4. Exhaust Emissions

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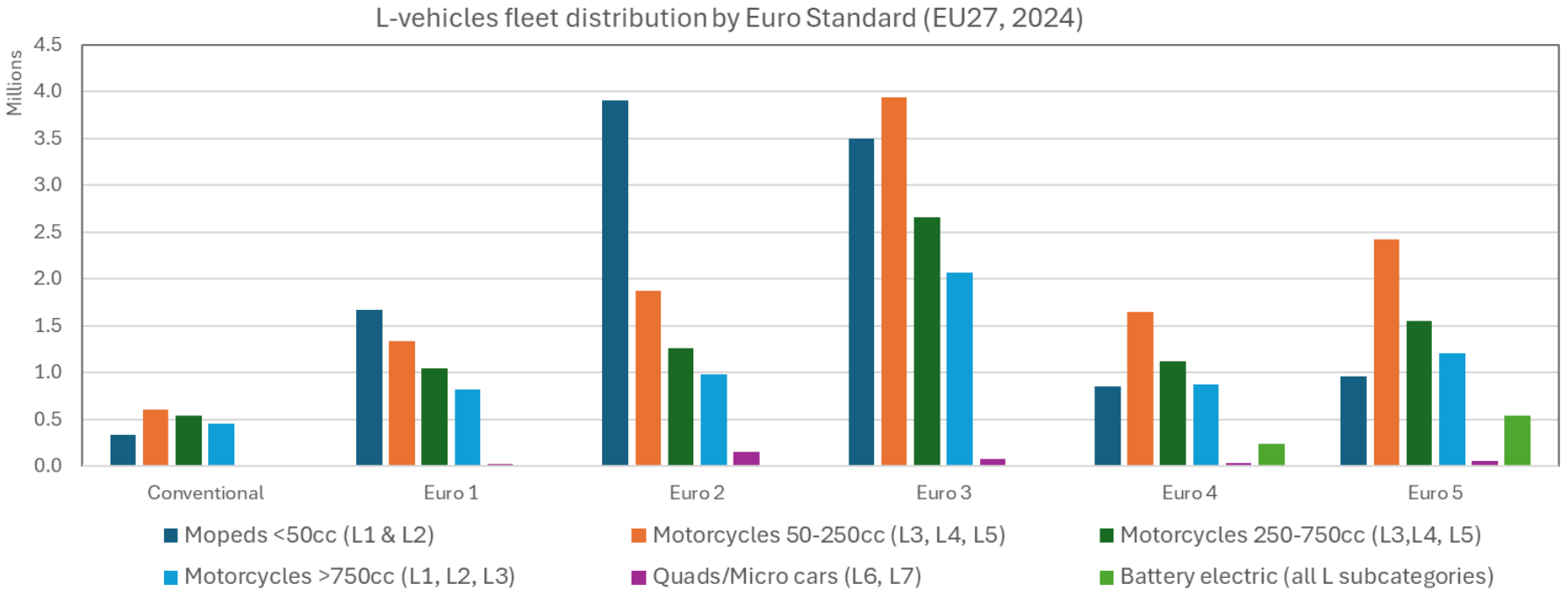
L-vehicles Emissions and Noise mitigation Solutions

Background and Methods

Population related to Emission Standards



Source: COPERT, 2024 (https://copert.emisia.com/)

Important outcomes

- Dominance of Euro 3: highest number of L-category vehicles are classified under Euro 3
- Few Euro 5 vehicles: indicating a slow transition. Old L-cat fleet.
- Mopeds have a significant decline in newer Euro categories.
- Battery electric vehicles remain a minority

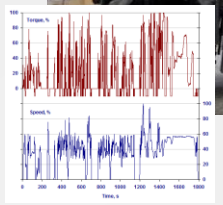
LENS L-vehicles Emissions and Noise mitigation Solutions

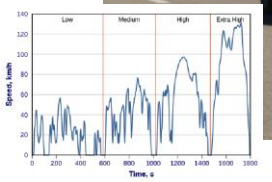
Comparison of LVs to LD & HD Vehicles

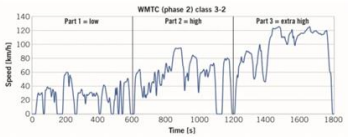
R(EU) 582/2011 Heavy-duty vehicles

R(EU) 2017/1151 Light-duty vehicles

R(EU) 168/2013 L-category vehicles







- PEMS: testing applicable from 2013
- Laboratory testing for engines
- Pollutants: CO, HC, CH4, NOx, PM, PN

- RDE: testing applicable from 2017
- Laboratory testing for complete vehicle
- Pollutants: CO, HC, NOx, PM, PN

- RDE: N/A
- Laboratory testing for complete vehicle
- Pollutants: CO, HC, NOx, PM

L-vehicles Emissions and Noise mitigation Solutions

Comparison of LVs to LD & HD Vehicles

R(EU) 2017/1151 Light-duty (LD) vehicles

Passenger Cars According to Euro 6d Standard								
Procedure	Powertrain	CO	HC	NMHC	HC+NOx	NOx	PM	PNt
		g/km						#/km
WLTC	Petrol	1.0	0.1	0.068	-	0.06	0.0045	6.0 E+11
	Diesel	0.5	-	-	0.17	0.08	0.0045	6.0 E+11
RDE	Petrol	1.0	0.1	0.068	0.17	0.06	0.0045	6.0 E+11
	Diesel	0.5	-	-	0.17	0.08	0.0045	6.0 E+11

R(EU) 168/2013 L-category (L-Cat) vehicles

PM is for DI & CI engines only

L-Category vehicles According to Euro 5 Standard							
Procedure	Category	Powertrain	CO	THC	NMHC	NOx	PM
			g/km				
Revised WMTC	L1e-A	All	0.5	0.1	0.068	0.06	0.0045
	L1e-B - L7e	Petrol	1.0	0.1	0.068	0.06	0.0045
		Diesel	0.5	0.1	0.068	0.09	0.0045

*Euro 5 thresholds for L-category vehicles are the same as those for Euro 6 Light Duty vehicles

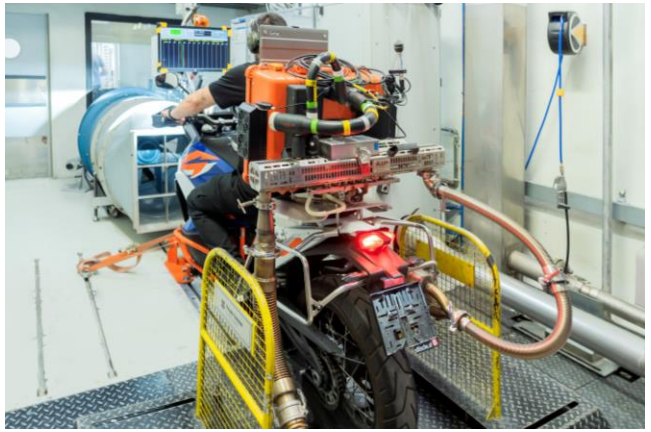
- Same regulated pollutants limits in LD and L-Cat
- PN is not regulated
- PM regulated just for DI & CI engines

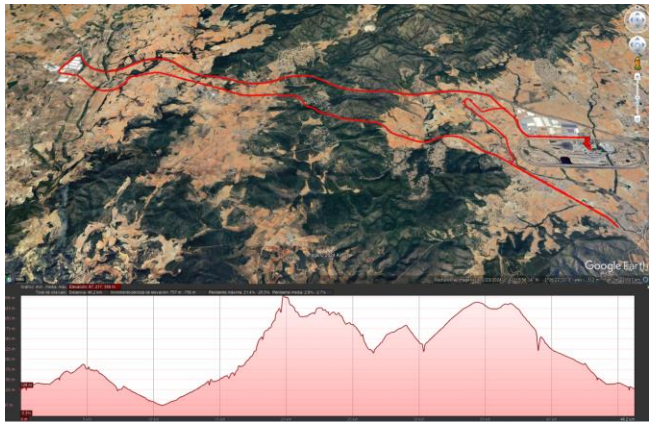
L-vehicles Emissions and Noise mitigation Solutions

Measurement procedure

Tests performed

- Chassis Dyno: Type Approval (WMTC)
  - CO2 & Regulated Pollutants:
    CO, NMHC, NOx, (PM)
  - Non-Regulated Pollutants:
    PN23/10, NH3, N2O, CH4
- Chassis Dyno: Real Driving Cycle (RDC)
  - Specific designed Real Driving Cycle
- On-Road: Real Driving Emissions (RDE)
  - Prototype and standard equipment
  - Newly developed procedure and method
  - Routes developed by use-case

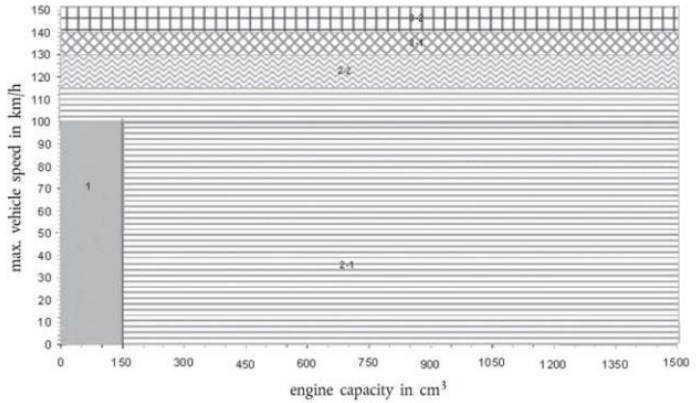




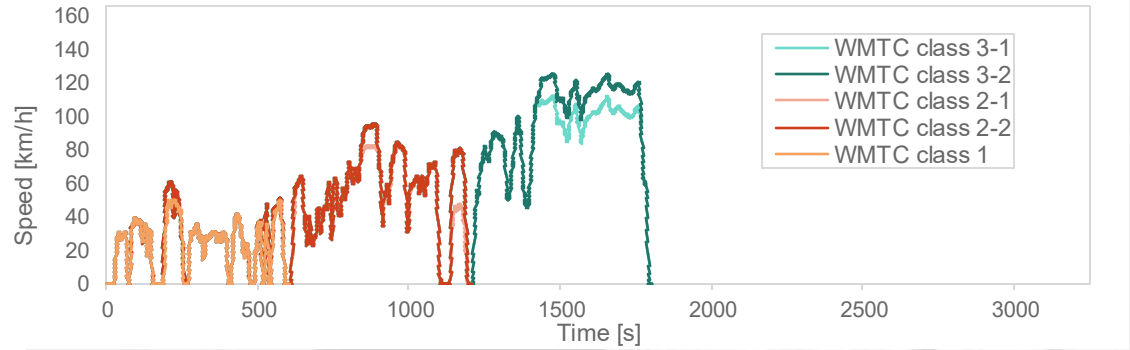
Measurement Procedure

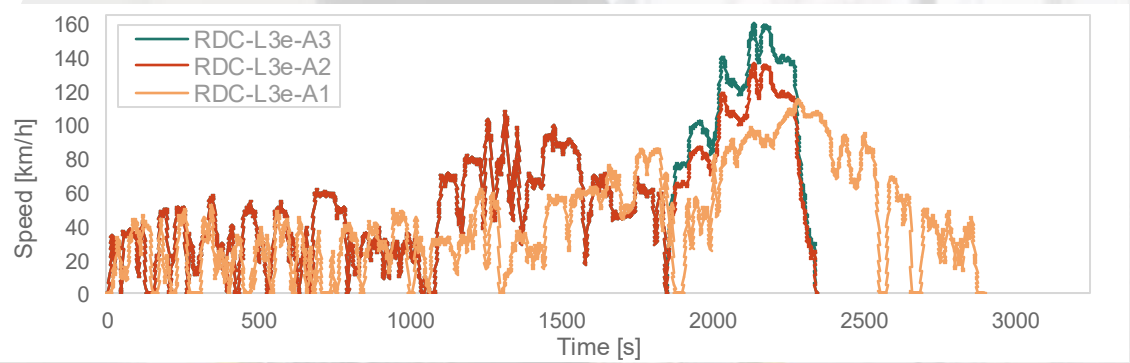
Tests performed

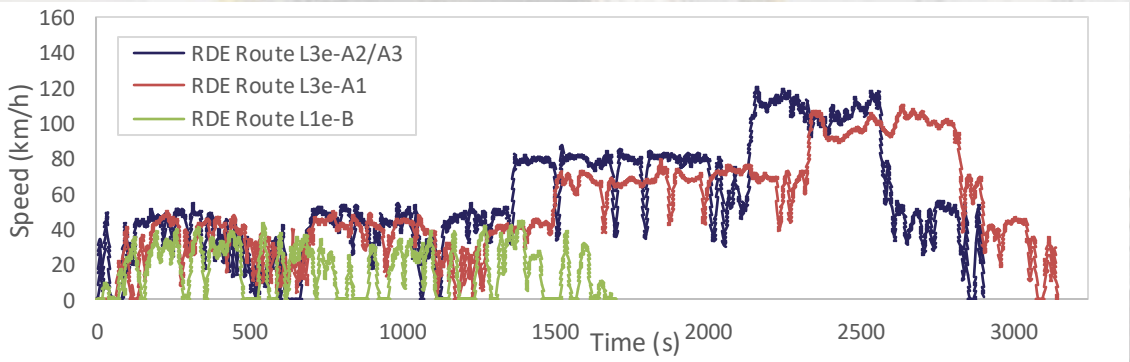
- Type Approval (TA) WMTC cycle
  - Chassis dyno test according to the vehicle characteristics (Engine capacity and maximum speed)



- Real Driving Cycle (RDC)
  - Dyno profile developed with real-world GPS data. More dynamic than TA.
- Real Driving Emissions (RDE)
  - On-road driving. Specific routes for each sub-category







LENS L-vehicles Emissions and Noise mitigation Solutions

Vehicles measured

- Total of +150 vehicles and +250 measurements
  - 26% TA measurements
  - 24% RDC measurements
  - 50% RDE measurements

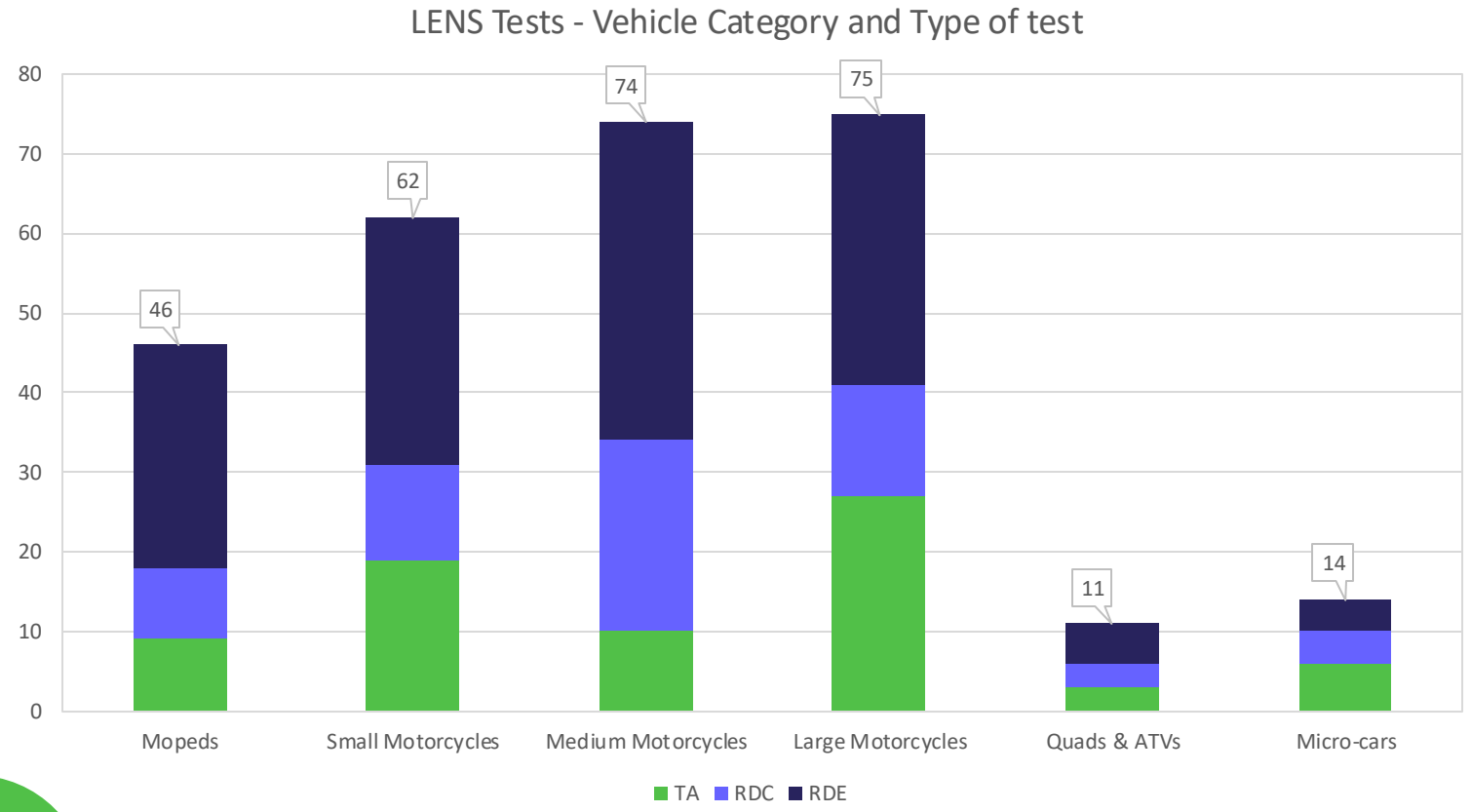
*(24x vehicles measured for both RDE and chassis dyno (TA and/or RDC)

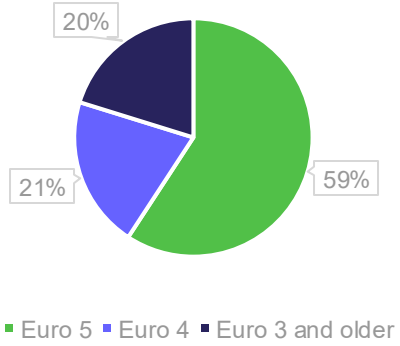
+10.000 km Total

+6.500 km RDE

+230h Total

+165h RDE

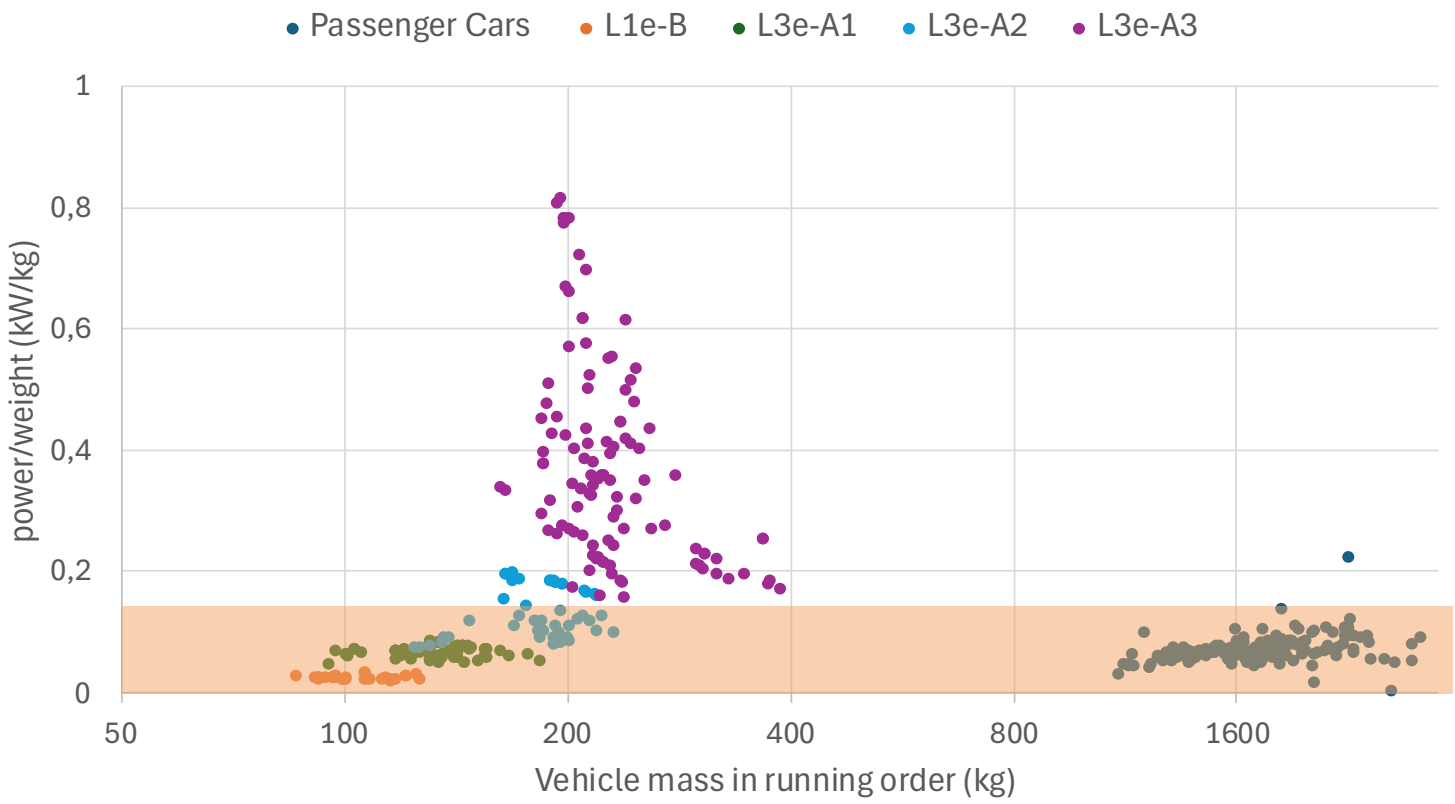




L-vehicles Emissions and Noise mitigation Solutions

L-Category Vehicles Characteristics

- High performance/engine capacity ratio
- High Power-to-Mass ratio



Sources: 1. Sebastian Schurl, TU Graz, 2025 , 2. IDIADA, 2025

- L-category vehicles have much higher PtoM ratio than passenger cars.
- PtoM ratio is strongly dependant on the L-subcategory.
- High performance motorcycles have wide spread of PtoM ratio ranges.

Typical P/M Ratio for passenger cars

LENS L-vehicles Emissions and Noise mitigation Solutions

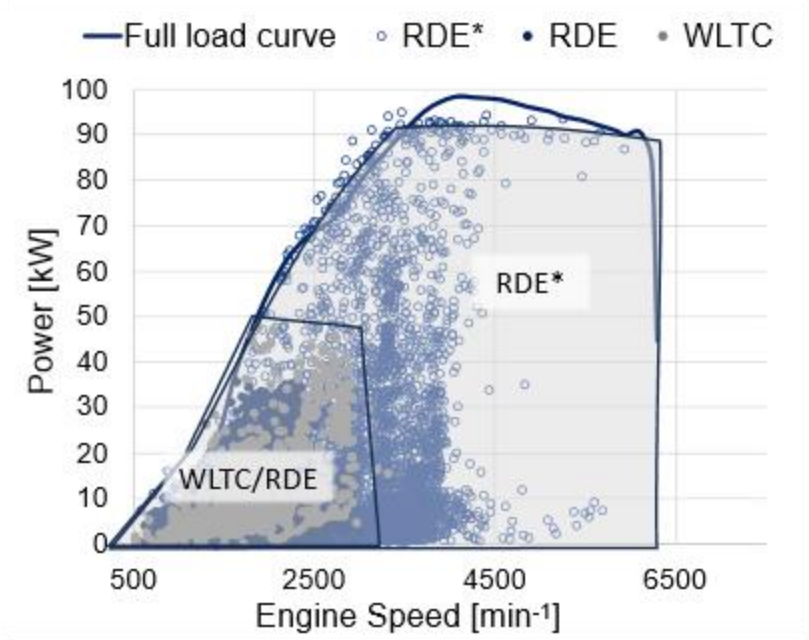
Difference between TA and RDE

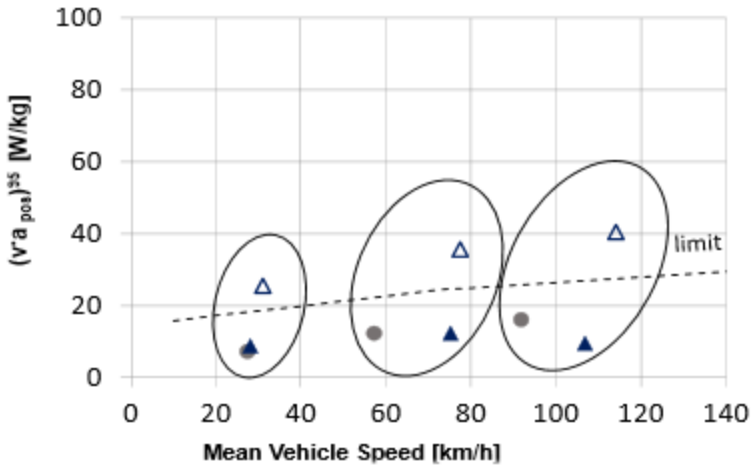
- High driving dynamics (v·a,pos 95th) in standard L3e-A3 motorcycles compared to passenger cars.
- WMTC does not represent regular real driving of motorcycles, specially for L3-A3.

RDE: RDE in regular driving

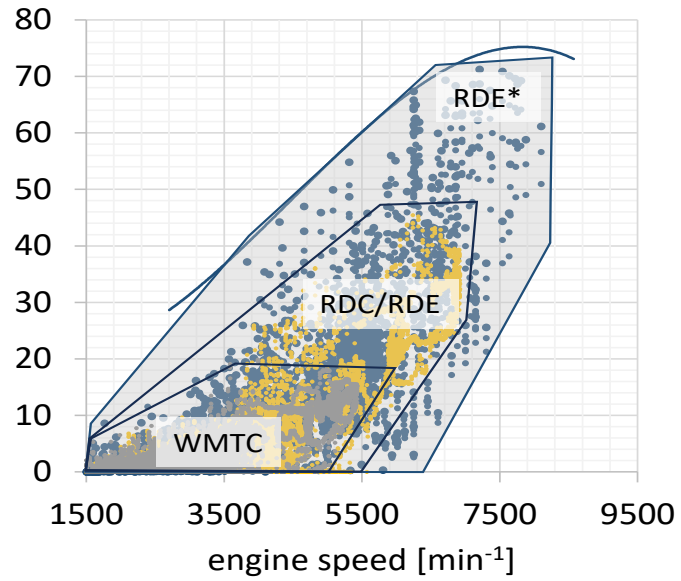
RDE*: RDE in high dynamic driving

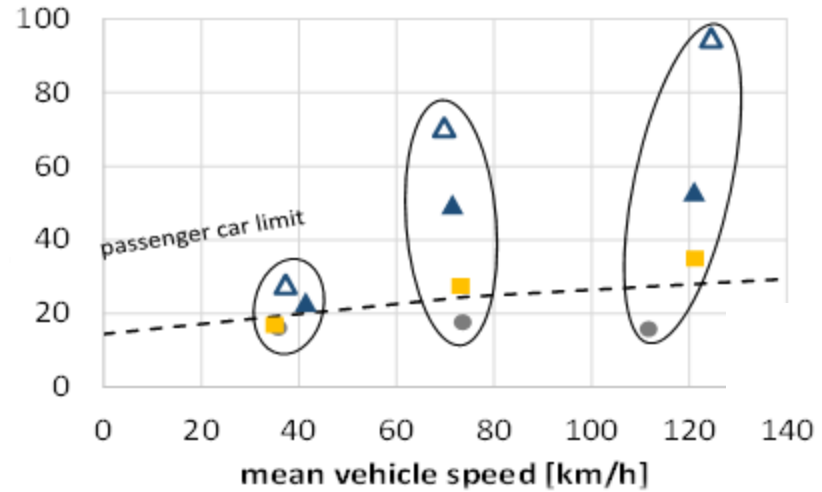
Passenger Car





L3e-A3 Motorcycle





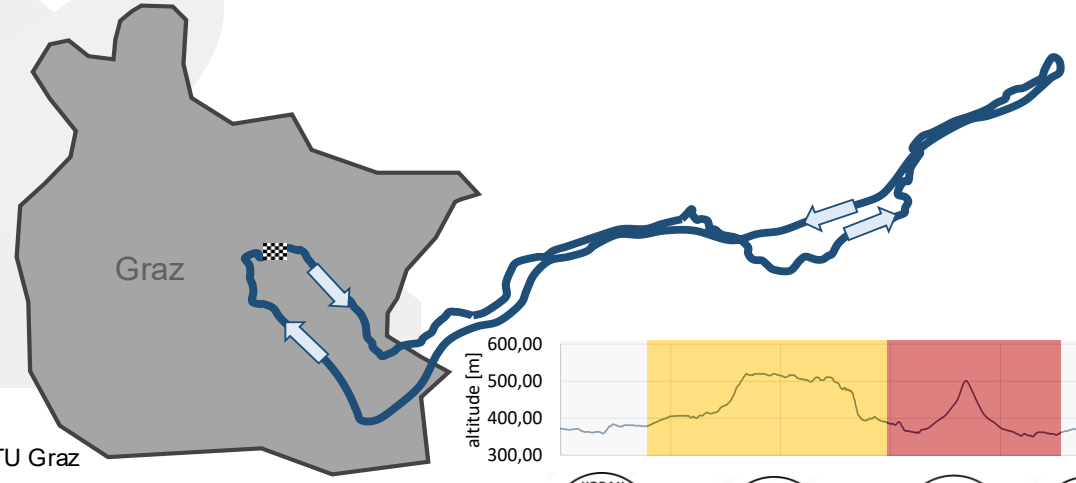
Measurement Procedure

RDE Trips

RDE Routes have been specifically developed according to:

- Dedicated urban route for Mopeds (L1e, L2e), light quads (L6e)
- Specific manoeuvres for better covering L-Cat dynamics capabilities
- Standard and dynamic driving dedicated routes

Graz (Austria)



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Prague (Czech Republic)

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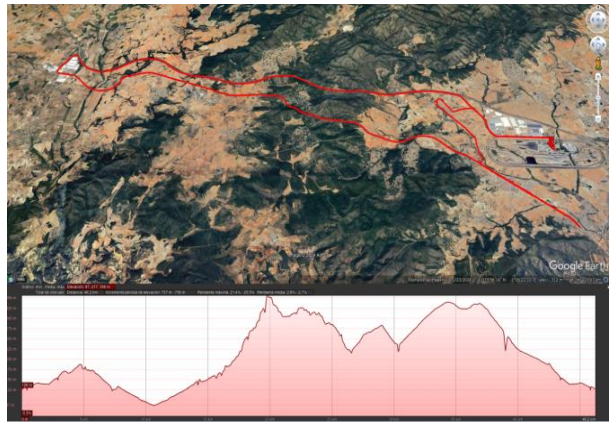
Santa Oliva (Spain)



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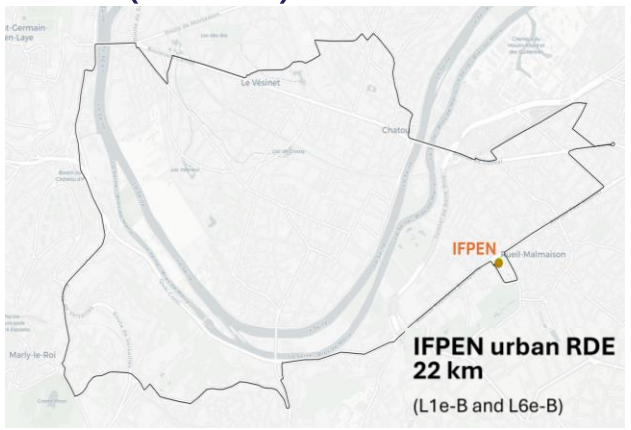
Paris (France)



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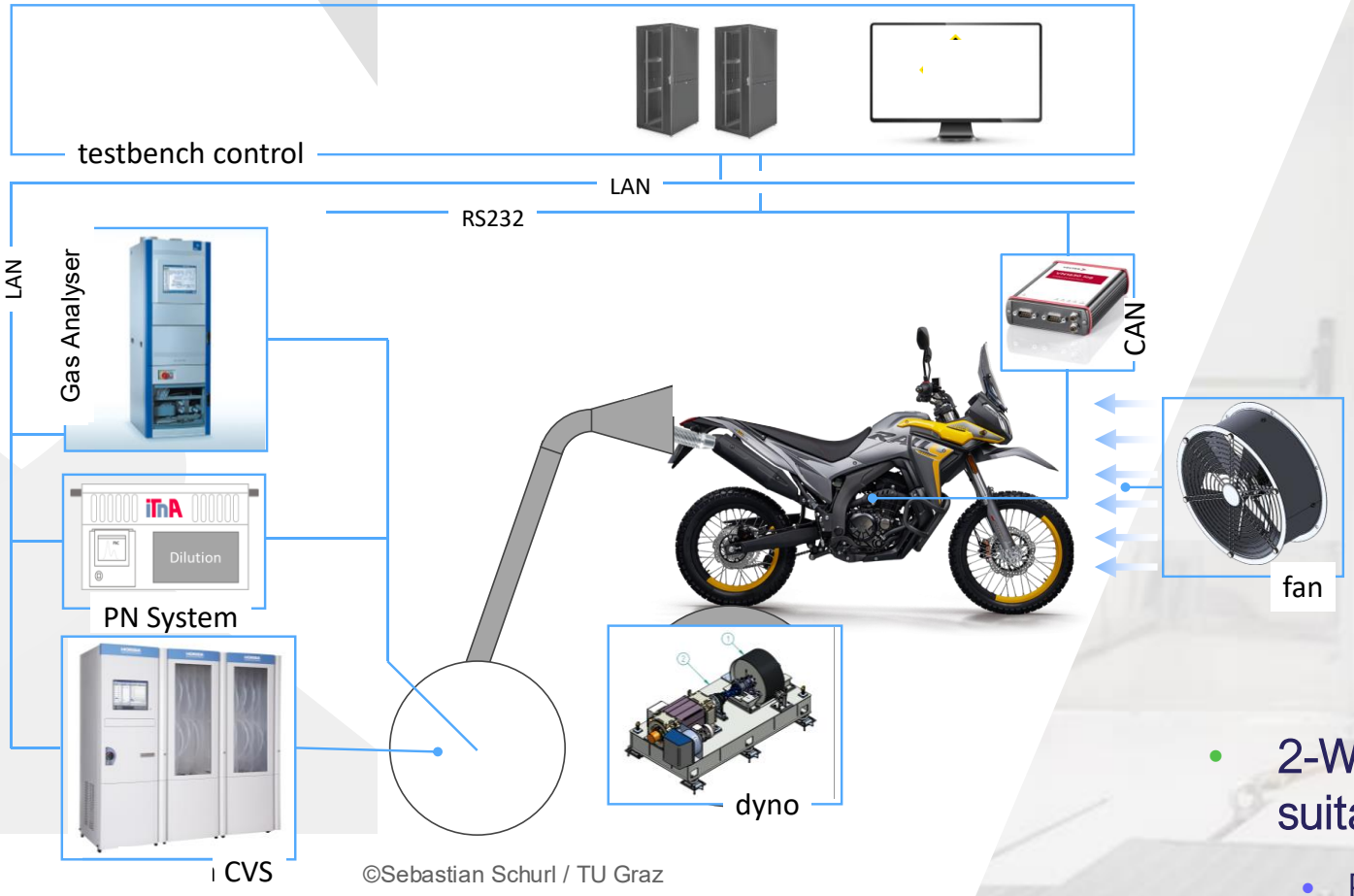
LENS L-vehicles Emissions and Noise mitigation Solutions

Measurement equipment

Laboratory Equipment Configuration



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© IDIADA

- 2-Wheeler Chassis dyno with restricted suitability for High Power Motorcycles:
  - Rear Wheel Slip
  - Power and speed restrictions of the standard chassis dynamometer

Measurement Equipment

RDE Equipment Configuration

© TU Graz

Instrumentation

- Big and heavy devices for LVs, new prototypes used.
- Mounting adaptation to the bike in case-by-case basis
- Exhaust pipe adaptation: Wide range of exhaust configurations, diameter and geometry
- External sensors for <EU4 (no OBD read out)

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L-vehicles Emissions and Noise mitigation Solutions

Measurement Equipment

Adapted & newly developed on-road measurement equipment

HORIBA SEMS & Mini-PEMS

©Horiba

- Weight 8-13kg
- NOx + EFM (Horiba SEMS)
- CO2, CO, NO + EFM (Horiba Mini-PEMS)

*EFM: Exhaust Flow Meter with Pitot Tube

*GPS + ambient temperature

IFPen Real-e SEMS

©IFPEN

- Weight 25kg
- CO, CO_2, O_2, NO, NO_2, NOx
- C_3H_8, NH_3, SO_2
- PN

EMISIA ReTEMS with MAURUS Sensor

©EMISIA

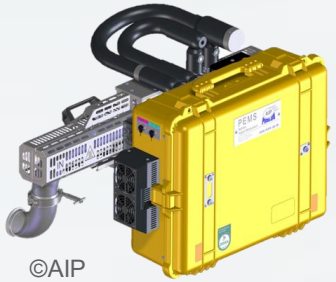
- Weight 14kg
- Maurus BCPM prototype optoacoustic sensor
- CO & NO (electrochemical)
- CO2 (NDIR)

CZU Prague mFTIR

©CZU Prague

- Weight 35kg
- CO, CO2, NO, NO2, NOx
- N2O, NH3, CH4, C4H10, C3H8, Ethylene, Formaldehyde, Acetaldehyde

AIP Standard PEMS



©AIP

- Weight ~40kg
- CO, CO2, NOx, PN

LENS L-vehicles Emissions and Noise mitigation Solutions

Measurement Equipment

Newly developed Mobile FTIR

35 kg, 5 Hz @ 0.5 cm^{-1}
~250 W @ -10 C

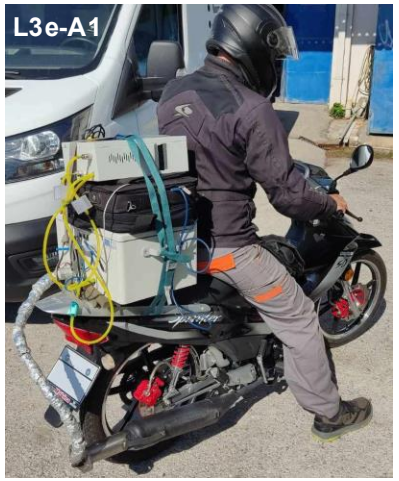
Measuring Euro 7 components:
CO, HCHO,
Reactive nitrogen species:
NO, NO_2, NH_3
GHG: CO_2, CH_4, N_2O

Instrument carried by the driver with its weight resting on passenger seat

LENS L-vehicles Emissions and Noise mitigation Solutions

Measurement Equipment

On-Road RDE Equipment Configuration



LENS L-vehicles Emissions and Noise mitigation Solutions

Measurement Equipment

Newly developed PN2.5 Sensor for On-road and in-lab testing

Condensation Particle Counter

- Reduced upper PN limit
- Elaborate detection method

Diffusion Charger

- Inherent size dependency
- Low sensitivity < 10 nm

Current methods unsuitable for high-concentration measurement of 2.5 nm.

Condensation Diffusion Charging (CDC)

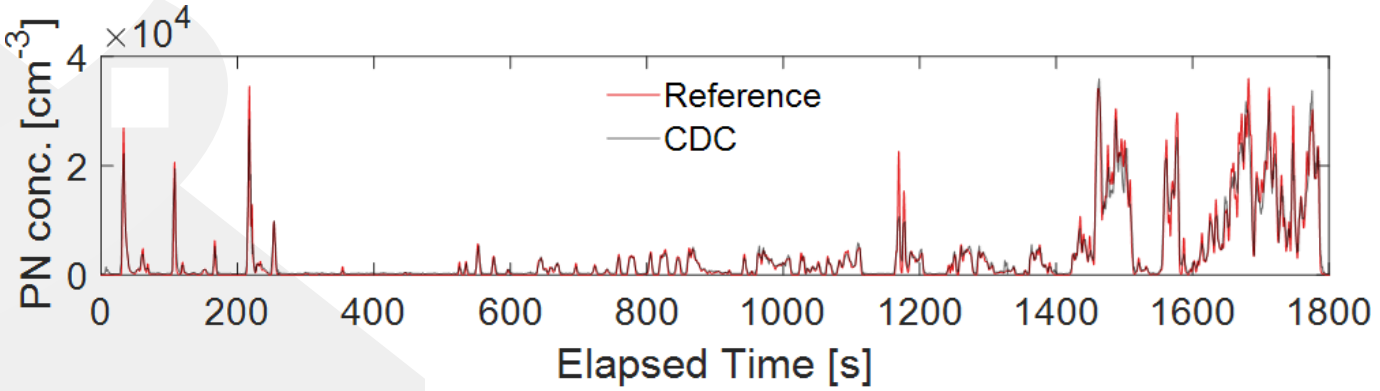
- High concentrations
- Simplified detection

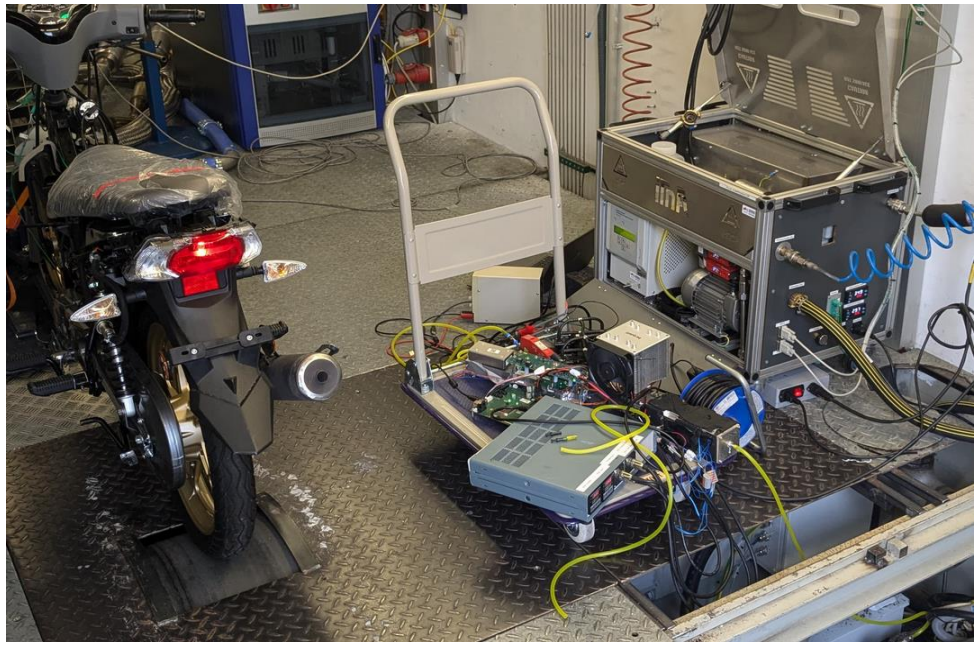
- Sensitivity down to < 3 nm
- No size dependent counting

Measurement Equipment

Newly developed PN2.5 Sensor for On-road and in-lab testing

Proof of concept: Chassis dyno tests vs 2.5 nm reference system





LENS L-vehicles Emissions and Noise mitigation Solutions

Results

Results

- Type Approval measurements
  - Average emission from all Type Approval (TA) tests
  - TA results for current emission class Euro 5
  - Comparison of tampered and non-tampered vehicles Euro 5
  - Emission evolution for TA Euro steps
- RDC results for selected sub-categories and emission classes
- Comparison between lab and on-road tests
- Non-regulated emission components

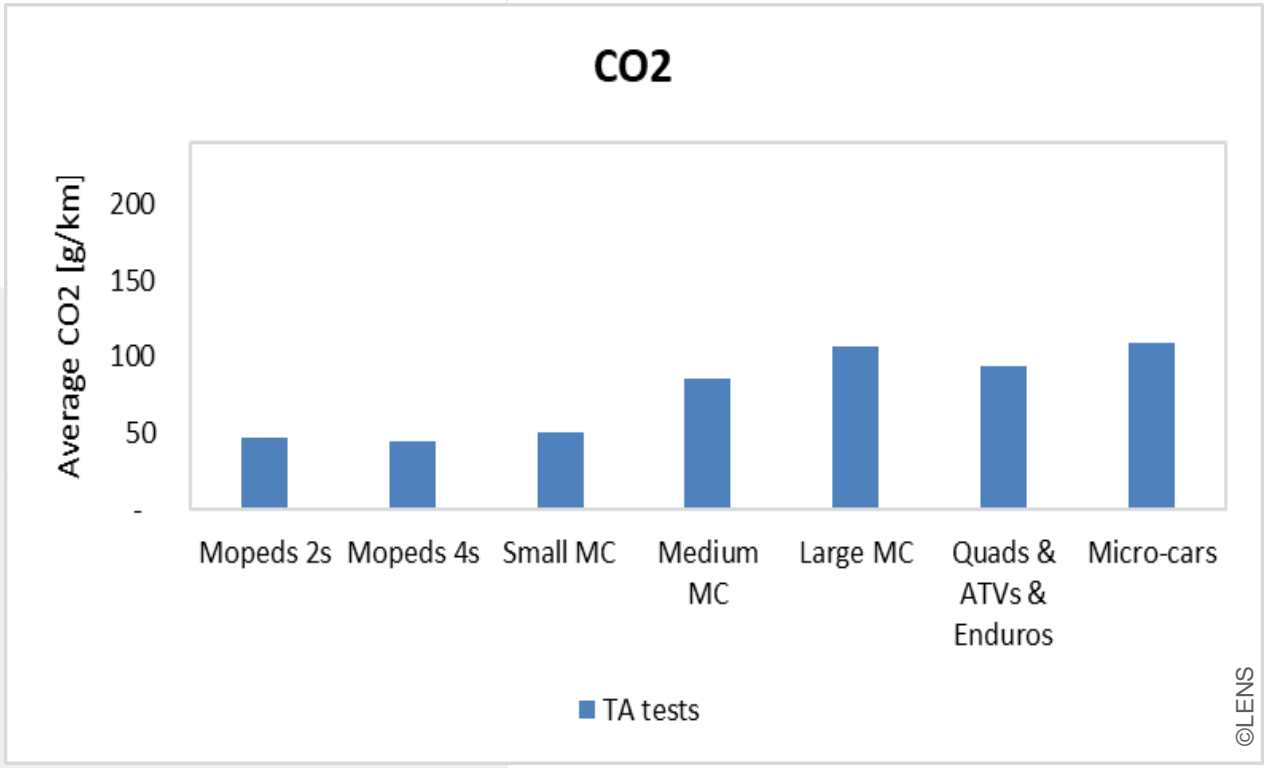
Results Type Approval Tests

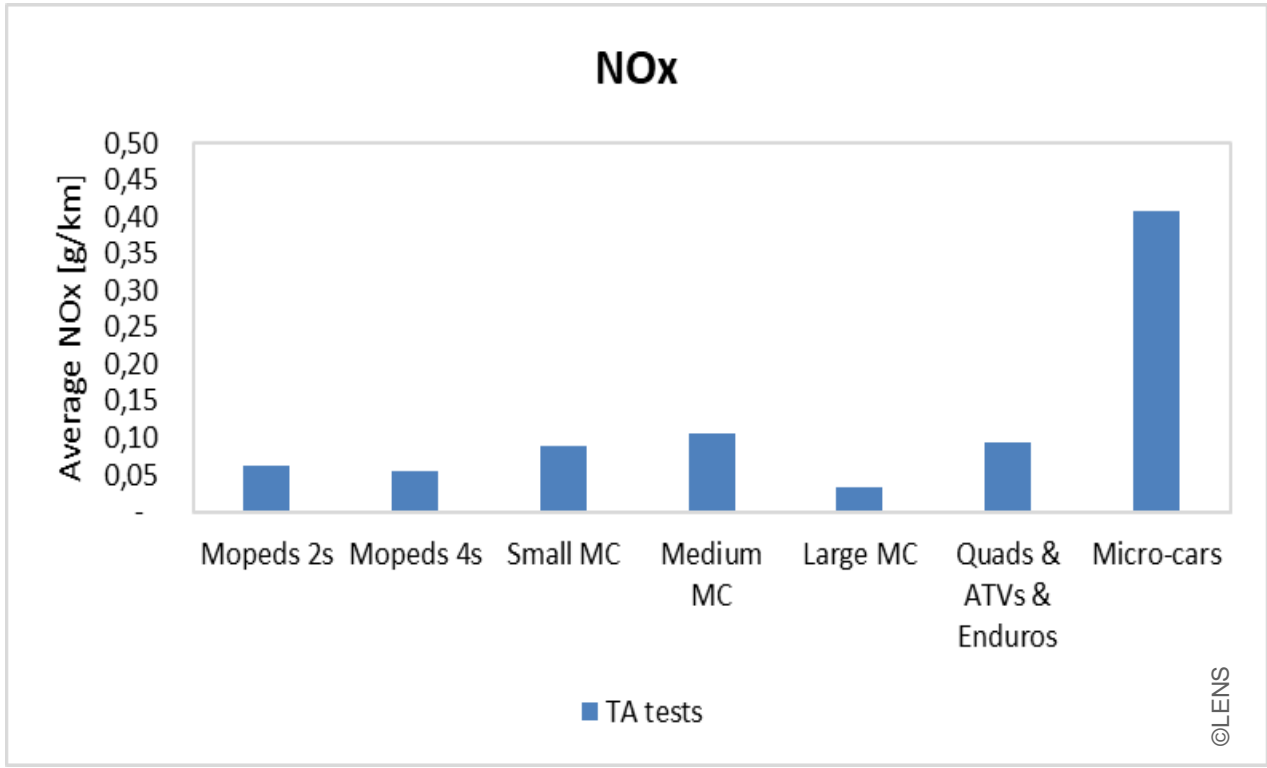
Measured Sample Emission Type Approval Test

- 2-Wheelers / Quads & ATV & Enduros / Micro-Cars
- Measured sample (+150 vehicles)
- Incl. obviously tampered vehicles
- Mix of emissions classes

Results Type Approval Tests

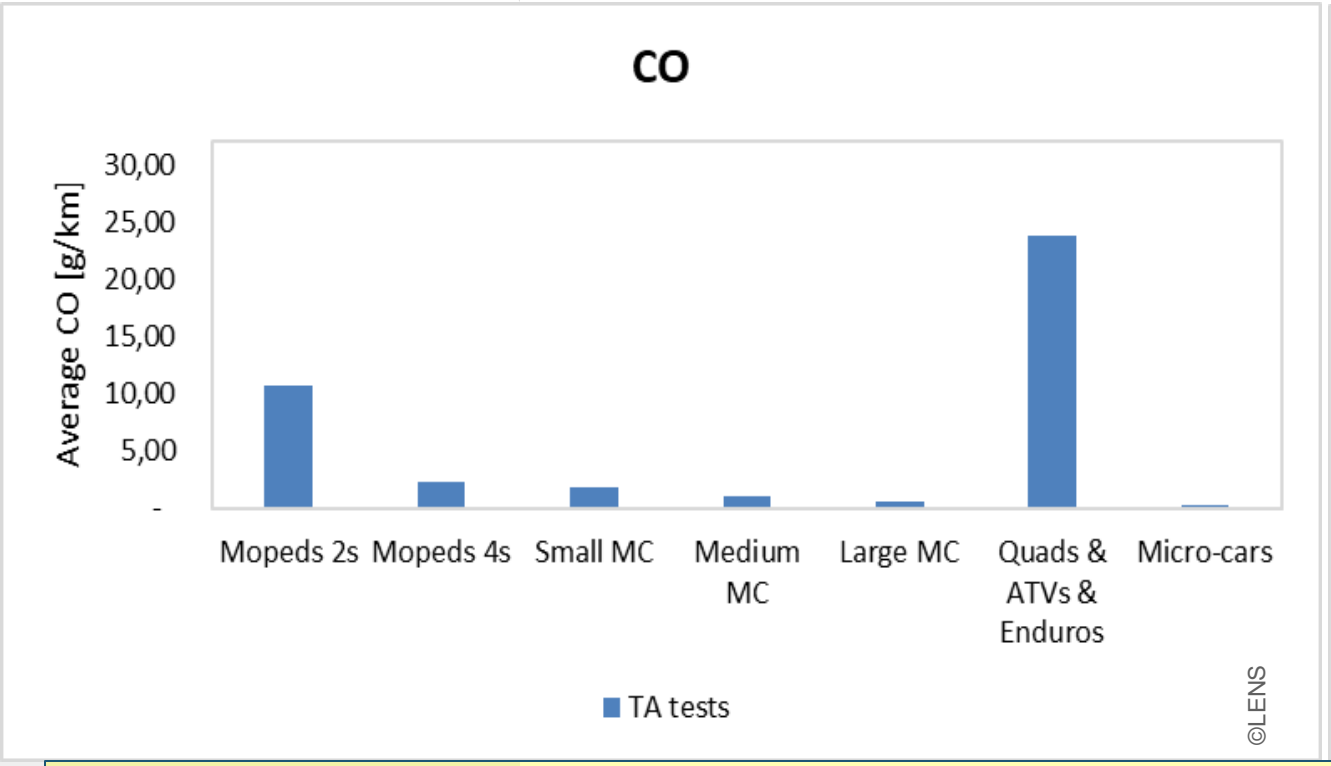
Measured sample TA emission regulated pollutants & CO2

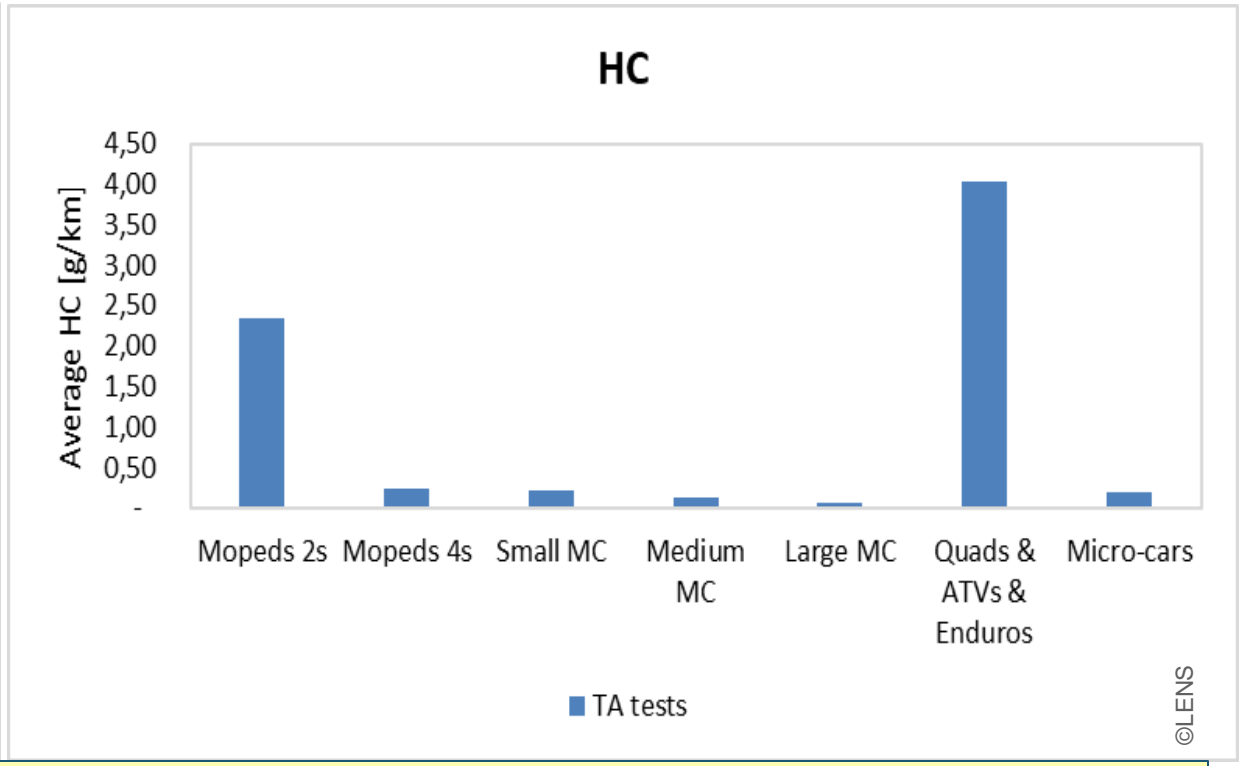




Results Type Approval Tests

Measured sample TA emission regulated pollutants & CO2





Different emission levels for different L-categories; outliners have big influence on average

LENS L-vehicles Emissions and Noise mitigation Solutions

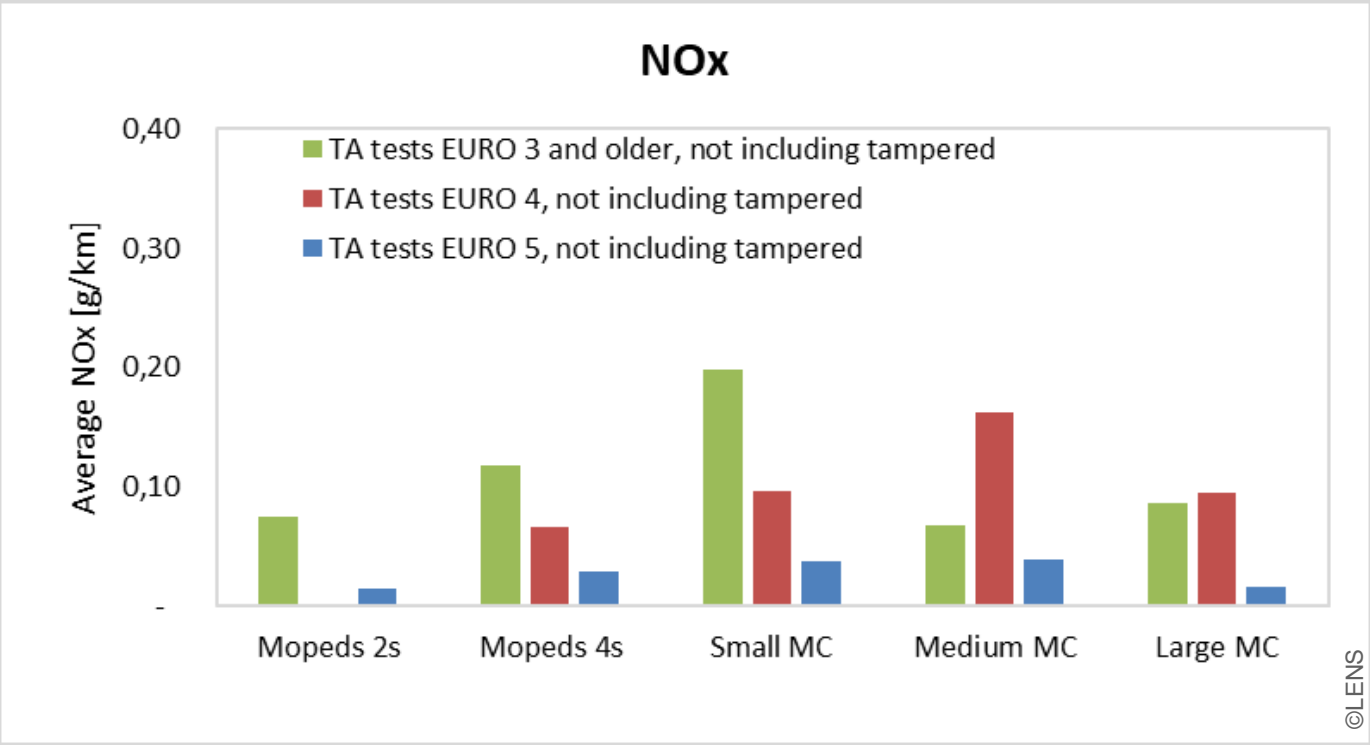
Results Type Approval Tests

Evolution emission with TA Euro standard

- 2-Wheelers
- Euro 5, Euro 4, Euro 3 and older vehicles
- Not obviously tampered vehicles

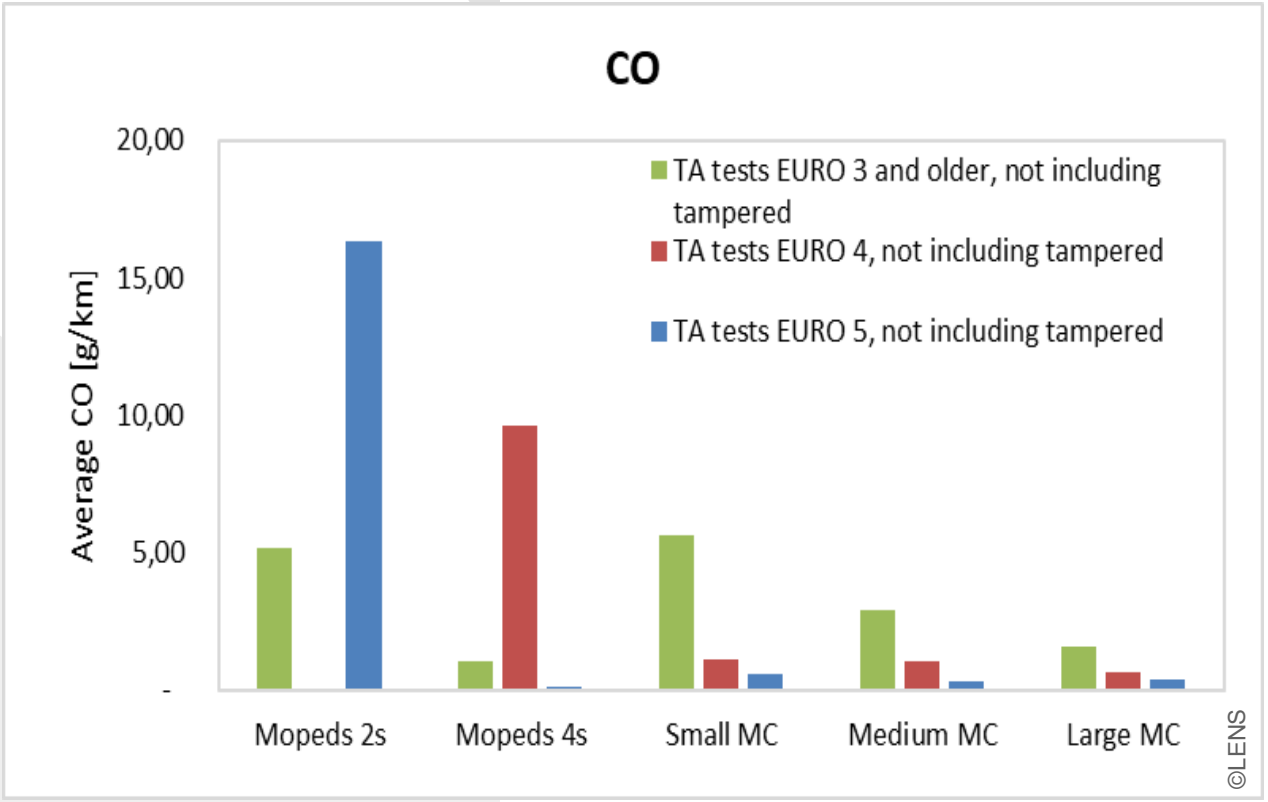
Results Type Approval Tests

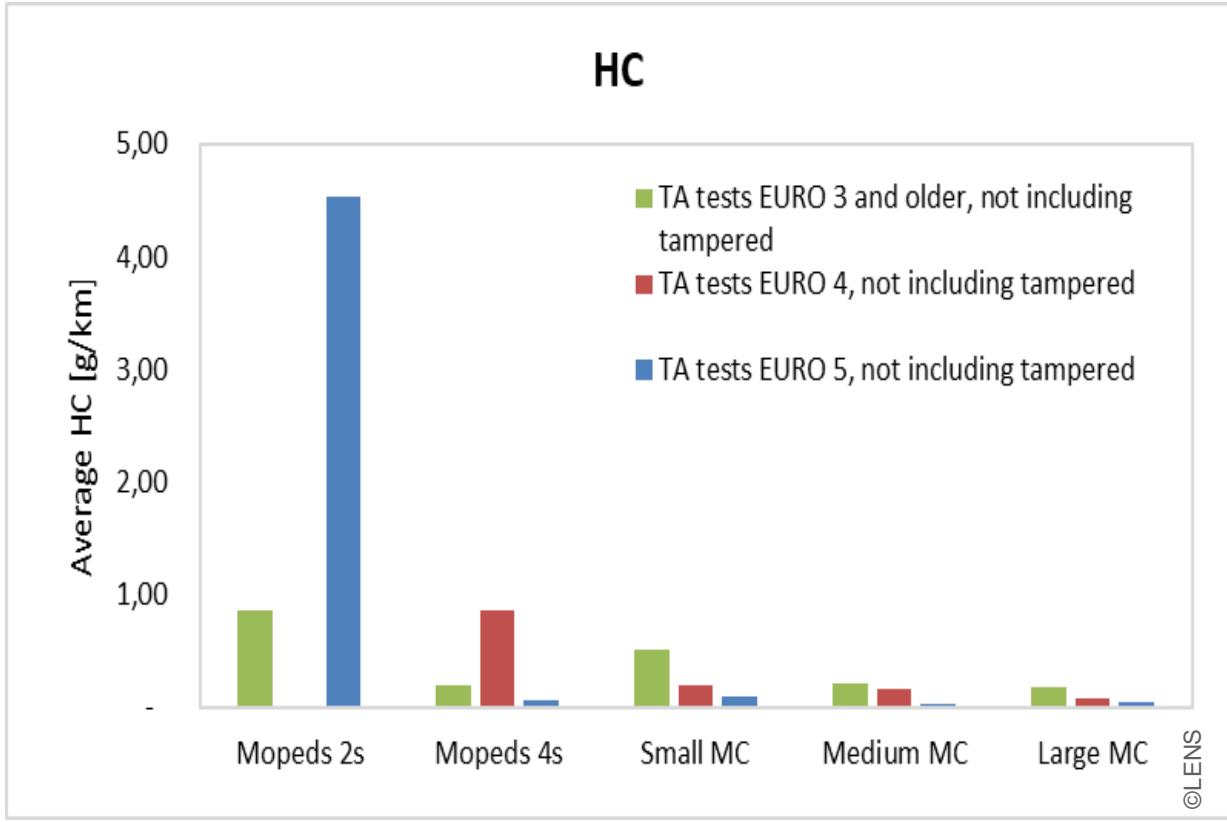
Emission evolution for TA Euro standard



Results Type Approval Tests

Emission evolution for TA Euro standard





Evolution of Euro standards reduced emission in type approval test

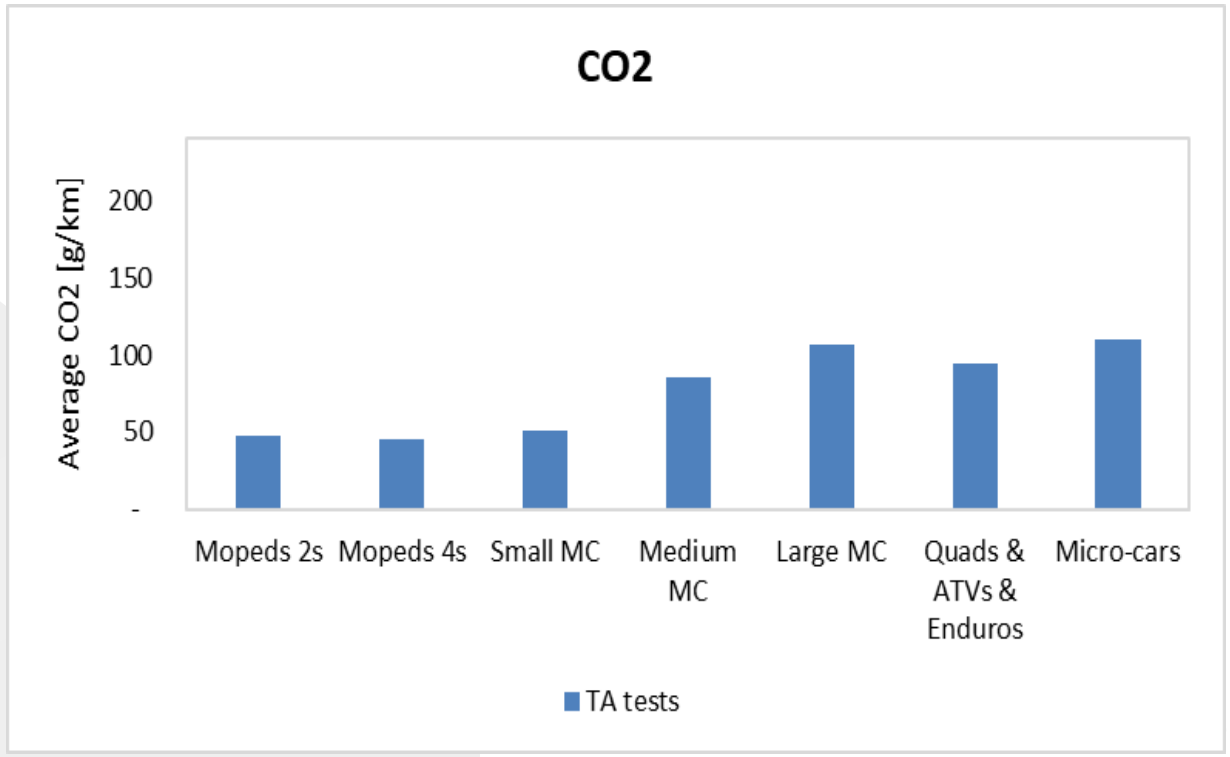
Results Type Approval Tests

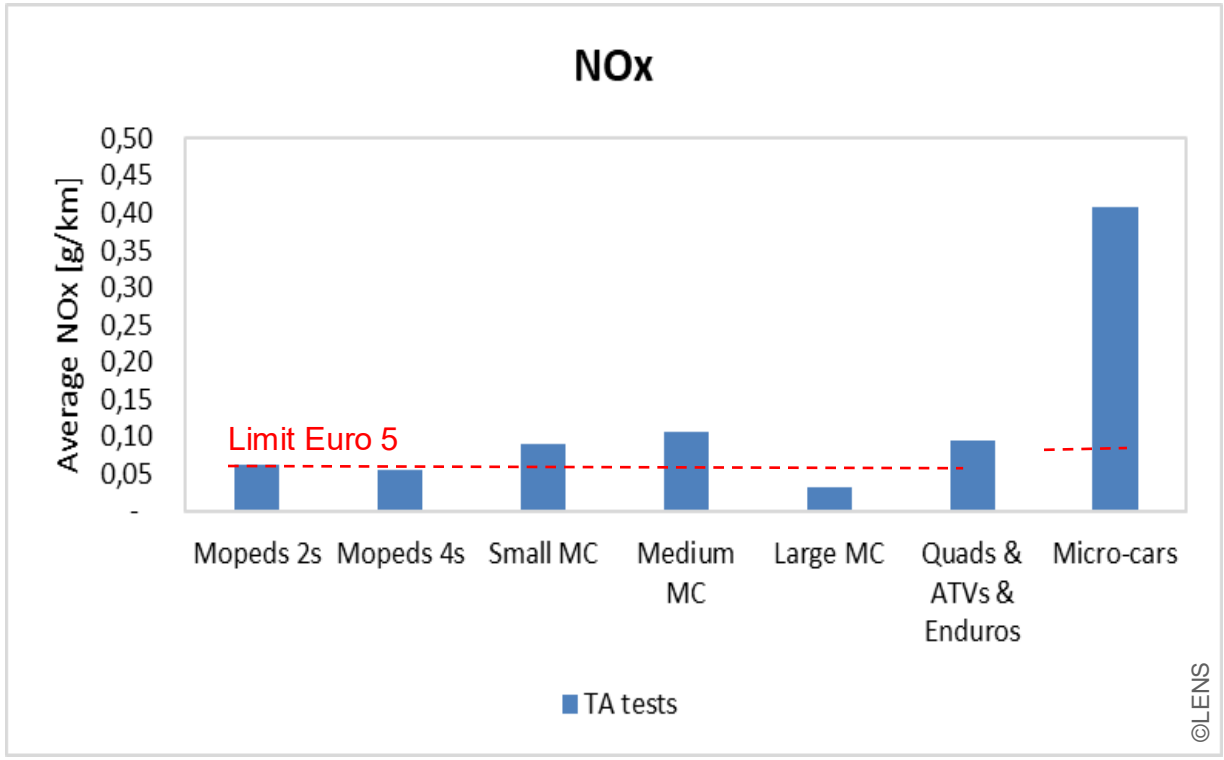
Type Approval Test Emission Euro 5

- 2-Wheelers / Quads & ATV & Enduros / Micro-Cars
- Euro 5 vehicles
- Euro 5 limits
- Incl. vehicles that are obviously tampered

Results Type Approval Tests

Euro 5 TA* emission regulated pollutants



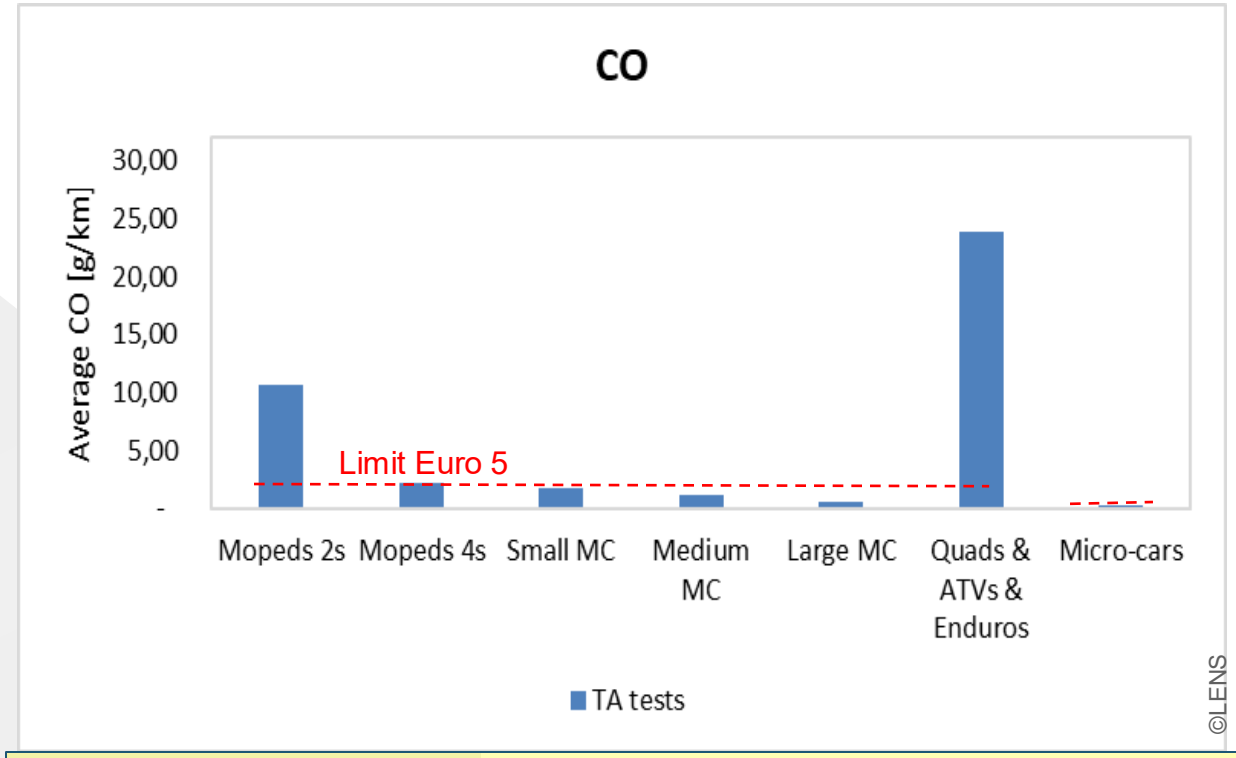


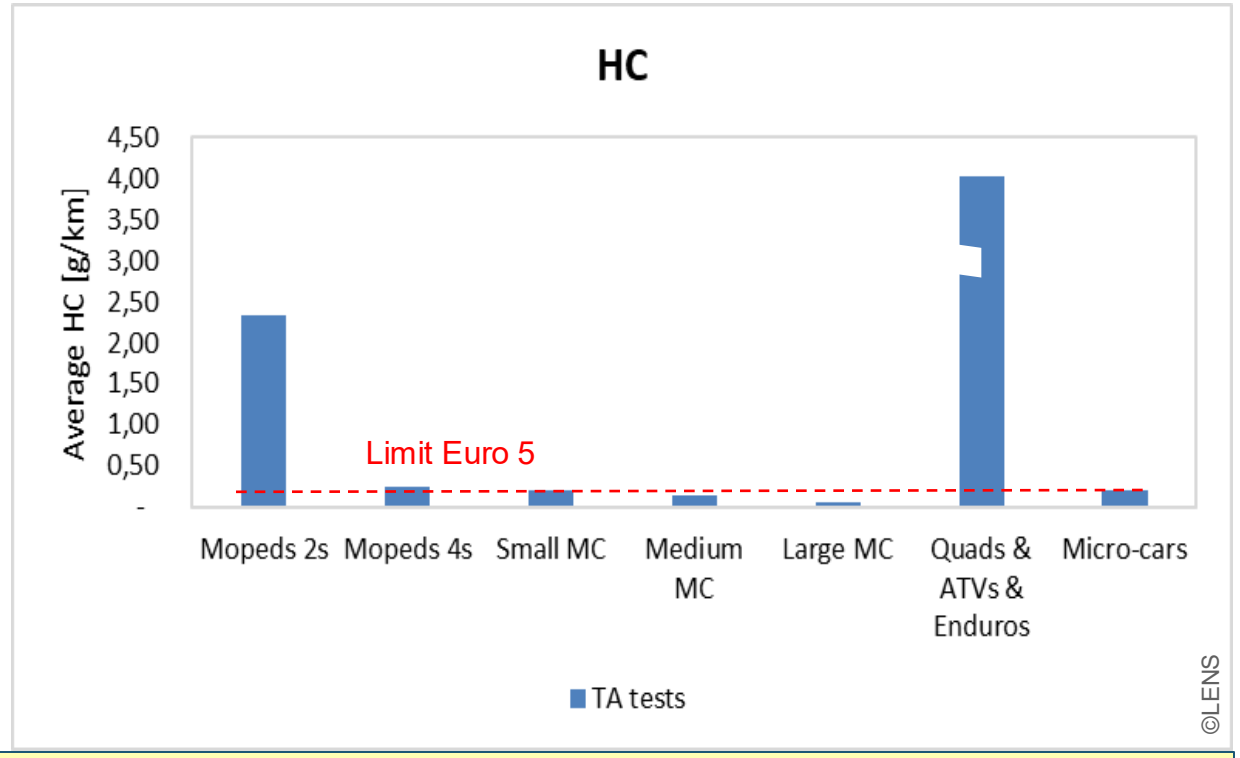
* incl .tampered vehicles

LENS L-vehicles Emissions and Noise mitigation Solutions

Results Type Approval Tests

Euro 5 TA* emission regulated pollutants





Majority of categories are within Euro 5 limits, except for Quads, ATV & 2S-Mopeds

L-vehicles Emissions and Noise mitigation Solutions

* incl .tampered vehicles

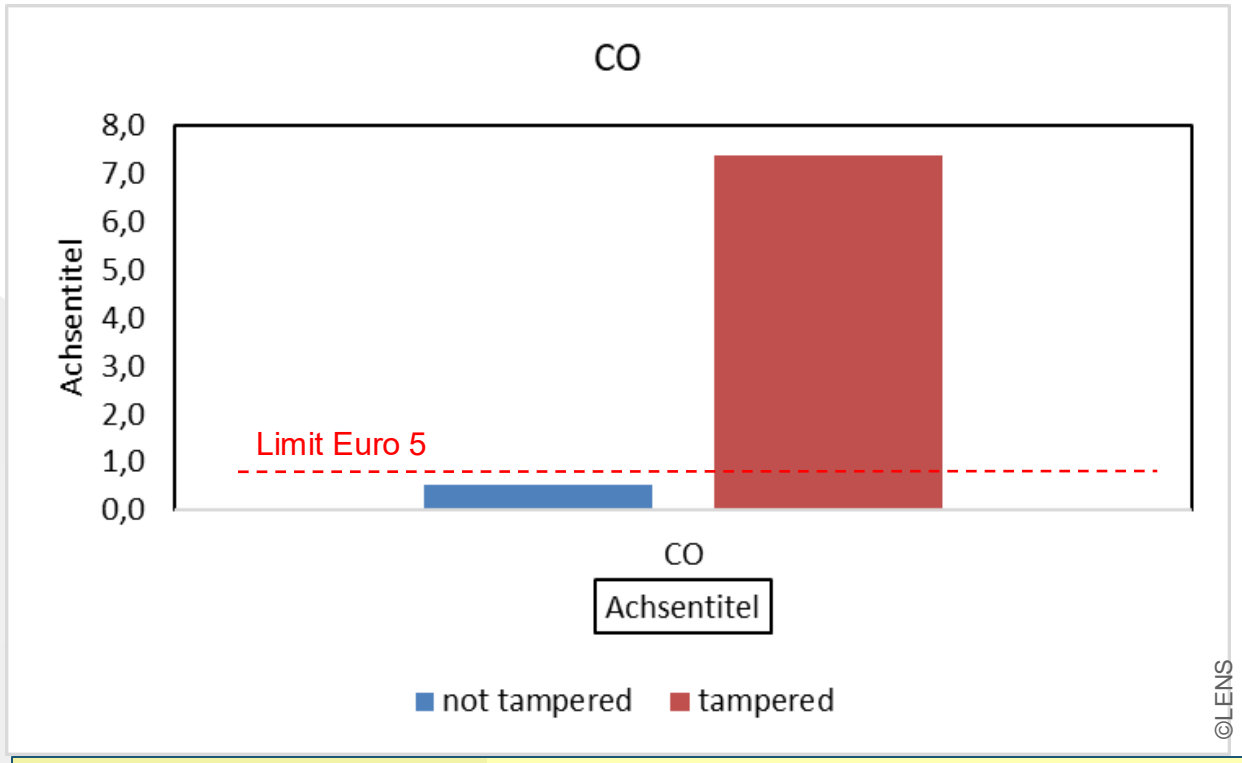
Results Type Approval Tests

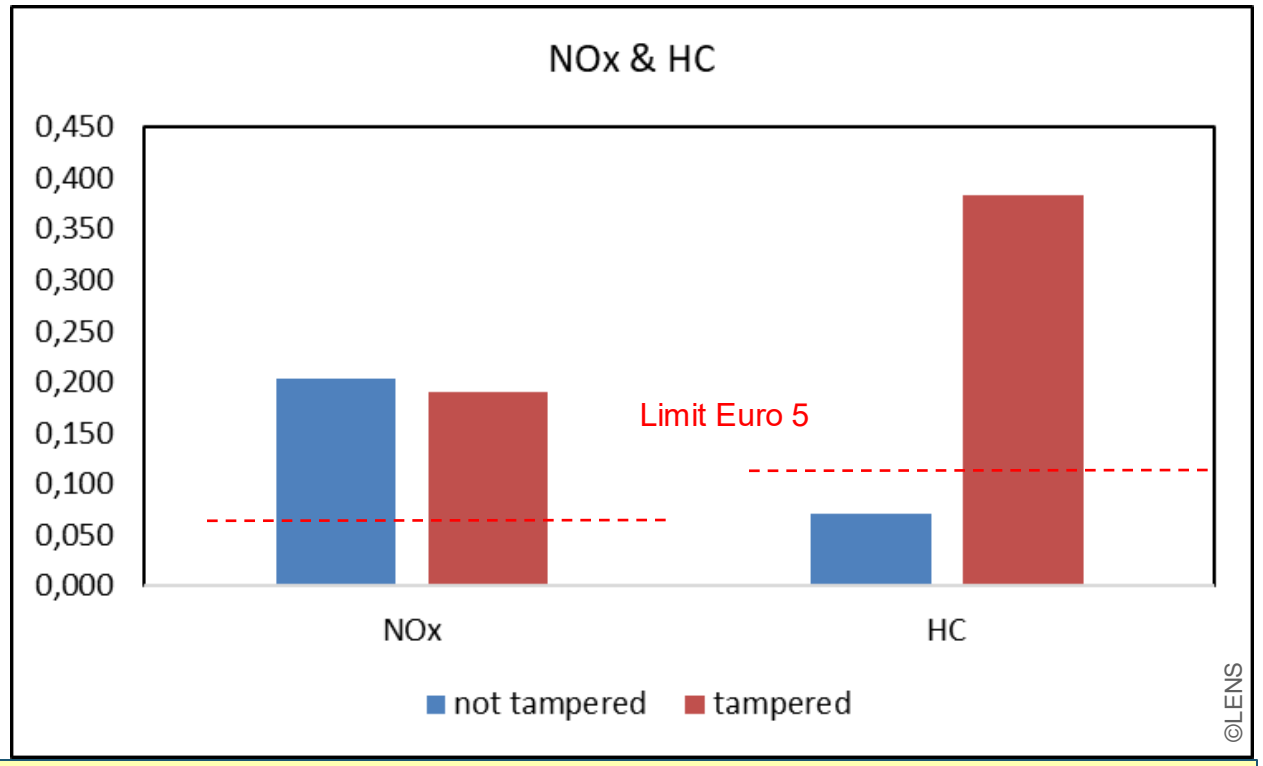
Example for influence of tampering on exhaust emission

- 2-Wheeler
- Euro 5
- WMTC
- Exhaust & fuel map modification, vs non-tampered vehicle

Results Type Approval Tests

Euro 5 TA comparison non-tampered / tampered





Tampering has a big influence on emission

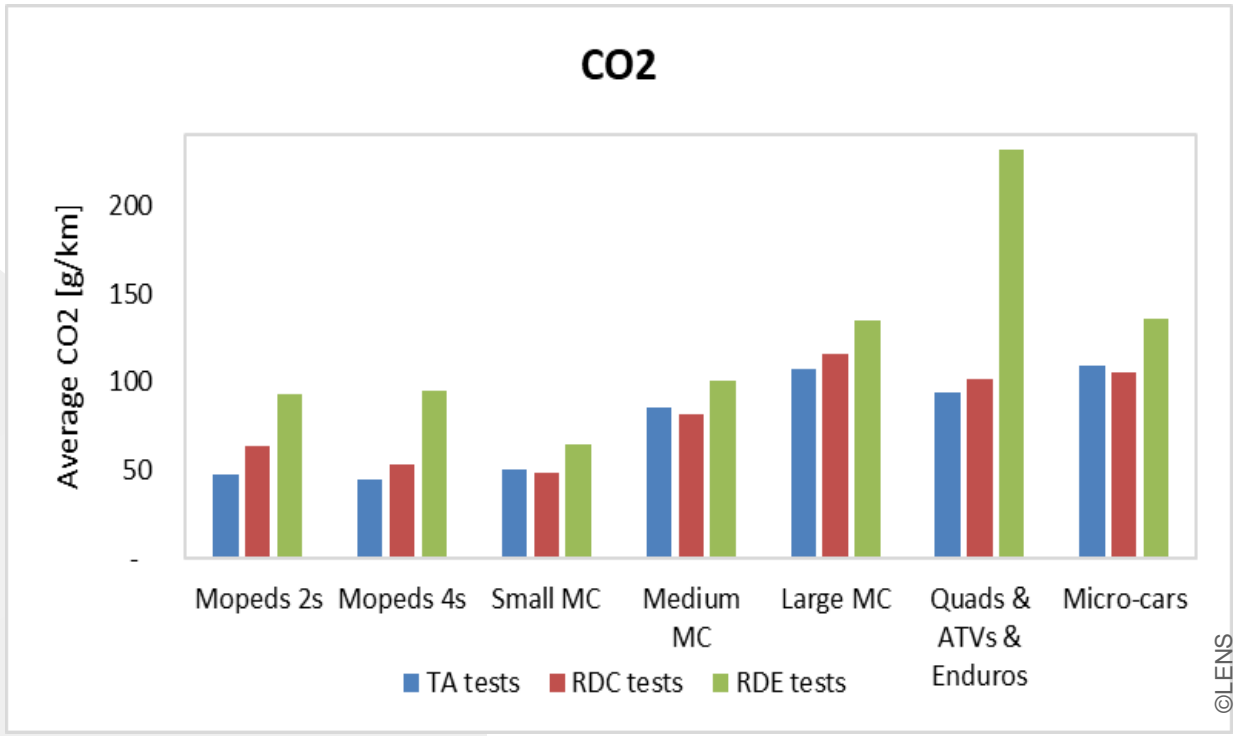
Real World Emission

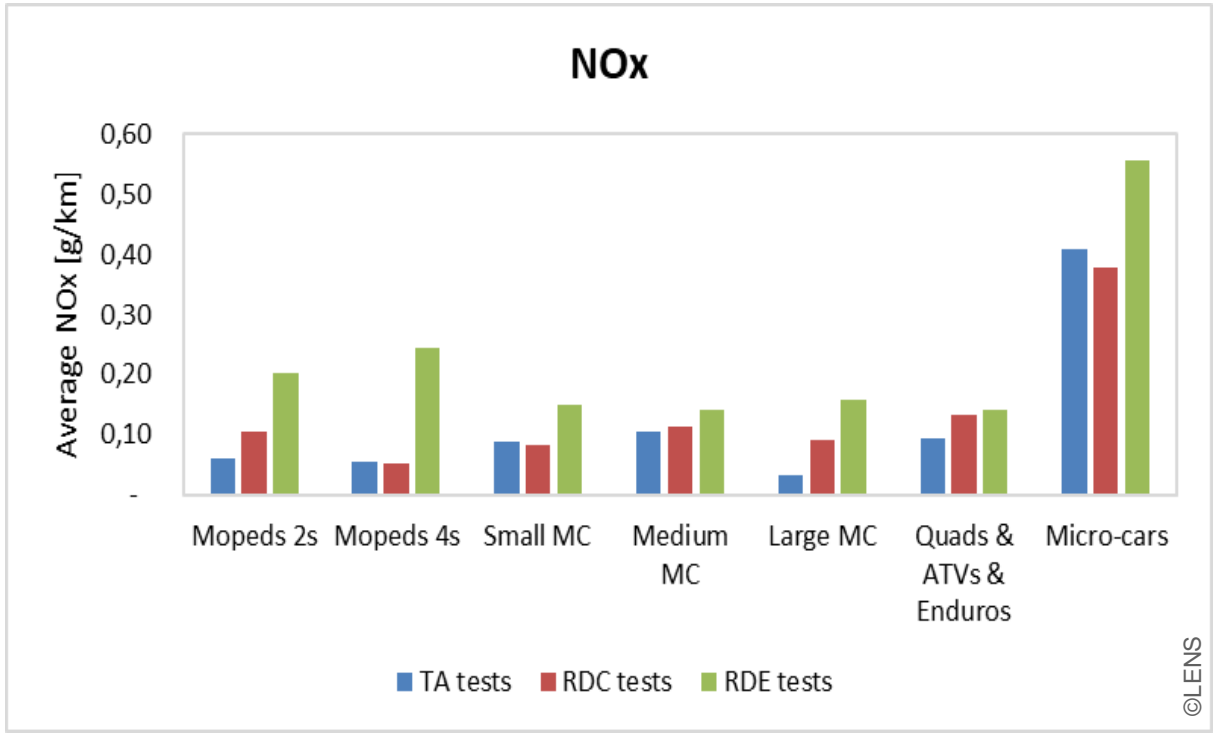
Real Drive Emission & Emission from Real Drive cycles

- 2-Wheelers
- Euro 5
- Incl. tampered vehicles

Real World Emission

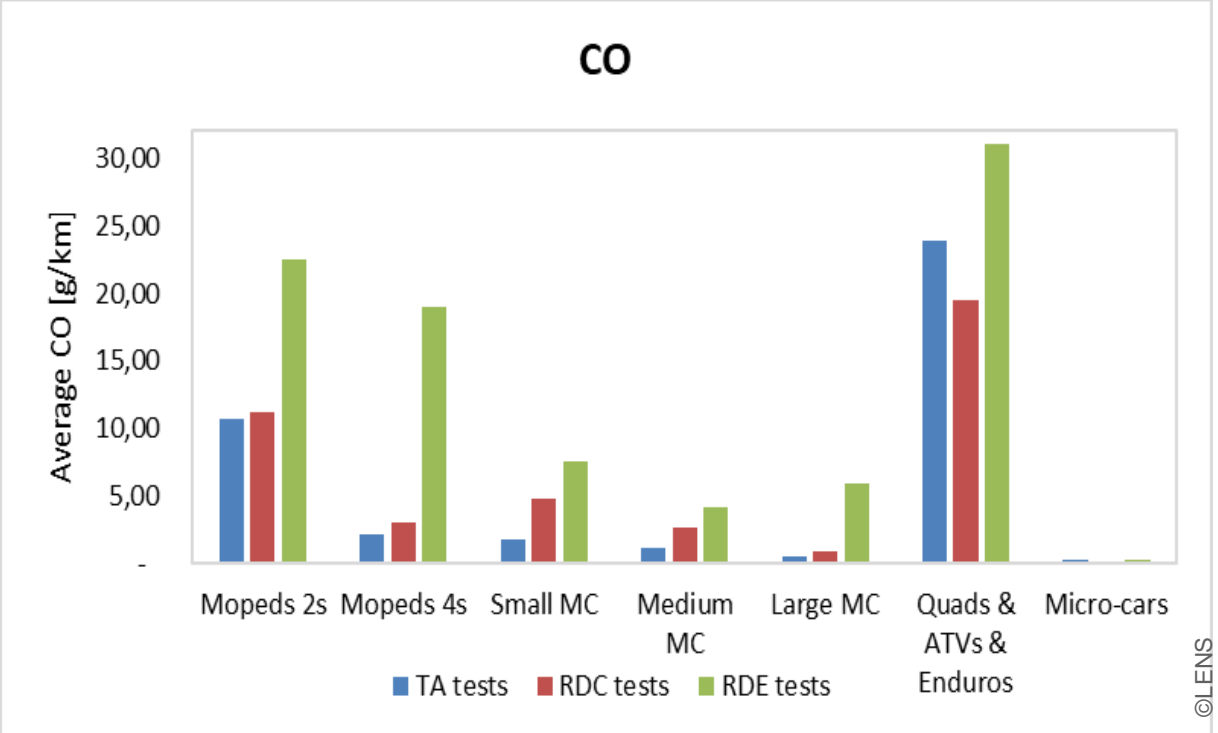
Emissions & CO from Real Drive & Real Drive Cycles

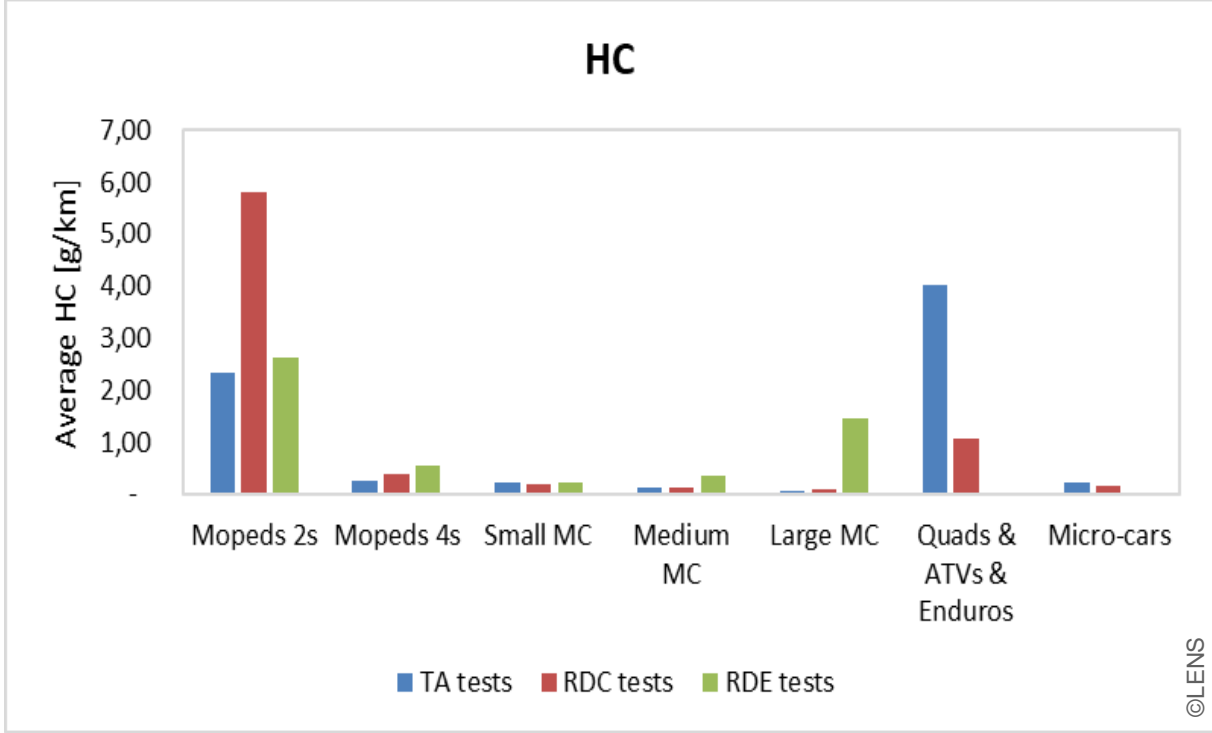




Real World Emission

Emissions & CO from Real Drive & Real Drive Cycles





Emission are higher in Real drive scenarios than in TA

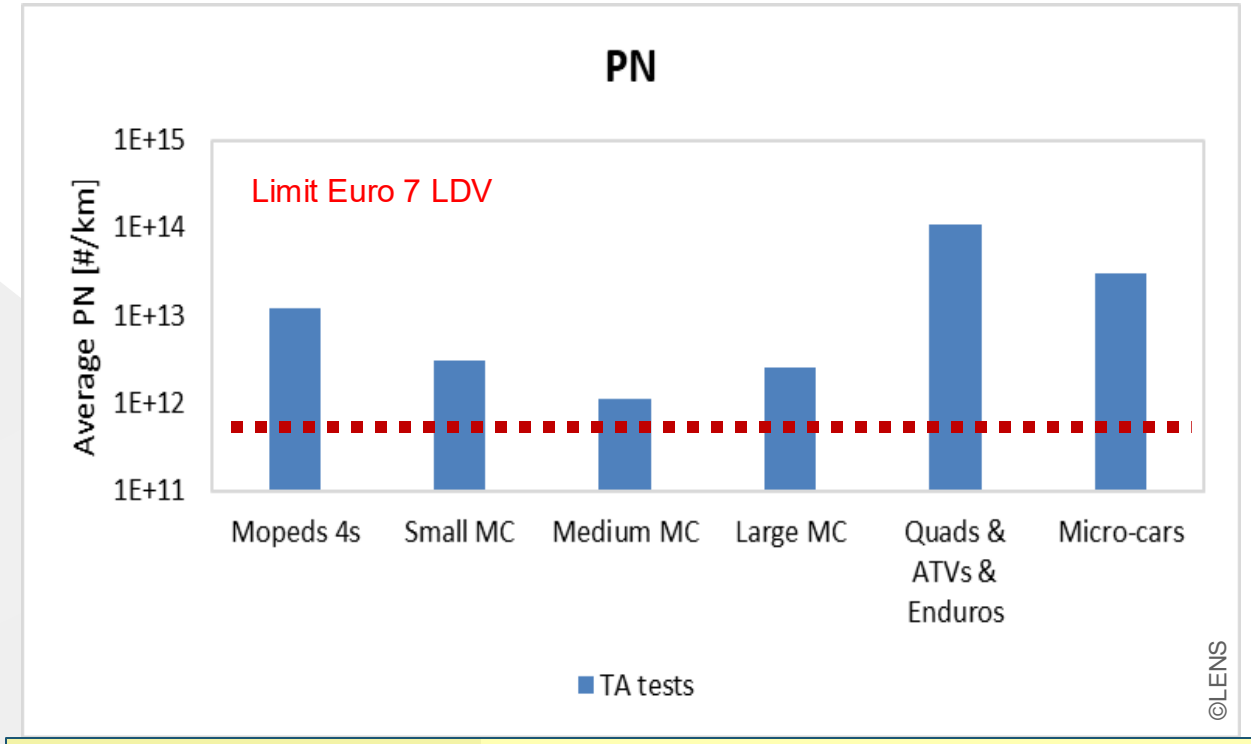
Non-regulated Emission Components

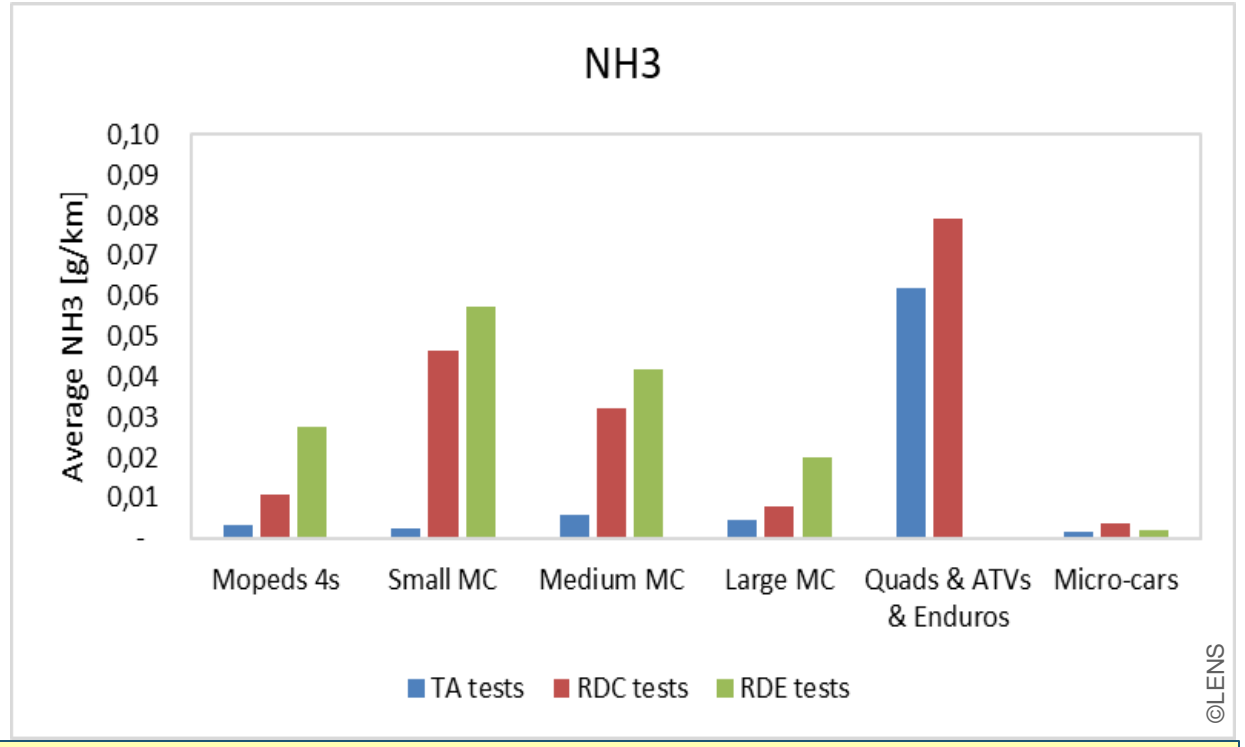
Non-regulated Emission in TA-test, RDC & RDE

- 2-Wheelers / Quads & ATV & Enduros / Micro-Cars
- Euro 5
- Incl. Tampered vehicles

Non-regulated Emission Components

Non-regulated emission*





PN emission and NH3 reach relevant levels

LENS L-vehicles Emissions and Noise mitigation Solutions

* PN10 mainly

Conclusions

Exhaust gas emission measurement

- Only selected commercially available PEMS equipment suitable for bigger motorcycles
- Equipment with restricted significance possible for smaller vehicles. Further development and commercialisation necessary.
- Crux: assessment of the exhaust mass flow, especially for low cylinder number
- Lab measurements with real world driving traces possible for lower power demands → smaller vehicles

Conclusions

Fleet emission I

- Type approval vs. On-road measurement
  - Difference between TA emission and on-road emission levels
  - Influence of driving style
- Type approval measurements
  - Average fleet emission well below the limits
  - 2-Stroke powered high, L7 cat in almost all cases type approved as T-category (tractor)

Conclusions

Fleet emission II

- On-road emission
  - L-vehicles fleet average on-road emissions seem to be reduced in the same pace as the Euro emission limits
  - Big difference between high-emitters and low-emitters
  - Big challenge for roadside instruments to measure LV pollutant emissions

TA Assessment

Observed weaknesses of the current TA method

- No coverage of the whole operating area
- Lower driving dynamics as possible and used by higher powered motorcycles
- Load factors are not "real-life" driving resistance factors
- Limit to rather low acceleration and speed due to wheel slip, not representative for real world driving

TA Assessment

Suggestions to cover the differences between real world emission and type approval tests

- Driving Cycle adaption for lab tests
  - Modified road load factors
  - No mandatory gear regulation
  - Adaption of WMTC cycles
  - Real Drive cycles
- On-Road Real Drive Emission RDE

Thank you for your attention!

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