The RDE legislation; PEMS opportunities & challenges

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An overview of passenger car emission legislation in EU

- Large and ambitious leaps in emission reduction has been deployed throughout the history ofEU emission legislation
  - E.g. since 2000 (Euro 3) to Euro 6 → NOx limit for diesels has been decreased from 500 mg to 80 mg NOx/km
- Since the Diesel scandal, it was publicly understood that fundamentally, the methodology and thus correlation between laboratory and real world emissions was a huge problem
- Since the deployment of Euro 6, great development has been seen
  - Laboratory tests: NEDC → WLTP
  - Deployment of RDE testing
    - Requirements for RDE testing were gradually improved
  - + Durability and ”in service conformity” (ISC) requirements
- Eventually, Euro 7 has been provisionally agreed and announced, waiting for formal approval

CI (Diesel)	
Emission class (EU)	NOx emissions mg/km
Euro 3	500
Euro 4	250
Euro 5	180
Euro 6	80

An overview of Euro 6 and Euro 7 emission regulation													
Emission regulation	Class	Type	Date	CO	HC	NMHC	NOx	THC + NOx	PM	PN23	PN10	Durability requirements	
				g/km						#*10^11/km		km	years
Euro 6	M1	PI	Sep 2014	1000	100	-	60	-	5	6	-	100 000	5
	M1	CI	Sep 2014	500	170	-	80	170	5	6	-	100 000	5
Euro 7	M1	PI	2025/2026?	1000	100	68	60	-	4.5	-	6	160 000/200 000*	8/10*
	M1	CI	2025/2026?	500	-	68	80	170	4.5	-	6	160 000/200 000*	8/10*

**additional lifetime*

PI = positive ignition, ie. petrol/gasoline vehicles
CI = Compression ignition, ie. diesel vehicles

The Evolution of RDE testing

- In early 2010 JRC/EU launched a program for development of a regulatory RDE procedure
- RDE regulation was initially deployed in 2016, and has since then been revised multiple times
- The amendments set continuously lower limits for real-world emissions (conformity factors), thus improves correlation between real world conditions and in lab measurements
- Euro 7 follow the similar path, with further improvements in both ISC and durability requirements
- **But, what is the true emission characteristics in real world conditions of pre/post RDE vehicles?**

RDE procedure	Regulation phase	Published	New type approvals	All vehicles	NO_x CF	PN CF
-	Euro 6 a	-	-	-	-	-
-	Euro 6 b	-	-	-	-	-
1st RDE package	Euro 6 c	March 2016	September 2017	September 2018	Monitoring only	
2nd RDE package	Euro 6 d-TEMP	April 2016	September 2017	September 2019	2.1	-
3rd RDE package		June 2017	September 2017	September 2018		1.5
4th RDE package	Euro 6 d	November 2018	January 2020	January 2021	1.43	
Euro 6e RDE	Euro 6 e	August 2022	September 2023	September 2024	1.1	1.34
Euro 7 RDE	Euro 7	April 2024, waiting for formal approval	30 months from entry into force	42 months from entry into force	1	1
Euro 7 RDE	Euro 7 "additional lifetime"	April 2024, waiting for formal approval	30 months from entry into force	42 months from entry into force	1.2	1.2

Regulation phase	RDE NOx [mg/km]		RDE PN [#*10^11/km]
	PI	CI	PI/CI
Euro 6 d-TEMP	126	168	9.0
Euro 6 d	86	114	9.0
Euro 6 e	66	88	8.0
Euro 7	60	80	6.0
Euro 7 "additional lifetime"	72	96	7.2

Demonstration of Euro 6 diesel car emissions - A PEMS campaign in Helsinki

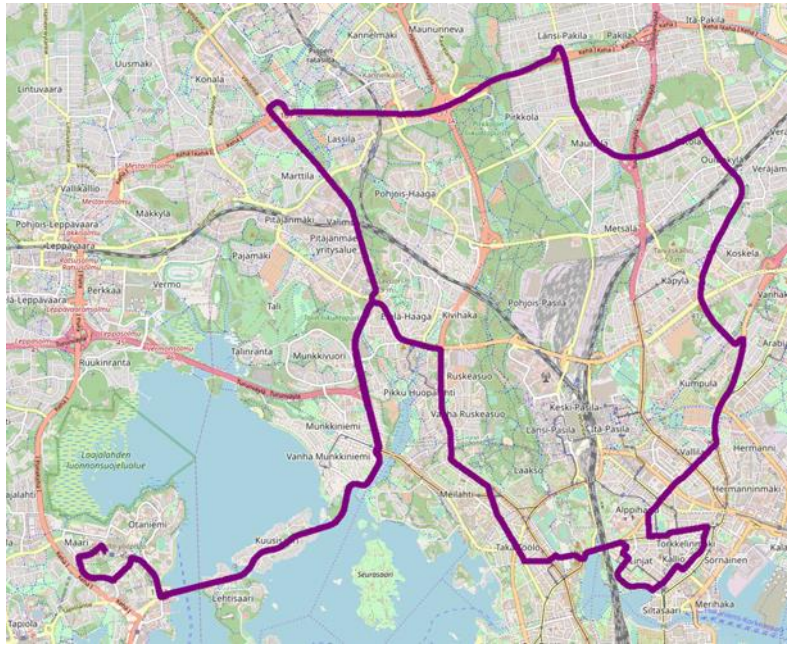
- The emission performance of 4 diesel vehicles were demonstrated
  - Non RDE regulated Euro 6 b + RDE regulated Euro 6 d-temp
  - Both LNT and SCR vehicles included
- Goal: Determine and quantify typical emission performance (NOx & PN) in various ambient conditions

Car id.	*Type*	*Model year*	*Emission class*	*Engine displacement [l]*	*NO_x conformity factor*	*PN conformity factor*	*Transmission*	*EATS*	*Vehicle mileage [km]*
Car A	Estate	2015	Euro 6 b*	1.6	-	-	M6	DOC+DPF + LNT	73 500
Car B	Estate	2017	Euro 6 b*	1.6	-	-	M5	DOC+DPF + LNT	24 800
Car C	Estate	2014	Euro 6 b*	1.6	-	-	M6	DOC+DPF + SCR	59 100
Car D	Hatchback	2018	Euro 6 d-temp	1.5	2.1	1.5	AT8	DOC+DPF + 2xLNT	2000

*vehicle type-approved outside RDE regulation, i.e. no RDE testing nor RDE limit applied

Test conditions

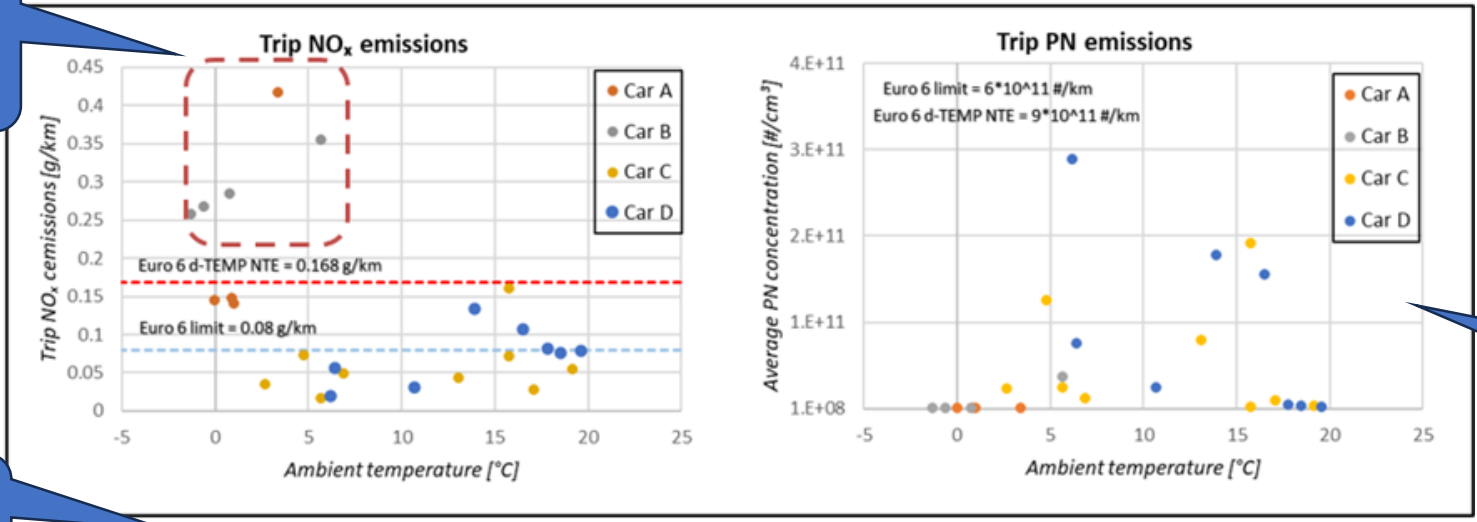
- RDE compliant test route in Helsinki metropolitan area
- Ambient conditions varied between – 1.3 °C to ca. 20 ° C
- 4 to 7 tests per vehicle conducted, 24 in total



Car	Number of PEMS tests	Average trip ambient temperature range [°C]
Car A	4	0.9 to 3.4
Car B	4	-1.3 to 5.7
Car C	9	2.7 to 19.2
Car D	7	6.2 to 19.6
Total	24	0.9 to 19.6

Trip average emissions – NOx/PN

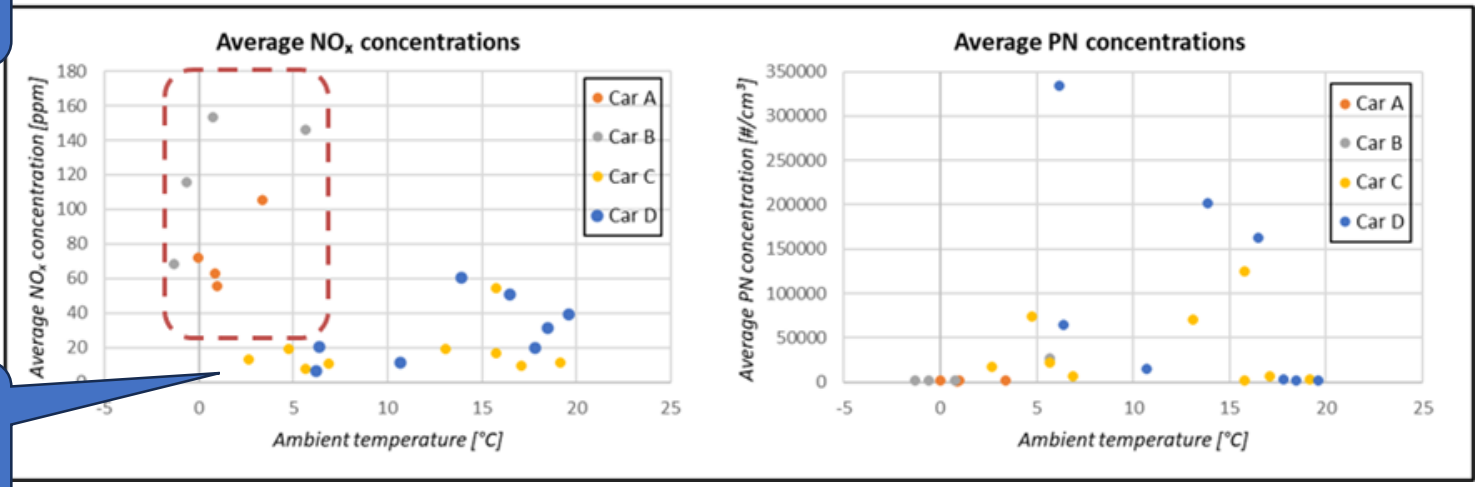
Car B resulted in highest trip NOx emissions
(Car was comparable to Car A)



Car id.	*Emission class*	*EATS*
Car A	Euro 6 b	DOC+DPF + LNT
Car B	Euro 6 b	DOC+DPF + LNT
Car C	Euro 6 b	DOC+DPF + SCR
Car D	Euro 6 d-temp	DOC+DPF + 2xLNT

PN emissions well below threshold with all cars

Car A and B resulted correspondingly in highest average NOx concentrations over test

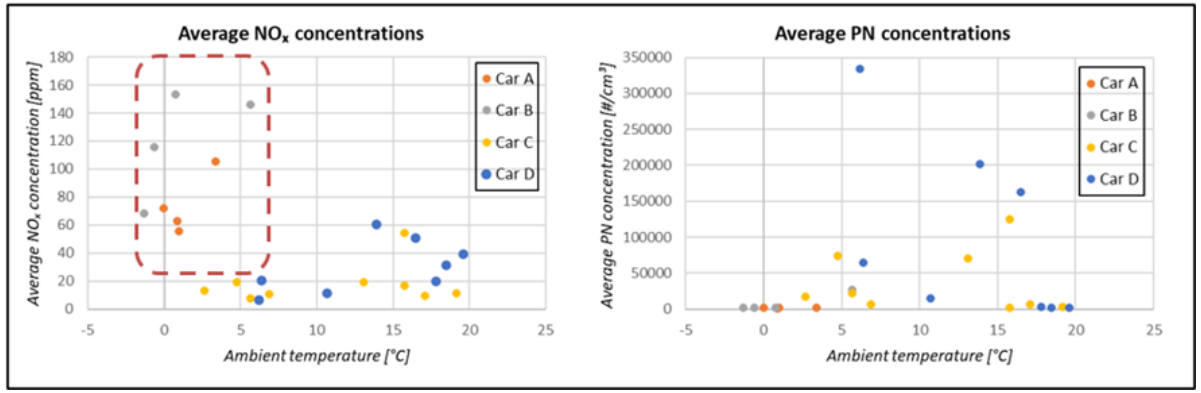


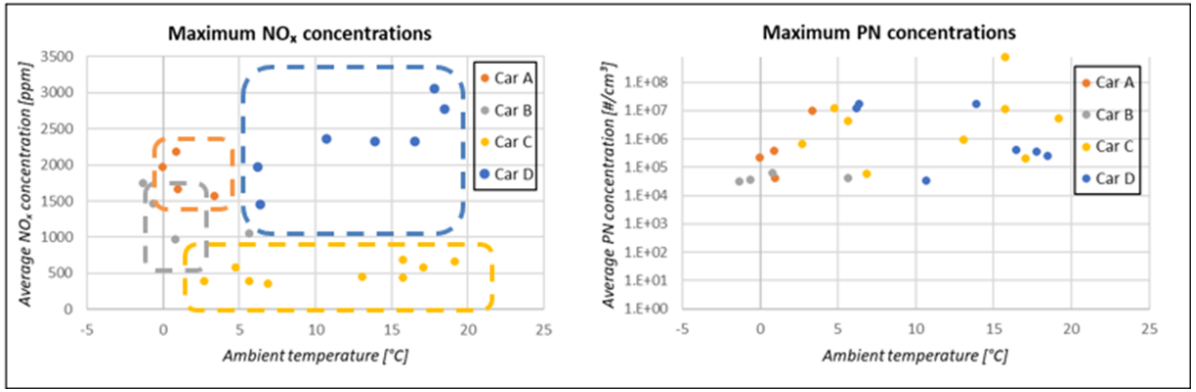
Spread in avg NOx concentration lower for Car C and D even in varying amb. temperatures!

Correlation between average and peak emissions – NOx/PN

- However, correlation between average and peak emissions was found surprisingly low!
- High momentary NOx emissions during acceleration and during transient load
  - → E.g. Car D (Euro 6 d-TEMP), low average NOx recorded but on contrary, produce highest momentary peak NOx concentrations
  - → Typically, LNT cars produced higher momentary NOx compared to SCR vehicle
    - → Euro 6b vehicle, Car C with SCR, NOx peaks below 1000 ppm in all tests
    - → Euro 6d-TEMP, Car D with twin LNT produced NOx peaks between 1500 ppm to 3000 ppm!

Car id.	*Emission class*	*EATS*
Car A	Euro 6 b	DOC+DPF + LNT
Car B	Euro 6 b	DOC+DPF + LNT
Car C	Euro 6 b	DOC+DPF + SCR
Car D	Euro 6 d-temp	DOC+DPF + 2xLNT

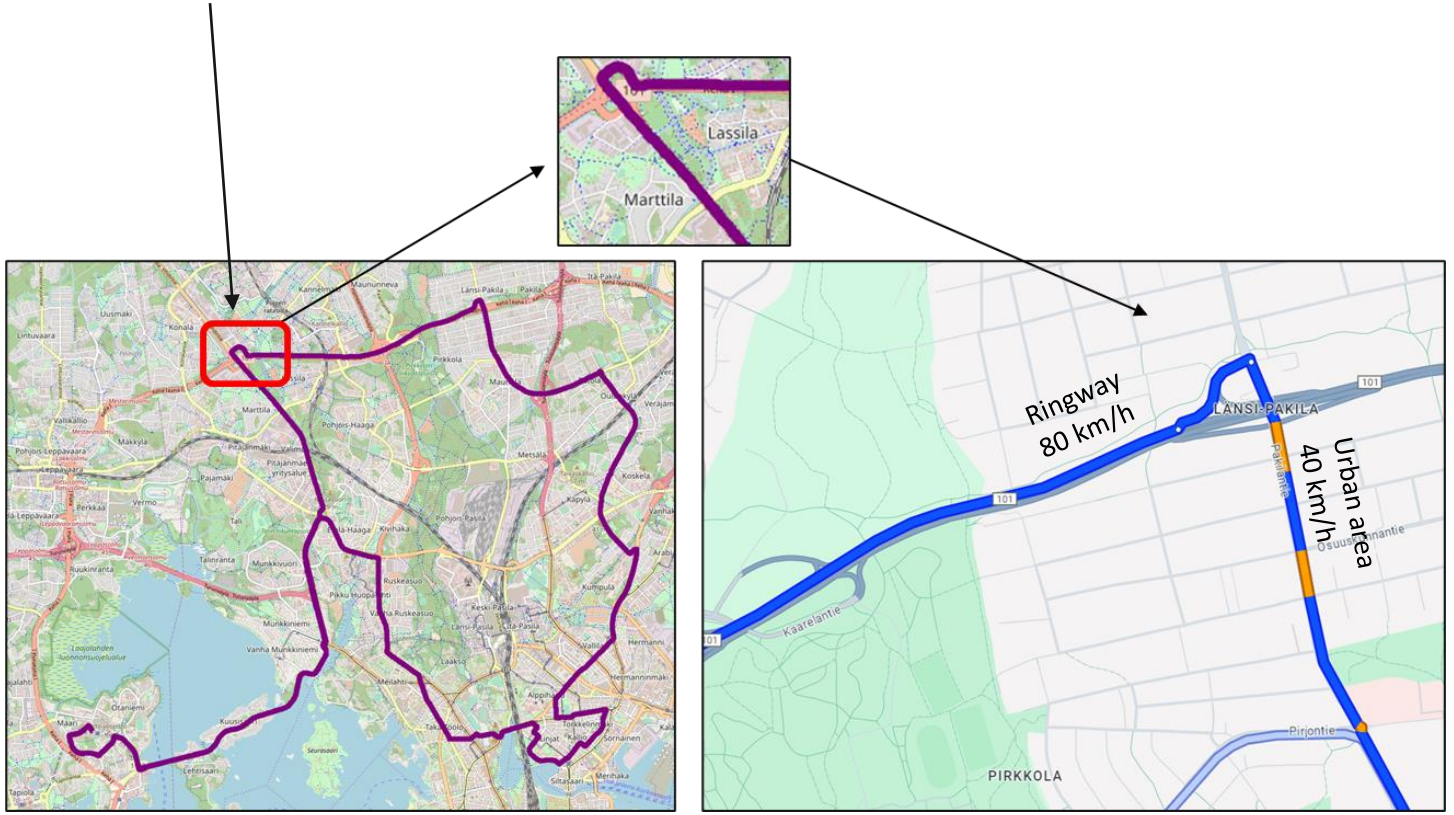




Examples of momentary emission behavior (1/2)

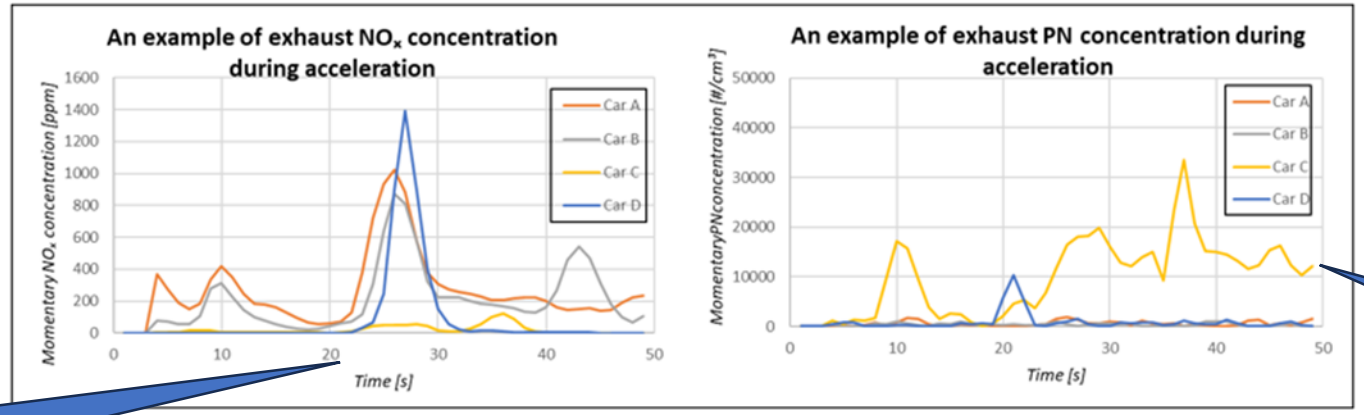
- It was found that the emission peaks were emitted in certain areas

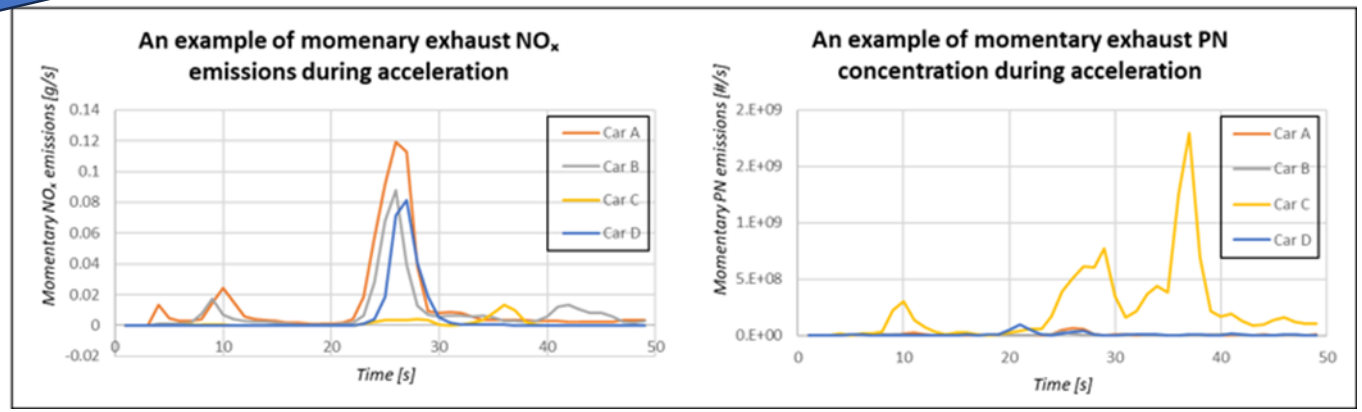
  → e.g. in junctions when accelerating from urban areas to highways



Examples of momentary emission behavior (2/2)

Car id.	*Emission class*	*EATS*
Car A	Euro 6 b	DOC+DPF + LNT
Car B	Euro 6 b	DOC+DPF + LNT
Car C	Euro 6 b	DOC+DPF + SCR
Car D	Euro 6 d-temp	DOC+DPF + 2xLNT





Car C with SCR produces remarkably lower momentary NOx during acceleration…

…but on contrary, produces higher PN during the same event.
Vehicles with LNT produced extremely low PN!

What can we learn?

- The deviation in emission performance for pre/post RDE era cars seem be rather large
- Influence of EATS strategy is high especially for NOx emissions , e.g. SCR vs LNT
  - The difference in NOx characteristics in transient events between LNT and SCR were in this case evident
  - SCR performance was excellent even during rapid accelerations for the Euro 6 b vehicle
  - High momentary NOx emissions are possible even for cars with low overall NOx emissions
    - Vehicle EATS should be considered if evaluated with RES monitoring!
- Cars equipped with DPF did in this demonstration perform overall very well
  - Similarly, as for the NOx characteristics, PN trends could be classified depending on used NOx reduction technology
    - The car with SCR produced evidently higher PN during acceleration, most likely due to particulate formation from urea injection
  - However, due to low particulate concentrations, defect or tampered DPF devices could be easily identified

Summary & conclusions

- From the regulatory perspective, the higher the emission class, the likelihood for high momentary emissions during real world driving decreases and more consistent emissions performance is expected
  - Correlation between laboratory testing and RDE response increase significantly
  - Considering later Euro 6 class cars and Euro 7, very good emission performance is expected

  → The difference between a defect/tampered/abnormal EATS compared to expected values higher
- This does not however seem to be the case for early RDE regulated vehicles (e.g. Euro 6 d-TEMP)
  - Based on momentary emissions obtained, identification of high emitters within early Euro 6 can be challenging
    - E.g. durability obligations due to age and high mileage is furthermore dominant (Euro 6 d-TEMP launched in 2016/2017)
  - Results indicate that car specific EATS should be considered when evaluating momentary emissions, e.g. in RES measurements, as shown for SCR vs LNT

Thank you!

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