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Real-driving emissions from Bharat Stage VI (phase 1) passenger cars and a light commercial vehicle in India – PEMS testing

Anirudh Narla, Ashok Deo, Bharadwaj Sathiamoorthy, and Tim Dallmann

Automobile pollution is a serious concern in Indian cities and the Bharat Stage VI (BS VI) emission rules that took effect April 1, 2020 marked a big step forward in efforts to reduce vehicle emissions. The BS VI standards include real-driving emissions (RDE) regulations that are mostly consistent with the third package of the European Union's RDE regulations (see Appendix A for full details). They include on-road emissions testing and laboratory-based emission tests, and implementation of the RDE regulations marked the first time vehicles in India were subject to on-road emission limits, which have proven critical to reducing real-world emissions in other regions.

This paper explores two key questions by analyzing the real-world emissions from four light-duty vehicles (LDVs) in India registered during the monitoring phase (BS VI phase 1) of the RDE regulations:

1. Though no compliance was required, what was the real-world emissions performance of these vehicles?
2. How effective are different emission control strategies deployed by vehicle manufacturers?

We begin by explaining the current RDE regulatory environment in India and then explore the exhaust aftertreatment systems of the LDVs analyzed. We next present the testing methodology by detailing both the laboratory and real-world emissions tests performed. Finally, we summarize the emissions performance of the vehicles and conclude with some ways that policy could enhance the air quality benefits of the BS VI emission standards.

www.theicct.org

communications@theicct.org

@theicct.org

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BACKGROUND

The implementation of the BS VI emission standards on April 1, 2020 marked the beginning of the 3-year monitoring period for RDE regulations for LDVs. Since the end of the monitoring period on April 1, 2023, all vehicles produced and sold in India have been required to have real-world driving emissions within a specified range of laboratory test limits.

The Modified Indian Driving Cycle (MIDC) is currently used for type-approval tests performed in a laboratory on a chassis dynamometer, but it has been shown to be lacking in its ability to represent typical driving operations of LDVs on roads in India. For example, an analysis of BS IV passenger cars commissioned by the International Council on Clean Transportation found that real-world emissions exceeded type-approval limits by a factor of 5–7 times for nitrogen oxides (NO_x) emissions and 10–22 times for carbon monoxide (CO) emissions (International Centre for Automotive Technology, 2017). Studies such as this led to interest in real-world emission limits.

For BS VI LDVs, the Ministry of Road Transport and Highways (MoRTH) notified that during type-approval and conformity of production, RDE measurements using a portable emissions measurement system (PEMS) are to be carried out for data collection purposes and that the real-driving emission limits would apply starting April 1, 2023 (MoRTH, 2016). To address uncertainties in PEMS-based measurements, a conformity factor (CF) was introduced. The CF is a multiplicative adjustment to the limit on laboratory emissions that establishes the real-world emissions limit for each pollutant. In the European Union, the CF applied for RDE tests was reduced over time. Table 1 presents the stages of CF reduction that were followed in the European Union and the present CFs in India for NO_x and particulate number (PN).

Table 1
Conformity factors for RDE tests in India and the European Union

Pollutant	India BS VI	Euro 6d-Temp[a]	Euro 6d[b]	Euro 6e[c]
NO_x	1.43	2.1	1.43	1.10
PN	1.5	1.5	1.5	1.34

[a] For new type-approvals since September 2017 and for all new vehicles since September 2019
[b] For new type-approvals since January 2020 and for all new vehicles since January 2021
[c] For new type-approvals since September 2023 and for all new vehicles starting September 2024

OVERVIEW OF EMISSION REDUCTION TECHNOLOGIES

This study evaluates the performance of internal combustion engines and aftertreatment systems in reducing emissions in real-world operating conditions following the implementation of the BS VI emission standards. We tested vehicles that allowed us to assess two key NO_x-reduction technologies of BS VI diesel LDVs: lean NO_x trap (LNT) and selective catalytic reduction (SCR).

All modern diesel vehicles use exhaust-gas recirculation (EGR) systems to reduce engine-out emissions. These systems recycle a portion of the exhaust gas into the combustion chamber; this reduces peak combustion temperatures because it decreases the oxygen content and increases the specific heat capacity of the cylinder filling. The use of EGR curtails NO_x emissions to some extent by mitigating the temperature-related increase in NO_x production. However, EGR also increases the formation of particles that must be addressed so they are not emitted from the vehicle's tailpipe.

A diesel particulate filter (DPF) is an essential emissions control device in diesel automobiles. It has a porous ceramic substrate that traps particulate matter (PM) while allowing exhaust gases to pass through. Two regeneration methods, passive regeneration through high exhaust temperatures and active regeneration involving fuel injection to burn off trapped soot, ensure continuous DPF functionality.

A diesel oxidation catalyst (DOC) is an emissions control device that facilitates the oxidation of CO and hydrocarbons (HC) to carbon dioxide (CO_2) and water vapor. Because a DOC does not reduce NO_x emissions, a separate NO_x aftertreatment system like SCR or LNT is needed to supplement the NO_x reduction from EGR and bring emissions down below regulatory limits.

LNTs adsorb and store NO_x during normal, lean diesel engine operation. LNT regeneration requires fuel-rich exhaust and ideally results only in nitrogen gas (N_2) and water vapor. LNT regeneration is required every few minutes.

SCR is an advanced NO_x-reduction technology used in diesel-engine vehicles. A reductant, usually an aqueous urea solution that is also referred to as diesel exhaust fluid or AdBlue, is injected into the exhaust upstream of the SCR catalyst. Ammonia released from the urea solution is used in the SCR catalyst to convert NO_x into nitrogen and water vapor.

In gasoline-engine vehicles, three-way catalytic converters (TWCs) are used to reduce CO, HC, and NO_x emissions. TWCs are coated with precious metals that facilitate emissions reduction.

Like DPFs, gasoline particulate filters (GPFs) reduce PM and PN emissions. However, GPFs require less active control for regeneration than DPFs because of the higher exhaust temperatures generated by gasoline engines.

VEHICLE SPECIFICATIONS AND TESTING METHODOLOGY

Our testing was carried out to understand the real-world emissions performance of BS VI-certified vehicles equipped with different emissions reduction technology packages. HORIBA India was contracted to source the test vehicles and execute all testing activities. The testing was carried out in 2022 and the real-world tests were performed on three passenger vehicles (PVs) and one light commercial vehicle (LCV) on select routes in and around the city of Pune.

Characteristics of the four vehicles, labeled in this paper as *PV1*, *PV2*, *PV3*, and *LCV1*, are in Table 2. The vehicles were selected based on a mix of factors, including the popularity of vehicle segments, the top-selling models within those segments, and to ensure that different aftertreatment systems were represented. PV1 and PV3 are M1 category diesel passenger cars, considered to be compact sport utility vehicles (SUVs) in the Indian market. PV2 is a popular M1 category gasoline passenger car compact SUV. Finally, LCV1 is a popular N1 category light goods vehicle.

All test vehicles had accrued more than the minimum 3,000 km mileage required by the regulation for RDE testing and all were registered during the first phase of BS VI (April 2020 to March 2023), which required RDE monitoring but not compliance.

Table 2
Test vehicle characteristics

Vehicle	PV1	PV2	PV3	LCV1
Class	M1	M1	M1	N1
Mileage (km)	42,000	7,000	17,000	55,000
Power (kW)	85	88	126	60
Fuel/injection	Diesel/CRDi	Gasoline/GDI	Diesel/CRDi	Diesel/CRDi
Displacement (L)	1.5	1	2	1.5
Turbocharger with intercooler	Yes	Yes	Yes	Yes
Exhaust gas recirculation (EGR)	Yes	Yes	Yes	Yes
Exhaust aftertreatment technology	DOC+DPF+LNT	TWC, no GPF	DOC+DPF+SCR	DOC+DPF+LNT
Gross vehicle weight / maximum payload (kg)	1,750/475	1,540/320	2,085/525	3,495/1,860

Notes: CRDi=common rail direct injection; GDI=gasoline direct injection; DOC=diesel oxidation catalyst; DPF=diesel particulate filter; GPF=gasoline particulate filter; LNT=lean NO_x trap; SCR=selective catalytic reduction; TWC=three-way catalytic converter. Gross vehicle weight includes curb weight and payload.

As part of the procurement process and prior to the commencement of testing, all four vehicles were checked for potential engine or aftertreatment malfunction via visual inspection and an on-board diagnostics scanning tool. No diagnostic trouble codes or issues were detected, and all vehicles were deemed to be in good condition. Certified values from Form 22, which are detailed in Appendix B, were obtained to compare with the test results.[1]

A GPS device and a weather station that measures ambient pressure, temperature, humidity were used as PEMS auxiliary devices. In addition, an on-board diagnostics data logger was connected to the vehicles along with the PEMS equipment for all tests. The test setup, preparations, calibrations, sampling, and pre- and post-checks were compliant with the RDE regulatory requirements. The PEMS device validation tests with constant volume sampler (CVS) equipment were conducted first, prior to the on-road tests; this was done on a chassis dynamometer using the MIDC.

ON-ROAD TEST ROUTES

Each vehicle was driven over two test routes, one we label as "India RDE" and the other we label as "India real-world." The India RDE route is compliant with the trip requirements prescribed in Automotive Indian Standards (AIS) 137 for real-driving emissions. In contrast, the India real-world route contains trips that are not compliant with AIS 137 and are limited by the organic traffic conditions encountered by the vehicle. The India real-world route was also chosen to retain the same share of the three trip sequences (urban/rural/motorway) as the India RDE route, as shown in Table 4.

The India real-world testing was done in addition to the India RDE testing because the fixed driving pattern required for the AIS trips can be detected by the engine control unit (ECU) and could therefore trigger alternative emission or engine control strategies to improve emissions during type-approval or in-service conformity testing. The non-

1 The Form 22 certificate, issued with the signature of the manufacturer, states that the vehicle aligns with emission regulations. Form 22 emissions data for CO, NO_x, PN, PM, and THC was obtained for the four test vehicles.

AIS trips thus help in identifying use of any emissions-related strategies or so-called defeat devices. The vehicle payload of up to 90% of the maximum payload was used for the India RDE test. Table 3 details the characteristics of the trips performed.

Table 3
Design of the India RDE and India real-world trips for testing

Trip name	Sequence	Maximum stop/idle time	Maximum urban speed (M1/N1)	Maximum duration >100 km/h	Minimum urban share of trip distance
India RDE (AIS compliant)	Urban-rural-motorway	5 min	45/40 km/h	< 3% of motorway duration	25%
India real-world (Non-AIS)	Randomized	8 min	35 km/h	No limit applied	37%

Details of the 10 on-road tests performed on the test vehicles are listed in Table 4. For PV3, the additional India real-world2 test was included because the criteria for minimal normality requirement (discussed below) in the motorway phase under the RDE regulations was not met in the initial India real-world1 test. Additionally, for LCV1, the minimal normality requirement in the motorway phase under the RDE regulations was not met during the India RDE1 test route; the test was rerun as India RDE2 with slightly increased motorway operation and reduced payload, but it still failed to meet the minimum normality requirement. Following this, the India real-world test was run, and that also failed the normality criteria for the motorway operation. For all vehicles, all tests started with a coolant temperature of 27±3°C.

Table 4
Trip characteristics for the four test vehicles

	Route	Trip duration (min) / distance (km)	Average trip speed (km/h)	Average urban speed (km/h)	Composition (%) (urban/ rural/ motorway)	Stop/ idle time (%)	Payload (%)	Average ambient temperature (°C)	Average trip altitude (m)
PV1	India RDE (AIS)	118/66.9	33.8	19.5	38.6/35.5/25.0	21.7	93	26.8	672
	India real-world (Non-AIS)	135/62.9	27.9	14.6	39.4/31.3/29.3	28.3	93	23.9	576
PV2	India RDE (AIS)	111/62.9	33.7	19.5	38.6/33.6/27.8	25.7	97	36.5	665
	India real-world (Non-AIS)	131/70.0	31.9	15.0	32.7/30.1/37.1	32.2	55	30.7	581
PV3	India RDE (AIS)	115/65.0	33.8	19.5	39/31.6/29.4	24.5	95	38.7	663
	India real-world (Non-AIS)	127/70.4	33.1	17.8	39/25.9/35.1	27.7	95	33.8	580
	India real-world (Non-AIS) iteration 2	111/51.0	27.5	15.9	49/2.8/48.2	31.0	55	32.6	587
LCV1	India RDE (AIS)	119/61.7	30.9	17.6	38.3/33.6/28.0	26.2	95	33.9	667
	India RDE(AIS) iteration 2	114/64.1	33.6	20.0	38.3/31.9/29.8	18.1	53	34.7	667
	India real-world (Non-AIS)	139/57.7	24.9	13.5	40.7/29.6/29.7	25.8	95	32.3	580

EMISSIONS CALCULATION

Mass emissions were calculated from the instantaneous concentration and exhaust mass. In assessing trip validity and calculating the final RDE emissions, we used the moving average window (MAW) data processing method to integrate the instantaneous emissions calculated, as defined in the AIS 137 regulation. Under the MAW calculation principle, instead of computing mass emissions for the entire dataset, the calculation is performed on data subsets, or windows. The length of each window is defined by the CO_2 mass emitted during the period covered by the window. The CO_2 mass of each window equals the CO_2 mass emitted during the MIDC type-approval test.

The MAWs were determined with a frequency of 1 Hz. Each MAW covers the preceding time span where the reference CO_2 mass was emitted. For each MAW, the average speed and distance-specific CO_2 emissions were calculated. This was then compared with the characteristic curve, defined by the MIDC phase CO_2 emissions. At least 50% of the windows must be within the primary tolerance band (+/- 25%) around the characteristic curve for a trip to meet normality criteria. Each window was then weighted according to its distance from the characteristic curve. If it was within +/- 25% of the characteristic curve value, it was counted as 1 and if it was outside the +/- 50% tolerance, it was counted as 0. In between, linear interpolation was applied.

EMISSIONS COMPARISON

The results presented compare the raw distance-specific mass emissions from PEMS and the weighted average of the windows emissions. This is done to see the impact of the data processing method on the emissions results and compare it with untreated raw data from PEMS. Then the weighted average of the windows emissions, which are used for compliance assessment under the RDE regulation, are compared with emissions readings from the laboratory CVS MIDC tests and the BS VI emission limits. Finally, the ratio of weighted average of the windows emissions to BS VI emission limits are then compared with the CFs defined for NO_x and PN.

RESULTS

LABORATORY EMISSIONS PERFORMANCE AND PEMS VALIDATION

An MIDC test was performed prior to the real-world tests to validate the PEMS equipment and its installation; this was done using the CVS-based measurement equipment. The validation tests check that the deviation between PEMS measurements (hereafter “PEMS MIDC”) and CVS measurements (hereafter “CVS MIDC”) is within the permissible tolerances defined in the AIS regulations. These CVS MIDC measurements are used for the assessing the emissions performance of the four test vehicles under laboratory conditions.

As detailed in Table 5, the CVS MIDC values of the four vehicles tested were typically higher than their certified values (from Form 22), but well within the BS VI emissions limits for the three passenger cars. The values for LCV1 that exceeded the BS VI limits are highlighted in red. The vehicle performed poorly for NO_x emissions during the MIDC test, with values are more than twice the BS VI limit.

Table 5
Tests results on the MIDC compared with certified values and BS VI limits

Vehicle	Emissions from	CO (mg/km)	CO_2 (g/km)	NO_x (mg/km)	PN (#/km)
PV1	Certified values	299.80	—	33.49	1.63E+08
	CVS MIDC	381	136.05	63.39	4.99E+08
	PEMS MIDC	348.26	146.41	70.37	9.05E+08
	BS VI limit	500	—	80	6.00E+11
PV2	Certified values	190.56	—	14.08	7.40E+11
	CVS MIDC	159	160.26	12.42	6.66E+11
	PEMS MIDC	117.21	181.84	14.82	1.02E+12
	BS VI limit	1,000	—	60	6.00E+12[a]
PV3	Certified values	23.94	—	30.77	7.20E+10
	CVS MIDC	20	170.87	42.65	4.30E+10
	PEMS MIDC	7.16	175.88	46.44	4.34E+10
	BS VI limit	500	—	80	6.00E+11
LCV1	Certified values	56.3	—	56.9	—
	CVS MIDC	57.36	179.64	268.63	5.24E+11
	PEMS MIDC	60.61	192.54	296.21	6.01E+11
	BS VI limit	750	—	125	6.00E+11

[a] The PN emissions limit is 6.0E+11 per km for BS VI LDVs, but an optional limit of 6.0E+12 per km was allowed for GDI vehicles upon choice of the manufacturer until April 2023.

REAL-WORLD EMISSIONS

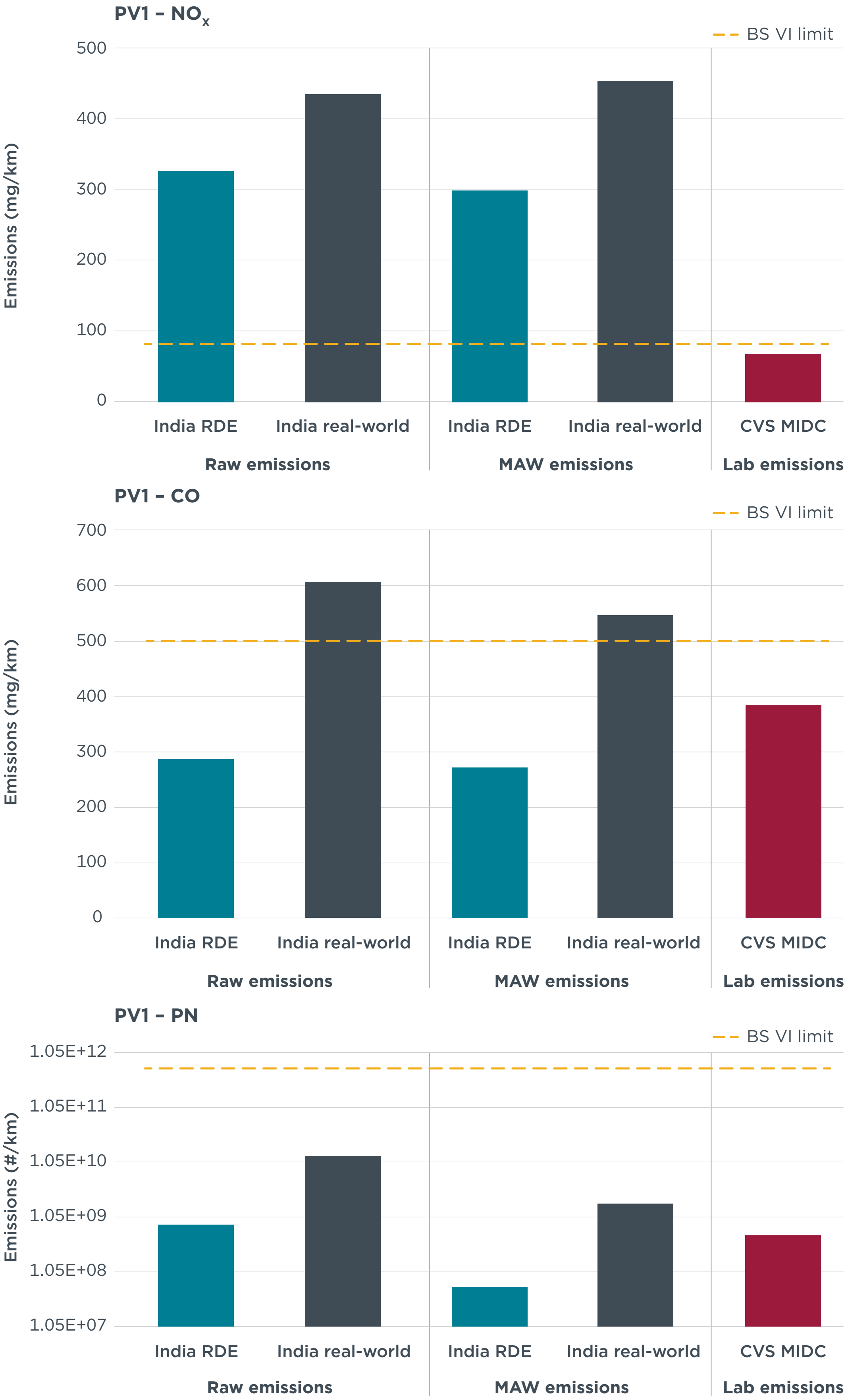
For all four vehicles, the raw PEMS emissions are referred to as "raw emissions" and the calculated weighted average of window emissions as defined in the AIS 137 regulation are the "MAW emissions."

Test vehicle PV1

The NO_x, CO, and PN emissions from PV1 are illustrated in Figure 1. For PN, the MAW emissions were much lower than the raw emissions, and minimal differences between the raw and MAW emissions were observed for NO_x and CO. Note that in Figure 1 (and in Figures 2 through 4 below), NO_x and CO are shown on linear scale and PN emissions are shown on logarithmic scale; this is primarily due to the wider range of PN emissions.

Figure 1

PV1 emissions from real-world and lab tests



Note: The dashed lines for the BS VI limits are for representative purposes, to demonstrate the variation of emissions from the BS VI limits.

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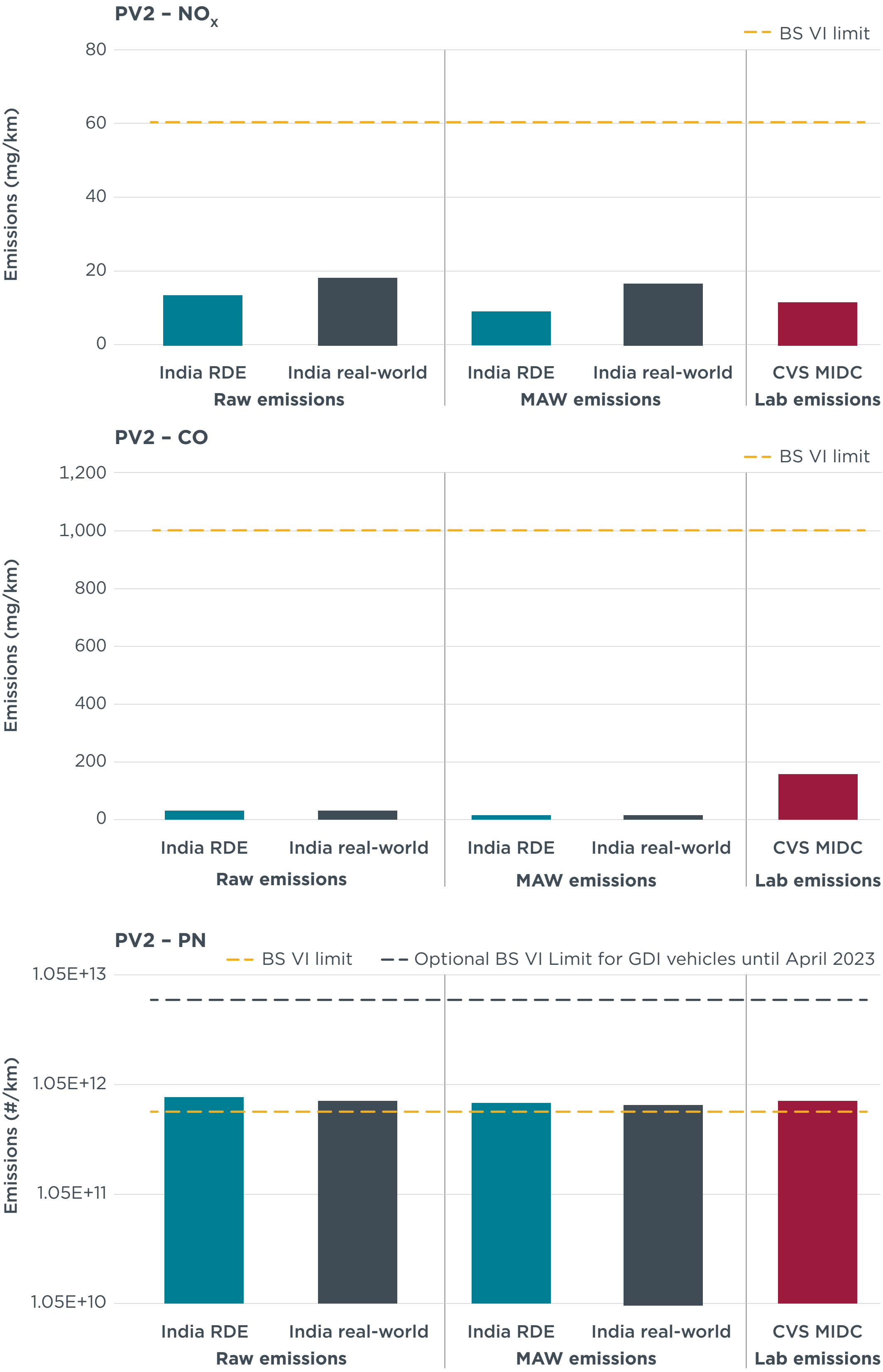
The emissions from PV1 in real-world conditions were higher than the emissions recorded in the controlled laboratory environment for all three pollutants. PV1 is equipped with an LNT and exhibited significantly higher NO_x MAW emissions than the laboratory CVS MIDC test showed; this was 4.7 times higher for the India RDE test and 7.1 times higher for the India real-world test. The PN MAW emissions in the India RDE test were considerably lower than the lab emissions but in the India real-world test they were 4.0 times higher than lab emissions. The CO MAW emissions from the India real-world test were around 1.5 times higher than the lab values, but during the India RDE test, they were lower than lab emissions.

The PN emissions in both the laboratory and real-world tests were considerably lower than the BS VI limit. For NO_x emissions, although the lab test results were below the BS VI limit, the India RDE test showed MAW emissions 3.7 times higher than the limit and the India real-world test revealed even higher MAW emissions at 5.7 times over the BS VI limit. CO emissions in both the lab and India RDE tests remained below the BS VI limit; however, in the India real-world test, CO MAW emissions were slightly elevated, at 1.1 times the BS VI limit.

Test vehicle PV2

Figure 2 illustrates the results for PV2. CO and PN MAW emissions were similar to raw emissions, but slightly lower. The difference between raw and MAW NO_x emissions is relatively high for PV2, as compared with the other pollutants.

Figure 2
PV2 emissions from real-world and lab tests



Note: The dashed lines for the BS VI limits are for representative purposes, to demonstrate the variation of emissions from the BS VI limits.

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The NO_x MAW emissions from the India RDE test were below the lab emissions but were almost 1.4 times the lab emissions during the India real-world test. The CO MAW emissions were significantly lower than the lab values for both the real-world tests. The PN MAW emissions were the same as lab emissions for India real-world test and 1.1 times the lab value for the India RDE test.

The lab and MAW emissions for both NO_x and CO from PV2 were comfortably below the BS VI emission limits. The PN emissions from both lab and on-road tests met the optional limit of 6.0E+12 per km for GDI vehicles until April 2023. However, they were higher than the limit of 6.0E+11 per km that would apply beginning April 1, 2023, by a factor of 1.1 for the lab and India real-world tests and 1.2 for the India RDE test (PN MAW). The GDI-based PV2, with no GPF, had the highest real-world PN emissions among all the vehicles tested.

Test vehicle PV3

Figure 3 illustrates the results for PV3. As mentioned earlier, an additional India real-world test, labelled “India real-world2,” was performed for PV3. For CO, there was no substantial difference between the raw emissions and the MAW emissions. However, for NO_x and PN, the MAW emissions were lower than the raw emissions in all three tests.

Figure 3

PV3 emissions from real-world and lab tests

Note: The dashed lines for the BS VI limits are for representative purposes, to demonstrate the variation of emissions from the BS VI limits.

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The real-world CO MAW emissions were higher than the laboratory emissions across all three tests. Specifically, the India RDE test showed CO emissions 1.5 times greater than the laboratory test, and the India real-world tests exhibited 2.2 and 3.1 times higher CO MAW emissions. The NO_x MAW emissions were lower than laboratory emissions across all three tests. For PN emissions, two tests were within the laboratory emissions range, and the India real-world2 test had MAW emissions that were 1.4 times higher than the laboratory emissions.

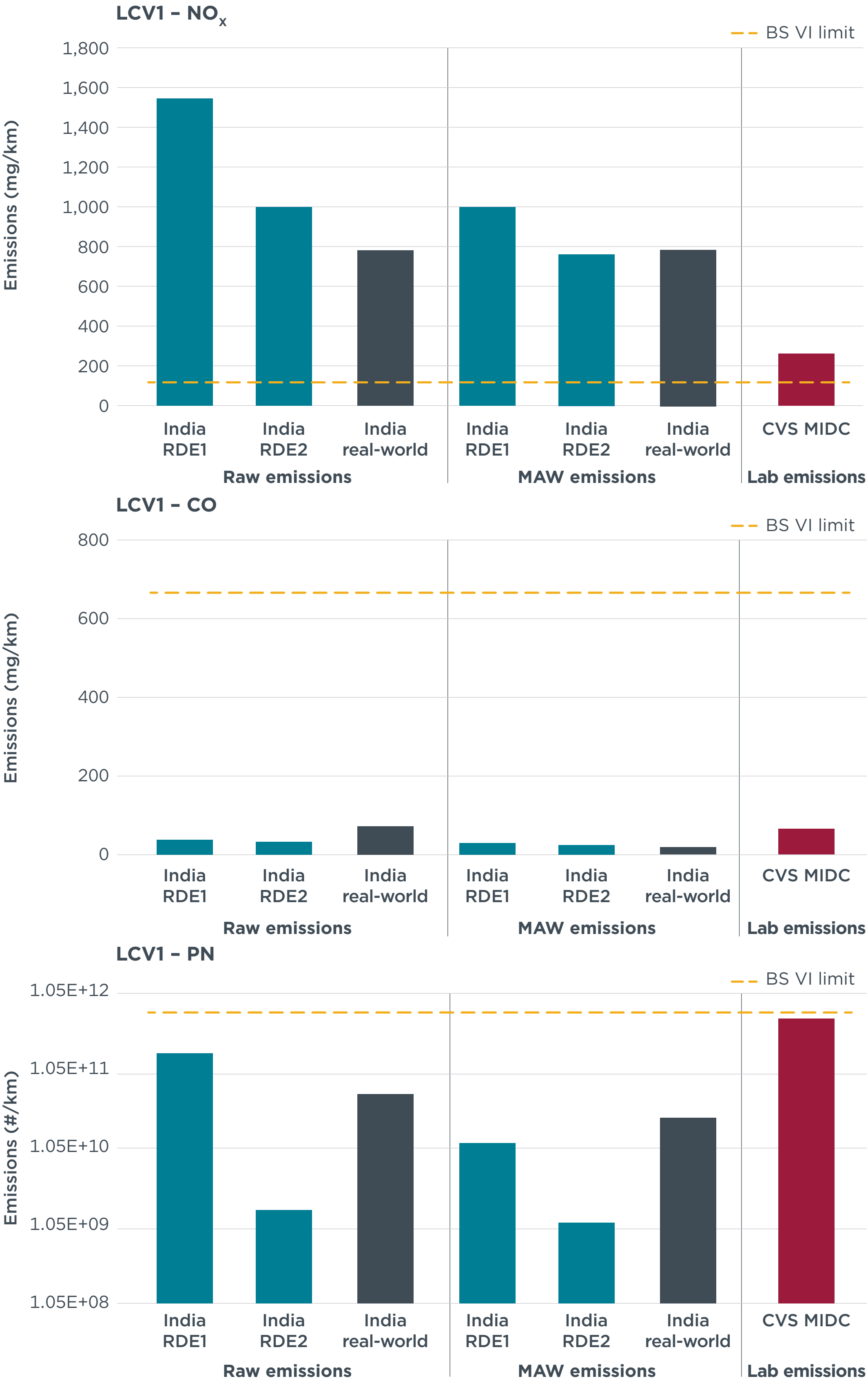
All NO_x, CO, and PN emissions from PV3, which is equipped with SCR, were below the BS VI limits.

Test vehicle LCV1

Figure 4 presents the results for LCV1. As mentioned earlier, an additional India RDE2 test was performed for LCV1. The MAW emissions for NO_x, CO, and PN were lower than the raw emissions in all three tests.

Figure 4

LCV1 emissions from real-world and lab tests



Note: The dashed lines for the BS VI limits are for representative purposes, to demonstrate the variation of emissions from the BS VI limits.

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LCV1, which was equipped with an LNT, had the worst NO_x emissions performance of the four test vehicles. In both of the India RDE tests, the NO_x MAW emissions were notably higher—2.9 and 3.7 times—compared with the laboratory emissions. The India real-world test also showed NO_x MAW emissions 2.9 times higher than the lab value. Conversely, CO MAW and PN MAW emissions across all three tests were lower than the lab values. Both the raw and MAW PN emissions of LCV1 were considerably lower than the laboratory emissions in all three tests.

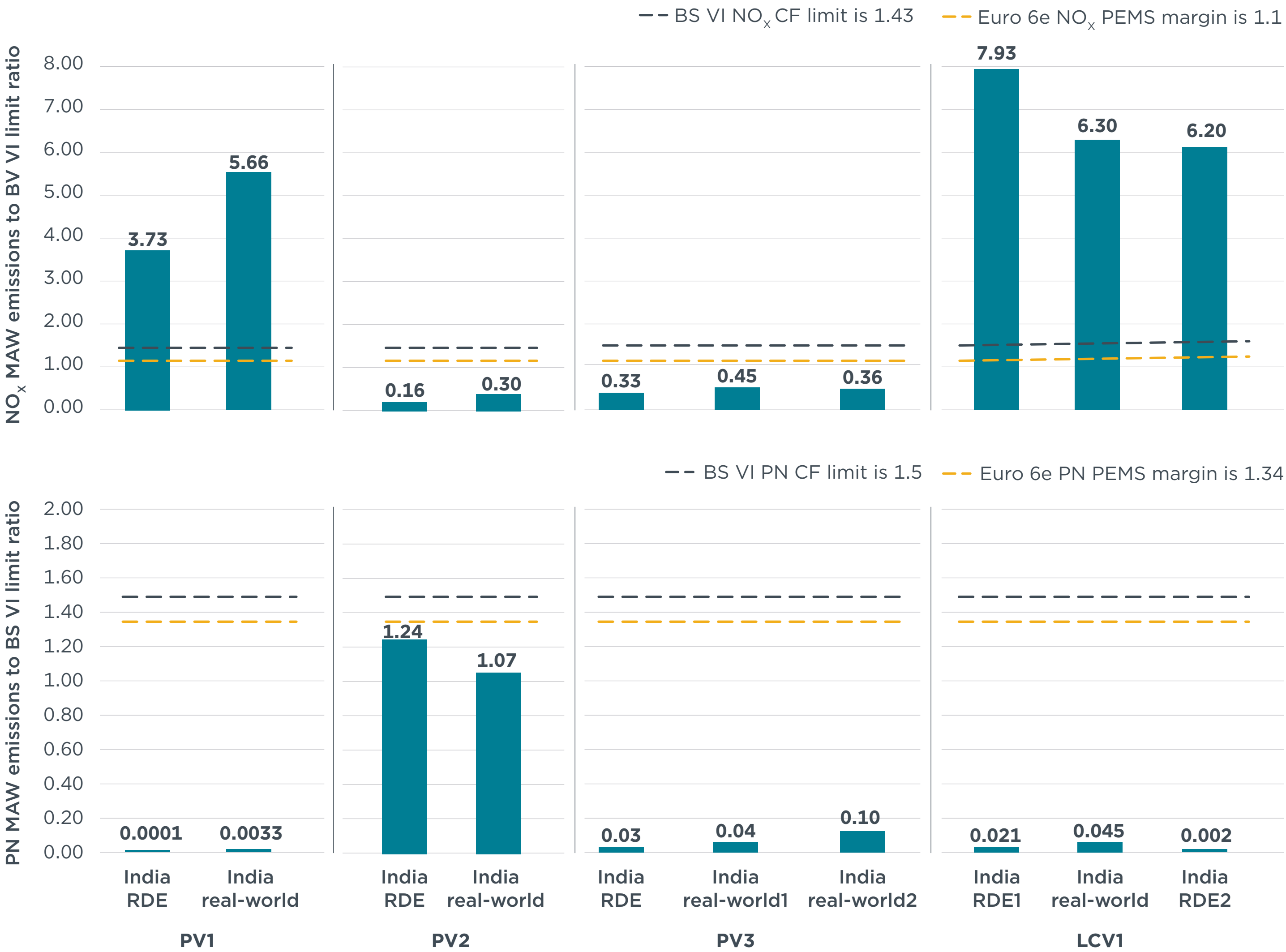
The NO_x MAW emissions in all on-road tests were much higher than the BS VI limit. In the India RDE tests, they were 6.2 and 7.9 times higher, and in the India real-world test they were 6.3 times above the limit. All results for CO and PN were lower than the BS VI emission limits.

COMPARISON WITH CONFORMITY FACTORS

As mentioned in Table 1, MoRTH notified the pollutant CFs for NO_x and PN for RDE measurements using PEMS. CF is a measure of the deviation or tolerance allowed between the real-world emissions measured and the regulatory emission limits. CFs are used to calculate not-to-exceed (NTE) limits for NO_x and PN (NTE = CF x emissions limit). For the four test vehicles, we compare the ratio of MAW emissions and BS VI emission limits with BS VI CFs for NO_x and PN applicable from April 2023 onward and to the more stringent Euro 6e CFs (which continue as Euro 7 CFs), called the PEMS margin in the regulation, in Figure 5.

Figure 5

NO_x and PN emissions of all four test vehicles compared with the BS VI and Euro 6e conformity factors



Notes: Enforcement of the CFs began with BS VI (phase 2) on April 1, 2023. We show the comparisons with BS VI (phase 1) vehicles for representative purposes.

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PV1 exceeded the future 1.43 CF limit for NO_x in both its tests, and LCV1 was the worst performer for NO_x with much higher ratios than the future CF limit in all three of its tests. Among the three diesel vehicles tested, only the SCR-equipped PV3 exhibited NO_x emissions well within the future CF limit. PV2, a GDI vehicle, was within the future CF limits for both NO_x and PN, though it had significantly higher PN MAW emissions compared with the BS VI limit ratios than the other three test vehicles. The PN levels were within the future CF limit of 1.5 for all four vehicles.

The comparison with Euro 6e CF limits also has the same results as the comparison with India CF limits. All four vehicles meet the stringent Euro 6e CF limits except for the NO_x ratios of PV1 and LCV1.

These results are in line with what was observed about the efficacy of LNT and SCR systems in Europe. The application of LNT in diesel cars did not lead to improvements in real-world NO_x emissions in Euro 6 diesel cars (Yang et al., 2015). Though the tested SCR-equipped PV3 is cleaner than the other models, it could further optimize its after-treatment system to achieve the kind of reduced emissions performance seen in of state-of-the-art Euro 6d vehicles (International Council on Clean Transportation, 2021). The PN emissions from PV2 with GDI were the highest of all four vehicles. Global studies showed that a GDI vehicle with GPF, whether provided by default or retrofitted, performs much better in terms of PN control (Association for Emissions Control by Catalyst, 2017). In the Indian context, too, emission estimates point toward significant reduction of PN emissions with the adoption of GPFs for gasoline vehicles (Sharma & Shakya, 2022).

CONCLUSION

This study analyzed the emissions from three passenger cars and one LCV based on testing in both laboratory and on-road conditions. The four vehicles tested are certified to the BS VI emission standards and were tested in 2022, when it was not mandatory for them to be compliant with RDE regulations. The results help us compare the performance of the aftertreatment technologies at the time with the RDE requirements that would come into force in April 2023. The following observations emerge from the anaylsis and could inform future policies to support emission reductions in real-world driving:

Only the diesel vehicle with SCR and the gasoline vehicle had low emissions under real-world conditions. This is in line with observations in other markets and is evidence that technologies for low emissions exist. These technologies can be optimized to achieve further emission reductions and widely implemented in India to achieve cleaner transportation.

Low PN emissions can only be achieved with particulate traps. Implementing stringent PN limits across all types of engines and vehicles in India would effectively control and reduce particulate emissions. Extending these limits to include particles as small as 10 nanometers, in line with Euro 7 standards, would further protect air quality and public health.

The moving average window method strongly affects calculated emission levels as compared with raw emissions. Real emissions were much higher than MAW emissions and this could be addressed via a shift to the European Union's RDE 4th package, which only uses the MAW for trip validity checks and not for calculating emissions.

The lower PEMS conformity factors used in the European Union reflect the latest advancements in emission measurement technologies and regulatory practices. Adopting the Euro 6e conformity factors in India could ensure that vehicle emissions are measured and regulated more stringently, and lead to lower overall emissions and improved air quality.

The high-emitting commercial vehicle (LCV1) showed no indication of malfunction. This suggests that India would benefit from strong enforcement through in-service conformity and market-surveillance testing, including by independent third parties.

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APPENDIX A

Table A1

Components of the Euro 6 RDE (3rd stage) and India RDE regulations

	Euro 6 RDE (3rd stage) regulation	India RDE regulation
Altitude	Moderate: ≤ 700 m Extended: ≤ 1,300 m	
Temperature	Moderate: 0 °C to 30 °C Extended: – 2 °C to 0 °C and 30 °C to 35 °C	Moderate: 10 °C to 40 °C Extended: 8 °C to 10 °C and 40 °C to 45 °C
Correction for extended conditions emissions	Divide by 1.6	
PEMS validation cycle	Worldwide harmonized Light vehicles Test Cycle (WLTC)	Modified Indian Driving Cycle (MIDC)
Data evaluation	Moving average window (MAW)	
CO_2 weightage for MAW window	• Half of the CO_2 mass (g) over WLTC	• 100% of the CO_2 mass (g) over MIDC
Cold start period	• Included • Average speed: 15-40 km/h • Maximum speed: 60 km/h	• Included • Average speed: 15-30 km/h • Maximum speed: 45 km/h for M1 and 40 km/h for N1
Urban operation	• 34% of the trip distance (±10% allowed but not less than 29%) • Speeds £ 60 km/h • Average speed: 15-40 km/h • Stop periods: 6%–30% of urban duration • Minimum distance: 16 km	• 34% of the trip distance (±10% allowed) • Speeds < 45 km/h for M1 and < 40 km/h for N1 • Average speed: 15–30 km/h • Stop periods: 6%–30% of urban duration • Minimum distance: 16 km
Rural	• 33% of the trip distance(±10% allowed) • Speeds > 60 km/h and £ 90 km/h • Minimum distance: 16 km	• 33% of the trip distance (±10% allowed) • Speeds ≥ 45 km/h to < 65 km/h for M1 and ≥ 40 km/h to < 60 km/h for N1 • Minimum distance: 16 km
Motorway	• 33% of the trip distance (±10% allowed) • Speed range: 90–110 km/h • Above 100 km/h at least for 5 min • Minimum distance: 16 km	• 33% of the trip distance (±10% allowed) • Speed range: 65 km/h to legal limit for M1 and 60 km/h to 80 km/h for N1 • M1: Above 75 km/h at least for 5 min • N1: Above 70 km/h at least for 5 min • Minimum distance: 16 km
Trip duration	90-120 min	
Payload	Does not exceed 90% of maximum payload	
Minimum mileage run-in	3,000 km	3,000 km or as per manufacturer's recommendation
Permissible tolerances for PEMS validation	As defined in Table 1 of the regulation	Same as Euro 6 3rd stage regulation
Final CF	NO_x: 1.43 PN: 1.5	

APPENDIX B

Table B1

Form 22 certified values from the manufacturers and the regulatory BS VI limits

Vehicle (fuel)	Vehicle class	Emissions	CO (mg/km)	NO_x (mg/km)	PN (#/km)	PM (mg/km)	THC+NO_x (mg/km)	THC (mg/km)
PV1 (diesel)	M1	Certified values	299.802	33.497	1.63E+08	0.027	90.919	—
		BS VI limit	500	80	6.0E+11	4.5	170	—
PV2 (gasoline)	M1	Certified values	190.56	14.08	7.42E+11	0.458	—	28.62
		BS VI limit	1,000	60	6.0E+12[a]	4.5	—	100
PV3 (diesel)	M1	Certified values	23.94	30.77	7.2E+10	0.835	11.07	—
		BS VI limit	500	80	6.0E+11	4.5	170	—
LCV1 (diesel)	N1	Certified values	56.3	56.9	—	1.4	34.1	—
		BS VI limit	740	125	6.0E+11	4.5	215	—

[a] PN emission limit is 6.0E+11 per km for the BS VI LDVs but an optional limit of 6.0E+12 per km was allowed for GDI vehicles upon choice of the manufacturer until April 2023.

www.theicct.org

communications@theicct.org

@theicct.org

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