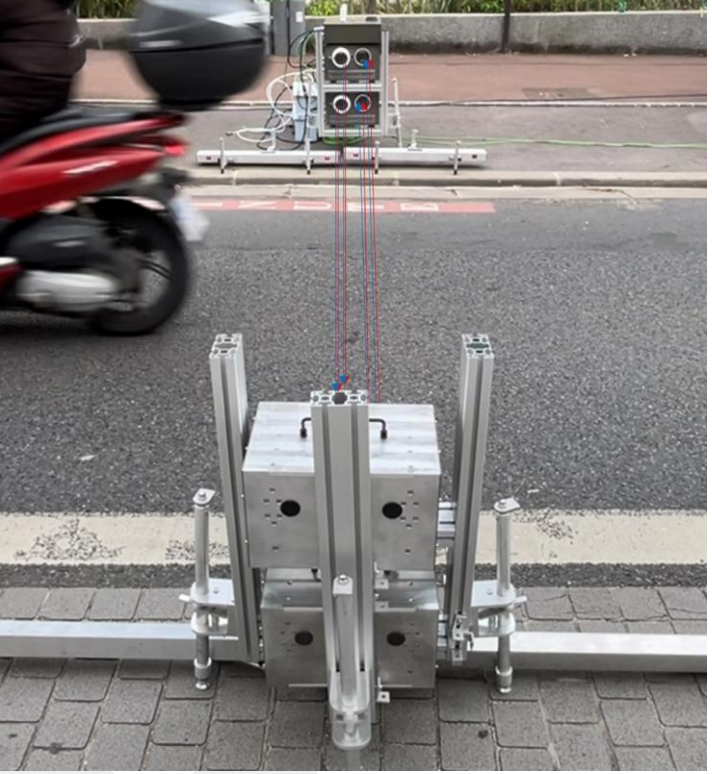
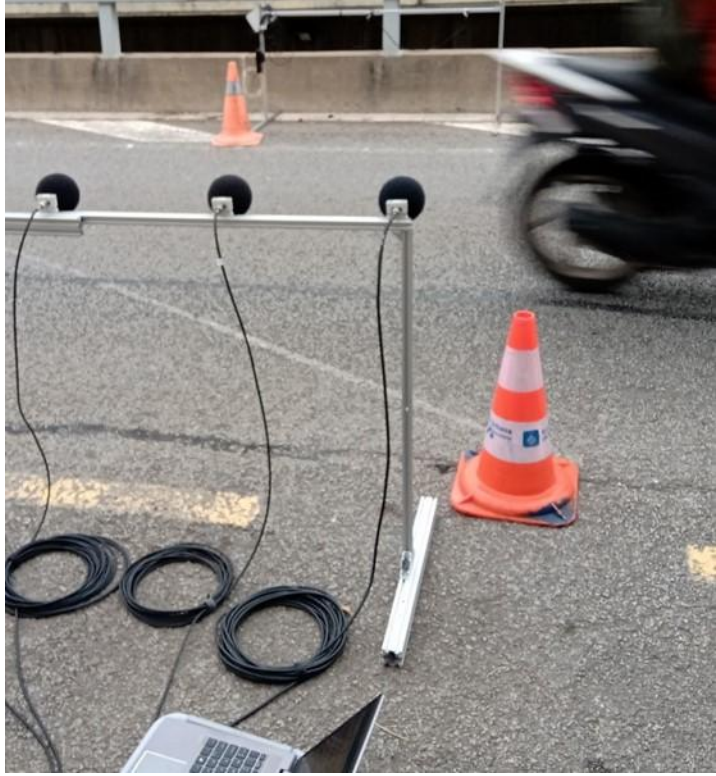




L-vehicle in-field surveys

Åke Sjödin, IVL Swedish Environmental Research Institute
Hervé Denayer, KU Leuven

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

L-vehicles Emissions and Noise mitigation Solutions

Overview

Three city measurement campaigns in 2024

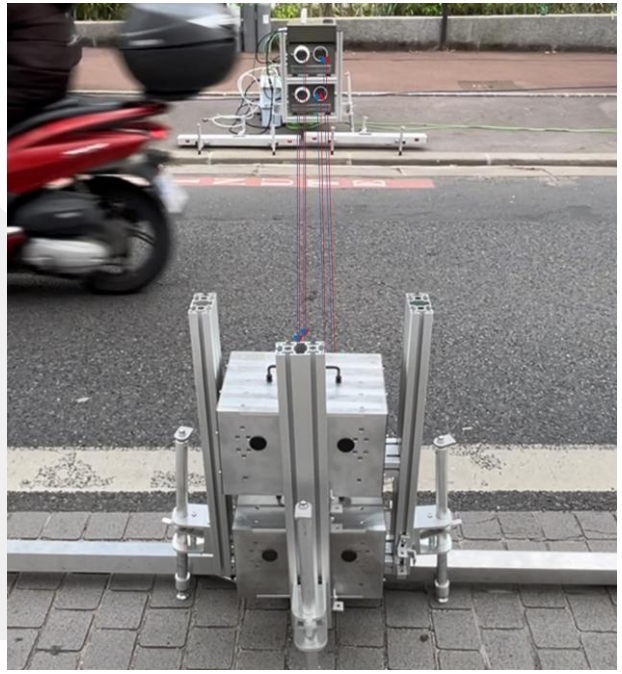
- Leuven (May)
  - ≈300 roadside LV measurements
  - 165 LVs inspected at the roadside

- Paris region - Rueil Malmaison & Dampierre-en-Yvelines (September)
  - ≈900 roadside LV measurements
  - No roadside inspections

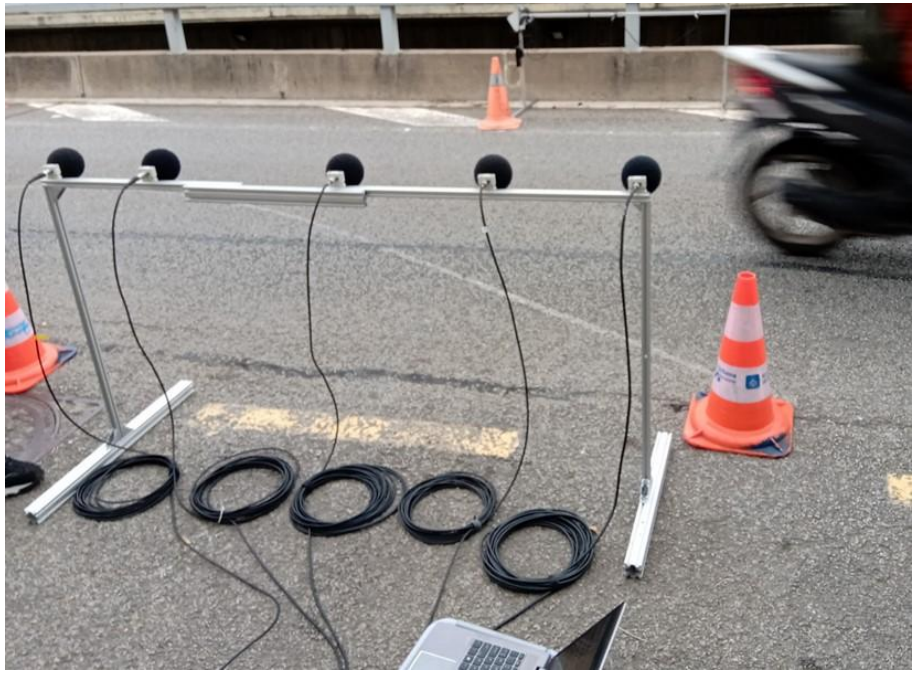
- Barcelona (October)
  - ≈1100 LV roadside measurements
  - 95 LVs inspected at the roadside

Measurement instruments

- All emission instruments measure **concentrations of pollutants and CO_2 in the exhaust plume** immediately after a vehicle has passed
- The measured **concentration ratios of pollutant to CO_2** is used to derive instantaneous **emission factors in** the unit **g/kg fuel burnt**

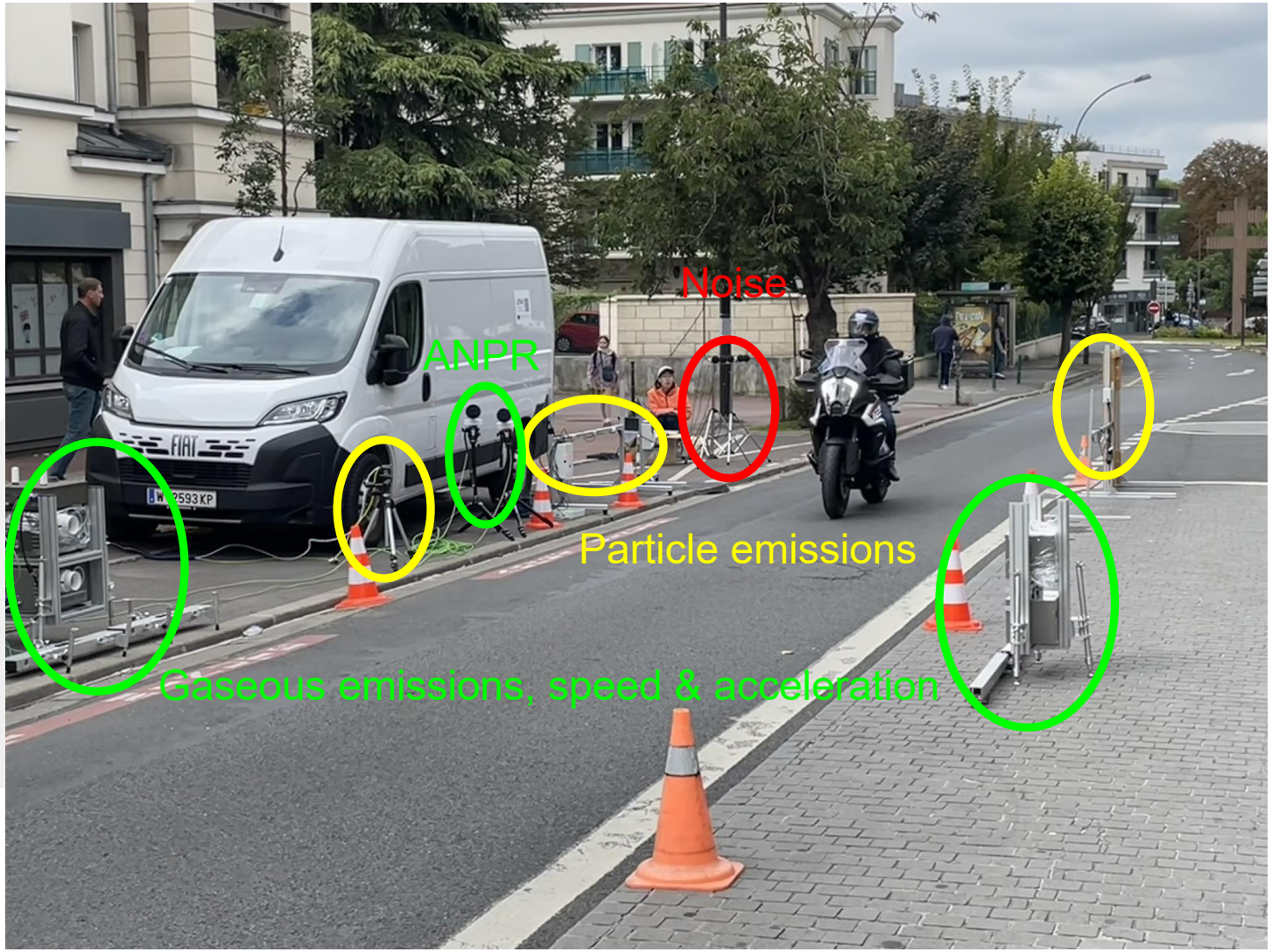


KU Leuven microphone array noise measurement system



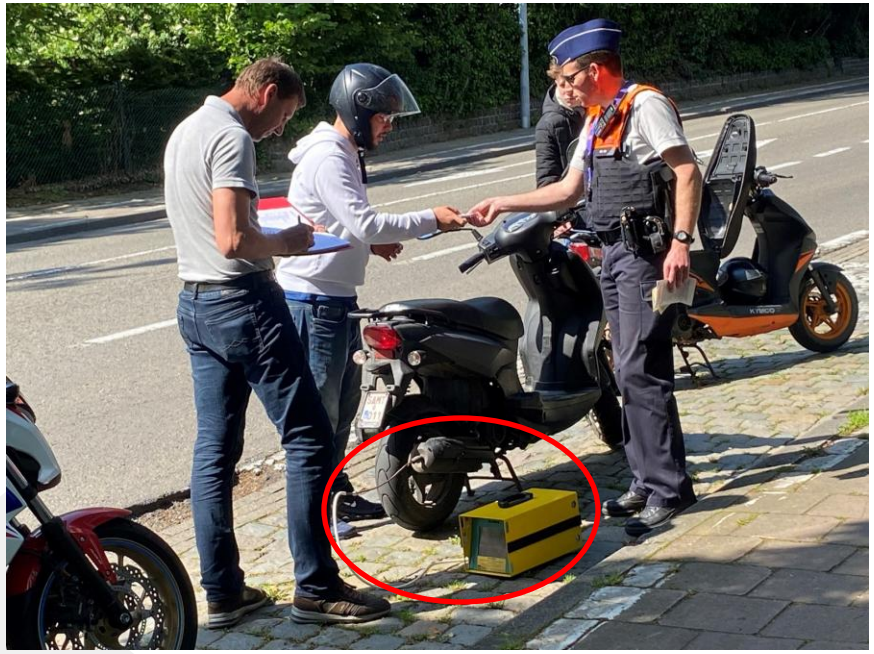
L-vehicles Emissions and Noise mitigation Solutions

Typical measurement set-up



L-vehicles Emissions and Noise mitigation Solutions

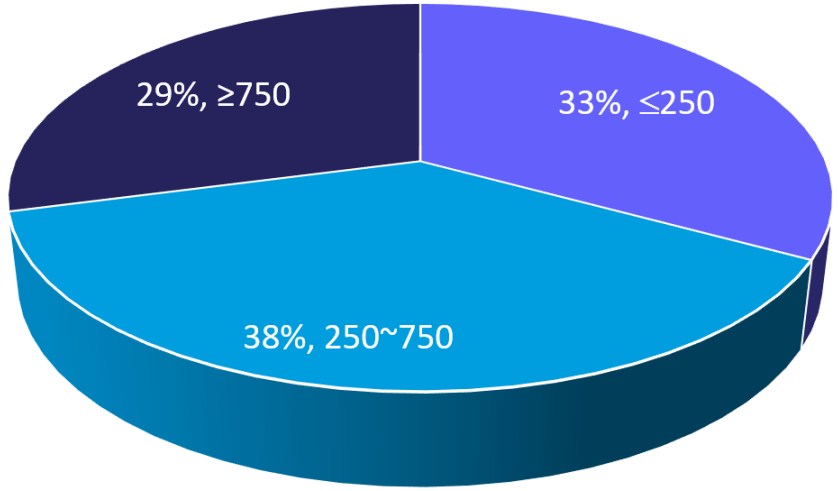
Roadside inspections in Leuven and Barcelona



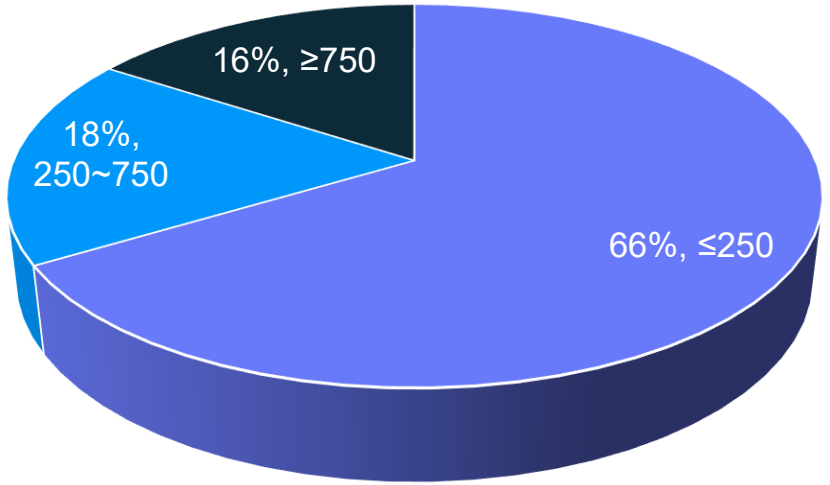
- Check of vehicle documents
- CO and HC idle emission test
- Stationary noise test
- Visual inspection

Distribution of measured LVs by **engine size**

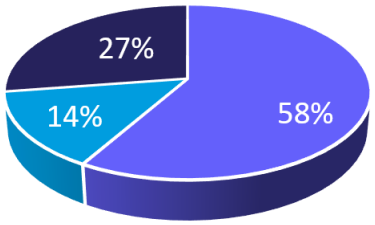
On-road measurements (Opus)



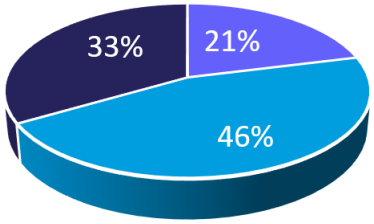
Roadside inspections



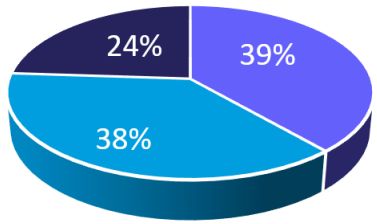
a) Leuven



b) Paris



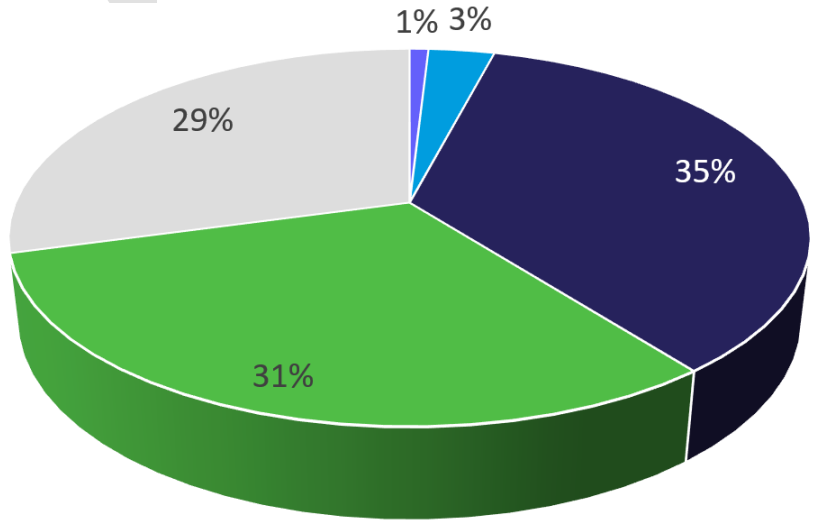
c) Barcelona



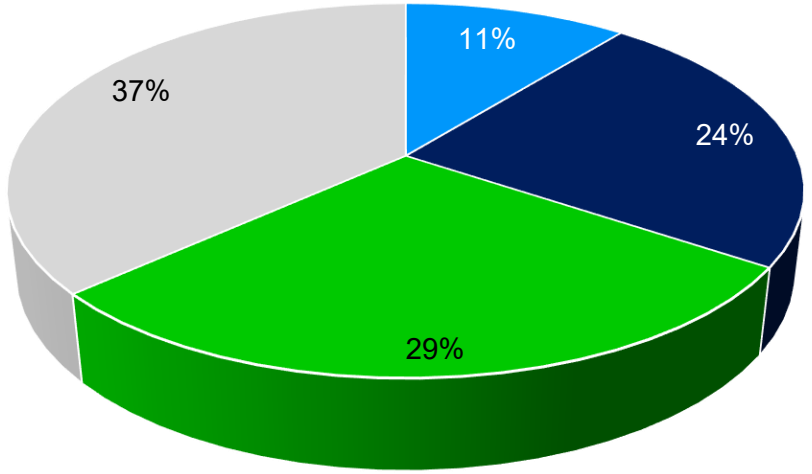
L-vehicles Emissions and Noise mitigation Solutions

Distribution of measured LVs by **Euro class**

On-road measurements (Opus)

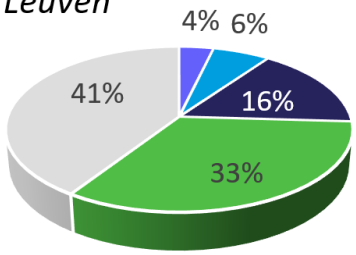


Roadside inspections

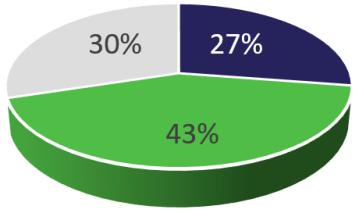


Euro 1 Euro 2 Euro 3 Euro 4 Euro 5

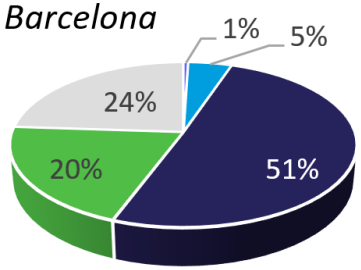
a) Leuven



b) Paris



c) Barcelona

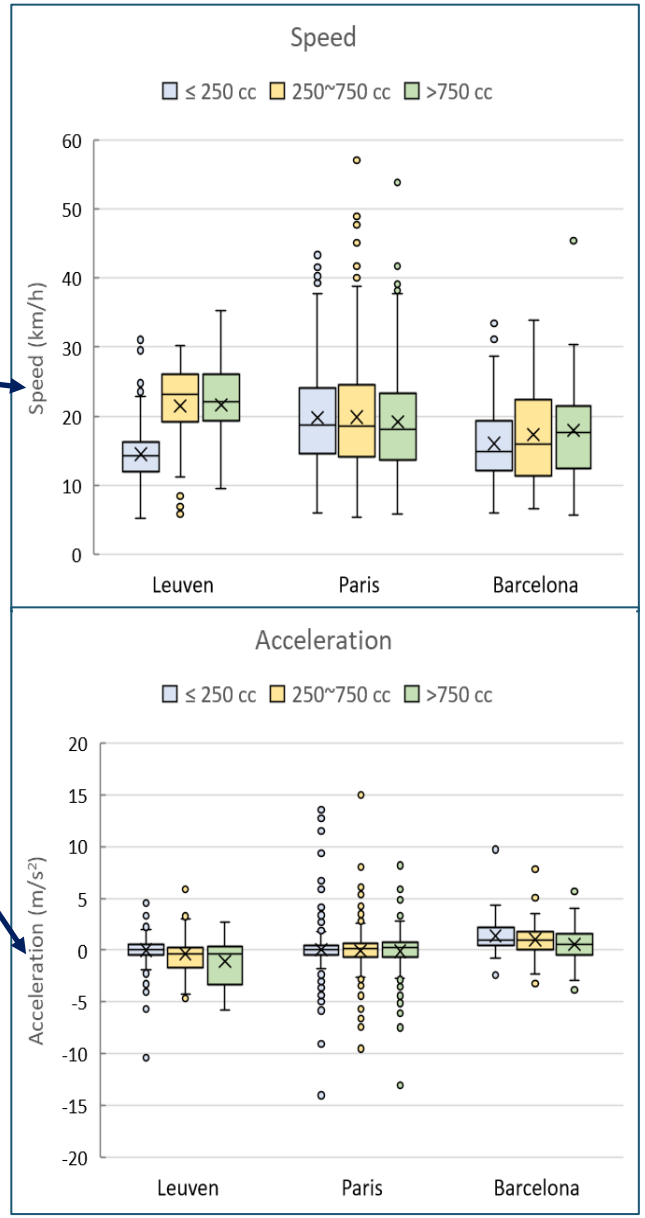


LENS L-vehicles Emissions and Noise mitigation Solutions

Driving conditions

- Average **speed** was around 20 km/h (10-40 km/h; typical urban driving)
- Mostly constant speeds or slight **acceleration** (although decelerations also occurred)
- **Road grades** were in the range **1-3%**
- Two main types of **driving behavior** were observed:
  - Drivers who's driving was not affected by the instruments along the roadside (most common)
  - Drivers that reacted to the instruments (or were forced in congestion situations) and slowed down upon approaching and accelerated after having passed the instruments

→ Mostly moderate engine loads

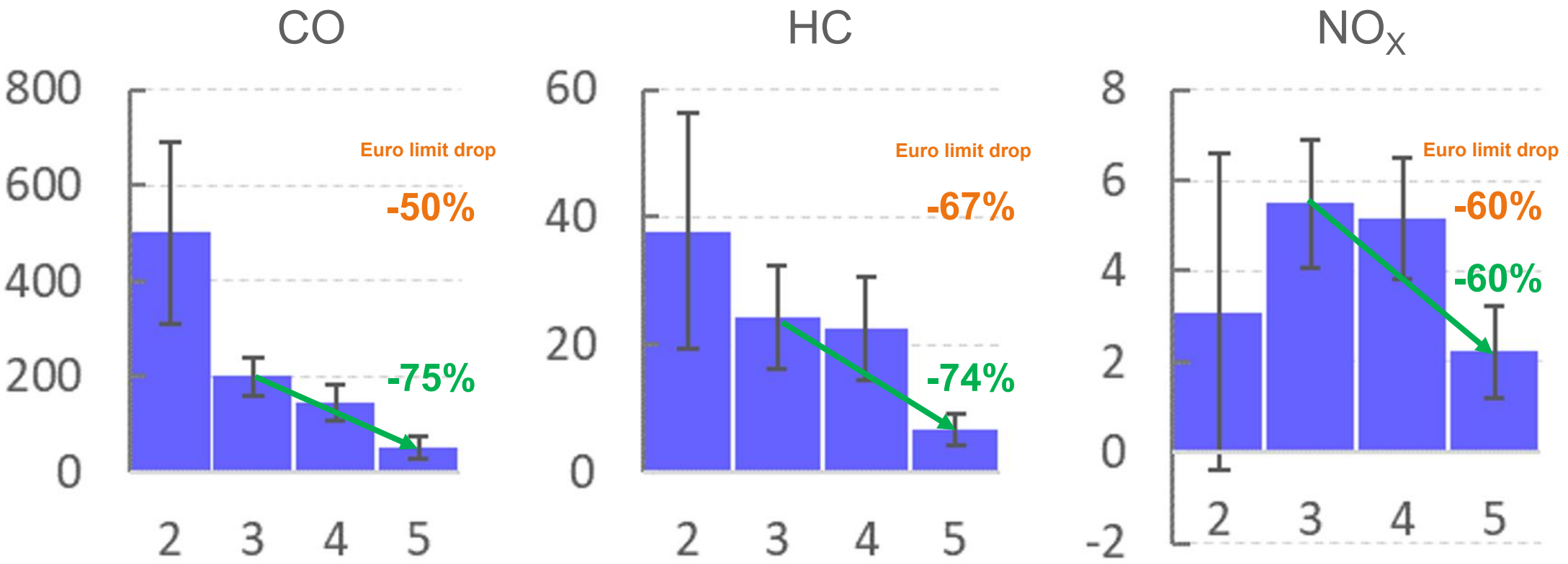


LENS L-vehicles Emissions and Noise mitigation Solutions

Roadside emission measurements results

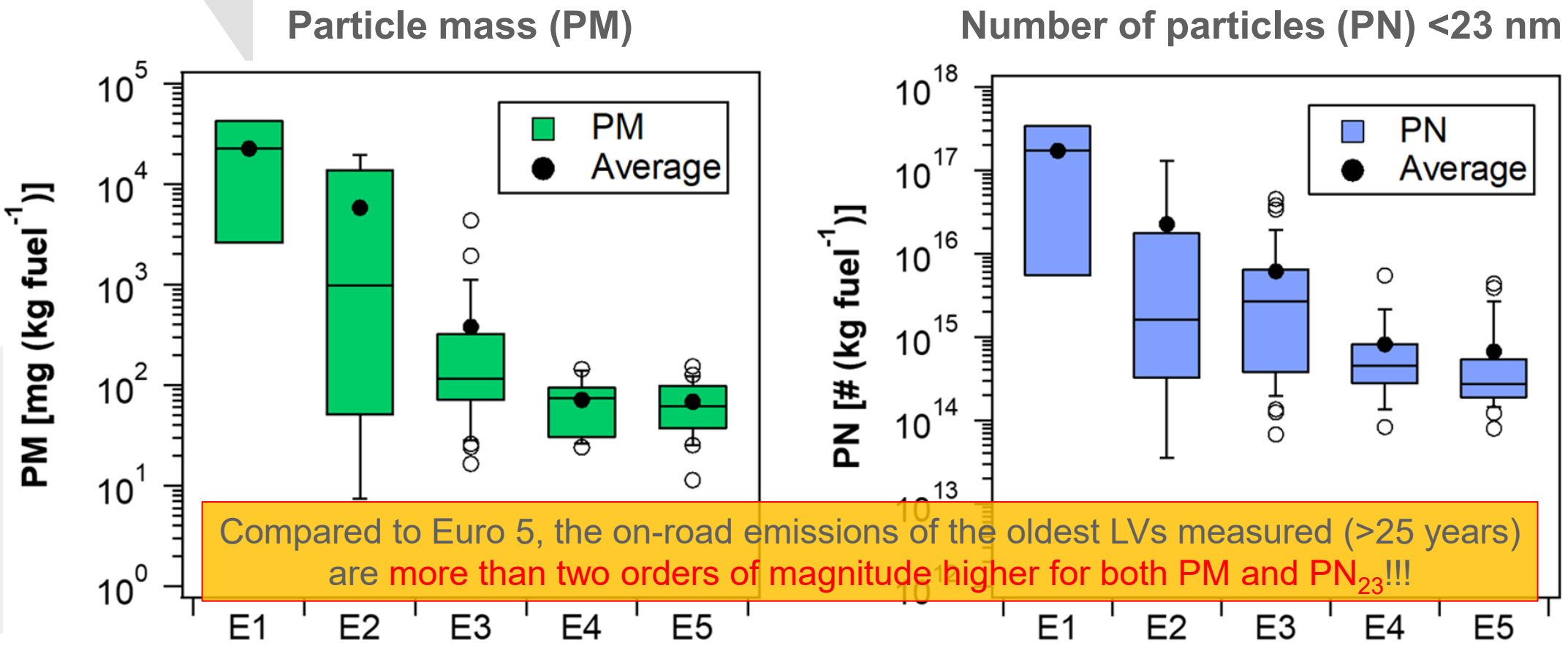
Newer LVs have much lower on-road emissions than older ones (1)

Average emissions (in g/kg fuel) by Euro class:



LENS L-vehicles Emissions and Noise mitigation Solutions

Newer LVs have much lower on-road emissions than older ones (2)



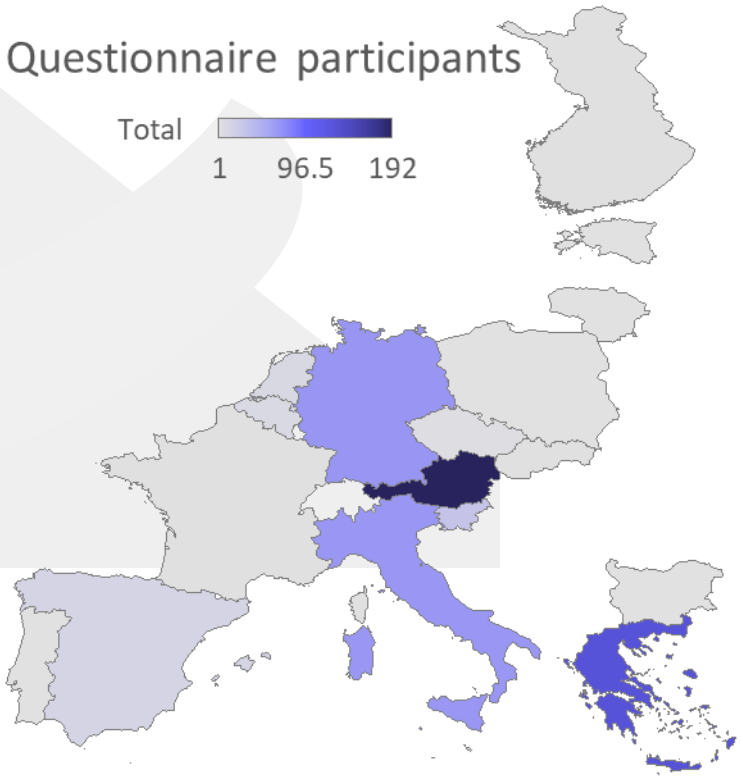
Compared to Euro 5, the on-road emissions of the oldest LVs measured (>25 years) are more than two orders of magnitude higher for both PM and PN_{23}!!!

LENS L-vehicles Emissions and Noise mitigation Solutions

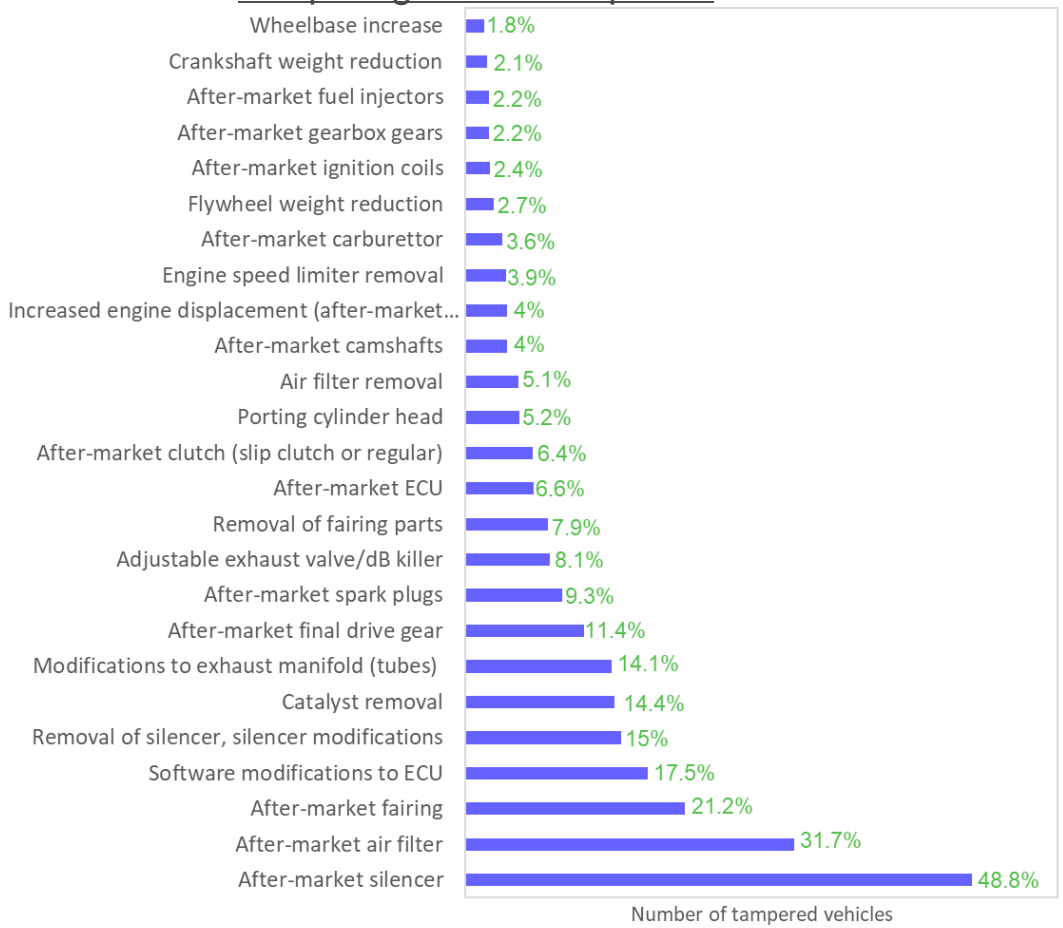
Emission tampering results

Understanding tampering (LENS D5.1)

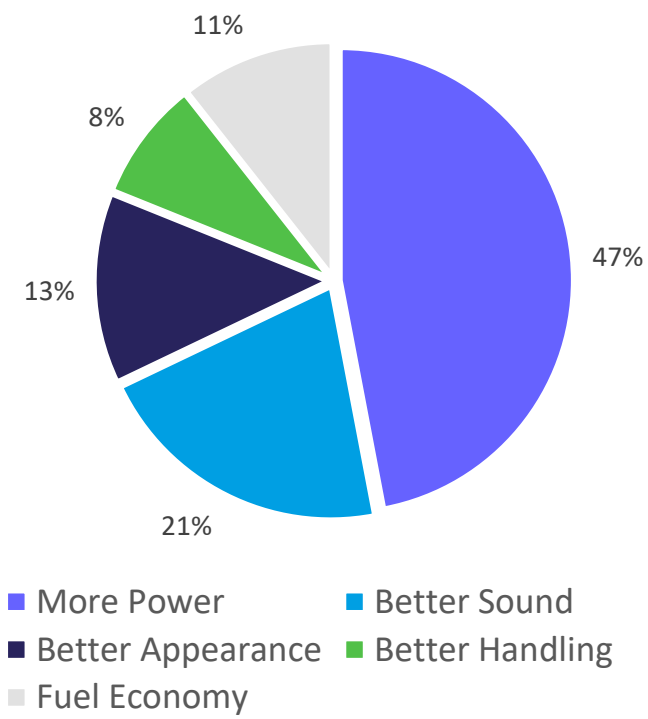
- >600 online questionnaires & >60 interviews with OEMs, service shops, LV owners & enthusiasts from 15 EU countries
- Most LV tampering attempts aim to modify the exhaust system, and the most common tampering method is the replacement of the original silencer with an after-market one.
- Tampering is mostly motivated by the urge to increase engine power.



Tampering methods reported

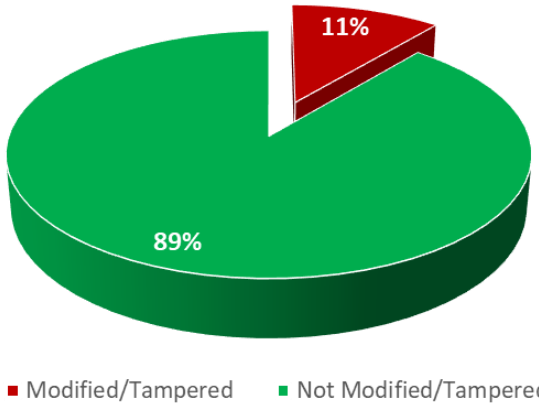


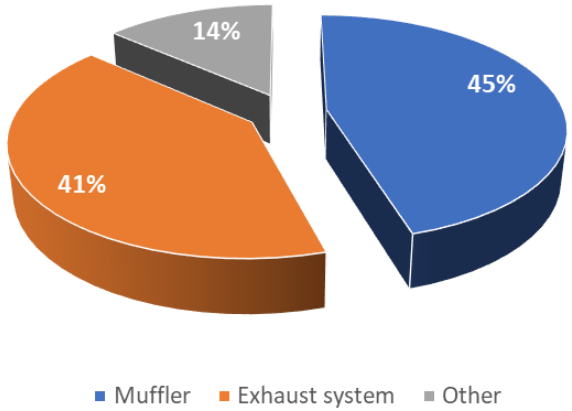
User justification for tampering



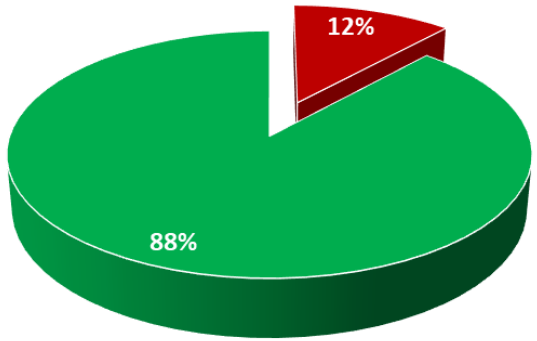
Roadside inspection tampering results

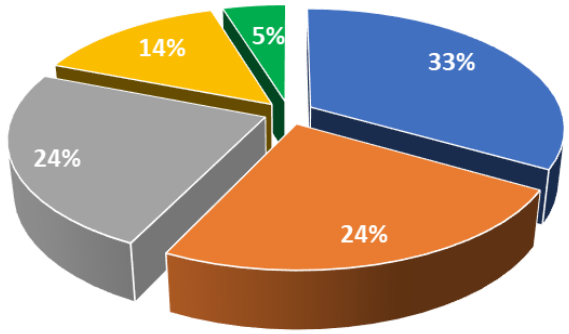
- Leuven





- Barcelona



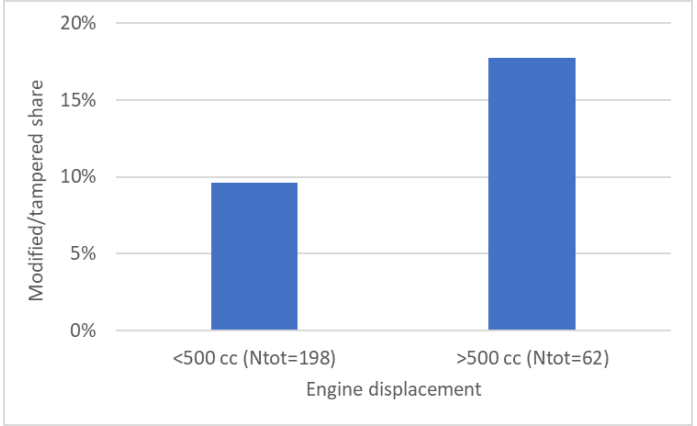


L-vehicles Emissions and Noise mitigation Solutions

What characterized the tampered LVs?

Compared to the not tampered LVs:

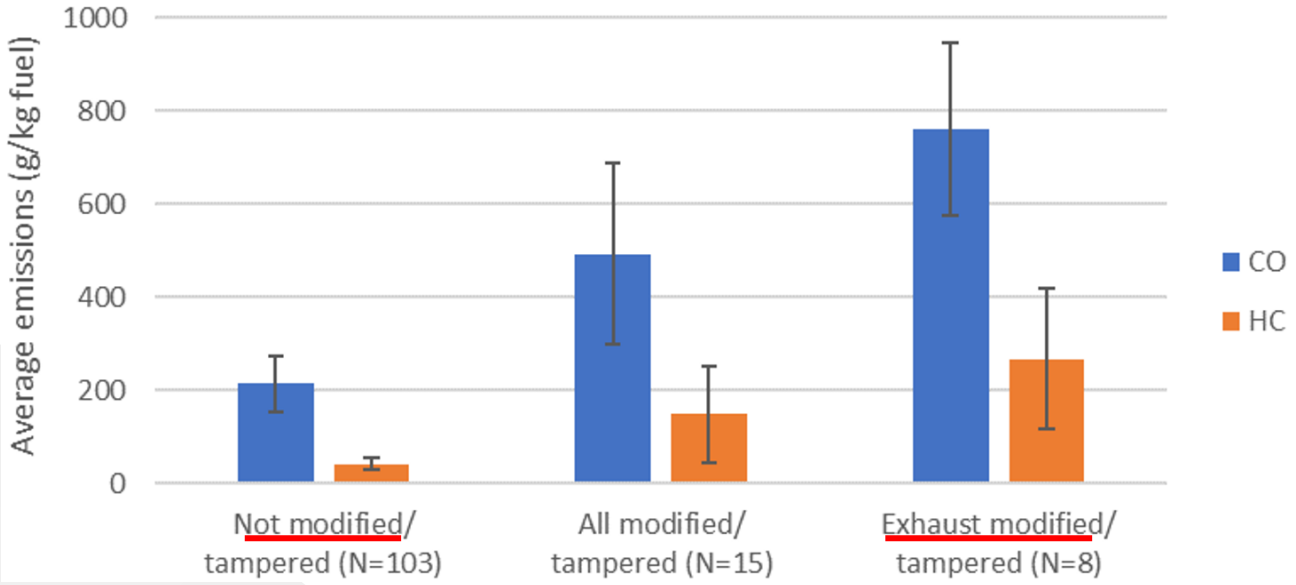
- They had a higher share of **2-stroke engines**: 23% (vs 3%)
- Their average **engine size** was higher: 446 cm^3 (vs 285 cm^3)
- Their average **age** was about two years higher



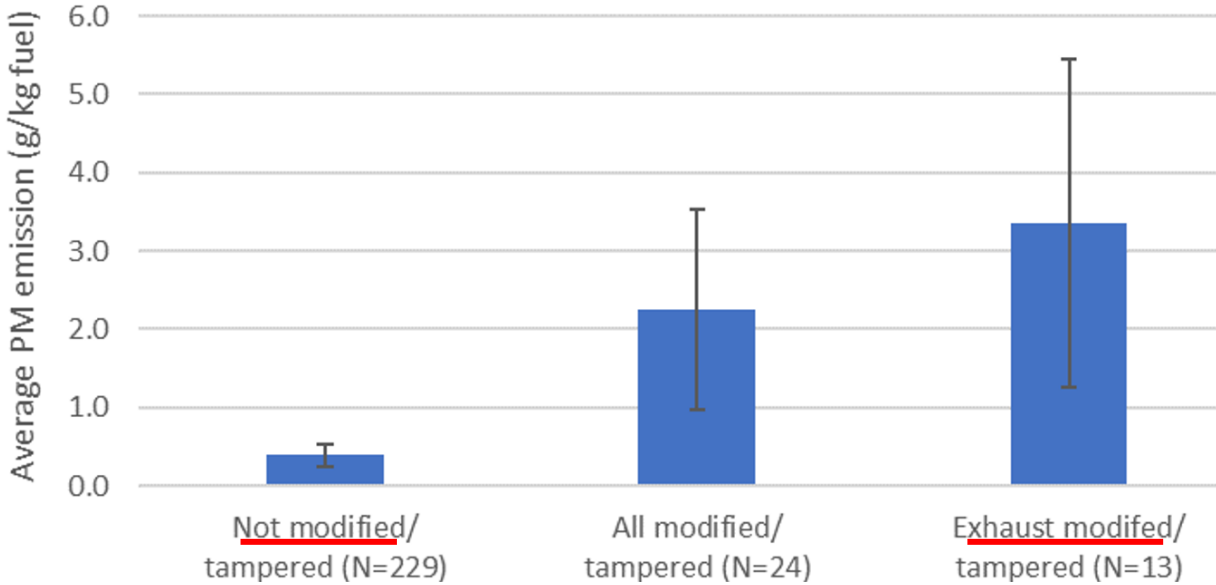
- There were **no significant differences in average Euro class or vehicle mileage**

Tampering may affect on-road emissions substantially

CO and HC



PM



An emission impact factor of about 5-10, depending on pollutant.

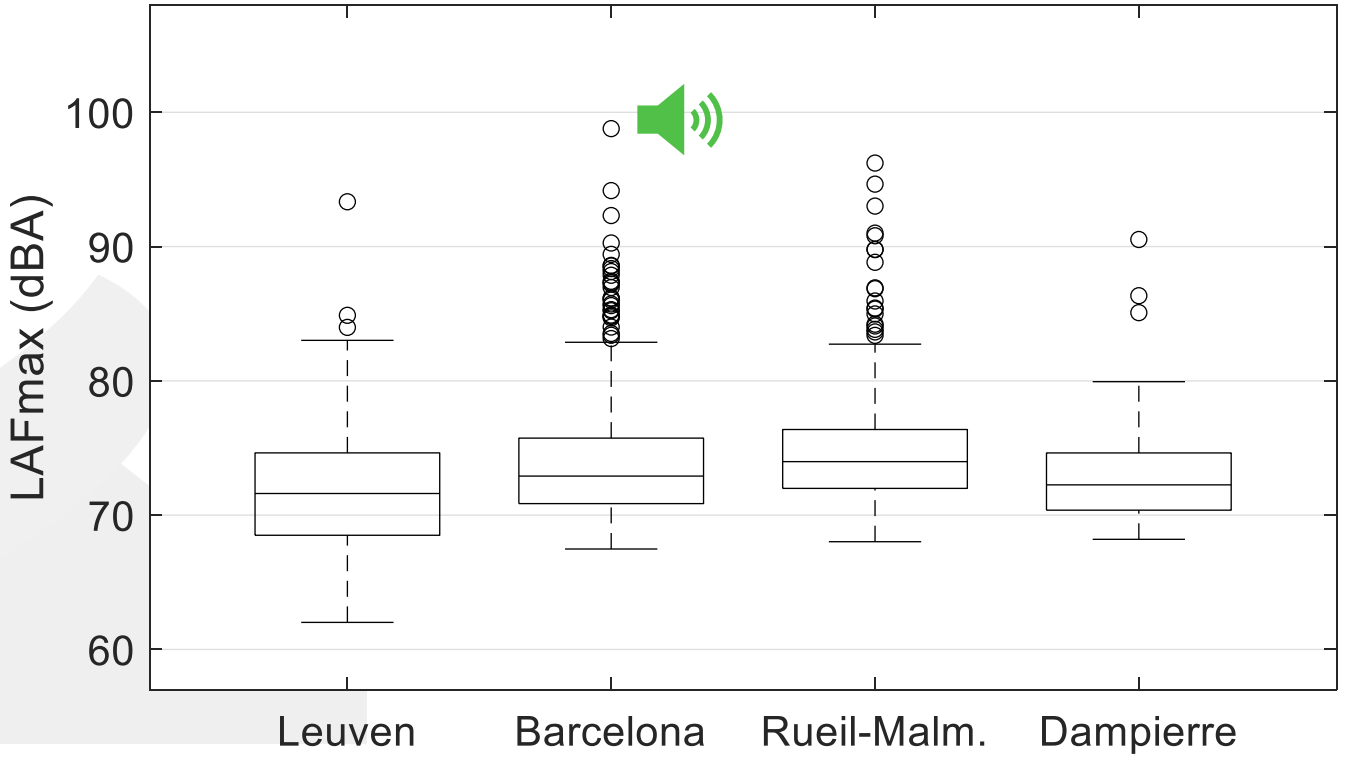
Impact on NO_X emissions tends not to be significant.

LENS L-vehicles Emissions and Noise mitigation Solutions

Roadside noise measurements results

Roadside sound pressure level

LAFmax per measurement site

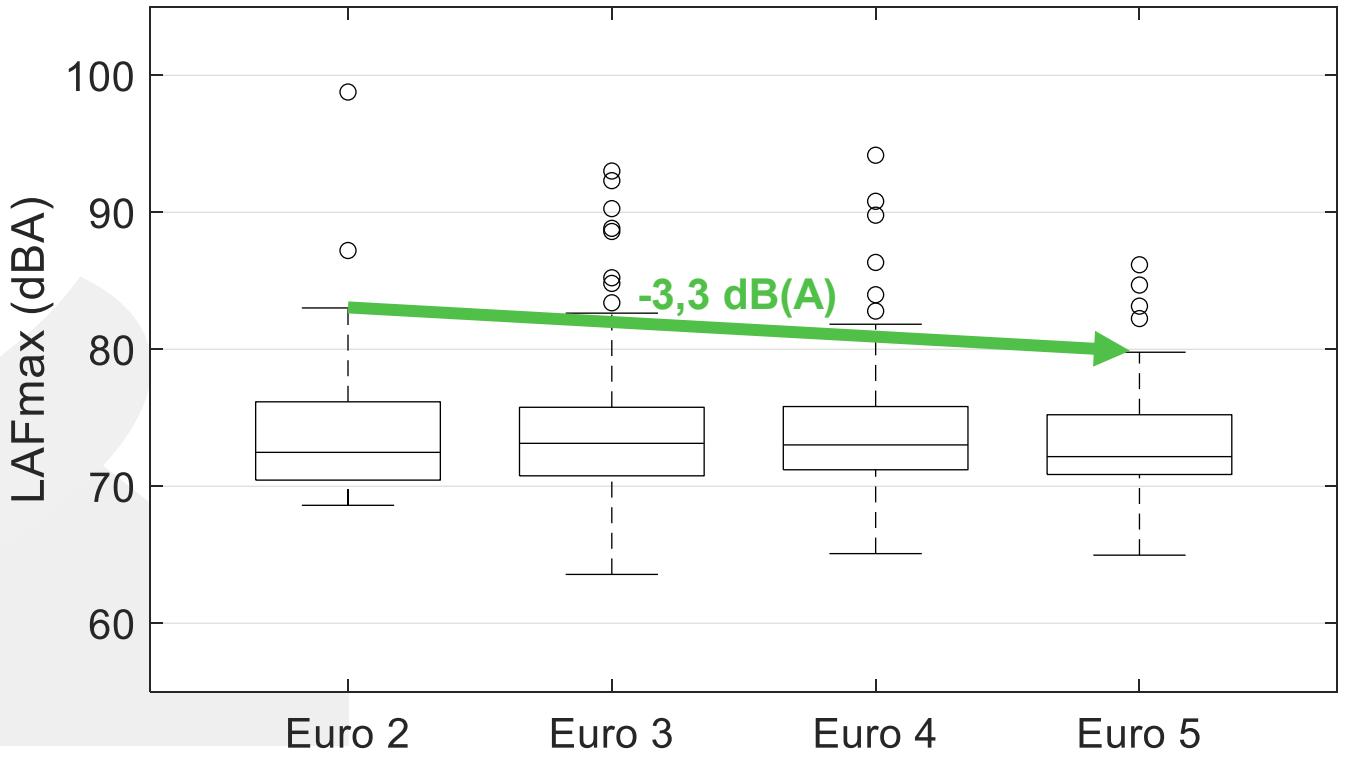


- Measured roadside noise levels, not comparable to type approval
- Comparable levels at all sites, slightly higher at urban sites
- Many outliers to higher levels (circles in the figure)
- Strong influence of driving conditions

LENS L-vehicles Emissions and Noise mitigation Solutions

Roadside sound pressure level

LAFmax per Euro class



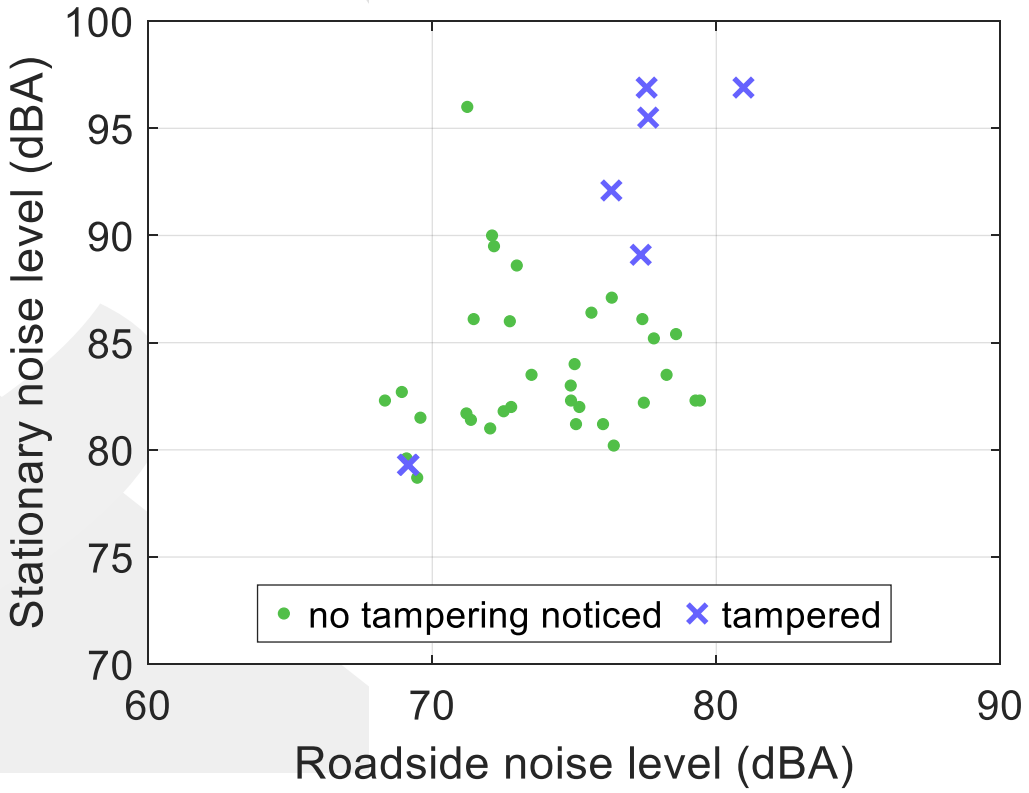
- Median levels within 1 dB(A) from each other, but maximum levels (excluding outliers) decrease
- Improvements in type approval procedures for noise are not reflected in the in-field observations
- Many other parameters affect this result: fleet composition within each class, vehicle condition, operation of the vehicle, etc.

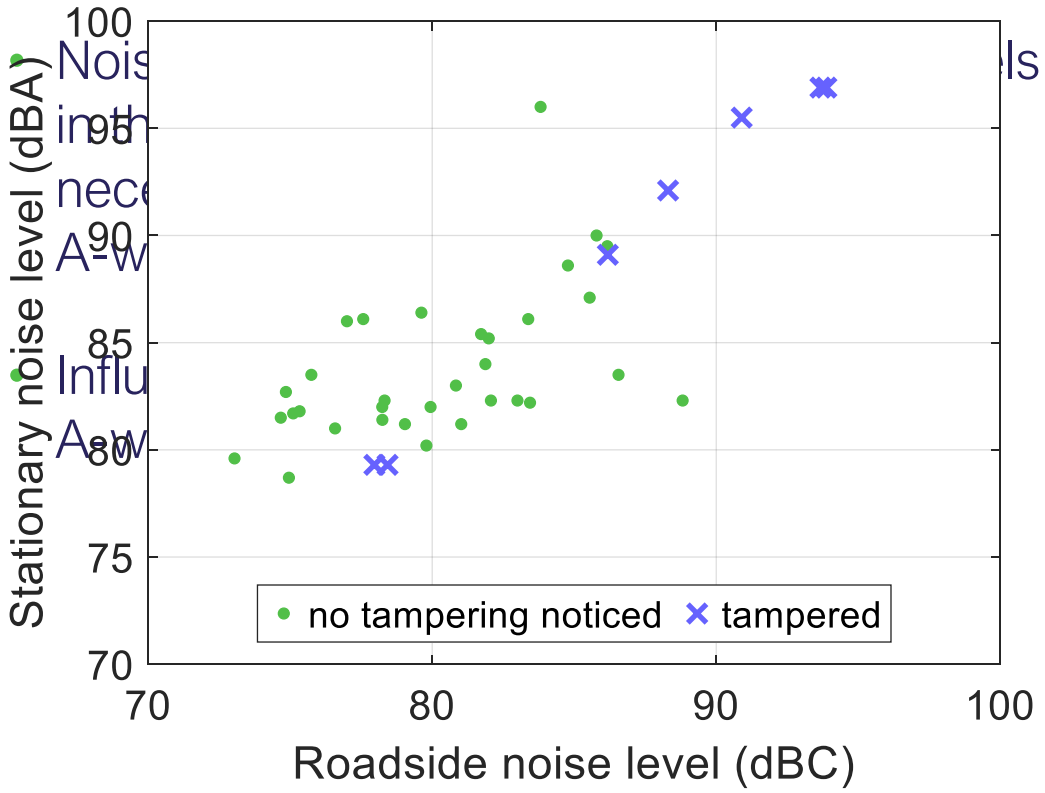
LENS L-vehicles Emissions and Noise mitigation Solutions

Noise tampering results

Effect of tampering

Stationary vs roadside noise level





L-vehicles Emissions and Noise mitigation Solutions

- (Noise) tampered vehicles stand out more clearly in the measured roadside noise levels if C-weighting is used

Effect of tampering

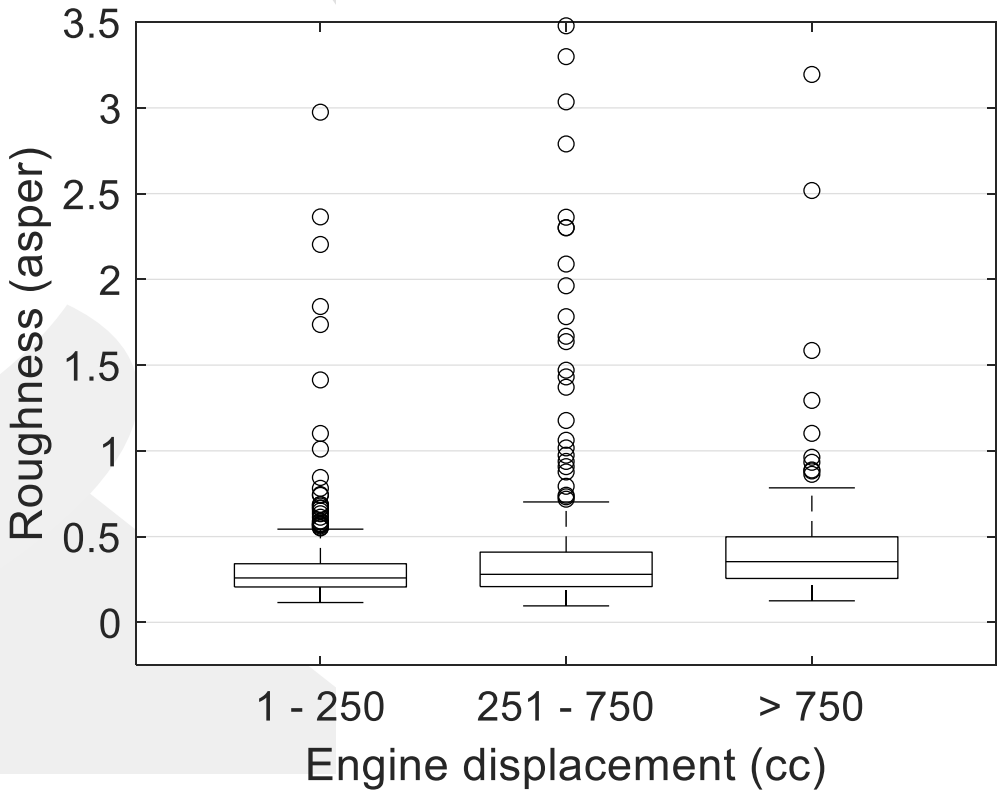
Sound character: example

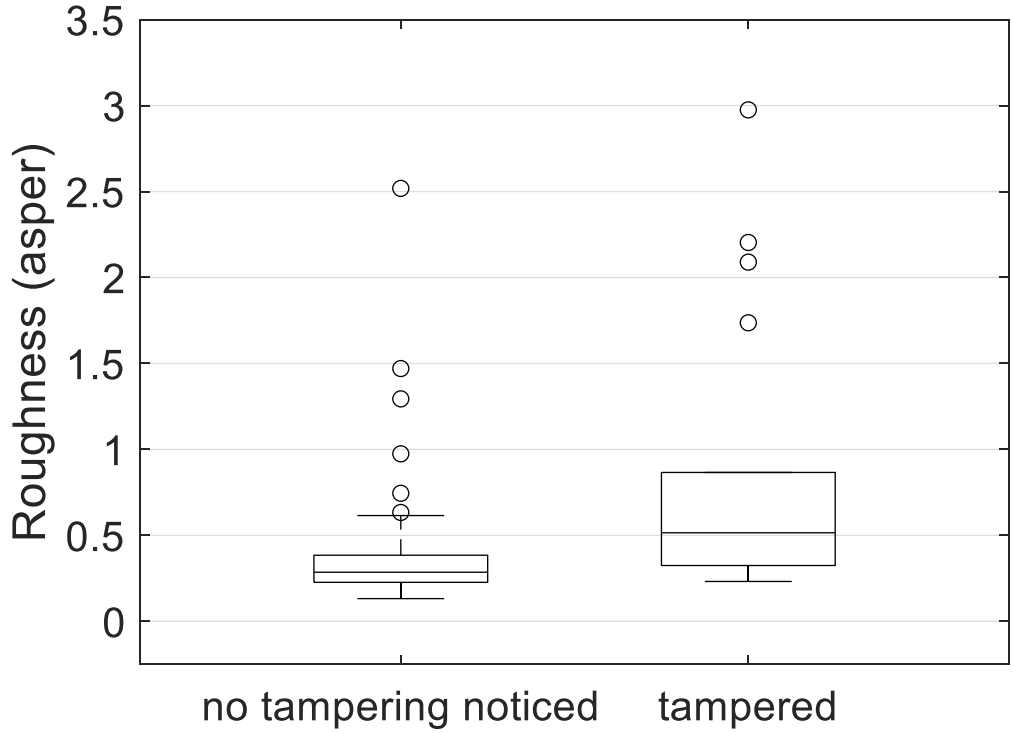
	Tampered	Noise level (stationary)	LAFmax (roadside)	LCFmax (roadside)	Roughness (roadside)
	No tampering noticed	82,0 dB(A)	72,8 dB(A)	78,2 dB(C)	0,33 asper
	No tampering noticed	82,3 dB(A)	74,9 dB(A)	78,3 dB(C)	0,16 asper
	Yes: muffler changed, no dB killer	92,1 dB(A)	76,3 dB(A)	88,3 dB(C)	0,58 asper

- Tampering affects not only the noise level, but also the sound character
- Other noise metrics can be used to assist in identifying tampered vehicles

Sound character: psychoacoustic metrics

Example: roughness





Tampering detection

- Analysis of the effect of tampering on a large number of signal features
  (sound pressure levels, psycho-acoustics, signal statistics, condition monitoring features)
- Classification models:
  - Overfitting due to unbalanced dataset with too few tampered vehicles
  - Feature ranking: peak-to-peak, roughness and kurtosis or Shannon entropy

Conclusions

Conclusions - pollutant emissions

- On-road emissions of all regulated pollutants CO, HC and NO_X have been reduced substantially from early Euro classes to Euro 5, with reductions in the range of ≈60 – 90%, depending on pollutant. For particle mass and number, reductions are even larger.
- Compared to cars, the hit-rates for measuring emissions from passing L-vehicles from the roadside (remote emission sensing) are very low, making such measurements less effective.
- Emission modifications/tampering increase the on-road emissions of CO, HC and PM by a factor of 5-10, whereas NO_X emissions tend not to be impacted.
- According to the roadside inspections, the share of tampered LVs was slightly above 10%, including both emission and noise tampering, Since not all tampering options were included in the inspections, this share represents a minimum.

Conclusions - noise

- The improvements in the type approval procedures for noise are not reflected in the evolution of A-weighted sound pressure levels measured from the roadside as a function of Euro class. However, factors such as fleet composition, vehicle condition, driving conditions, etc. affect these results.
- Noise tampering (muffler, dB-killer) has an impact on the noise levels measured in the stationary test, but the choice of the metric (e.g. A- or C-weighted sound pressure level) has a major influence on the observed differences in noise levels measured from the roadside.
- Noise tampering changes the sound character of the LV and various aspects of this character can be quantified using objective metrics (e.g. roughness).
- Signal features could assist in identifying tampered vehicles, but the number of noise recordings of inspected LVs was too low to train a reliable classification model for detecting tampered vehicles based on their sound signatures.

Thank you for your attention!

Questions?

Full report downloadable from:

https://lens-horizoneurope.eu/wp-content/uploads/2025/09/LENS_D5.3_Results-of-field-surveys-on-LV-tampering_final.pdf