www.theicct.org
berlin@theicct.org
twitter @theicct

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION
NEUE PROMENADE 6 | 10178 BERLIN

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ICCT's COMMENTS AND TECHNICAL RECOMMENDATIONS ON FUTURE EURO 7/VII EMISSION STANDARDS

The ICCT welcomes the Euro 7/VII proposal put forward by the CLOVE consortium in the AGVES meetings during the month of April of 2021. Ambitious Euro 7/VII standards will bring mature emission control technologies into the market. These in turn will deliver substantial health benefits through the improvement of air quality.

However, to achieve the goal of *Zero Pollution Ambition*, we consider it important for Euro 7/VII to place a stronger focus on urban emissions. This document provides ICCT's recommendations to strengthen the CLOVE Euro 7/VI proposal, and offers a critical assessment of the arguments put forward by other stakeholders on the feasibility and benefits of stringent pollutant emissions standards.

A. ICCT's assessment of health benefits from stringent Euro 7/VII standards

In our modeling, we define stringent Euro 7 standards for NO_x as those that achieve a limit of 15 mg/km for passenger cars and 23 mg/km for vans when averaged over all real-world driving conditions and for the useful life of the vehicle. We define stringent Euro VII standards for NO_x as those that achieve a 90% reduction in NO_x emissions for trucks and buses compared to Euro VI step C when averaged over all real-world driving conditions and for the useful life of the vehicle. We evaluated the benefits of these stringent Euro 7/VII standards assuming implementation for all new vehicle sales and registrations in 2027. We then quantified the NO_x emission benefits, the impacts of these NO_x emission reductions on ambient $PM_{2.5}$ and ozone levels in each EU member state, and avoided premature deaths and disability-adjusted life years (DALYs) from

2027–2050. We calculated these health impacts using the methods of the latest Global Burden of Disease study.[1]

We provide sensitivity analysis of the benefits of stringent Euro 7/VII standards considering projected uptake of zero-tailpipe emission vehicles (ZEVs) (a) based on currently adopted regulations and (b) assuming new policies that achieve 100% ZEV sales for cars and vans by 2035 and for trucks and buses by 2040. These ZEV pathways are consistent with the *Adopted* and *Moderate Ambition* scenarios published in a recent ICCT briefing paper.[2] In both cases, we estimated only the impacts associated with changes in tailpipe NO_x emissions. Because our estimates do not consider tailpipe emission reductions for other pollutants, our estimates of the air quality and health benefits of Euro 7/VII are conservatively low.

Currently adopted policies are projected to steadily reduce tailpipe NO_x emissions over the next thirty years: we estimate that adopted policies will reduce NO_x emissions by 88% for light-duty and 82% for heavy-duty vehicles by 2050 compared to 2020 levels. Implementation of stringent Euro 7/VII standards in 2027 could achieve these emission reductions much earlier—by 2040 for light-duty and 2035 for heavy-duty vehicles.

Considering ZEV projections under adopted policies, Euro 7/VII standards could avoid 4.2 million tonnes of NO_x cumulatively from 2027–2050, compared to a scenario with only adopted policies. Increasing ZEV sales in line with our *Moderate Ambition* scenario would increase the cumulative NO_x benefits of Euro 7/VII combined with ZEV uptake to 5 million tonnes.

These reductions in tailpipe NOx emissions are projected to improve air quality across the EU-27, in particular by reducing ambient $PM_{2.5}$ and ozone levels. Considering ZEV projections under adopted policies, Euro 7/VII standards could avoid approximately 35,000 premature deaths and 568,000 DALYs across the EU-27 cumulatively from 2027–2050, compared to a scenario without Euro 7/VII standards. Increasing ZEV sales in line with our *Moderate Ambition* scenario would increase the cumulative health benefits of Euro 7/VII combined with ZEV uptake to approximately 42,000 premature deaths and 682,000 DALYs.

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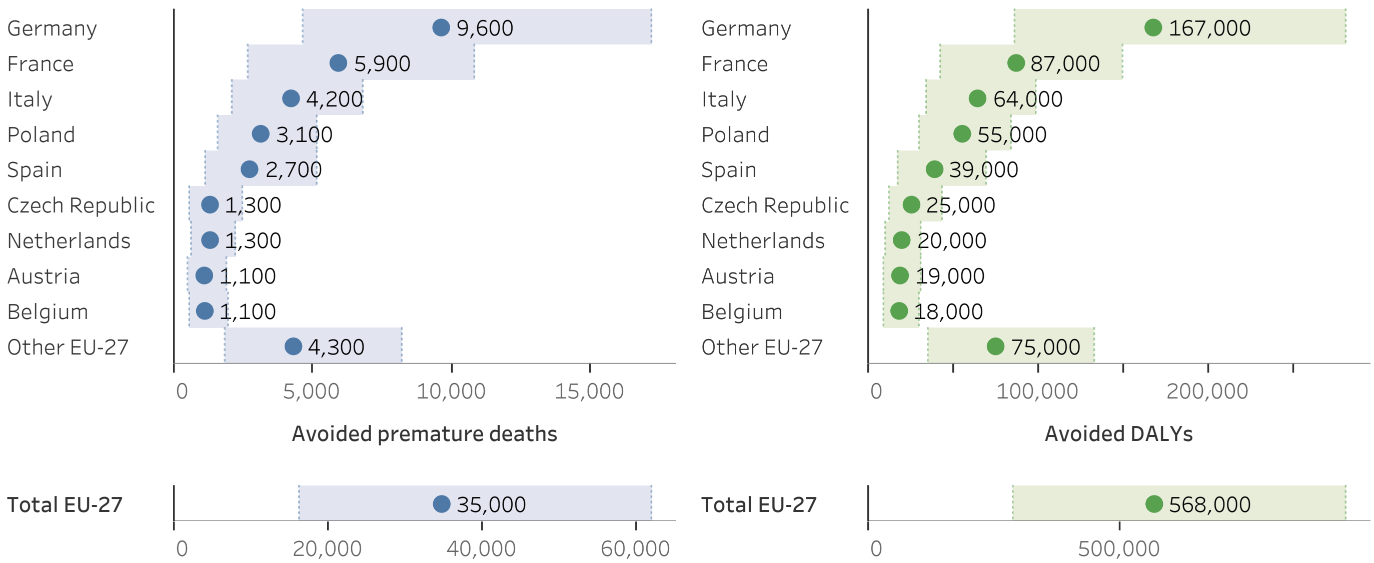
[1] Institute for Health Metrics and Evaluation, “Global Burden of Disease (GBD),” 2020, http://www.healthdata.org/gbd/2019.

[2] Claire Buysse et al., “What the Stringency of the European Union’s Vehicle CO2 Standards Means for the European Green Deal” (Washington, D.C.: International Council on Clean Transportation, March 29, 2021), https://theicct.org/publications/eu-standards-green-deal-fs-mar2021.

Cumulative health benefits of Euro 7/VII standards compared to adopted policies, 2027–2050



Data labels shows central estimates. Dashed lines and bars show the uncertainty range of the concentration-response functions. Results are shown individually for all countries with more than 1,000 avoided premature deaths.

B. LDV comments

ICCT welcomes the proposal made by the CLOVE consortium on April 27. We propose below recommendations for strengthening this proposal.

1. Emissions budget in urban operation

The current CLOVE proposal suggests an emission budget based on 16 km, when typical urban trips in European cities can be significantly shorter.

Average trip started/ended in a city – Germany[3]	10.3 km
Average inner-city trip – Germany[4]	5.5 km
Median city trip – Paris[5]	5.2 km

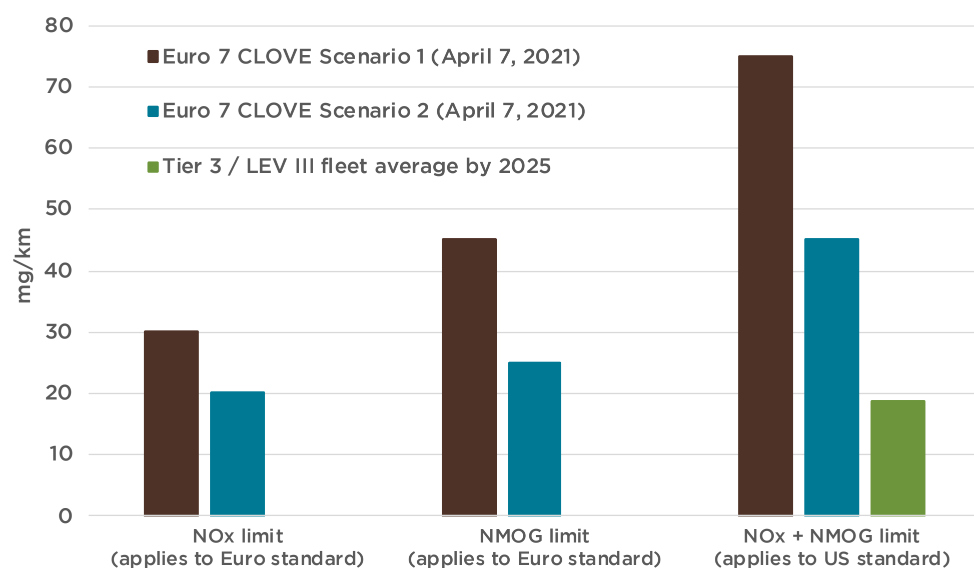
The Euro 7 emission budget proposal (CLOVE Scenario 1) based on 16 km would allow vehicles to emit NO_x on the first 5 km an equivalent of about 90 mg/km in normal conditions, and approximatively 270 mg/km in extended conditions.

[3] TU-Dresden (SrV-2018)
[4] TU-Dresden (SrV-2018)
[5] IFPen – GecoAir database (Etude Emissions Euro 6d-TEMP)

To ensure Euro 7 delivers low emission in conditions typical of European cities, ICCT suggests shortening the emission budget to a maximum distance of 8 km, adjusting the budget limit accordingly, and recognizing the disproportionate impact of cold-start emissions in such operations.

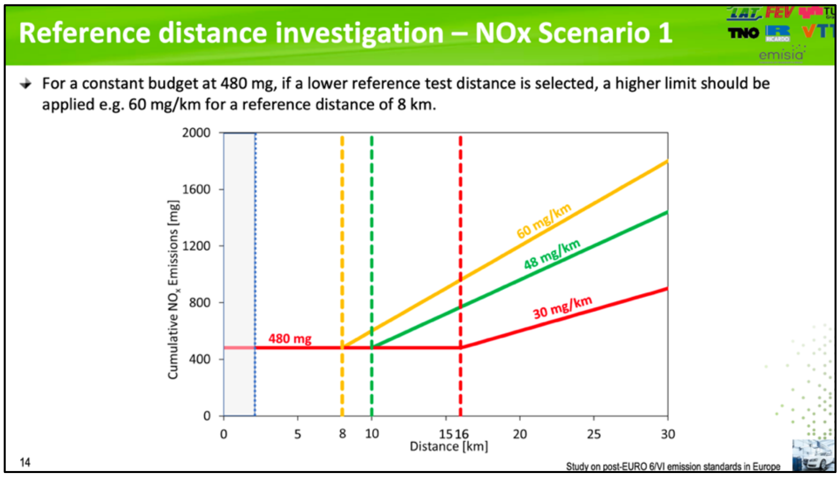
2. Technology feasibility for more stringent limits than proposed by CLOVE

A comparison with the US emission standard in 2025 indicates that Euro 7 would be lagging behind in regard of NO_x + NMOG emission limits. Even the most stringent CLOVE scenario 2 (NOx limit of 20 mg/km) would lead to a higher limit than in the US for NO_x and NMOG combined (18.6 mg/km). We understand that this comparison only refers to laboratory conditions, but those should be indicative of what can be achieved in warm operation—i.e., after the emissions budget.

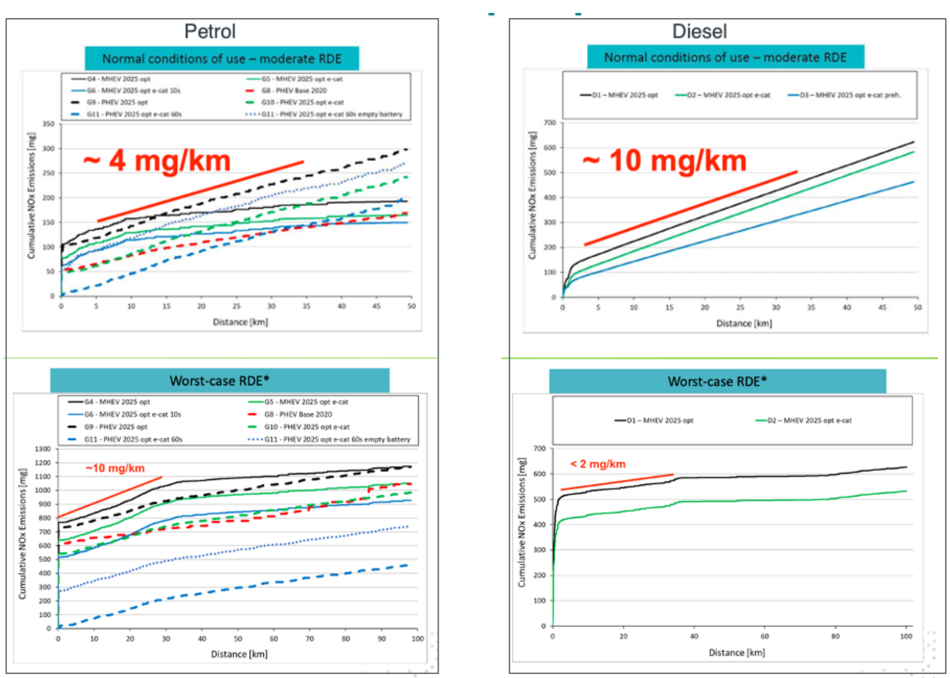


It is evident that the CLOVE proposal limit in warm operation is largely determined by the budget, and CLOVE suggested that a lower limit and a shortened urban distance for the emission budget would necessarily imply higher emission limits (in mg/km) in the hot phase—we refer to the CLOVE figure below from April 27, 2021. **We disagree with this rationale for setting the limits, and argue that the cold-started urban emission limits (i.e., the budget in mg) must be decoupled from the hot emission limits (i.e.**

the slope in mg/km) to pull the adoption of technologies already demonstrated by several suppliers[6] and engineering service providers.



ICCT acknowledges that engine cold-start needs particular handling to be able to control emissions whilst maintaining technically feasible legislation. However, evidence from the CLOVE consortium (April 7, 2021) show that emissions after 5 km can be controlled to very low levels with the appropriate management.



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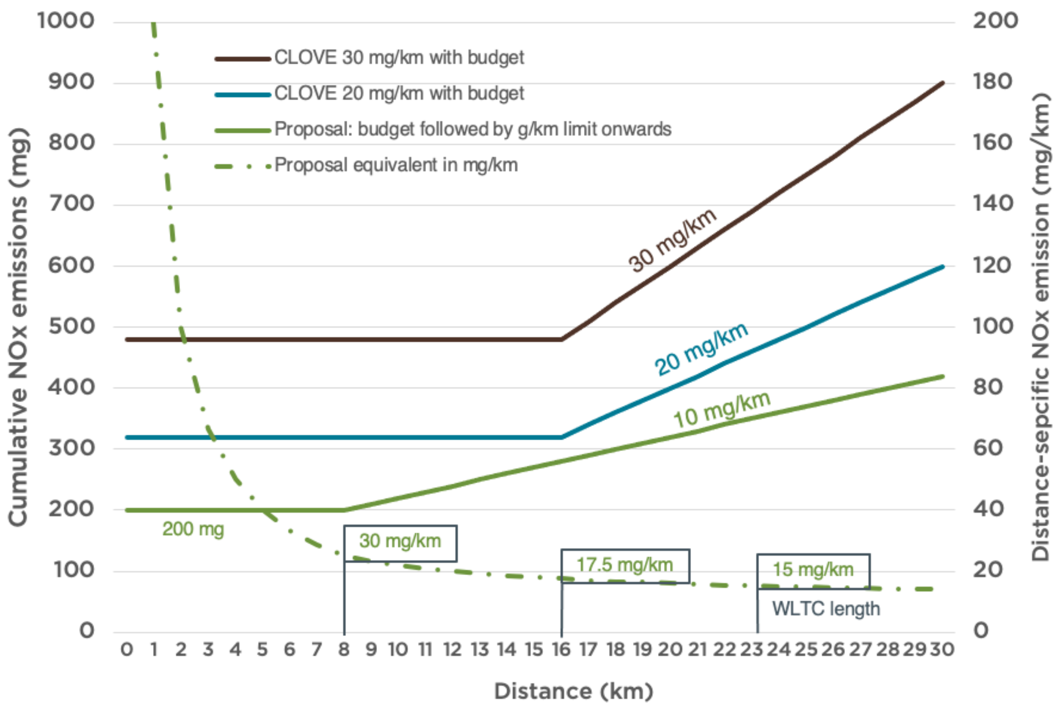
[6] For example: J. Demuynck et al., "Integrated Diesel System Achieving Ultra-Low Urban and Motorway NO_x Emissions on the Road," 2019, http://www.aecc.eu/wp-content/uploads/2019/04/190516-AECC-IAV-IPA-Integrated-Diesel-System-achieving-Ultra-Low-NOx-on-the-road-Vienna-Symposium.pdf.

The ICCT proposes a more ambitious Euro 7 scenario that can achieve lowest achievable emission limits by decoupling the budget allowable for short distances while keeping emissions lower than the current proposal onwards for longer trips. **The figure below presents an example of a proposal for on-road NO_x, with a fixed 200 mg budget running up to 8 km, and a 10 mg/km limit onwards in normal conditions.** The equivalent distance-specific emission limit depends on the trip length and would yield to 30 mg/km at 8 km and close to 15 mg/km for the length of a WLTC.



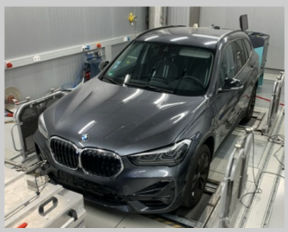
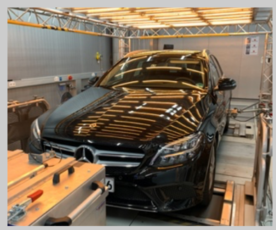
A similar approach is proposed for on-road CO and PN emission limits and meet the stringency levels of the COLVE consortium at 16 km, although yield to lower emission limits on shorter and longer trips.

	Budget distance (km)	Budget (mg or #)	Limit after the budget (mg or # /km)	Limit at 8km (mg or # /km)	Limit at 16km (mg or # /km)	Limit at WLTC length (mg or # /km)
NO_x	8	200	10	25	17.5	15.2
CO	8	4,800	200	600	400	337.6
PN	8	1.2E+12	5.00E+10	1.5E+11	1E+11	8.4E+10

This proposal was compared to emissions testing performed by the ICCT between September 2020 and March 2021 on 3 cars, a gasoline mild-hybrid, a

gasoline plug-in hybrid, and a diesel vehicle as shown in the table below. All vehicles were type-approved according to the latest Euro 6d-ISC-FCM emission standard. The two gasoline vehicles had a low mileage at test start; the Audi odometer showed a value of 1,220 km and the BMW 2,300 km. Therefore, some improvement in the emission values, especially for the PN emissions, are expected considering the running-in effect of particulate filters.

Test vehicle specifications

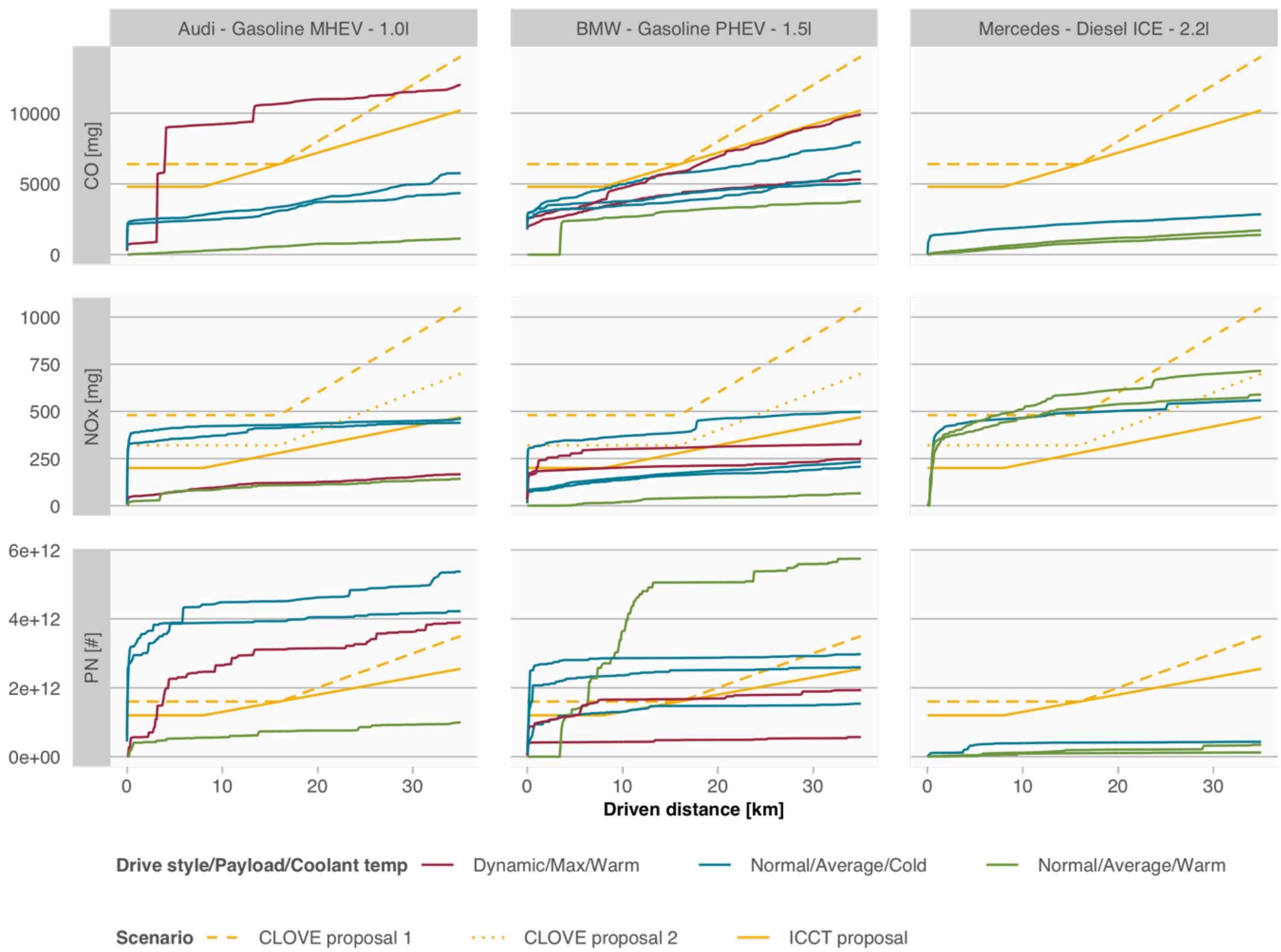
Parameter	BMW X1 xDrive 25e	Mercedes C220d T	Audi A3 30 TFSI
			
Powertrain architecture	Plug-in Hybrid	ICE only	Mild Hybrid
Fuel type	Gasoline (E10)	Diesel (B7)	Gasoline (E10)
Transmission	DCT - 6 gears	Automatic - 9 gears	DCT - 7 gears
Powered axle(s)	Front: ICE+BSG[3)] Rear: EM	Rear	Front
Chassis type	SUV	Station Wagon	Hatchback
Emission standard (EU) 2018/1832	Euro 6d-ISC-FCM (Euro 6 AP)	Euro 6d-ISC-FCM (Euro 6 AP)	Euro 6d-ISC-FCM (Euro 6 AP)
ICE capacity	1499 cm^3	1950 cm^3	999 cm^3
Cylinder configuration	In-line 3	In-line 4	In-line 3
Rated power – ICE[1)]	92 kW	143 kW	81 kW
Rated power – EM[2)]	BSG 15 kW Rear axle 70 kW	N/A	BSG 9.4 kW
Exhaust aftertreatment system configuration	Close-coupled TWC[4)] Underfloor GPF[5)]	Close-coupled DOC[6)] Close-coupled SCRF[8)]/SCR[7)] Underfloor SCR + AOC[9)]	Close-couple coated GPF Underfloor TWC

Abbreviations: 1) Internal combustion engine; 2) Electric motor; 3) Belt starter generator; 4) Three way catalyst; 5) Gasoline particulate filter; 6) Diesel oxidation catalyst; 7) Selective catalytic reduction catalyst 8) SCR coated filter; 9) Ammonia oxidation catalyst

Cumulative emissions from on-road tests

The vehicles were tested on road using an AVL MOVE PEMS to measure pollutant emissions. Tests were performed on two different routes, applying normal and more dynamic driving style and both normally loaded and exploiting the maximum RDE payload. The tests with high dynamicity were outside the RDE boundaries due to exceeding the $v*a_{pos}$ requirements in urban, rural and for most tests also for highway driving.

The figure below shows the NO_x, CO and PN emissions of each test accumulated over the driven distance. As the main focus is on the emissions during the first phase of a drive cycle, the plot shows a zoom of the data for the first 35 km. **The yellow lines present the Euro 7 emission limits proposed by the CLOVE consortium as scenario 1 and 2. In addition we added our proposal, indicated by a dotted yellow line.**



Cumulative emissions measured with PEMS during on-road tests on two different routes for 3 different Euro 6d-ISC-FCM vehicles. The yellow lines present three different emission limit scenarios with an emission budget for the first cycle phase. The graphs show a zoom in for 0 - 35 km driven distance.

The data shows that the CLOVE-scenario-1 emission limits for CO and NO_x are met or close to being met by Euro 6d technology vehicles. For the BMW, this is also the case for the dynamic/high payload test. The Audi shows for this test CO emissions above the proposed limit. Due to the very small engine capacity of only 1 liter, this cycle is especially severe for this vehicle and the high CO emissions likely coincide with fuel enrichment, a practice that is common in Europe but that could be eliminated if banned as done in the US regulation, which has limitations for fuel enrichment as an auxiliary emissions strategy over the US06 and SC03 certification cycles. To limit excessive enrichment, the U.S. Tier 3 standards mandate that the nominal air-fuel ratio cannot be richer at any time than the leanest air-fuel ratio required to obtain maximum torque.

Even though being equipped with particulate filters, both gasoline vehicles exceed the proposed PN limits. This could be due to the mentioned short run-in period of the vehicles, therefore the ash cake layer has not yet been formed, but also due to the design target of meeting only the current Euro 6d PN limits.

These results suggest that modern diesel and gasoline engines are almost fit to meet the CLOVE1 limits and therefore a more ambitious target is reasonable. The measurement data also shows, that the majority of the emissions is generated over the first few kilometers and therefore a shorter range for the emission budget than 16 km seems justified.

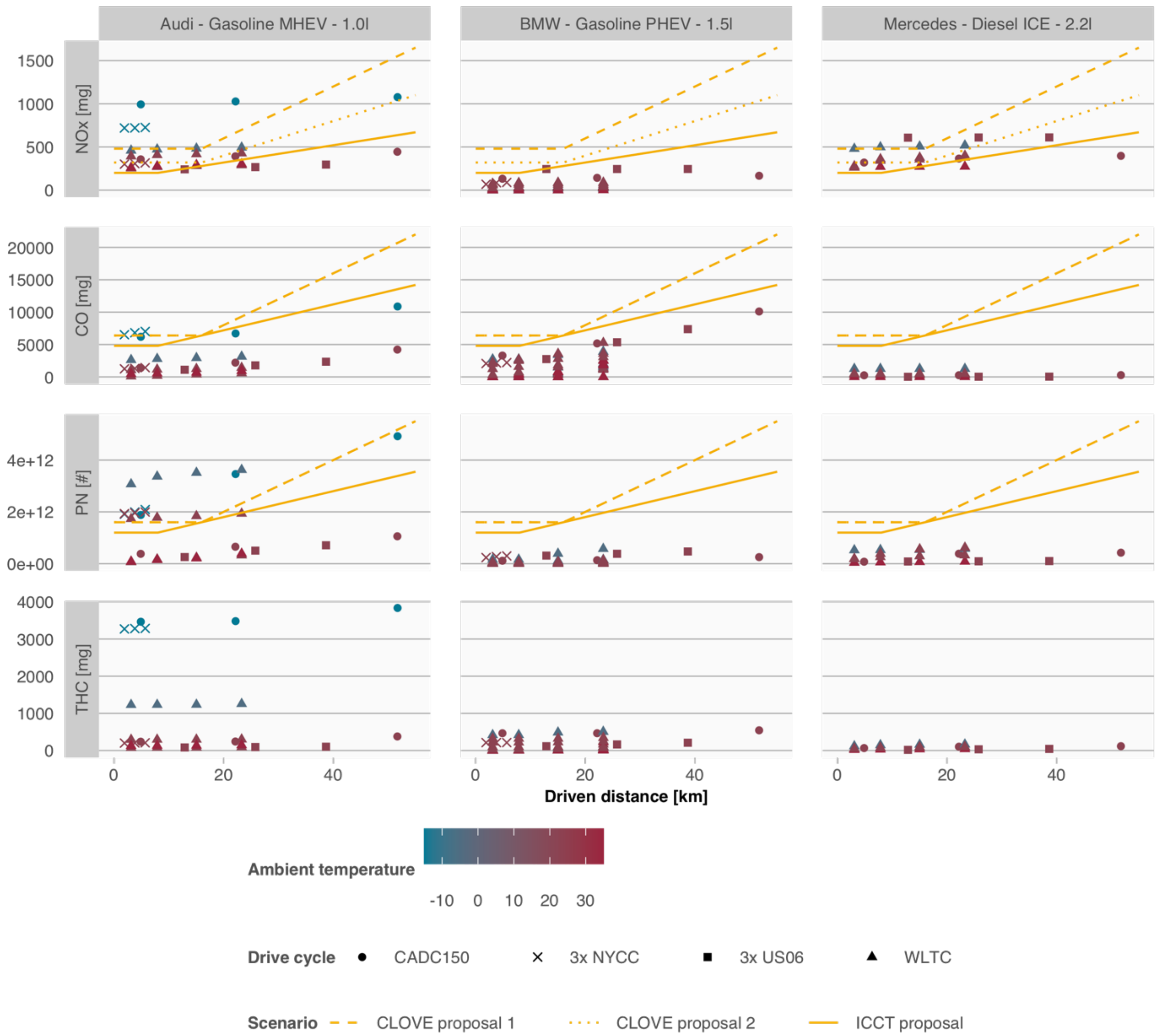
Chassis dyno emissions – regulated pollutants

The 3 vehicles were also emission tested on the chassis dyno for the cycles and conditions shown in the table below.

Chassis dyno tests

Cycle Type	Ambient temp. [°C]	AC status (on/off) [°C]	Coolant at start	BMW X1	Mercedes C-class	Audi A3
WLTC	23	Off	Cold	1x CS[1)], 1x CI[2)]	2	2
WLTC	23	Off	Hot	1x CS[1)]	1	1
WLTC	-5	On, 22	Hot	1x CS[1)]	1	1
WLTC	35 + solar radiation	On, 22	Hot	1x CS[1)]	1	1
3x NYCC	23	On, 22	Cold	1x CS[1)]	1	1
3x NYCC	-15	On, 22	Cold	-	-	1
CADC 150	23	On, 22	Cold	1x CS[1)]	1	1
CADC 150	-15	On, 22	Cold	-	-	1
3x US 06	23	On, 22	Hot	1x CS[1)]	1	1

To understand if the proposed Euro 7 limits would also be feasible under a wide range of ambient temperatures and driving patterns, we compared the emission results to the proposed limits, shown in the figure below.



Emission test results of 3 Euro 6d-ISC-FCM vehicles on chassis dyno. The data points reflect the emissions and distance accumulated up to each test phase of the respective cycle. All vehicles were tested in warm and cold started WLTC at -5, 23 and 35 °C. In addition, three other cycles were performed at 23 °C: a Common Artemis 150 (CADC150), 3 consecutive US06 and 3 consecutive New York City Cycles NYCC. The Audi performed in addition a CADC150 and 3x NYCC at -15 °C.

Similarly to the on-road observations, the CO and NO_x results for all tests in an ambient temperature range of -5 to 23 °C are within or close to the CLOVE-scenario-1 limits.

Even for the two tests at -15 °C performed with the Audi (one test consisting of 3 consecutive New York City Cycles and the other test was a Common Artemis 150 cycle) the CO emissions are within the limit and the NO_x emissions are well within the proposed tolerance of 3 times limit for low temperature tests. Except for the BMW WLTC tests at -5 °C, all vehicles are close to or at the proposed PN limit for all tests.

The chassis dyno results confirm that the CLOVE-scenario-11 limits are close to the emission levels that can be achieved with latest Euro 6d technology today. Therefore, more ambitious limits are justifiable to pull new emission control technologies to the market that goes beyond the current technology adoption.

3. Unregulated climate pollutants

Methane (CH_4) and nitrous oxide (N_2O) are both powerful GHGs that can be found in significant quantities in the exhaust of motor vehicles. The global warming potentials (GWPs) of CH4, are 84 when considering a 20-year time horizon and 28 in a 100-year period. The 20- and 100-year GWPs of N2O are significantly higher at 264 and 265, respectively. As a result of these high GWPs, small traces of these gases in the tailpipe emissions of modern motor-vehicles[7] can have substantial impact on the overall GHG performance.

Oxidation catalysts with specific chemistries to enhance the oxidation of CH_4, a very stable molecule, are already in the market. Still, even though there have been recent advances, the low-temperature reactivity as well as deactivation by water and sulfur needs to be further developed. Researchers have already identified paths to realize such improvements, including substrates with three-dimensionally ordered macropores structures and molecular sieves to maximize the surface area, the use of novel metal oxides to support the active Pd-group metals, and applying advanced Pd-based catalysts.[8]

N_2O formation in the emission control systems of diesel engines is a well-known issue. However, improvements can be made in the selectivity of SCR and ammonia slip catalyst (ASC). In state-of-the-art ASC with dual-layer architectures—composed of Pt-

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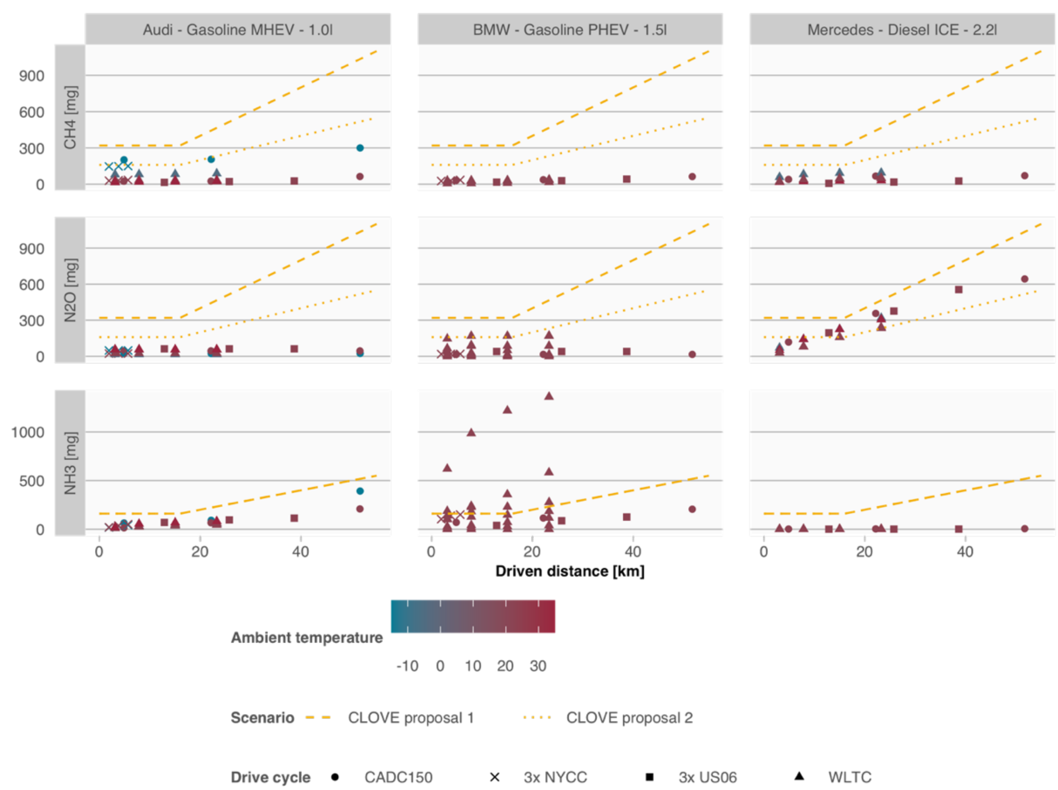
[7] Tommaso Selleri et al., “An Overview of Lean Exhaust DeNOx Aftertreatment Technologies and NOx Emission Regulations in the European Union,” *Catalysts* 11, no. 3 (March 2021): 404, https://doi.org/10.3390/catal11030404.
[8] Dong Jiang, Konstantin Khivantsev, and Yong Wang, “Low-Temperature Methane Oxidation for Efficient Emission Control in Natural Gas Vehicles: Pd and Beyond,” *ACS Catalysis* 10, no. 23 (December 4, 2020): 14304–14, https://doi.org/10.1021/acscatal.0c03338.

based bottom layer and a zeolite top layer—the composition of the Pt-based layer can be adjusted by reducing the platinum content, reducing the N_2O and NO_x selectivity, but slightly impacting the NH_3 oxidation performance.[9] This trade-off can be addressed with improvements in the on-board ammonia coverage modeling and urea dosing control, reducing NH_3 slip from the SCR.

Therefore, we disagree with industry claims on the infeasibility of meeting stringent CH_4 and N_2O targets, and on the availability of emission control technologies to address them.

<u>Chassis dyno – unregulated emissions</u>

On the chassis dyno, we were able to also measure NH_3, N_2O and CH_4 emissions for all tests except for the WLTCs with the BMW at -5 °C. The test results are shown in the figure below.



Emission test result for not or only indirectly regulated pollutants under Euro 6 standards.

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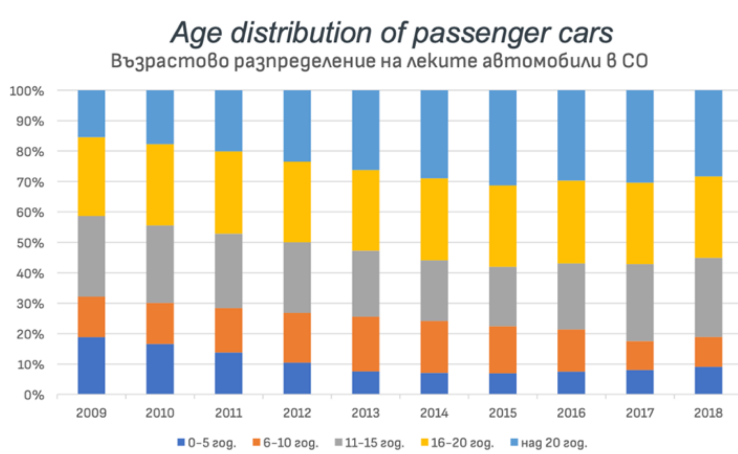
[9] Rajat Subhra Ghosh et al., "Enhanced Selective Oxidation of Ammonia in a Pt/Al2O3@Cu/ZSM-5 Core–Shell Catalyst," *ACS Catalysis* 10, no. 6 (March 20, 2020): 3604–17, https://doi.org/10.1021/acscatal.9b04288.

Even for the tests at -15 °C, methane emissions were even below or at the proposed CLOVE-scenario-1 limits. The N_2O emissions of all three vehicles were below the CLOVE-scenario-1 limit and the two gasoline vehicles even at or below the CLOVE-scenario-2 proposal. Both the Audi and the Mercedes emitted NH_3 levels below the proposed limit while the BMW showed emissions above the limit for only two tests at 23 °C. Both tests were part of a charge-depleting test sequence with the highest emissions occurring in the first test once the battery is depleted, i.e. when the engine is started first time. The cause of these high emissions is still unclear.

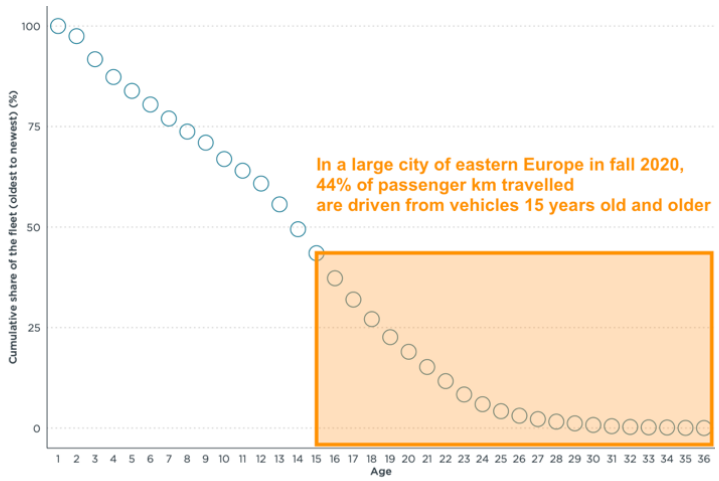
We conclude that the scenario 1 proposed by the CLOVE consortium is not necessarily an ambitious scenario for Euro 7 on unregulated pollutants.

4. Durability

Emissions deterioration can have a significant impact on the in-use emissions of on-road vehicle. The current proposal aligns Euro 7 with the US Tier 3 phased in since 2017 with an emission durability up to 15 years or 240,000 km (whichever comes first). Although, this is a significant improvement compared to Euro 6, we consider that this is the strict minimum we can expect from the European regulation expected in years. The retirement of cars can by much higher than 15 years, especially in eastern Europe, where the average age of car can exceed 15 years (Bulgaria, Romania, Lithuania, Estonia[10]). In Sofia, Bulgaria, among the most polluted city in Europe, over 50% of registered cars are older than 16 years old, and close to 30% are older than 20 years old.[11] During a fall 2020 fleet inventory performed in a large city of eastern Europe, passenger cars of 15 years old or older accounted for 44% of total kilometer travelled.



[10] Vehicles in-use report, ACEA (2021)
[11] Sofiaplan, Transportation report.



We recommend the CLOVE consortium to evaluate the technically feasibility in further extending the emission durability towards the average age of retirement, and developing adequate long life emission limits.

5. Evaporative emissions

The annual evaporative emissions, excluding refueling, from typical European gasoline cars have been estimated at approximately 1,000 grams per vehicle.[12] Using the typical annual mileage of passenger vehicles, this estimate translates to be approximately 80 mg/km—that is, in the same order of magnitude as tailpipe emissions.

The refueling emission factors are highly sensitive to the efficiency of the Stage II vapor recovery systems. In Stage II systems the vapors displaced from the vehicle's tank are returned to the service station's tank via special fittings in the dispensing nozzle. However, the in-use efficiency of such systems varies, particularly in poorly maintained systems.

Although the changes introduced by the WLTP Second Act represent notable improvements with respect to the previous regulation, the new EU evaporative emissions requirements are still the most lenient when compared to provisions in the United States, China, and Brazil. Therefore, the ICCT welcomes the CLOVE proposal for adjusting the diurnal emissions limit, allowing higher hot-soak temperatures, and introducing refueling emissions limits that would force the adoption of ORVR systems.

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[12] Theodoros Grigoratos, Giorgio Martini, and Massimo Carriero, "An Experimental Study to Investigate Typical Temperature Conditions in Fuel Tanks of European Vehicles," *Environmental Science and Pollution Research*, April 25, 2019, https://doi.org/10.1007/s11356-019-04985-7.

Early issues of incompatibility between Stage II vapor recovery at refueling service stations and ORVR systems are now better understood. While there are technology fixes available to eliminate any reduction in efficiency—e.g., adding a vapor processor, ensuring that the nozzle can recognize and throttle the assist system pump when fueling an ORVR vehicle, or adjusting the fill rate—the overall reduction in efficiency of this potential incompatibility is small however, estimated by EPA to be between one and ten percent by the US EPA.[13] Compatibility between Stage II and ORVR should not be a concern. For any stations that are not fully compatible, a slight decrease in control efficiency of ORVR systems will not significantly diminish the benefits of having both systems until ORVR becomes widespread.

Capturing emissions during refueling by the vehicle's canister is more effective than the current Stage II controls and avoids problems with Stage II system malfunctions. Experience in the United States and China shows that ORVR has a higher capture efficiency than Stage II and does not have the drawbacks, such as sensitivity to fuel composition, continuous maintenance and inspection requirements, or higher cost. Furthermore, the larger canister required by the ORVR system benefits diurnal emissions beyond the requirements of the 2-day test. The average cost to implement ORVR in European vehicles is approximately 25 euros per vehicle, representing a very cost-effective solution.

Therefore, we disagree with industry claims that Stage II is sufficient and ORVR is unnecessary, and fully support the proposal put forward by the CLOVE consortium.

6. TCI and OBM

Test Conformity Indicator TCI

We are fully supporting the idea of introducing a dashboard light to indicate conformity test readiness as it will encourage more in-service conformity ISC testing and will make results more robust and less contestable by the manufacturers. The arguments brought forward by the CLOVE consortium are in-line with our observations and concerns we already expressed when the in-service conformity requirements were developed. While it is already challenging to find and procure test vehicle suitable regarding ISC family membership, mileage and diversity, performing all checks required by (EU)

[13] U.S. EPA, "Air Quality: Widespread Use for Onboard Refueling Vapor Recovery and Stage II Waiver," May 16, 2012, https://www.federalregister.gov/documents/2012/05/16/2012-11846/air-quality-widespread-use-for-onboard-refueling-vapor-recovery-and-stage-ii-waiver.

2017/1151 after the vehicle was delivered makes the vehicle selection very time consuming and expensive. The TCI information could be used already before a vehicle is delivered to assess its suitability for testing. Furthermore, the requirement to read the OBD fault memory before testing is an easy way for a vehicle to detect that it might soon undergo in-service conformity testing.

A TCI would solve the raised issues and give the manufacturer the responsibility to indicate if the vehicle was misused or is not in a shape fit for in-service conformity testing for any other reason. In addition to the CLOVE proposal we recommend to discard the owner interview. Often ISC-vehicles are procured through specialized rental agencies, where the full history of the vehicle is usually not known. Therefore, even when the questionnaire defined in Appendix 1 to Annex II of (EU) 2017/1151 is filled in to the best of one's knowledge, it can always be challenged by the manufacturer. **We also suggest that the vehicle makes available at the OBD interface which event(s) triggered the TCI not being in a green state, also for past events that are healed again.**

On-board emission monitoring OBM

We understand OBM as one of the pillars to ensure emission compliance during real-world operation over the vehicles lifetime, and therefore want to encourage its introduction as part of Euro 7 as proposed by the CLOVE consortium. While ISC mainly targets the identification of systematic emission non-compliance due to defeat devices or premature emission treatment system ageing of entire vehicle families, OBM can monitor the emissions of individual vehicles and thereby detect high emissions due to tampering or failed components.

While we acknowledge that currently emission sensors are not available to monitor all pollutants, we expect that introducing OBM with the clear intent to monitor other pollutants depending on sensor availability will encourage suppliers to develop these sensors. Similarly we would expect that currently available sensors will be improved if incentivized by the regulation. For example, tightening the HC and CO limits required a faster switch from pre-controlled to lambda-based operation for stoichiometric gasoline engines. This has led to a development effort resulting in a substantial reduction of light-off time for these sensors. In case of the Bosch sensor the light-off time has reduced from about 30 seconds (LSU 4.2[14]) to 7 seconds and less in its current version[15].

[14] http://www.2d-datarecording.com/Downloads/Datasheets/KTM-Kit-Moto3/SA-LSU4.2-000.pdf
[15] https://www.bosch-mobility-solutions.com/en/solutions/sensors/wideband-lambda-sensor/

Incorporating NO_x OBM in both US and Chinese emission legislation shows that the accuracy and durability of current sensors is sufficient to perform emission monitoring and therefore we support the introduction of OBM already in the first phase of Euro 7, as proposed by the CLOVE consortium. We also support the introduction of monitoring NH_3 emissions of diesel engines while showing a clear path to also monitor gasoline engines once sensors for stoichiometric exhaust gas are available.

C. HDV comments

ICCT welcomes the proposal made by the CLOVE consortium on April 27. We offer the following recommendations for strengthening the proposal, mostly in areas applicable to urban emissions.

1. Emissions limits

ICCT supports the proposed policy design including separate limits for the 100th percentile, 90th percentile, and the emissions budget. The emissions budget at 3 times the work over the WHTC would represent around 3 hours of operation (at an average relative power of 11%) and around 60 km of driving (at an average speed of 20 km/h) in low-load, low-speed conditions—hardly representative of urban operation. Still, setting adequate limits for the 100th percentile would ensure the right level of technology deployment to address urban emissions.

A recent demonstration project by AECC[16] shows that the integration of close-coupled catalysts combined with the advanced controller have achieved high NO_x conversion efficiencies with a minimum NH_3 slip and results show good control of the N_2O under the conditions tested. The measured values—at 4.6 mg NH_3/kWh and 45 mg N_2O/kWh—are below the CLOVE proposal, particularly for the 90th percentile and the 3xWHTC budget NH_3 CLOVE limit.

The ICCT supports the latest CLOVE proposal, in particular the setting of the HD3 scenario limits for NO_x. However, the ICCT urges the Commission to set more stringent limits for NH_3 and N_2O than those proposed by CLOVE in hot operation. In general, the focus should be placed in setting the 100th and 90th percentile

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[16] Pablo Mendoza-Villafuerte et al., "Demonstration of Extremely Low NOx Emissions with Partly Close-Coupled Emission Control on a Heavy-Duty Truck Application" (42nd International Vienna Motor Symposium 2021, Vienna, 2021), 20, https://www.aecc.eu/wp-content/uploads/2021/05/210219_Vienna_HD-diesel-AECC-FEV-paper-final_v2.pdf.

limits at the level of what is technically feasible with future technologies, and not at what the best performing Euro VI vehicles can achieve.

2. Reference power correction

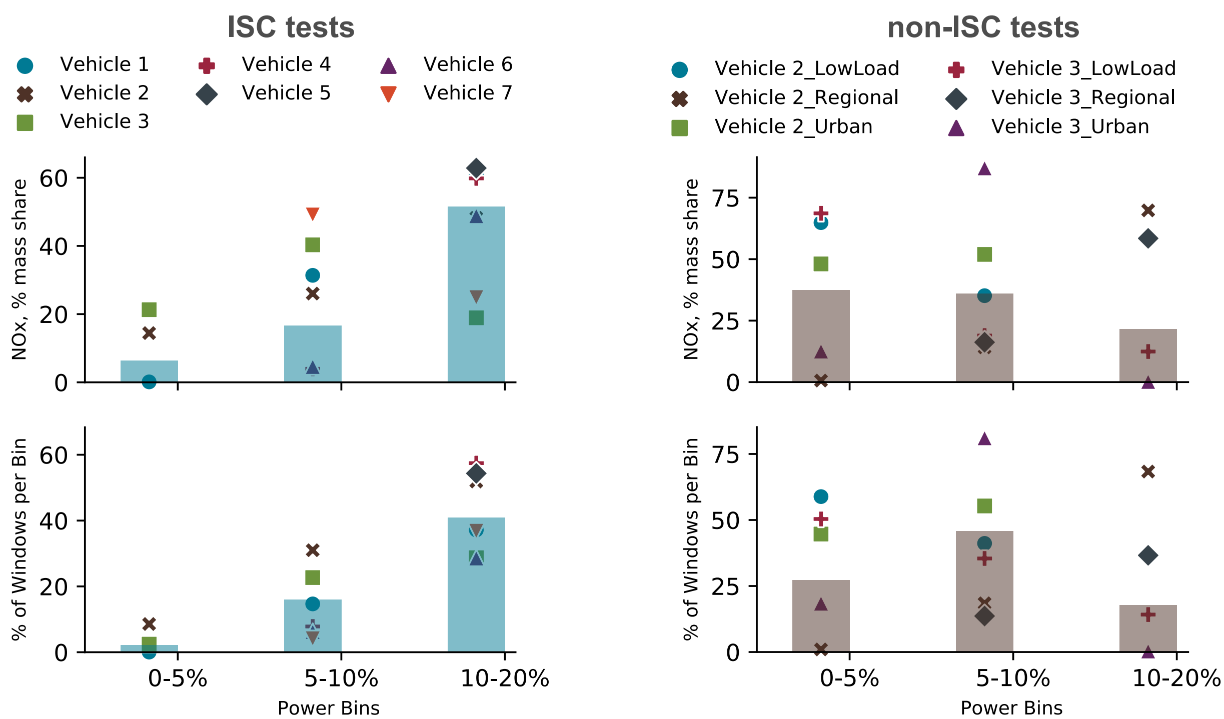
The CLOVE proposal from April 2021, includes provisions to adjust downwards the work-specific emissions when the vehicle is operated at low power, below 10% of the engine's rated power.

The ICCT commissioned or obtained test data from 7 Euro VI-D vehicles tested over a variety of conditions including both ISC-compliant and non-ISC compliant tests, but always respecting the payload requirements set by the regulation, of at least 10% payload. A summary of the vehicles and test conditions is summarized below.

Vehicle	Power [kW]	Speed [rpm]	Torque [Nm]	Engine Size [L]	WHTC Work [kWh]	GCVW [tonnes]	Axle/Body Configuration
Vehicle 1	194	2300	1000	7	17	16	4x2, rigid
Vehicle 2	375	1800	2884	12	36	40	4x2, tractor
Vehicle 3	175	1800	1000	8	17	15	4x2, rigid
Vehicle 4	427	1900	3000	16	42	40	4x2, tractor
Vehicle 5	338	2100	2300	13	32	40	4x2, tractor
Vehicle 6	345	1900	2600	13	34	40	4x2, tractor
Vehicle 7	338	2100	2300	13	32	40	4x2, tractor

Vehicle	ISC Tests		Non-ISC Tests			
	# of Tests	Payload	# of Tests	Payload	Route	Cold start
Vehicle 1	3	55%	1	20%	Low Load	Yes
Vehicle 2	3	10%	3	10%	Low Load, Urban, Regional	Yes
Vehicle 3	3	10%	4	10%	Low Load, 2xUrban, Regional	Yes
Vehicle 4	4	1x10%, 2x55%, 1x100%	1	55%	Vehicle's application	No
Vehicle 5	1	60%	3	60%	Regional	No
Vehicle 6	2	55%	0	-	-	Yes
Vehicle 7	2	60%	3	60%	Regional	No

The data shows that low-power operation is prevalent in large HDVs with light payloads. Note that the while the high-powered vehicles tested are tractor-trailer, the same engines are used in rigid trucks with lower GCVWs and lower payloads. The figure below shows the frequency of low power operation and the cumulative NO_x mass share emitted by the tested Euro VI-D trucks, power bins above 20% are not shown, but were analyzed. During ISC-tests—which also include a substantial portion of rural and motorway operation—engine operation below 10% of rated power represents over a third of the cumulative NO_x emissions for all vehicles tested with payloads below the 50% of the capacity (left side of figure).[17] Focusing now on non-ISC conditions for vehicles 2 and 3—a tractor-trailer and a small rigid truck a low payloads, right side of the figure—the low power operation below 10% of rated power represents about two-thirds of NO_x emitted and accounted for around 75% of all test conditions.



Given the prevalence of engine operation below 10% of rated power and the large impact that such operation conditions have on the overall NO_x emissions over a trip, Euro VII provisions should ensure that those conditions are adequately included, and that the regulation drives technology adoption targeted at them.

The ICCT encourages the Commission to disregard the proposal put forward by the CLOVE consortium to adjust downwards work-specific emissions through the reference power correction, or to at least modify such provision to power levels at a maximum of 5% of rated power, instead of 10% as currently proposed.

[17] Anecdotally, the vehicles tested at 10% payloads resulted failed to comply with all ISC provisions in several cases, due to the difficulties to meet the 10% power threshold of Euro VI-D provisions.

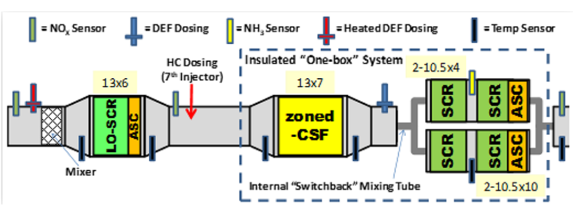
3. Technology feasibility

The technology feasibility to meet stringent HDV pollutant emission standards has been thoroughly demonstrated for the development of California's low-NO_x regulation[18] by Southwest Research Institute (SwRI),[19] and more recently by AECC[20] and their HDV demonstrator.

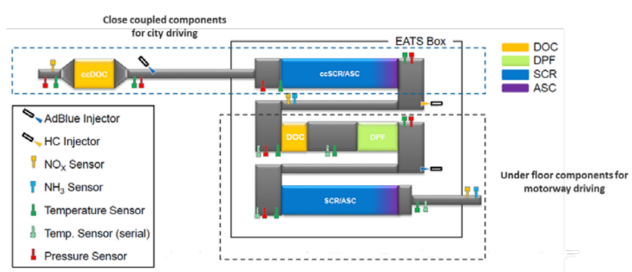
The SwRI demonstrator achieved NO_x emission levels—on a fully thermally and chemically aged emissions control system—of 30 mg/kWh over the FTP transient cycle and of 63 mg/kWh over the challenging Low-Load Cycle, which has an average power of just 4.6% of rated power, and a duration of 64% of the WHTC work.

AECC's demonstrator—which does not yet include all technologies assessed in the SwRI system such as closed coupled SCR, cylinder deactivation and EGR bypass—demonstrated on-road NO_x emission levels of around 100 mg/kWh for the 100th percentile[21] and of less than 50 mg/kWh for the 3xWHTC and less 25 mg/kWh for the 90th percentile on lightly-loaded ISC tests (10% of max payload) in an ambient temperature of around 10°C. That is, significantly lower levels than the NO_x limits proposed by CLOVE. AECC demonstrates that meeting the proposed CLOVE NO_x limits is feasible, even without a full technology deployment.

The SwRI and AECC systems are shown below.



SwRI low NOx system (cyl. deactivation not shown)



AECC Euro VII system

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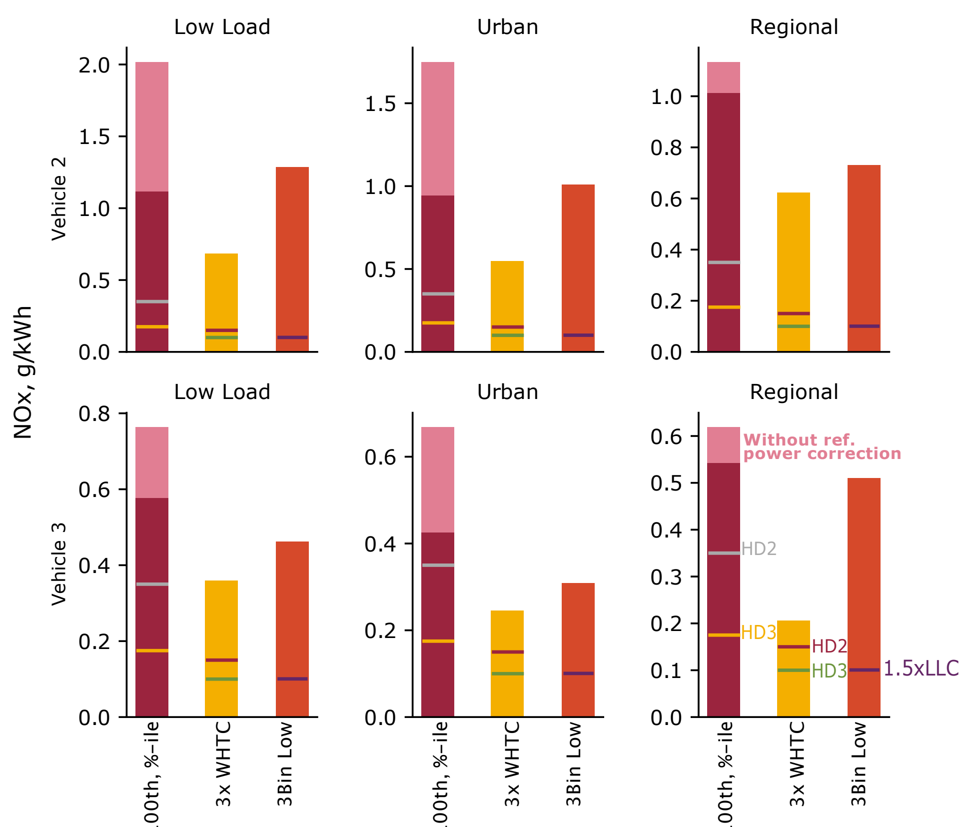
[18] California Air Resources Board, "Heavy-Duty Engine and Vehicle Omnibus Regulation and Associated Amendments," August 2020, https://ww2.arb.ca.gov/rulemaking/2020/hdomnibuslownox.
[19] Christopher Sharp et al., "CARB Low NOX Stage 3 Program - Final Results and Summary," SAE Technical Paper (Warrendale, PA: SAE International, April 6, 2021), https://doi.org/10.4271/2021-01-0589.
[20] Mendoza-Villafuerte et al., "Demonstration of Extremely Low NOx Emissions with Partly Close-Coupled Emission Control on a Heavy-Duty Truck Application."
[21] WHTC work estimated to be 37 kWh based on the engine power.

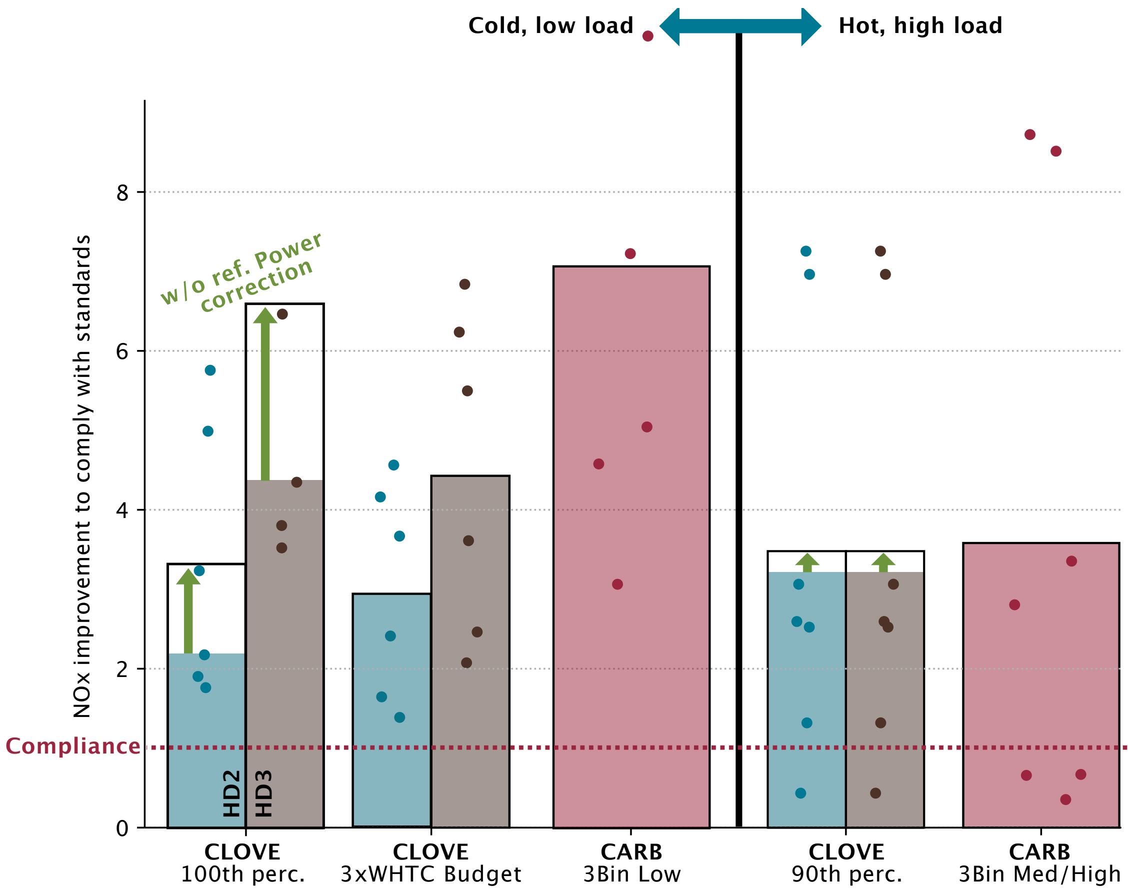
California's low-NO_x standards also set provisions to evaluate the in-use performance of HDVs. The test evaluation, called 3-bin method, requires a full day with engine idling and shutoffs allowed, requires cold start conditions (engine coolant temperature less than 30°C at test start), allows temperatures of down to -7°C and altitudes of up to 1,667 meters, and does not set any limits on the engine load. The data is evaluated in windows with a fixed size of 300 s, and sets 3 bins—idle, low, and mid/high—for establishing compliance. Emissions are averaged over all windows in a bin, and compliance is assessed separately for each bin. The 3-bin on-road test limits are shown in the table below.

Bin	CO_2 level	Limit (2027 onwards)
Idle	< 6%	7.5 g/h
Low	6 – 20%	100 mg/kWh
Mid/high	> 20%	40 mg/kWh

We estimated the level of improvement that CLOVE's proposal and that California's low NO_x rule would require for Euro VI-D trucks, using the aforementioned data. As an example, the results of both evaluation methodologies for the most challenging non-ISC trips for trucks 2 and 3 of the aforementioned data, are shown below.



In average for the 7 vehicles tested, California's standards would require larger relative improvements than CLOVE's proposal, particularly in low load and cold started operation. California's regulation would mandate approximately sevenfold improvement (i.e., 85% reduction from current NO_x emissions), compared to around fourfold from the most stringent CLOVE proposal, HD3 (see figure below). However, the elimination of the *reference power correction* would bring the relative improvement mandated by the 100th percentile limit closer to that estimated from California's regulation.

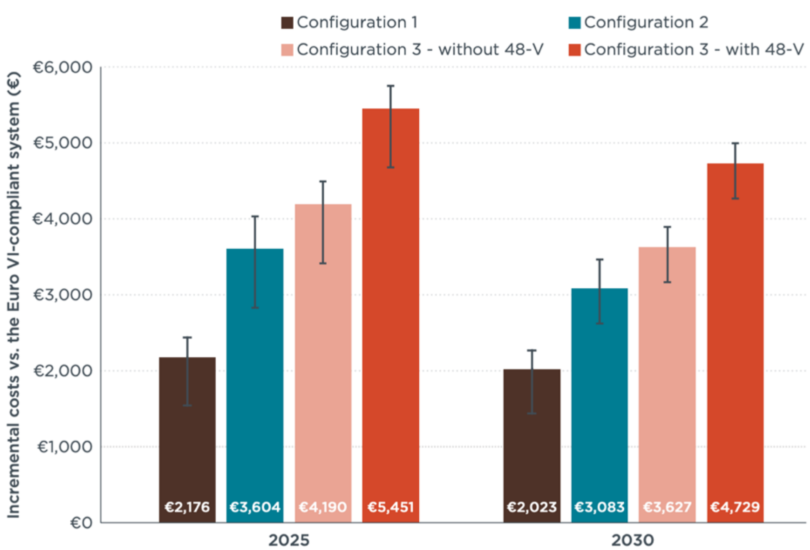


Based on the demonstration programs in the United States and the EU, ICCT concludes that the HD limits proposed by CLOVE are all feasible, and that to exploit the same level of technology potential as California will, the Euro VII limits should be set at least the HD3 level—as proposed by CLOVE—and avoid any use of work correction for low power operation, which would distort the work-specific regulatory metric.

4. Cost

The ICCT evaluated[22] the costs of compliance to future Euro VII standards, based on the several demonstrators and technologies proposed to meet stringent HDV pollutant emissions standards in both the EU and California, and in accordance with the CLOVE proposal from April 27. We estimated the incremental costs of meeting the Euro VII standards compared to a Euro VI-compliant emissions control system will be between €1,500 and €4,700 in 2025, and between €1,400 and €4,300 in 2030. Overall, we expect engine-out emissions control to represent 0%—41% of the incremental costs of compliance to Euro VII, while the rest accounts for improvements in the EATS.

Additionally, we estimated that increasing the required full useful life requirements of aftertreatment systems from the current 700,000 km to 970,000 km and 1,300,000 km would lead to average additional costs of approximately €700 and €1,000, respectively, in 2025. This corresponds to an increase between 12% and 22% in the cost of Euro VII aftertreatment systems. Overall, increasing the requirements of the durability to 1.3 million kilometers, which is slightly higher than the CLOVE proposal of 1.2 million kilometers, would increase full system costs in 1% of the truck price.



Estimated incremental costs of our potential Euro VII emissions control systems as compared to a Euro-VI compliant system. The main bar corresponds to our "low ambition" durability increase scenario (FUL = 970,000 km), while the lower and upper ends of the error bars represent the current (FUL = 700,000 km) and "high ambition" (FUL = 1,300,000 km) durability increase scenarios, respectively.

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[22] Pierre-Louis Ragon and Felipe Rodríguez, "Estimated Cost of Diesel Emissions Control Technology to Meet Future Euro VII Standards" (Washington, D.C.: International Council on Clean Transportation, April 28, 2021), https://theicct.org/publications/cost-diesel-emissions-control-euro-vii-apr2021.

ICCT estimates that Euro VII technologies will only result in a cost increase between 2% and 5% relative to the current price of new Euro VI tractor-trucks.

D. Critique of industry's air quality assessment

This year, AERIS published an impact assessment of the Euro 7/VII standards, contending that there is little air quality benefit to be gained over the currently adopted Euro 6d and Euro VI-D standards. AERIS claims that adopted policies will achieve a 79% reduction in NOx from diesel vehicles by 2035 and that the additional reduction of Euro 7/VII is capped at 4.6% for diesel cars and vans, and 2.4% for HDVs.

Although we project a similar result (76%) for the reduction in NOx from diesel vehicles expected by 2035 under adopted policies, we estimate the additional percentage-point benefit of Euro 7/VII for HDVs would be 7.4%—three times that of the AERIS study. We have identified several other areas of concern with the approach adopted by AERIS, which raises questions about the validity of their results. The following summarizes the areas of greatest concern:

a. **AERIS uses a flawed methodology to assess the air quality and health benefits of Euro 7/VII standards.**

b. **AERIS ignores the benefits of Euro 7/VII standards for gasoline vehicles.**

c. **AERIS cuts off their analysis at 2035, which is too short to adequately capture the benefits of Euro 7/VII standards.**

d. **AERIS makes overly optimistic assumptions about the NO_X emission factors of Euro VI HDVs**

e. **Euro 7/VII standards are under-ambitious**

a. AERIS uses a flawed methodology to assess the air quality and health benefits of Euro 7/VII standards.

AERIS erroneously uses the number of stations that comply with air quality guidelines as a proxy for air quality and health outcomes. Their approach ignores decades of epidemiology on the health response to air pollution and the persistence of health impacts from air pollution below the current air quality guideline thresholds.

Air pollution causes health impacts at levels well below air quality limit values. According to the EEA, exposure to fine particulate matter ($PM_{2.5}$), nitrogen dioxide (NO_2), and ozone (O_3) were responsible for approximately 412,500 premature deaths in the EU-27 in 2018.[23] The Global Burden of Disease 2019 (GBD 2019) study corroborates this magnitude of air pollution attributable premature deaths, finding that ambient $PM_{2.5}$ and ozone accounted for approximately 174,000 (127,000 – 227,000) premature deaths in the EU in 2019.[24] The EEA and GBD 2019 studies apply slightly different thresholds for the minimum exposure to air pollution above which health impacts are calculated. The EEA methodology applies thresholds of 0 $\mu g/m^3$ for $PM_{2.5}$, 20 $\mu g/m^3$ for NO_2, and 35 ppb for O_3. GBD 2019 applies thresholds based on a uniform distribution of 2.4–5.9 $\mu g/m^3$ (midpoint 4.1 $\mu g/m^3$) for ambient $PM_{2.5}$ and a uniform distribution of 29.1–35.7 ppb for ozone.[25] In both cases, the thresholds for health impacts are substantially lower than the current EU air quality limits of 25 $\mu g/m^3$ for annual average $PM_{2.5}$, 40 $\mu g/m^3$ for annual average NO_2, and 120 $\mu g/m^3$ (approximately 60 ppb[26]) for the maximum daily 8-hour mean of O_3.[27] The thresholds for health impacts attributable to $PM_{2.5}$ are also substantially lower than the World Health Organization guideline of 10 $\mu g/m^3$ for annual average $PM_{2.5}$.

Health impacts are a function of air pollution exposure
The epidemiological evidence demonstrates that air pollution-attributable health impacts increase as population exposure increases above the threshold. At air pollution levels above the minimum thresholds, reducing ambient $PM_{2.5}$ and ozone will reduce the incidence of premature deaths attributable to $PM_{2.5}$ and ozone exposure. Because current EU air quality limits are well above these minimum thresholds, this relationship holds true regardless of whether monitoring stations are compliant with air quality limits.

The relationship between vehicle tailpipe emissions and air pollution-attributable premature mortality is the strongest argument behind the implementation of Euro

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[23] European Environment Agency, Air Quality in Europe – 2020 report (EEA Report No 09/2020), https://www.eea.europa.eu/publications/air-quality-in-europe-2020-report

[24] Health Effects Institute. 2020. State of Global Air 2020. Data source: Global Burden of Disease Study 2019. IHME, 2020.

[25] GBD 2019 Risk Factors Collaborators (October 17, 2020), "Global Burden of 87 Risk Factors in 204 Countries and Territories, 1990–2019: A Systematic Analysis for the Global Burden of Disease Study 2019," The Lancet, https://doi.org/10.1016/S0140-6736(20)30752-2

[26] Danish Ministry of the Environment, Conversion between microgrammes/m3 and ppb, https://www2.dmu.dk/atmosphericenvironment/expost/database/docs/ppm_conversion.pdf

[27] European Environment Agency, Air Quality in Europe – 2020 report (EEA Report No 09/2020), https://www.eea.europa.eu/publications/air-quality-in-europe-2020-report

standards: reductions in vehicle air pollutant emissions will contribute to reductions in the immense societal costs and burden on national health systems of air pollution.

The AERIS study fails to evaluate the health benefits of Euro 7/VII standards
ICCT's analysis of the benefits of Euro 7/VII considers the impacts of tailpipe NO_x emissions on ambient $PM_{2.5}$ and ozone exposures and associated health outcomes. In contrast, the AERIS study fails to provide any quantitative analysis of the health benefits associated with reductions in vehicle emissions. AERIS quantifies only the number of air quality monitors that would comply or fail to comply with air quality guidelines. Their simplistic representation ignores the relationship between air pollution exposure and health outcomes, implicitly conflating compliance with air quality guidelines and an absence of health effects.

b. AERIS ignores the benefits of Euro 7/VII standards for gasoline vehicles.
AERIS only evaluates the emissions reductions of Euro 7/VII for diesel vehicles. Critically, gasoline vehicles are not modeled. This is particularly problematic for the estimated emission benefits of Euro 7 for light-duty vehicles, since stringent fuel-neutral Euro 7 standards would substantially reduce NO_x emissions from gasoline vehicles as well as diesel. By ACEA's own estimates, in 2018, gasoline was the dominant fuel for passenger cars, covering 54% of the total passenger car stock.[28] Failing to cover such a significant vehicle segment does not provide a fair analysis of the benefits of implementing stricter emission standards. ICCT's analysis finds that gasoline vehicles would account for 32% of the cumulative NO_x benefits of stringent Euro 7 standards for light-duty vehicles from 2027–2050.

c. AERIS cuts off their analysis at 2035, which is too short to adequately capture the benefits of Euro 7/VII standards.
AERIS considers implementation years of 2025 and 2027 for Euro 7/VII standards, whereas their time horizon for impacts extends only to 2030 and 2035. This time horizon is far too short to adequately capture the benefits of Euro 7/VII standards, since it considers only 5–10 years of fleet turnover. This is shorter than even the average age of vehicles on the road in the EU (ACEA estimates an average age of 11.5 years for passenger cars, 11.6 for vans, 13 for trucks, and 11.7 for buses).[29] The benefits of Euro standards extend much further beyond this timeline. Older vehicles will continue to retire and be replaced with Euro 7/VII vehicles well beyond 2035, thus a fair analysis would consider a much longer time horizon.

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[28] ACEA, “Vehicles in use Europe” (2019).
https://www.acea.be/uploads/statistic_documents/ACEA_Report_Vehicles_in_use-Europe_2019.pdf
[29] ACEA, "Average vehicle age", https://www.acea.be/statistics/tag/category/average-vehicle-age

In contrast, ICCT's analysis extends to 2050, by which point most vehicles on the roads would be Euro 7/VII vehicles (assuming implementation in 2027). We find that the annual NO_x emission reductions of Euro 7/VII standards in 2050 are more than 4 times the annual benefits in 2030 and twice the annual benefits in 2035.

d. AERIS makes overly optimistic assumptions about the NO_x emission factors of Euro VI HDVs

ICCT and AERIS emission factors on LDV are roughly aligned. However, we find that the NO_x emission factors applied to diesel HDVs provide an overly optimistic contribution to HDV emissions. In this analysis, HDV Euro VI-D is calculated as 32% lower than Euro VI-C values (as captured in the COPERT emission factors) for articulated trucks and 48% lower than Euro VI-C for rigid trucks. ICCT's analysis, including test data for several test of 12 Euro VI HDVs, found a reduction of just 12% for Euro VI-D compared to Euro VI-C. Similarly, as estimated by AERIS, we do not expect any relative improvement in Euro VI-E performance, given that step D diesel HDV can already comply with step E provisions. Thus, the reported benefits from Euro VI-D and Euro VI-E for HDVs are overstated in the AERIS report.

e. Euro 7/VII standards are under-ambitious

The AERIS analysis draws on 16 scenarios with varying levels of ambition on NO_x and PM. Their range of scenarios is presented in the table below. Extreme 0 mg/km NO_x scenarios are considered individually for diesel passenger cars and LCV N1-I, as well as LCV N1-II and LCV N1-III. The most ambitious collective scenario falls under Scenario 14, which proposes a 35mg/km limit for LDVs and 230mg/km for HDVs.

	NOx						PM					
	PC	LCV N1-I	LCV N1-II	LCV N1-III	LCV N2	HDV	PC	LCV N1-I	LCV N1-II	LCV N1-III	LCV N2	HDV
Baseline (Euro 6)	80mg/km	80mg/km	115mg/km	115mg/km	460mg/km	460mg/km	4.5mg/km	4.5mg/km	4.5mg/km	4.5mg/km	10mg/km	10mg/km
Scenario 1	60mg/km	60mg/km	75mg/km	75mg/km								
Scenario 2	25mg/km	25mg/km	25mg/km	25mg/km			2.5mg/km	2.5mg/km				
Scenario 3	35mg/km	35mg/km	35mg/km	35mg/km								
Scenario 4					400mg/km	400mg/km						
Scenario 5					230mg/km	230mg/km						
Scenario 6					100mg/km	100mg/km						
Scenario 7	0mg/km	0mg/km					0mg/km	0mg/km				
Scenario 8			0mg/km	0mg/km					0mg/km	0mg/km		
Scenario 9	Residential and commercial emissions of both NOX and PM2.5 were reduced to zero from 2025.											
Scenario 10	NH3 Emissions from Agricultural Sector: 50%											
Scenario 11	NH3 Emissions from Road Transport: 50%											
Scenario 12					30mg/km	30mg/km						
Scenario 13	60mg/km	60mg/km	75mg/km	75mg/km	400mg/km	400mg/km						
Scenario 14	35mg/km	35mg/km	35mg/km	35mg/km	230mg/km	230mg/km						
Scenario 15	VOC Emissions from Road Transport: Zero											
Scenario 16	VOC Emissions from Solvent and Product Use sector: 50%											

In comparison, the ICCT proposes a more stringent target for Euro 7 of 15 mg/km under WLTC for passenger cars (see the **LDV comments** section for details on the rationale of this emission factor). For LCVs, ICCT remote sensing data find that on a g/kg basis, NOx emission factors for LCV are generally about 10-25% higher than g/kg EFs for passenger cars. Thus, we propose a limit for LCVs of 23 mg/km for vans when averaged over all real-world driving conditions and for the useful life of the vehicle. For HDVs, Euro VII standards proposed relate to a 90% reduction in NOx emissions for trucks and buses compared to Euro VI step C when averaged over all real-world driving conditions and for the useful life of the vehicle. This aligns with the current proposed limits from the California Air Resource Board in the heavy-duty omnibus regulation.[30]

[30] https://ww2.arb.ca.gov/rulemaking/2020/hdomnibuslownox