Experience with emissions from a PHEV and RDE data evaluation methods

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Content

- PHEV programme
  - Programme set-up
  - Real-Driving Emissions (RDE) on the road
  - Towards RDE boundary conditions on the chassis dyno
  - Summary
- RDE data evaluation
  - AECC PEMS database
  - Terminology
  - Impact of RDE data evaluation methods on AECC PEMS data
  - Summary

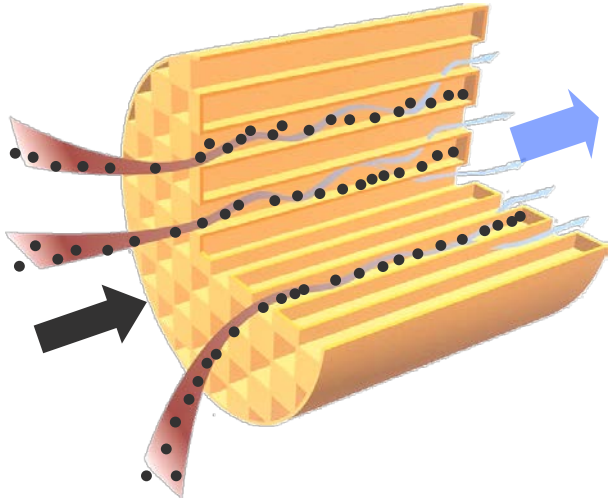
Test programme set-up

- Objective: measure the real-world behaviour of a market-representative Plug-in Hybrid Electric Vehicle (PHEV)
- Vehicle selected
  - C-segment PHEV with 1.5l-class GDI engine
  - Euro 6b certified
  - Rental car ~10 000 km mileage
  - 4 Driving modes: Electric, Hybrid, Charge and Sport
  - Official electric range: 50 km
- Emissions of PHEV are compared to similar GDI vehicle tested in 2016 AECC test programme*

* Real-World Emissions Measurements of a GDI Vehicle without and with a GPF, Demuynck, et al., SAE 2017-01-0985

Test programme set-up

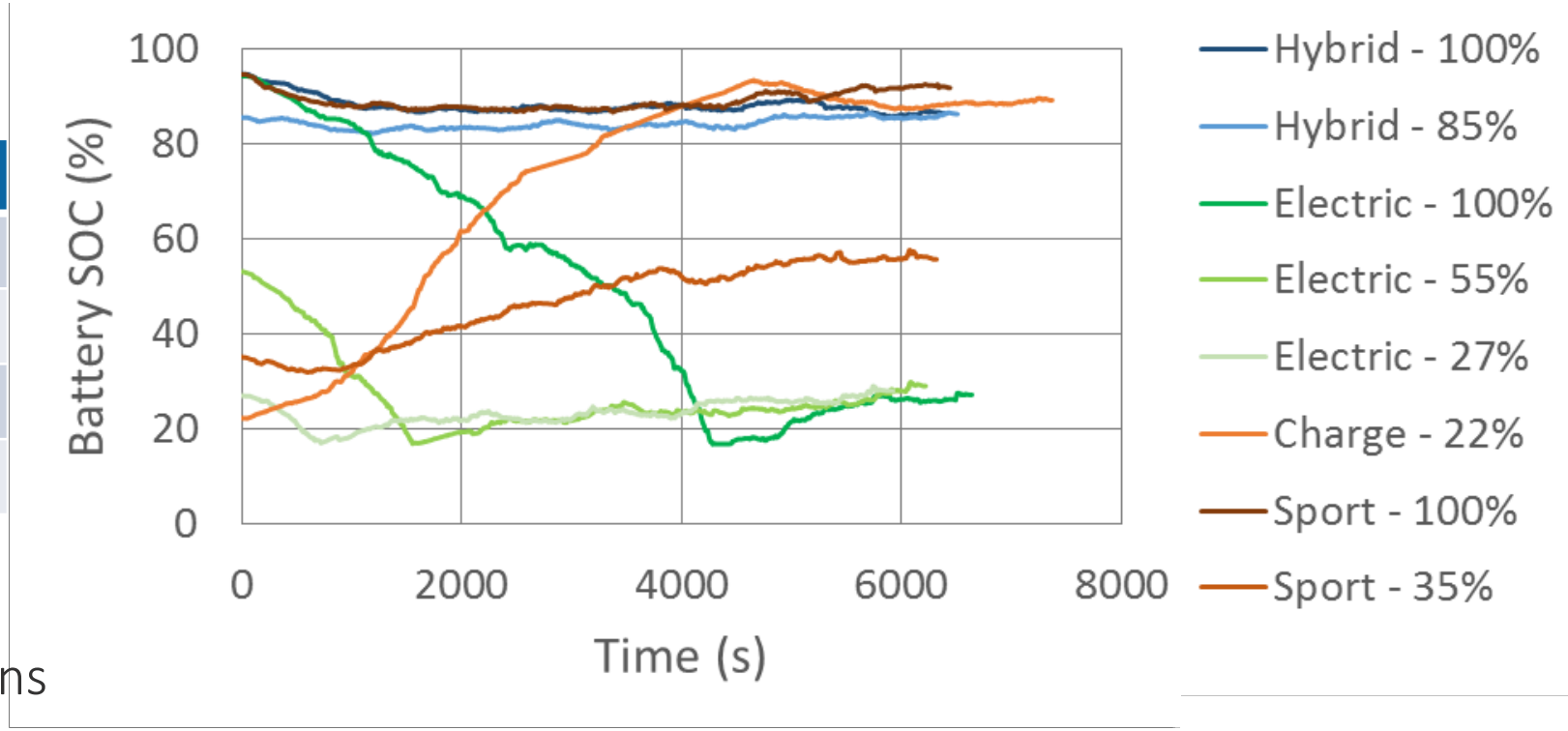
- Measurement details
  - At Ricardo (UK)
  - All tests on market E5 fuel
  - HORIBA PEMS OBS-ONE: CO, CO_2, NOx and PN
  - Raw data will be presented, without RDE post-processing
- Test Matrix
  - All 4 driving modes (Electric, Hybrid, Charge and Sport)
  - Variation in initial battery State of Charge (SOC)
  - RDE on-road and on the chassis dyno
  - 2 tests repeated with a coated Gasoline Particulate Filter (GPF) replacing the second (underfloor) Three-Way Catalyst (TWC)



8 combinations of mode and initial battery SOC tested

Change in battery SOC (State of Charge) during on-road RDE tests

SOC	Electric	Hybrid	Charge	Sport
100%	1x	1x	-	1x
85%		1x		
55%	1x			
25%	1x		1x	1x



- Comparison to WLTP definitions
  - Charge depleting: Electric – 100%
  - Charge sustaining: Hybrid – 85% and Electric – 25%

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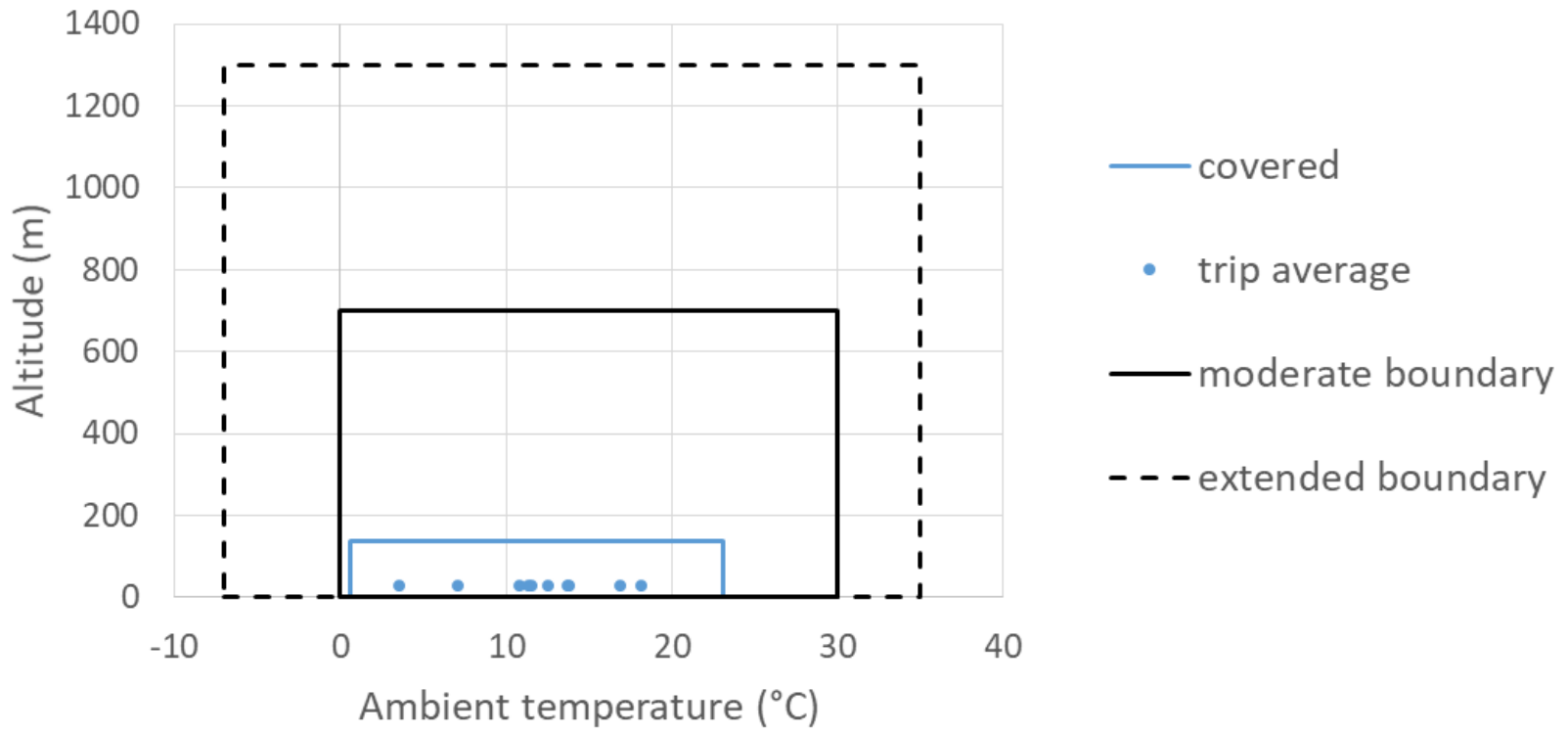
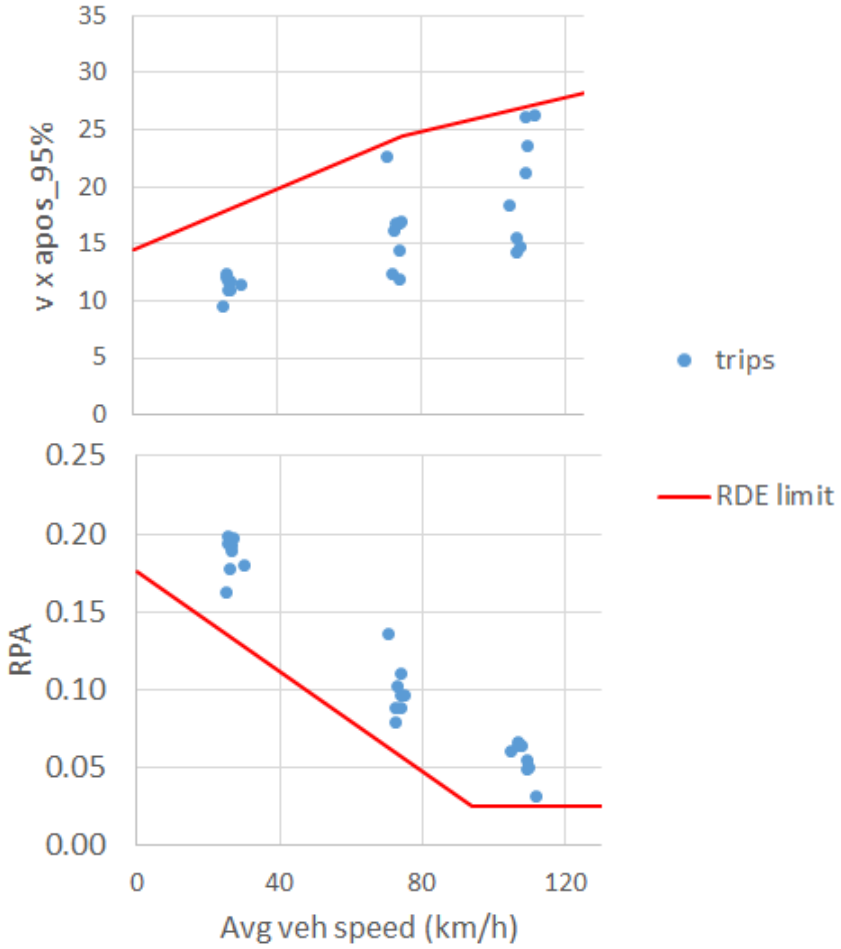
On-road RDE data within moderate boundary conditions

Engine start after overnight soak at temperature close to trip average

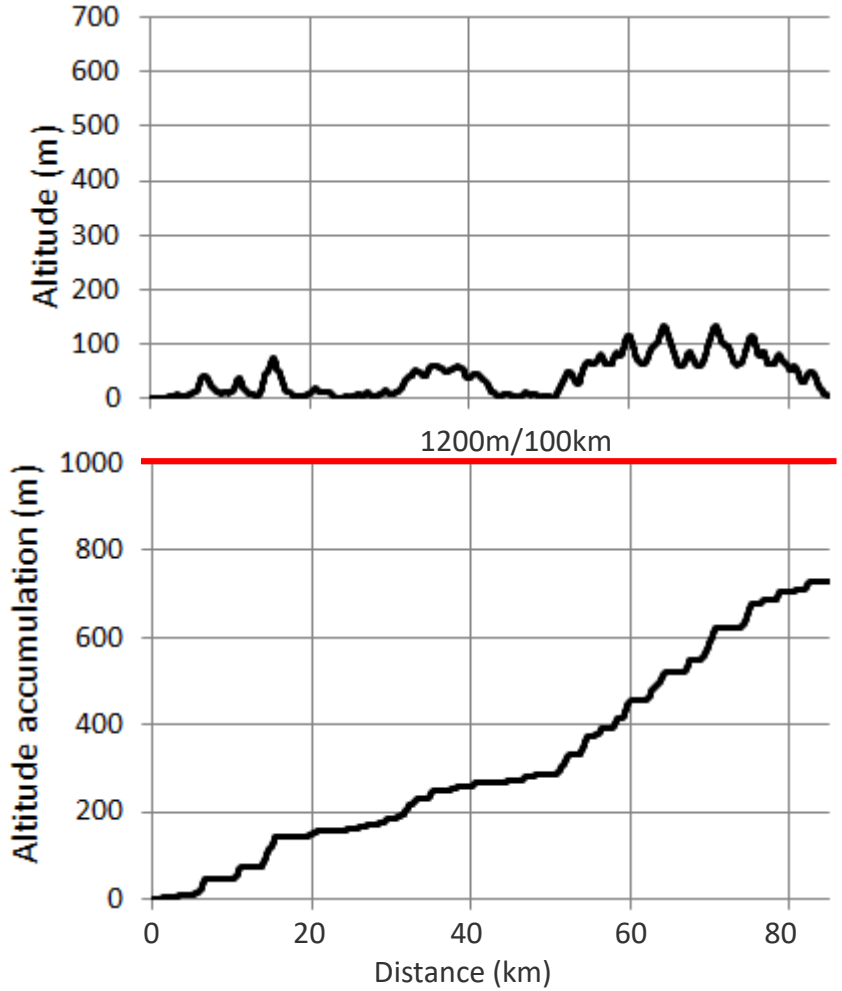


On-road RDE data within dynamic boundary conditions

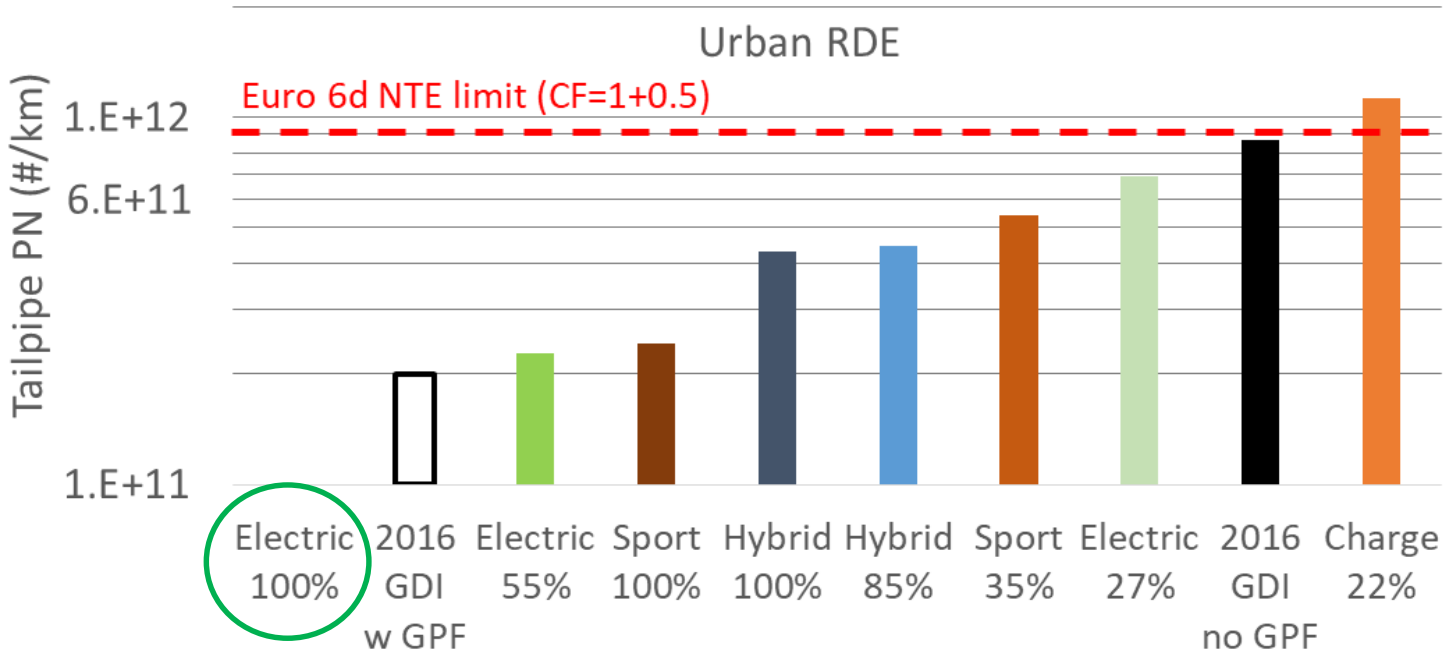
Excess or absence of driving dynamics



Altitude accumulation



Most urban PN emissions higher than GDI with GPF



- Electric mode – full battery: urban part entirely run electric → zero urban tailpipe PN emissions
- Charge mode – empty battery: high power demand on ICE → highest PN emissions

ICE: Internal Combustion Engine

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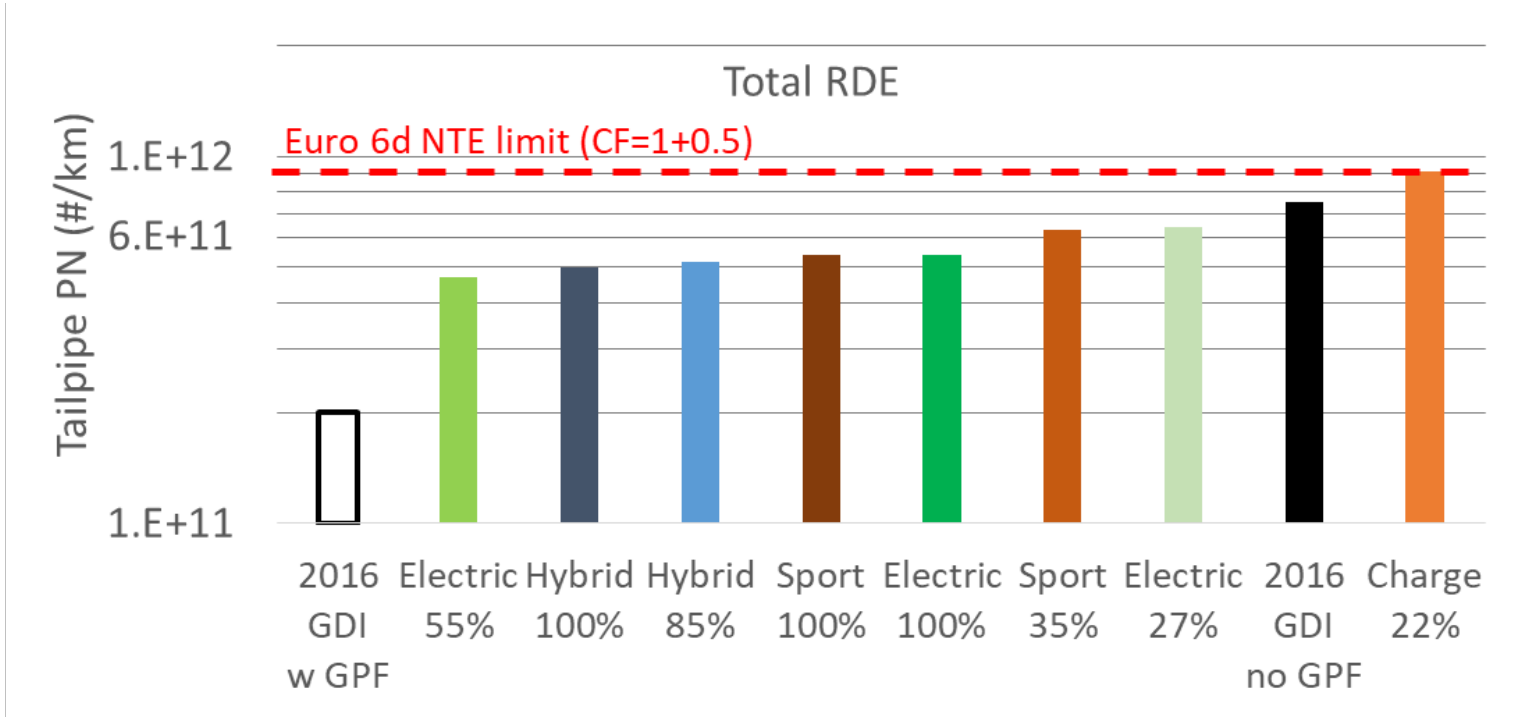
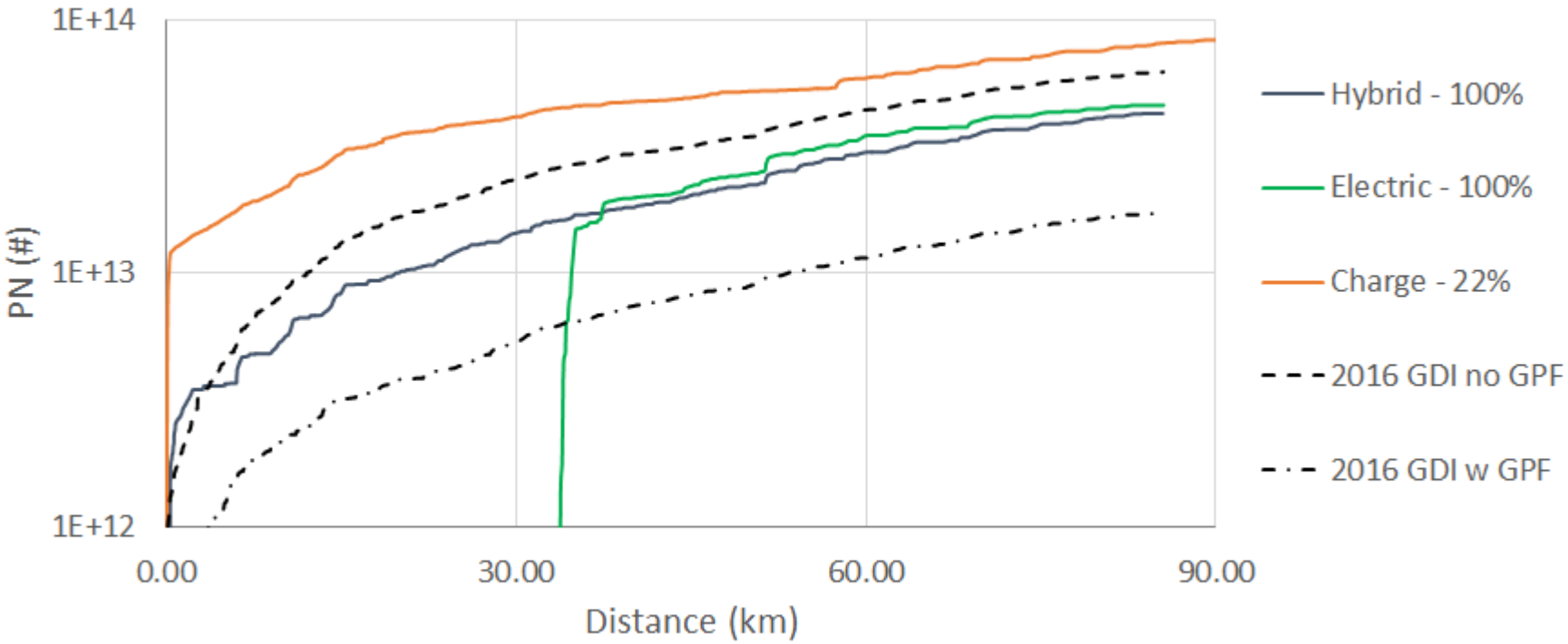
All total RDE PN emissions higher than GDI with GPF



- Electric mode – full battery: ICE operates for 2/3 of trip, but PN emissions as high as other modes
- Charge mode – empty battery: high power demand on ICE → highest PN emissions

ICE: Internal Combustion Engine

PN spikes at cold ICE start during high power demand

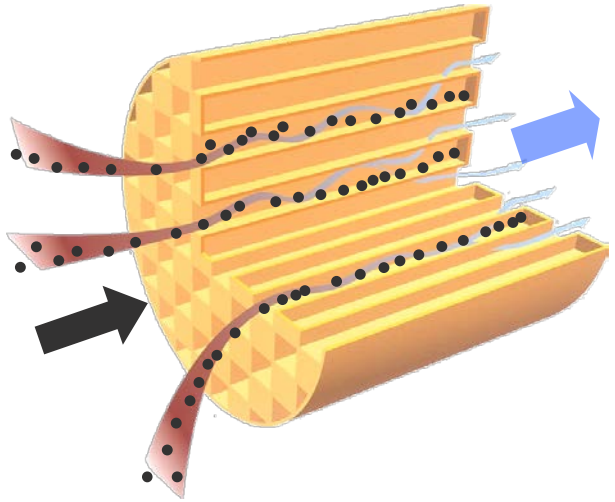


- Charge mode – empty battery: PN peak at start of trip → highest PN level
- Electric mode – full battery: PN peak in middle of trip → overall same PN level as other modes

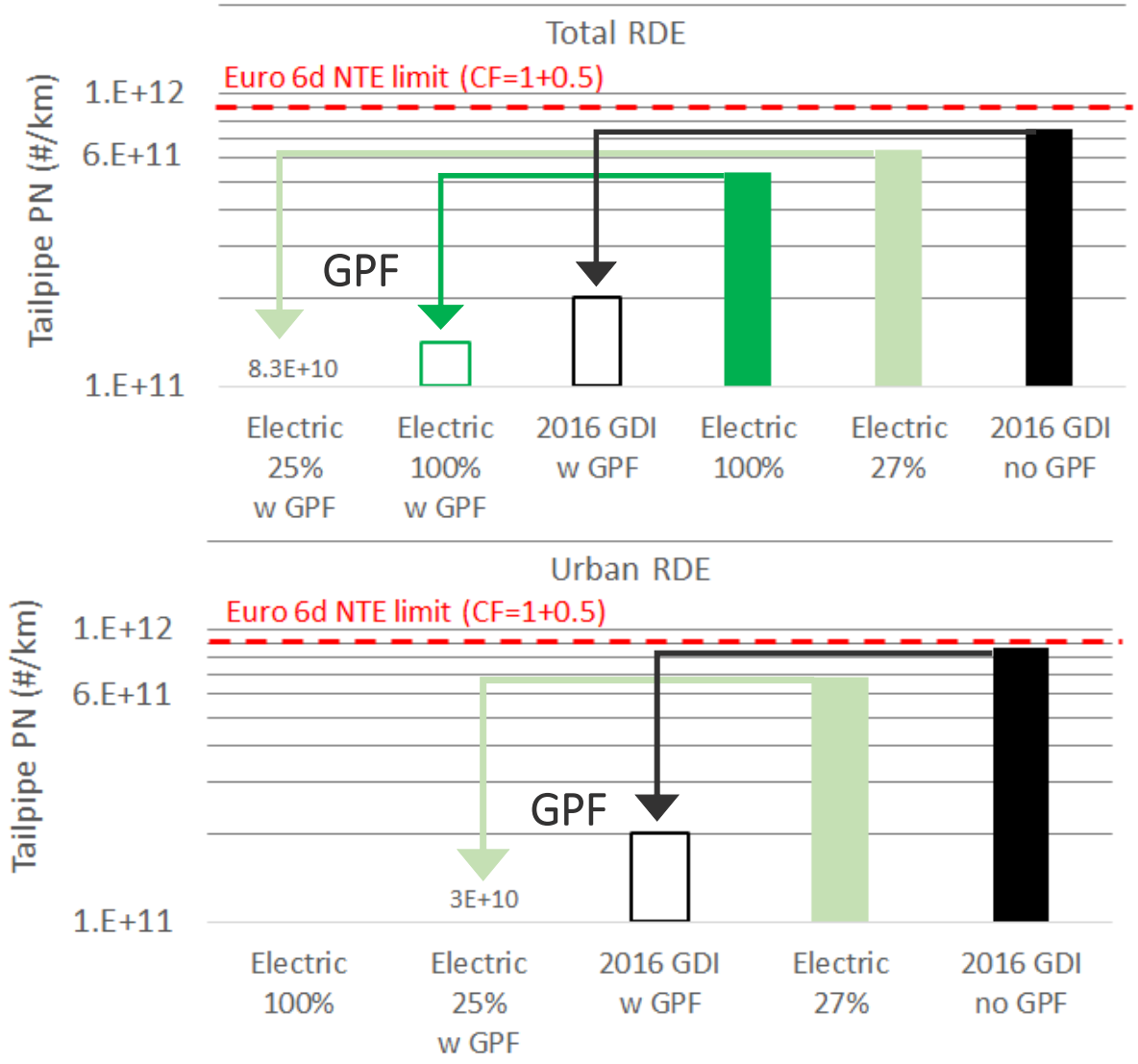
ICE: Internal Combustion Engine

GPF well controls PN spikes observed at ICE start

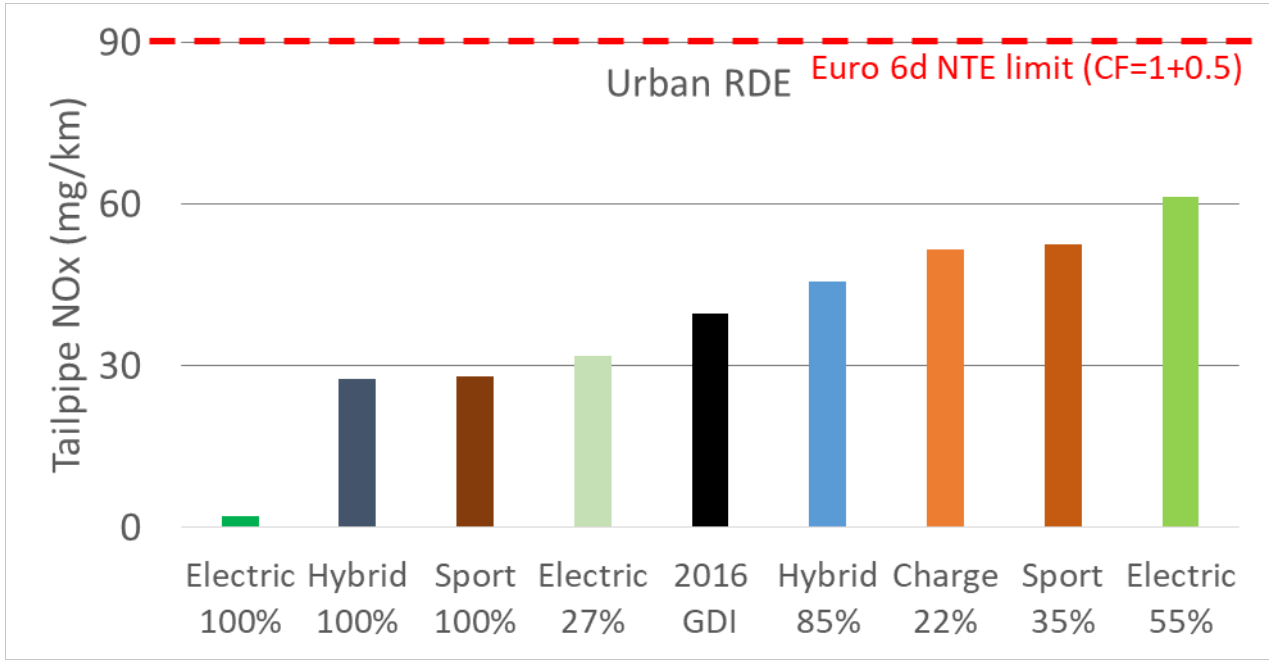
Tests in electric mode repeated with GPF



ICE: Internal Combustion Engine

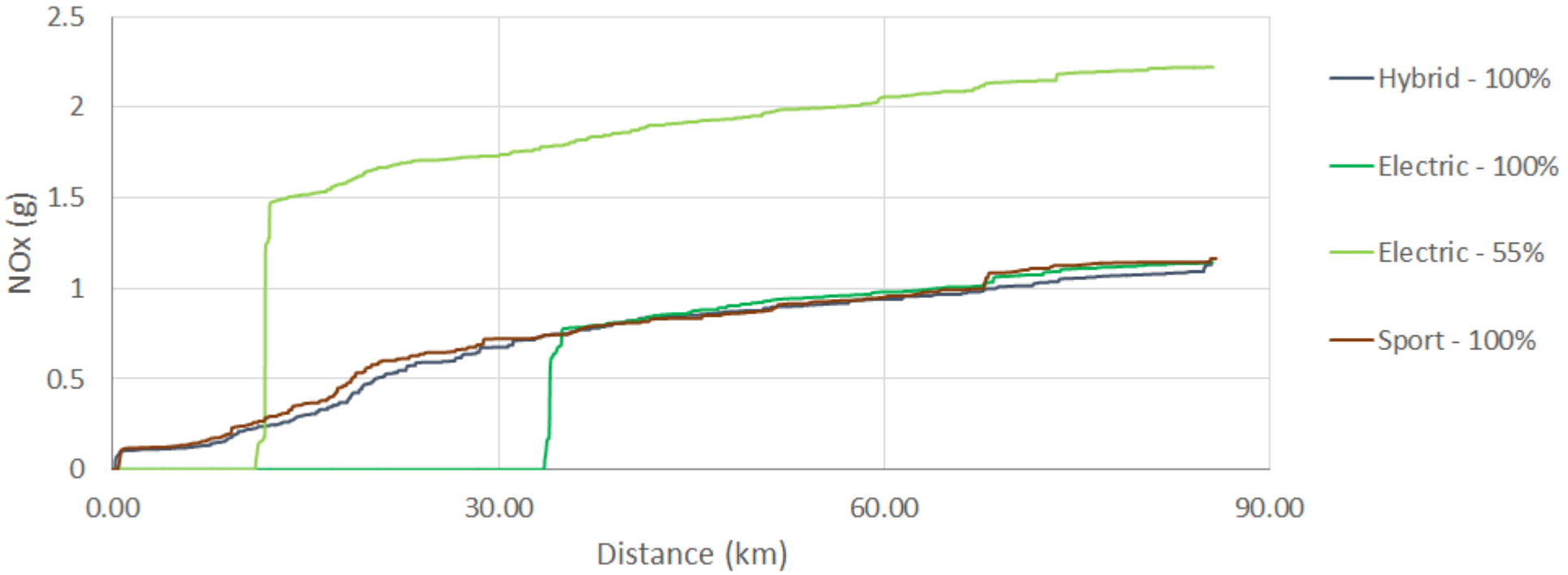


All RDE NOx emissions below Euro 6d NTE limit



- Reference GDI result is in the middle of PHEV urban NOx range
- NOx emissions of PHEV with fully-charged battery are consistently the lowest
- Electric mode – full battery: urban part entirely run electric → zero urban tailpipe NOx emissions
- Electric mode – 55% battery SOC: highest NOx emissions

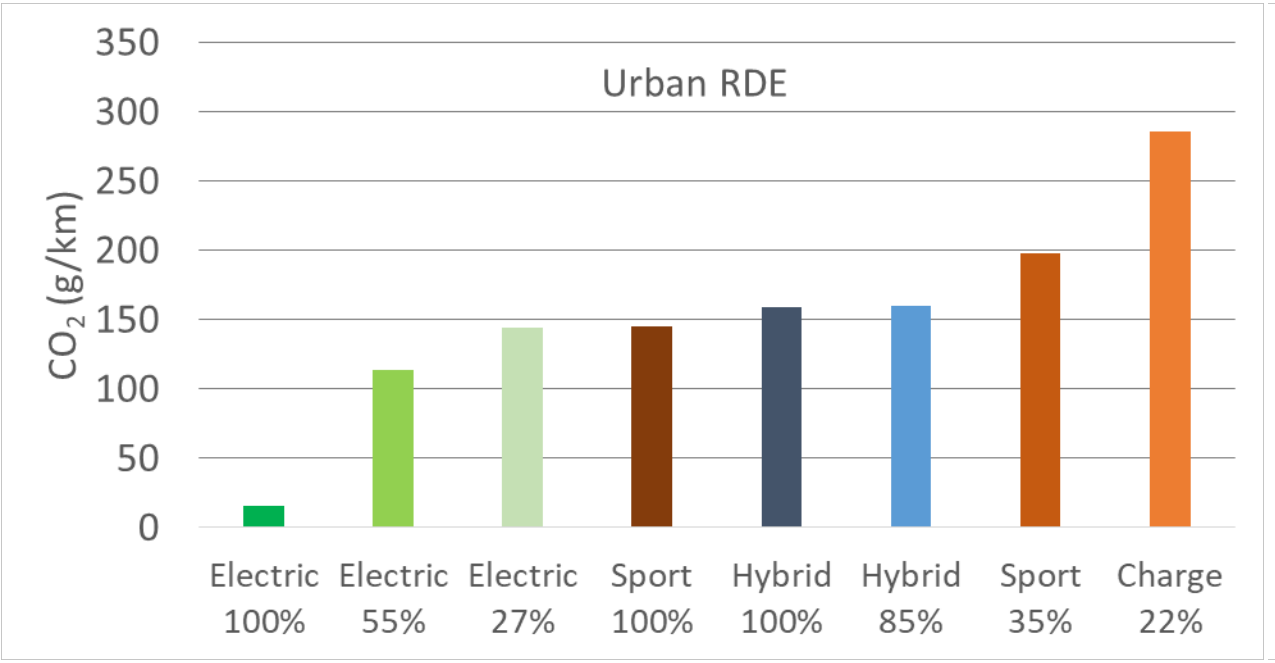
NOx spikes at cold ICE start with cold catalyst

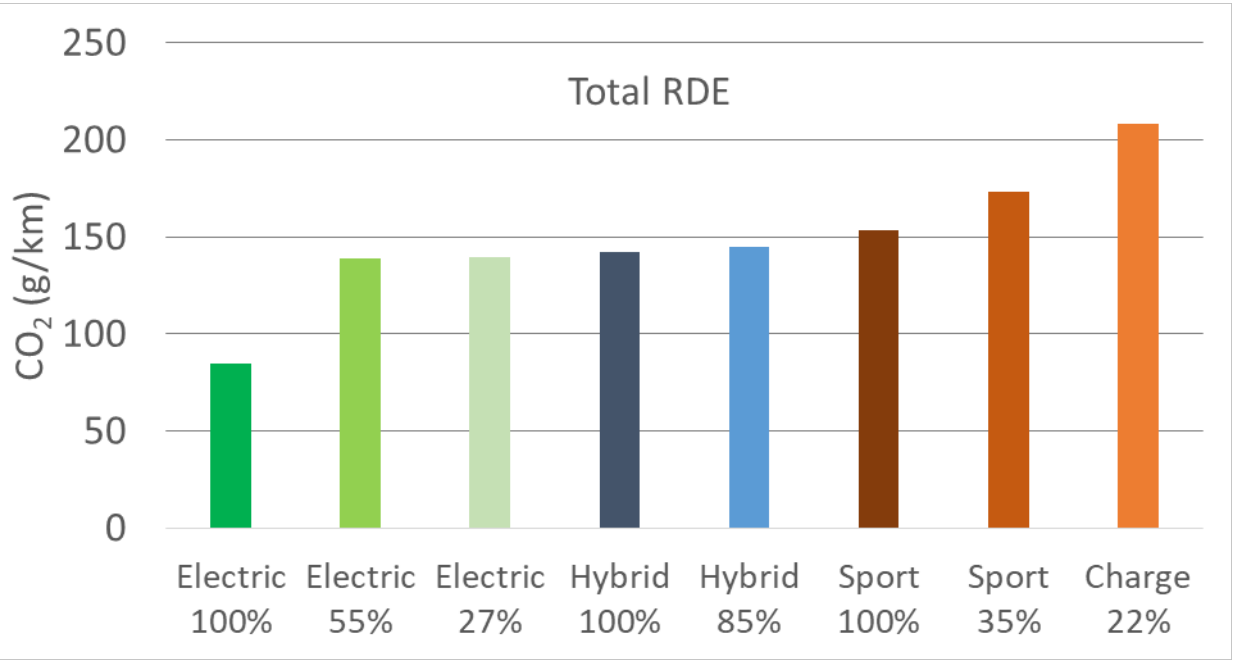


- Electric mode – 55% battery SOC: in middle of urban part → highest urban RDE NOx
- Electric mode – full battery: in middle of trip → similar NOx as other fully-charged tests

ICE: Internal Combustion Engine

Urban and Total RDE CO_2 emissions





- More straightforward effects than for PN and NOx emissions
  - Lowest CO_2 in Electric mode and increasing with decreasing initial battery SOC
  - Highest CO_2 when the ICE charges the battery in Sports and Charge mode
- Electric range achieved during RDE trip: ~35 km

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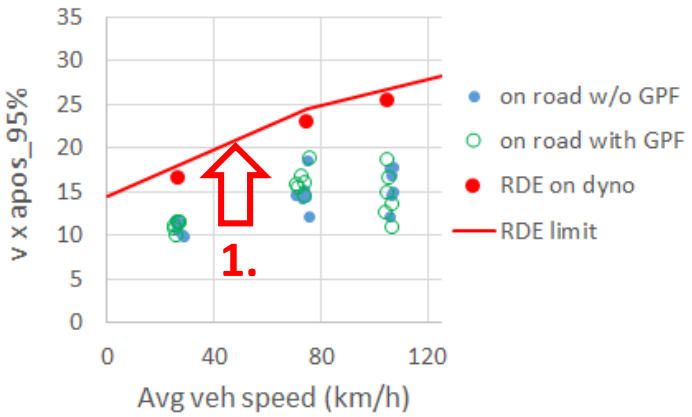
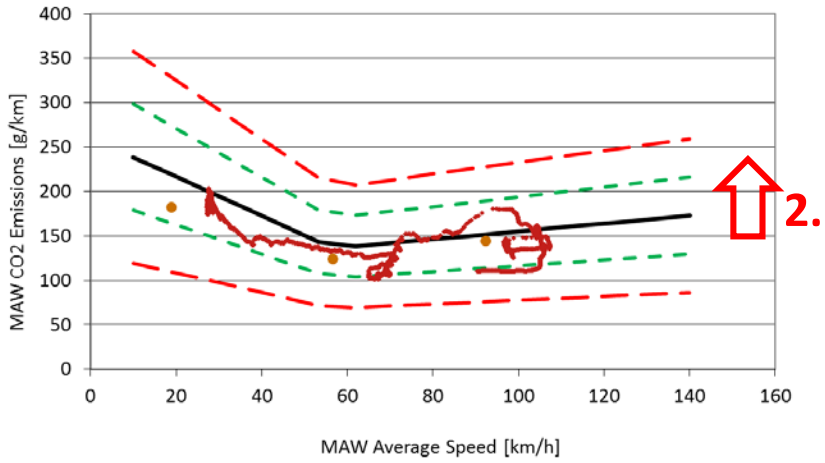
Impact of RDE boundary conditions tested on the chassis dyno

Severitized RDE (SRDE) visualised with 2016 GDI data; PHEV tests with combination of step 1-3

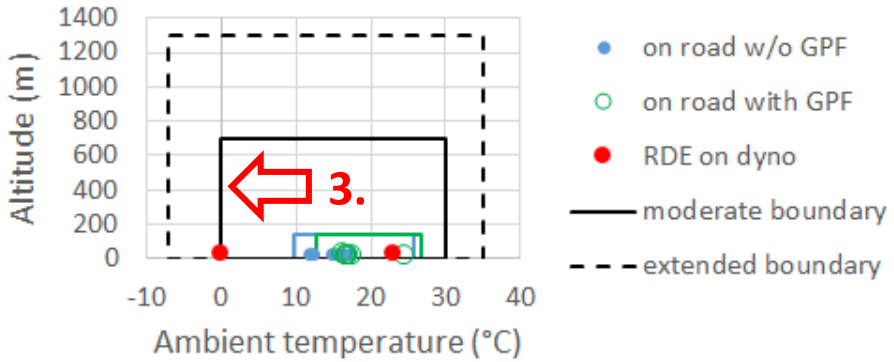
1. Change accelerations



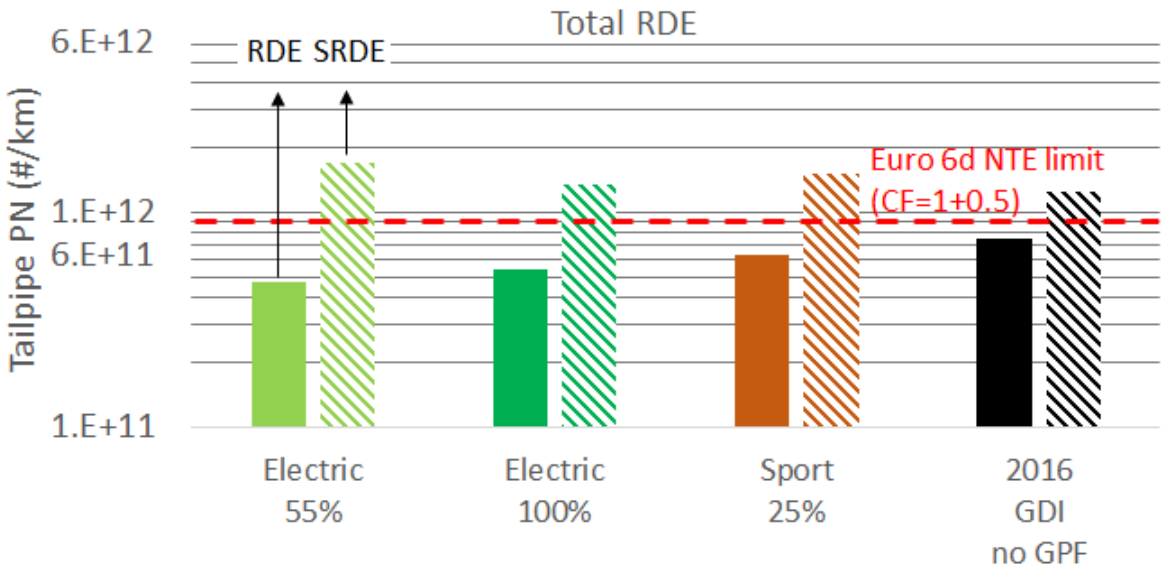
2. Change dyno load

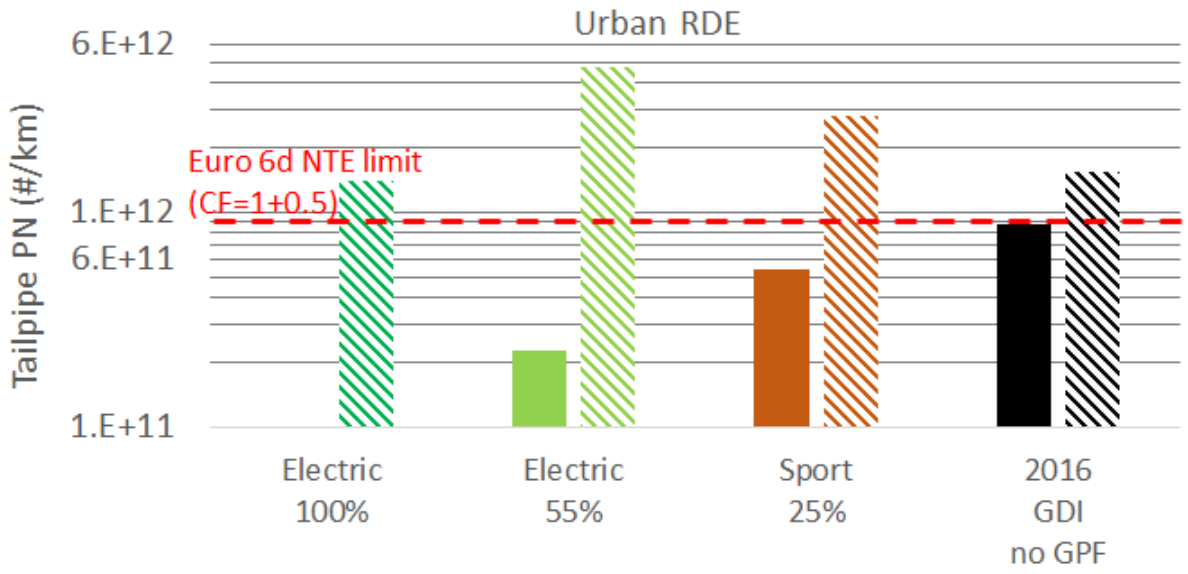


3. Change ambient temperature



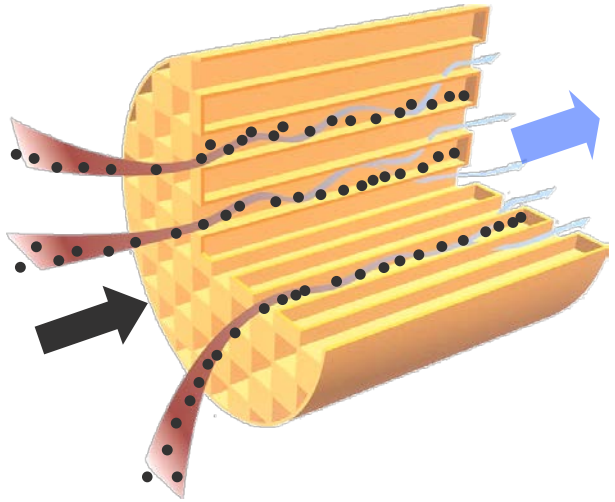
All Severitized RDE PN emissions above Euro 6d NTE limit

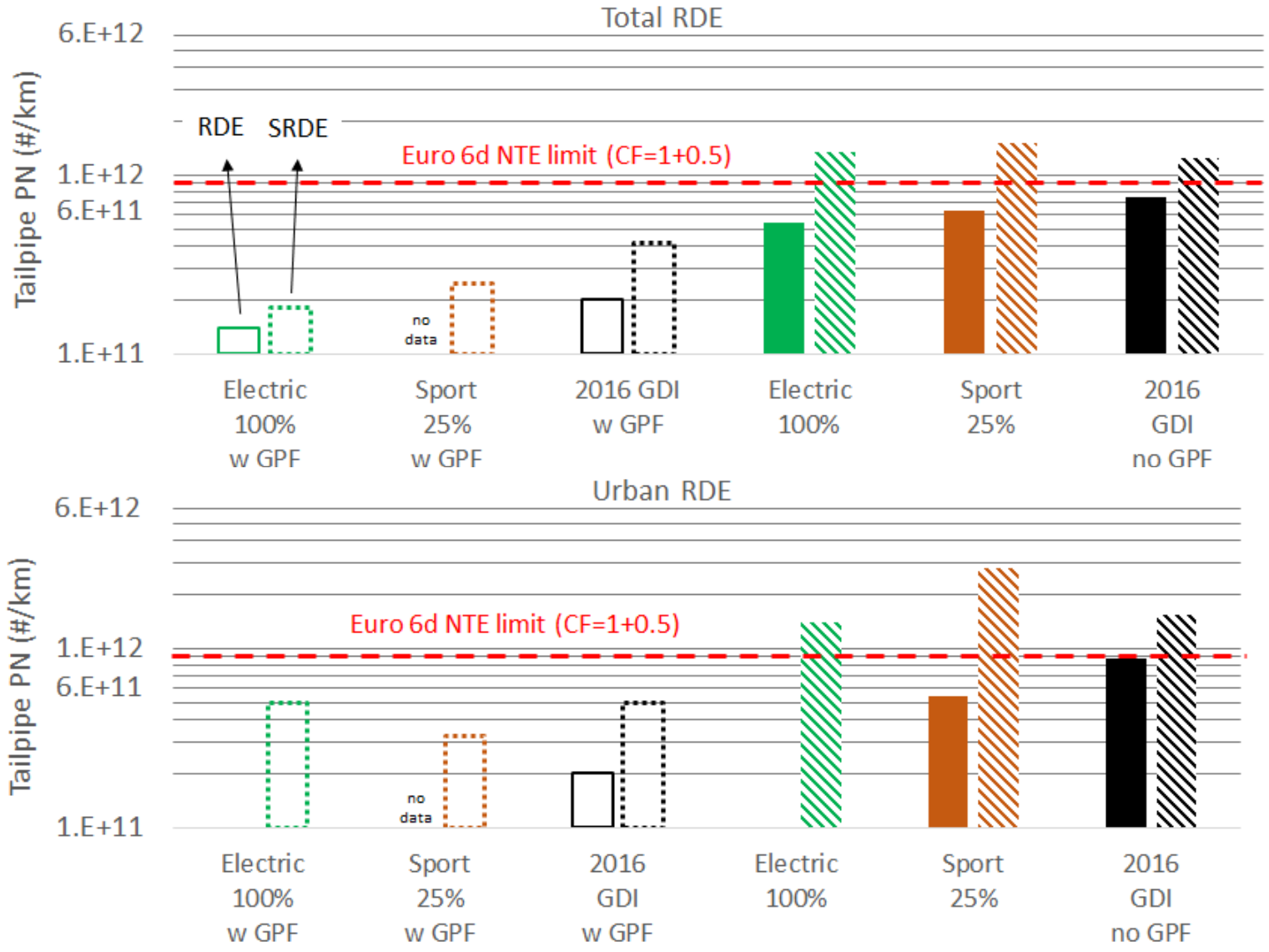




Note: 1.6 factor for extended ambient temperature included where applicable

All PN emissions with GPF below Euro 6d NTE limit





Note: 1.6 factor for extended ambient temperature included where applicable

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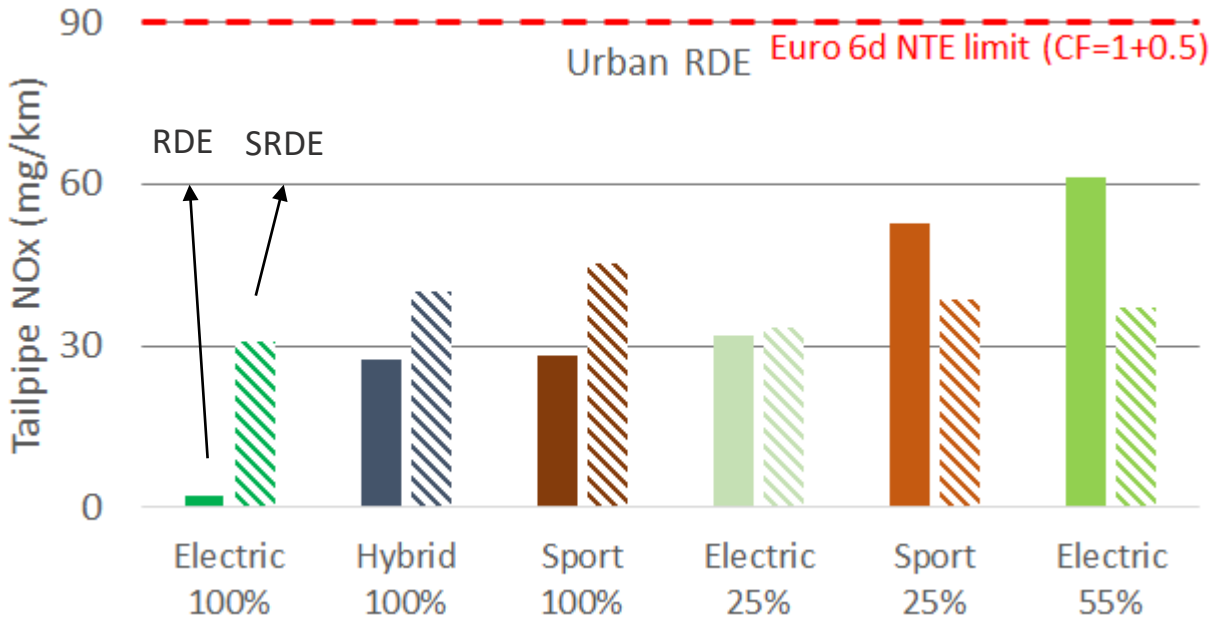
All Severitized RDE NOx emissions below Euro 6d NTE limit



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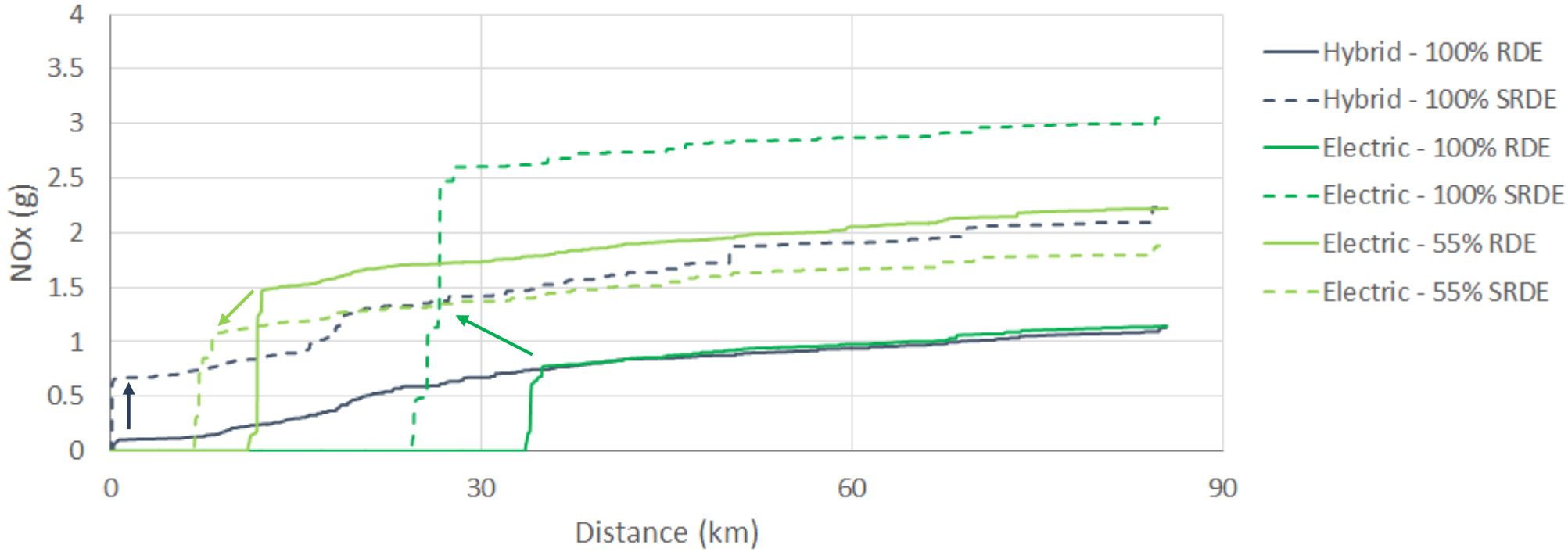
NOx peak at cold ICE start impacts overall NOx level



- Electric mode – full battery: higher peak in SRDE test → highest SRDE NOx level
- Electric mode – 55% battery SOC: lower peak in SRDE test → lower SRDE NOx level
- Hybrid mode – full battery: higher peak at start of trip → higher SRDE NOx level

ICE: Internal Combustion Engine

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Summary

- PHEV PN and NOx Real-Driving Emissions
  - Zero tailpipe emission capability at point of use
    - in electric mode when battery has been fully charged
    - trip distance within electric range
  - Higher emissions than reference GDI observed under other conditions
    - NOx results are all below Euro 6d NTE limit
    - timing of cold ICE start during RDE trip strongly impacts NOx and PN emissions
  - High PN spikes observed at cold ICE start are well controlled by GPF
- Well integrated exhaust aftertreatment is required to control emissions under all RDE conditions, including thermal management

Note: single Euro 6b C-segment gasoline PHEV tested with market fuel

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Overview of most recent AECC PEMS data

Data made available to the JRC and TNO for the review of RDE data evaluation methods

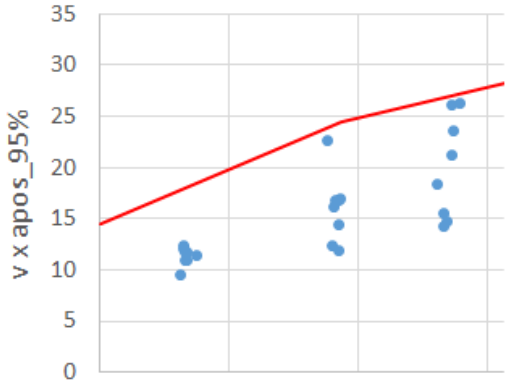
Year	Type	Series production/ demonstrator	Aftertreatment	Tests
2014	Diesel	Demonstrator	SCR on DPF	RDE on the road
2015	Diesel	Series	SCR on DPF	
2015	GDI	Series	With GPF	
2016	GDI	Series	Without GPF	RDE on the road Severitized RDE on the chassis dyno
		Demonstrator	With GPF	
2017	GDI PHEV	Series	Without GPF	
		Demonstrator	With GPF	

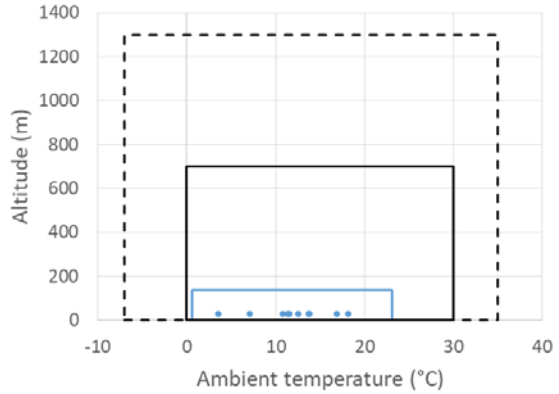
DPF: Diesel Particulate Filter GDI: Gasoline Direct Injection GPF: Gasoline Particulate Filter SCR: Selective Catalytic Reduction

RDE data evaluation terminology

As summarised by the European Commission in RDE meeting of 7/11/2017

- Normal RDE trip may explore areas not covered by WLTP within agreed boundaries





- Two steps in RDE data evaluation
  - Trip normalisation
    - Verification that trip characteristics fall within the agreed boundaries
    - Covered by boundary conditions and any data evaluation tool
  - Emissions normalisation
    - Potential correction of emissions if trip is partially outside of the boundaries
    - Covered by any data evaluation tool

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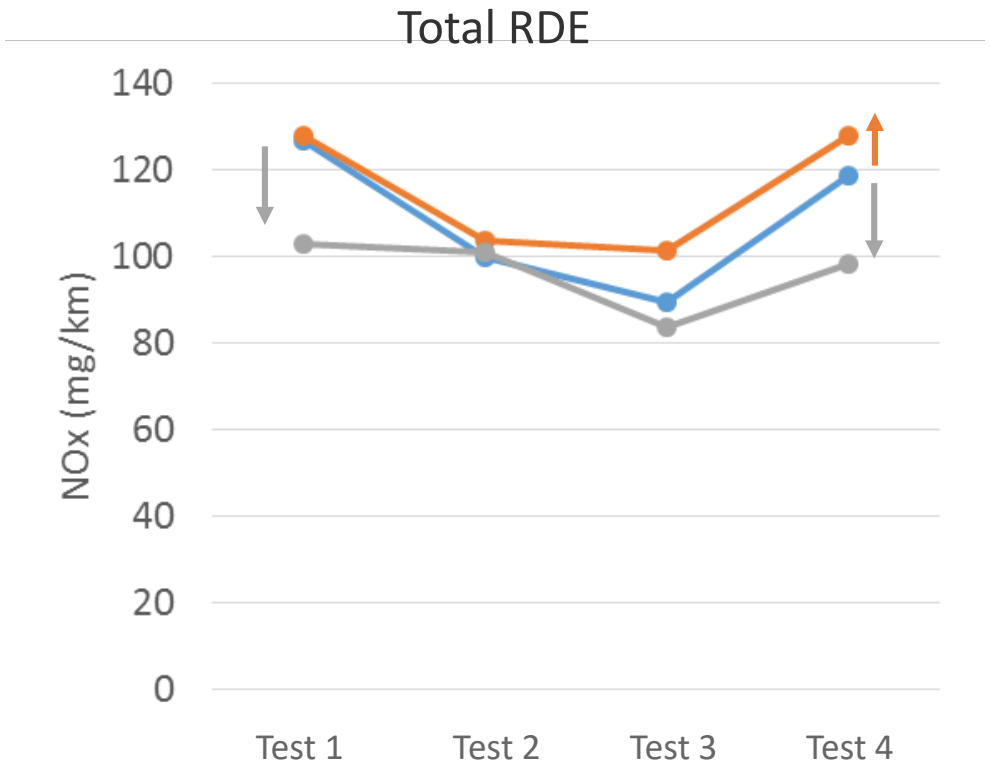
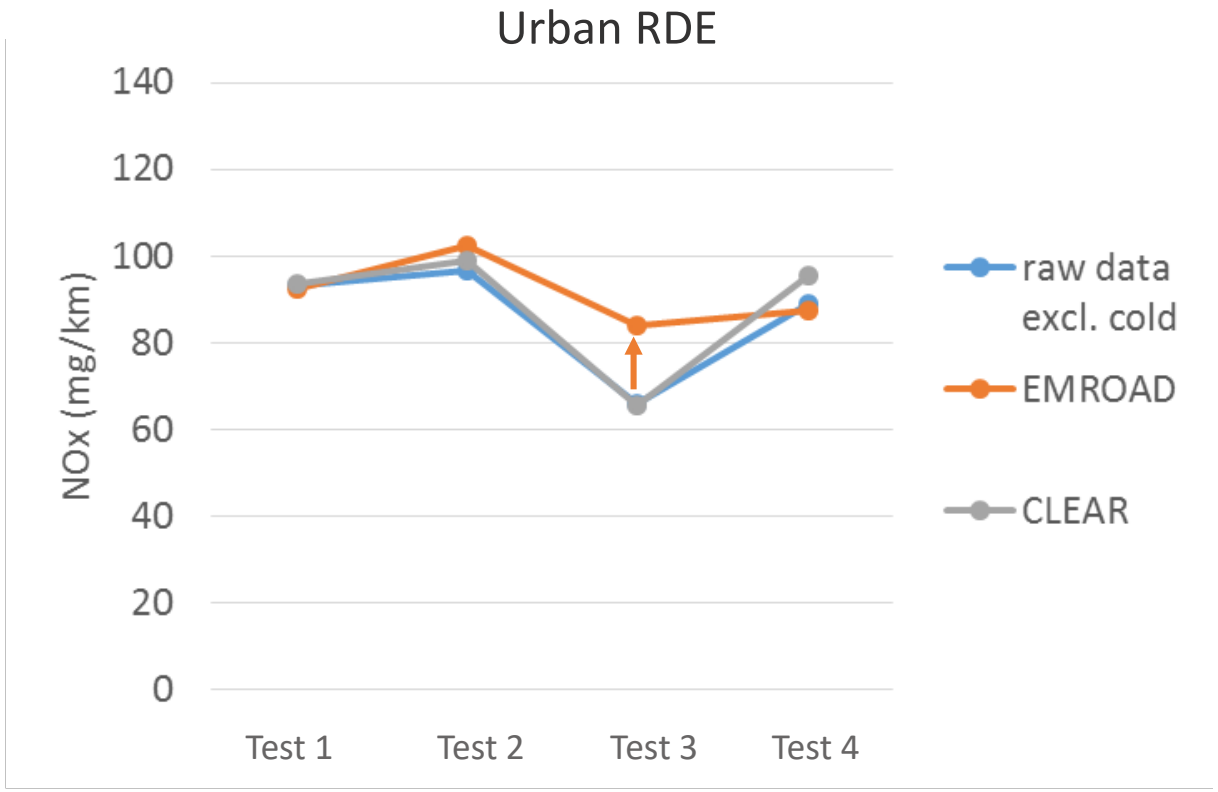
Current RDE evaluation tools can act in opposite directions

Example: NOx emissions of 2015 diesel vehicle





As presented by AECC at 2016 MinNOx conference: excluding cold start emissions; EMROAD v. 5.9B5; CLEAR v. 1.8.13

Remaining options for RDE data evaluation methods

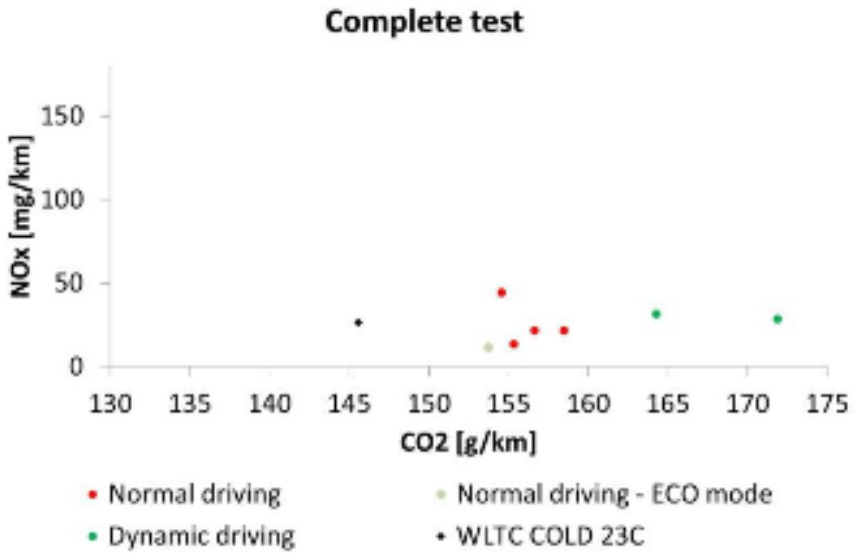
As presented by the European Commission in RDE meeting of 7/11/2017

- Baseline: EMROAD
- Option 1: Raw emissions
- Option 2: Raw emissions corrected by the ratio RDE_CO_2/WLTP_CO_2
  - ACEA proposes additional ratio: ICE_distance/total_distance
  - Two results will be presented in this presentation for urban RDE data
    - 'Raw/CO_2 total ref': using total WLTC CO_2
    - 'Raw/CO_2 urban ref': using CO_2 of WLTC phase 1+2

ICE: Internal Combustion Engine

Pollutant and CO_2 emissions are decoupled at the tailpipe

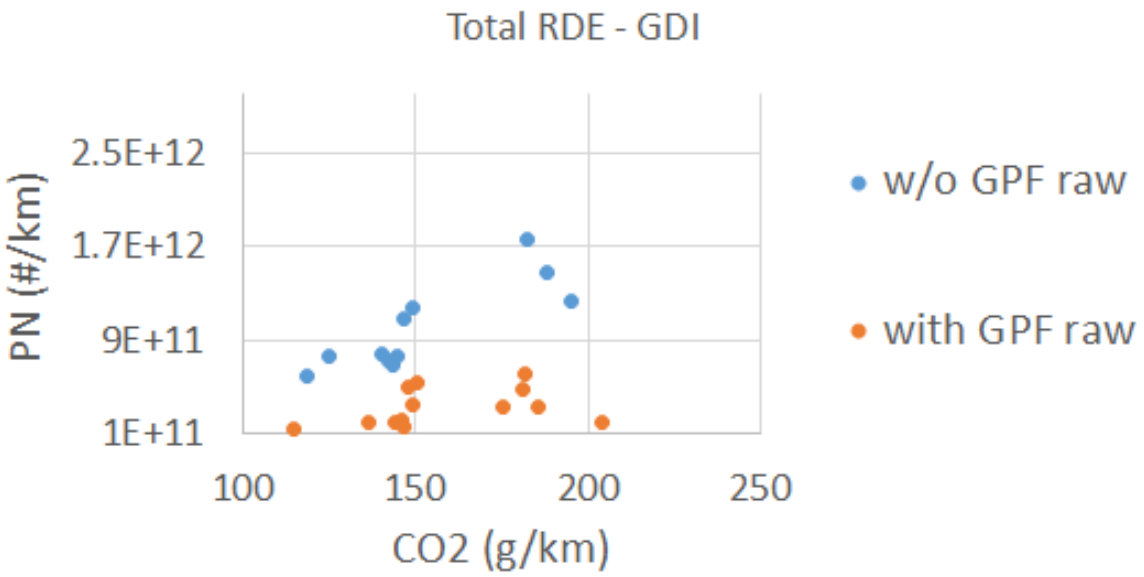
JRC data: NOx emissions of a Euro 6 diesel vehicle with EGR + LNT + SCR

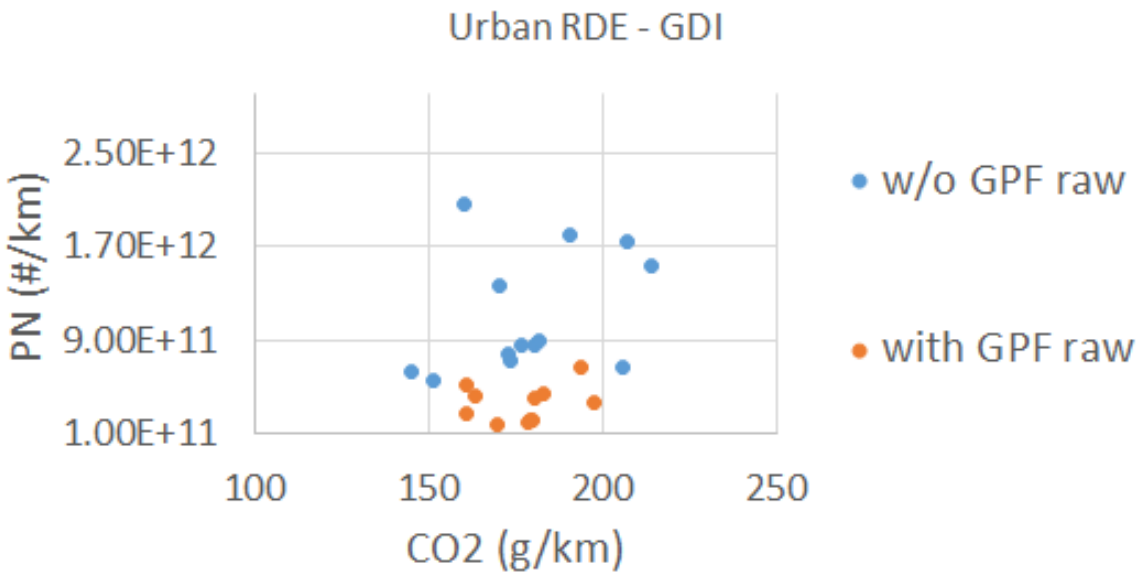


EGR: Exhaust Gas Recirculation LNT: Lean NOx Trap SCR: Selective Catalytic Reduction

Pollutant and CO_2 emissions are decoupled at the tailpipe

AECC data: PN emissions of 2016 GDI vehicle without and with GPF

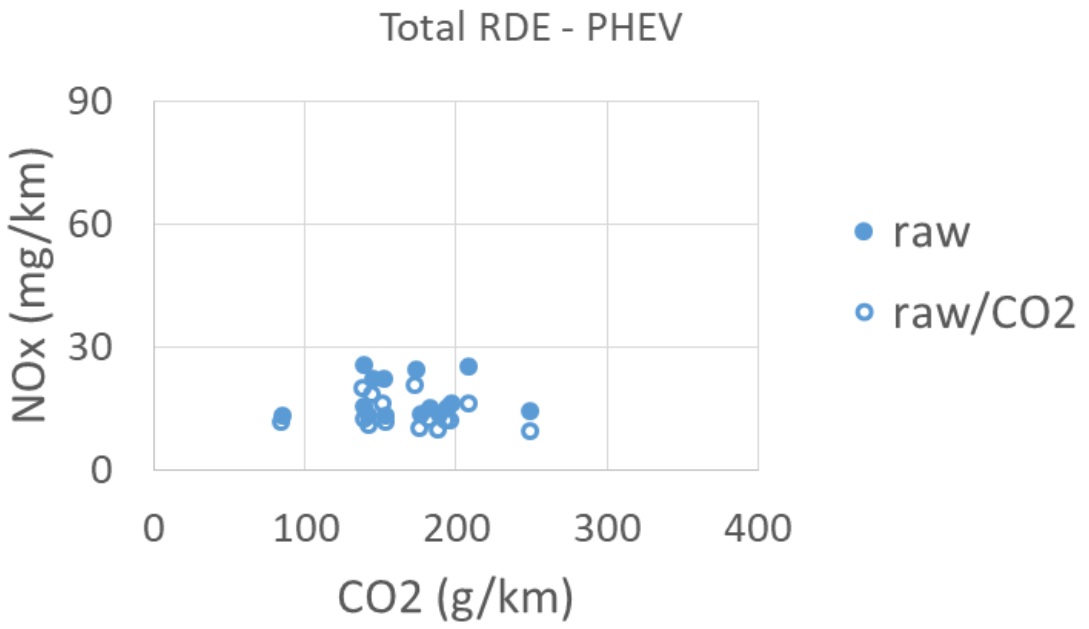


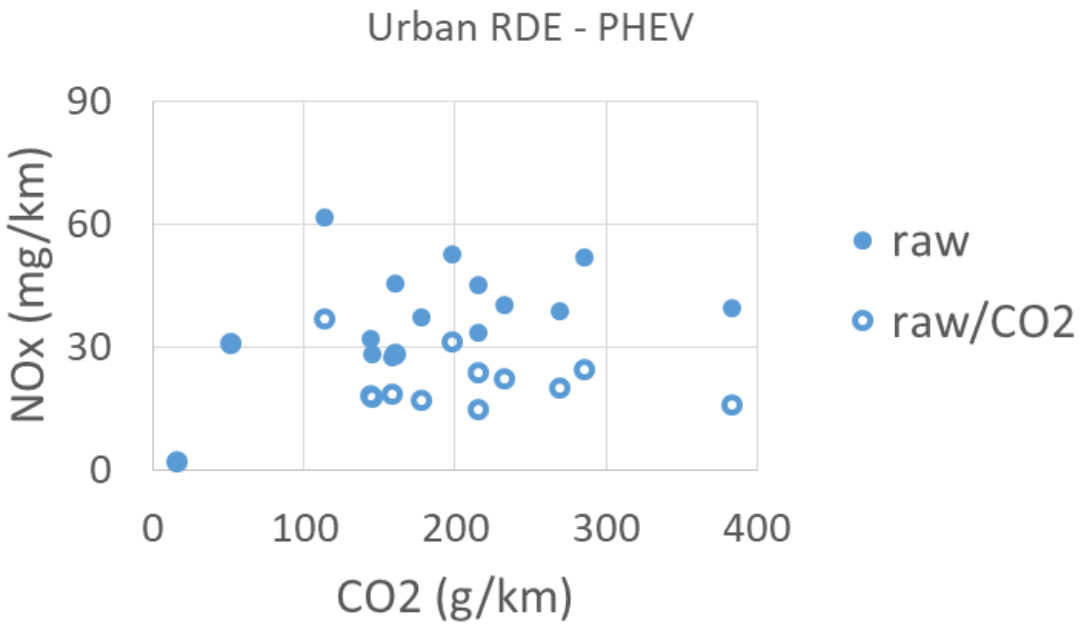


Note: 1.6 factor for extended ambient temperature included where applicable

Pollutant and CO_2 emissions are decoupled at the tailpipe

AECC data: NOx emissions of 2017 PHEV vehicle with 2 Three-Way Catalysts

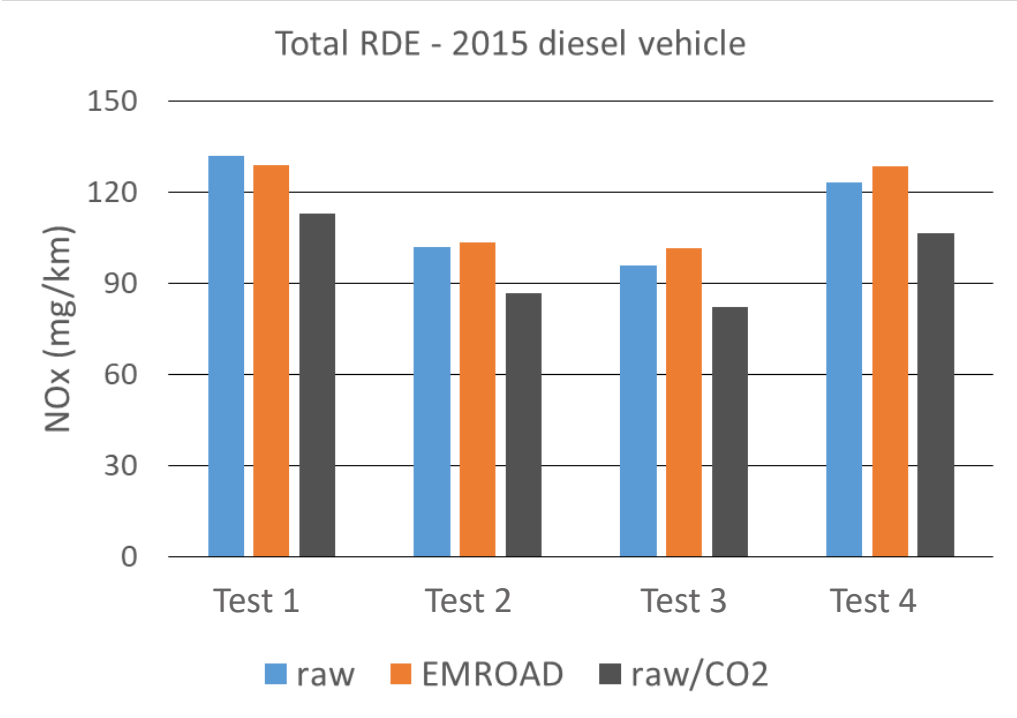


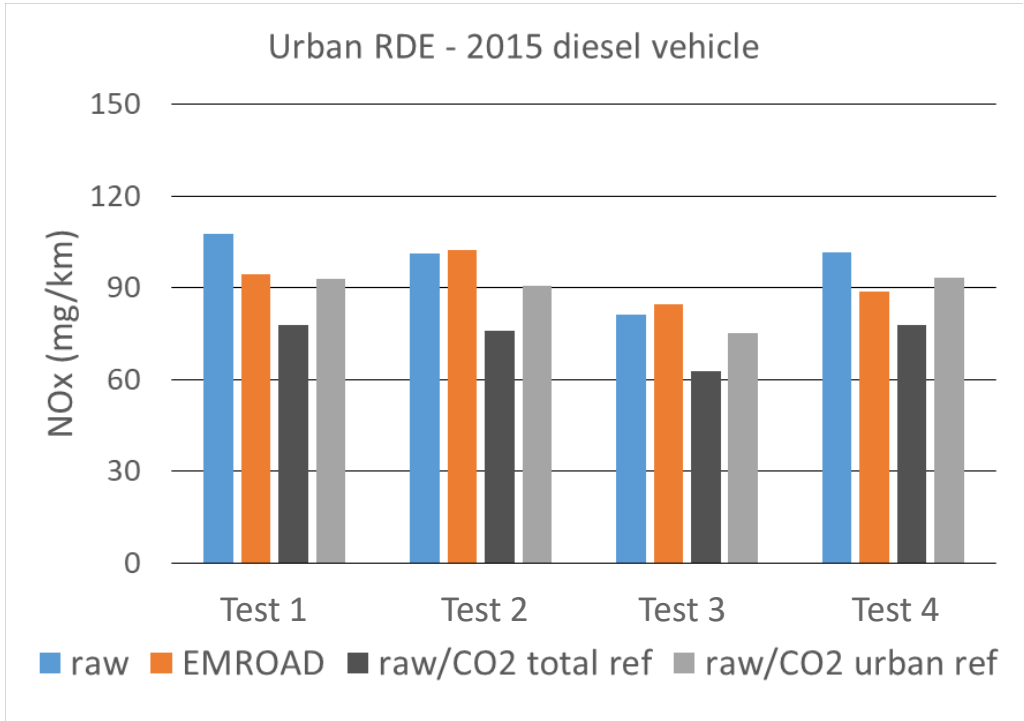


Note: 1.6 factor for extended ambient temperature included where applicable

Raw/CO_2 reduces NOx emissions of 2015 diesel vehicle

- Total RDE: up to 15% downward correction
- Urban RDE: 8% to 28% downward correction depending on WLTC reference





CO_2 (g/km)	Total	Urban
WLTC	129	154 (phase 1+2)
RDE	149 – 151	167 – 178

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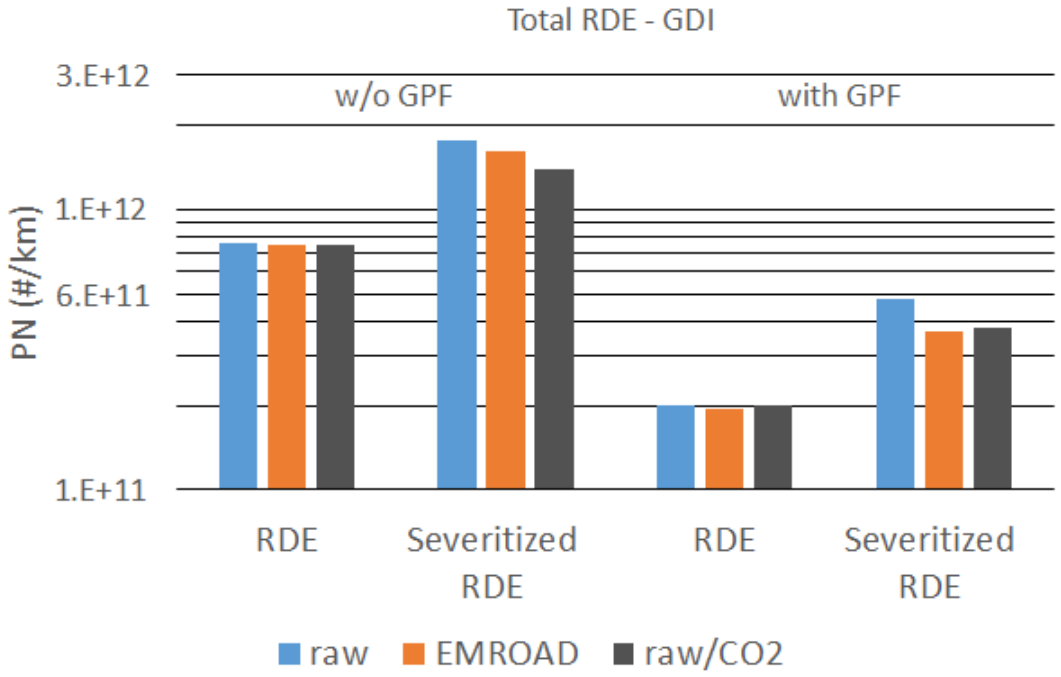
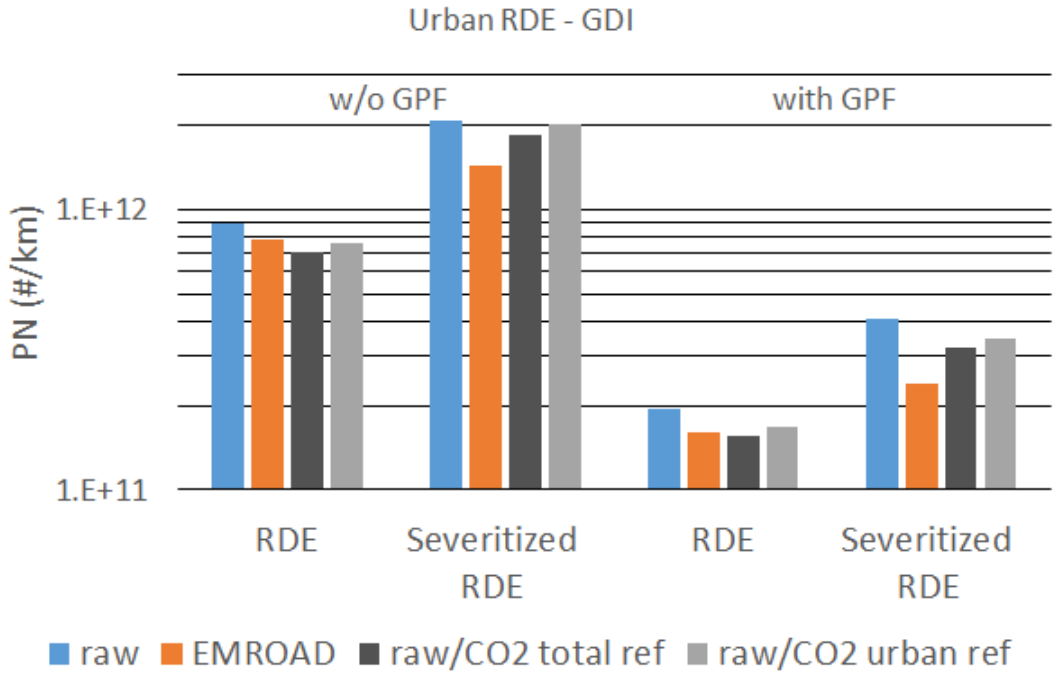
Raw/CO_2 reduces PN emissions of 2016 GDI vehicle

- Total RDE: up to 21% downward correction
- Urban RDE: 5% to 21% downward correction depending on WLTC reference





Note: 1.6 factor for extended ambient temperature included where applicable

CO_2 (g/km)	Total	Urban
WLTC	143	155 (phase 1+2)
RDE	144 – 145	179 – 181
Severitized RDE	181 – 182	160 – 181

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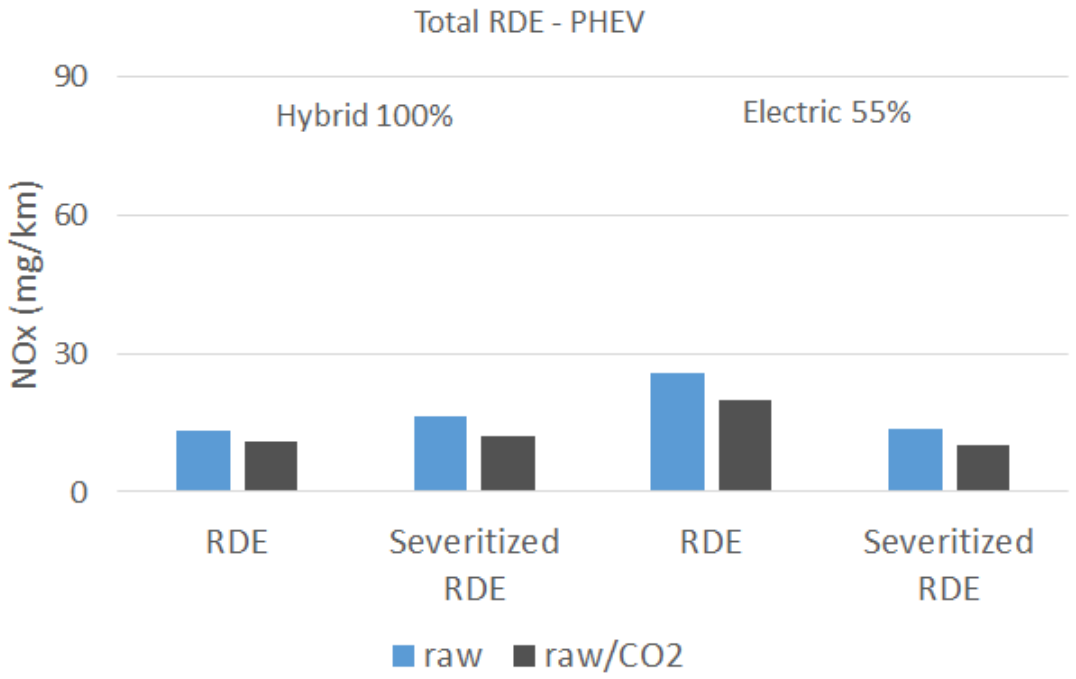
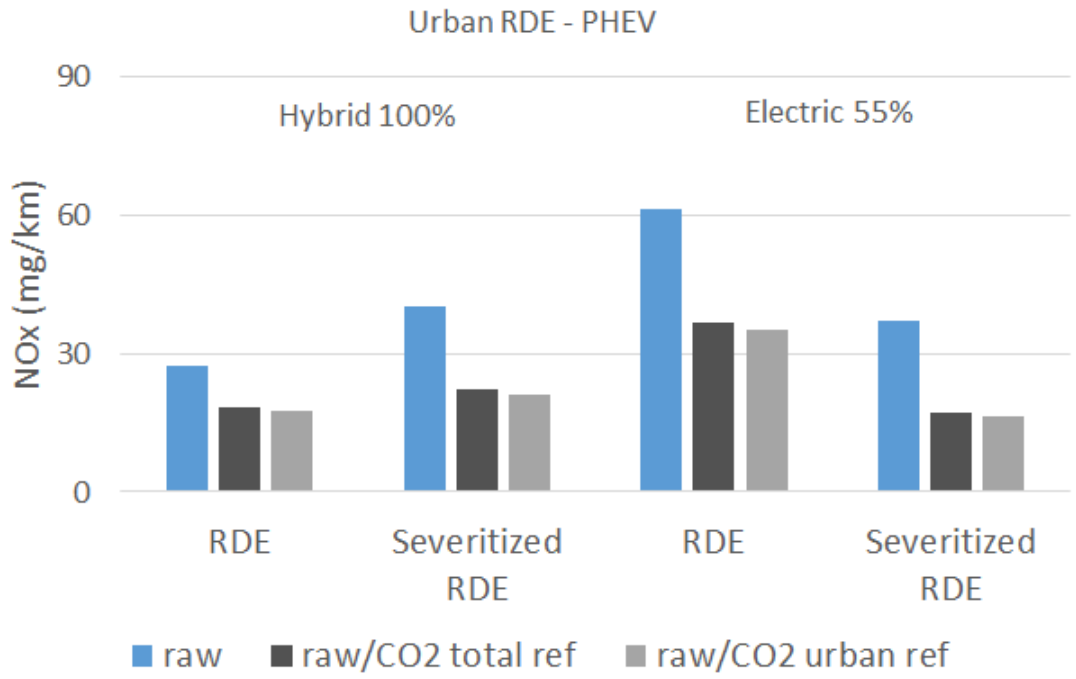
Raw/CO_2 reduces NOx emissions of 2017 PHEV

- Total RDE: up to 28% downward correction
- Urban RDE: up to 56% downward correction, no significant impact of WLTC reference





Note: 1.6 factor for extended ambient temperature included where applicable

CO_2 (g/km)	Total	Urban
WLTC ChS	140	134 (phase 1+2)
Final ratio evaluation	0.72 – 0.86	0.44 – 1.0

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  - Summary

Summary

- Actual tailpipe emissions impact air quality
- CO_2 emission is an indicator for engine work
- Exhaust gas aftertreatment decouples pollutant and CO_2 emissions at the tailpipe
- Emissions normalisation based on CO_2 will introduce undesirable artefacts

THANK YOU!

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