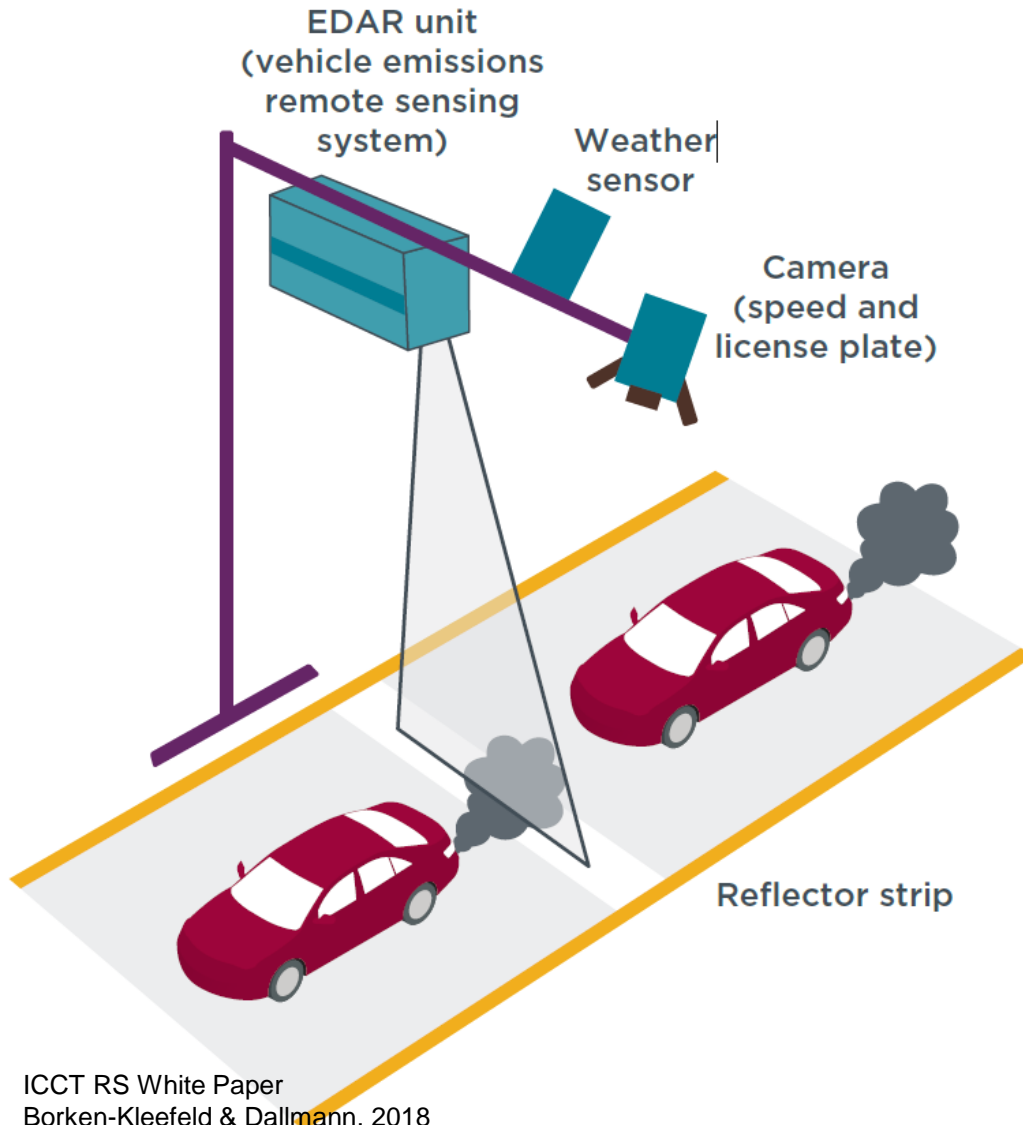

Remote (=contact-free) Sensing (=measurement) of Vehicle Exhaust Emissions

Jens Borken-Kleefeld

International Institute
for Applied Systems Analysis

Remote sensing (top-down scheme)



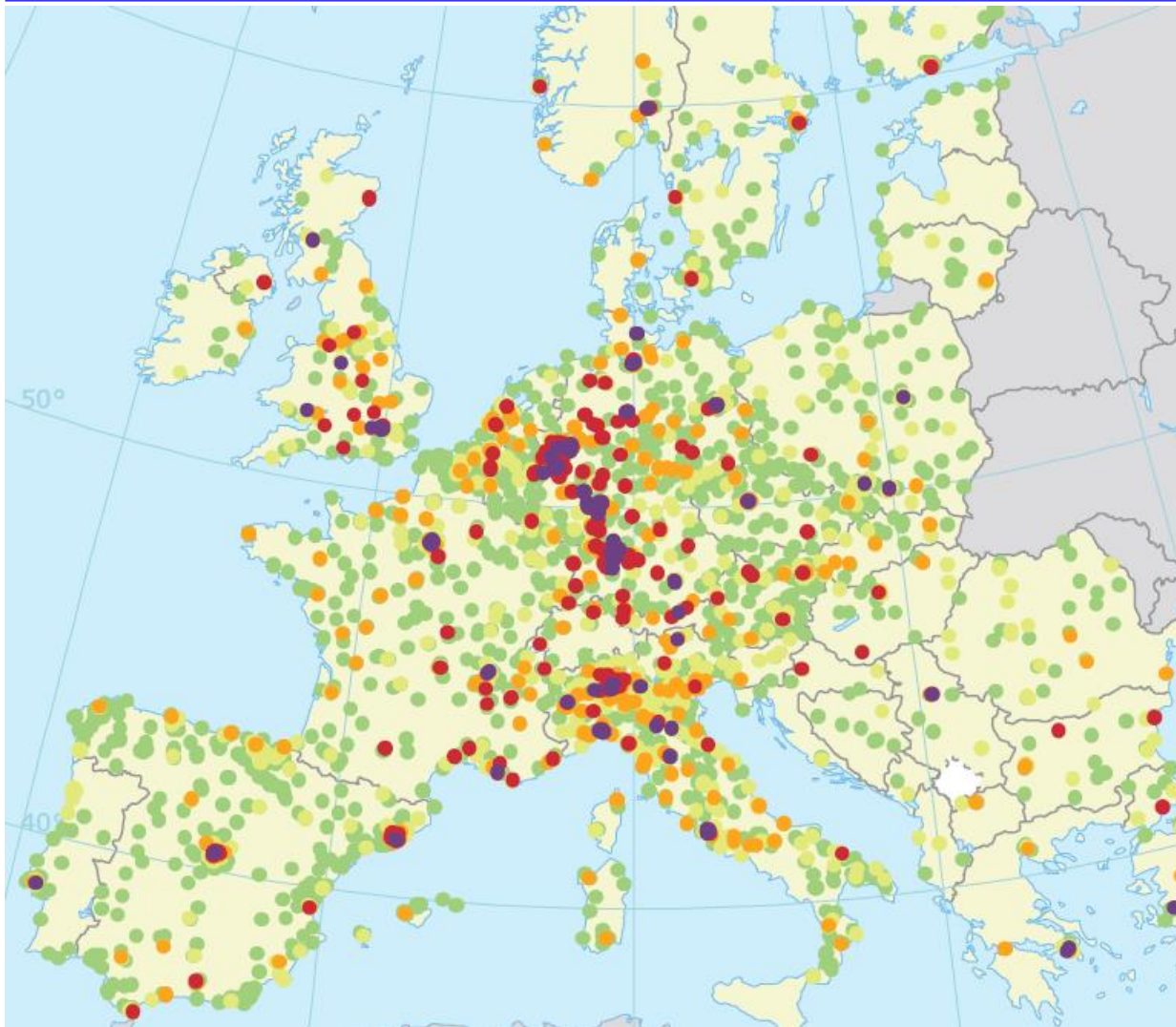
Autonomous
sampling 24/7

Non-intrusive
to traffic

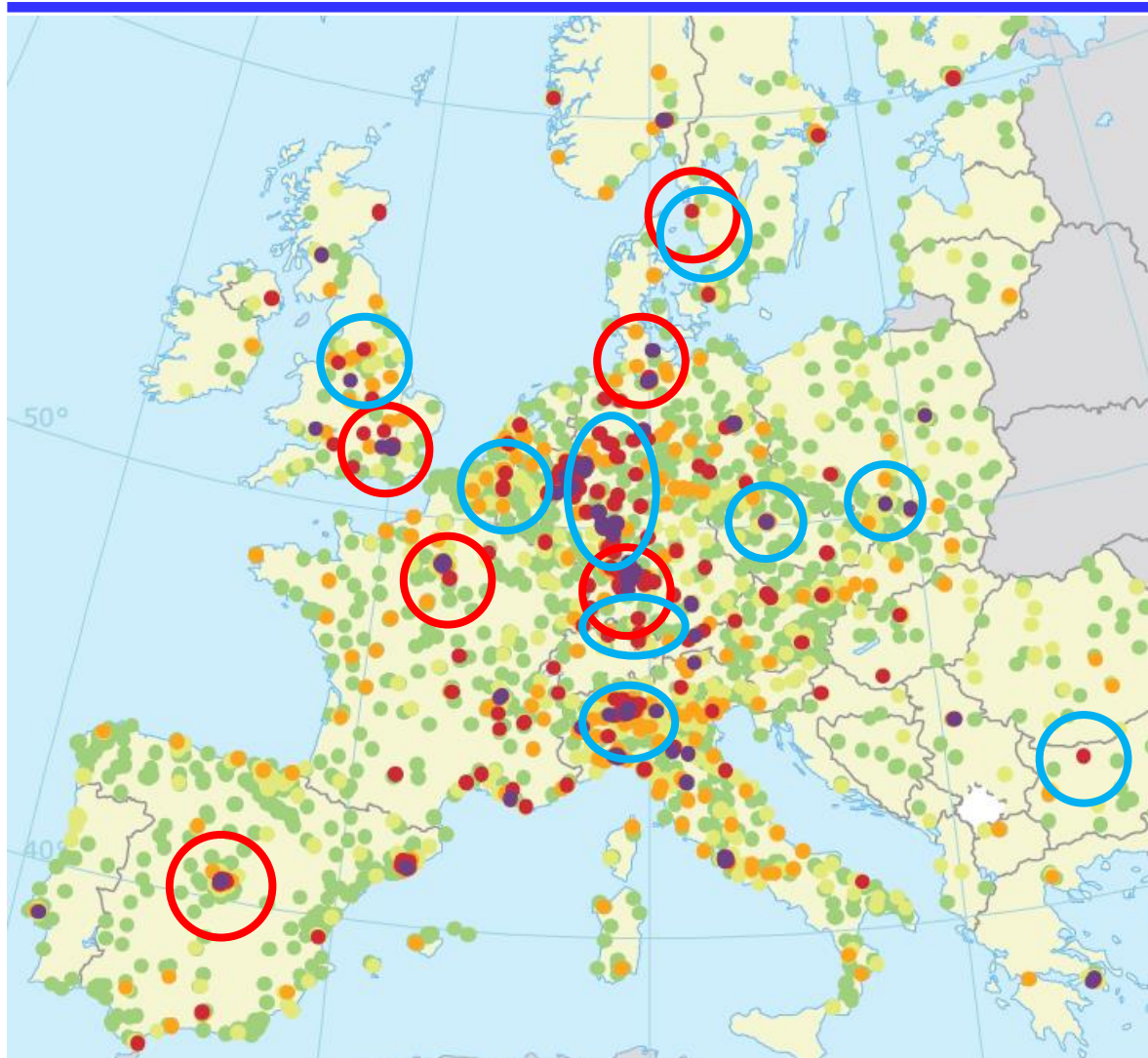
Measuring
cars, trucks, buses...
in one campaign

NO/NO₂, CO, HC,
PM* emission rates
per unit fuel
per km*

NO₂ exceedances & RS campaigns in Europe



NO₂ exceedances & RS campaigns in Europe



Several RS campaigns planned 2019ff., expanding notably to CEE looking into

- Fleet emissions,
- High emitters,
- Truck & bus emissions

Focus on

- NO/NO₂
- NH₃
- Experimental: PM/PN
- (CO, HC)

Issues with remote sensing



- Legislated power is important for serious use
 - EURO 6: “...to inform for market surveillance...”
 - High-emitter thresholds (for in-use compliance)
 - Low-emission zones
- Increasing applications in Europe and in particular China (>200 devices around country)
- Data handling, QA/QC issues \Leftrightarrow increasing analytical options and statistical power but ...

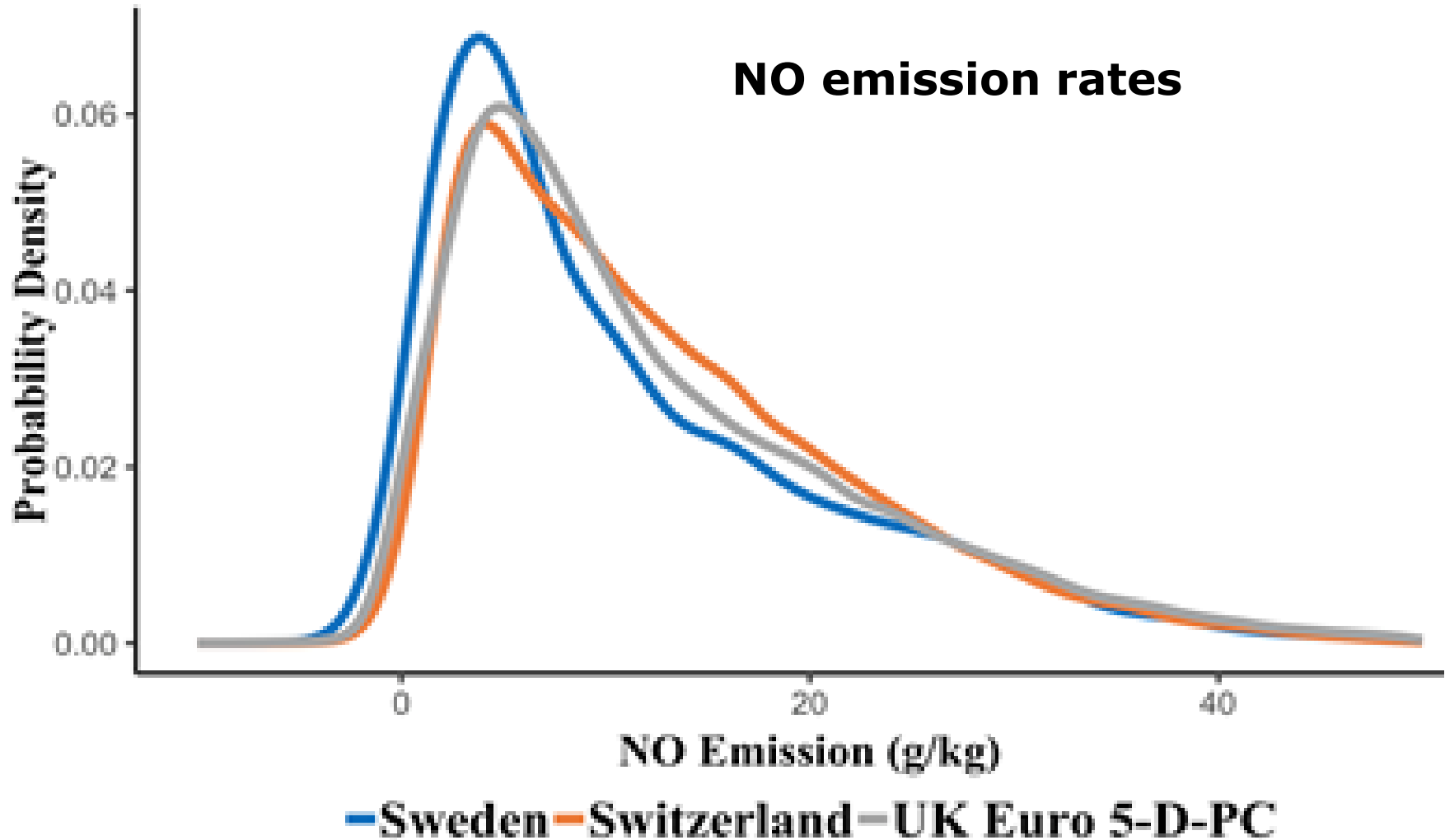
How many records are enough?



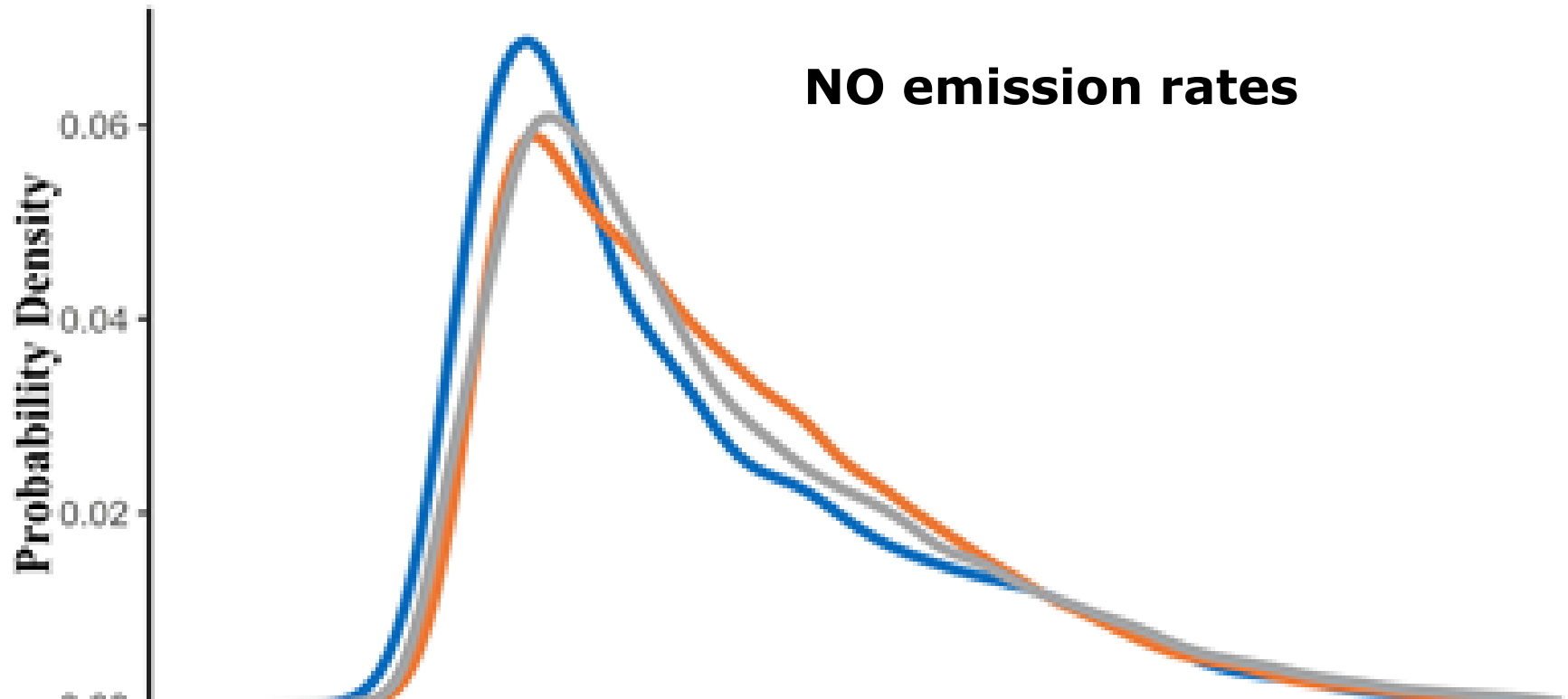
CONOx db has ~1 mio RS records from 20+ individual campaigns, each contributing 10...100,000 records.

Would a campaign sufficient with 1000...10,000...100,000 records?

NO emission rates distribution: EURO 5 d. cars



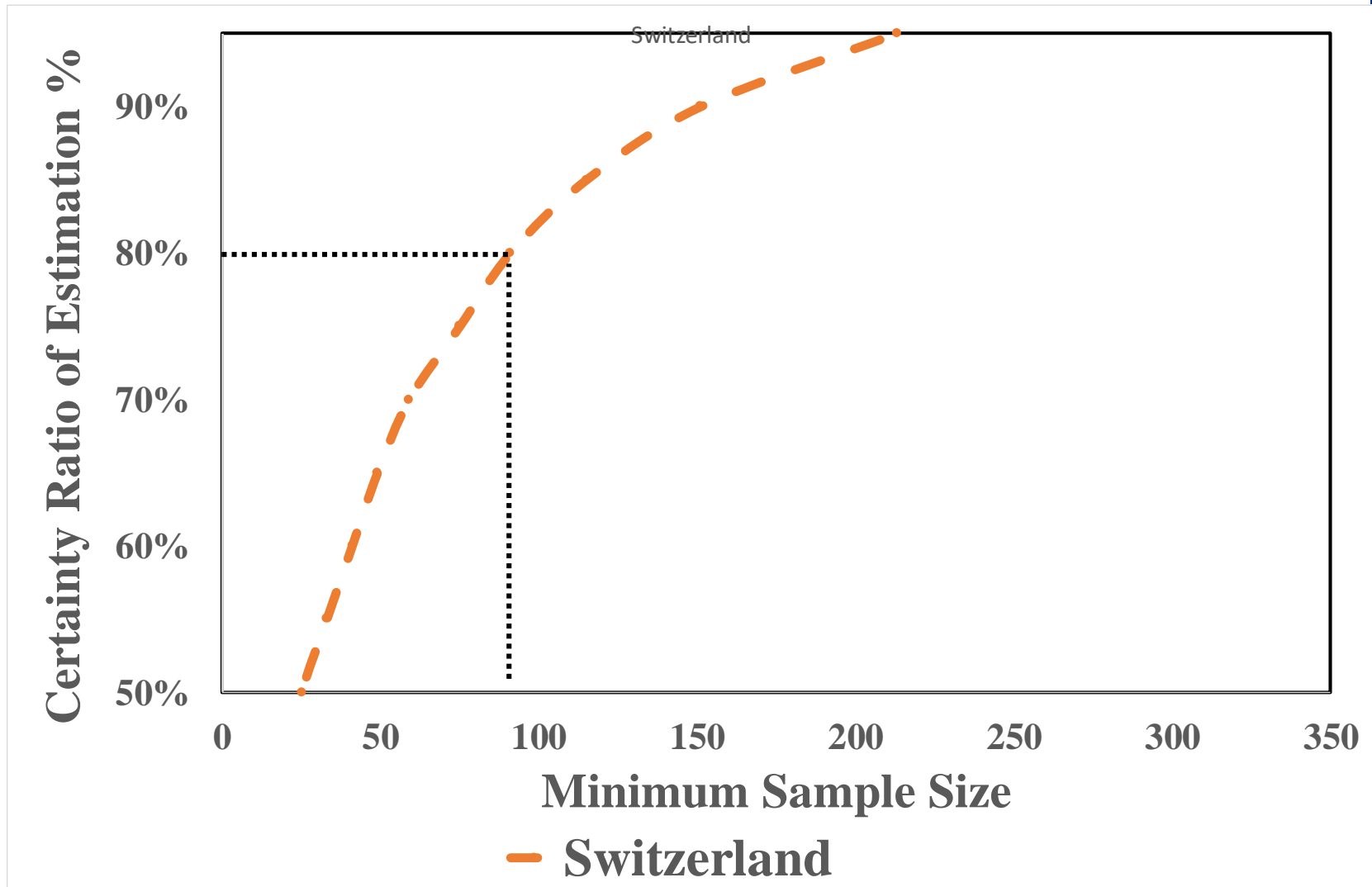
NO emission rates distribution: EURO 5 d. cars



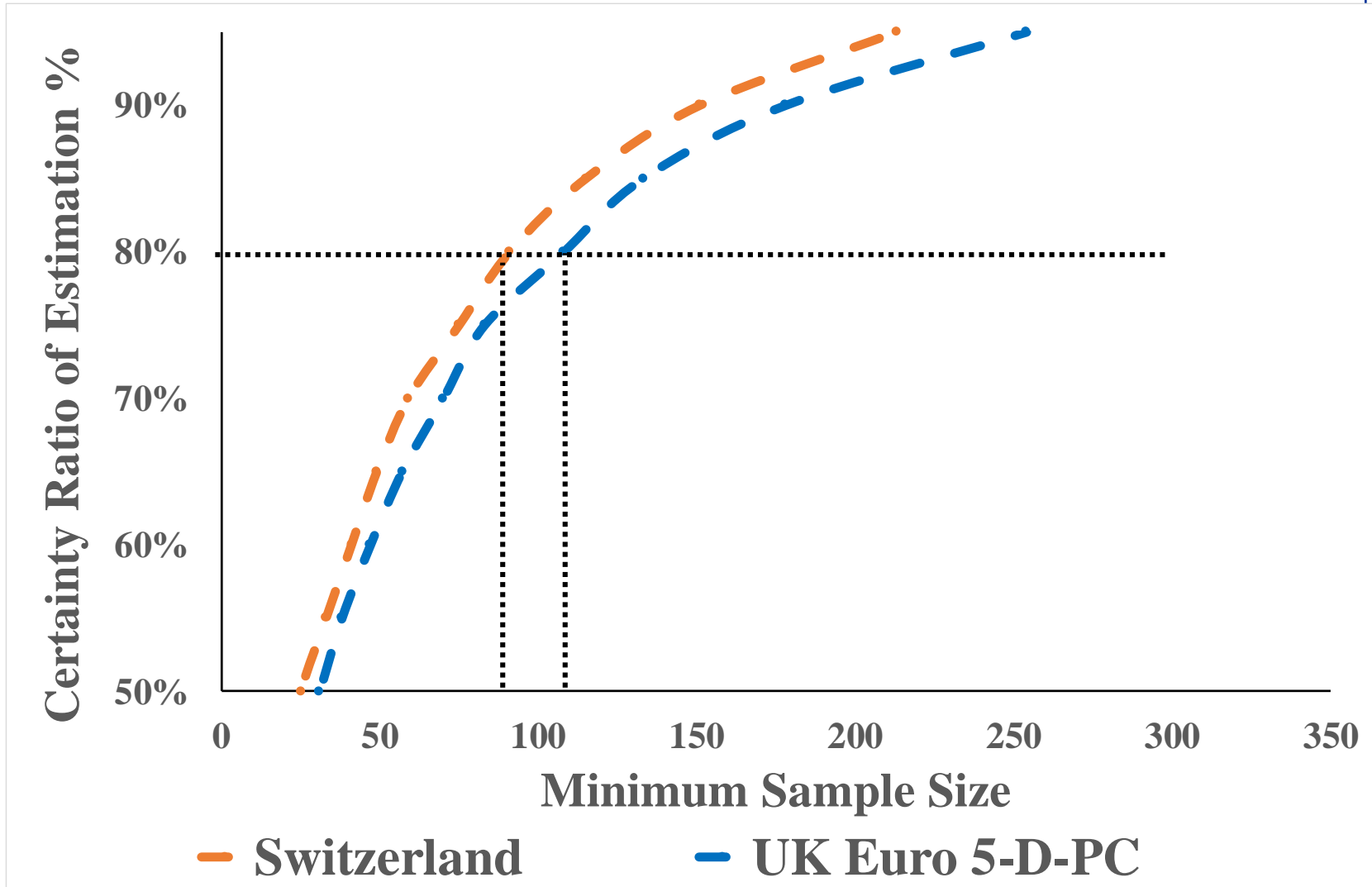
Reference value = mean of all records [66,000 for PC D5]

Monte Carlo simulation: Choose 100 random records and compute mean.
Repeat => Probability distribution around reference value.
Repeat with different sample sizes => Distribution of sample size as
function of probability & tolerance...

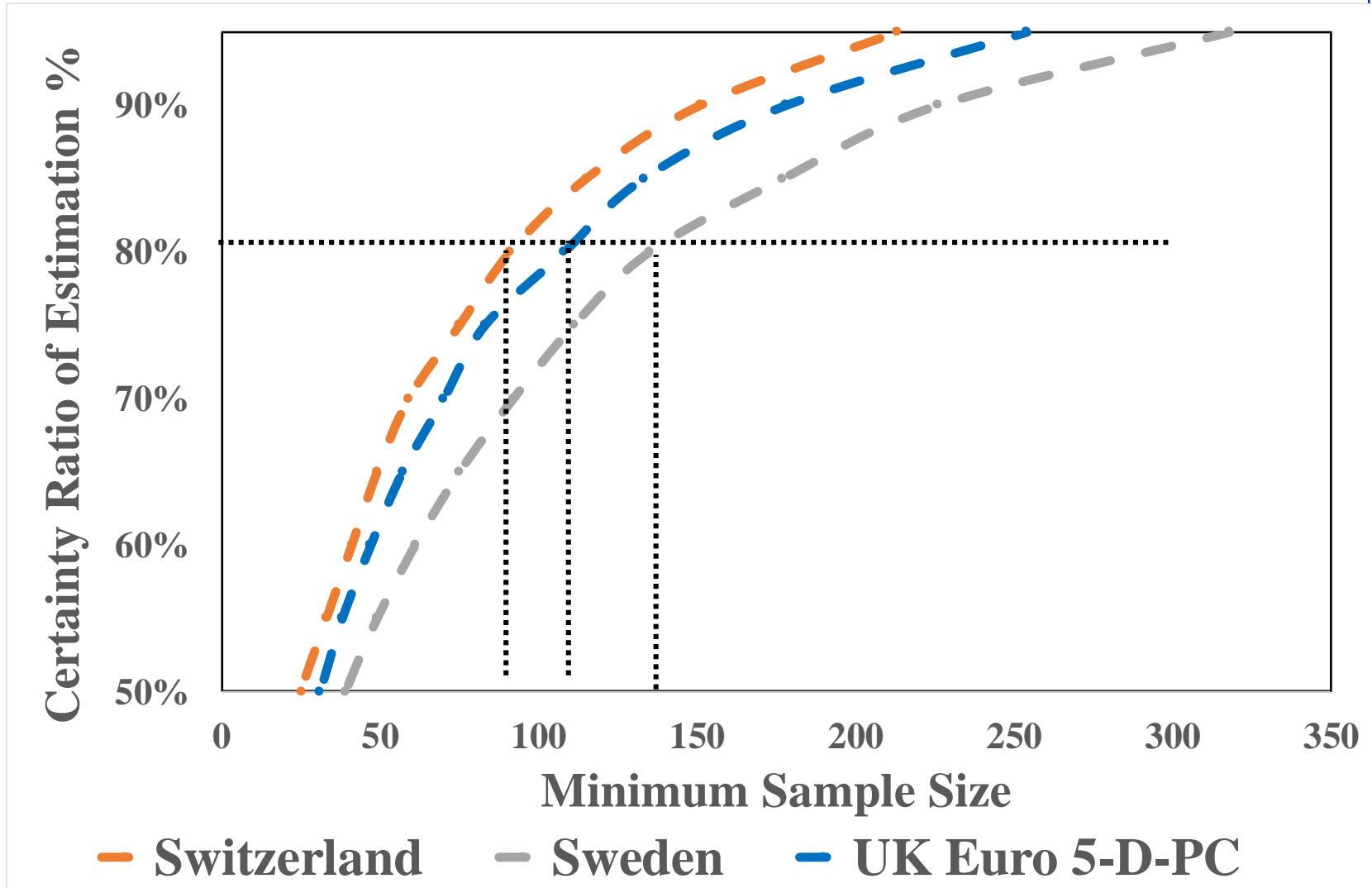
Minimum sample size diesel EURO 5 cars – for 10% tolerance



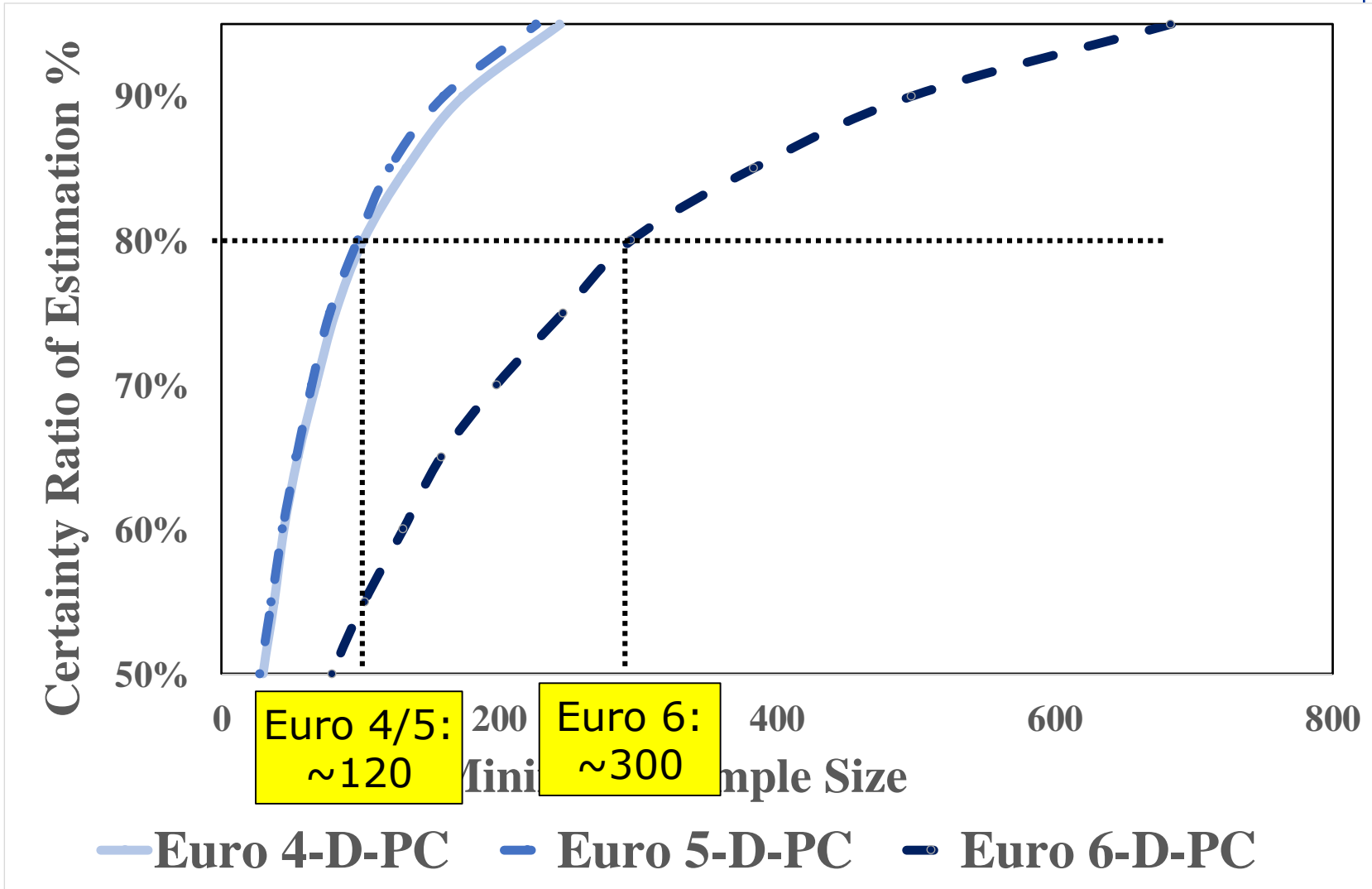
Minimum sample size diesel EURO 5 cars – for 10% tolerance



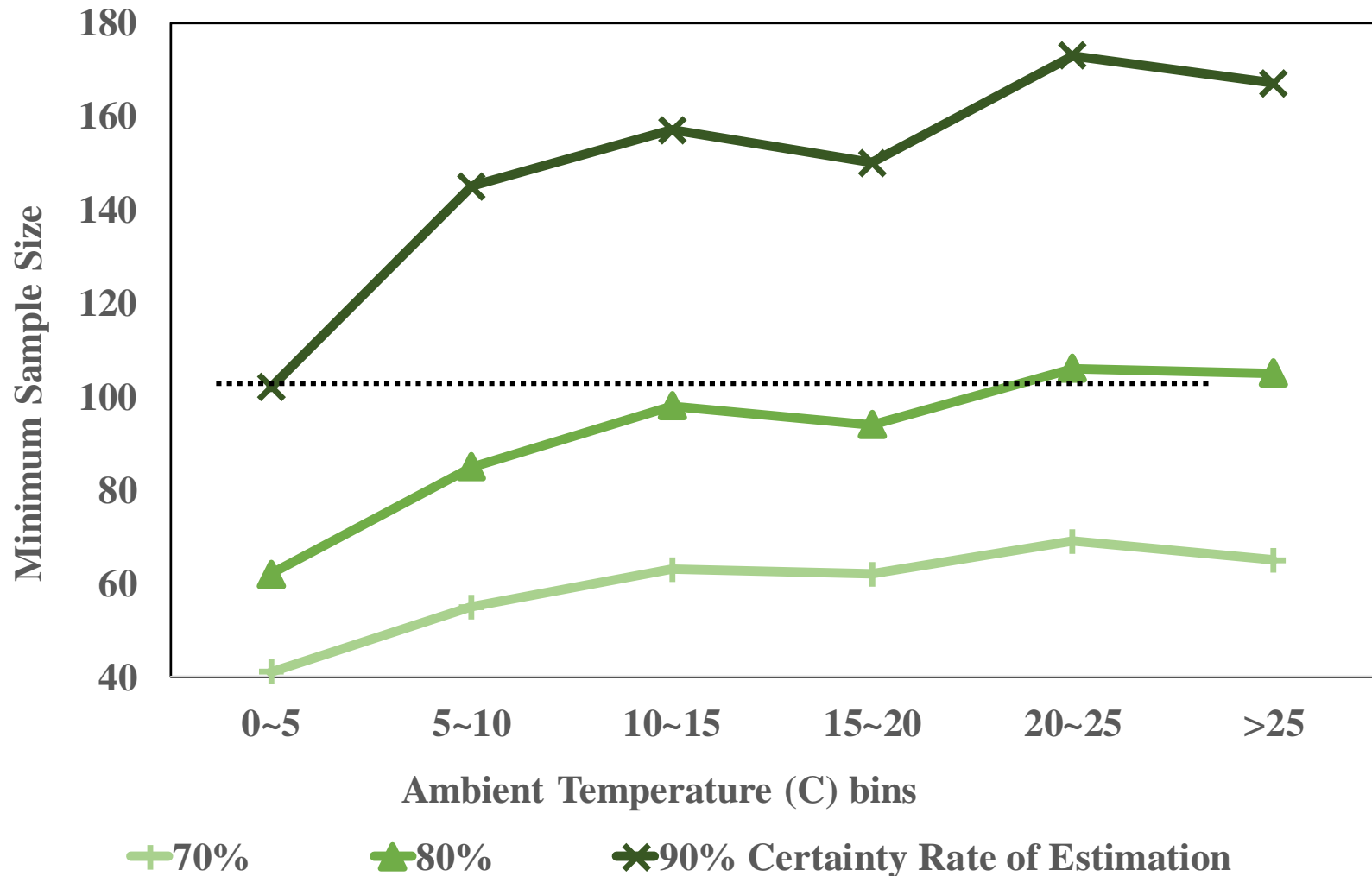
Minimum sample size diesel EURO 5 cars – for 10% tolerance



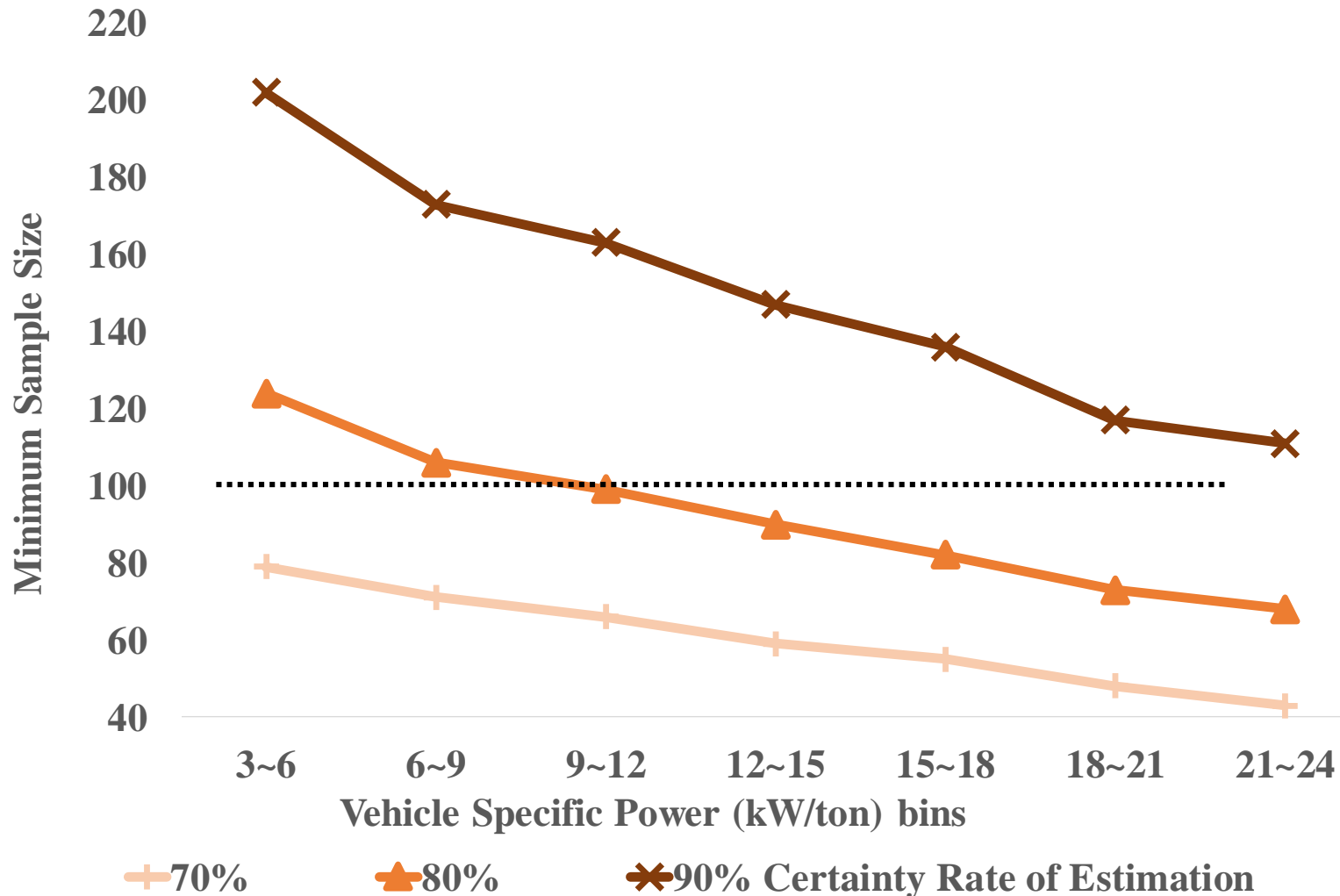
Minimum sample size diesel EURO 4/5/6 cars – for 10% tolerance



Minimum sample size EURO 5 d. cars by temperature - for 10% tolerance



Minimum sample size EURO 5 d. cars by eng. power - for 10% tolerance



Minimum sampling duration for diesel EURO 4/5/6 cars – for 10% tolerance for NO emission rate



~2000 cars per day	
@50% diesel share	1000 diesel cars
@25% EURO 4 & older	250 PC D4
@50% EURO 5	500 PC D4
@25% EURO 6	250 PC D6

- ~2 days of measurements for probing fleet average emission rate (NO!) – more days for other components
- ↔ Good for moving RS around for better coverage of fleets and driving conditions
- ~10-20 days of measurements for dissecting by broad vehicle families / technologies

Perspective

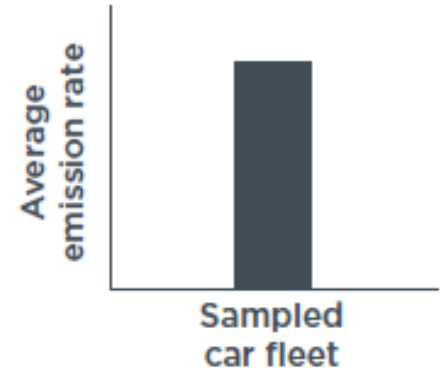


- **Create network of (semi-)mobile remote sensing**
 - In-use emissions of cars, **trucks**, buses
 - Track emission performance over time
 - Flag suspicious vehicles by model and model year
- **Coordinate measurements & exchange data**
 - Increase coverage of vehicle models,
 - Gain leverage,
 - Design complementary measurements
- Measure in Central & Eastern Europe,
in Africa, India, Indonesia, Russia, ...
Remote sensing for representative overview

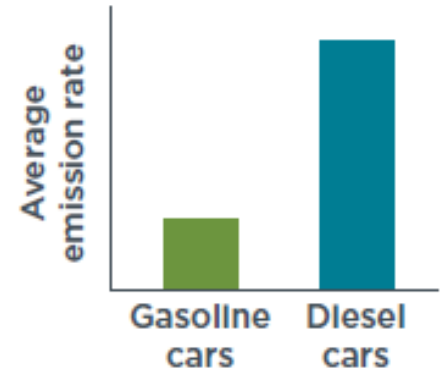
Backup slides

Chassis dynamometer / PEMS	Remote sensing
1...3 vehicles per day	~5000 vehicles per day
1000 continuous records	1-2 snapshots per veh.
Chosen cycle / test route, incl. idle & brake	As passing under load
Dedicated testing possible	Observation only
Thorough single veh. test	Classification of fleet & models
Is (can be) defeated	Hard to defeat
~5-25,000€ per test	~100,000€ for 100,000 records

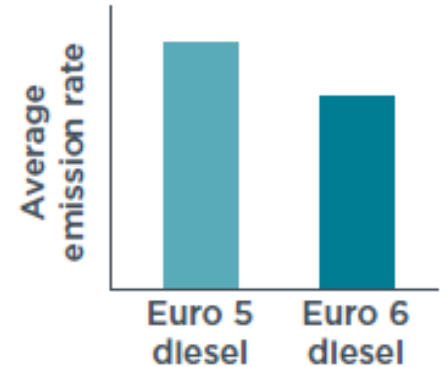
Fleet average (not just cars)



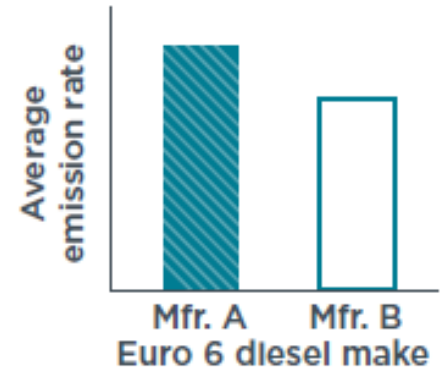
By vehicle category



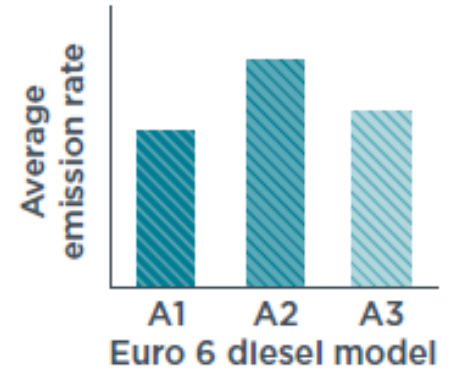
By emission standard



By manufacturer



By model....



By vehicle age, by ambient temperature, by catalyst technology, by last inspection, ...

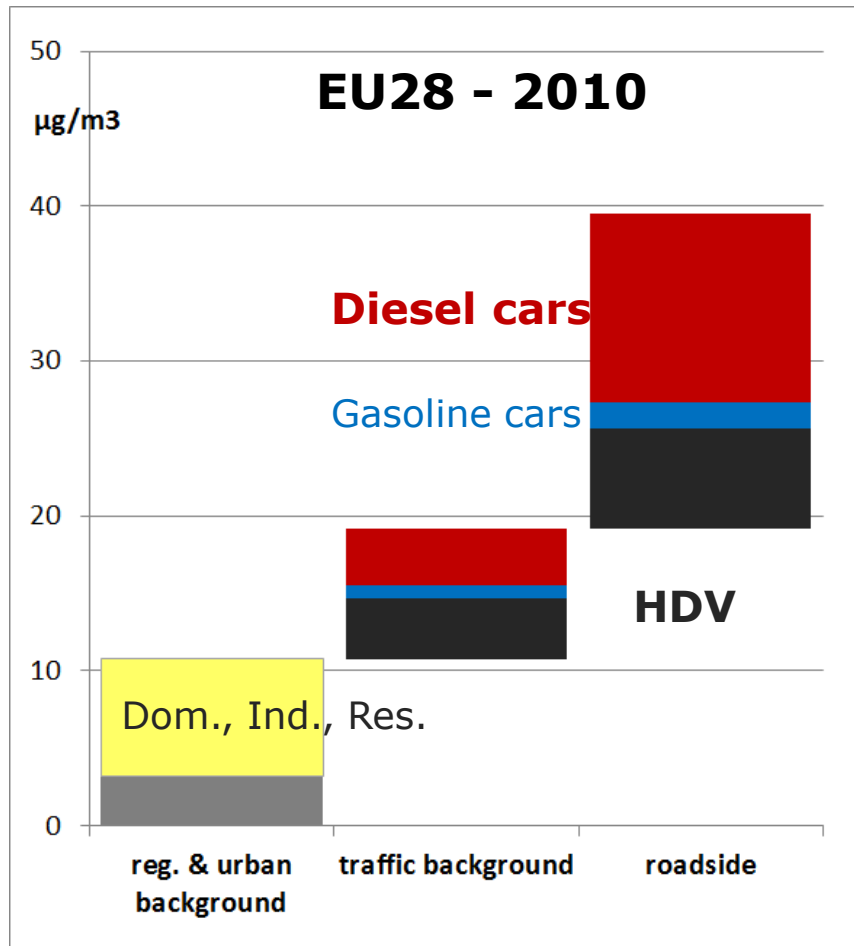
**Quality depends on sample size –
collaborate & exchange data!
-> CONOX -> TRUE**

References – further reading



- **ICCT Papers** on
 - Remote sensing of motor vehicle exhaust emissions (2018)
<https://www.theicct.org/publications/vehicle-emission-remote-sensing>
 - On-road vehicle emissions remote sensing (2013)
<https://www.theicct.org/publications/road-vehicle-emissions-remote-sensing>
- **CONox reports** on remote sensing data and methodological advances published by the Swiss Federal Office for the Environment (BAFU)
 - <https://www.bafu.admin.ch/bafu/en/home/topics/air/publications-studies/studies.html>
- Contact: Dr. Jens Borken-Kleefeld
International Institute for Applied Systems Analysis
borken@iiasa.ac.at / Tel.: ++43 2236 807 570

Sources for ambient NO₂ at traffic site - EU28



At traffic stations,
~75% of ambient NO₂
from road vehicles

⇔ Influence of **diesel** vehicles
much higher than their share in
national emissions

Contributions to ambient NO₂:
~**40% Diesel cars + LCV**
~25% Trucks & bus
~6% Gasoline cars
~25% all other sources
on average