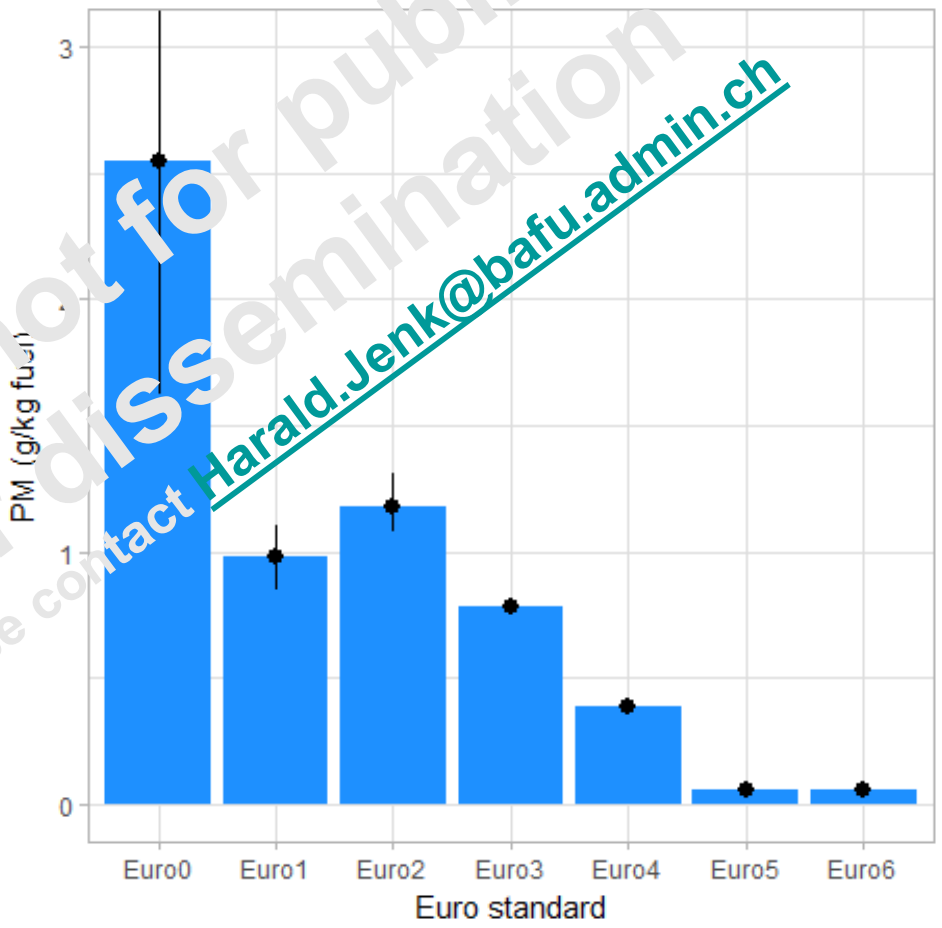
- Analysis of ~ **30,000 Euro 5** diesel passenger cars from CONOX database
- Indicates that NO_x emissions increase at both low and high ambient temperatures
- Low ambient temperatures are associated with stable atmospheres and poor dispersion:
  - high emissions **and** poor dispersion ⇒ high ambient concentrations
- New work planned in London will help add to lower temperature measurements



Annual mean temperatures for select cities

$PM_{2.5}$ emissions from diesel cars

- Analysis of > **65,000** diesel passenger cars from CONOX database
- Diesel Particulate Filter (DPF) introduced for Euro 5 (and some Euro 4)
- Very clear and substantial reduction in $PM_{2.5}$ emissions
- DPF is highly effective
- Continue to monitor to ensure DPF efficiency remains high



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Concluding remarks

- Co-ordinated European remote sensing database started with CONOX is highly valuable
- Enormous potential to provide data for input to emission inventories and air quality models
- Regular measurements e.g. annually will help robustly quantify how complex and sophisticated vehicle after-treatment systems perform in the longer term
- Measurement of the full fleet i.e. including HDVs, urban buses – balanced approach to emissions mitigation
- Large datasets give the opportunity to apply machine learning reveal much more