Real-Driving Emissions from a Plug-in Hybrid Electric Vehicle (PHEV)

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AECC
ASSOCIATION FOR EMISSIONS CONTROL BY CATALYST

Association for Emissions Control by Catalyst (AECC AISBL)

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- Exhaust emissions control technologies for original equipment, retrofit and aftermarket for all new cars, commercial vehicles, motorcycles and non-road mobile machinery

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- PHEV test programme set-up
- Real-Driving Emissions (RDE) on the road
  - PN without and with Gasoline Particulate Filter (GPF)
  - NOx
  - CO_2
- Towards RDE boundary conditions on the chassis dyno
  - PN without and with GPF
  - NOx
- Summary

Test programme set-up

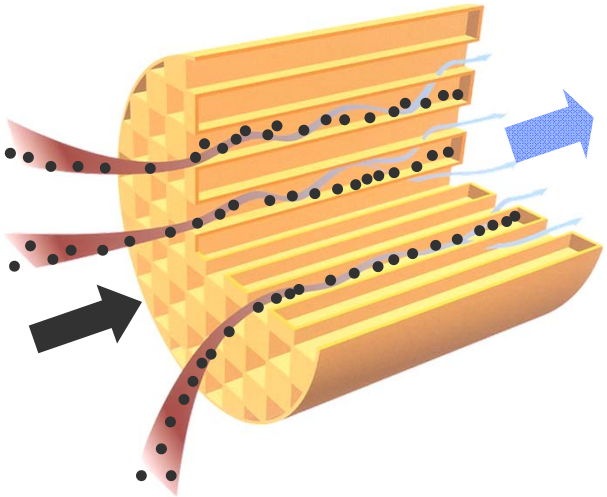
- Objective: measure the real-world behaviour of a market-representative Plug-in Hybrid Electric Vehicle (PHEV)
- Vehicle selected
  - C-segment PHEV with 1.5l class GDI engine
  - Euro 6b certified
  - Rental car ~10 000 km mileage
  - 4 Driving modes: Electric, Hybrid, Charge and Sport
  - Official 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

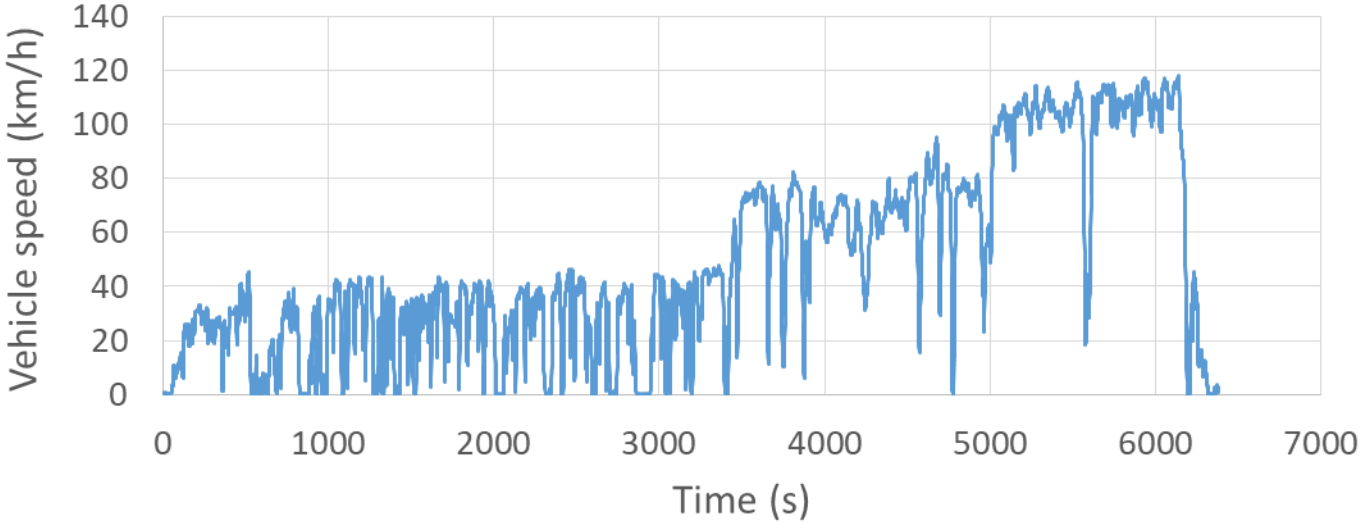
Test programme set-up

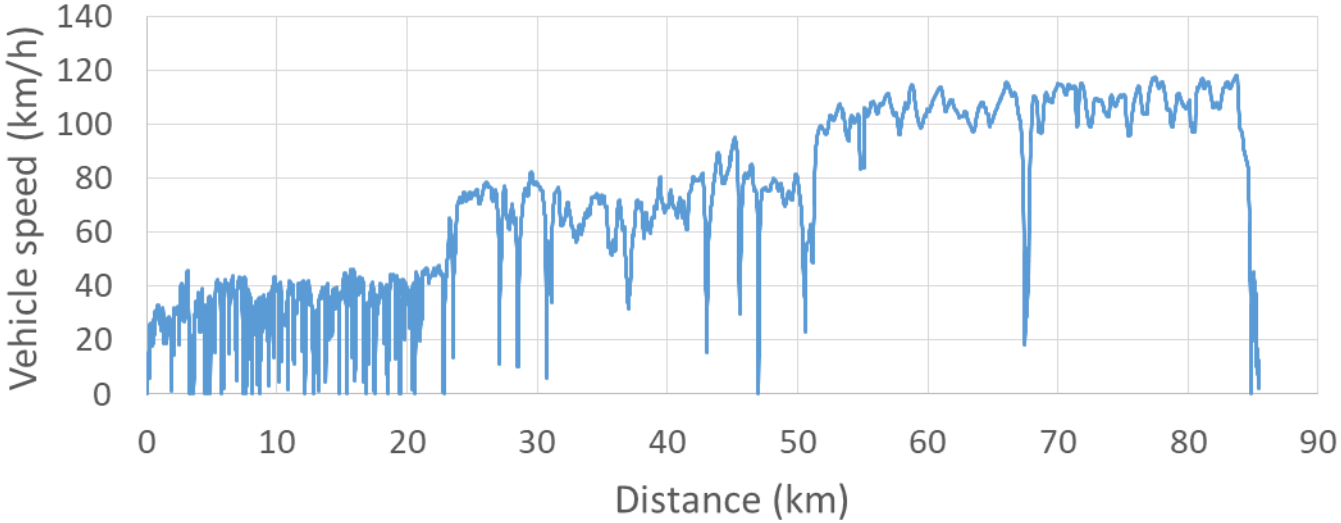
- Measurement details
  - At Ricardo (UK)
  - All tests on market E5 fuel
  - HORIBA PEMS OBS one: CO, CO_2, NOx and PN
  - Raw emissions data are presented, no RDE post-processing applied

- 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)



RDE route and speed profile

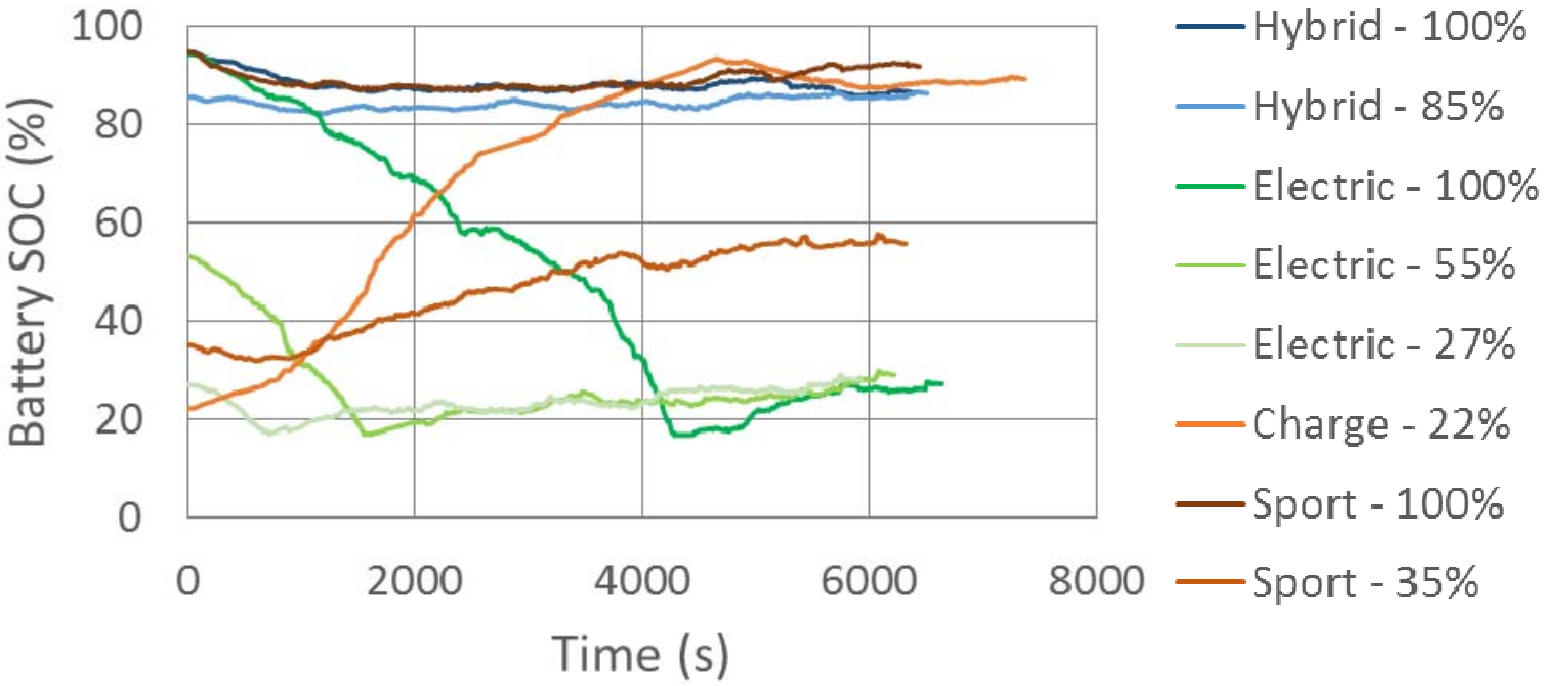




8 combinations of mode and initial battery SOC tested

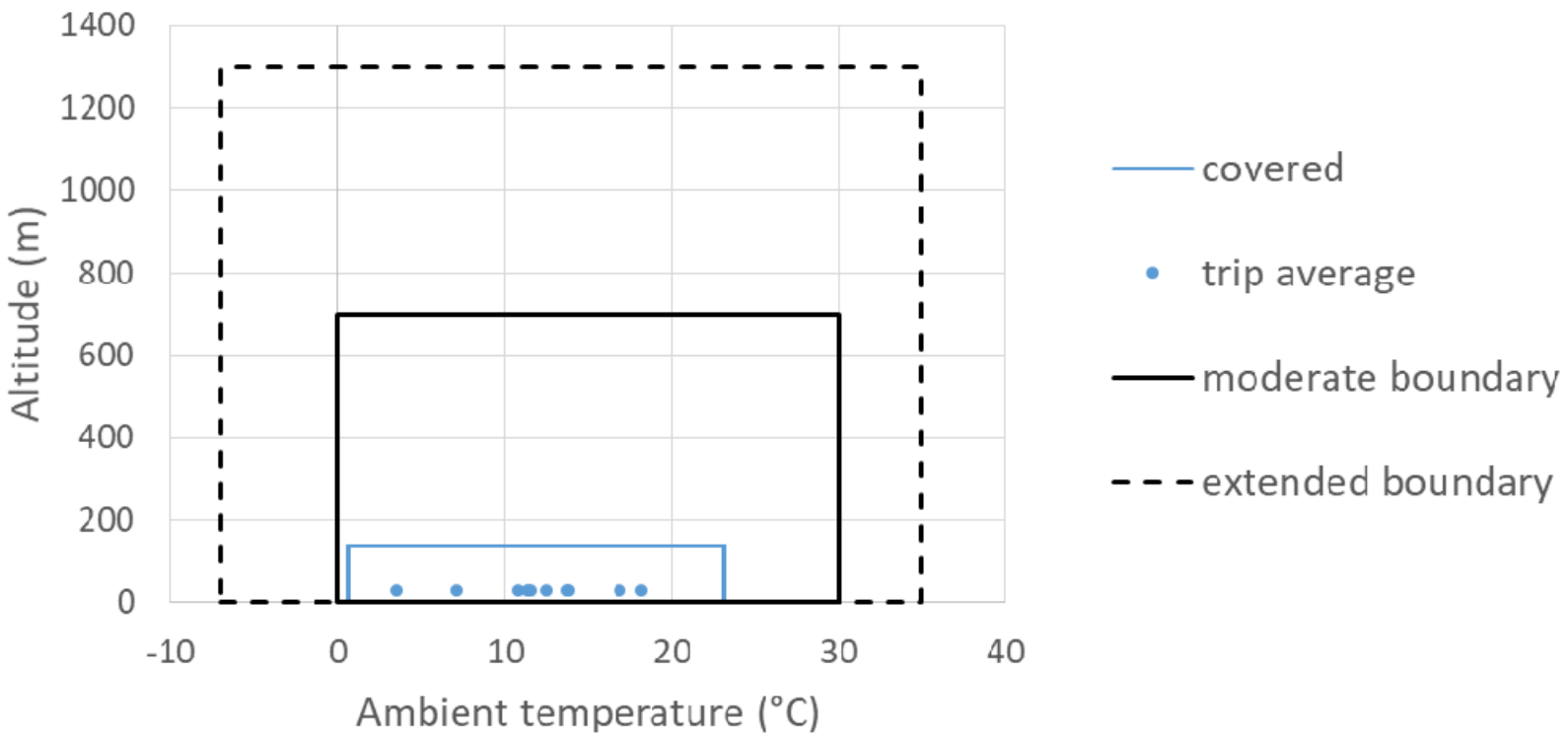
Change in battery SOC (State of Charge) during on-road RDE tests

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



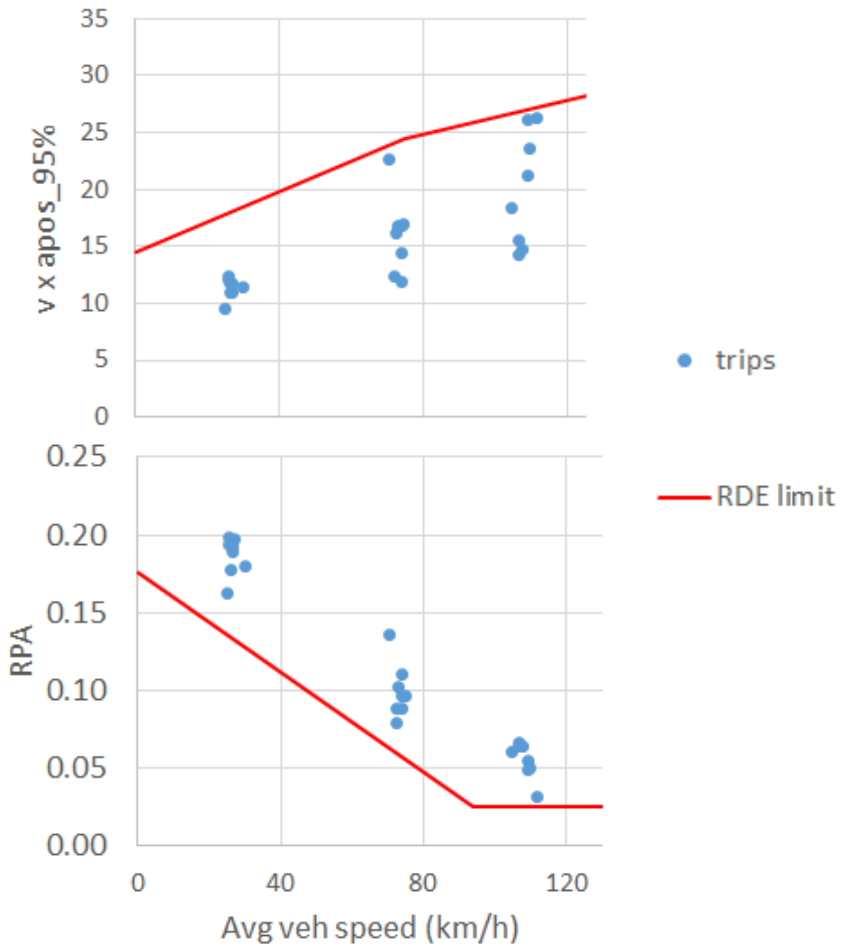
On-road RDE data within moderate boundary conditions

Engine start after overnight soak at temperature close to trip average

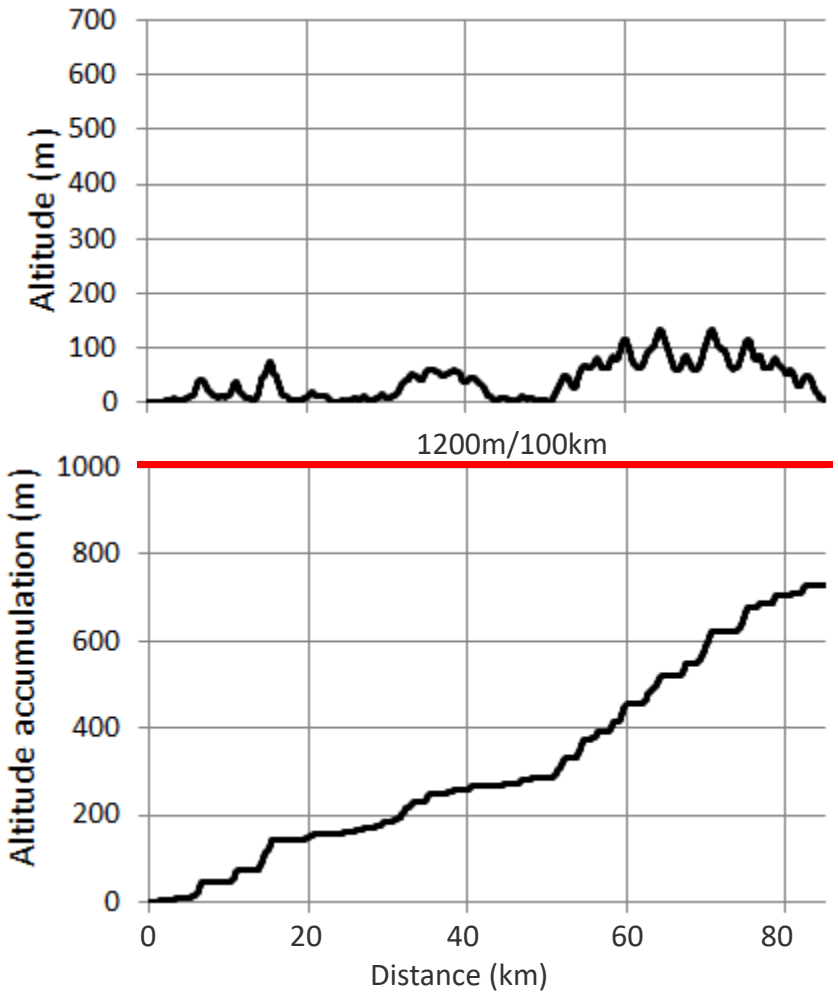


On-road RDE data within dynamic boundary conditions

Excess or absence of driving dynamics



Altitude accumulation



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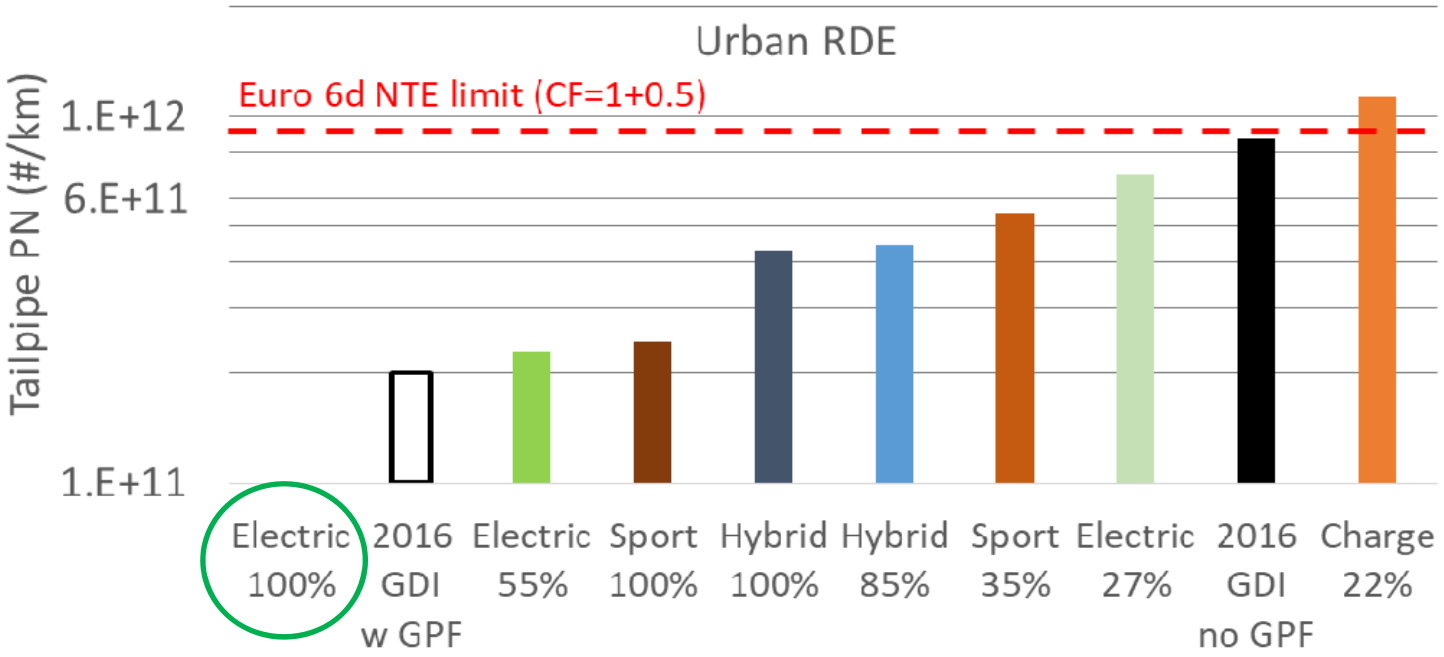
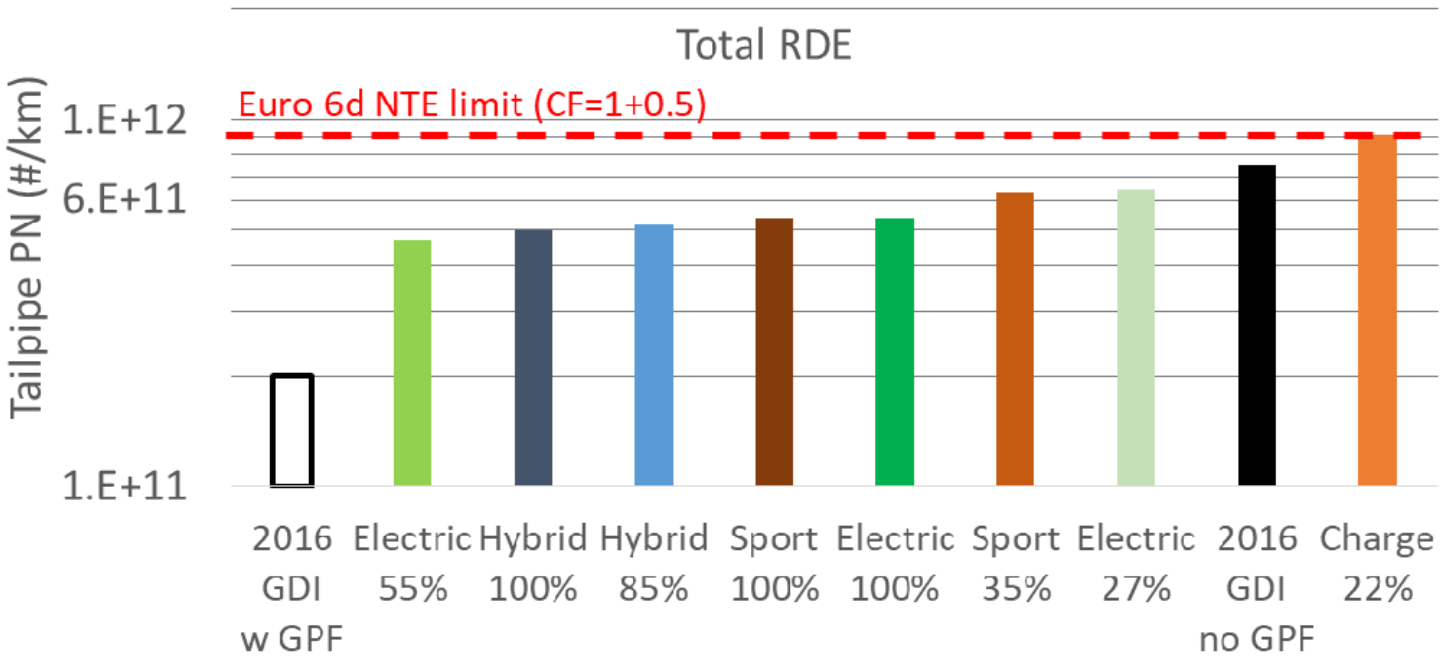
Most urban RDE PN emissions between GDI w/o & w GPF



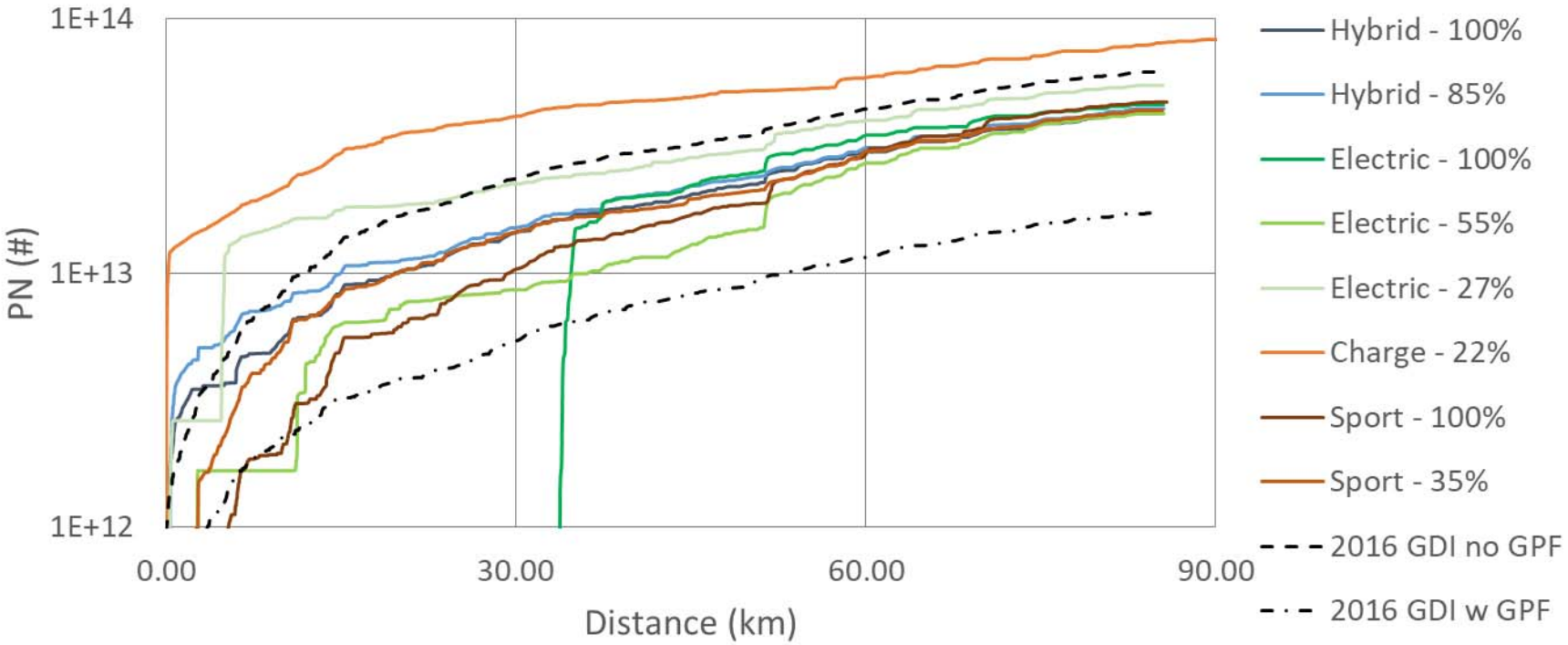
- Electric mode – full battery: urban part entirely run electric → zero urban tailpipe PN emissions
- Charge mode – empty battery: high power demand on IC engine → highest PN emissions

Most total RDE PN emissions between GDI w/o & w GPF



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

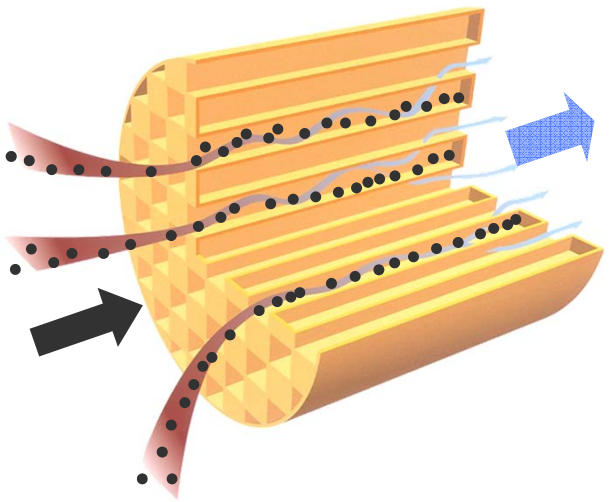
PN spikes at cold IC engine start during high power demand

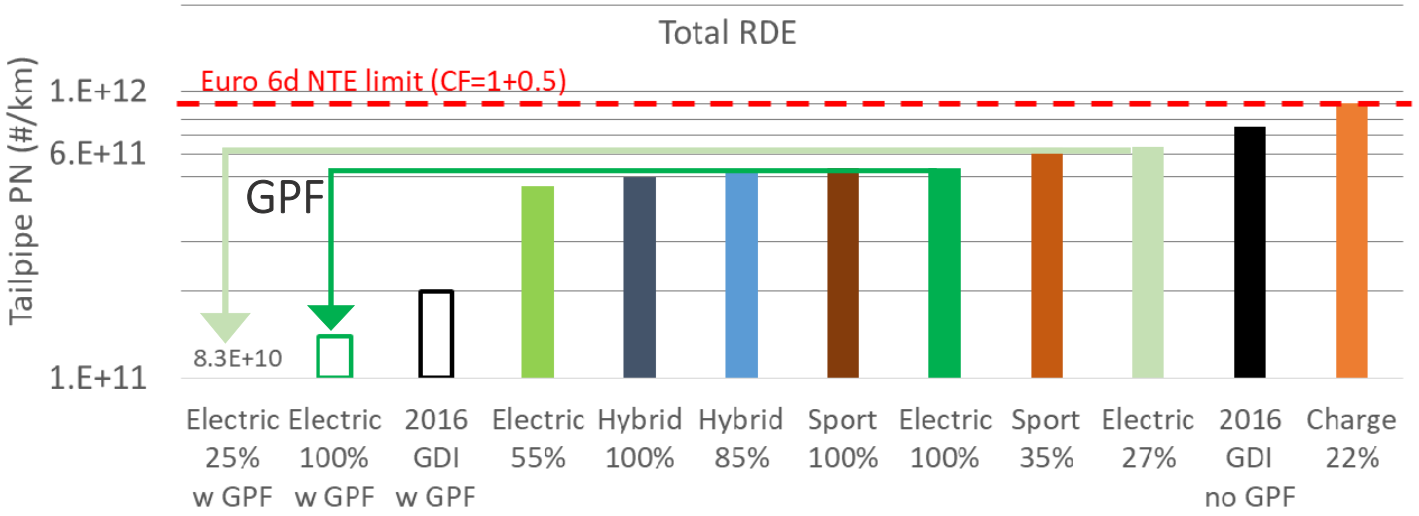


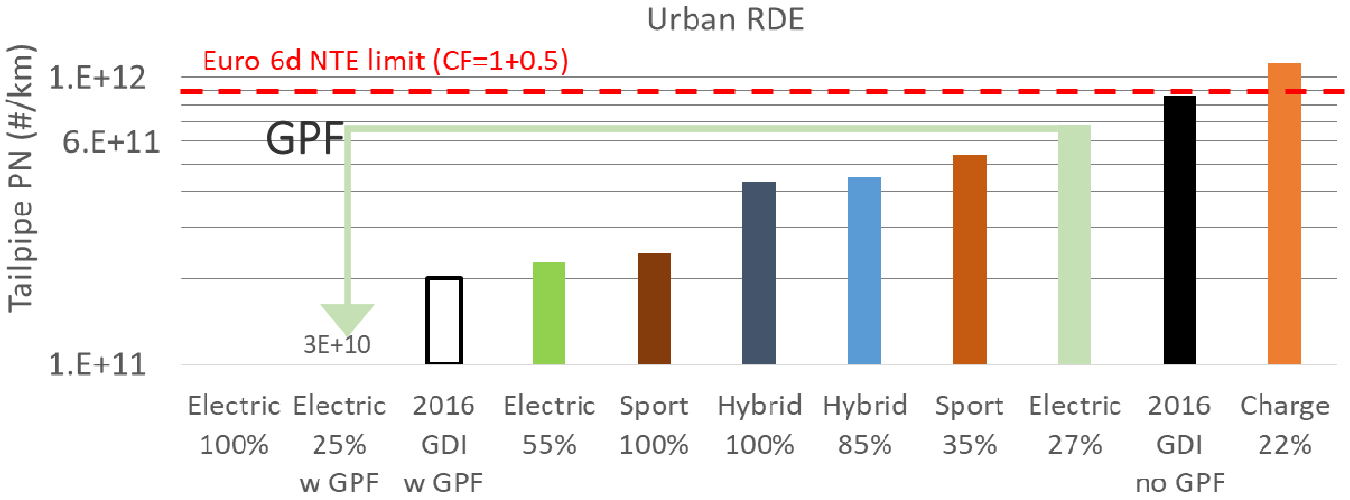
- Charge mode – empty battery: PN peak at start of trip → highest PN level
- Electric mode – full battery: PN peak in middle of trip → overall same PN level as other modes
- Electric mode – empty battery: PN peak in middle of urban part → second highest PN level

GPF well controls PN spikes observed at IC engine start

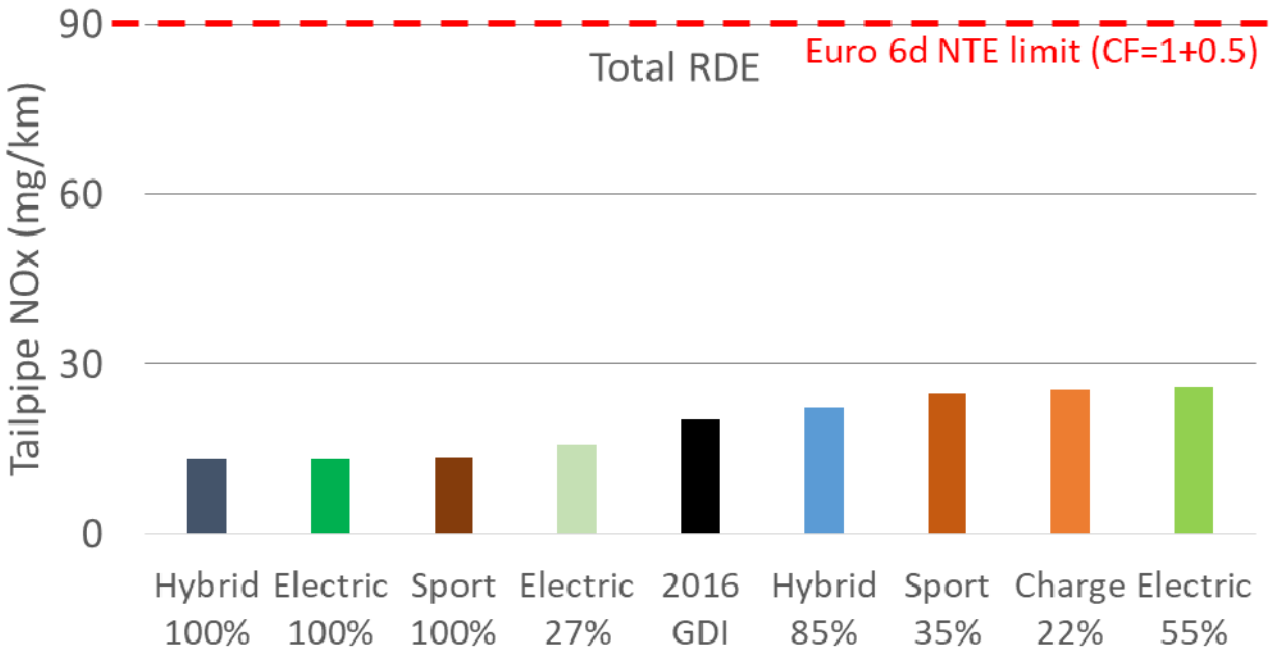
Tests in electric mode repeated with GPF





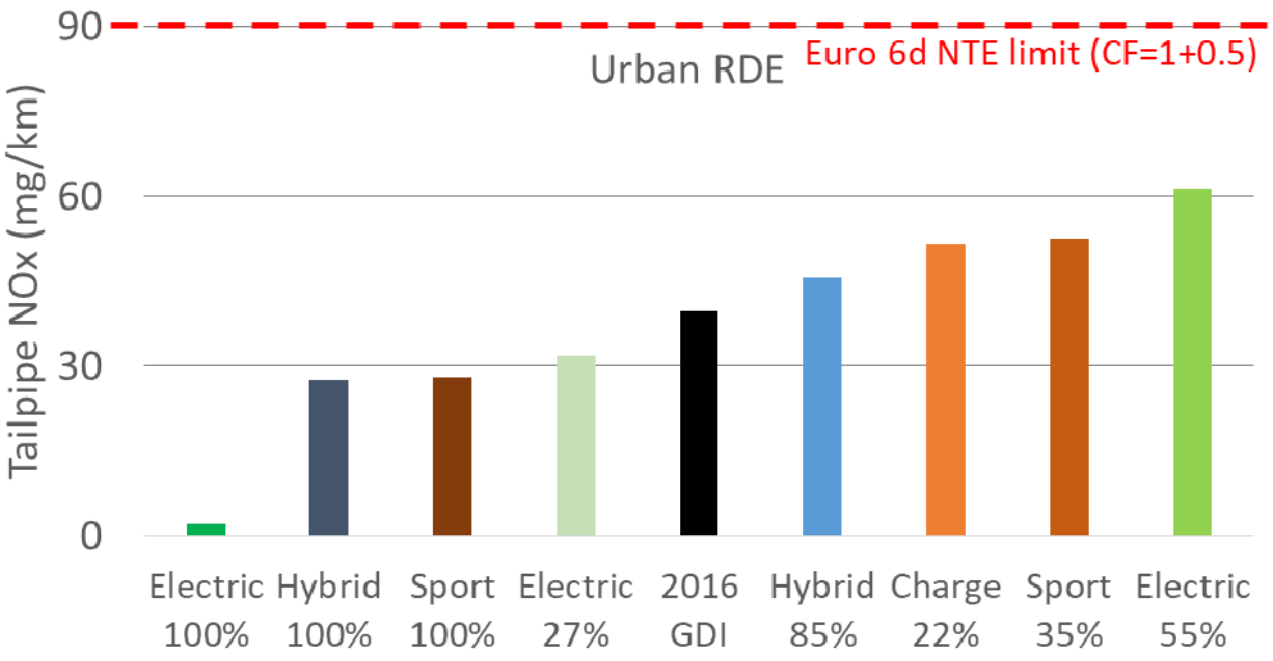


All total RDE NOx emissions below Euro 6d NTE limit



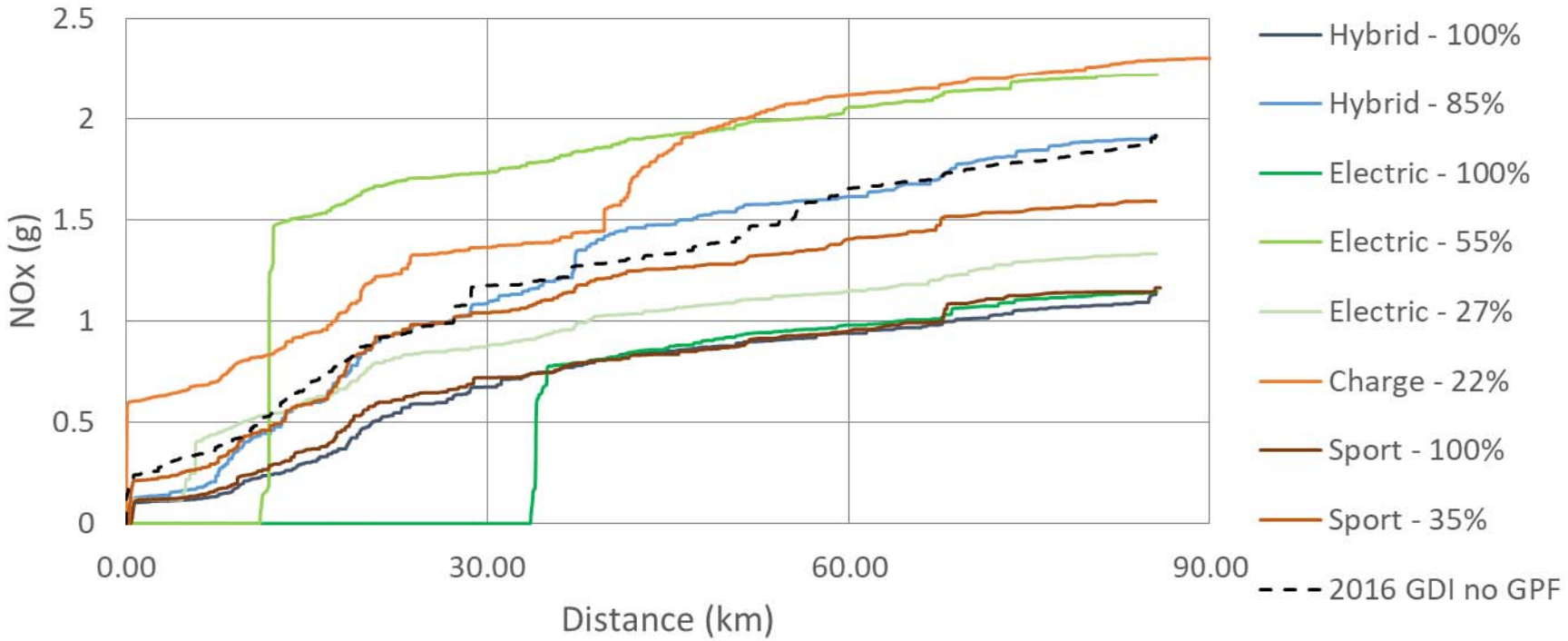
- Reference GDI result is in the middle of PHEV total NOx range
- Total NOx emissions of PHEV with fully-charged battery are consistently the lowest

All Urban RDE NOx emissions below Euro 6d NTE limit



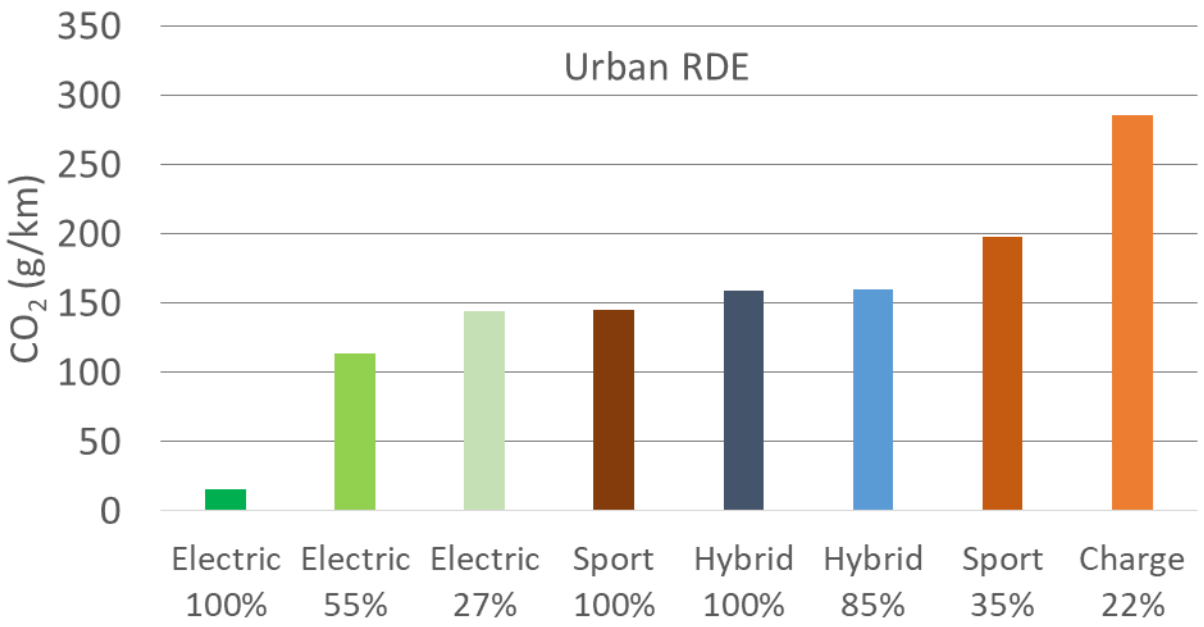
- Electric mode – full battery: urban part entirely run electric → zero urban tailpipe NOx emissions
- Electric mode – 55% battery SOC: highest urban NOx emissions
- Reference GDI result is in the middle of PHEV urban NOx range
- Urban NOx emissions of PHEV with fully-charged battery are consistently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

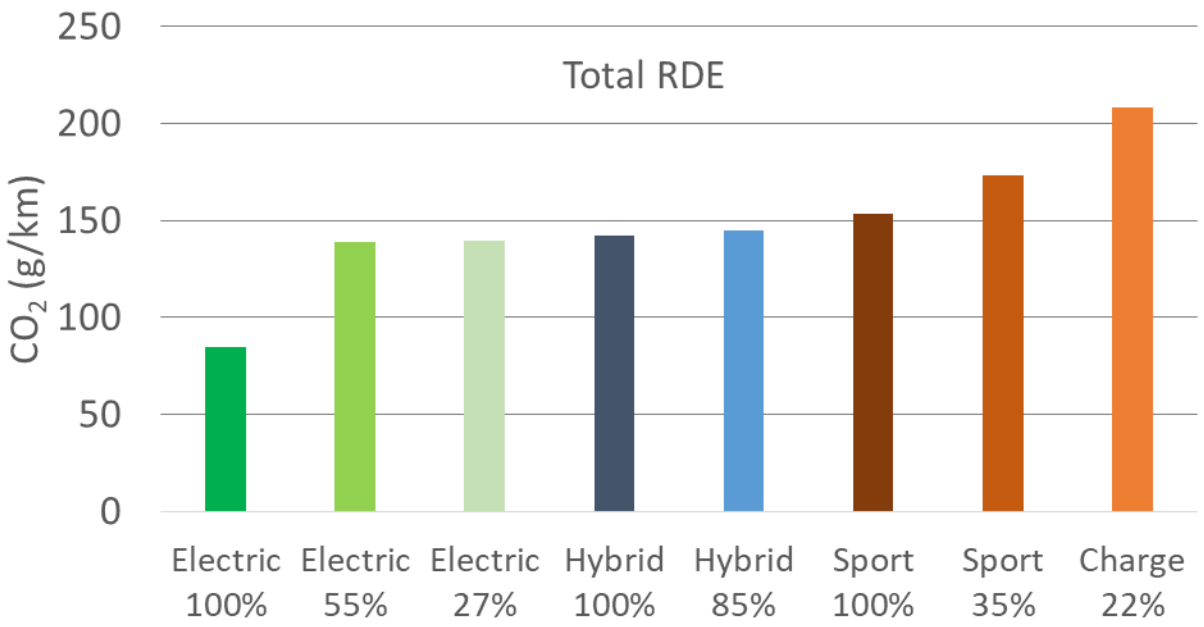
NOx spikes at cold IC engine start (with cold catalyst)



- Charge mode – empty battery: at start of trip
- 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

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 IC engine charges the battery in Sports and Charge mode
- Electric range achieved during RDE trip: ~35 km

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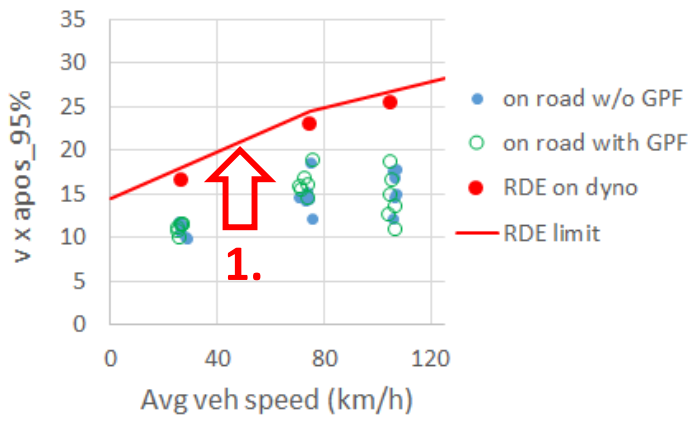
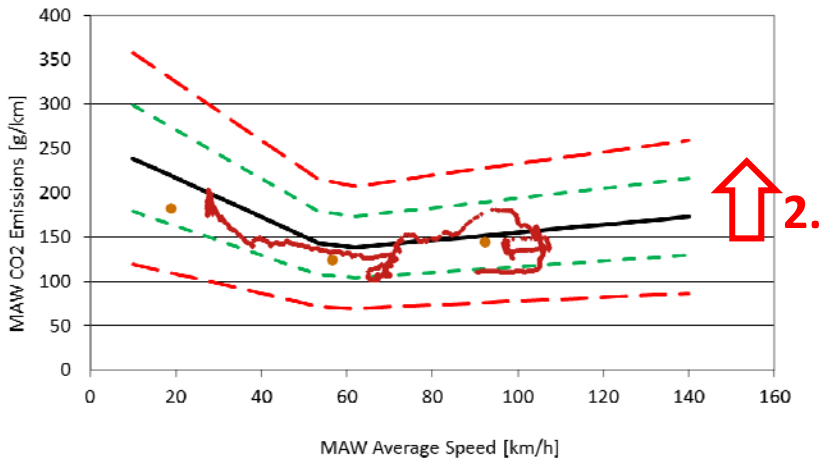
Impact of RDE boundary conditions tested on the chassis dyno

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

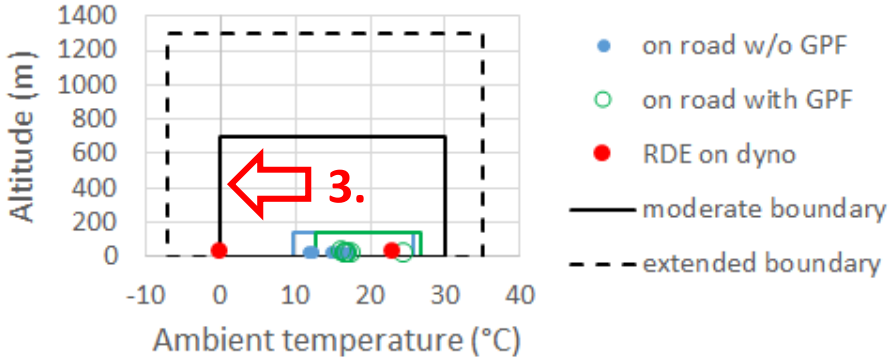
1. Change accelerations



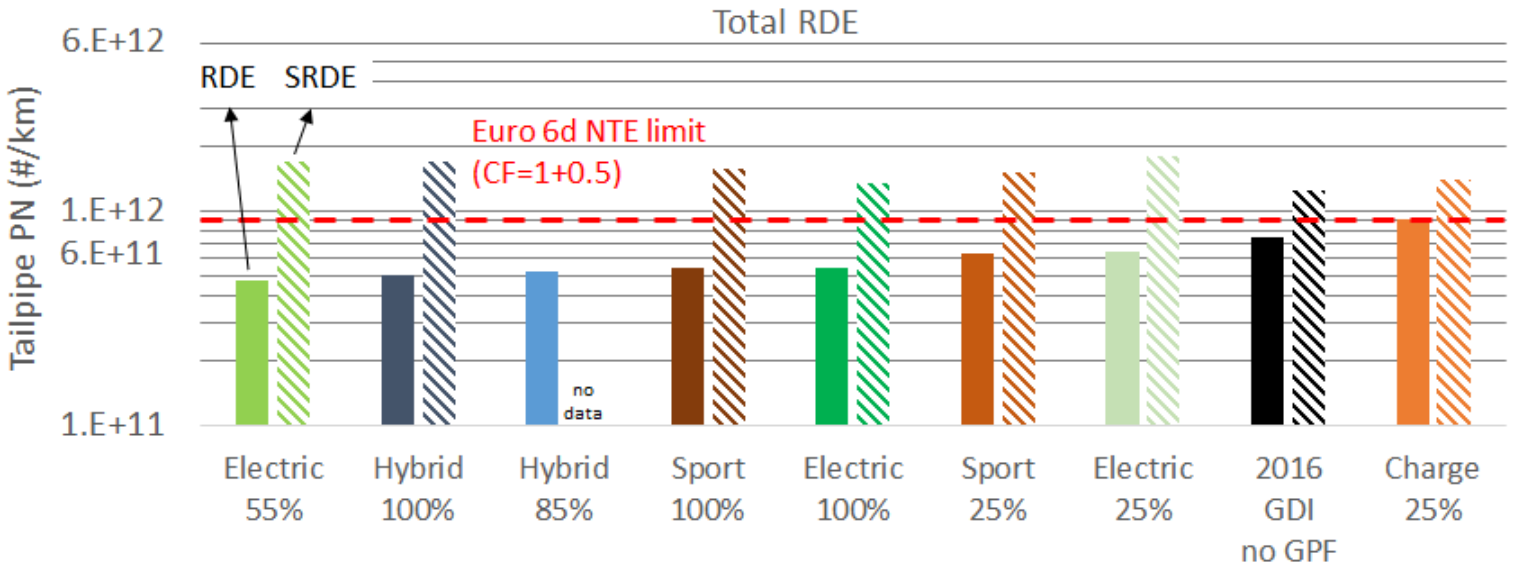
2. Change dyno load

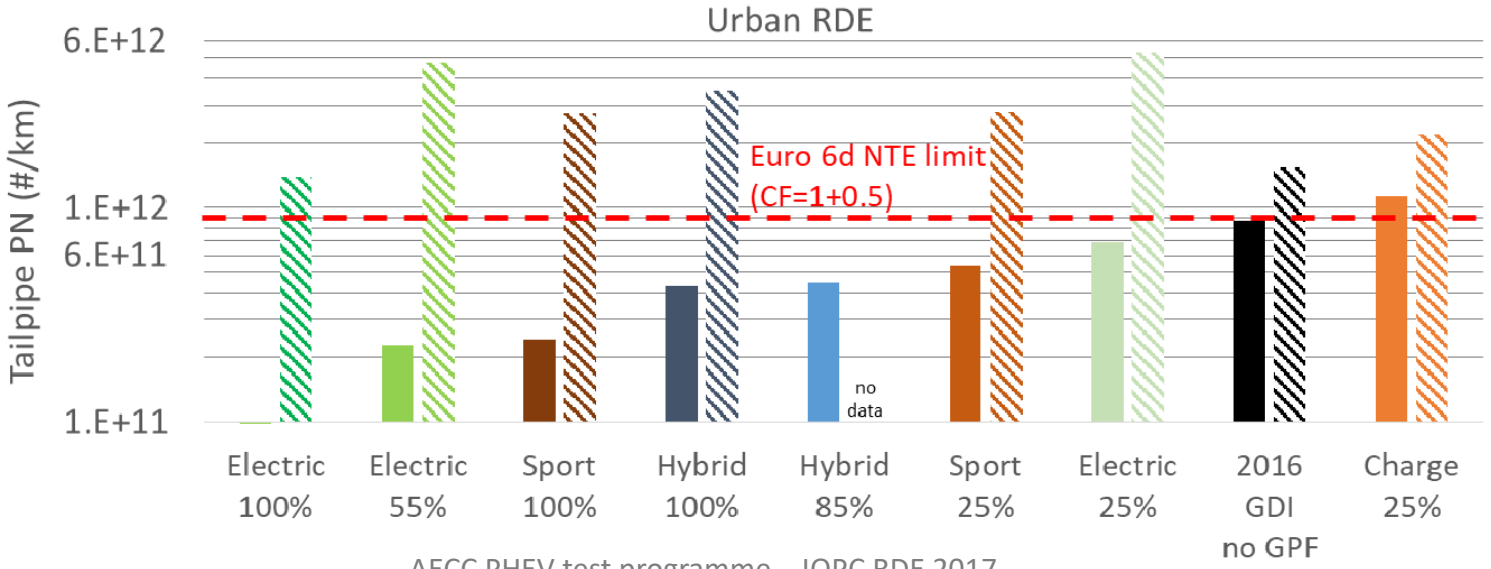


3. Change ambient temperature



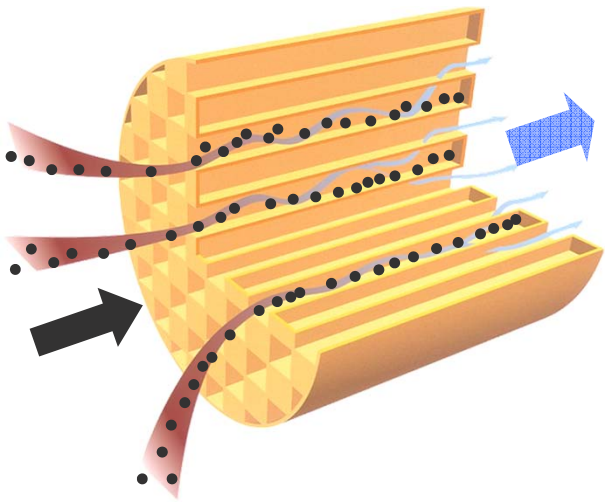
All Severitised RDE PN emissions above Euro 6d NTE limit



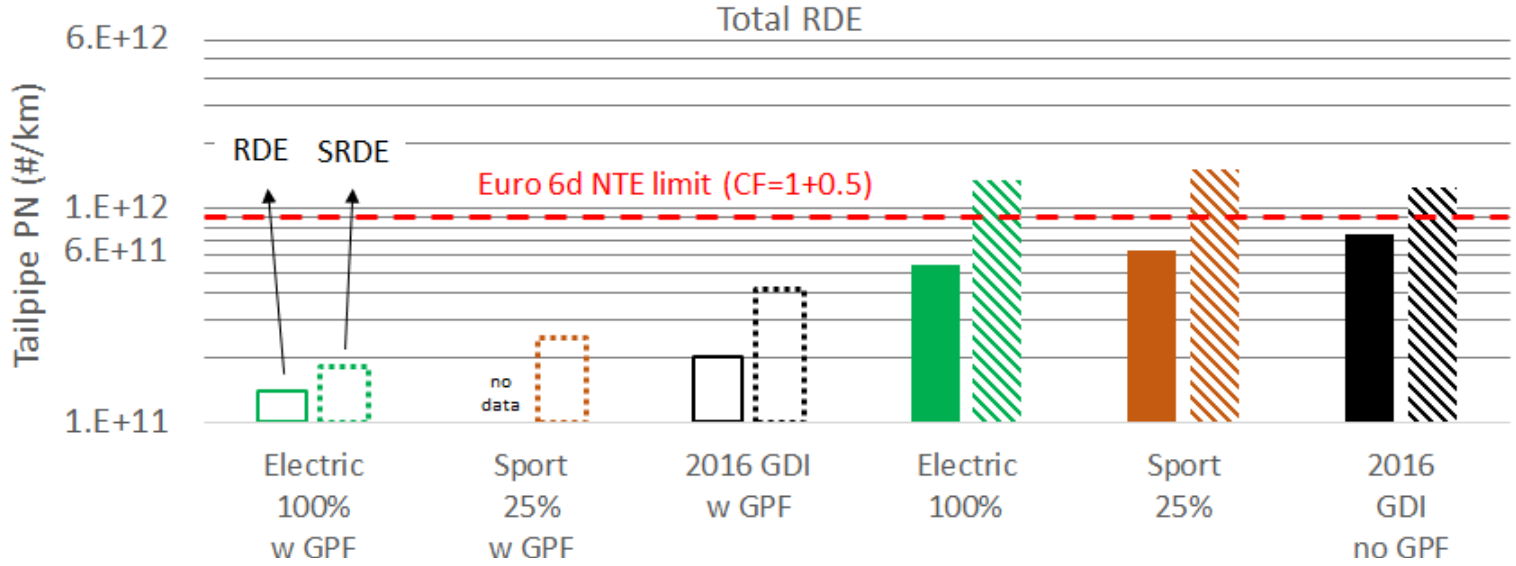


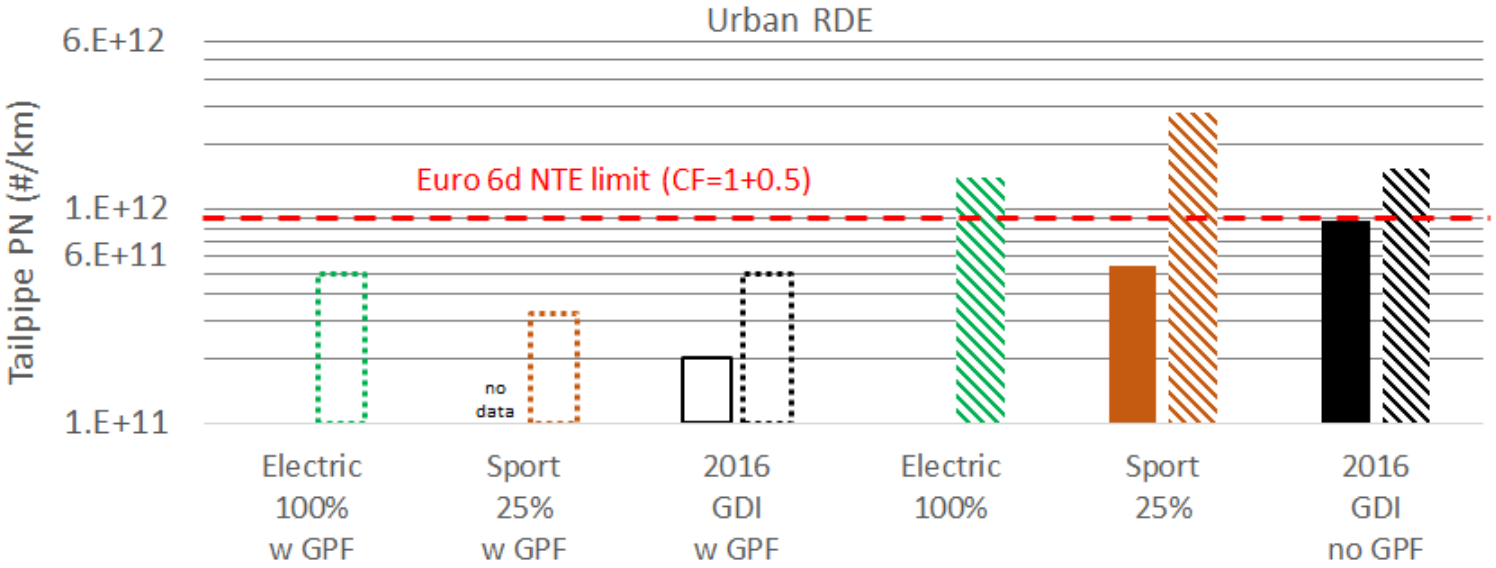
Note: 1.6 factor for extended ambient temperature applied

All PN emissions with GPF below Euro 6d NTE limit



Note: 1.6 factor for extended ambient temperature applied





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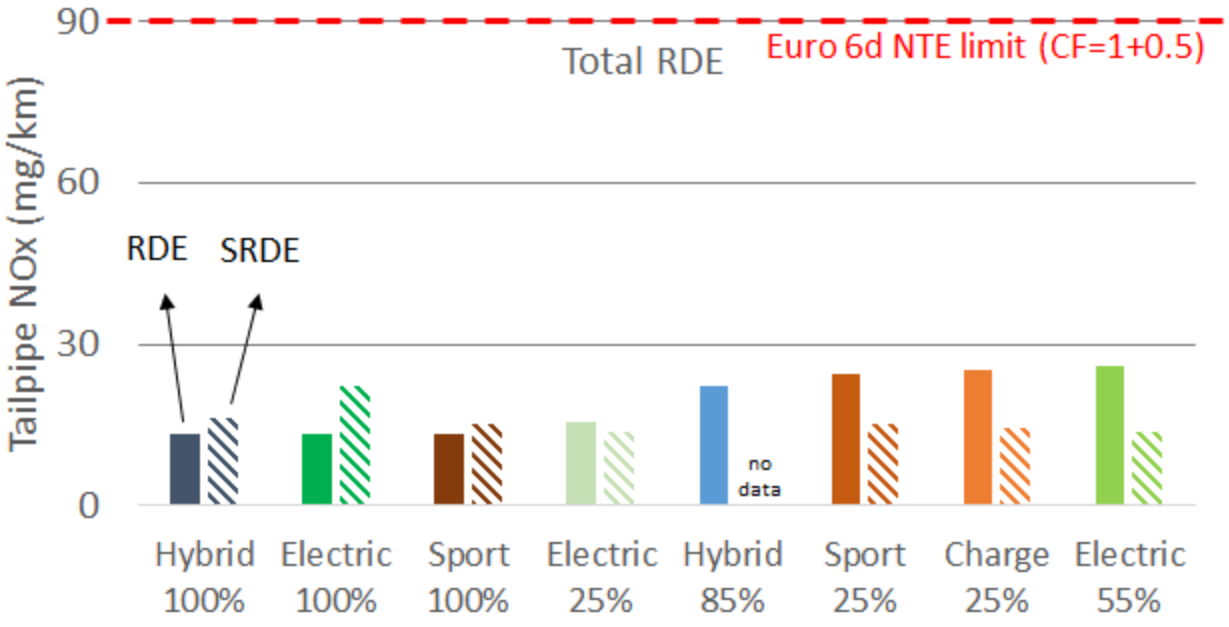
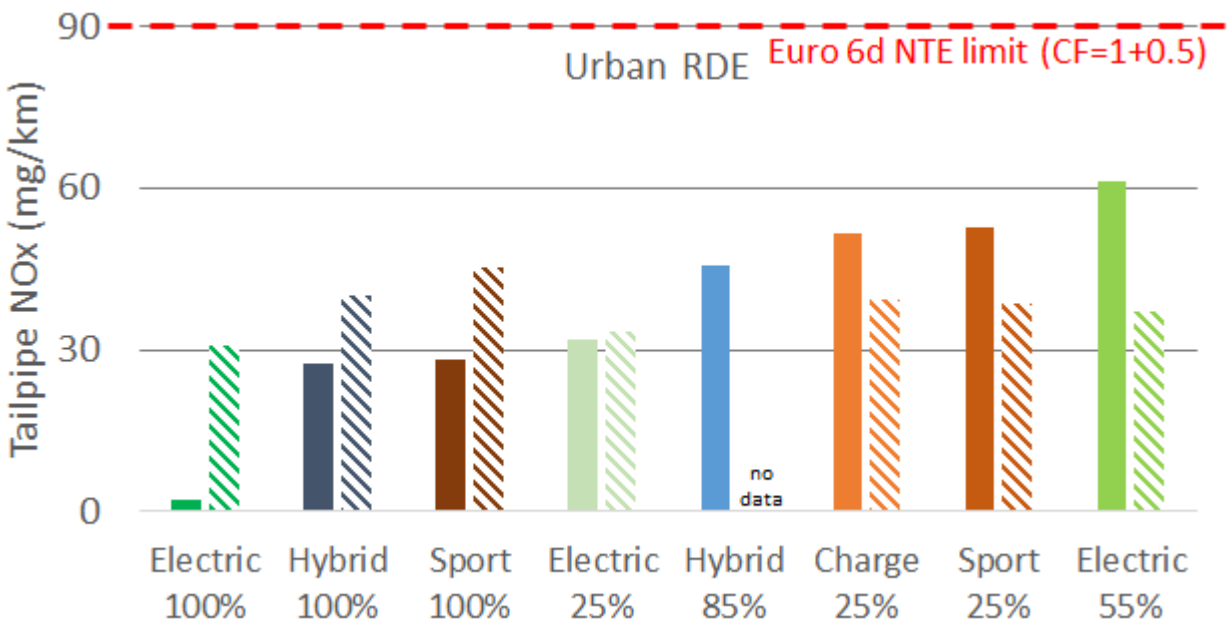
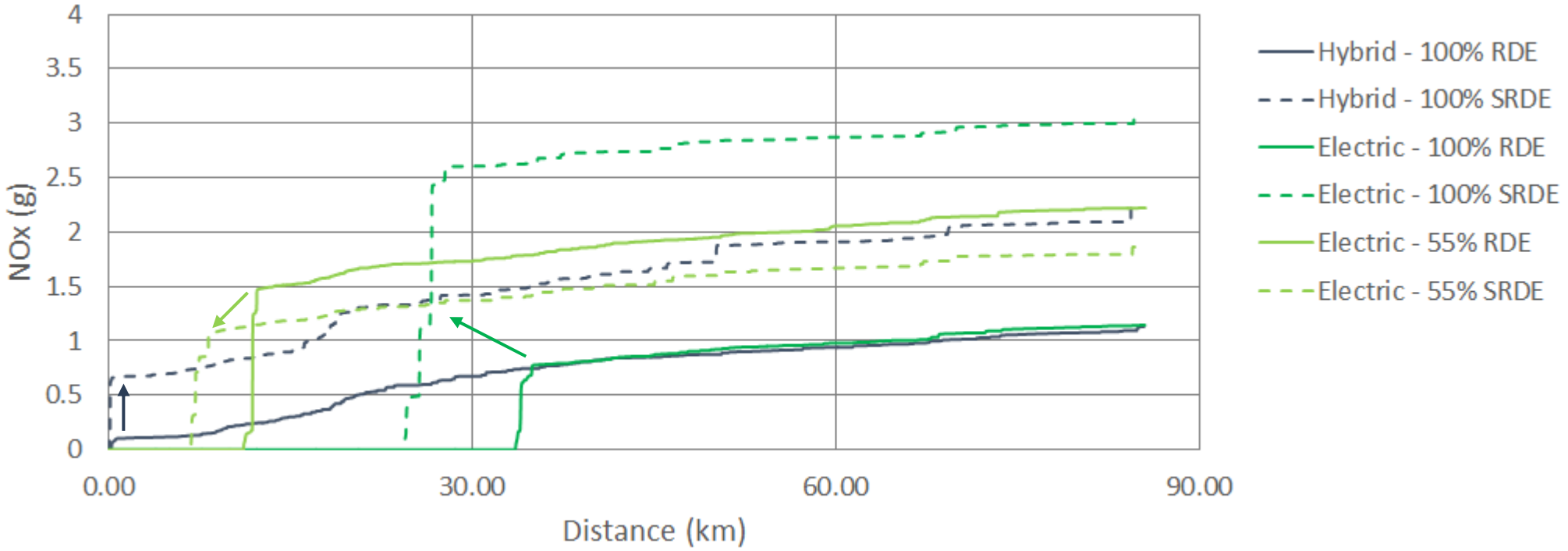
All Severitised RDE NOx emissions below Euro 6d NTE limit





Note: 1.6 factor for extended ambient temperature applied

NOx peak at cold IC engine 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

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Summary

- AECC PHEV test programme
  - Tested 1 Euro 6b C-segment vehicle
  - Raw data is shown, without RDE post-processing (still under review in RDE package 4)
- PN and NOx Real-Driving Emissions
  - Zero-emission capability in urban RDE is ensured in electric mode when battery has been fully charged
  - NOx results are all below Euro 6d NTE limit
  - On tested PHEV, 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 efficient GPF
  - Well integrated exhaust aftertreatment is required to control emissions under all RDE conditions, including thermal management

THANK YOU!

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