Mitigation measures

Georgios Triantafyllopoulos (EMISIA), Michael Dittrich (TNO), Heinz Steven

LENS Final Conference, Brussels, October 15th 2025

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

Mitigation measures for noise and exhaust emissions

- Several pollutant and noise emission mitigation measures were selected to be investigated
  - M1 Stricter regulation for noise and pollutant emission limits.
  - M2 Introduction of antitampering measures/regulation
  - M3 Changes in driving behavior
  - M4 Low emission zones / access restrictions
  - M5 Accelerated fleet renewal

- Simulations were conducted to quantify the emission reduction potential of these measures.
  - Future fleet evolution is projected
  - Baseline scenario: No introduction of mitigation measures
  - M1-M5 scenarios: Introduction of mitigation measures M1-M5

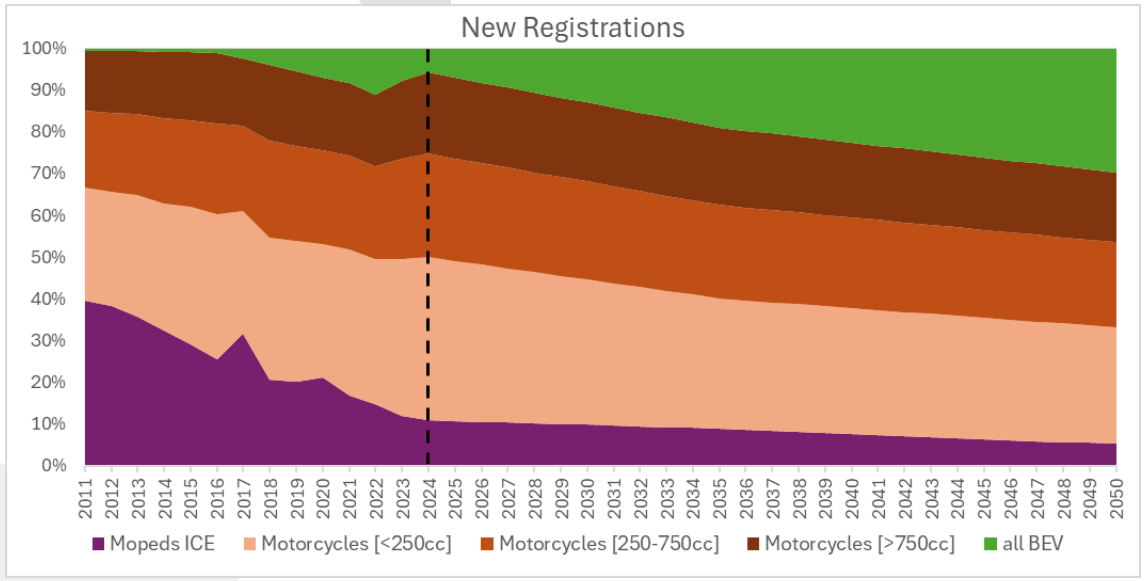
Baseline – Fleet evolution

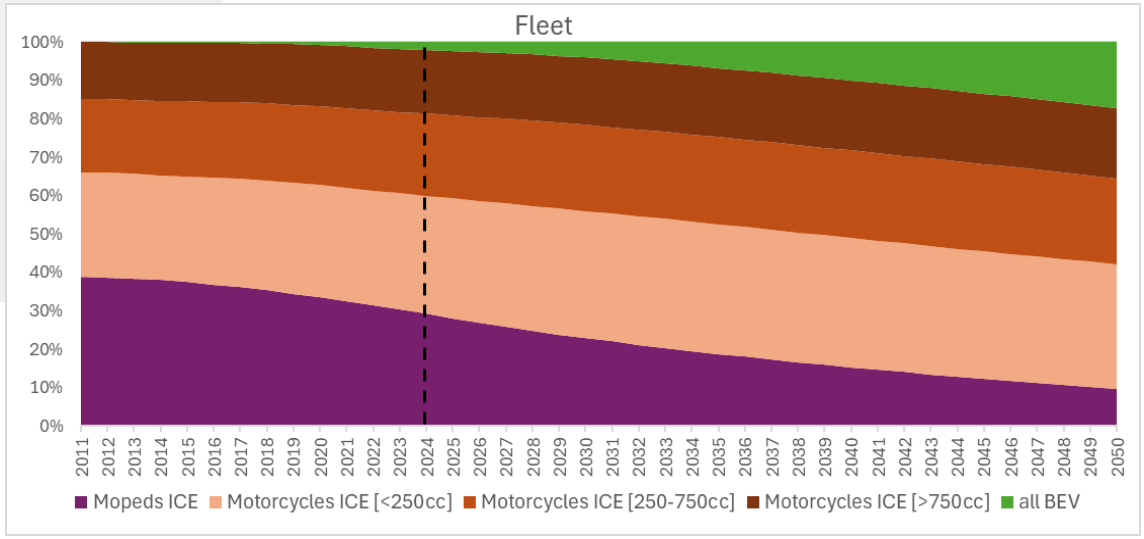
Assumptions:

- New registration growth rate =1% per year constant (same as average of latest 5 years).
- New registrations share of Mopeds:
  - 97% 4stroke
  - 3% 2stroke
- New registrations share of Motorcycles (same as 2022, latest data):
  - 47% Motorcycles <250 cm^3
  - 30% Motorcycles 250 – 750 cm^3
  - 23% Motorcycles >750 cm^3
- Yearly removal of existing vehicles (same as average of latest 5 years):
  - 3.5% for Mopeds
  - 1.7% for Motorcycles
- Share of tampered LVs:
  - 45% for Mopeds
  - 15% for Motorcycles
- Electrification: 2 sub-scenarios
  - Low electrification
  - High electrification

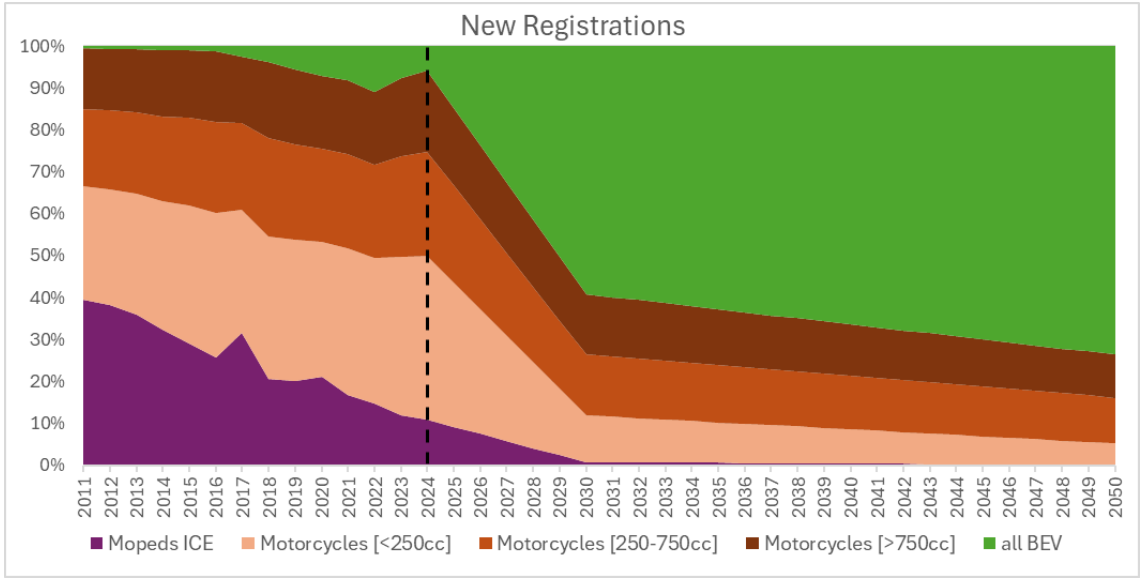
Baseline – Fleet evolution

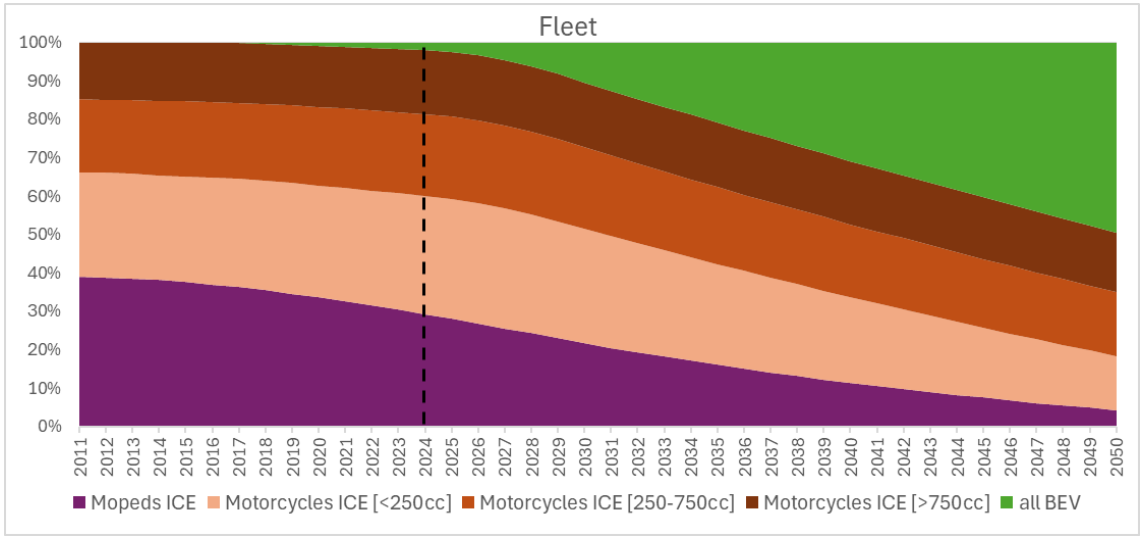
- Low electrification scenario (17% electric L-cat vehicles in 2050)





- High electrification scenario (50% electric L-cat vehicles in 2050)





Noise emission mitigation measures

Regulations – Scenarios - Impact

L-vehicles Emissions and Noise mitigation Solutions

Regulatory instruments related to noise

International regulations

EU, UNECE, Member states

UNECE

	Noise type test and limits
R41	Motorcycles
R9	Trikes
R63	Mopeds
R92	Aftermarket exhausts

EU

EU 168/2013

LV approval and market surveillance, referring to UN regs

EU Roadworthiness package

Directive 2014/45/EU	Periodic roadworthiness tests(PTI)
Directive 2014/47/EU	Technical roadside inspections
Directive 1999/37/EC	Vehicle registration documents and data

Environmental Noise Directive 2002/49

Noise mapping

Action plans

Impact assessment

Transposition

National and local regulations

Ministries, Vehicle authorities, Infrastructure managers, Police, Municipalities, Regional authorities

National law

Traffic regulations

Vehicle regulations

Noise regulations

Penalties and automation

Low emission zones

Policing

Enforcement

Noise cameras

Local regulations

Speed limits

Road access

Noise

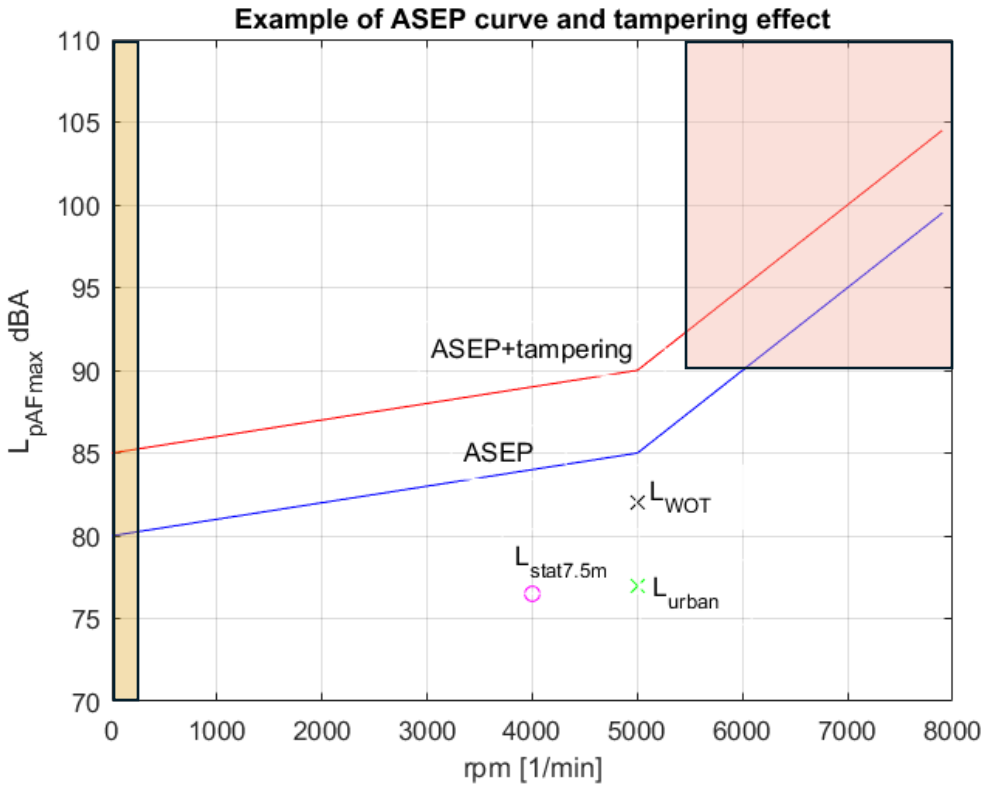
Disturbance orders

Scenarios for noise mitigation

Scenario	Control parameters	Fleet affected	Timescale
M1: improved type approval legislation	Sound emission level of new vehicles; Portion of new vehicles in fleet complying with new legislations	New fleet	2029- 2029+vehicle life
M2: Reduced tampering	Sound emission level of existing vehicles with and without tampering	Existing fleet	2027-2050
M3: Local regulations for driving behaviour	Speed and engine speed, causing reduced sound power (driving behaviour)	Existing and new fleet	2027-2050
M4: Access restrictions for vehicle groups, roads and zones	On urban streets (residential – main, speed limit 30 to 70 km/h) a) motorcycles > 250 cm^3 only b) all Lcat vehicles	Existing and new fleet	2027-2050
M5: Vehicle replacement (incentives for electrification)	Reduction in sound emission level Replacement rate - > electrification New registration increase by 20% for constant fleet size	Existing fleet	2027-2050 (17-50% in 2050)

Scenario 1: Improved Type approval UN regulations

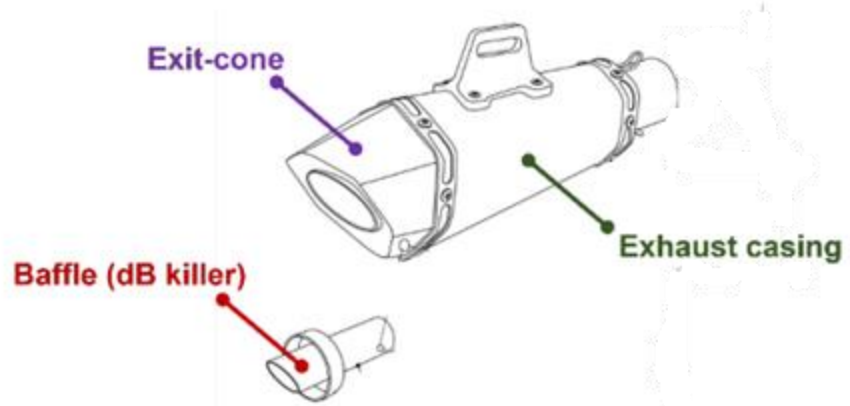
- Improved ASEP in UN reg 41 (motorcycles)
- Cover full operational driving conditions, especially loud ones
- Include full engine rpm range and speed range
  Also include for other L-categories
- Limit very high sound levels (>90 dB(A)) in ASEP
- Stricter sound limits for L_{WOT}
- Effect: UNR41 mainly for **new vehicles** 2-5 dB
- UN reg 92 for replacement exhausts (NORESS) , most effect on tampering, mainly existing vehicles
- Timescale: from 2029 (+ vehicle life)
- Actors: UNECE GRBP, EU

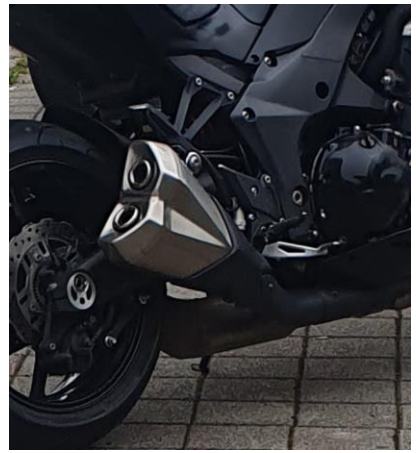


LENS L-vehicles Emissions and Noise mitigation Solutions

Scenario 2: Reduced tampering /vehicle modifications

- Include noise tampering in vehicle inspection (Periodic technical Inspection incl. change of owner)
- Support tools for enforcement and inspection staff: apps + info resources on tampering
- Information on effects of tampering and modifications to owners
- Automated detection (apps for roadside and PTI inspection)
- Stricter regulations and penalties for tampered vehicles
- Antitampering provisions in UN regulations for vehicles and aftermarket parts
- Effect: large, 5-10 dB in single events
- Timescale: 2027-2050
- Actors: Local and national authorities, EU (RWP)





L-vehicles Emissions and Noise mitigation Solutions

Scenario 3: Local regulations to control driving behaviour

- Speed limits (less acceleration, lower rpm)
- Infrastructure changes (e.g. humps, warnings)
- Attended enforcement of driving behaviour (speeding, aggressive driving, revving, high rpm etc)
- Automated enforcement, such as mobile or fixed noise cameras – **need for local sound limits**
- Citizen monitoring and feedback, signalling by wardens
- Effect: up to about 10 dB in single events at local level
- Timescale: 2027-2050
- Actors: Local and national authorities, EU RWP

LENS L-vehicles Emissions and Noise mitigation Solutions

Scenario 4: Local access restrictions

- Partial or total entry restrictions for certain vehicle types
- Existing no entry signs
- Low emission zone (exist for emissions but not for noise)
- Pedestrian zones and traffic restricted areas
- Individual driving bans
- Effect: 10 dB or more in single events where applied
- Timescale: 2027-2050
- Actors: Local and national authorities

No entry for motorcycles

No entry for motorised vehicles

No entry for mopeds and scooters with running engine

Low emission zone (exhaust)

No entry for motorcycles with stationary noise level of more than 95 dB(A) (Austria)

LENS L-vehicles Emissions and Noise mitigation Solutions

Scenario 5: Fleet replacement

- Incentives for replacement of old/noisy vehicles
- In particular to incentivise electric vehicles
- Subsidy programmes
- Link to low emission zones for noise

- Effect: mainly existing fleet, around 10 dB in single events
- Timescale: 2027-2050 (17%-50% in 2050)
- Actors: National authorities, EU

Other mitigation options

- Driver communication, awareness and attitude – warnings and info
- Market surveillance of aftermarket and add-on parts
- CNOSSOS-EU traffic noise model
  Increase sound emission levels for L-vehicles
  Adjust dose-effect relationship for L-vehicles

Benz et al, 2023

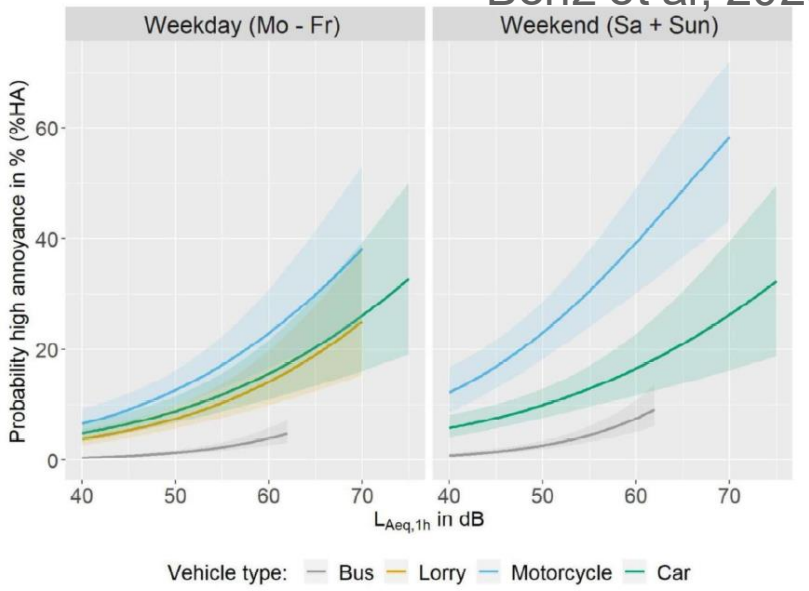
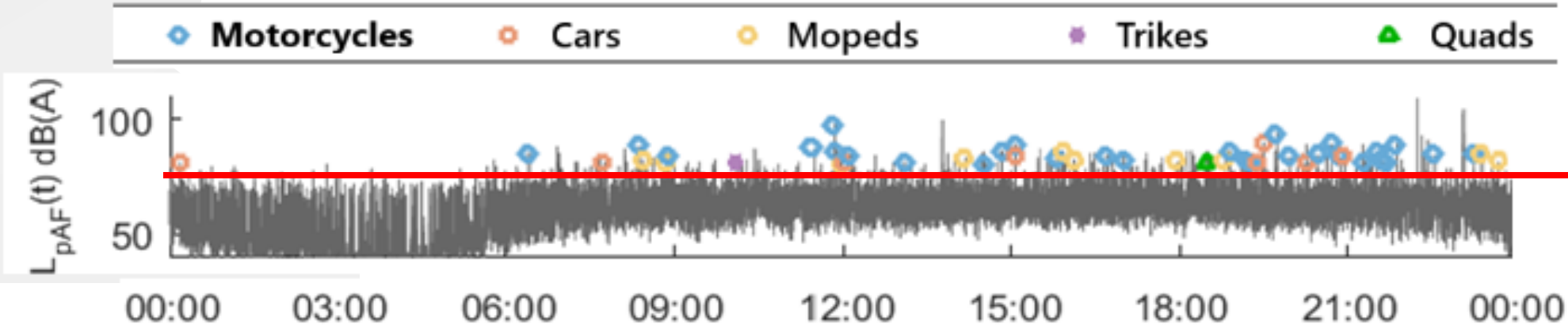


Figure 4: Exposure-response relationship for $L_{Aeq,1h}$ of the vehicle types motorcycle, car, lorry, coach, and $\%HA_V$ of the corresponding vehicle types.

L-vehicles Emissions and Noise mitigation Solutions

Impact assessment for scenarios

- Based on effect on long term Lden averages, simulation
- Based on peak noise levels (single events) , simulation
  See LENS report D6.4
- Numbers of highly annoyed and highly sleep disturbed - > health impacts
- Higher dose-effect relationship for L-cat compared to other vehicles

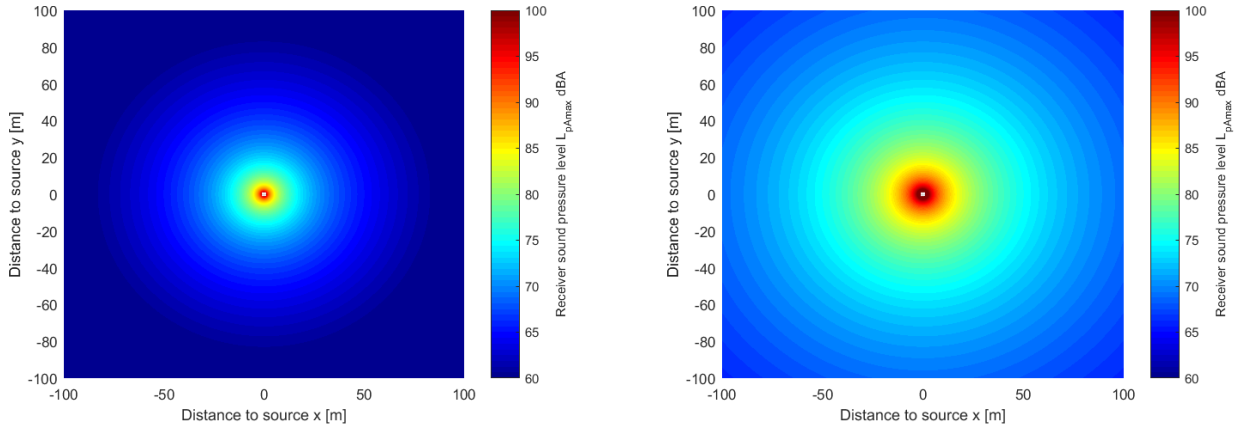


Urban roadside sound level 24h

LENS L-vehicles Emissions and Noise mitigation Solutions

Aspects of single events for L-cat vehicles

- For irregular, high peak noise levels such as loud motorcycles, single events are important for noise perception, complaints and sleep disturbance (awakening)
- Sound fluctuation, impulsiveness and tonality also play a strong role in the perception of L-cat noise, but are not taken into account - a penalty would be justified
- For 10 dB increase in source level, around 10 times more people are exposed



- The event duration (including increase and decrease) is longer for higher levels

L_{den} calculations with TRANECAM

- Lden is the calculated long term average traffic noise level near the road
- The TRANECAM model contains average noise emissions for different road types, traffic load situations, road gradients, vehicle categories and noise emission stages.
- The noise emission stages are linked to the noise emission type approval legislation in the EU
- It includes cars, light and heavy duty vehicles, buses, motorcycles<=250 cc, motorcycles>250 cc, mopeds vmax<50km/h
- Also pure electric vehicles (PEV) for all categories

Emission stages and tampered vehicles

- Motorcycles and mopeds include original and tampered vehicles with 10 dB higher sound levels than original vehicles.
- Shares of tampered vehicles: motorcycles 15% and mopeds 45%.
- For motorcycles > 250 cm³ tampered vehicles increased to 30% to consider the effect of high rev driving (15% tampered and 15% high rev driving).
- The shares of small (<= 250 cm³) and large (> 250 cm³) motorcycles and PEVs (low and high electrification rates) same as for the exhaust emission calculation

Road categories and traffic load data

- The road categories and traffic load data used for the calculations are
- urban streets
  - Residential, speed limit 30 km/h, 500 vehicles per day,
  - Main, speed limit 50 km/h, 15000 vehicles per day,
  - Main, speed limit 70 km/h, 40000 vehicles per day,
  - Motorway, speed limit 100 km/h, 40000 vehicles per day
- Rural roads
  - Speed limit 90 km/h, 15000 vehicles per day
  - Motorway, speed limit 120 km/h, 40000 vehicles per day.
- Calculations made for EU North and EU South regions with higher Lcat shares in the South.
- Based on the approach used in the “Study on Euro 5 sound level limits of L-category vehicles” (Papadimitriou, G., Ntziachristos, L., Durampart, M., Dittrich, M., Steven, H., October 2017)

Results: Scenario 5, urban main, 50 km/h speed limit

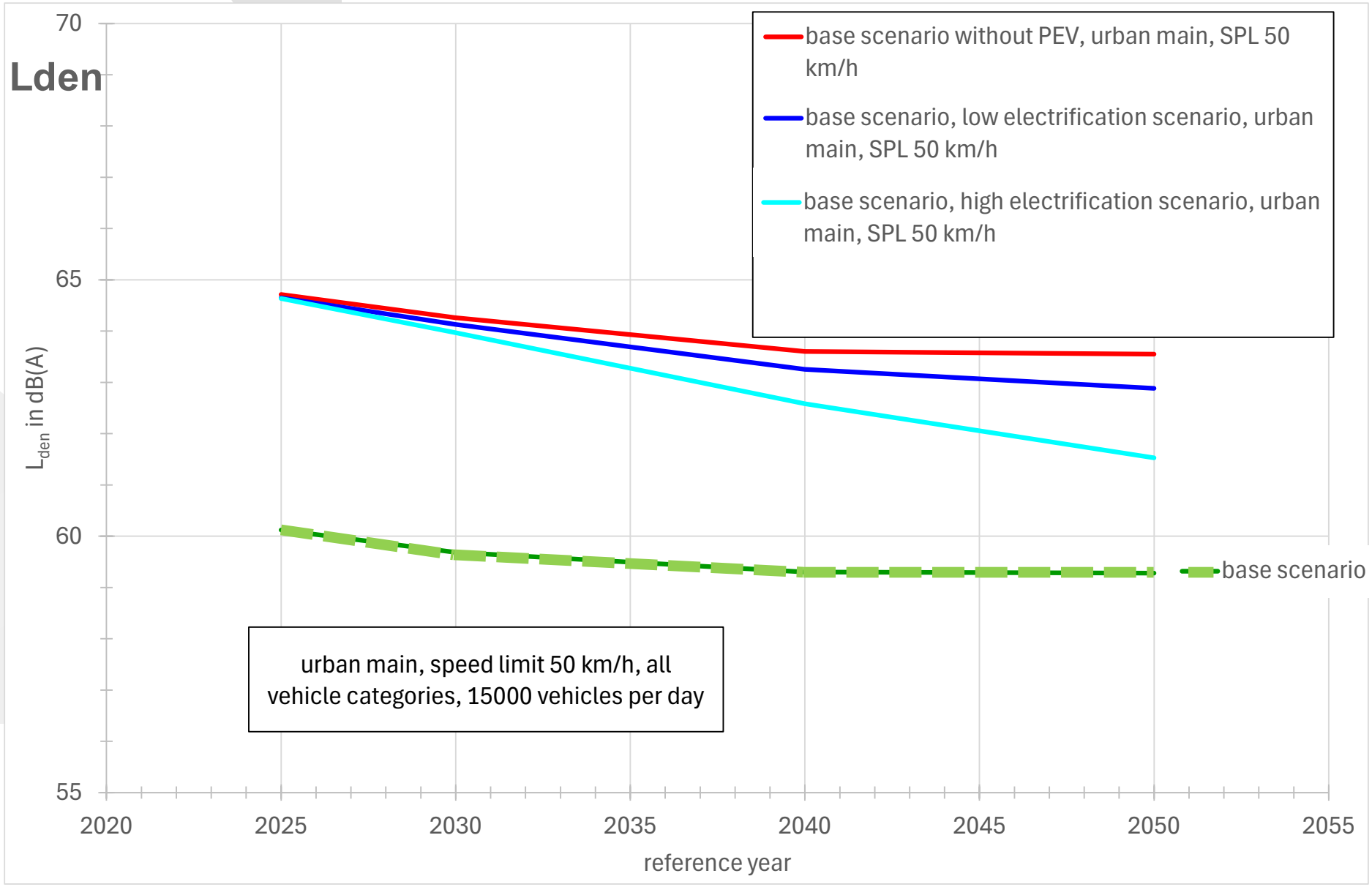


Figure 1

L-vehicles Emissions and Noise mitigation Solutions

Results: Scenarios 2-4, access-residential, 30 km/h speed limit

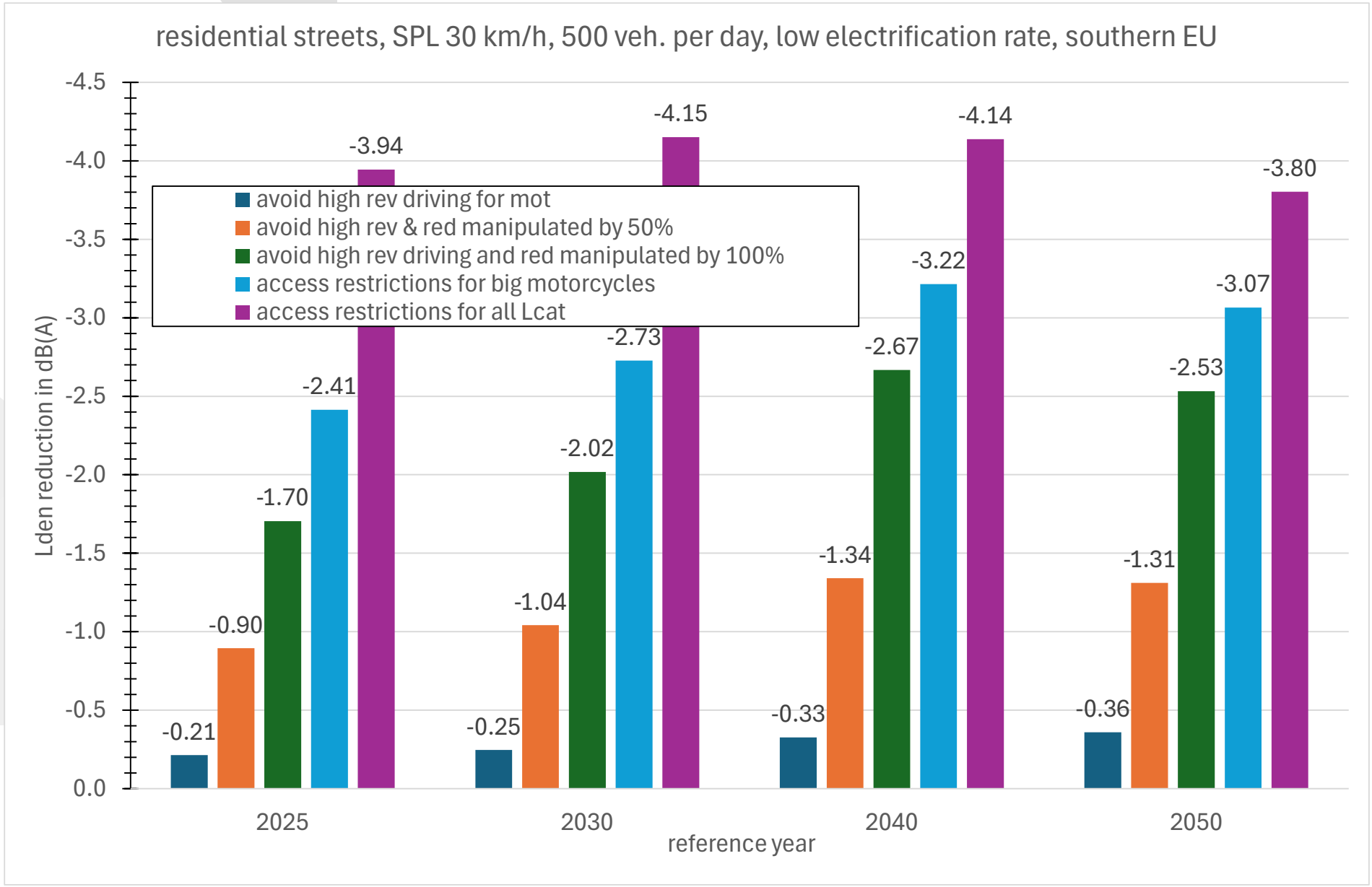


Figure 2

L-vehicles Emissions and Noise mitigation Solutions

Results: Scenarios 2-4, urban main, 50 km/h speed limit

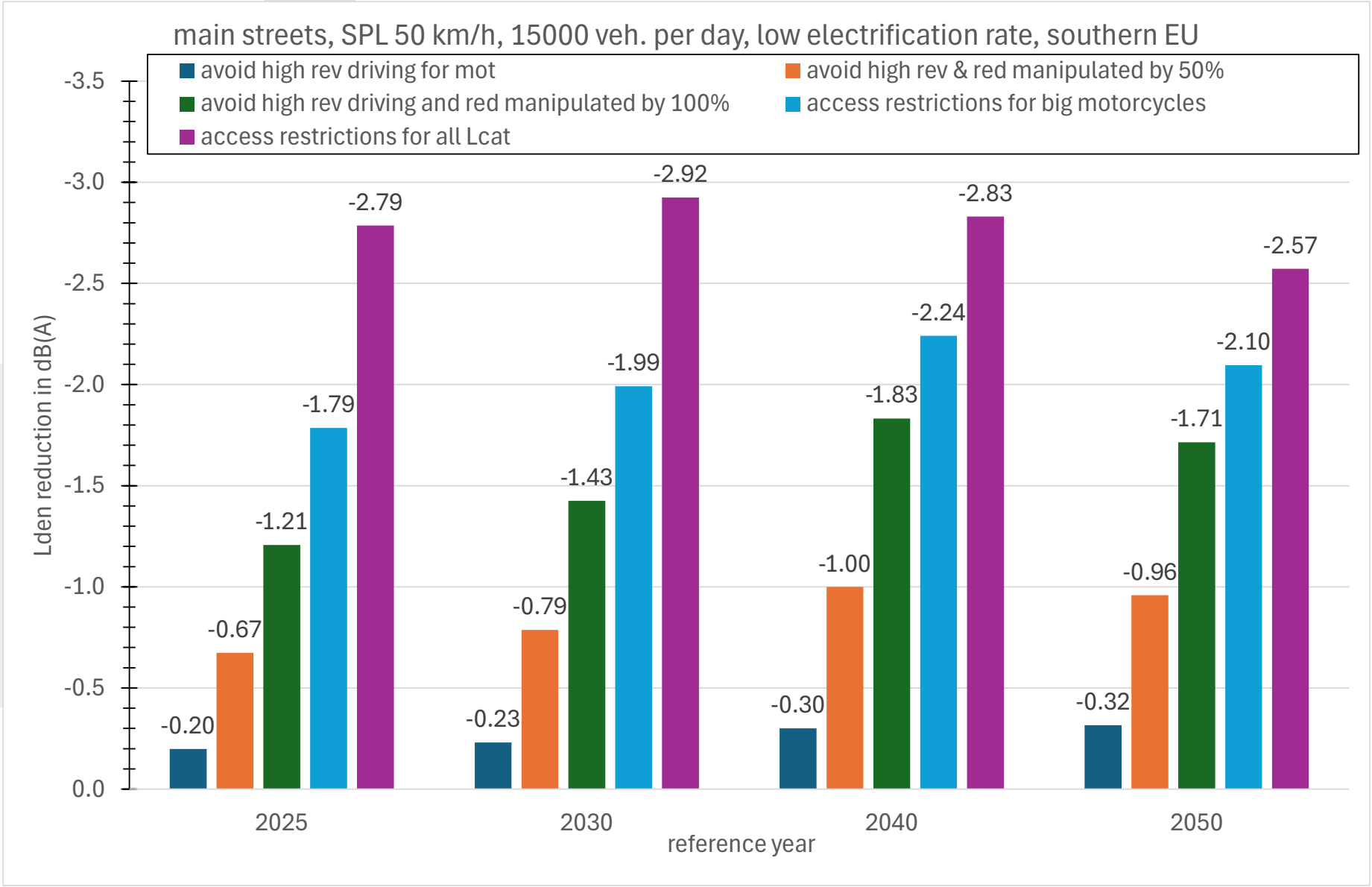


Figure 3

L-vehicles Emissions and Noise mitigation Solutions

Results: Scenarios 2 to 4, urban main, 70 km/h speed limit

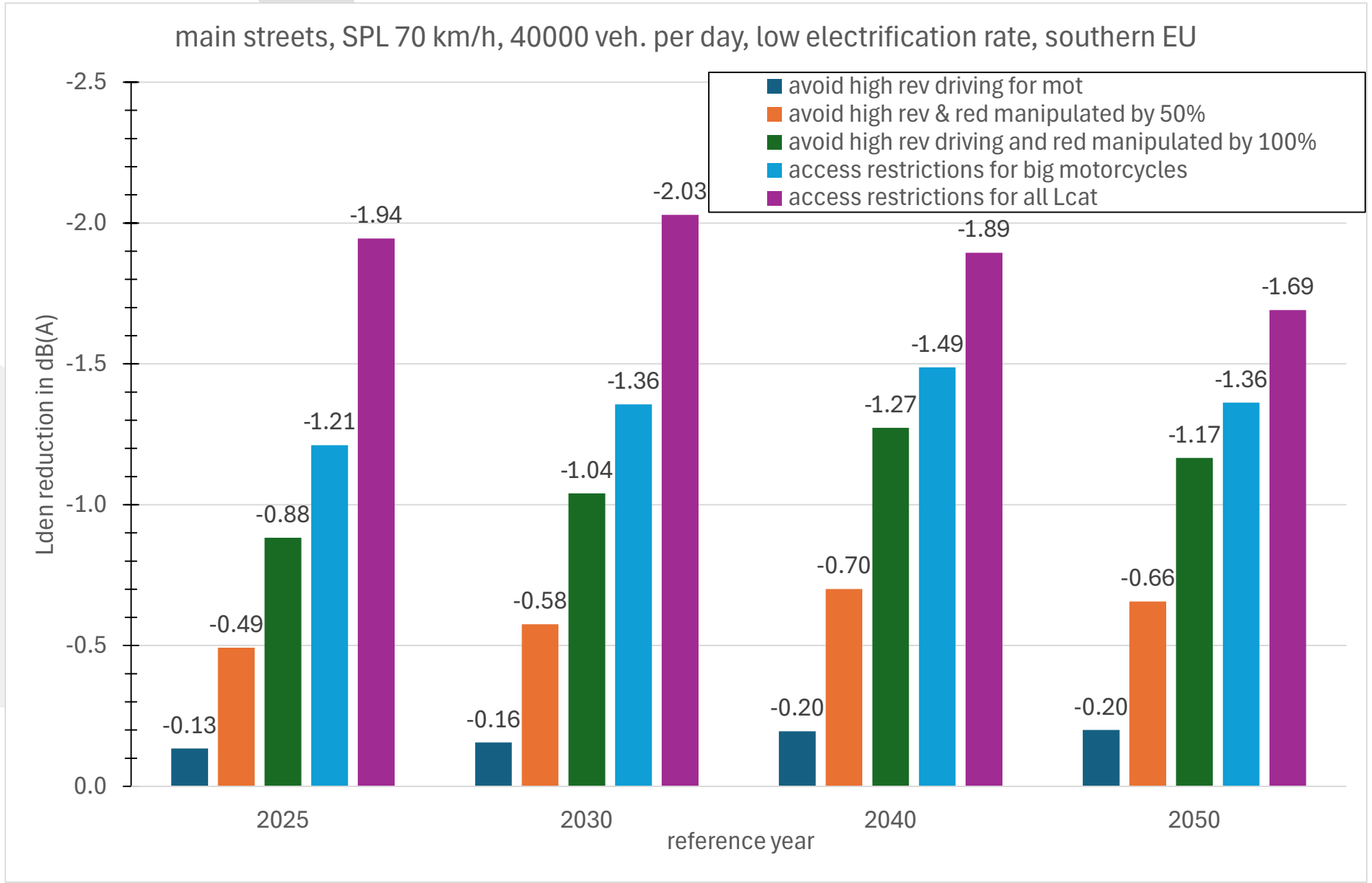


Figure 4

L-vehicles Emissions and Noise mitigation Solutions

TRANECAM calculations - conclusions

- The effect of electrification on the L_{den} decreases with increasing vehicle speed due to the tyre/road noise influence of non-Lcat vehicles.
- The measures of scenario 3 (driving behaviour related measures) have only a limited effect on the L_{den} values.
- But in combination with scenario 2 (reduction of the shares of tampered vehicles) the L_{den} reductions become significant (0,5 to 1,3 dB(A) for 50% reduction of tampered vehicles, 0,9 to 2,7 dB(A)) depending on vehicle speed and share of electrified vehicles.
- Scenario 4 shows the highest effects on L_{den} (1,2 to 3,2 dB(A) for restrictions for big motorcycles and 1,7 to 4,15 dB(A) for restrictions for all Lcat vehicles).

Conclusions for noise

- UNECE regulations can help reduce **noise of new vehicles**, and partly, exhaust noise for existing vehicles
- Reduction of **tampering and vehicle modifications** can be effective, by roadside inspection and PTI, potentially automated, requiring both a national and EU approach to achieve broad effect
- Improved **enforcement and traffic regulations** can help reduce excessive noise due to **driving behaviour**, also by automation and digital support
- General or specific **vehicle access restrictions** can be very effective where feasible
- **Fleet electrification** is a potential means to reduce LV noise substantially but is expected to take many years for the motorcycle fleet
- Other options include driver communication, both online and in traffic
- Some legislation and regulations need updating to enable some changes

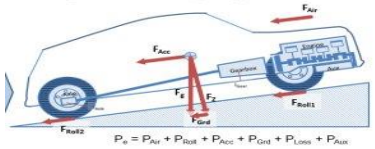
Pollutant emissions mitigation measures

Pollutant emission simulations

Resources

LENS DB
(on road & lab emission measurement data)

PHEM
Passenger car and Heavy duty Emission Model



+ HBEFA

THE HANDBOOK OF EMISSION FACTORS FOR ROAD TRANSPORT

copert

sibyl

EF of Euro 5 vehicles

copert → EF of Euro 4 and older vehicles

Other assumptions

- Deterioration Factor (multiplication factor of EF)

Estimated, using all LENS emissions tests

Mileage [km]	CO	NOx	NH_3	HC	PM & PN
0	x1	x1	x1	x1	x1
30,000	x2.4	x1.4	x3.7	x1.4	x1
60,000	x4.8	x2.1	x4.9	x2.2	x1

- Effect of tampering (multiplication factor of EF)

Estimated using a few LENS emissions tests and confimed by literature review

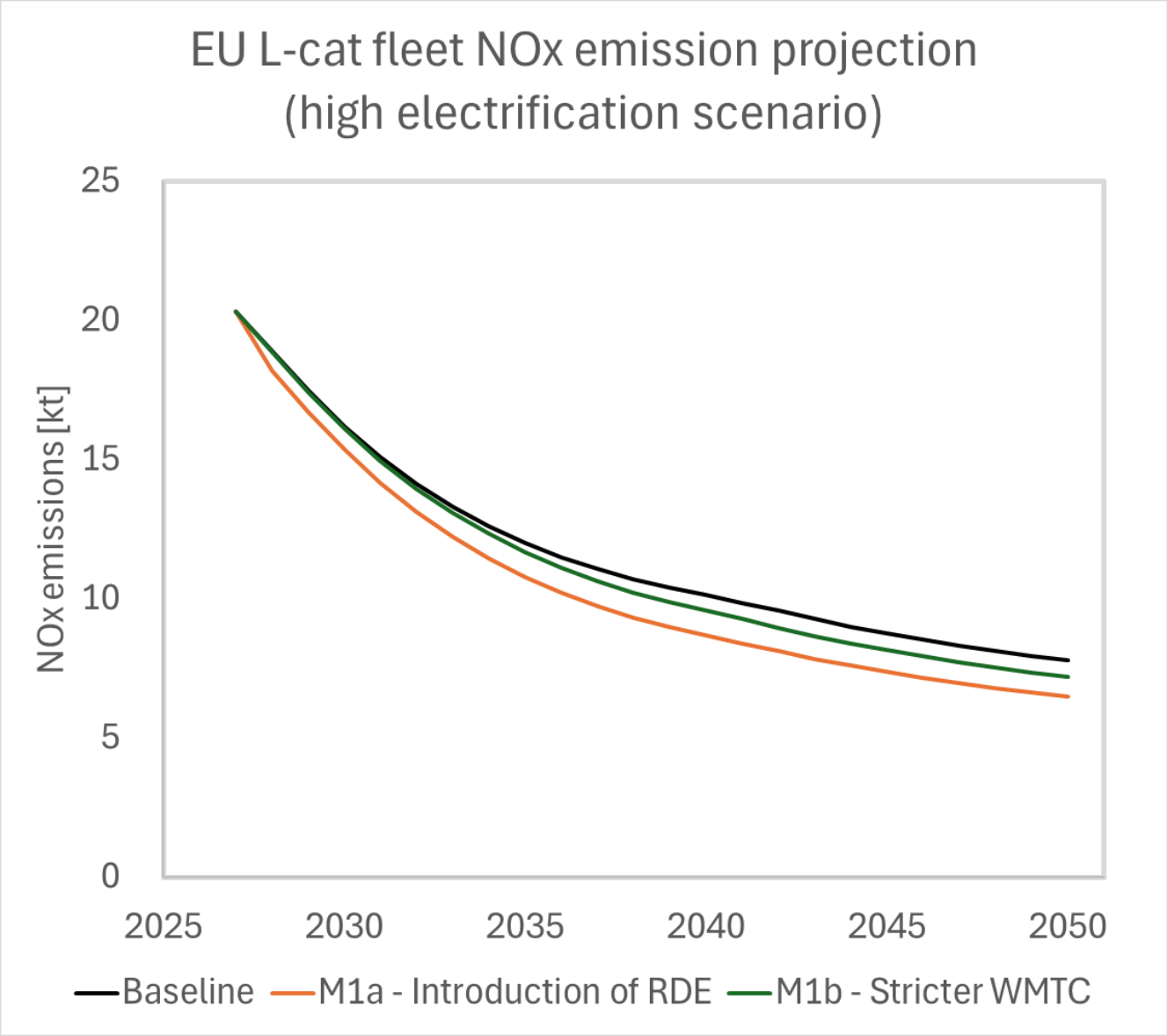
	CO	NOx	NH_3	HC	PM & PN
All vehicles	x5.9	x2.1	x1.1	x3	x1.3

Scenarios for emission mitigation

Scenario	Control parameters	Changes	Fleet affected	Timescale
M1a: Introduction of RDE limits	For driving conditions outside WMTC*: $EF_{outside\text{-}WMTC}$ is reduced.	$EF_{outside\text{-}WMTC} = EF_{inside\text{-}WMTC}$	New fleet	2028-2050
M1b: Stricter WMTC emission limits	For driving conditions inside WMTC*: $EF_{inside\text{-}WMTC}$ is reduced	15% reduction	New fleet	2027-2050
M2: Anti-tampering	Share of tampered vehicles is reduced.	MC: from 15% to 5% MP: from 45% to 10%	New fleet	2027-2050
M3&4: Changes in driving behavior	Assumed reduction of average driving load by 10%.	Direct reduction of EF	Existing and New fleet	2027-2050
M5: Accelerated fleet renewal	Yearly new registrations increased (new vehicles replace old ones, total vehicle fleet constant)	20% increase	New fleet	2027-2040

*On average, the driving conditions of vehicles are 20% outside the operating points of WMTC and 80% inside the operating points of WMTC.

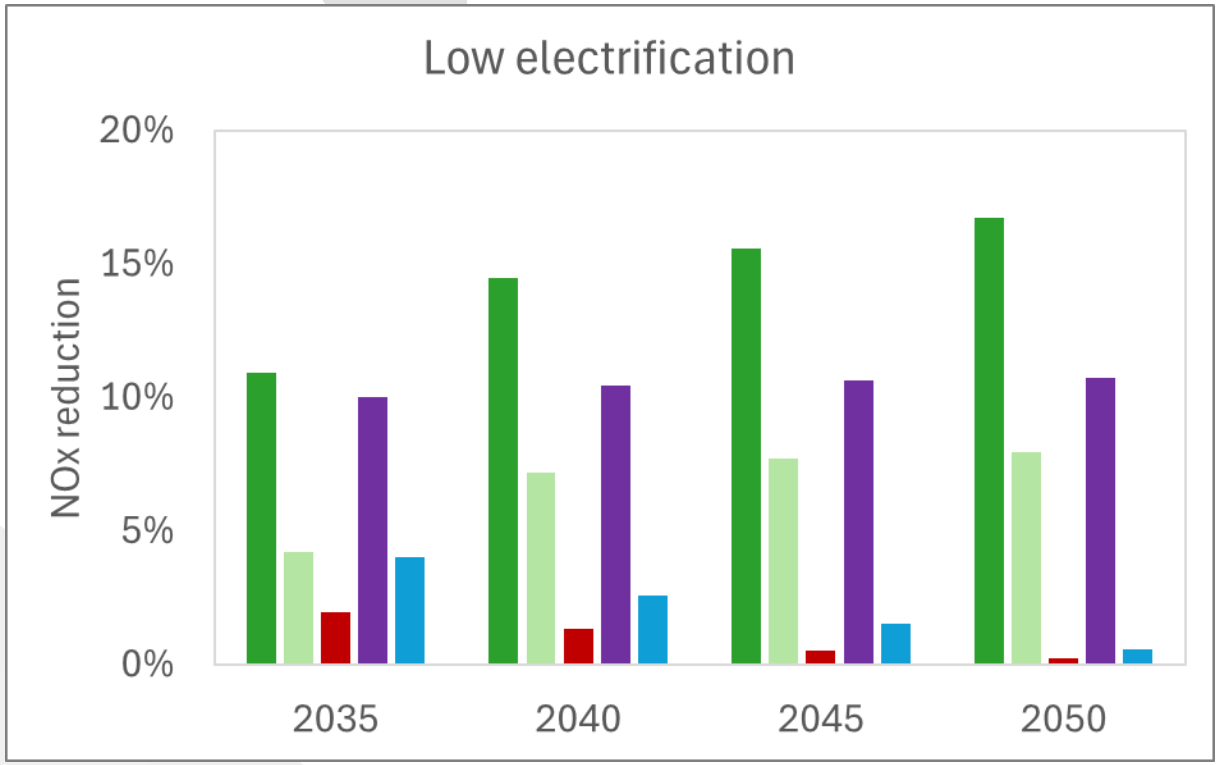
Example simulation result – M1 on NO_x emission

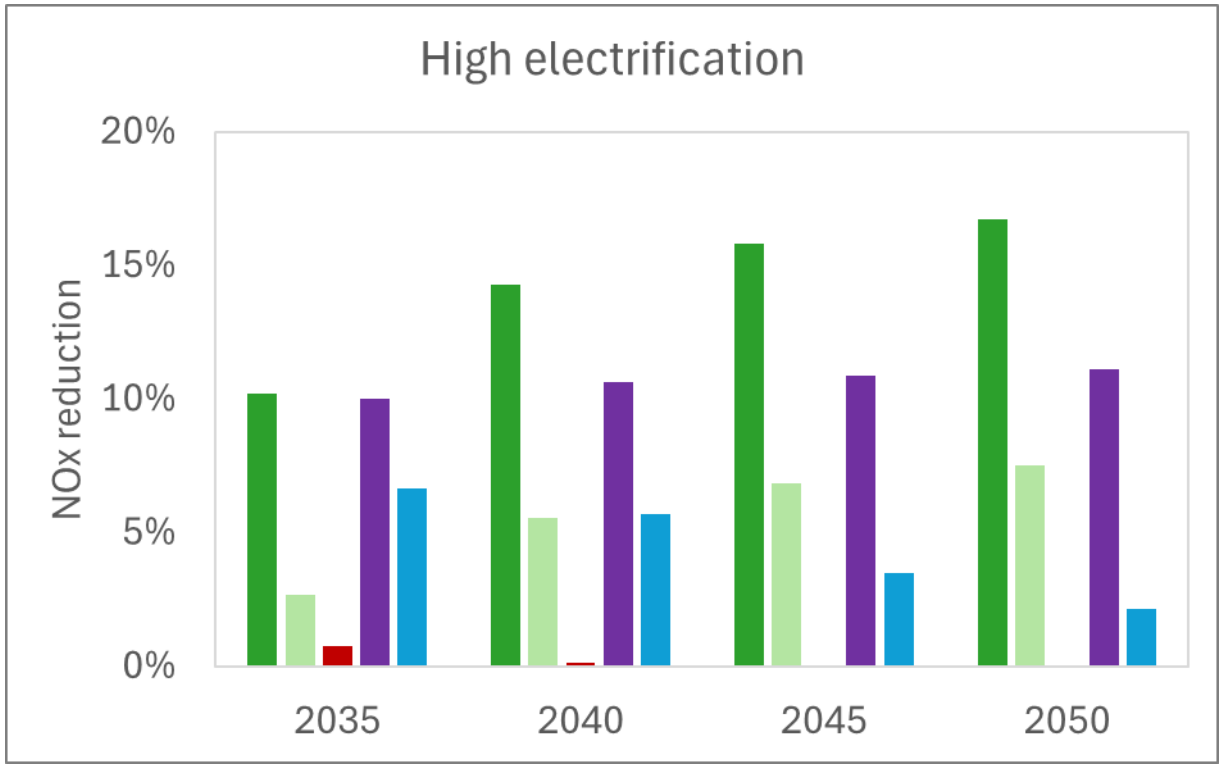


- Baseline NO_x emissions decrease over time due to electrification.
- M1a more effective than M1b for NO_x emission reduction

L-vehicles Emissions and Noise mitigation Solutions

NO_x Reductions



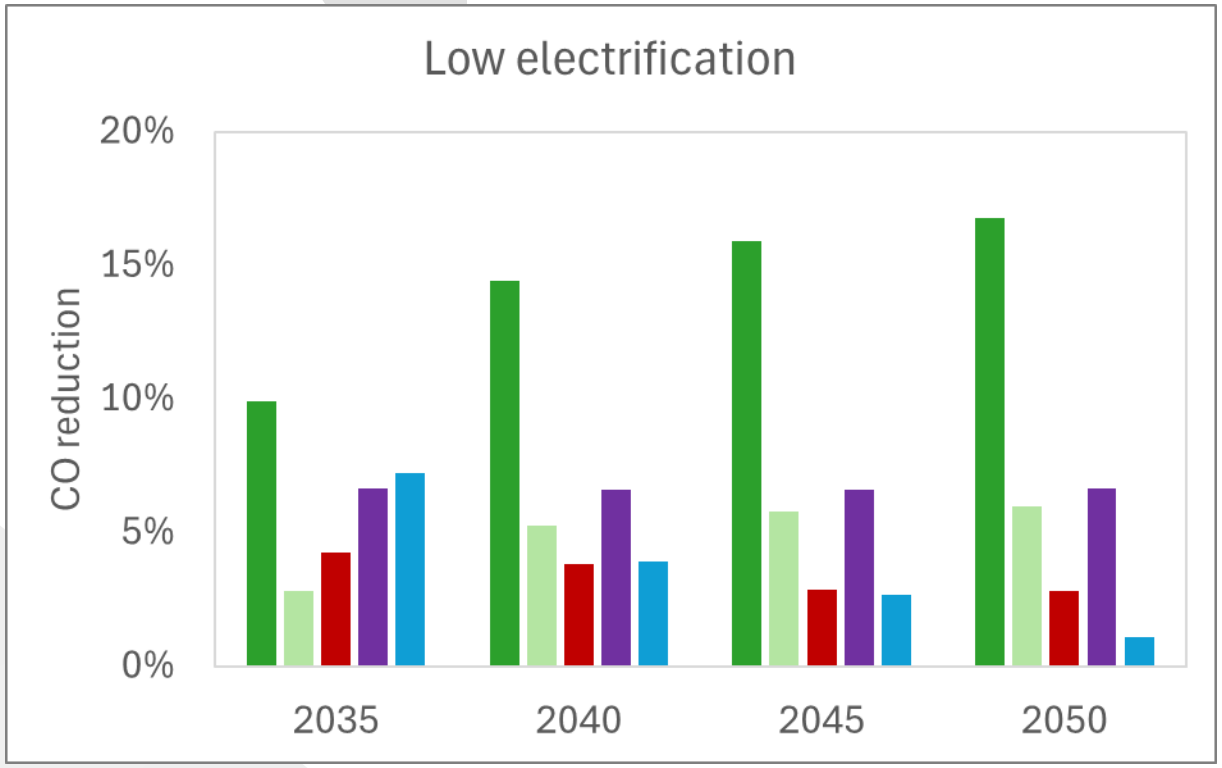


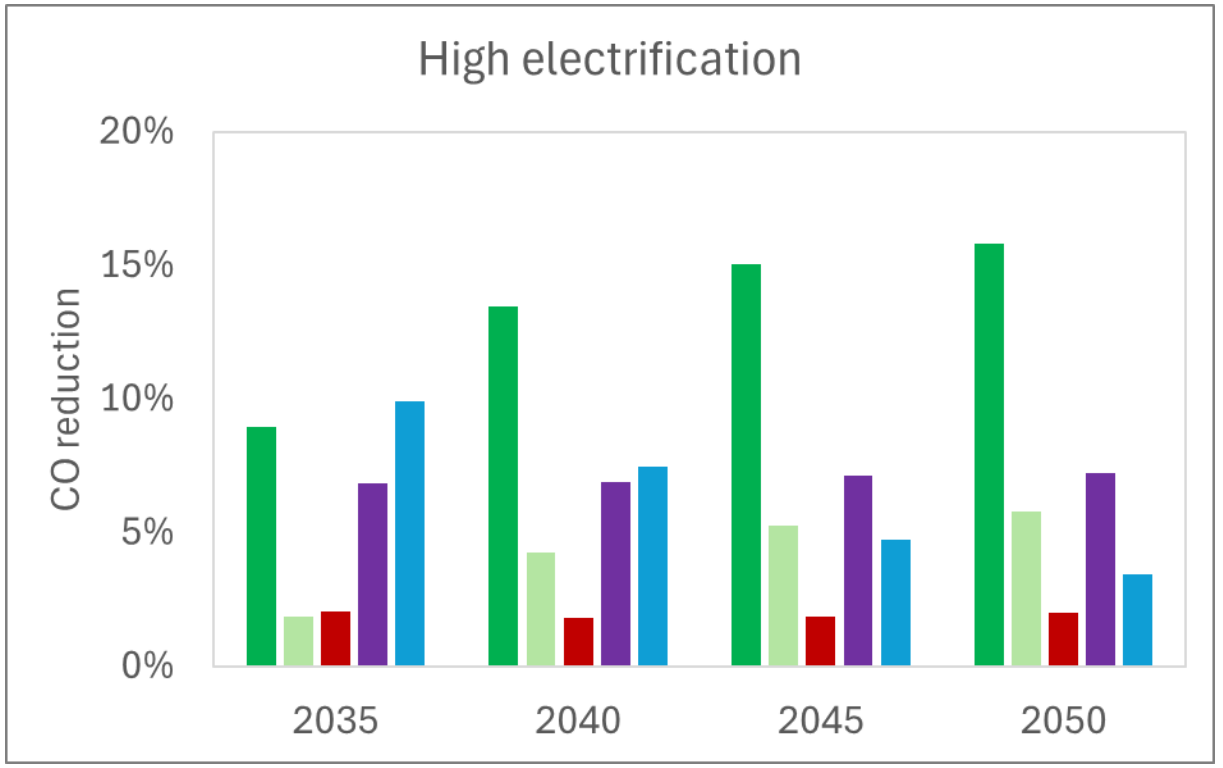
- M1a – Introduction of RDE highest impact
- M3&4 – Changes in driving behavior significant impact

M1a - Introduction of RDE
M1b - Stricter WMTC
M2 - Anti-tampering
M3&4 - Changes in driving behavior
M5 - Accelerated fleet renewal

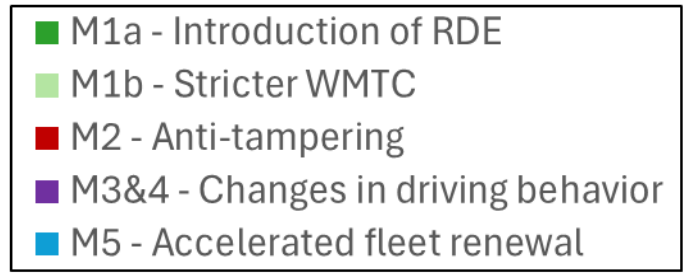
LENS L-vehicles Emissions and Noise mitigation Solutions

CO Reductions



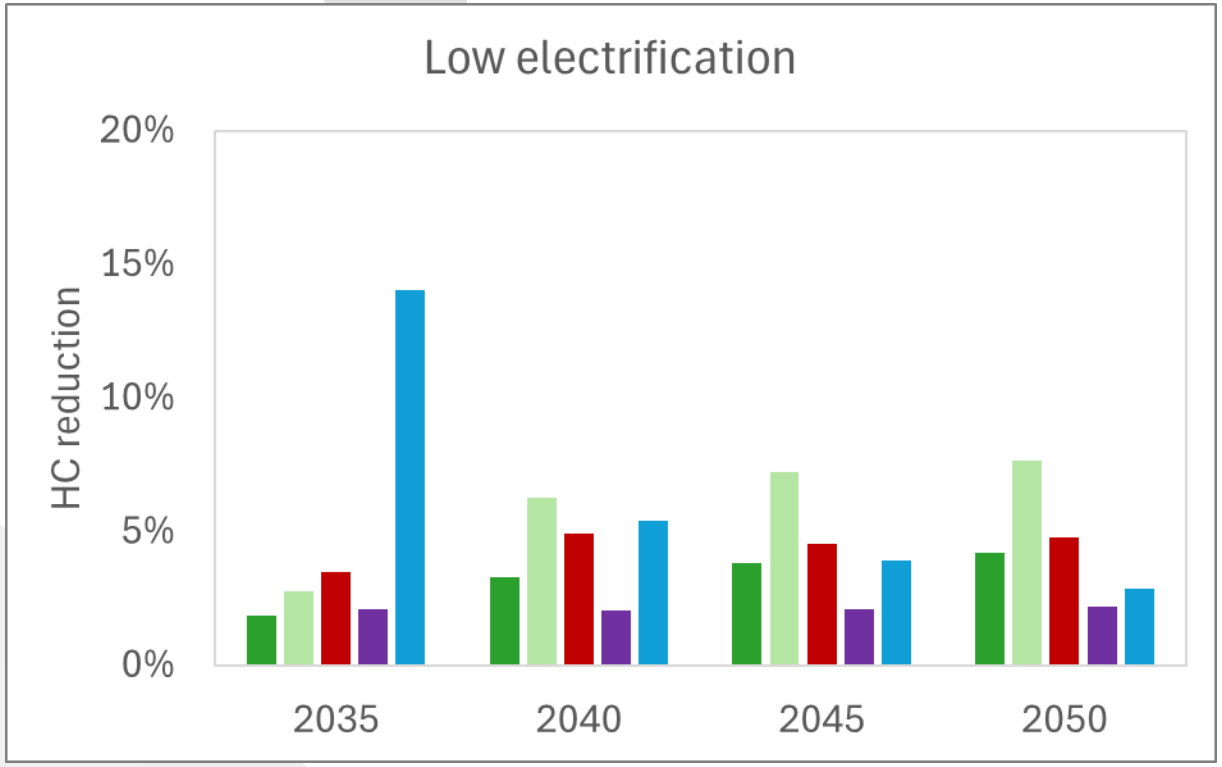


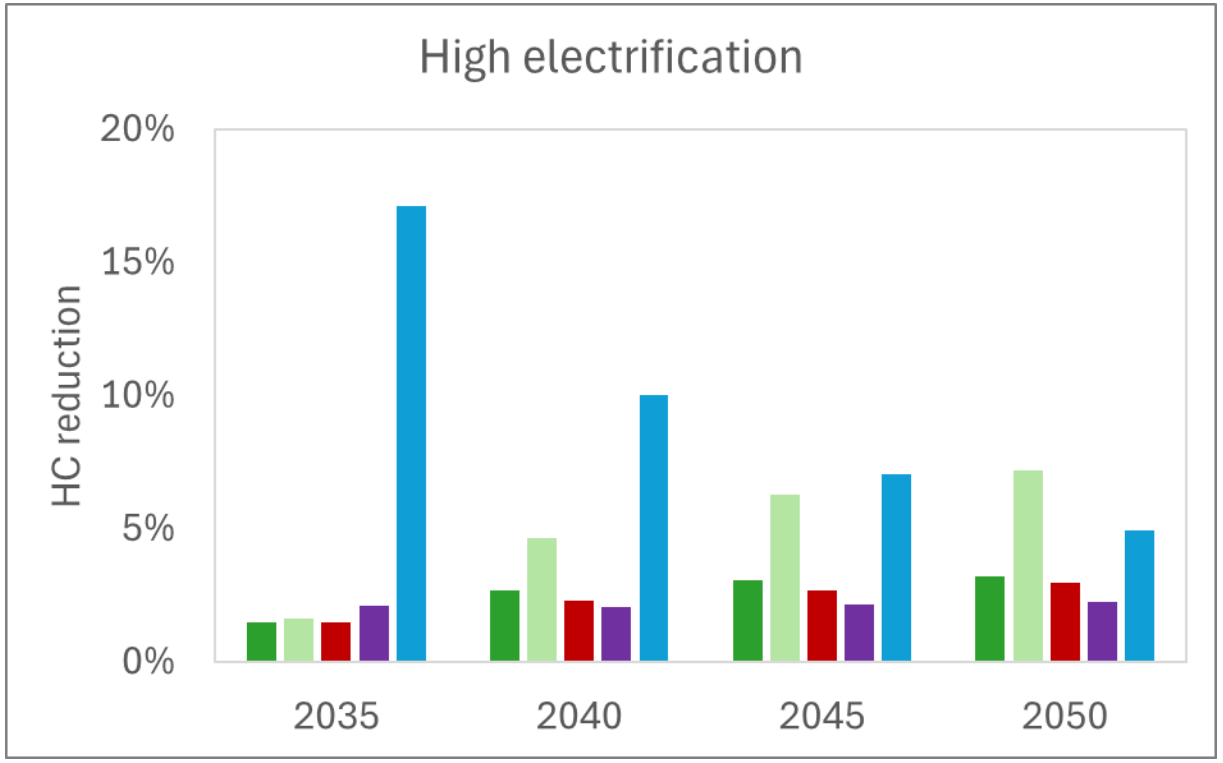
- M1a – Introduction of RDE highest impact



LENS L-vehicles Emissions and Noise mitigation Solutions

HC Reductions



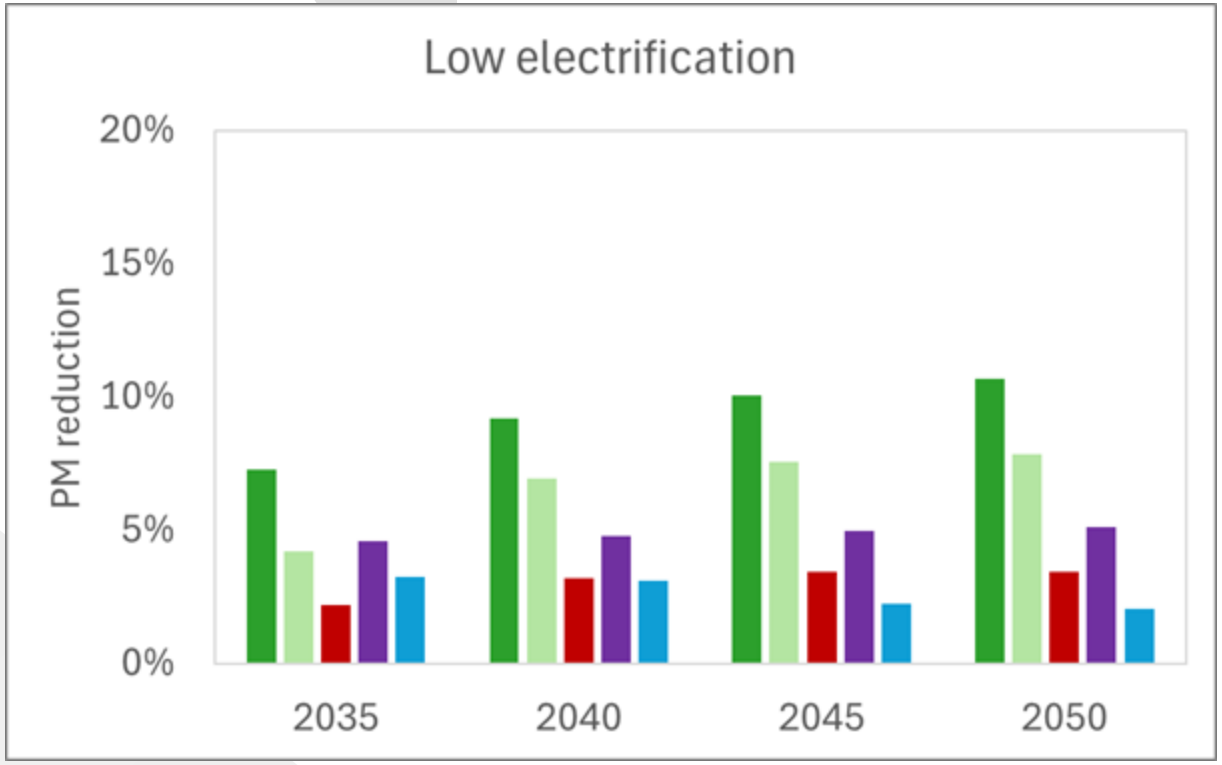


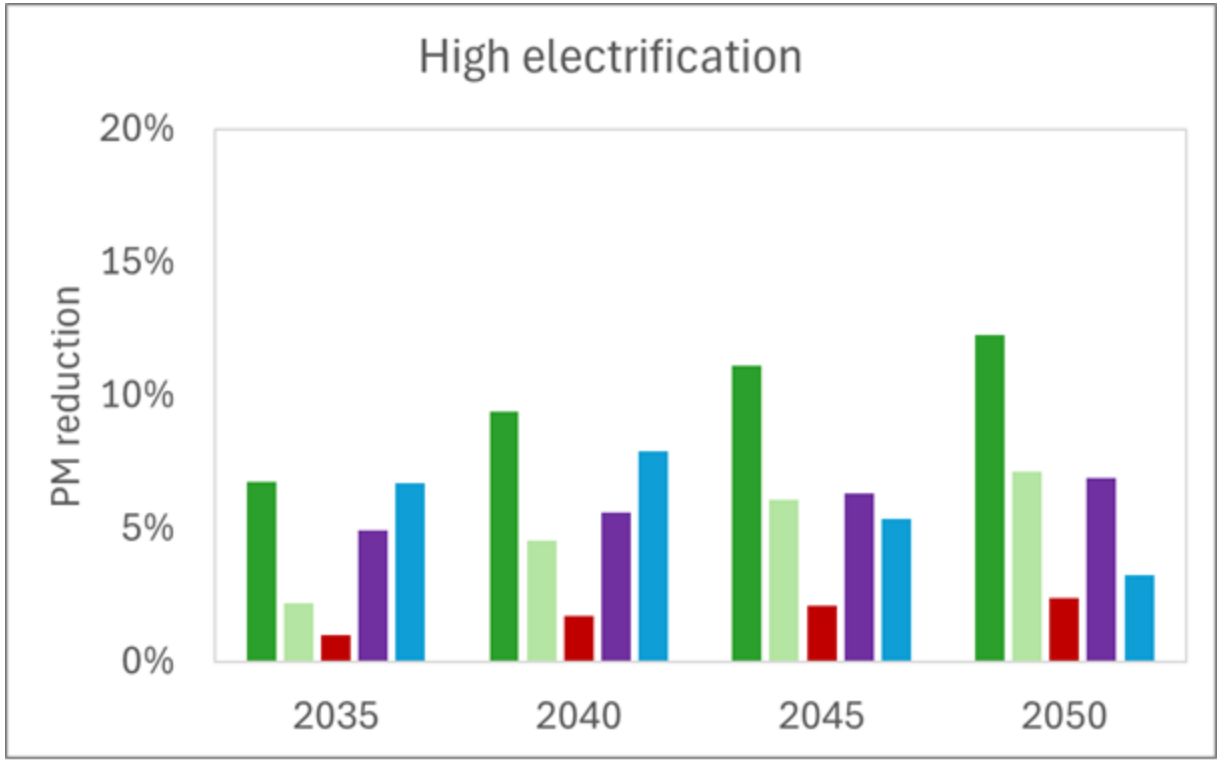
- M5 – Accelerated fleet renewal highest impact
  - Lesser effect by 2050 (fleet renewal ends at 2040)

- M1a - Introduction of RDE
- M1b - Stricter WMTC
- M2 - Anti-tampering
- M3&4 - Changes in driving behavior
- M5 - Accelerated fleet renewal

LENS L-vehicles Emissions and Noise mitigation Solutions

PM Reductions



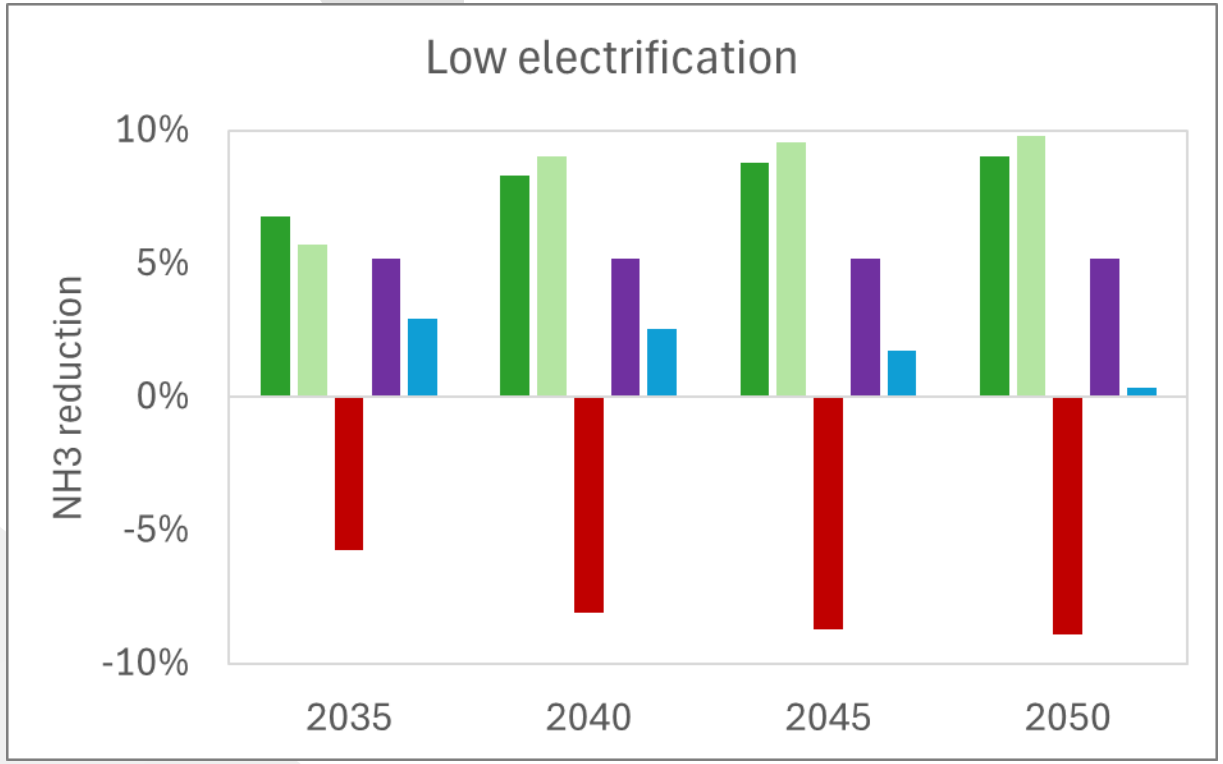


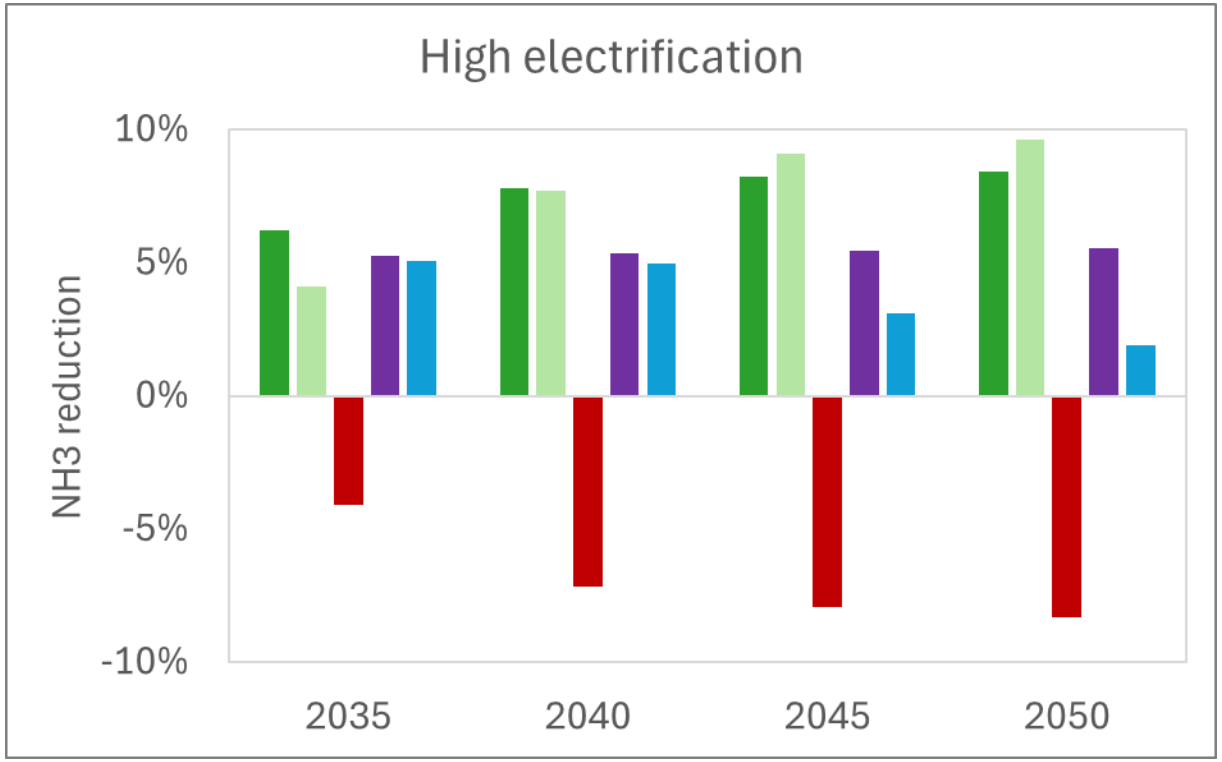
- M1a – Introduction of RDE highest impact

M1a - Introduction of RDE
M1b - Stricter WMTC
M2 - Anti-tampering
M3&4 - Changes in driving behavior
M5 - Accelerated fleet renewal

LENS L-vehicles Emissions and Noise mitigation Solutions

NH_3 Reductions





- M1a (RDE) & M1b (lower WMTC limits) highest impact
- M2 – Anti-tampering measures increase NH_3 emissions
  - NH_3 emission of tampered LVs is low due to catalyst absence

- M1a - Introduction of RDE
- M1b - Stricter WMTC
- M2 - Anti-tampering
- M3&4 - Changes in driving behavior
- M5 - Accelerated fleet renewal

LENS L-vehicles Emissions and Noise mitigation Solutions

Conclusions for emissions

- All measures provide significant emission reductions
- Emission reductions are significant even at high electrification
- Introduction of RDE has the highest effect
- Introduction of RDE seems more effective than stricter WMTC emission limits
- For even higher emission reductions combination of measures may be considered

Thank you

L-vehicles Emissions and Noise mitigation Solutions

Contacts

Georgios Triantafyllopoulos
giorgos.t@emisia.com

Michael Dittrich
michael.dittrich@tno.nl

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

Backup slides

Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

Emission Factor Calculation overview

General scheme for calculating emissions of a pollutant for a specific year and vehicle category:

$$E_{p,j,x} = N_{j,x} \; x \; M_{j,x} \; x \; EF_{p,j,x}$$

- E = total annual emissions
- N = number of vehicles in operation
- M = annual mileage per vehicle
- EF = estimated emission factor in g/km
- p = pollutant (Air Pollutants)
- j = vehicle category
- x = year of calculation

$$EF_{final} = EF_{combined} \cdot (1 - Tamp.share) \cdot DF + EFcombined \cdot (Tamp.share) \cdot TR$$

- EF_{final} = the final estimated emission factor in g/km
- $EF_{combined}$ = emission factor depending on the Euro standard vehicle technology in g/km
- DF = deterioration factor of emissions at mean fleet mileage
- TS = % share of tampered vehicles
- TR = tampering emission rate

For Euro 5:

$$EF_{combined} = (w_1 \cdot EF_{WMTC} + w_2 \cdot EF_{nonWMTC}) + EF_{cold\ effect}$$

- w1, w2 = fraction of mileage inside, outside WMTC conditions ($w_1 + w_2 = 1$)
- $EF_{insideWMTC}$, $EF_{outsideWMTC}$ = average emission level in g/km in the operating points inside WMTC and outside WMTC
- $EF_{cold\ effect}$ = mean excess emissions due to cold starting in g/km

For Euro 0-4:

$EF_{combined}$ → copert

LENS L-vehicles Emissions and Noise mitigation Solutions

Specific effects of loud vehicles

- Known effects of loud vehicles on citizens:
  Annoyance, sleep disturbance, concentration loss, stress, perception of ‘unnecessary’ noise
  - > Complaints and petitions, highest for all vehicle types

- Noise characteristics including strong fluctuation, tonality, impact -> high dose-effect relationship

- Irregular loud noise peaks are not sufficiently reflected in long term noise averages such as Lden
  -> also single event analysis

- Need for link to health effects of repeated high peaks

Current practice for noise

- Fining for excessive noise – police checks and measurement – evidence required
- Roadside test for stationary noise – time consuming, trained staff, limited effect
- Vehicle annual inspection (PTI) – vehicle authority (not in all countries for motorcycles) but no in use conformity
- Noise type approval test for new vehicles, passby and stationary
- Introduction of noise cameras
- No roadside noise limits for in use vehicles
- Environmental noise mapping – no peaks, low source levels; action plans

Additional options – Driver communication, awareness and attitude

- Road signing and warning displays
- Information for L-vehicle owners on noise impact, penalties driving behaviour, vehicle maintenance, tampering and aftermarket parts
- Include in driving lessons, websites, magazines
- Digital innovation: on board indicator for excessive noise (when is noise excessive?)
- Effects: precautionary and feedback to drivers
- Timescale: 2025-2050
- Actors: Local and national authorities, vehicle authorities, driving schools/authorities,
  drivers, dealers

Additional options – END Directive

- Increase source levels for L-vehicles in CNOSSOS-EU traffic noise model
- Introduce separate dose-effect relationship for L-vehicles, especially motorcycles
- Effects:

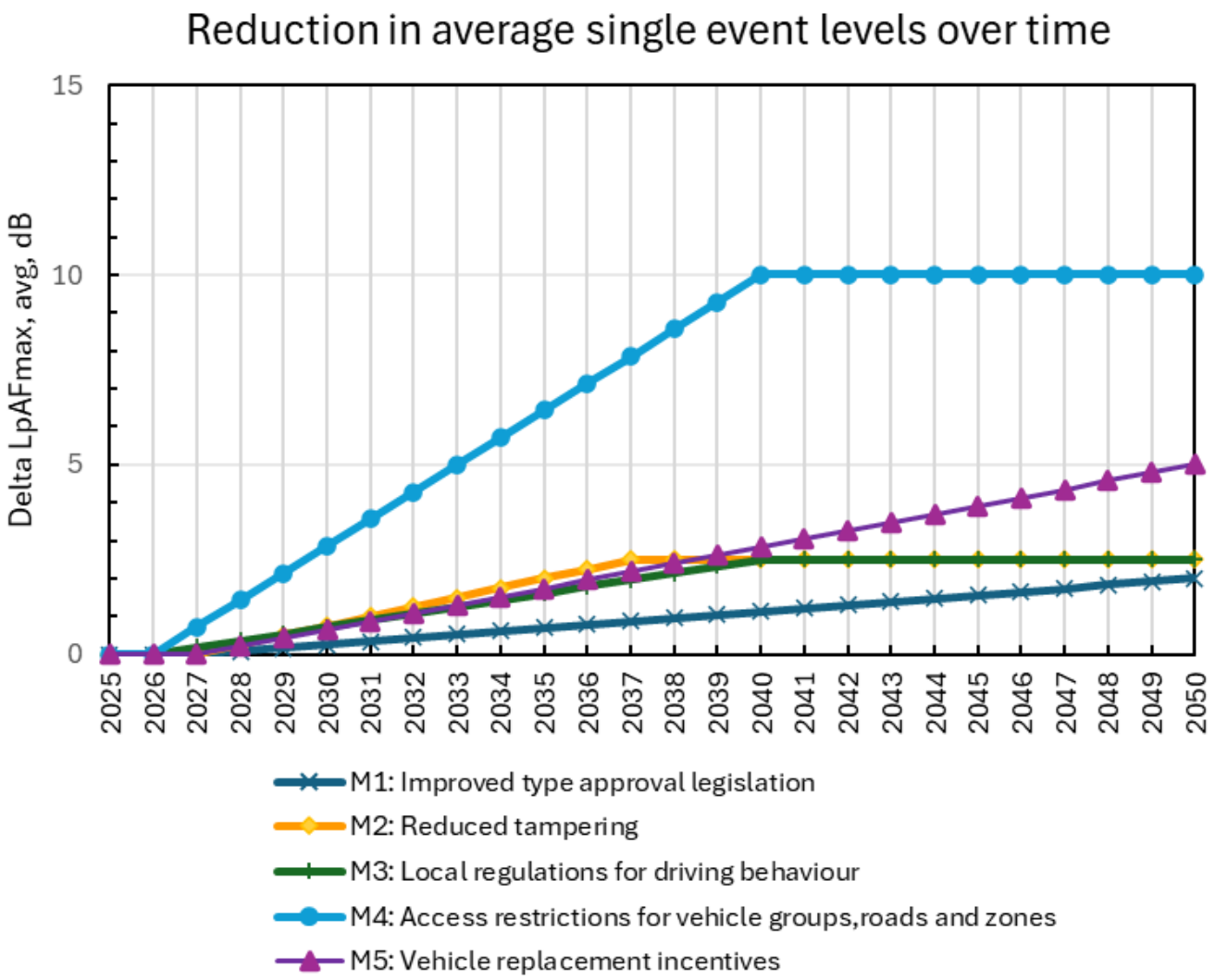
  Better accounting for L-vehicle noise in environmental management and information to the public

- Trigger for **Action plans for critical locations** with high L-vehicle noise
- Timescale: 3-4 years (END amendment + Implementation)
- Actors: EU + member states

Additional options – market surveillance of aftermarket and add-on parts

- Monitoring and inspection of import and sales of non compliant and noise increasing parts including exhausts, sound systems, derestriction kits, ECU flash systems
- Effects: Reduce availability of noncompliant parts
- Timescale: 2026-2050
- Actors: vehicle authorities, market inspection authorities, vehicle owners, dealers

Single event average level reduction over time



Evolution of average single event levels
Per scenario

Local regulations and access restrictions only affect the roads where applied

L-vehicles Emissions and Noise mitigation Solutions

Estimation of monetised of benefits per scenario, EU27

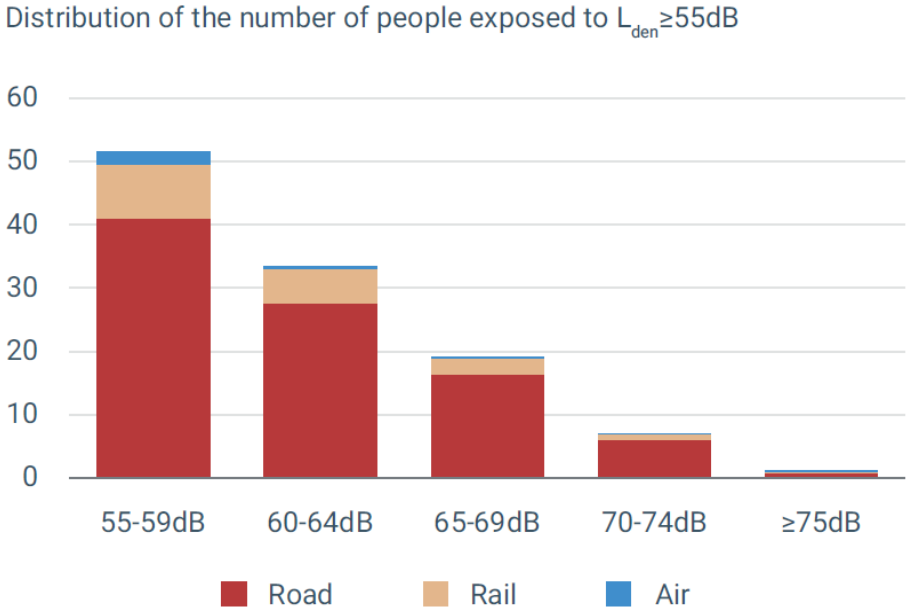
			Benefits calculation based on 0,001 Euro/dB/household			
			Average single event reduction	Accumulated Benefits all roads up tp 2050	Remarks	
Scenario	Percentage of roads affected	Effectuation time in years	dLAmax dB	MEuro		
M1: Improved type approval legislation	100%	15	2	651	Improved type test covering all conditions and antitampering	Starts from date of introduction, grows to max effect
M2: Reduced tampering	100%	10	2.5	1317	Enforcement/inspection/parts market	Starts from date of introduction, grows to max effect
M3: Local regulations for driving behaviour	20%	10	2.5	247	Speed limits+driving behaviour+enforcement	Gradually increases and stays constant
M4: Access restrictions for vehicle groups,roads and zones	20%	10	10	989	Total or vehicle selective, or LEZ	Can start im short term and remains continuous
M5: Vehicle replacement incentives	100%	15	10	1627	Electrification incentives or rules	Starts from date of introduction, grows to max effect after full or partial fleet replacement

Cost indication per scenario

		Costs estimate, accumlated 2025-2050							
		R&D (Industry)	Manufac-turing (Industry)	Enforcement staff and equipment	Vehicle inspection and handling	State subsidies	Infra-structure costs	Total	Remarks
Scenario	**Effectuation time in years**	**MEuro**	**MEuro**	**MEuro**	**MEuro**	**MEuro**	**MEuro**	**MEuro**	
M1: Improved type approval legislation	5	x	x						Improved type test covering all conditions and antitampering
M2: Reduced tampering	5			x	x				Enforcement/inspection/parts market
M3: Local regulations for driving behaviour	10			x			x		Speed limits+driving behaviour+enforcement
M4: Access restrictions for vehicle groups,roads and zones	10			x			x		Total or vehicle selective, or LEZ
M5: Vehicle replacement incentives	10					x			Electrification incentives or rules
	Note: for implemen-tation						Note: also revenues from fines etc.		

Health impacts (EEA 2025)

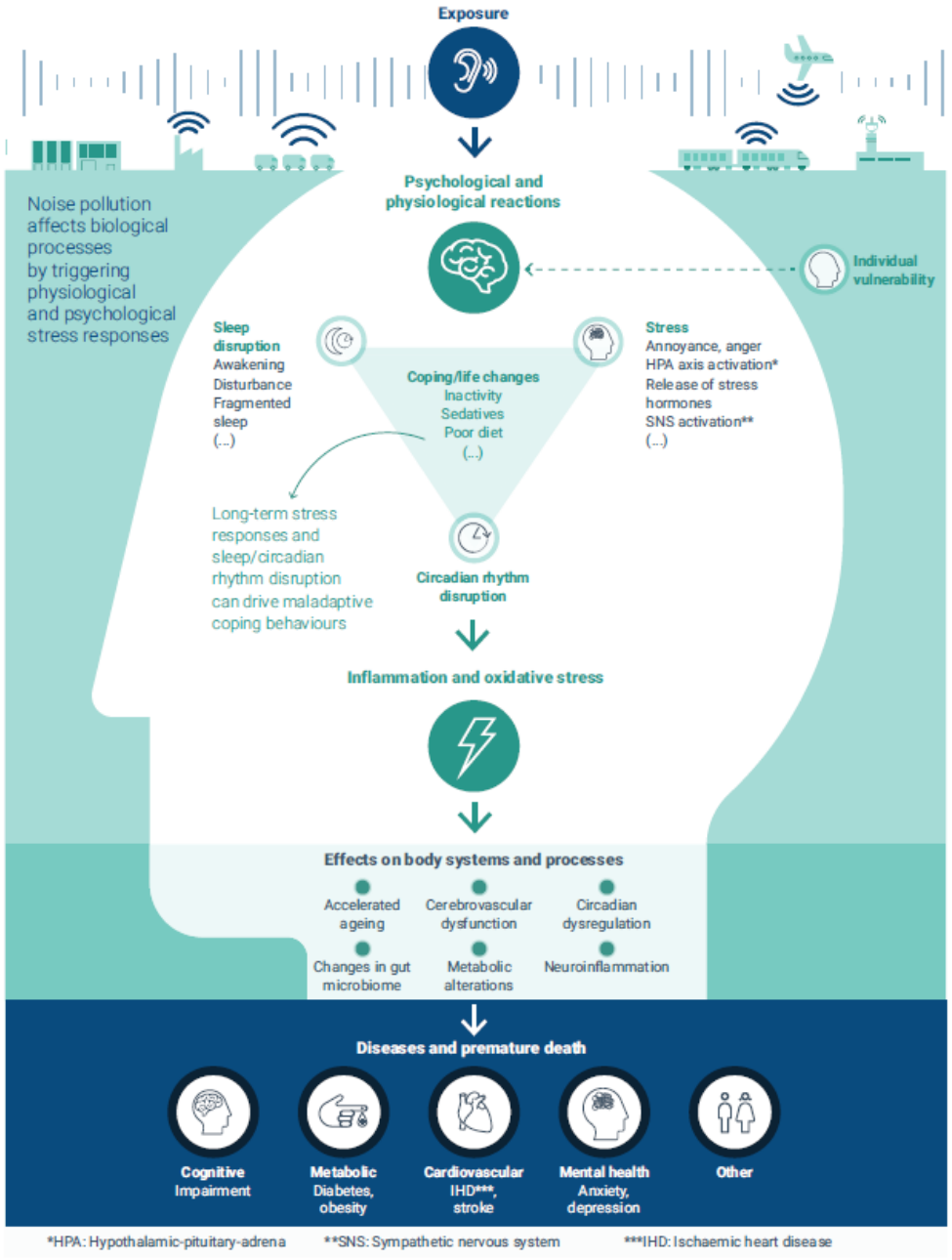
Distribution of the number of people exposed to noise from road, rail and air traffic in 5dB bands for the L_{den} period



Distribution of the number of people exposed to noise from road, rail and air traffic in 5dB bands for the L_{night} period

Health effects above Lden 55 dB

Figure 3.1 Biological indirect pathways through which environmental noise impacts health



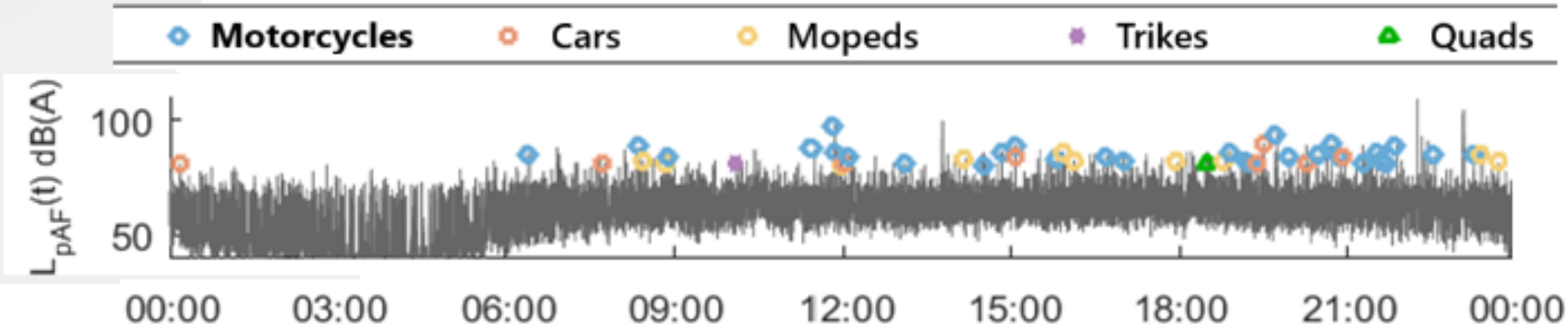
Note: Non-exhaustive list of diseases or risk factors or system disfunctions.

Sources: Adapted from Arregi et al., 2024; Münzel et al., 2018; Hahad et al., 2024; Phan and Malkani, 2019.

vehicles Emissions and
oise mitigation Solutions

What is loud and how many vehicles?

- 10 dB or more above average car pass-by noise levels
- Typically more than 80 dB(A) at roadside
- About 10-30% of motorcycles, depending on situation and driving
- About 0.04% - 0.2% of cars (NL cities)
- Causes: driving behaviour and vehicle modifications/tampering/tuning, ‘Sports’ settings



Urban roadside sound level 24h