Potential for miniPEMS to identify high emitters via advanced inspection and maintenance methods

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Outline

List of Results

slide #

Periodic Technical Inspection (PTI) Background

- European Union methods of inspection and maintenance, Periodic Technical Inspection (PTI) of exhaust emissions are out of date (No PN, no NOx)
- This is progressing – PN is included in some member state PTI regulations and on 20 March 2023 EU published a recommendation[1] outlining guidelines around PTI PN measurement to aid harmonization
- Many groups are working to strengthen the EU PTI legislation (including incorporating a NOx test)

[1] https://transport.ec.europa.eu/system/files/2023-03/C_2023_1796.pdf

Enhanced PTI Test Pilot – Opus Sweden

Aims and Objectives of the PTI Pilot Test Campaign

- PTI format:

Engine Conditioning	Repeatability	NOx Protocols	Minimize Test Time

- Vehicle pollutant trends compared to:

Vehicle Euro Standard	Model type approval results	Vehicle properties	Vehicle PTI Results

- Identification of high emitters
- Investigation of thresholds for pass/fail at PTI

3datx.com/ptipilot/ full presentation and time-series charts for each vehicle

Objectives covered in this presentation

- PTI format:

Engine Conditioning	Repeatability	NOx Protocols	Minimize Test Time

- Vehicle pollutant trends compared to:

Vehicle Euro Standard	Model type approval results	Vehicle properties	Vehicle PTI Results

- **Identification of high emitters**
- Investigation of thresholds for pass/fail at PTI

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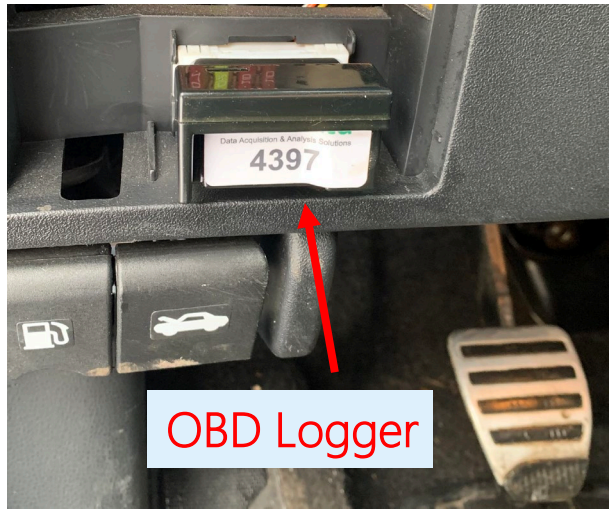
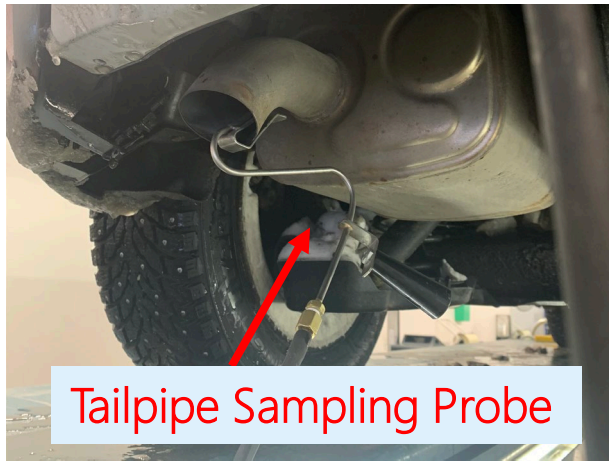
Test Site – Borås, Sweden

- Tests were conducted at the Borås Opus Bilprovning PTI Test Centre





Device used - The parSYNC iPEMS

➢Lightweight & Easy To Use

- Total System Weight: 6.7 kg (22.1 lb)
  - parSYNC® Weight: 4.1 kg (13.7 lb)
  - CUBE™ Weight (with one battery): 2.6 kg (8.4 lb)

➢Battery Life

- 4-5 hours typically

➢GasMOD™ Sensor Cartridge

- Electrochemical: NO (0-5000ppm) & NO_2 (0-300ppm)
- NDIR: CO_2 (0-20%), CO (0-15%)

➢Particulates Sensor Cartridge

- PN/PM (10 to 10,000nm = 0.01 to 10µm)

HEM Data OBD Mini Logger recorded parameters including: vehicle speed, engine speed, lambda, MAF, engine coolant temperature, catalyst temperatures, engine load, and EGR rate info.

https://hemdata.com/products/dawn/obd-mini-logger/

The new parSYNC FLEX iPEMS

Gases – CO, CO_2, NO, NO_2 + **HC and O_2**

Particulates - Ionization, Scattering, and Opacity, **with advanced temperature control**

Diffusion charging-based particle number counter coming soon, to meet PTI requirements

Enhanced chiller and volatile particle removal

Hot-swap Milwaukee Li-Ion batteries for full-day of testing

Onboard display and data storage + WiFi Access-point

Full CAN + support for external sensors

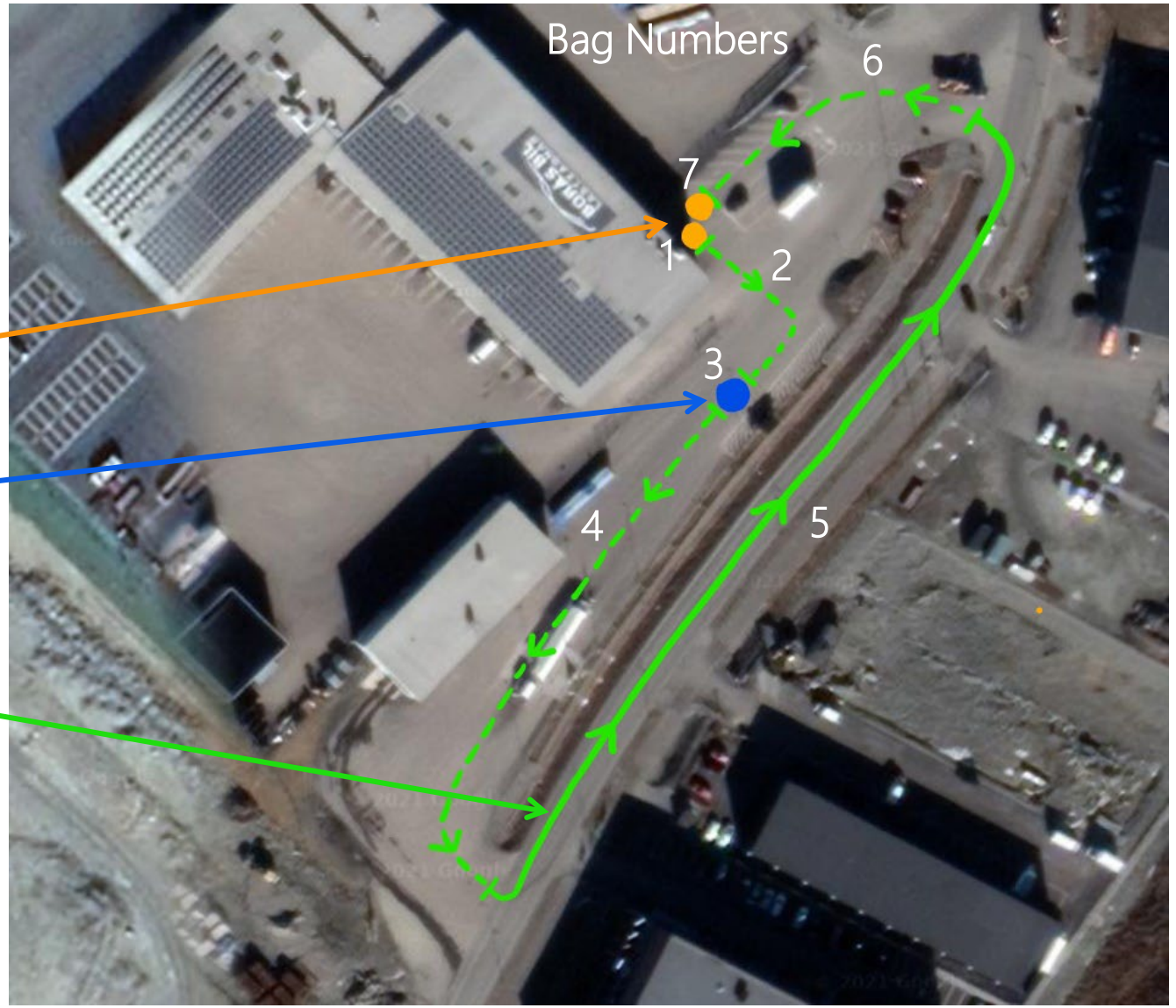
Integrated GPS and Ambient Pressure, Temperature, Humidity

Integrated wireless OBD reader for LD and HD

... and still light-weight (11 kg) and installs in minutes

Test Protocol – Extra 5 Minutes onto PTI

Bag No.	parSYNC Location	Description
0	Bench	Sample clean air while parSYNC is on the bench.
Zeroing	Bench	Zero the parSYNC. Idle the vehicle.
0	Vehicle	Move parSYNC to vehicle. Sample exhaust gas for ~10 seconds.
1	Vehicle	Idle protocol – 60 seconds of idle – conducted while car is at garage
2	Vehicle	Drive to emissions shed
3	Vehicle	High Idle – Follow standard PTI protocol for gasoline and diesel vehicles*
4	Vehicle	Drive to NOx Acceleration test start point
5	Vehicle	Acceleration – *Idle for 10 seconds*, then accelerate quickly to 30 kph, then brake normally (not hard) to a complete stop, *idle for 10 seconds*
6	Vehicle	Drive back to garage.
7	Vehicle	Idle protocol – 60 seconds of idle
8	Bench	Disconnect parSYNC. Sample clean air for at least 60 seconds.
Zeroing	Bench	Zero the parSYNC.



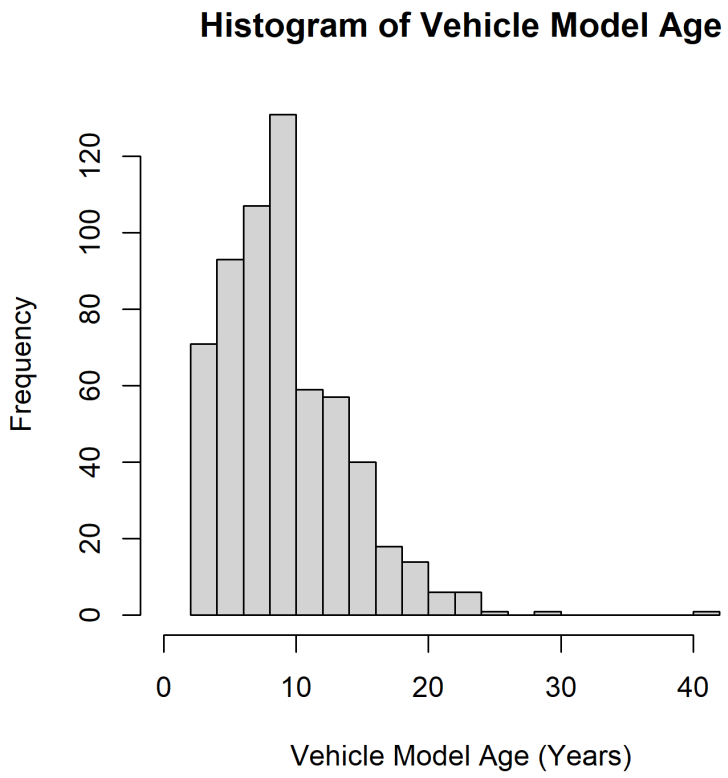
* First 106 vehicles all followed PTI protocol for gasoline on high idle test, i.e. constant high idle, rather than diesels following a rapid high idle

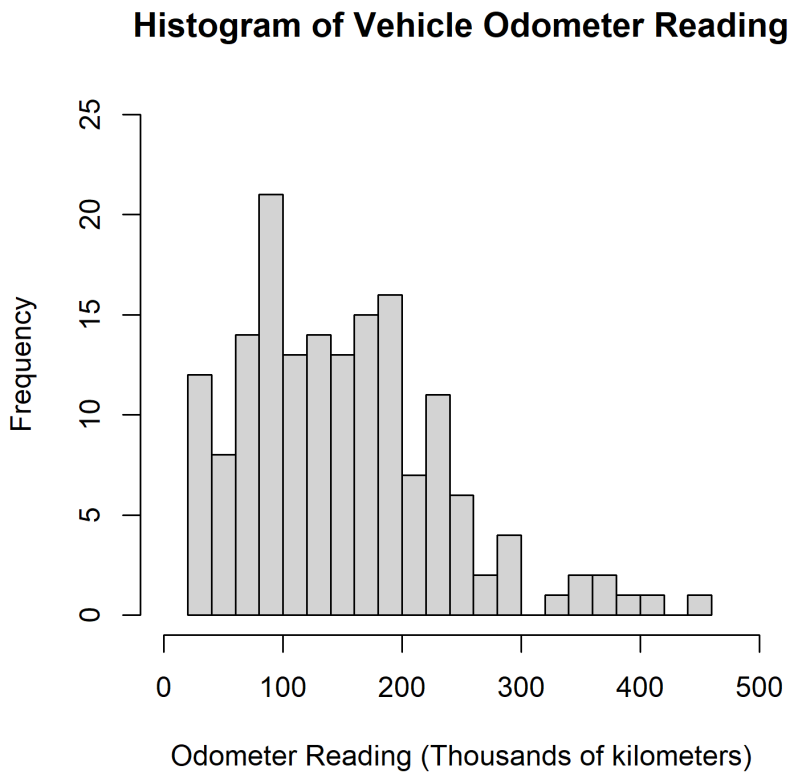
Characteristics of the Test Fleet

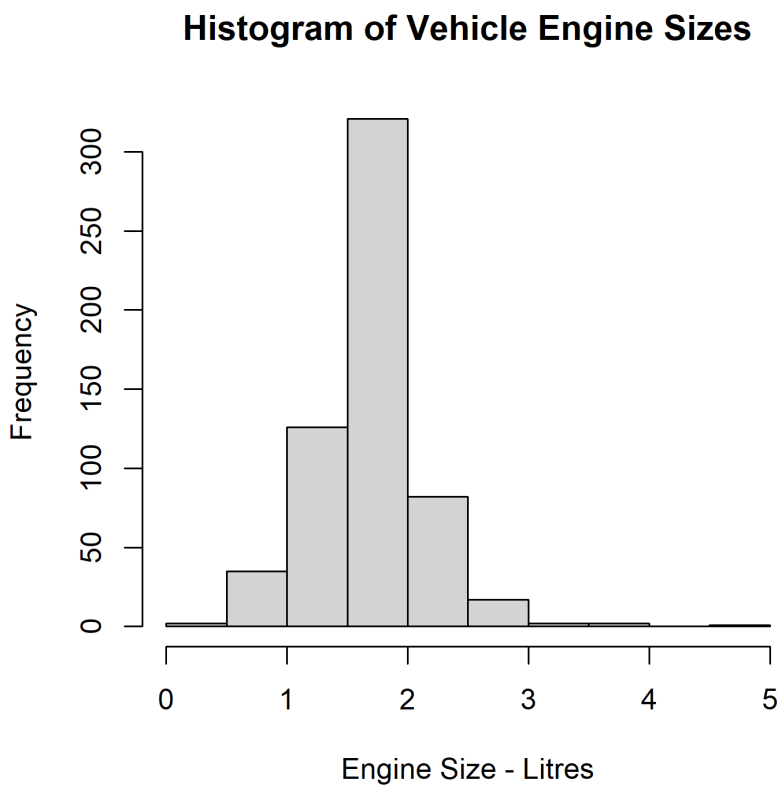
Age, Mileage, Engine Size, Fuel, Euro Std

Fleet Composition – Vehicle and Engine Information

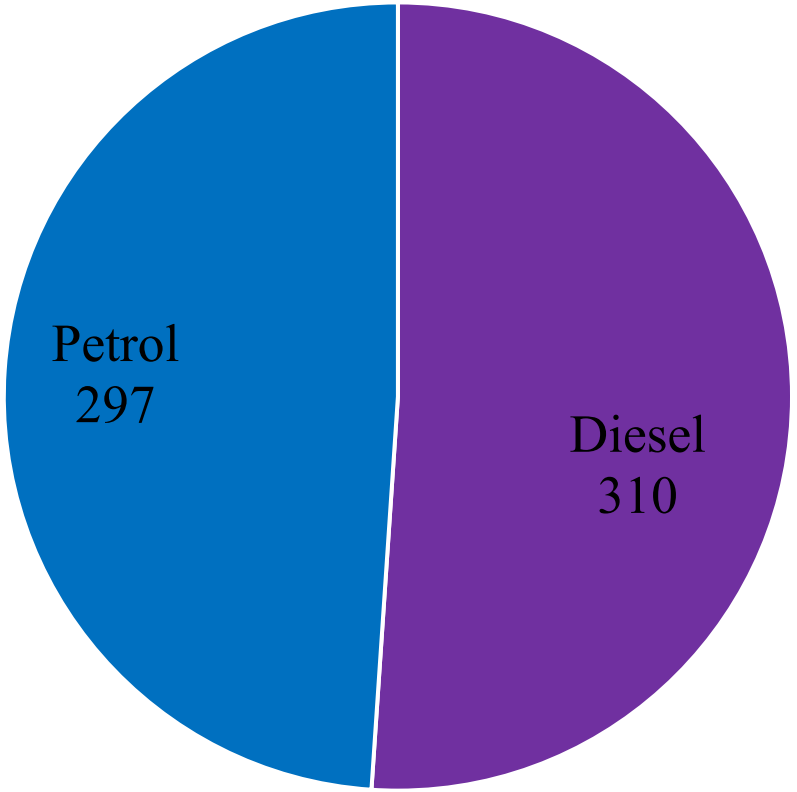
606 passenger vehicles underwent enhanced PTI testing at the Borås Opus Bilprovning PTI Test Centre during January 2021 – June 2022

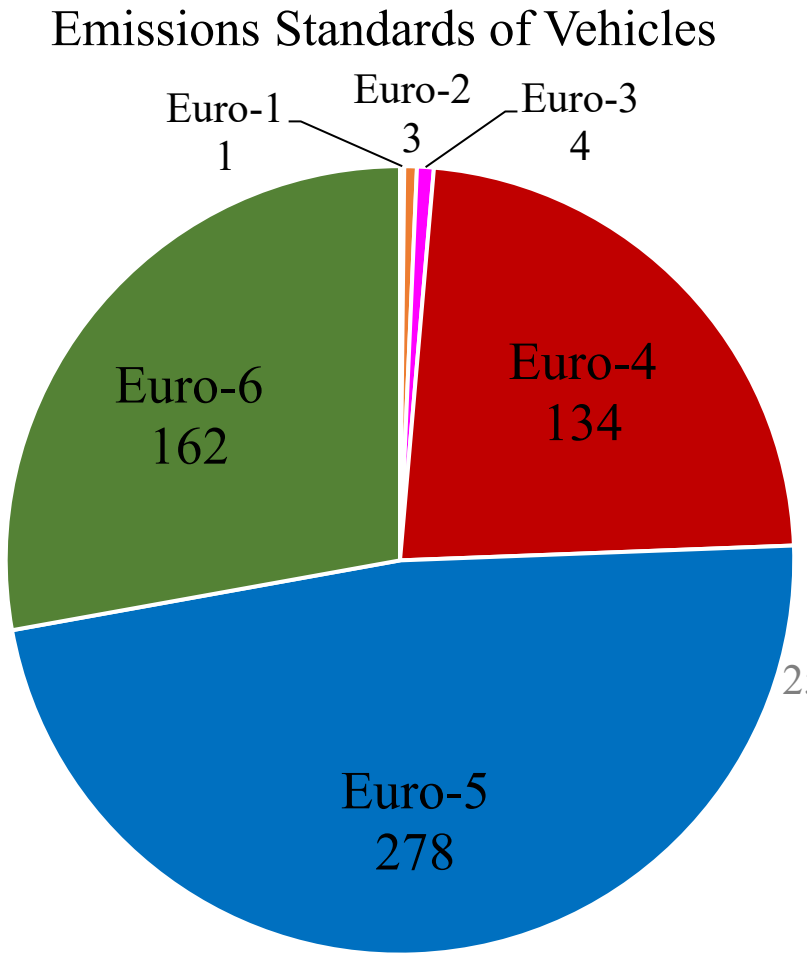






Fleet Composition – Fuel Types and Emission Standards





EURO	MY*
1	1993
2	1997
3	2001
4	2006
5	2011
6	2015

* First registration

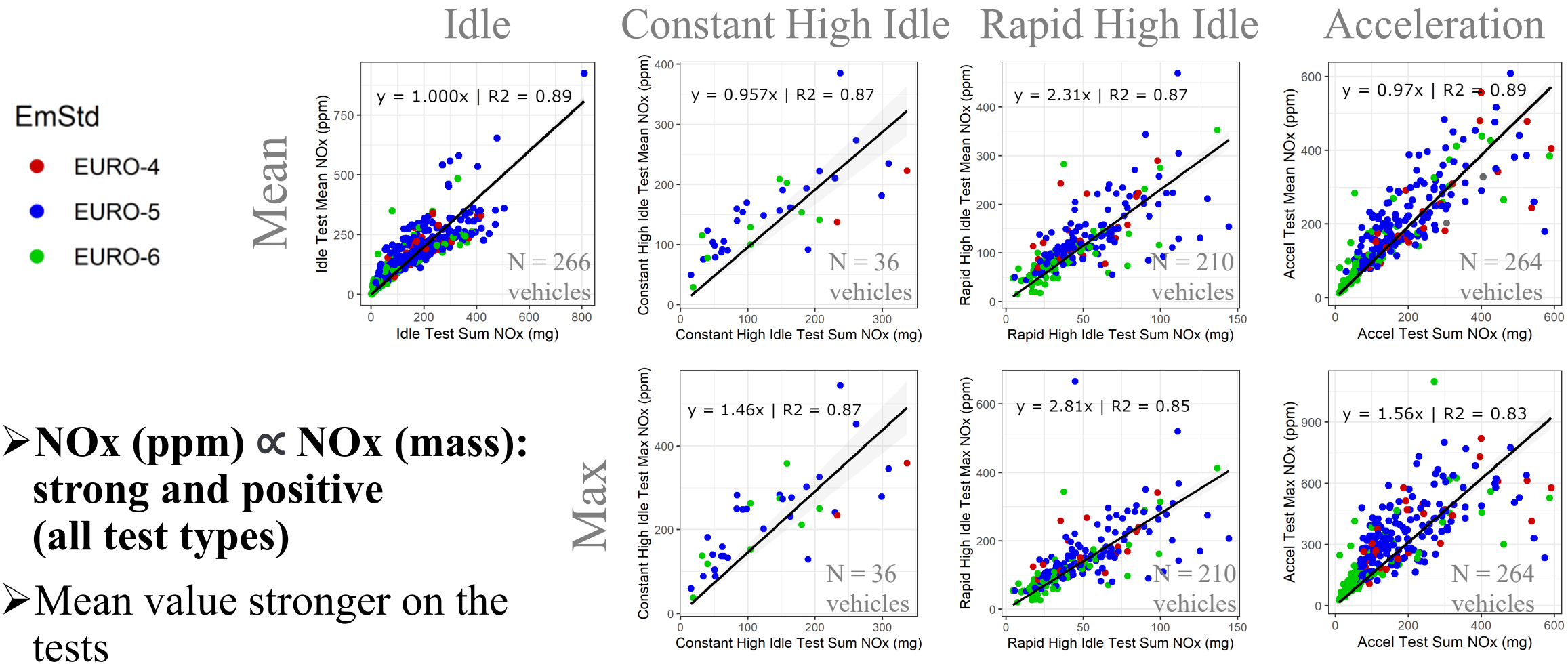
25 vehicles were of pre-Euro or unknown Euro standard

Investigation of Different Test Types

for I/M or PTI Testing

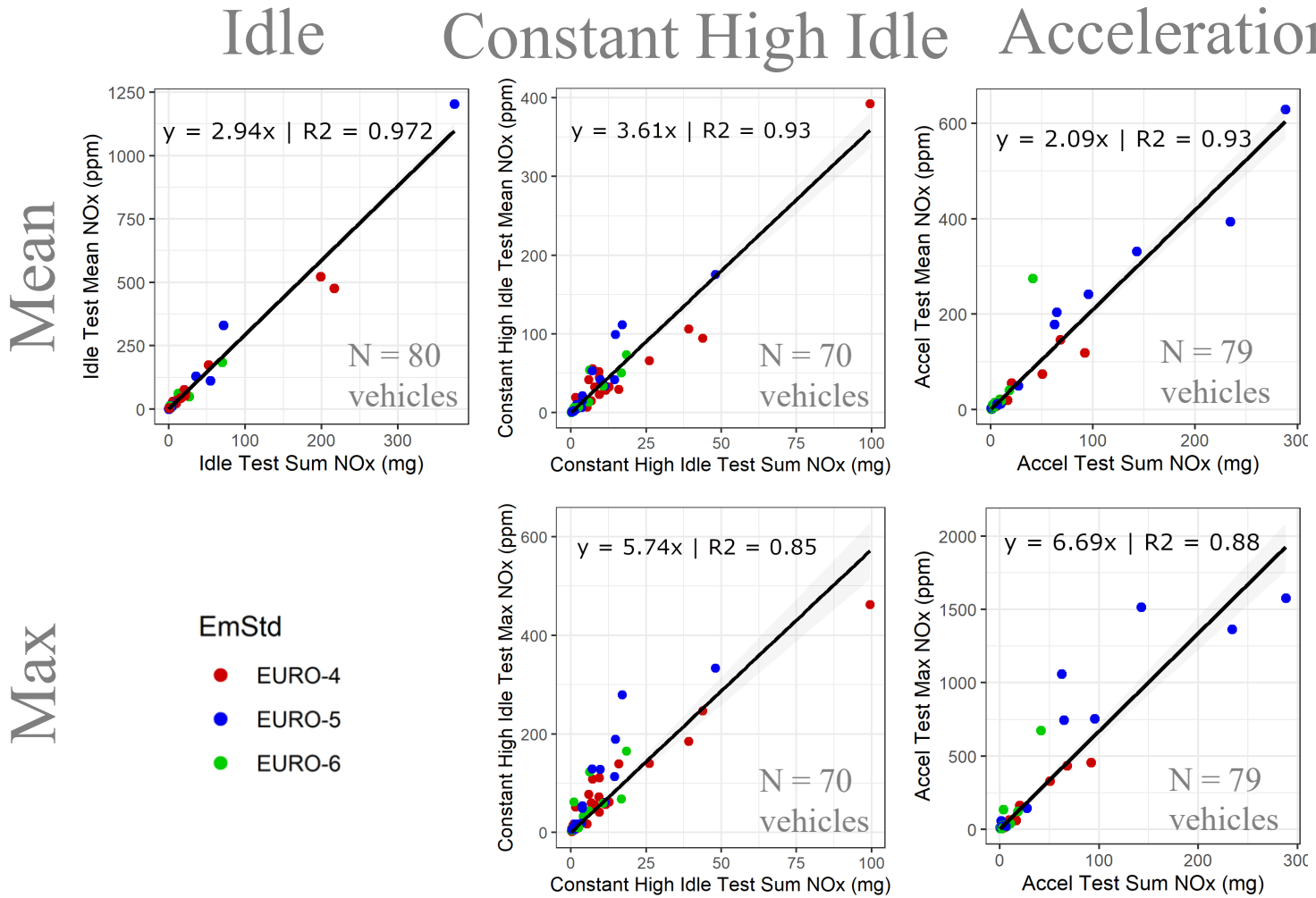
Diesel NOx Emissions – Concentration vs Mass

- **NOx (ppm) ∝ NOx (mass): strong and positive (all test types)**
- Mean value stronger on the tests



Petrol NOx Emissions – Concentration vs Mass

- **NOx (ppm) ∝ NOx (mass)… strong +ve**
- Mean values give stronger correlation than mass
- **Idle test gives highest correlation** (high idle and acceleration tests are similar)



Intra-Vehicle Test Repeatability

- The coefficients of variation (COV) for different test characteristics was calculated from triplicated data (106 vehicles) for each test type

Quantity	Idle Test	Constant High Idle Test	Acceleration Test
Average NOx (ppm)	19%	21%	33%
NOx (mg)	26%	26%	44%
Average Engine RPM	0.24%	3.3%	11%
Average Load (%)	4.7%	6.4%	17%
Average Commanded EGR (%)	45%	34%	23%

$$COV = \frac{Standard\ Deviation}{Mean}$$

Quantity	Acceleration Test
Average VSP_pos (kW/tonne)	29%
Maximum VSP_pos (kW/tonne)	24%
va_{pos} [95] (m^2/s^3)	27%
RPA (m/s^2)	20%

- The COV for these three test types are acceptable
- Acceleration test has most variation, then high idle, *except for* EGR
- EGR needs to be more carefully controlled during testing

RPM—revolutions per minute; EGR—exhaust gas recirculation; VSP—vehicle-specific power; va_{pos} 95—95th percentile of the product of velocity and positive acceleration; RPA—relative positive acceleration.

Inter-Vehicle Test Variability

- The coefficients of variation (COV) for different test characteristics was calculated from vehicle data (all vehicles) for each test type

Quantity	Idle Test	Constant High Idle Test	Rapid High Idle Test	Acceleration Test
Average NOx (ppm)	168%	275%	168%	133%
NOx (mg)	122%	148%	104%	116%
Average Engine RPM	9%	18%	17%	16%
Average Load (%)	41%	49%	59%	41%
Average Commanded EGR (%)	81%	179%	127%	73%

$$COV = \frac{Standard\ Deviation}{Mean}$$

Quantity	Acceleration Test
Average VSP_pos (kW/tonne)	19.99%
Maximum VSP_pos (kW/tonne)	12.19%
va_{pos} [95] (m^2/s^3)	12.56%
RPA (m/s^2)	21.85%

- The coefficients of variation of NOx are much greater than engine RPM, Load and EGR – the tests are highlighting differences in NOx performance between vehicles

Identification of High Emitters using the Enhanced PTI protocol

(1) Illegal Modification

A vehicle was brought to the garage with an illegal KCR box identified.

Make	Model	Model Year	Odometer (km)	Engine Size (L)	Fuel Type	Engine Power (kW)	Euro#
VOLVO	XC70	2013	86K	2.4	Diesel	133	EURO-5

More power and torque

Bring out the hidden potential in your engine with a KCR box. You get more power, which makes overtaking faster and safer. Of course, you also get a sportier drive.

Lower consumption

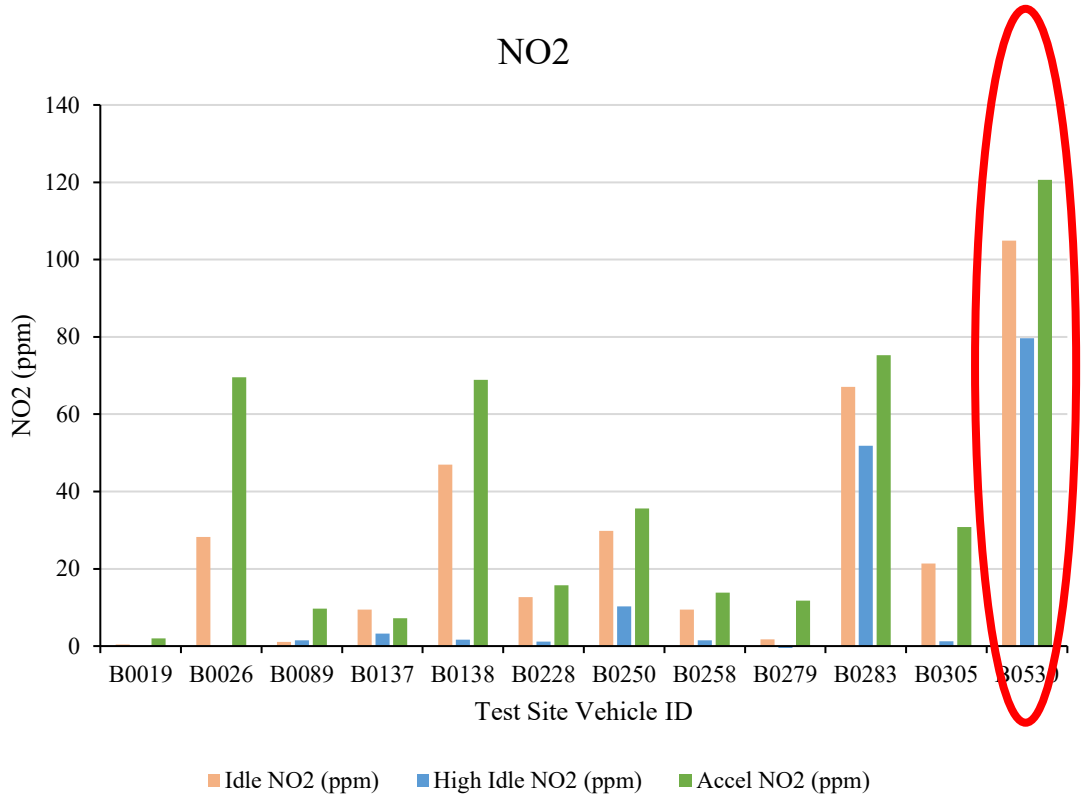
Go further per tank. Our customers usually save between 5-15% diesel with our power boxes.

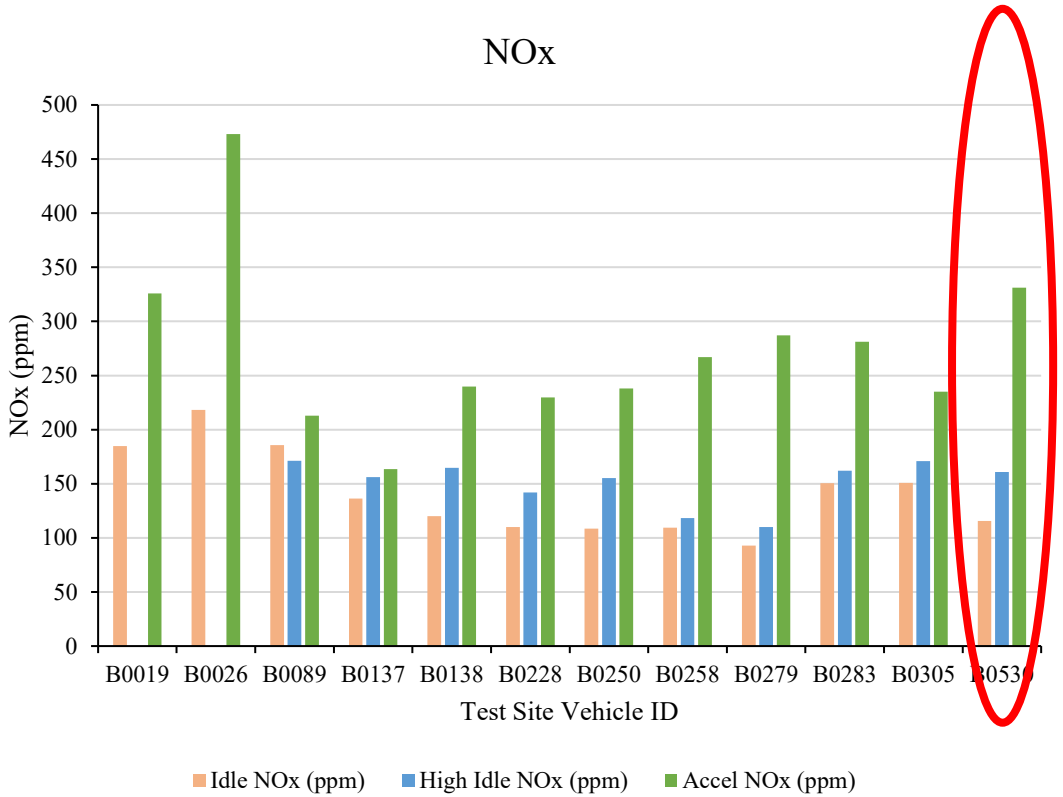
Quick recovery

As easy as it is to mount, just as quickly you can remove and restore the engine to original.

(1) Illegal Modification

This vehicle had the highest NO_2 (on all tests) compared to other 2.4L Diesel Euro 5 Volvos tested in 2021, while overall NOx was only high in acceleration test (and CO was insignificant).



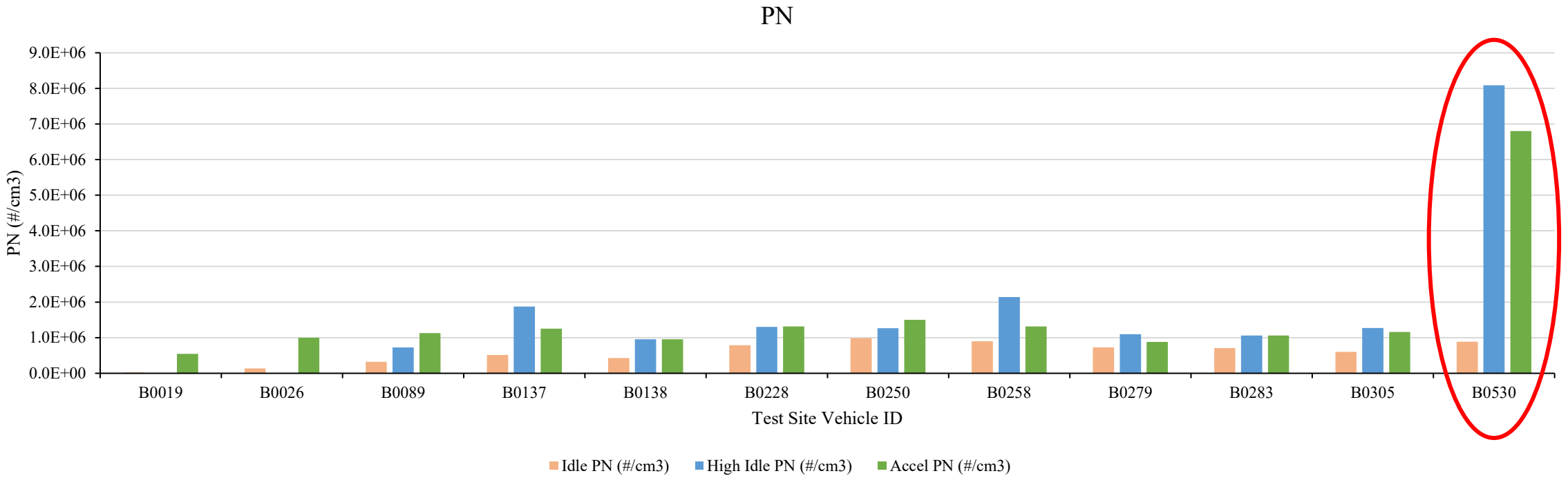


(1) Illegal Modification

This vehicle then had the greatest PN – on high idle and acceleration tests only – compared to other 2.4L Diesel Euro 5 Volvos tested in 2021

Does this indicate an idle PN test is insufficient to catch some high emitters?

The vehicle passed its official PTI smoke opacity test (0.14 result vs 1.5 limit)

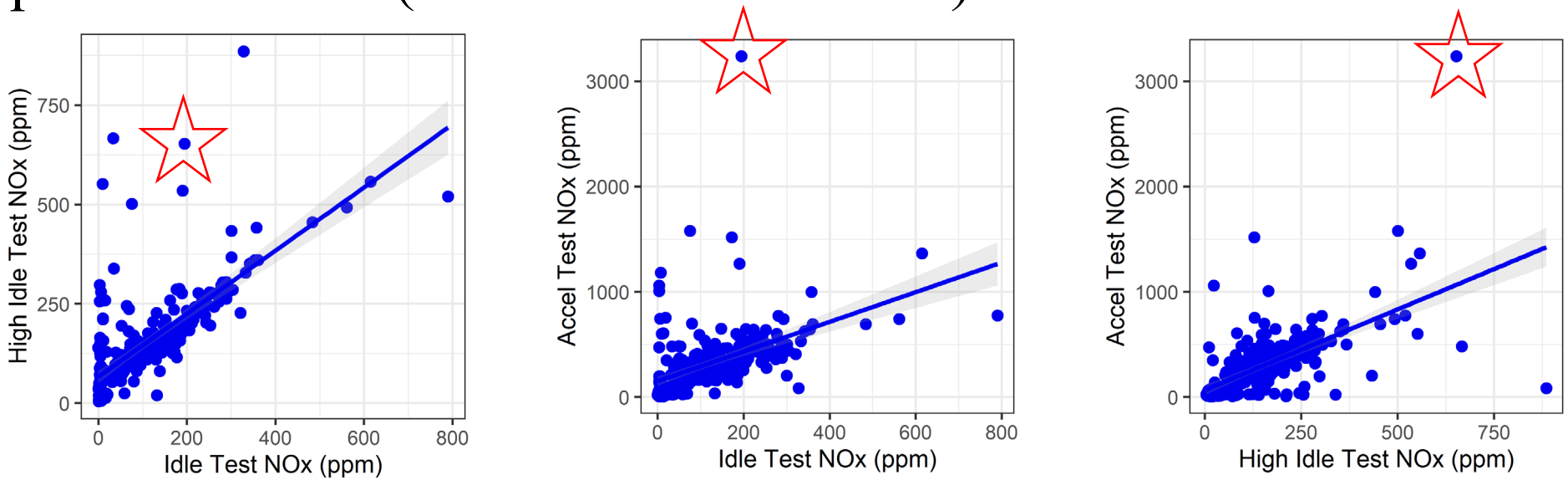


(2) High NOx emitter

Vehicle with high NO emissions on High Idle and Acceleration tests.
The vehicle passed its official PTI test, with low CO concs on all tests.

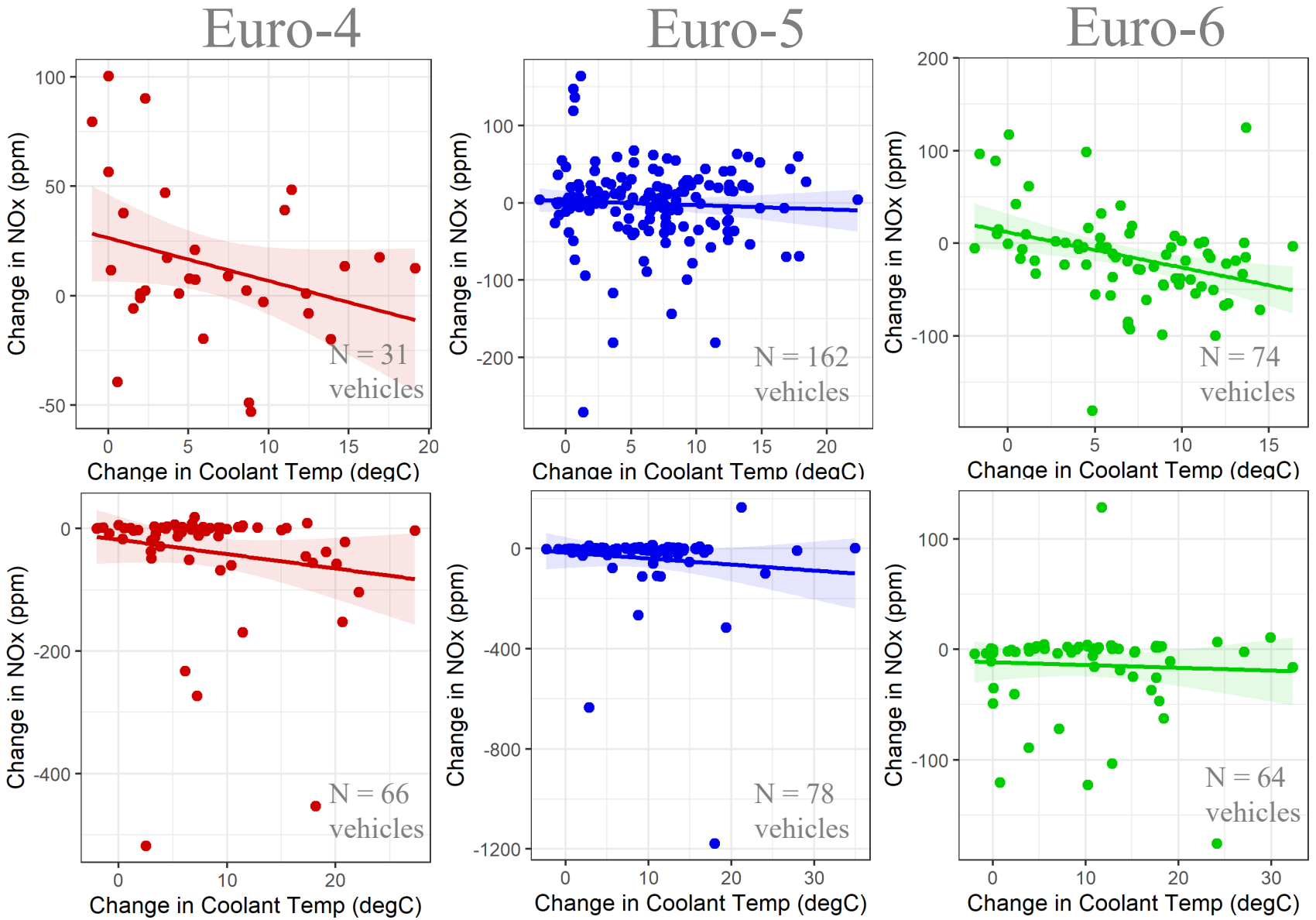
Make	Model	Model Year	Odometer (km)	Engine Size (L)	Fuel Type	Engine Power (kW)	Euro#
SKODA	SUPERB	2011	179	1.4	Petrol	92	EURO-6

Fact vehicle is not high-emitting on the Idle test indicates a loaded test required for NOx (Acceleration test best).



Investigation of Temperature Conditioning
for NOx

Does NOx change with changing Engine Coolant Temp?

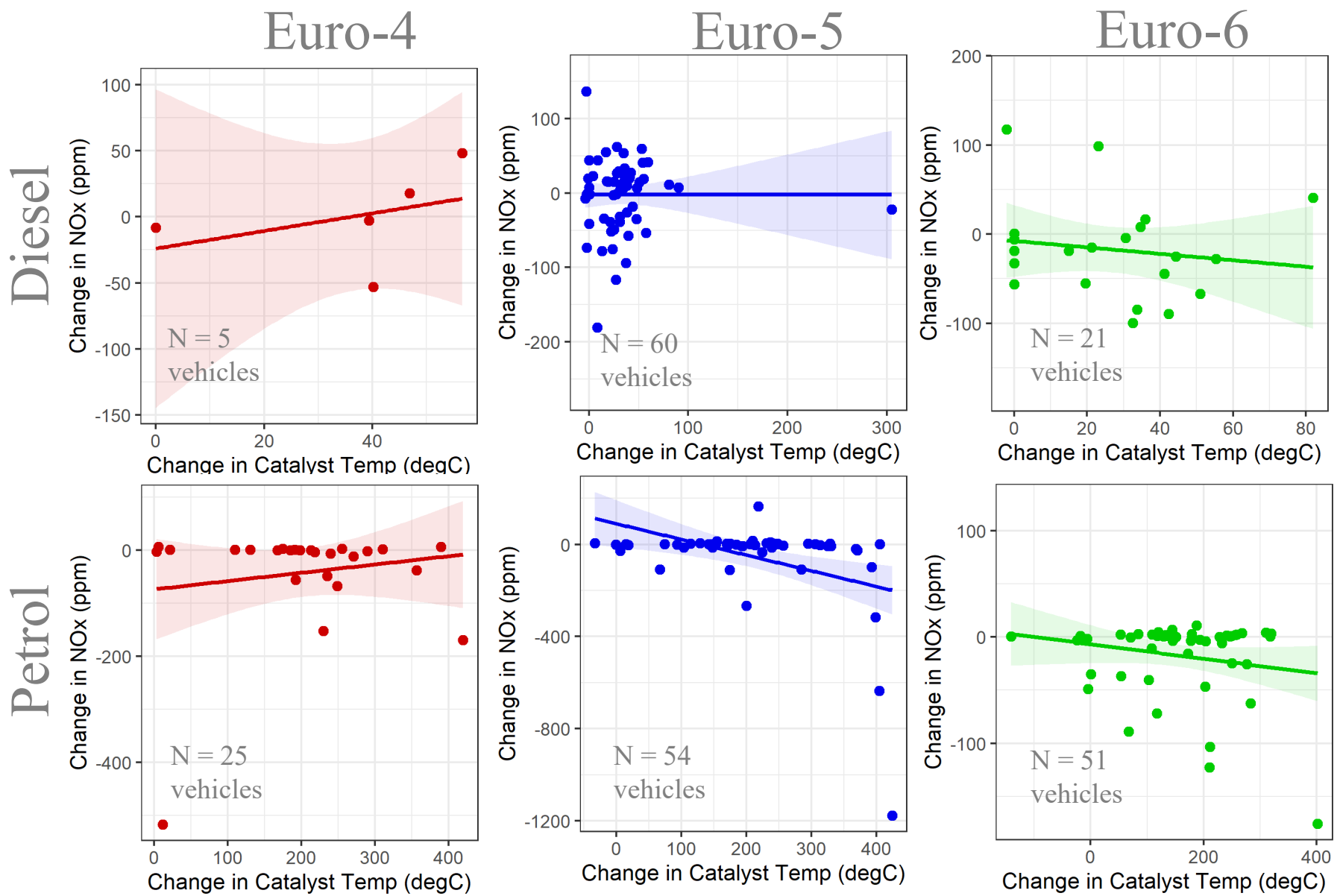


Change in NOx concentration *vs* change in engine coolant temperature, between Idle 1 and 2 tests

NOx concentrations on an *idle* test do not appear to be greatly affected by changes in the engine coolant temperature.

Note: No trend was seen between absolute engine coolant temperature and NOx between vehicles, either.

Does NOx change with changing Catalyst Temp?



Change in NOx conc. *vs* change in catalyst temp. between Idle sections 1 and 2 (i.e. start and end of protocol).

Idle NOx seems unaffected by catalyst temperature changes (similar for absolute acceleration test values)

BUT diesel catalyst temp does not always seem correct – true aftertreatment temperature should be provided by OEMs

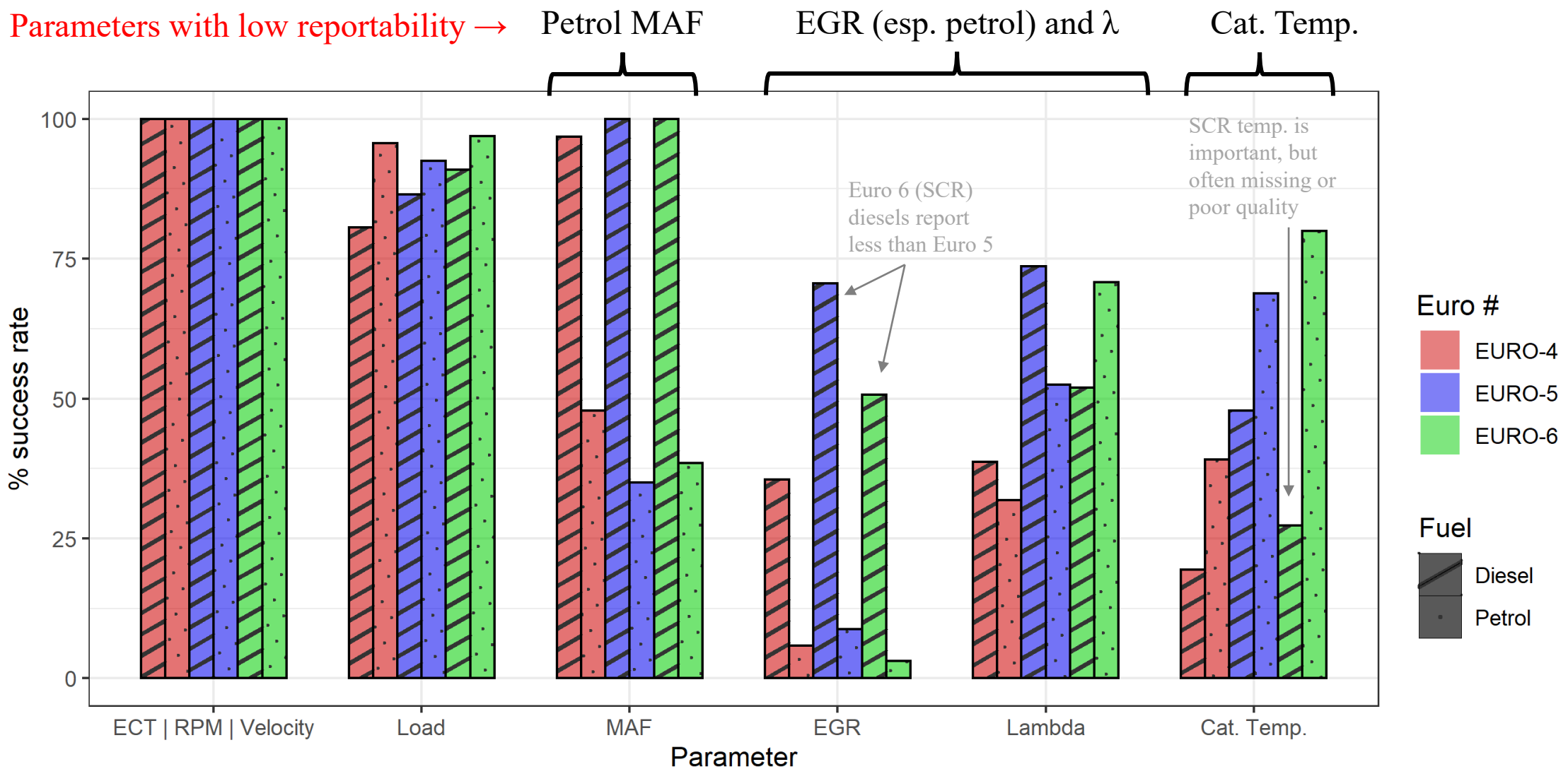
Causes of large differences in NOx:

1. *Changes in EGR rate;*
2. *NO_2 constantly increasing from SCR diesels*
3. *Some petrol vehs had very high NO on startup (i.e. PN_1)*

Investigation of ECU Parameter Availability

for I/M or PTI Testing

Investigation of OBD Parameter Availability



Conclusions

Summary

- Concentration values are a good representation of mass emissions on *all* test types, with mean concentration values being better than maximum
- Repeatability of the test types is acceptable but EGR on idle tests should be controlled
- Variability study of all vehicles shows that NOx differences are being highlighted by the tests
- Only loaded testing can identify some of the high emitters
- No trend of emissions with engine coolant, catalyst or ambient temperature seen *but* data capture was incomplete or suspect quality
- Requirement of additional sensors to capture some relevant parameters in current vehicles as OBD system not accessible enough, particularly catalyst temperature indicators and EGR rate information

Thank you for listening

See ***Atmosphere*** journal article for more info – https://www.mdpi.com/2073-4433/14/3/536

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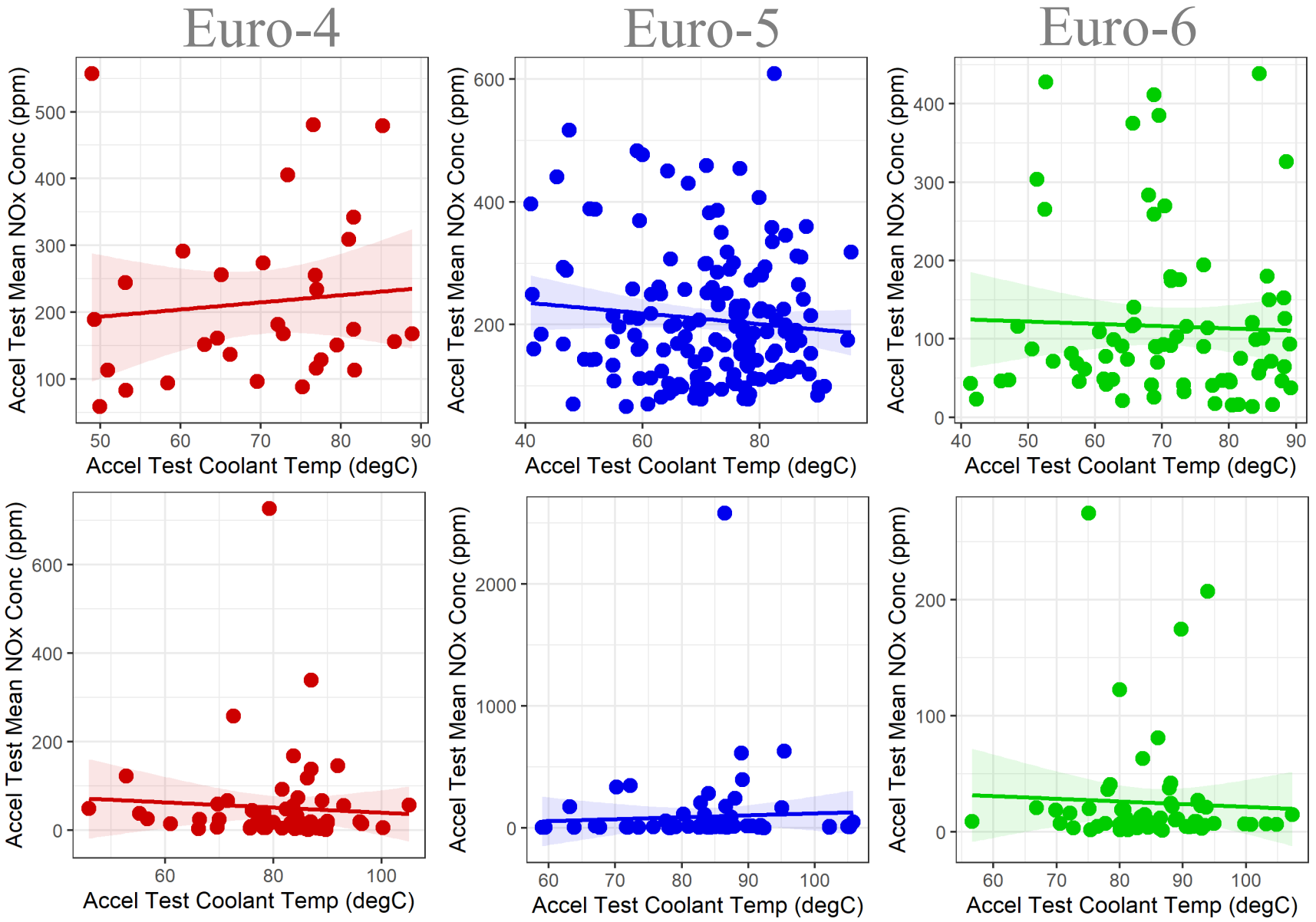
Further Info

Full study and time-series graphs of ALL tested vehicles:

https://3datx.com/ptipilot/

Additional Slides

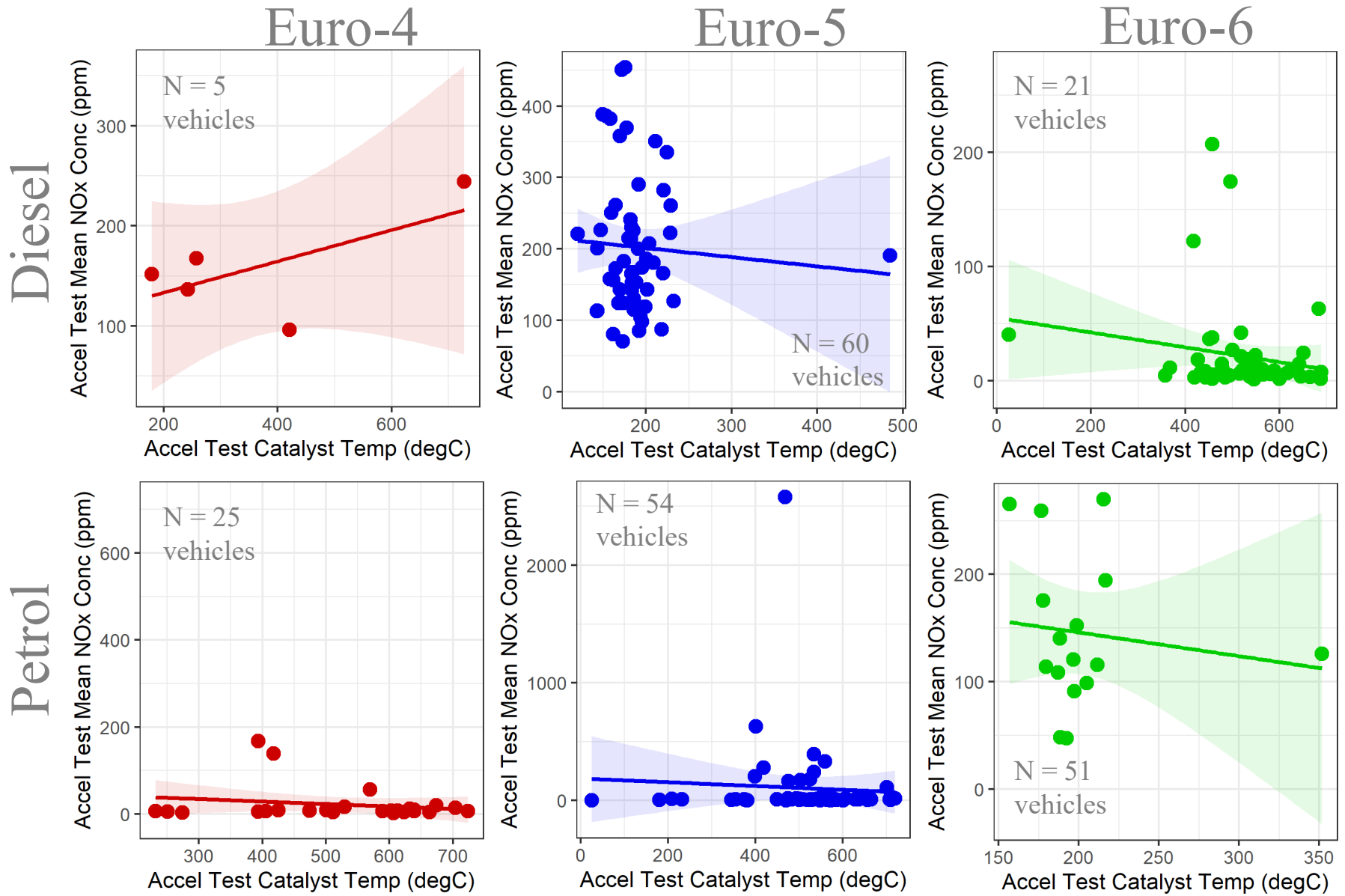
Does NOx change with Engine Coolant Temp?



NOx concentration *vs* engine coolant temperature, on Acceleration test

- Does not appear to be greatly affected by the engine coolant temperature.

Does NOx change with Catalyst Temperature?

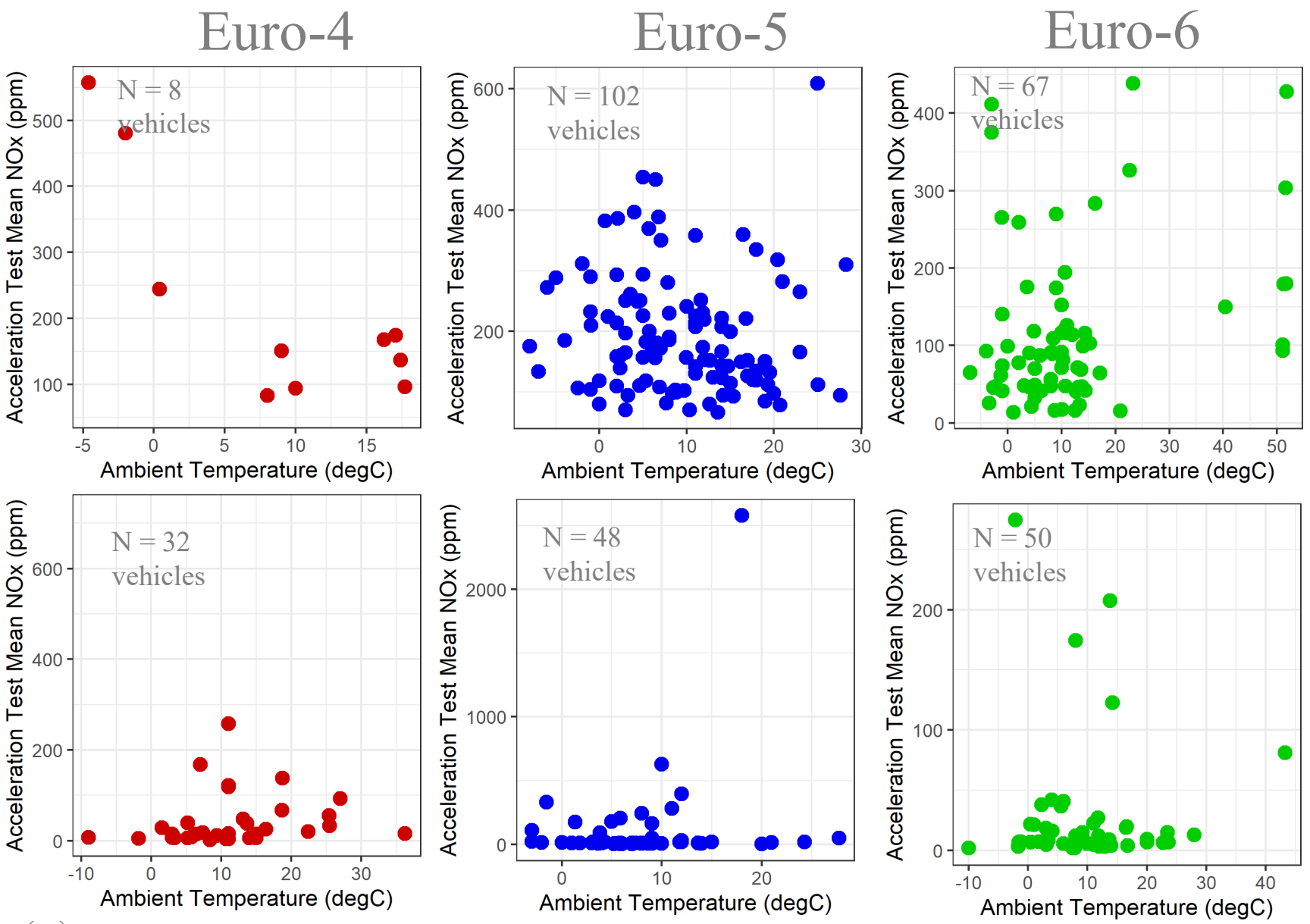


NOx conc. *vs* catalyst temp. on Acceleration Test

- Acceleration Test NOx seems unaffected by catalyst temperature

BUT the diesel catalyst temperature does not always seem correct/meaningful – true aftertreatment temperature should be provided by OEMs

Does NOx trend with Ambient Temperature?



Mean NOx concentration *vs* mean ambient temperature (from ECU), for the Acceleration test.

No correlations seen. Acceleration Test NOx is not greatly affected by ambient temperature.

Note: This ambient temperature does not always seem correct when considering the Swedish climate – true ambient temperature should be provided by OEMs. We will use weather station data for further analysis.