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Emissions performance of Euro VI-D buses and recommendations for Euro 7 standards

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Introduction and regulatory background

On-road diesel vehicle emissions, primarily in the form of nitrogen oxides (NO_x), play a crucial role as precursors to the formation of particulate matter ($PM_{2.5}$) and ground-level ozone. According to the European Environment Agency, 307,000 premature deaths resulted from exposure to fine particulate matter in the 27 Member States of the European Union (European Environment Agency, 2021).

Heavy-duty vehicles (HDVs), which include commercial buses and trucks with a gross vehicle weight above 3.5 tonnes, have a disproportionate effect on air pollution, accounting for 35% of total NO_x emissions from all road transport, despite accounting for only 2.5% of the vehicle stock (Mulholland et al., 2021). Emission measurements using remote sensing show that older HDVs, certified to Euro III, Euro IV, and Euro V emission standards, have emissions that are up to an order of magnitude higher than Euro VI HDVs, highlighting the effectiveness of well-designed emission standards (Kazemi Bakhshmand et al., 2022).

The European Commission has released a regulatory proposal to set new pollutant emission standards for trucks and buses, Euro 7 (European Commission, 2022). The standards, which are to be implemented in 2027, set lower emissions limits than the current regulation, Euro VI, while expanding the driving conditions that are evaluated.

Comparisons of the Euro VI and Euro 7 standards for diesel vehicles and of the driving conditions allowed during on-road testing are presented in Table 1 and Table 2.

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Table 1. Pollutant emissions current (Euro VI) and proposed (Euro 7) limits for heavy-duty diesel vehicles in on-road tests

	Euro VI [a]*	Euro 7 100th %ile (cold-start emissions)	Euro 7 90th %ile (warm-start emissions)	Euro 7 3*WHTC budget
NO_x (mg/kWh)	1.5 * 460	350	90	150
PN (#/kWh)	1.5 * 6 $\times 10^{11}$	5 $\times 10^{11}$	2 $\times 10^{11}$	3 $\times 10^{11}$
PM (mg/kWh)	10	12	8	10
NMOG (mg/kWh)	1.5 * 160	200	50	75
HCHO (mg/kWh)	-	30	30	-
CH_4 (mg/kWh)	1.5 * 500	500	350	500
NH_3 (mg/kWh)	-	65	65	70
N_2O (mg/kWh)	-	160	100	140
CO (mg/kWh)	1.5 * 4,000	3,500	200	2,700

[a] Euro VI provisions include a conformity factor equal to 1.5. Such a conformity factor is not part of the Euro 7 proposal. NMOG refers to non-methane organic emissions, which under Euro VI were regulated as total hydrocarbons for diesel engines. On-road PN limits only apply from Euro VI-E, and not for Euro VI-D.

Table 2. Conditions for testing compliance

	Euro VI	Euro 7 Normal conditions	Euro 7 Extended conditions
Emissions divider*	None	None	2
Ambient temperature	-7 to 38°C	-7 to 35°C	-10 to -7°C or 35 to 45°C
Altitude	> 82.5kPa (< 1,700 m)	1,600 m	1,600 to 1,800 m
Payload	≥ 10% of max payload	≥ 10% of max payload	< 10% of max payload
Engine load	> 10% of rated power	Any	Any
Coolant temperature	> 30°C	Any	Any
Trip composition	Fixed split of urban, rural and motorway	As per usual use	As per usual use

* Applies to measured emissions only during the extended conditions.

This study provides insight into the emissions performance of the latest generation of diesel buses in Europe. The ICCT collaborated with VTT Technical Research Centre of Finland Ltd (VTT) to perform a series of on-road measurements on two buses type-approved to the Euro VI-D standard over various duty cycles. The emissions data were evaluated using the moving average window approach and compared against the proposed limits under Euro 7. This report is a summary of the key findings. Additional details and results can be found in a related VTT publication (Pettinen, 2022) and a peer-reviewed paper (Zacharof et al., 2022).

Vehicles tested

Two Euro VI-D transit buses, shown in Figure 1, were selected for testing. Bus 1, manufactured by VDL Bus & Coach and powered by a Cummins engine, has a gross vehicle weight of 15 tonnes and a 4x2 axle configuration. Bus 2, produced by Scania, has a gross vehicle weight of 24.6 tonnes and a 4x2 axle configuration. Both buses are representative of buses found in European cities, with these two commonly operating in the Helsinki metropolitan region. Further technical specifications are in Table 2.

Figure 1. Tested Euro VI-D buses. Bus 1 on the left, Bus 2 on the right.

Table 2. Technical specifications

Parameter	Bus 1	Bus 2
Vehicle make and model	VDL Citea LLE 120-255	Scania Citywide LE
Axles	4x2	6x2
Length	11.98 m	14.65 m
Engine make and model	Cummins B6.7E6D250B	Scania DC09 108 320
Engine capacity	6.7 L	9.3 L
Engine power	182 kW	235 kW
WHTC work	17.5 kWh	23.7 kWh
Curb weight	9,570 kg	15,013 kg
Maximum payload	5,300 kg	9,587 kg
Gross vehicle weight	14,870 kg	24,600 kg
Mileage at test start	157,934 km	214,811 km
Emissions standard	Euro VI-D	Euro VI-D
Emissions control [a]	EGR, DOC, DPF, SCR, ASC	EGR, DOC, DPF, SCR, ASC

[a] Exhaust Gas Recirculation (EGR), Diesel Oxidation Catalyst (DOC), Diesel Particulate Filter (DPF), Selective Catalyst Reduction (SCR), and Ammonia Slip Catalyst (ASC).

Methodology

Duty cycles and payloads

Three types of tests were performed on each bus. The tests covered different operating conditions that occur real-world driving, as outlined below:

» In-service conformity (ISC) test: The ISC test is compliant with the Euro VI regulations (EU) 2011/582, the step-D implementation of Euro VI (EU) under 2016/1718, and the step-E provisions under (EU) 2019/1939. This test includes PN measurement and cold-start considerations. Distinct repetitions of this test are referenced as ISC1 and ISC2.

» City bus route test: This test (City), replicates an actual route of urban buses in Helsinki, with conditions such as frequent stops with their typical duration, including those experienced during rush hour traffic, and with a representative distance and duration. Despite representing the actual operation of city buses, these tests do not meet the requirements set in the regulations for ISC testing, due to the trip composition and average engine load. Distinct repetitions of this test are references as City1 and City2.

- Low load cycle (LLC) test: This test is based on the engine dynamometer cycle recently adopted as part of California's heavy-duty omnibus regulation (Kelly & Sharpe, 2022). The test is designed to evaluate the performance of the emissions control system during three types of operation in urban driving: Sustained low load, high load to low load transition, and low load to high load transition. Distinct repetitions of this test are referenced as LLC1 and LLC2.

The payload used during testing corresponded to the weight of the driver, the measuring equipment, and the operator of these devices. For Bus 1, this amounted to 18% of the maximum payload. For Bus 2, the test weight amounted to 11% of the maximum payload. This testing payload met the regulatory requirements for ISC testing, which must exceed 10% of the full vehicle payload.

The tests were performed in typical Nordic conditions during the winter period. The ambient temperature fluctuated from -12˚C to 4˚C. Further details on the test characteristics can be found in the accompanying report from VTT (Pettinen, 2022).

Figure 2 illustrates sample drive cycle tests that were performed on Bus 1.

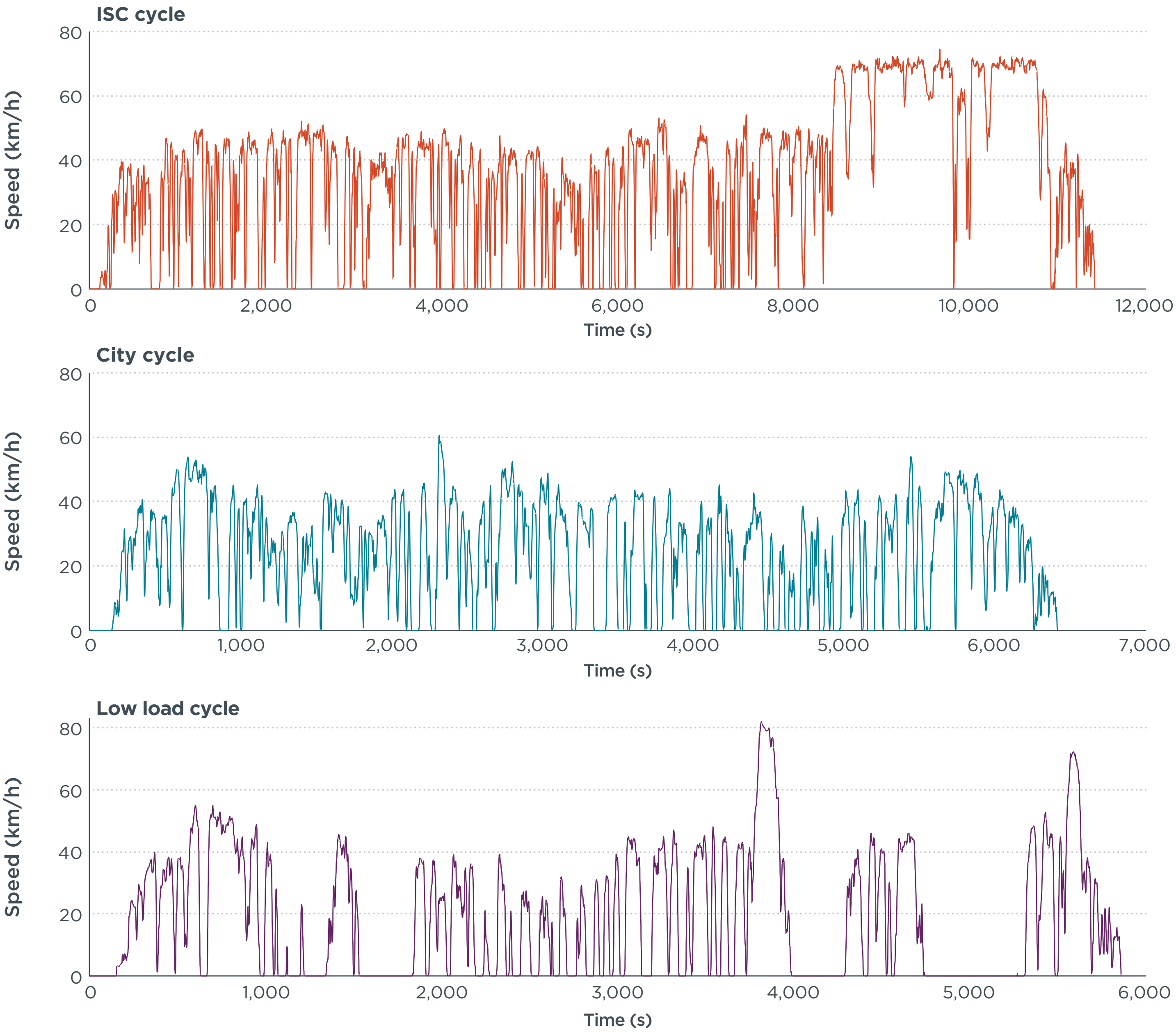

Figure 2. Driving cycle examples from Bus 1: ISC, City, and LLC

Table 3 shows the engine work exerted over each test. While some tests are below the threshold of 3 times the WHTC work, the analysis focuses on the 90th and 100th percentile evaluations.

Table 3. Engine work done by each bus over each test type

	ISC	City	LLC
Engine work done by Bus 1	~ 90 kWh ~ 5*WHTC	~40 kWh ~2.3*WHTC	~35 kWh ~2.1 WTHC
Engine work done by Bus 2	~ 120 kWh ~ 4.9*WHTC	~55 kWh 2.2*WHTC	~ 35 kWh ~1.5*WHTC

Measurement devices

A conventional portable emissions measurement system (PEMS) was used to measure the on-road emissions of currently regulated pollutants, namely CO_2, CO, NO_x, and the number of particles larger than 23 nm (PN_{23}).

Unregulated gaseous pollutants, namely ammonia (NH_3) and nitrous oxide (N_2O), were measured by performing Fourier transform infrared spectroscopy (FTIR) with a portable device.[1] The number of particles larger than 10 nm (PN_{10}) was measured with a condensation particle counter with a cut-off diameter of 10 nm.

Emissions performance

The PEMS data were analyzed using the moving average window (MAW) method, as defined in the Euro VI regulation, and renamed to moving window (MW) under the Euro 7 proposal. The MAW notation is used in this paper. Under the MAW method, emissions data are evaluated in subsets, or windows, of a complete data. The window size is defined by the engine work or the CO_2 emissions over the window, which must be equal to the work or CO_2 emissions over the World Harmonized Transient Cycle (WHTC).

Under Euro VI-D—the Euro VI step that the test buses were certified to—a vehicle is deemed compliant if the emissions of at least 90% of all valid windows—that is, the 90^{th} percentile MAW emissions (hereafter MAW-90%)—are below the ISC limit. Under Euro 7, the MAW-90% represents a stricter evaluation method since all windows are valid. Furthermore, the 100^{th} percentile (hereafter MAW-100%), corresponding to the highest emitting window by definition, is also used to assess compliance.

Figure 3 shows the boxplots of the MAW emissions for each pollutant considered. The results were processed excluding and including cold start. For Euro VI-D, the cold start period starts at the beginning of the test and ends when the engine coolant temperature reaches 70°C. The average emissions over the complete trip were also assessed and are shown in Figure 3.

1 FTIR analyzers measures the absorption or transmission of infrared radiation by gases in a sample, and then uses a mathematical process called a Fourier transform to analyze the spectrum and quantify the concentrations of specific pollutants present.

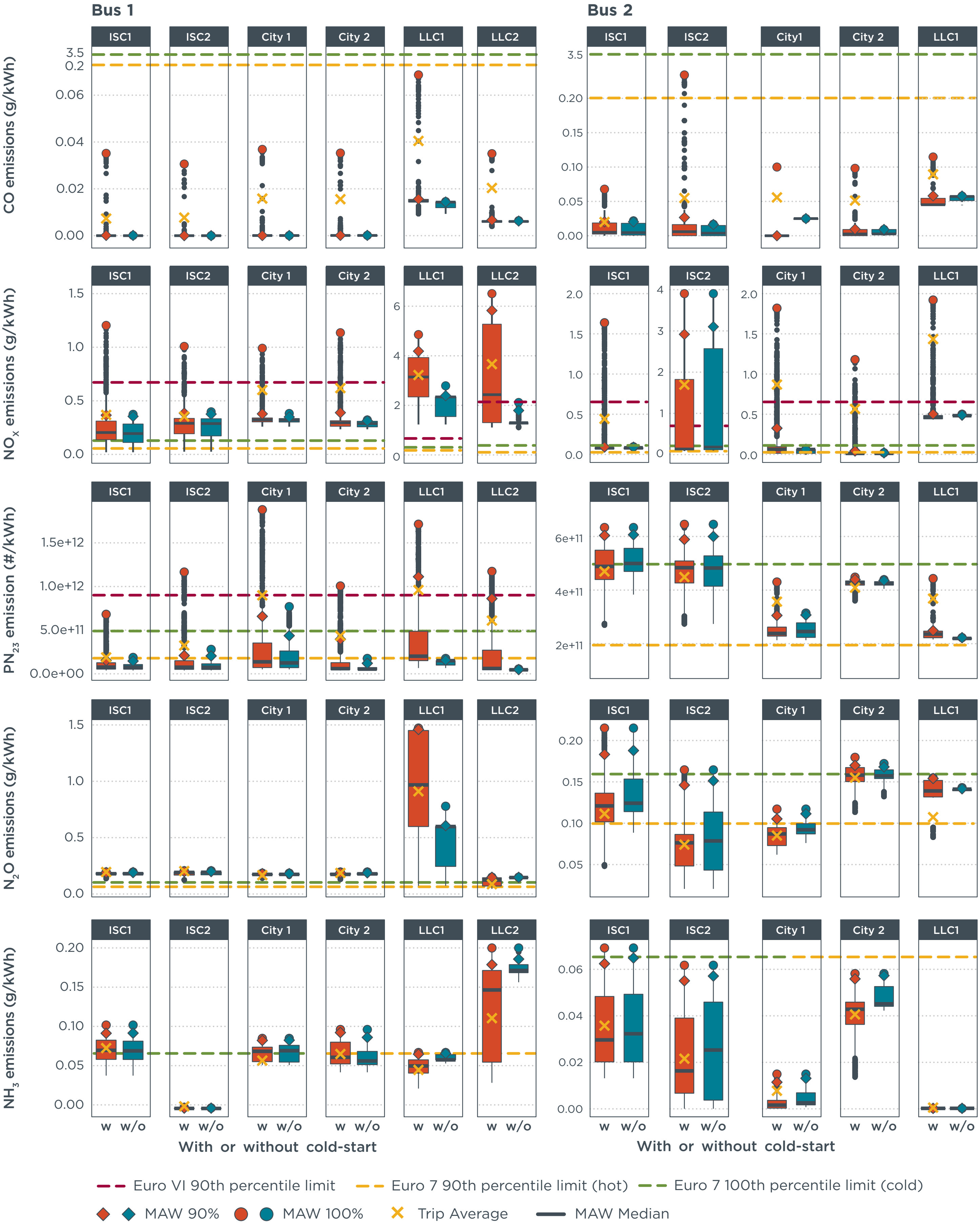

Figure 3. CO, NO_X, PN_{23}, N_2O, and NH_3 emissions performance over all valid PEMS tests. Results show the MAW and trip average analyses.

Euro VI compliance assessment

The MAW-90% emissions were compared with the Euro VI on-road limits for all regulated emissions (see Table 1). While the MAW-90% calculation was performed with and without including the cold-start emissions, the ISC test results excluding cold-start emissions were used to assess compliance with Euro VI limits.

Bus 1 exhibited MAW-90% NO_x emissions of 350 mg/kWh in the ISC1 test and 375 mg/kWh in the ISC2 test. Both are well below the 690 mg/kWh on-road NO_x Euro VI limit. Bus 2's NO_x emissions over the ISC1 test were lower at 90 mg/kWh. However, the emissions over the subsequent test, ISC2, were over an order of magnitude higher at 3,100 mg/kWh, exceeding the Euro VI limit by a factor of 4.5. VTT researchers could not identify the root cause for the steep increase in NO_x emissions over the ISC2 test for Bus 2, as an active regeneration of the diesel particulate filter (DPF) did not occur, and no error codes could be read in the on-board diagnostic system (OBD).

Since both buses were type-approved to Euro VI-D, they were not required to be tested for PN during on-road PEMS testing. Still, both buses showed MAW-90% emissions of PN_{23} below the Euro VI on-road limits, first implemented under step E, of 9×10^{11} #/kWh. Bus 1's MAW-90% emissions were between 1.5×10^{11} and 2×10^{11} #/kWh. The MAW-90% emissions of PN_{23} of Bus 2 were somewhat higher at 6×10^{11} #/kWh over both ISC tests.

Both buses show a large margin of compliance with the CO emissions limit of 6 g/kWh with the MAW-90%. Bus 1 had CO emissions close to the PEMS detection limit, resulting in a MAW-90% value of less than 1 mg/kWh. Bus 2's MAW-90% CO emissions were 20 mg/kWh.

NO_x and NH_3 emissions analysis

Fixed nitrogen[2] in the exhaust gas of diesel engines comes in the form of NO_x and NH_3 emissions. Fixed nitrogen emissions react in the atmosphere to form particulate matter ($PM_{2.5}$), the air pollutant with the highest impact on human health. As pollutant emission regulations continue to tighten NO_x limits, they must also ensure that the technologies deployed for NO_x control, such as selective catalytic reduction (SCR) systems, do not lead to higher NH_3 emissions. Given that each gram of NH_3 contains the same amount of fixed nitrogen as 2.7 grams of NO_x, ammonia's contribution to $PM_{2.5}$ formation can become more dominant than that of NO_x if NH_3 emissions remain unchecked in the on-road test.

Compared to the Euro VI on-road limit of 690 g/kWh, the Euro 7 proposal removes limitations on window validity, and tightens the NO_x limits to 90 mg/kWh in hot operation and 350 mg/kWh in cold operation. For the first time, the Euro 7 regulation would set a mass limit for on-road NH_3 emissions of 65 mg/kWh during cold and hot operation. Currently, the Euro VI standards only include a 10-ppm concentration limit, evaluated only in the engine dynamometer test in the laboratory.

The results in Figure 3 indicate that the inclusion of cold-start emissions has the largest impact on MAW-100% evaluation of the emissions performance; that is, the highest emitting window typically occurs during cold-start. This does not come as a surprise, as selective catalytic reduction systems must achieve their activation temperature—typically 200°—to reduce NO_x emissions efficiently.

Bus 1 exhibited MAW-100% NO_x emissions between 1,000 and 1,250 mg/kWh during cold operation over the ISC and city route tests; that is, between 2.8 and 3.6 times

2 Nitrogen gas (N_2) is called "free" nitrogen, meaning it is not combined with other kinds of atoms. Nitrogen is fixed when it is combined with other elements to form nitrogen-containing compounds, such as NO, NO_2, and NH_3, among others.

higher than the Euro 7 limit. Over the LLC test, MAW-100% cold start NO_x emissions were significantly higher, achieving values above 6,000 mg/kWh. MAW-90% NO_x emissions, representative of hot operation, were substantially lower at around 365 mg/kWh over the ISC and city route tests; that is, about four times higher than the Euro 7 limit of 90 mg/kWh. MAW-90% emissions over the LLC route oscillated around 2,000 mg/kWh.

Disregarding the ISC2 test, as explained in the previous section, Bus 2 exhibited substantially lower MAW-90% NO_x emissions than Bus 1, at 90 mg/kWh over the ISC route test (same as the proposed Euro 7 limit), between 40 and 320 mg/kWh over the city route test, and at 500 mg/kWh over the LLC test. Notwithstanding, Bus 2 showed higher MAW-100% NO_x emissions over the ISC and City route tests in cold operation, ranging from 1,200 to 1,800 mg/kWh.

NH_3 emissions did not exhibit a strong dependence on the temperature of the aftertreatment system, supporting the European Commission's proposal of setting the same limit for cold and hot emissions. MAW-100% NH_3 emissions were, on average, just 10% higher than MAW-90% emissions. Bus 2 showed a better NH_3 emissions performance, with MAW-100% cold emissions averaging 40 mg/kWh over all the tests; that is, about 40% lower than the proposed Euro 7 limit. Bus 1's performance averaged 90 mg/kWh across all tests.

Consequently, the proposed Euro 7 NH_3 limits are not expected to drive a significant improvement compared to current HDV ammonia emissions at the fleet level.

PN_{23} and PN_{10} emissions analysis

Euro VI sets emission limits for PN_{23}, that is, for solid particles larger than 23 nm. Volatile, semi-volatile, and solid particles smaller than 23 nm are currently not regulated, despite their detrimental health effects through direct exposure and the formation of $PM_{2.5}$.

Compared to the Euro VI-E on-road limit of 9×10^{11} #/kWh, Euro 7 would set stricter limits of 2×10^{11} #/kWh for MAW-90% and 5×10^{11} #/kWh for MAW-100%. Furthermore, Euro 7 would lower the size threshold from 23 nm to 10 nm (PN_{10}).

PN_{10} emissions measurements are only available for a chassis dynamometer test of Bus 1 and for the on-road routes of Bus 2, due to malfunctioning of the measurement device.

Bus 1's PN_{23} emissions exhibited a substantial temperature dependence, as indicated by the significant difference between the MAW-100%, which ranged between 6.8×10^{11} #/kWh and 1.9×10^{12} #/kWh, and MAW-90% emissions, which fluctuated between 1.5×10^{11} #/kWh and 1.1×10^{12} #/kWh. PN_{10} emissions over the chassis dynamometer test ranged between 1.7 and 1.9 times higher than PN_{23} emissions.

Bus 2's PN_{23} emissions exhibited better performance and a more homogeneous trend than Bus 1, with MAW-100% being up to 10% higher than MAW-90% emissions in three tests, and over 40% higher in the remaining two tests. PN_{23} emissions averaged about 5.2×10^{11} #/kWh for the MAW-100% evaluation and about 4.4×10^{11} #/kWh for the MAW-90% evaluation. The ratio of PN_{10} to PN_{23} emissions over the five on-road tests ranged from 1.6 to 2.0, exhibiting similar behavior to Bus 1.

To meet Euro 7 MAW-100% requirements, the cold filtration efficiency of current Euro VI diesel particulate filters would need to improve by approximately one order of magnitude.

Greenhouse gas emissions analysis

Carbon dioxide emissions are a direct and unavoidable consequence of combusting diesel fuel. N_2O emissions, on the other hand, are formed inside the emissions control systems during the catalytic reduction of NO_x to nitrogen. N_2O is a potent greenhouse gas with a global warming potential (GWP) of 298 over a 100-year period. N_2O is not only a powerful GHG but also the most important ozone-depleting substance and is not regulated by the Montreal Protocol (Ravishankara et al., 2009).

N_2O is not currently regulated under the Euro VI standards. The Euro 7 proposal would introduce N_2O limits of 100 mg/kWh for the MAW-90% evaluation and 160 mg/kWh for the MAW-100% evaluation.

Bus 1 exhibited MAW-90% and MAW-100% N_2O emissions of around 200 mg/kWh, with an outlier test over the LLC test registering about 1,500 mg/kWh of N_2O. That is, the emissions were nearly two times higher than the proposed Euro 7 limit of 100 mg/kWh. Bus 2 exhibited similar behavior, with MAW-90% N_2O emissions averaging 150 mg/kWh across all tests and MAW-100% averaging 165 mg/kWh, just a 10% difference.

The slight difference observed between the MAW-90% and MAW-100% emissions suggests that the higher cold limit (MAW-100%) might be superfluous, as higher N_2O emissions are not correlated with lower emission control temperatures (i.e., cold-start) but are intermediate, unwanted products of the catalytic reduction of NO_x to nitrogen in warmed-up conditions. Aftertreatment systems can produce N_2O at temperatures around 250°C through the decomposition of ammonium nitrates. At temperatures above 500°C, the primary mechanism for N_2O formation is NH_3 oxidation in the ammonia slip catalysts. Therefore, contrary to NO_x emissions, cold-start is not the primary source of N_2O emissions (Selleri et al., 2022; Zhang & Yang, 2018).

Bus 1 exhibited CO_2 emissions between 660 and 690 g/kWh over the ISC and city route tests. The CO_2 emissions of Bus 2 were between 800 and 850 g/kWh over the same tests. Accounting for N_2O emissions using its 100-year GWP would increase the GHG emissions of these buses between 7% and 9%.

The testing results show that the limits proposed by Euro 7 are close to what can be achieved with current emissions control technologies, under the conditions tested at low payloads. As NO_x emissions limits are tightened, a robust N_2O limit under Euro 7 is important to prevent backsliding from current Euro VI performance.

Conclusions and policy recommendations

In this study, two diesel transit buses certified to the Euro VI-D standard were tested on the road over various drive cycles. These included an in-service conformity test according to the regulatory provisions, a city test representative of the typical operation of an urban bus in Helsinki, and a challenging low load test similar to California's new engine dynamometer test. The tests were performed on the road during the Nordic winter. The data evaluation was performed including and excluding the cold start period. The analysis focused on the emissions of the following types of pollutants:

» Regulated pollutants

» Particulate emissions with a size between 10 and 23 nm

» Ammonia

» Nitrous oxide

Considering the results from both buses over the ISC and city route tests, we found:

» **Both buses exhibited emissions performance in accordance with the Euro VI-D type-approval requirements.** However, Bus 2 showed abnormal behavior over one in-service conformity test, leading to steep NO_x emissions; the on-board diagnostic system reported no error and no DPF regeneration took place.

» **The proposed Euro 7 limits are expected to improve the NO_x performance of transit buses substantially.** The NO_x emissions over the highest emitting windows were three to five times higher than the proposed Euro 7 cold limit. NO_x emissions in hot operation ranged between one and four times the proposed Euro 7 hot limit.

» **The PN requirements under Euro 7 would demand higher filtration efficiency than what current technologies offer.** The number of particles in the 10 to 23 nm size range, which would also now be regulated under Euro 7, is substantial and would increase the PN count between 60% and 100%. To meet the proposed Euro 7 requirements, particle filters must improve their filtration efficiency up to an order of magnitude.

» **Ammonia limits proposed under Euro 7 limits would prevent backsliding from current performance as NO_x emissions are reduced.** Bus 2 exhibited an emissions performance 40% below the proposed limit, and Bus 1 40% above it. The proposed Euro 7 limits would prevent an increase in ammonia emissions from current levels as NO_x emissions are reduced. Under Euro 7, ammonia and NO_x are expected to contribute similarly to the emissions of fixed nitrogen.

» **Nitrous oxide emissions contributed 7% to 9% of the greenhouse gas emissions of the buses tested. Euro 7 limits would prevent backsliding from current N_2O performance as NO_x emissions are reduced.** The proposed limits are close to what can be achieved with current emissions control technologies. Like ammonia, the proposed limits would prevent an increase in nitrous oxide emissions from current levels as NO_x emissions are reduced.

We recommend adopting the proposed Euro 7 limits for trucks and buses, which are technically feasible and cost-effective. Compared to Euro VI emission control technologies, the Commission's Euro 7 proposal will drive substantial improvements in the emissions of NO_x and particles. Several technologies are ripe for commercialization, simultaneously reducing NO_x and CO_2 emissions. The economies of scale created by similarly stringent standards in the United States will ensure that truck and bus manufacturers can cost-effectively deploy such technologies.

References

European Commission. (2022). Proposal for a Regulation of the European Parliament and of the Council on type-approval of motor vehicles and engines and of systems, components and separate technical units intended for such vehicles, with respect to their emissions and battery durability (Euro 7) and repealing Regulations (EC) No 715/2007 and (EC) No 595/2009 (COM(2022) 586 final). https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6495

European Environment Agency. (2021). Air quality in Europe 2021. https://www.eea.europa.eu/publications/air-quality-in-europe-2021/

Kazemi Bakhshmand, S., Mulholland, E., Tietge, U., & Rodríguez, F. (2022). *Remote sensing of heavy-duty vehicle emissions in Europe*. International Council on Clean Transportation. https://theicct.org/publication/remote-sensing-of-heavy-duty-vehicle-emissions-in-europe/

Kelly, S., & Sharpe, B. (2022). *California's heavy-duty omnibus regulation: Updates to emission standards, testing requirements, and compliance procedures*. International Council on Clean Transportation. https://theicct.org/publication/california-us-hdv-omnibus-reg-jan22/

Mulholland, E., Miller, J., Braun, C., Jin, L., & Rodríguez, F. (2021). *Quantifying the long-term air quality and health benefits from Euro 7/VII standards in Europe*. International Council on Clean Transportation. https://theicct.org/publication/quantifying-the-long-term-air-quality-and-health-benefits-from-euro-7-vii-standards-in-europe/

Pettinen, R. (2022). An in depth analysis of postprocessing methods on heavy duty Euro VI exhaust emissions. VTT Technical Research Centre of Finland Ltd.

Ravishankara, A. R., Daniel, J. S., & Portmann, R. W. (2009). Nitrous Oxide (N2O): The Dominant Ozone-Depleting Substance Emitted in the 21st Century. *Science, 326*(5949), 123–125. https://doi.org/10.1126/science.1176985

Selleri, T., Gioria, R., Melas, A. D., Giechaskiel, B., Forloni, F., Mendoza Villafuerte, P., Demuynck, J., Bosteels, D., Wilkes, T., Simons, O., Recker, P., Lilova, V., Onishi, Y., Steffen, M., Grob, B., Perujo, A., & Suarez-Bertoa, R. (2022). Measuring Emissions from a Demonstrator Heavy-Duty Diesel Vehicle under Real-World Conditions—Moving Forward to Euro VII. *Catalysts, 12*(2), Article 2. https://doi.org/10.3390/catal12020184

Zacharof, N., Bakhshmand, S. K., Niu, T., Rodriguez, F., Su, S., Lu, T., Soderena, P., Pettinen, R., & Weller, K. (2022). *Pollutant emissions from the latest generation of heavy-duty vehicles in Europe and China* (SAE Technical Paper No. 2022-01-1024). SAE International. https://www.sae.org/publications/technical-papers/content/2022-01-1024/

Zhang, D., & Yang, R. T. (2018). N2O Formation Pathways over Zeolite-Supported Cu and Fe Catalysts in NH3-SCR. *Energy & Fuels, 32*(2), 2170–2182. https://doi.org/10.1021/acs.energyfuels.7b03405