THE REAL URBAN
EMISSIONS INITIATIVE

Real-world motor vehicle exhaust emissions in Delhi and Gurugram using remote sensing

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This study was co-funded through the generous support of the Clean Air Fund. FIA Foundation and the ICCT have established The Real Urban Emissions (TRUE) Initiative. The TRUE Initiative seeks to supply cities with data regarding the real-world emissions of their vehicle fleets and equip them with technical information that can be used for strategic decision making.

EXECUTIVE SUMMARY

Delhi has had poor air quality for decades, and the transport sector is a major contributor to air pollution. The nearby city of Gurugram also struggles with poor air quality, especially in winter. Despite numerous initiatives by various agencies to reduce vehicle tailpipe emissions, including important work to enhance public transport, the growing number of vehicles on the road continues to offset the progress made.

In collaboration with authorities in Delhi and Gurugram, the TRUE Initiative and the ICCT, which led analysis on this project, conducted emissions testing of on-road vehicles with non-intrusive remote sensing technology. This resulting study offers insights into real-world tailpipe emissions from vehicles and supports evidence-based policymaking to reduce vehicle pollution. To ensure a varied and representative mix of vehicle types and driving conditions, the on-site testing spanned 65 days across 20 test sites; most of the sites were in Delhi and a few were in Gurugram.

The campaign captured more than 111,000 valid measurements. Exhaust emissions of nitrogen oxides (NO_X), carbon monoxide (CO), hydrocarbons (HC), and ultraviolet smoke, a proxy for particulate matter (PM), were measured from several vehicle types: two- and three-wheelers (2Ws and 3Ws), private cars (PCs), taxis, light goods vehicles (LGVs), and buses. As the vehicle fleets in Delhi and Gurugram contain a significant portion of vehicles powered by compressed natural gas (CNG), this work is a unique opportunity to evaluate CNG's performance in the context of a transition to cleaner modes of transportation.

The study results illustrated in Figure ES1 show that India's strategy of leapfrogging from Bharat Stage (BS) IV to BS VI emission standards had positive effects and led to substantial reductions in tailpipe emissions across all vehicle types captured. The analysis also found disparities across vehicle types, and commercial segments like LGVs, taxis, 3Ws, and buses generally exhibited higher emission levels than PCs and 2Ws. This highlights the potential of promoting deployment of cleaner technologies through measures including stricter emission regulations, as those could lower tailpipe emissions from such vehicles in the future.

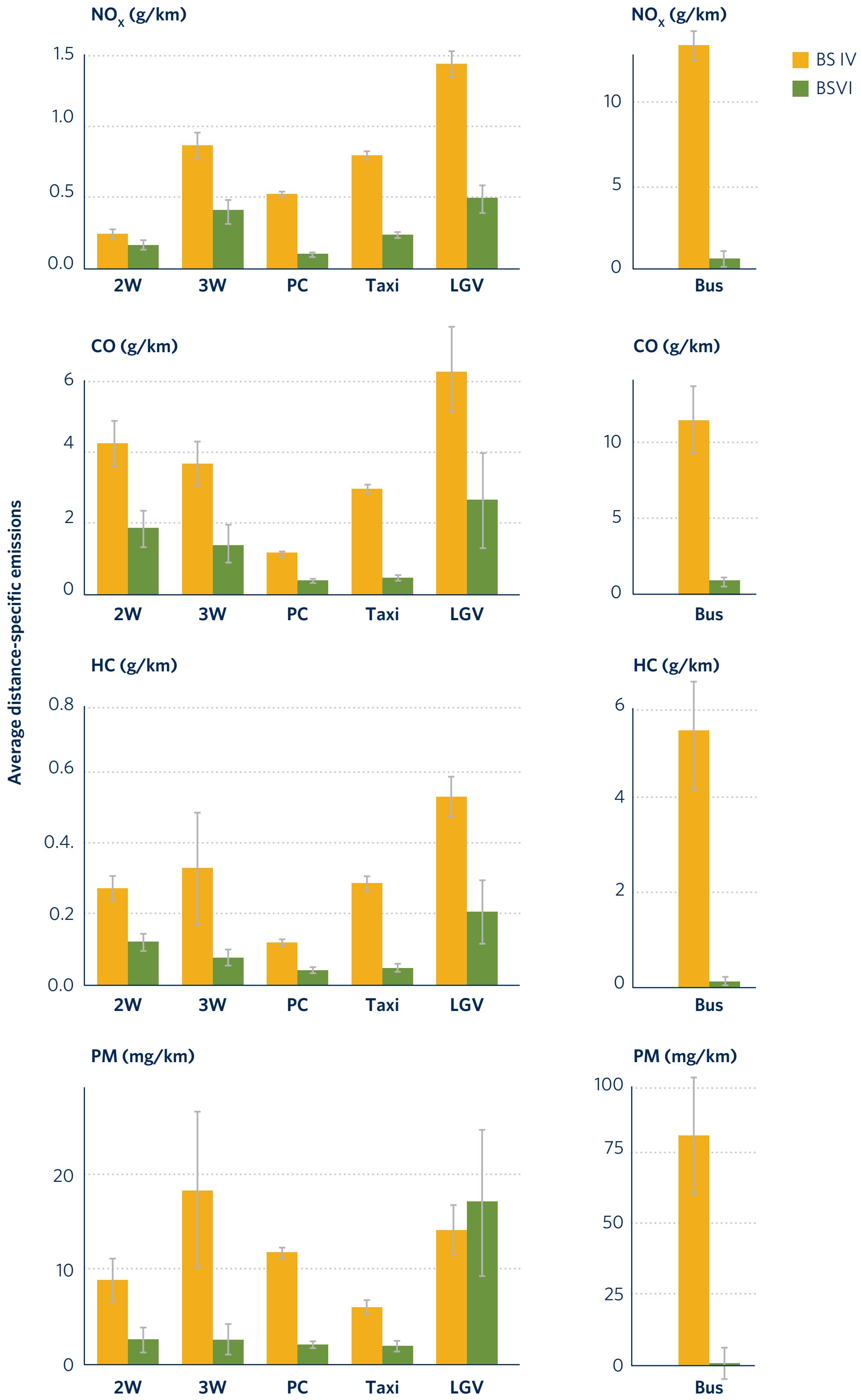

Figure ES1. Average distance-specific emissions across captured BS IV and BS VI vehicle fleets

Note: Whiskers represent the 95% confidence interval of the mean.

Additionally, even in the BS VI fleet, which is the cleanest of those captured, results show real-world emissions were much higher than type-approval limits, particularly for NO_X. Figure ES2 illustrates the real-world NO_X emissions of the BS VI CNG fleet. For 3Ws, PCs, taxis, LGVs (Class I and II), and buses, NO_X emissions were found to be 3.2 times, 2.0 times, 4.0 times, 4.9 times, 14.2 times, and 1.5 times higher, respectively, than type-approval limits. These findings suggest that the combined benefits of stricter emission standards and an accelerated shift to zero-emission vehicles (ZEVs), at least in the commercial vehicle segments such as LGVs, taxis, 3Ws, and buses, may be needed to substantially improve air quality in the Delhi National Capital Region (NCR).

That pre-BS VI CNG vehicles were found to have particularly high NO_X emissions may be because proper aftertreatment systems are absent or because some of those measured are retrofitted vehicles with inferior emission control systems. Importantly, this study's findings align with previous data from European cities and Abu Dhabi, and all challenge the conventional view that CNG is

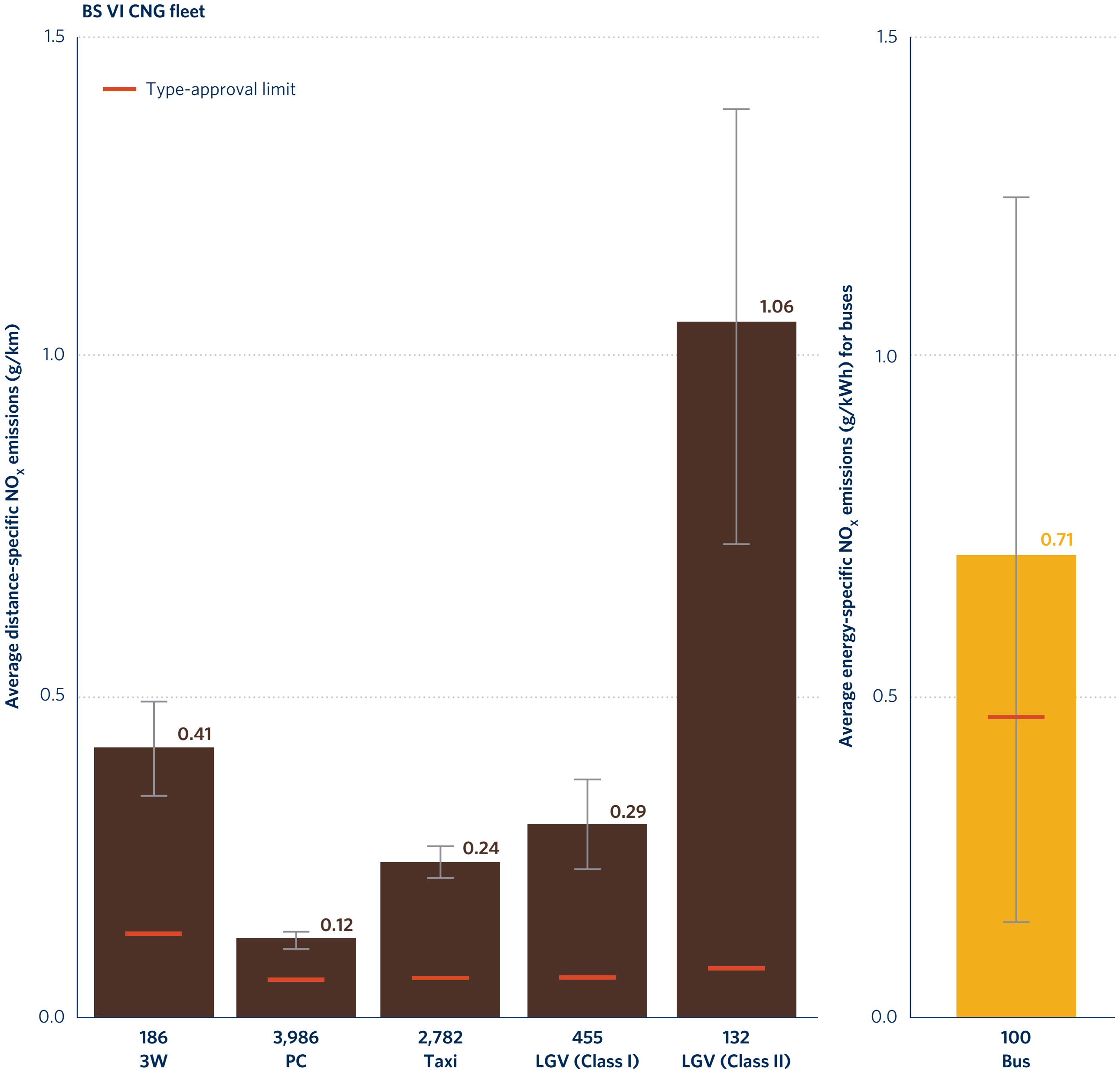

Figure ES2. Average real-world NO_x emissions from BS VI CNG vehicles compared with type-approval limits

Note: The number of measurements are presented at the bottom of each bar and whiskers represent the 95% confidence interval of the mean.

a “clean” alternative fuel. Treating CNG vehicles as a viable alternative or a transitional step toward ZEVs may not be the right approach, especially not in regions suffering from poor air quality like Delhi and Gurugram.

The data captured in this study importantly identifies the vehicle types with high emissions that are operating in both cities. This information supports action in a few key policy areas:

1. **Consider an accelerated shift to ZEVs in commercial vehicle segments in the NCR.** Agencies like the Commission for Air Quality Management in NCR could implement polices such as a ZEV sales mandate and a combustion engine phaseout program targeted at highly polluting vehicle segments. Other agencies, including the Delhi Pollution Control Committee and the Departments of Transport and Environment, could help enable such policies.
2. **At the national level, a two-step regulatory approach is recommended to further reduce emissions from combustion engine vehicles.** In the short term, implementing new BS VI phases, similar to Euro 6-VI/-e/E in Europe, can help narrow the gap between real-world emissions and type-approval limits by introducing measures like a reduced conformity factor and wider on-road testing conditions. This phase can be implemented within 1-2 years. In the longer term, the transition to BS VII could be pursued; this would further lower type-approval limits and introduce on-board emissions monitoring, and this step could potentially be realized by 2028.
3. **In the draft AIS 170 standard aimed at remote sensing of real-world vehicular emissions in India, consider changing the approach to setting remote sensing thresholds and choosing the more reliable alternate retesting methods for vehicles identified as high emitters by remote sensing measurements**. Additionally, the most benefits would result from commencing the proposed remote sensing monitoring period as soon as possible. There are underutilized funds from the National Clean Air Programme available for the NCR that could be leveraged to support this.

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INTRODUCTION AND BACKGROUND

Delhi has struggled with poor air quality for decades, and data from 1990 to 2022 points to the transport sector as one of the leading contributors.[1] In addition to anthropogenic sources, the meteorological conditions of Delhi influence pollution levels. In summer, dust storms increase particulate buildup, and winter is the most critical season for air quality because the cold, dry air and ground-based inversion combine with low wind speeds to trap pollutants. Delhi was the most polluted capital city in the world in 2023, with fine particulate matter ($PM_{2.5}$) levels at times reaching 100 times higher than the limit recommended by the World Health Organization.[2]

Gurugram, a satellite city few kilometers to the southwest of Delhi in the state of Haryana, has similarly poor air quality. A 2018 source apportionment study for the National Capital Region (NCR), which includes Gurugram, also pointed to transport as a major source of $PM_{2.5}$ and PM_{10} emissions.[3] (In the remainder of this paper, PM includes $PM_{2.5}$ and PM_{10}.) Both Delhi and Gurugram have enforced frequent closure of schools in the winter due to poor air quality.

Multiple national, subnational, state, and city agencies, all listed in Table 1, have worked on measures to reduce emissions from road transport in Delhi and Gurugram. Many of these measures are aimed at curbing emissions from internal combustion engine vehicles. For example, the BS II, BS III, and BS IV emission and fuel standards were implemented in the NCR and select cities prior to being implemented nationwide (Figure 1).

During periods of peak pollution in winter, certain vehicle segments are banned from operating in the NCR under the Graded Response Action Plan, and an odd-even restriction policy for vehicles is also implemented.[4] Additionally, in Delhi there is strict enforcement of a retirement age of 15 years for petrol and compressed natural gas (CNG) vehicles and 10 years for diesel vehicles. The permit validity for non-CNG and non-electric vehicle (EV) taxis is

Table 1. Key agencies instrumental in achieving road transport emission reductions in Delhi and Gurugram

National	Subnational	State/City
• The Supreme Court of India • The National Green Tribunal • Ministry of Road Transport and Highways (MoRTH) • Ministry of Environment, Forest and Climate Change • Central Pollution Control Board (CPCB) • Convergence Energy Services Limited	• Commission for Air Quality Management (CAQM) in National Capital Region and Adjoining Areas • Environment Pollution (Prevention and Control) Authority – now dissolved[a] • National Capital Region Transport Corporation	Delhi • Transport Department of Delhi • Environment Department of Delhi • Delhi Pollution Control Committee (DPCC) • Delhi Police Department • Delhi Transport Corporation (DTC) • Delhi Metro Rail Corporation Gurugram • Transport Department of Gurugram • Gurugram Police Department • Haryana State Pollution Control Board • Gurugram Metropolitan City Bus Limited

[a] After being functional for 22 years, was replaced by CAQM in 2020.

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[1] Sarath K. Guttikunda, Sai Krishna Dammalapati, and Gautam Pradhan, *What Is Polluting Delhi's Air? A Review from 1990 to 2022* (Transportation Research and Injury Prevention Centre, Indian Institute of Technology, 2023), https://urbanemissions.info/wp-content/uploads/docs/2023-02-MDPI-Sus-Delhi-AQ-Review.pdf.

[2] "Delhi Tops List of World's Most Polluted Capital Cities in 2023," *Indian Express*, March 19, 2024, https://indianexpress.com/article/cities/delhi/delhi-tops-list-of-worlds-most-polluted-capital-cities-in-2023-9223253/.

[3] The NCR includes Delhi and additional districts from the neighboring states of Haryana (Gurugram lies in this state), Uttar Pradesh, and Rajasthan. The Automotive Research Association of India and The Energy and Resources Institute, *Source Apportionment of PM2.5 & PM10 of Delhi NCR for Identification of Major Sources* (2018), https://www.teriin.org/sites/default/files/2018-08/Report_SA_AQM-Delhi-NCR_0.pdf.

[4] The Delhi odd-even policy is a vehicular traffic control measure where private vehicles with odd and even numbered license plates are only allowed to drive on alternate days to reduce air pollution.

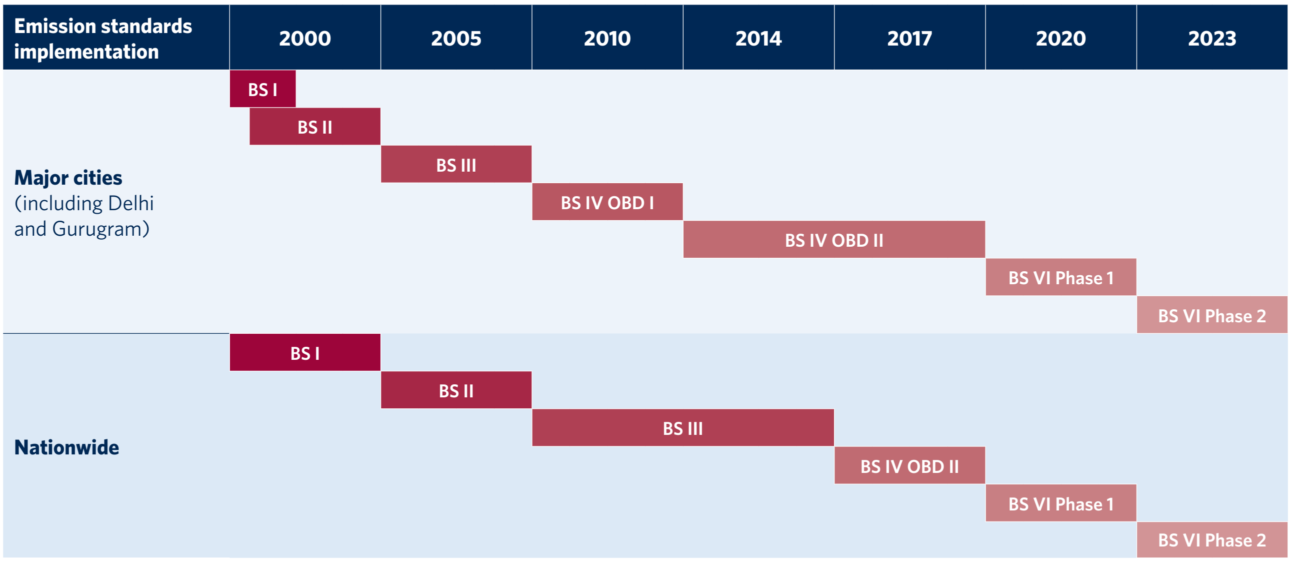

Figure 1. Implementation timeline of the Bharat Stage (BS) emission standards for the vehicle fleet in India, including the leapfrog from BS IV to BS VI

restricted to 8 years.[5] Limiting diesel vehicle registrations and encouraging the uptake of CNG vehicles in commercial vehicle segments, including via retrofitting, were key actions in the past, especially before the advent of EVs. Restricting the entry of older inter-state diesel buses into the NCR from states including Punjab, Himachal Pradesh, Madhya Pradesh, Uttarakhand, and Jammu and Kashmir, with a transition to cleaner vehicles by the end of 2024, are also in place.[6]

An Air Ambience Fund was created by levying a ₹0.25 per liter fee on the sale of diesel in Delhi, and the funds raised are used to promote clean technologies. Dealers within the NCR also must pay an Environmental Protection Charge on diesel vehicle sales with engines greater than 2,000 cc (1% of the ex-showroom price). In addition, an Environment Compensation Charge based on axle category is levied on trucks entering Delhi, irrespective of fuel type. The phaseout of two-stroke engines in three-wheelers (3Ws) and a cap on the number of 3Ws (100,000 in total) that can ply in Delhi are in place.[7] Penalties of ₹10,000, along with provision for suspension of vehicle license, are imposed for operating without a valid pollution-under-control certificate.

Delhi has also implemented a progressive EV policy. There is a non-binding target for 100% electrification of the DTC bus fleet by 2028, and the share of electric buses in the on-road fleet increased to 25% in July 2024.[8] Delhi has also introduced the country's first demand-side EV mandates for aggregators of buses, two-wheelers (2Ws), 3Ws, and four-wheeler passenger car fleets.[9]

Enhancing public transport connectivity is another key measure. Delhi operates India's longest and busiest metro network, spanning 393 km.[10] The regional rapid rail transit project currently under construction will connect regional nodes in the NCR with Delhi and Gurugram in Phase 1,

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[5] "CNG or Electric Taxis in Delhi to Get 15-year Permits Now," *Hindustan Times*, May 20, 2023, https://www.hindustantimes.com/cities/delhi-news/cng-or-electric-taxis-in-delhi-to-get-15-year-permits-now-101687285300277.html.

[6] Priyangi Agarwal, "Inter-city Buses entering Delhi to Switch to Cleaner Fuels by Year-end," *Times of India*, June 26, 2024, https://timesofindia.indiatimes.com/city/delhi/inter-city-buses-entering-capital-to-switch-to-cleaner-fuels-by-year-end/articleshow/111269705.cms.

[7] Abraham Thomas, "SC Refuses to Remove the Cap of 100,000 on Delhi's Auto-Rickshaws," *Hindustan Times*, July 10, 2024, https://www.hindustantimes.com/cities/delhi-news/sc-refuses-to-removethe-cap-of-100-000-on-delhis-autorickshaws-101720630164339.html#google_vignette.

[8] Deepanshu Taumar and Shubhangi Bhatia, "Delhi Bus Fleet to be Fully Electric by 2028, Says Transport Commissioner Ashish Kundra," *ET Auto*, September 22, 2023, https://auto.economictimes.indiatimes.com/news/commercial-vehicle/mhcv/delhi-bus-fleet-to-be-fully-electric-by-2028-says-transport-commissioner-ashish-kundra/103837439; "Delhi LG Flags Off 320 Electric Buses, Says They Will Strengthen Fight Against Pollution," *Hindustan Times*, July 30, 2024, https://www.hindustantimes.com/cities/delhi-news/delhi-lg-flags-off-320-electric-buses-says-they-will-strengthen-fight-against-pollution-101722332674285.html.

[9] The Delhi Motor Vehicles Licensing of Aggregator (Premium Buses) Scheme 2023 (F. No. F(12)/Policy/AS/STA/2016/105228), Transport Department, Government of National Capital Territory of Delhi, November 20, 2023, https://transport.delhi.gov.in/sites/default/files/Transport/circulars-orders/250157_1.pdf; Delhi Motor Vehicle Aggregator and Delivery Service Provider Scheme 2023 (No. FDC/EV/TPT/2021/02/49957), Transport Department, Government of National Capital Territory of Delhi, November 21, 2023, https://jmkresearch.com/wp-content/uploads/2023/11/Delhi-Motor-Vehicle-Aggregator-Delivery-Service-provider-scheme-2023.pdf.

[10] Delhi Metro Statistics, Delhi Metro Rail Corporation, accessed June 26, 2024, https://www.delhimetrorail.com/corporate

with a cumulative corridor length of 349 km.[11] Additionally, there are plans to increase the DTC bus fleet size from 7,582 in March 2024 to over 10,000 by 2025.[12]

Despite these initiatives, transport sector emissions remain high within Delhi. The DPCC's 2023 source apportionment study for PM identified transport as one of the leading sources, just behind secondary inorganic aerosols and biomass burning.[13] Although the measures listed above have been effective in reducing on-road emissions, the increasing number of vehicles on the roads is offsetting the gains achieved from improved vehicle and fuel standards and other traffic-mitigation measures.[14]

OBJECTIVES OF THIS STUDY

To help inform policymakers, regulators, consumers, and manufacturers in cities around the world, The Real Urban Emissions (TRUE) Initiative provides technical analyses using real-world vehicular emissions data. The TRUE Initiative has helped more than 10 cities, including Mexico City, Jakarta, and London, to understand their vehicle fleet emissions by collecting and analyzing data from remote sensing testing.

This study was led by the International Council on Clean Transportation (ICCT) in engagement with the Transport Department of Delhi, the office of the Gurugram Deputy Commissioner, the Delhi Police Department, the Gurugram Police Department, and the National Highways Authority of India. Real-world vehicular emissions testing campaigns were conducted in the cities of Delhi and Gurugram from December 2022 to April 2023, with the following objectives:

- Develop a new understanding of the real-world tailpipe emissions of the Delhi and Gurugram vehicle fleets.
- Demonstrate remote sensing technology and provide evidence to support recommendations for its broader application in India.
- Provide an independent evaluation of the tailpipe emissions from Indian vehicles to support evidence-based policymaking and offer guidance to decision-makers that connects the findings to policies and actions that mitigate vehicle pollution.

CURRENT EMISSIONS TESTING REGIME IN INDIA

For emissions testing during type-approval and conformity of production assessment, India uses laboratory chassis dynamometer testing for 2Ws, 3Ws, and four-wheeler light-duty vehicles (LDVs), and engine dynamometer testing for heavy-duty vehicles including buses and trucks. In addition, the Real Driving Emissions (RDE) norms for LDVs introduced in April 2023 mandate on-road emissions testing, starting with BS VI (phase 2) vehicles.[15] In-service conformity (ISC) testing, conducted periodically on vehicles that are already in service, has also been introduced for BS VI (phase 2) LDVs and heavy-duty vehicles.[16] The RDE and ISC tests for all internal combustion engine vehicles are performed using a portable emissions measurement system.

Finally, the pollution-under-control certification (PUCC) test is used to assess in-use internal combustion engine vehicles after sale. This is generally done once every 12 months for BS IV and BS VI vehicles and once every 3 or 6 months for pre-BS IV vehicles, depending on state rules. These tests use multi-gas analyzers to capture concentrations of carbon monoxide (CO) and hydrocarbon (HC) emissions during idling for petrol, CNG, and liquefied petroleum gas vehicles, and the smoke opacity meter measurements from the free acceleration tests are used for diesel vehicles as a proxy for PM.

These tests, along with the progression to the latest BS VI emission standards, have been fruitful in the transition to cleaner vehicle fleets. At the same time, some challenges remain. For one, the RDE and ISC tests tend to be expensive and time consuming, and only a limited number of vehicles can be tested at any one time. In addition, the tests only cover a limited range of vehicle types, and they currently exclude 2Ws and 3Ws. Use of a portable emissions measurement system is relatively expensive for testing, and the PUCC test does not capture on-road

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[11] Project Details, National Capital Region Transport Corporation, accessed June 26, 2024, https://ncrtc.in/details/

[12] "Electric Buses to Fuel Public Transport Growth, But Several Schemes Relegated to Back Burner," *ET Auto*, March 5, 2024, https://auto.economictimes.indiatimes.com/news/commercial-vehicle/electric-buses-to-fuel-public-transport-growth-but-several-schemes-relegated-to-back-burner/108220368.

[13] Delhi Pollution Control Committee, *Real-Time Source Apportionment and Forecasting for Advance Air Pollution Management in Delhi* (2023), https://www.dpcc.delhigovt.nic.in/uploads/news/819b9fef9cf4a2a574a10d3bbc421cfd.pdf

[14] Guttikunda, Dammalapati, and Pradhan, *What Is Polluting Delhi's Air?*

[15] Anirudh Narla et al., *Real-Driving Emissions from Bharat Stage VI (Phase 1) Passenger Cars and a Light Commercial Vehicle in India – PEMS Testing* (International Council on Clean Transportation, 2024), https://theicct.org/publication/real-driving-emissions-from-bharat-stage-vi-ldv-testing-india-pems-testing-jul24/.

[16] Bharadwaj Sathiamoorthy, Anup Bandivadekar, and Huzeifa Badshah, *Real-World Emissions Performance of a Bharat Stage VI Truck and Bus* (International Council on Clean Transportation, 2021), https://theicct.org/publication/real-world-emissions-performance-of-a-bharat-stage-vi-truck-and-bus/.

emissions and fails to report pollutants such as NO_X and PM. Moreover, though there are software-based PUCC systems in a few states, including Delhi, data are mostly recorded manually in many states and reporting can introduce errors and allow for interference with the test results. The low failure rates suggest a need to reconsider the reliability and authenticity of the tests.[17]

REMOTE SENSING OF REAL-WORLD VEHICULAR EXHAUST EMISSIONS

To help ensure that vehicles perform consistently well in real-world operating conditions, monitoring and enforcement programs can be used to supplement periodic emissions inspection.[18] Remote sensing technology has the capacity to non-intrusively screen tailpipe emissions from vehicles on a mass scale under real-world operations and aid in the identification of highly polluting vehicles. As vehicles pass the remote sensing equipment, the technology uses infrared and ultraviolet light to remotely measure the absorption of species like NO_X, CO, HC, and opacity of PM from vehicle exhaust. Vehicle speed and acceleration are also recorded, and that allows the estimation of vehicle specific power, a proxy for engine load. Subsequently, a camera captures the vehicle's license plate, and that enables the retrieval of technical specifications from the vehicle registration database. Further details on remote sensing are available in a previous ICCT publication.[19] While the above description pertains to open path cross-road remote sensing devices, the same ones used for this study, there are others like the open-path overhead systems and extractive samplers.[20]

GLOBAL EXAMPLES OF VEHICLE REMOTE SENSING

Remote sensing technology has been used to monitor vehicle emissions for decades in the United States, Europe, China, and South Korea.[21] Multiple U.S. states have used remote sensing for research and to screen vehicle fleets as part of market surveillance.[22] Some states also use remote sensing to identify individual high- or low-emitting vehicles; in these cases, the points at which a vehicle is considered high emitting are higher for older vehicles and lower for newer vehicles, and they typically follow the tailpipe limit that applies during periodic inspection and maintenance under chassis dynamometer tests.[23]

In Europe, countries including Sweden, Switzerland, Spain, the United Kingdom, Germany, and France have deployed remote sensing technology for research activities, monitoring of fleet emissions, and detecting vehicle tampering.[24] The European Commission added remote sensing to its vehicle emissions type-approval regulation, especially to identify of high-emitter vehicles for ISC tests.[25]

China issued and implemented its first national-level remote-sensing regulation in July 2017 and it was for measuring exhaust pollutants from diesel vehicles.[26] A vehicle is determined to be noncompliant if it exceeds the defined remote-sensing emission limits for the same pollutant in two or more consecutive remote-sensing tests in 6 months.[27] The city of Beijing has made remote sensing part of its inspection and maintenance programs since 2013 and there were 60 remote sensing sites as of 2021.[28]

South Korea has used remote sensing for its periodic inspection program since 2013, and has measured the emissions of 2–3 million vehicles per year across 39 different locations. While the emissions of all vehicles

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[17] Environment Pollution (Prevention and Control) Authority for Delhi NCR, *Report of Assessment of Pollution Under Control (PUC) Programme in Delhi and NCR: Recommendations for Improvement to Ensure Pollution From In-use Vehicles is Under Control* (2017), https://www.epca.org.in/EPCA-Reports1999-1917/EPCA-Report-73-PUC-programme%20-NCR.pdf.

[18] Michelle Meyer et al., *Reassessment of Excess NOx from Diesel Cars in Europe Following the Court Justice of the European Union Rulings* (International Council on Clean Transportation, 2023), https://theicct.org/publication/diesel-gate-emissions-diesel-cars-europe-mar23/.

[19] Jens Borken-Kleefeld and Tim Dallmann, *Remote Sensing of Motor Vehicle Exhaust Emissions* (International Council on Clean Transportation, 2018), https://theicct.org/publication/remote-sensing-of-motor-vehicle-exhaust-emissions/.

[20] Yoann Bernard, John German, and Rachel Muncrief, *Worldwide Use of Remote Sensing to Measure Motor Vehicle Emissions* (International Council on Clean Transportation, 2019) https://theicct.org/publication/worldwide-use-of-remote-sensing-to-measure-motor-vehicle-emissions/.

[21] Bernard, German, and Muncrief, *Worldwide Use of Remote Sensing*.

[22] Bernard, German, and Muncrief, *Worldwide Use of Remote Sensing*.

[23] Liuhanzi Yang, Yoann Bernard, and Tim Dallmann, *Technical Considerations for Choosing a Metric for Vehicle Remote-Sensing Regulations* (International Council on Clean Transportation, 2019), https://theicct.org/publication/technical-considerations-for-choosing-a-metric-for-vehicle-remote-sensing-regulations/.

[24] Bernard, German, and Muncrief, *Worldwide Use of Remote Sensing*.

[25] Regulation (EC) 2018/1832, Official Journal of the European Union, November 5, 2018, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R1832.

[26] Measurement method and specifications for exhaust pollutants from in-use diesel vehicles by remote sensing method, July 27, 2017, https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/dqhjbh/dqydywrwpfbz/201708/W020170802605590990126.pdf.

[27] Zifei Yang, *Remote-Sensing Regulation for Measuring Exhaust Pollutants from in-Use Diesel Vehicles in China* (International Council on Clean Transportation, 2017), https://theicct.org/publication/remote-sensing-regulation-for-measuring-exhaust-pollutants-from-in-use-diesel-vehicles-in-china/.

[28] Zifei Yang et al., *Review of Beijing's Comprehensive Motor Vehicle Emission Control Programs* (International Council on Clean Transportation, 2015), https://theicct.org/publication/review-of-beijings-comprehensive-motor-vehicle-emission-control-programs/; Liuhanzi Yang and Yoann Bernard, *CARES: Summary Report on Applications and Results in EU and China* (City Air Remote Emission Sensing, 2023), https://cares-project.eu/wp-content/uploads/2023/06/CARES-814966-Deliverable-D3.7-Summary-report-on-applications-and-results-in-EU-and-China.pdf.

passing the remote sensing equipment are measured, only petrol and liquefied petroleum gas vehicles are subject to in-use emission limits.[29]

Hong Kong has deployed remote sensing since 2014 to identify high emitters among petrol and liquefied petroleum gas vehicles.[30] The instruments are rotated among 100 sampling sites throughout the city to provide greater coverage of the in-use vehicle fleet. Results from remote sensing measurements are compared with predetermined points at which vehicle emissions are considered high, and this applies to vehicles meeting different emission standards. Those identified as being higher than the predetermined points are first given a chance to service or repair any emissions defects within 12 working days and are then required to undergo a subsequent emissions test on a chassis dynamometer for a fee of HK$620. The test uses a short driving cycle that is 200 seconds in duration and was developed by TÜV Rheinland. This test cycle is designed to mimic the kinematic characteristics of the New European Driving Cycle, which is of much longer duration.[31] If the vehicle fails to pass the chassis dynamometer test, the vehicle license is canceled. Approximately 20% of the vehicles in the liquefied petroleum gas taxi fleet were cited as high emitters through this program and the overall rate of vehicles failing during remote sensing was approximately 2%.[32] Hong Kong is currently developing remote sensing limits for diesel vehicles.

REMOTE SENSING OF VEHICLE EMISSIONS IN INDIA

There is currently no national-level regulation in India mandating the use of remote sensing for vehicular emissions. There have been a few pilots, and one remote sensing device was deployed in the city of Kolkata in 2009, as directed by an order from the Calcutta High Court.[33] The city is now set to deploy 20 more remote sensing devices.[34] Additionally, the city's Transport Department leveraged Rule 116(1) of the Central Motor Vehicle Rules to identify high emitters using remote sensing and direct them to undergo a new PUCC test.[35]

In 2015, the National Green Tribunal remarked that emissions measurements of stationary vehicles (idle-state PUCC test) "would never depict correct data" and directed the CPCB and DPCC to acquire appropriate mechanisms and instruments for testing emissions of moving vehicles.[36] In its directions to state governments within NCR in 2015 and later to 131 cities across India under its National Clean Air Programme in 2019, the CPCB identified remote-sensor-based PUC system as one of the action items to address transport emissions, and the devices were supposed to be deployed within 90 days of the directive.[37] However, as of July 2024, no National Clean Air Programme funds have been utilized for such deployment, at least not in the NCR. Subsequently, based on a recommendation from the Environment Pollution (Prevention & Control) Authority and the International Centre for Automotive Technology's findings from a remote sensing pilot, the Supreme Court issued directives to implement remote sensing for vehicular emissions in Delhi in 2018 and 2019; these included the observation that remote sensing of emissions was effective in Kolkata.[38]

A draft Automotive Industry Standard (AIS) 170 was published by MoRTH in September 2020.[39] The draft standard proposes a monitoring phase to capture

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[29] Liuhanzi Yang et al., *Remote Sensing of Motor Vehicle Emissions in Seoul* (TRUE Initiative, 2022), https://www.trueinitiative.org/publications/reports/remote-sensing-of-motor-vehicle-emissions-in-seoul.

[30] Yang, Bernard, and Dallmann, *Technical Considerations for Choosing a Metric.*

[31] Code of Practice for Designated Vehicle Emission Testing Centres, Commissioner for Transport, September 17, 2021, https://www.epd.gov.hk/epd/sites/default/files/epd/tc_chi/environmentinhk/air/guide_ref/files/Code_of_Practice%20_Volume_3.pdf.

[32] Borken-Kleefeld and Dallmann, *Remote Sensing of Motor Vehicle Exhaust Emissions.*

[33] National Green Tribunal, Original Application No. 33/2014/EZ, August 11, 2016, http://www.indiaenvironmentportal.org.in/files/auto%20emission%20Kolkata%20Howrah%20NGT%20Judgement.pdf.

[34] Krishnendu Bandyopadhyay, "Remote Sensor to Monitor Vehicular Emission Lying Defunct Since Nov," *Times of India*, April 6, 2024, https://timesofindia.indiatimes.com/city/kolkata/remote-sensor-to-monitor-vehicular-emission-lying-defunct-since-nov/articleshow/109077388.cms.

[35] The Central Motor Vehicles Rules, 1989, Ministry of Road Transport and Highways, https://www.scobserver.in/wp-content/uploads/2023/07/Central-Motor-Vehicles-Rules.pdf.

[36] National Green Tribunal, Original Application No. 21/2014 and 95/2014 and 303/2015, October 7, 2015, https://greentribunal.gov.in/gen_pdf_test.php?filepath=L25ndF9kb2N1bWVudHMvbmd0L2Nhc2Vkb2Mvb3JkZXJzL0RFTEhJLzIwMTUtMTAtMDcvY291cnRzLzEvZGFpbHkvMTU5MjM3ODQ5NjQ4MDAyNDY5MzVlZTljNDgwZTU3ZTEucGRm

[37] Directions regarding prevention, control or abatement of air pollution and improvement in ambient air quality in Delhi NCR, Central Pollution Control Board, December 29, 2015, https://cpcb.nic.in/uploads/direction/Directions30-12-2015.pdf; Ministry of Environment, Forest and Climate Change, *NCAP National Clean Air Programme* (2019), https://prana.cpcb.gov.in/ncapDashboard/download_public_portal_file/NCAP_Report.pdf

[38] Supreme Court of India, Writ Petition No. 13029/1985, Order May 10, 2018, https://api.sci.gov.in/supremecourt/1985/63998/63998_1985_Order_10-May-2018.pdf; Supreme Court of India, Writ Petition No. 13029/1985, Order August 19, 2019, https://api.sci.gov.in/supremecourt/1985/63998/63998_1985_4_302_16137_Order_19-Aug-2019.pdf

[39] Ministry of Road Transport and Highways, *Remote Sensing Devices for on-road Emissions Monitoring – Product Specifications and Programme Guidelines* (September 2020), https://morth.nic.in/sites/default/files/ASI/Draft%20AIS-170%20-%20RSD_DF_Sep_20200930_C.pdf

vehicular emissions data using remote sensing; the data is to be used to define polluter thresholds based on vehicle category, emission standard, and fuel type. The standard also proposes that identified high emitters be pulled from the roads and subjected to a PUCC test. The final version of AIS 170 remains unpublished after four years, and this has delayed the start of the monitoring phase. In July 2024, the Supreme Court intervened by ordering the expedited implementation of remote sensing technology, beginning with the NCR states.[40] Detailed suggestions for changes to AIS 170 that stem from this analysis are in Appendix A.

DELHI AND GURUGRAM STUDY OVERVIEW

DATA COLLECTION

Opus Remote Sensing Europe (Opus RSE) was contracted to carry out the remote sensing measurement activities in Delhi and Gurugram. The open path cross-road setup shown in Figure 2 was used.

The testing was carried out across 20 test sites on 65 days, the first in December 2022 and the last in April 2023. The test sites, shown in Figure 3, were chosen over a wide area to include a representative mix of vehicle types and driving conditions; the majority of the sites were in Delhi, and a few were in Gurugram. The campaign measured tailpipe emissions of NO_X, CO, HC, and ultraviolet smoke, a proxy for PM, from different vehicle types, including 2Ws, 3Ws, private cars (PCs), commercial cars (taxis), LGVs, and buses. For all vehicles, information such as registration date and state of registration, vehicle type, fuel type, emission standard, engine displacement, gross vehicle weight, curb weight, engine power, manufacturer, and model details were retrieved from the vehicle registration database.[41]

DATA PREPARATION AND ANALYSIS METHODS

The campaign captured 278,626 measurements, of which 111,712 were found to be valid and were used for the emissions analysis.[42] The Opus RSE instrument distinguishes valid from invalid emissions measurements via the series of absorption records along each exhaust plume. The road and traffic conditions at the test sites and driving patterns resulted in many records with measured speed or acceleration outside of the desired limits. These records were considered invalid due to vehicle specific

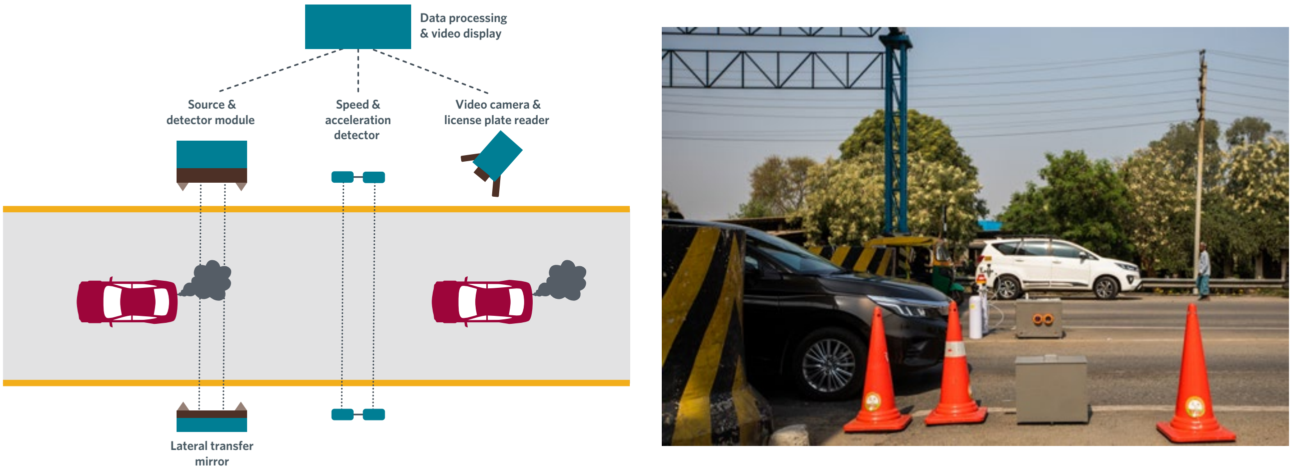

Figure 2. Schematic for cross-road open-path remote sensing system (left) and equipment setup (right) at the Kherki-Daula toll plaza during the TRUE Delhi-Gurugram study

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[40] Supreme Court of India, Writ Petition No. 13029/1985, Order July 26, 2024, https://api.sci.gov.in/supremecourt/1985/63998/63998_1985_6_15_54056_Order_26-Jul-2024.pdf.

[41] For more information about the testing campaign, refer to this document: https://www.opusrse.com/projects/delhi/

[42] To qualify as valid record, there must have been valid technical details in the registration database, the emissions readings must have been valid for at least one pollutant, CO_2 must have been detected in the plume, and the vehicle specific power must have been positive.

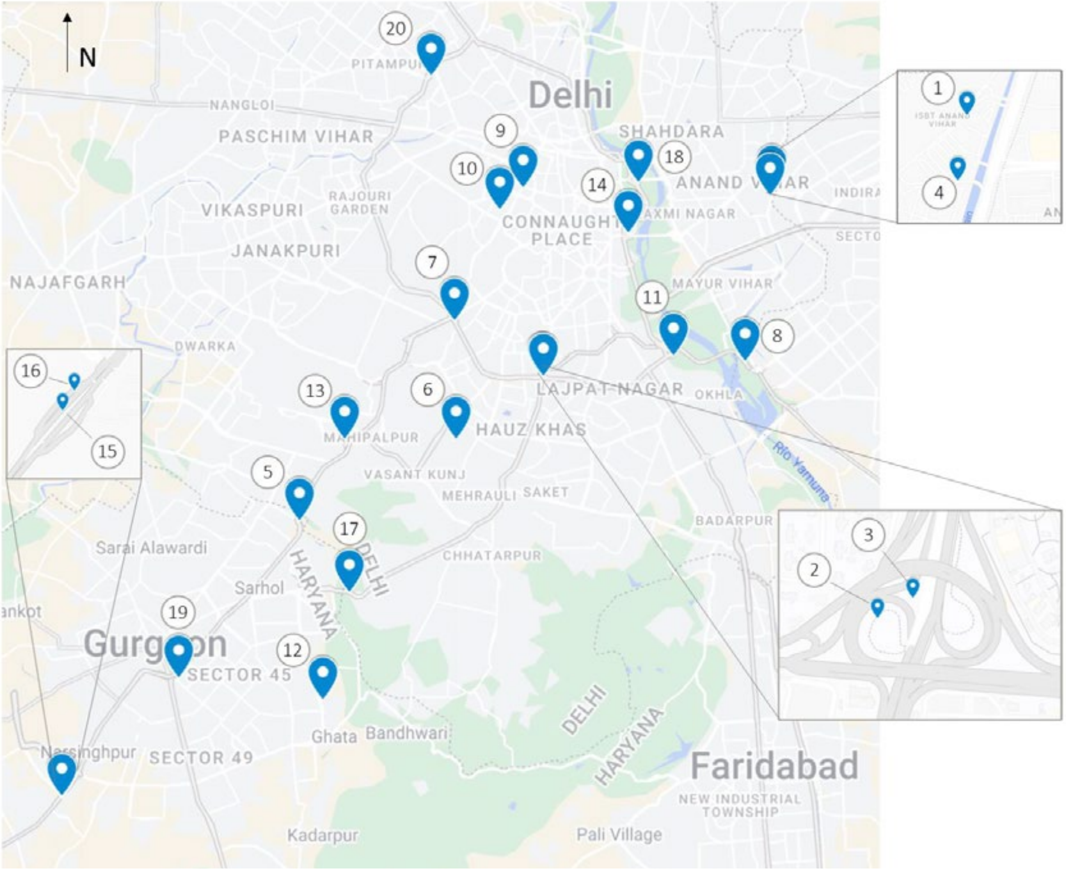

Figure 3. Locations of measurement sites for the remote sensing campaign

Source: Opus RSE

power conditions.[43] Additional filtering was done to remove measurements from vehicles without valid license plate information or valid emission readings. We also only considered records with plausible values in line with previous TRUE studies.[44] The methods used to prepare and analyze the remote sensing data collected during the TRUE Delhi and Gurugram study follow those developed and applied in previous studies led by the ICCT and TRUE.[45]

Additionally, PM records with implausible negative emission ratio readings were filtered out. Negative readings can occur when the pollutant concentration in the plume is lower than it is in the background ambient air.[46] Measurements with negative PM readings are typically rare, but they were more prevalent in this study than in others led by the ICCT and TRUE; this could be because of high-emitting vehicles that might have passed prior and because the background ambient PM concentrations measured at stations were several times higher than what was encountered in any previous TRUE study. The resulting average PM emissions reported in this study are thus

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[43] The vehicle specific power, or the instantaneous power to mass demand, is reported in kilowatts per ton (kW/ton) and is determined by speed, acceleration, road grade, and generic values of the aerodynamic and rolling resistance of vehicles. It is a proxy of the engine load that was used to filter out negative or null measurements with likely little or no exhaust emissions. See also U.S. Environmental Protection Agency, Office of Transportation and Air Quality, *Guidance on Use of Remote Sensing for Evaluation of I/M Program Performance* (2004), https://nepis.epa.gov/Exe/ZyPdf.cgi?Dockey=P1002J6C.pdf.U.S. Environmental Protection Agency, Office of Transportation and Air Quality, *Guidance on Use of Remote Sensing for Evaluation of I/M Program Performance-* July 2004), https://nepis.epa.gov/Exe/ZyPdf.cgi?Dockey=P1002J6C.pdf.

[44] The thresholds for plausible values were -11.5 $\mathrm{g/kg_{Fuel}}$ and 165 $\mathrm{g/kg_{Fuel}}$ for $\mathrm{NO_X}$, -126 $\mathrm{g/kg_{Fuel}}$ and 12,640 $\mathrm{g/kg_{Fuel}}$ for CO and -63 $\mathrm{g/kg_{Fuel}}$ and 6,320 $\mathrm{g/kg_{Fuel}}$ for HC. One difference from previous studies is the negative thresholds for plausible results were revised for PM to filter out measurements below -2 $\mathrm{g/kg_{Fuel}}$. More explanation is below.

[45] Yoann Bernard et al., *Determination of Real-World Emissions from Passenger Vehicles Using Remote Sensing Data* (TRUE Initiative, 2018), https://www.trueinitiative.org/publications/reports/determination-of-real-world-emissions-from-passenger-vehicles-using-remote-sensing-data.

[46] Negative emission ratios of lower intensities can however be representative of the measurement noise around zero and were retained to avoid skewing the data toward positive readings. Even with all these precautions taken, vehicles with low exhaust PM concentration that does not significantly differ from the ambient PM concentration are perceived as near-zero emissions.

believed to be conservatively low. Although the absolute PM values therefore cannot be treated as emission factors, the relative differences observed between vehicle groups and fuel types nonetheless provide insight into the PM emissions of different vehicle groups.

For LDVs, emission ratios were converted to distance-specific estimates in grams per kilometer (g/km), the unit used in Indian type-approval regulations, by combining the average pollutant emissions from the remote sensing records with vehicle type-approval carbon dioxide (CO_2) emission limits and real-world fuel consumption values.[47] As reliable real-world fuel consumption or CO_2 data is not available for every vehicle type and model captured in the study, the ICCT sourced the vehicle type-approval CO_2 values of all models and applied a conservative 20% increase for real-world values.[48]

For buses and heavy-duty trucks, the conversion to the relevant Indian regulations is per unit of produced mechanical energy, in grams per kilowatt-hour (g/kWh), and we assumed an average engine efficiency.[49] The g/km values were also calculated for heavy-duty vehicles for comparison purposes (see Figure 6), because the type-approval CO_2 information was available.

We compared the g/km and g/kWh with the type-approval limits defined for different combinations of vehicle types, fuel types, and emission standards. Given that PM is derived from opacity measured by the remote sensing device, a comparison with type-approval limits was not performed; the gravimetric analysis used for the type-approval testing method differs significantly from the PM reporting by the remote sensing device.

Additionally, for vehicles certified to BS VI standards, we compared the emissions per manufacturer by fuel type for private cars and LGVs with type-approval limits. The manufacturer names have been anonymized. To compare with PUCC limits for BS IV and BS VI petrol and CNG vehicles, we used the combustion equation for carbon balance to convert the emission ratios from the remote sensing device to estimate concentrations of CO (%) and HC (parts per million, ppm). A similar comparison for diesel vehicles is not possible because remote sensing measures pollutants-to-CO_2 ratios in the diluted plume and the PUCC test measures only tailpipe opacity (proxy for PM) for diesel vehicles. The unknown tailpipe CO_2 concentration for diesel prevents estimating tailpipe pollutant concentration.[50]

We highlight the following points before presenting the emissions results:

- **The vehicles captured in this study are certified to emission standards that do not require RDE or ISC testing, and they are not subject to any associated on-road emissions compliance requirements. Thus, the comparisons with type-approval limits or PUCC limits below are for representation/information purposes only.**
- For sub-groups of vehicles by type, emission standard, and fuel type, a minimum sample size of 100 was used to reduce the uncertainty of the mean emissions. Furthermore, the automaker comparison was done only for BS VI PCs (the segment with the highest mix of manufacturers) and LGVs (the segment with substantially high emissions, even in BS VI).
- The analysis does not account for payload or the operating temperature of the vehicles. Both can influence emissions performance.
- The study does not differentiate between private and commercial 2Ws because of the current rules for issuing license plates to 2Ws in Delhi and Gurugram.

OVERVIEW OF VALID EMISSION MEASUREMENTS

The campaign captured 111,712 valid tailpipe emissions measurements. Figure 4 shows the mix by vehicle and fuel type. Around 90% of the vehicles are passenger cars, comprising PCs (75.4%) and taxis (14.4%). The 2Ws and 3Ws comprise around 6% of the data, LGVs around 2.5%, and buses 1.3%. The study captured very few medium- and heavy-duty trucks; this is due to restrictions on the movement of these vehicles in and around Delhi during

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[47] Bernard et al., *Determination of Real-World Emissions.*

[48] The gap between real-world and type-approval CO_2 has been well documented in Europe. Although no equivalent data exists for India, the type-approval procedure is adapted from the European NEDC test, for which real-world CO_2 has been at least 20% higher than type-approval levels since 2010 in Europe. See: Jan Dornoff, Victor Valverde Morales, and Uwe Tietge, *On the Way to 'Real World' CO_2 Values? The European Passenger Car Market after 5 Years of WLTP* (International Council on Clean Transportation, 2024), https://theicct.org/publication/real-world-co2-emission-values-vehicles-europe-jan24/.

[49] The pollutants in g/kg_{fuel} are multiplied by the engine efficiency expressed in g_{fuel}/kWh. For diesel and CNG heavy-duty vehicles, average efficiencies of 40% (212 g_{fuel}/kWh) and 37% (205 g_{fuel}/kWh), respectively, were assumed for the conversion from emission ratio to fuel burnt to energy produced. For diesel, a detailed method is described in the report from Sina Kazemi Bakhshmand et al., *Remote Sensing of Heavy-Duty Vehicle Emissions in Europe* (International Council on Clean Transportation, 2022), https://theicct.org/publication/remote-sensing-of-heavy-duty-vehicle-emissions-in-europe/.

[50] Yang, Bernard, and Dallmann, *Technical Considerations for Choosing a Metric.*

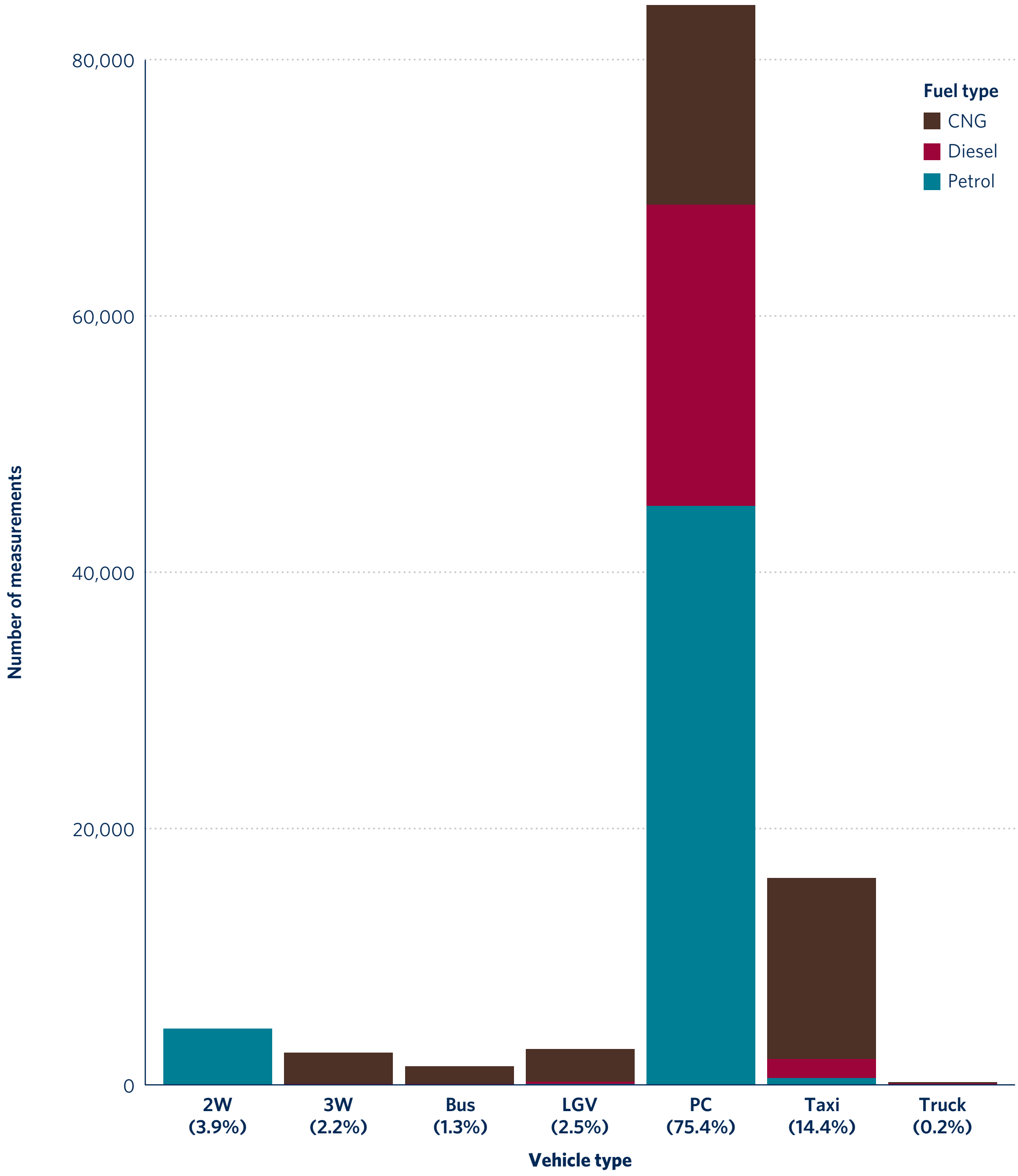

Figure 4. Number of valid real-world emissions records by vehicle and fuel type, with the percentages showing the share of total records for each vehicle type

the testing period. The sample size for trucks was not sufficient and they are not included in this study.

Petrol is the most common fuel type for PCs, followed by diesel and then CNG. The commercial taxi segment is predominantly fueled by CNG, followed by diesel and then petrol. The 2W fleet is entirely comprised of petrol models, whereas the 3Ws, LGVs, and buses captured are all fueled by CNG. Relative to other TRUE study locations, Delhi and Gurugram have a large share of CNG vehicles, and this is a unique opportunity to evaluate their real-world emissions.

Within the entire fleet with valid readings, petrol has the highest share of about 45%, followed by CNG at 32% and diesel at 23%. Vehicles recorded as petrol/hybrid and diesel/hybrid in the vehicle registration database comprise of 2.8% and 0.9% of the mix, respectively, and are considered either petrol or diesel in this analysis. Vehicles recorded as petrol/CNG, which could be either factory-fitted CNG vehicles, retrofits, or (very few) bi-fuel vehicles, were also part of the captured fleet. Such vehicles typically use CNG as the primary fuel and hence are under the CNG category.

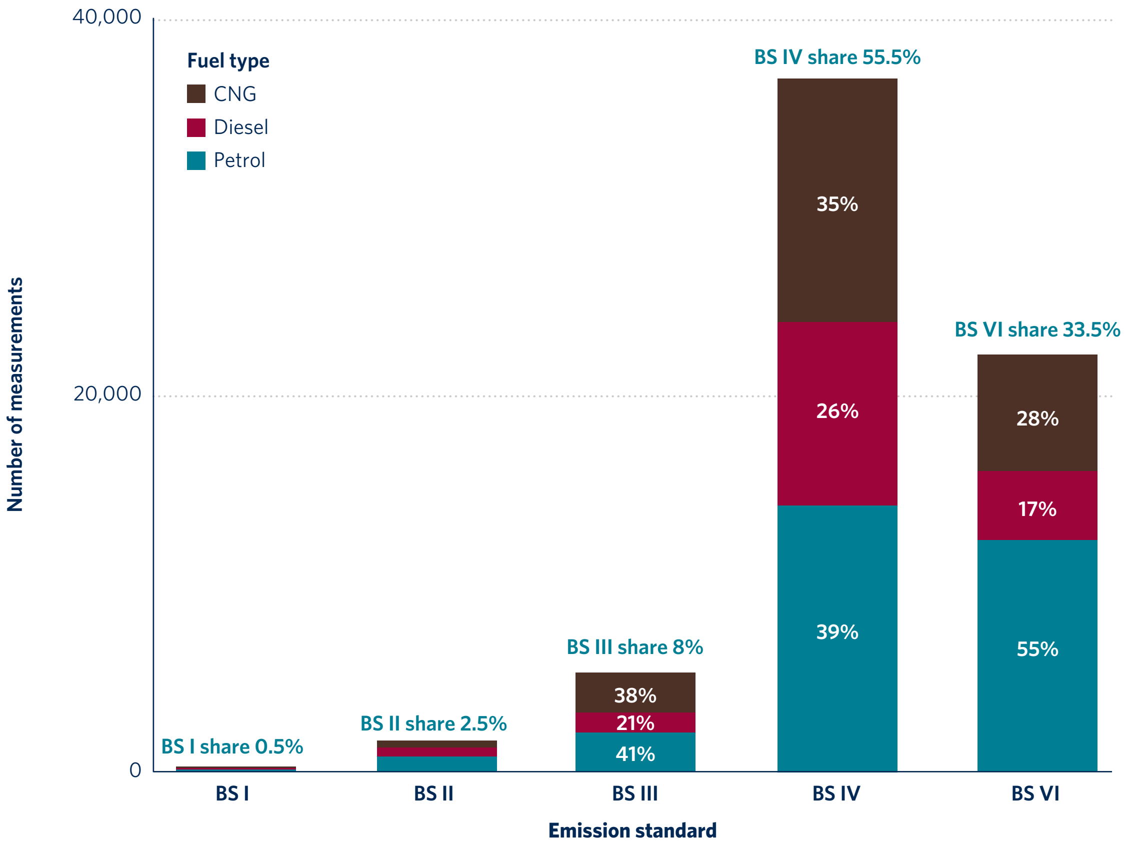

Figure 5. Shares of emission standards within the captured fleet and different fuel types within each standard

Almost 89% of the vehicles with valid measurements are certified to BS IV or BS VI standards, with BS IV being the most common. Pre-BS IV vehicles accounted for around 11% of measured fleet, as shown in Figure 5. The high share of BS IV vehicles could be attributed to the early implementation of this emission standard in Delhi and Gurugram. Additionally, policies detailed earlier, including age-related restrictions, have also enabled the adoption of BS VI vehicles.

Vehicles registered in Delhi, Haryana, and Uttar Pradesh comprised of nearly 94.5% of the captured fleet, with Delhi making up more than half. This is likely because most of the test sites were within Delhi and further details of fleet composition by state are in Appendix B.

RESULTS

This section first provides an overview of the average emissions of four pollutants by vehicle type and emission standard. It then presents detailed results for each vehicle type, starting with PCs, taxis, and LGVs because of their dominant share of the measurements. For each vehicle type, the measurements are compared with type-approval limits for each emission standard and pollutant, except for PM, which is not compared with the limits for reasons mentioned earlier. For PCs and LGVs, we additionally provide a comparison of emissions by automaker for the BS VI fleet. Lastly, we present PUCC test limit exceedances for petrol and CNG vehicles and summarize the type-approval limit exceedances found for all vehicle and fuel types.

EMISSIONS BY VEHICLE TYPE AND EMISSION STANDARD

As vehicles progress from BS I to BS VI standards, we found a decline in average NO_X, CO, HC, and PM emissions for most types, as shown in Figure 6. Two-wheelers, 3Ws, PCs, taxis, and LGVs consistently showed reduced emissions with each stricter standard. However, for BS IV buses, emissions were higher for all pollutants than they were for the BS III bus fleet. This could be because of the fleet-average engine size and type-approval CO_2 of the buses increased from BS III to BS IV.[51] While there is a decrease in engine size and type-approval CO_2 for the BS VI bus fleet, all the captured BS VI bus models included three-way catalysts that play a crucial role in reducing emissions from CNG vehicles by catalyzing the conversion of NO_X, CO, and HC into less harmful or inert compounds.

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[51] The fleet average engine displacements for the captured BS III, BS IV and BS VI CNG bus fleets are 1,497 cc, 5,332 cc and 2,596 cc, respectively. In addition, the fleet average type-approval CO_2 (g/km) for the CNG buses captured in this study almost doubled from BS III to BS IV, and then decreased to near BS III levels for BS VI.

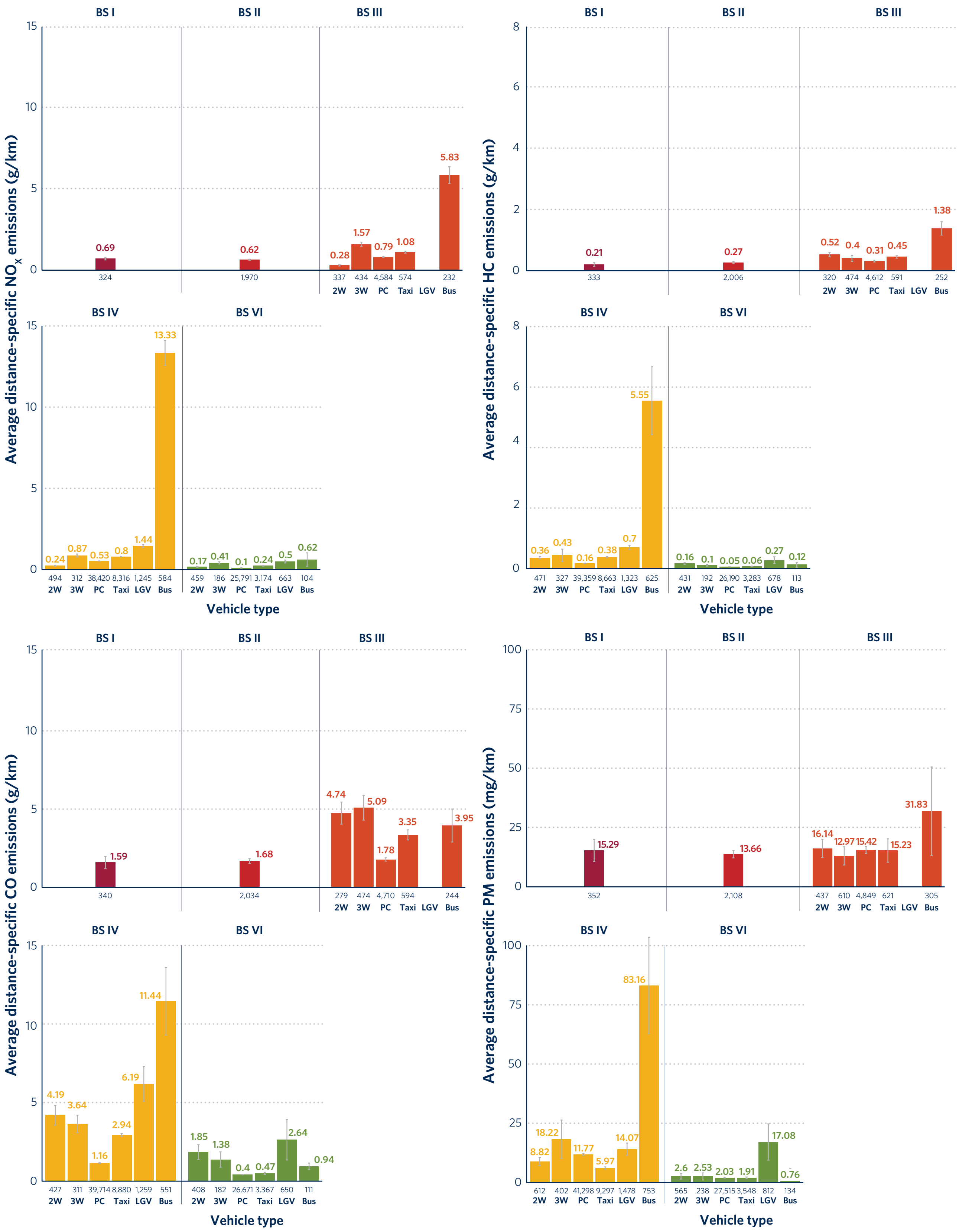

Figure 6. Summary of fleet-average emissions by vehicle type and emission standard for NO_x, CO, HC, and PM

Note: The number of measurements are presented at the bottom of each bar and whiskers represent the 95% confidence interval of the mean.

One clear trend evident from Figure 6 is that the emissions of the measured commercial vehicles are higher than those of the private vehicles. In the BS VI four-wheeler category, LGVs had 5 times and 2 times higher NO_X emissions, 7 times and 6 times higher CO emissions, and 5 times and 4 times higher HC emissions than PCs and taxis, respectively. Within the passenger car segment, commercial taxis consistently had higher emissions than PCs. There were also multiple instances where 3Ws had higher emissions than passenger cars. Further details regarding emissions by vehicle type and age group are in Appendix G.

PRIVATE CARS

Measurements of vehicles in the PC segment covered a wide range of emission standards. This was the only segment that had the required sample sizes of BS I and BS II vehicles. CNG cars comprised almost 18.5% of the captured PCs fleet, and the rest were petrol and diesel.

COMPARING PC FLEET EMISSIONS WITH TYPE-APPROVAL LIMITS

Overall, the trends across pollutants within each emission standard were the same for the three fuel types (Figure 7). Diesel PCs consistently had the highest NO_X and PM emissions and they were followed by CNG; petrol vehicles performed relatively better. The high NO_X and PM emissions from diesel vehicles are similar to the trends seen in previous emissions testing campaigns carried out by the ICCT and TRUE in Europe and other regions, where diesel vehicles were previously found to have significantly higher emissions in real-world operating conditions than in laboratory testing conditions. The high NO_X emissions measured from CNG vehicles also aligns with the findings of studies conducted in European cities and Abu Dhabi which found that passenger cars powered by natural gas had higher average NO_X emissions than those powered by petrol.[52]

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[52] Rohit Nepali, Yoann Bernard, and Kaylin Lee, *Evaluation of Real-World Vehicle Emissions in Abu Dhabi* (TRUE Initiative, 2023), https://www.true-initiative.org/publications/reports/evaluation-of-real-world-vehicle-emissions-in-abu-dhabi.

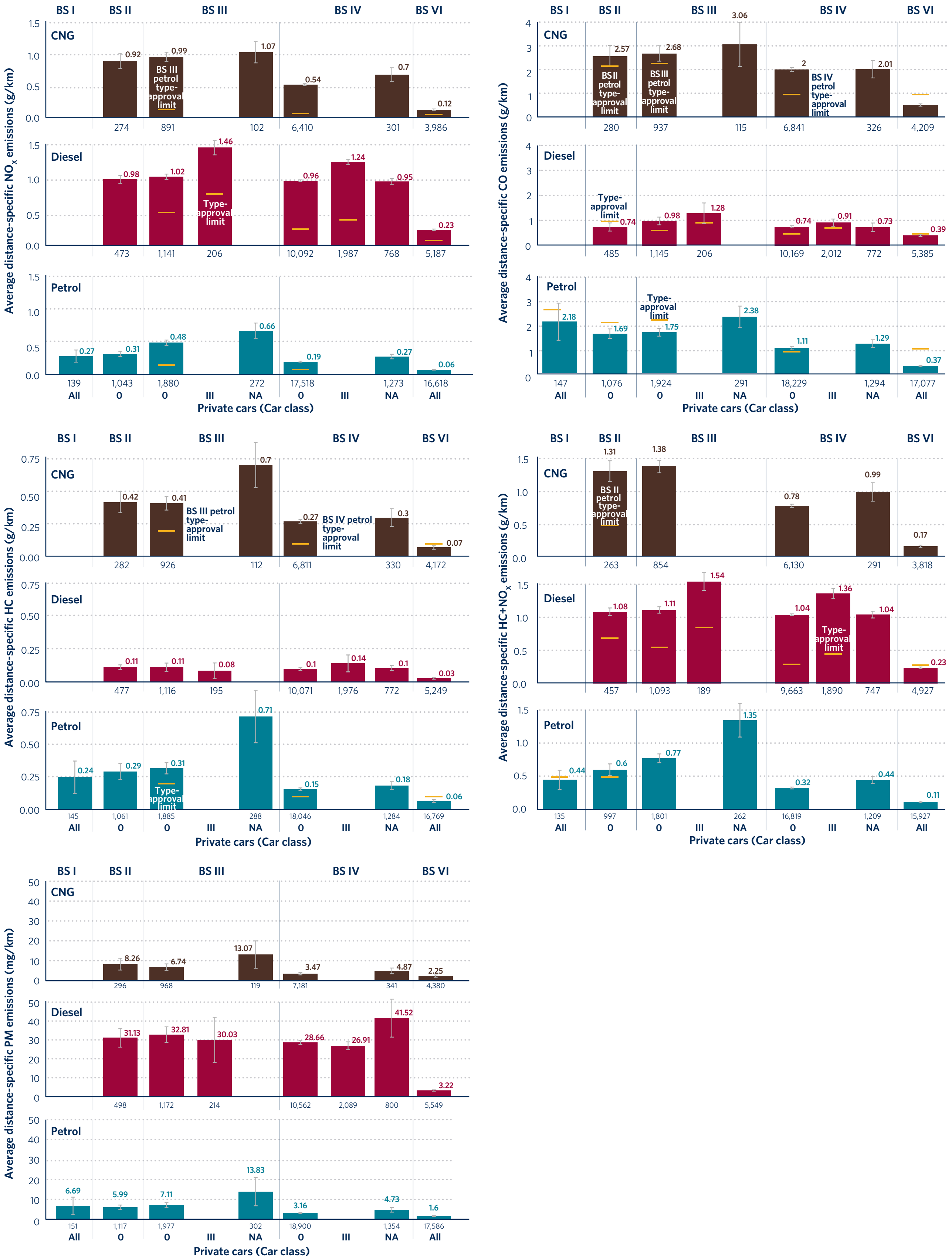

Figure 7. Private car fleet's average distance-specific emissions

Note: The number of measurements is presented at the bottom of each bar and whiskers represent the 95% confidence interval of the mean.

Concerning CO and HC emissions, CNG vehicles had the highest emissions across emission standards, followed by petrol vehicles and then diesel vehicles. This could be attributed to some portion of pre-BS VI CNG cars being retrofits and the absence of closed-loop electronically controlled systems designed for CNG, as that affects the combustion process and emissions performance. In addition, a significant portion of HC emissions measured from CNG cars could be methane emissions, and methane has a high global warming potential.

One clear takeaway from Figure 7 is the significant reduction of emissions across all four pollutants with the progression of emission standards. This was pronounced from BS III to BS IV and the most significant improvements were from BS IV to BS VI. Petrol PCs had their largest reduction in NO_X emissions of 61% from BS III to BS IV, and diesel vehicles showed a 77% reduction in NO_X and an 89% reduction in PM emissions from BS IV to BS VI. Full details of these results and those for all other vehicle types are in Appendix D.

The real-world NO_X emissions of BS VI vehicles were found to be above the type-approval limits, with diesel emitting 2.9 times and CNG vehicles emitting 2 times the limit. For CO and HC, PC BS VI fleets of all three fuel types were within the limits, and the CNG fleets showed the highest emissions for these pollutants.

For vehicles certified to older standards, the difference between real-world emission measurements and type-approval limits is even more pronounced. BS IV Class 0 diesel vehicles were found to emit NO_X at 3.8 times the limit, while CNG vehicles had emissions 6.8 times the petrol limit.[53] In addition, PM emissions from diesel vehicles were found to be 8–9 times higher than those from petrol and CNG vehicles. The heavier Class III diesel cars certified to BS IV had higher NO_X, CO, and HC+NO_X emissions than Class 0 diesel vehicles, with NO_X emissions 3.2 times the limit and HC+NO_X emissions 3 times the limit. In the BS III category, the Class 0 CNG vehicles measured showed NO_X emissions 6.6 times higher than the petrol limit, and diesel vehicles emitted 4.5 times more PM emissions than petrol and CNG.

Measurements from PCs certified to BS II standards also showed emissions above the type-approval limits, with CNG vehicles showing HC+NO_X emissions 2.6 times above the petrol limit, and diesel vehicles emitting nearly 4 times more PM than petrol and CNG. For BS II vehicles, diesel and petrol PCs had CO emissions within type-approval limits, and the CNG fleet exceeded the petrol limit by 1.2 times. Similarly, HC emissions were highest in CNG vehicles at 2.1 times the petrol type-approval limit.

COMPARING EMISSIONS FROM BS VI PC FLEET BY MANUFACTURER

Among the PCs, which made up about 75% of the measurements, there was a lot of diversity of original equipment manufacturers (OEMs) in BS VI fleet. At least 13 OEMs had minimum sub-grouping sizes of 100, as shown in Figure 8. Out of the 13 OEMs of petrol cars, seven were found to have average real-world NO_X emissions 1.1 times to 2.5 times the type-approval limit. Out of the six diesel OEMs, five had NO_X emissions higher than the type-approval limit, and they ranged from 1.9 times to 4.9 times higher. All three OEMs of CNG vehicles also exhibited real-world NO_X emissions higher than the type-approval limit.

Measurements from all petrol and CNG cars from all OEMs show average real-world emissions within type-approval limits for CO and HC emissions, and three diesel OEMs out of nine were slightly over the CO limit. Note that diesel cars typically had lower CO emissions than petrol and CNG ones, but the CO type-approval limit for diesel was also much more stringent (0.5 g/km) compared with that of petrol and CNG (1.0 g/km). For real-world HC+NO_X from diesel PCs, four OEMs out of seven exhibited average emissions 1.2 to 2.5 times higher than the limit. For PM emissions, the diesel fleets of most OEMs were the highest emitters, although there was one OEM which had higher PM emissions from its petrol fleet than its diesel fleet.

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[53] The type-approval limits for four-wheelers (cars and LGVs) are defined based on gross vehicle weight and reference mass. These are divided into classes that are detailed in Appendix H. Additionally, pre-BS VI standards did not specify a limit for CNG vehicles in multiple cases. In BS VI standards, the limits for petrol and CNG (spark-ignition) are clearly stated and are identical. Hence, petrol type-approval limits are used for representative comparison in pre-BS VI.

Figure 8. Emissions from private car fleets by manufacturer

Note: The number of measurements is presented at the bottom of each bar and whiskers represent the 95% confidence interval of the mean.

TAXIS

Like the PC fleet, the measured taxi fleet has a mix of all three fuel types. Here there was a large portion of CNG vehicles, 87%, and diesel was second most common at 9%.

COMPARING TAXI FLEET EMISSIONS WITH TYPE-APPROVAL LIMITS

Figure 9 shows that the petrol and CNG taxi fleets were found to have NO_X emissions that were as high as those from diesel vehicles. For CO and HC emissions, the CNG and petrol fleets were the worst performers, and for PM, the diesel fleet was the highest emitter. In line with the PC segment, the progression in emission standards resulted in reductions in emissions from BS III to BS IV and even more significantly from BS IV to BS VI. The measured CNG taxis showed an 87% reduction for both CO and HC emissions from BS IV to BS VI, and the diesel fleet's NO_X and PM emissions were reduced by almost 80% and 72%, respectively.

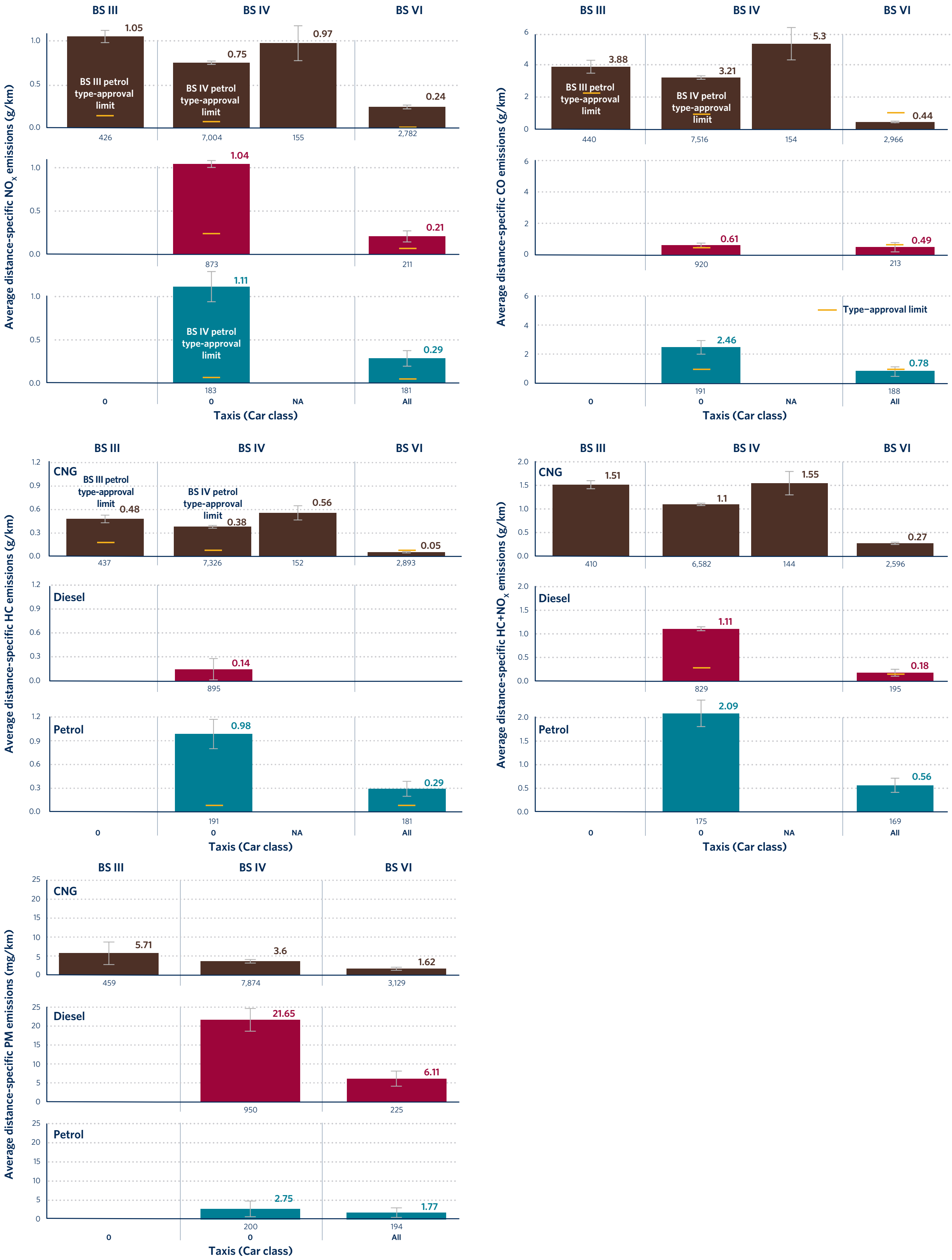

Figure 9. Taxi fleet's average distance-specific emissions

Note: The number of measurements is presented at the bottom of each bar and whiskers represent the 95% confidence interval of the mean.

The measured BS IV petrol taxi vehicles showed the highest real-world NO_X emissions at 13.9 times the limit, followed by the BS III CNG fleet at 7 times the petrol limit and the BS IV diesel fleet at 4.2 times the limit. The CNG BS IV taxi fleet had NO_X real-world emissions of 9.4 times the petrol limit. Within the BS VI fleet, petrol had the highest real-world NO_X emissions at 4.8 times the limit, followed by CNG at 4 times the limit and diesel at 2.6 times the limit. BS IV CNG taxis with no class information available (NA in the figure), also showed considerably high real-world NO_X emissions. As mentioned earlier, this result also aligns with the findings from European cities and Abu Dhabi that challenge the idea that CNG is a "clean" fuel.

For CO emissions, the average of the measured BS VI taxi fleet was within type-approval limits, and BS IV CNG taxis (NA in the figure) had the highest CO emissions of all measured taxis. BS III CNG taxis (Class 0) showed CO emissions at 1.7 times the petrol type-approval limit, followed by the BS IV CNG taxis (Class 0) at 3.2 times the limit, BS IV petrol taxis (Class 0) at 2.5 times the limit, and BS IV diesel taxis (Class 0) at 1.2 times the limit.

For real-world HC emissions, the BS VI CNG taxi fleet was within the type-approval limit and the BS VI petrol fleet was found to be 2.9 times higher than the limit. Worst performing in terms of HC emissions was the BS IV petrol fleet (Class 0) at 9.8 times the limit, followed by the BS III CNG fleet (Class 0) at 2.4 times the petrol limit and then the BS IV CNG fleet at 3.8 times the petrol limit. Given that limits are defined for diesel vehicles for $HC+NO_X$ and not HC, no limit for HC is represented in the figure. The BS IV diesel fleet (Class 0) was found to be 3.7 times higher than the type-approval limit and the BS VI diesel fleet was 1.1 times the limit.

The PM emissions were highest for the diesel taxi fleet, followed by the CNG fleet and then the petrol fleet. In addition, a reduction in PM emissions from BS IV to BS VI taxi fleet was observed.

LIGHT GOODS VEHICLES

Unlike cars, the captured LGV fleet in Delhi and Gurugram is 100% CNG vehicles. This reflects the shift away from diesel vehicles due to restrictions imposed in the NCR, the major one being that vehicle lifetime was limited to 10 years for diesel vehicles. That only BS IV and BS VI LGVs were captured indicates that Delhi's LGVs are relatively young.

COMPARING LGV FLEET EMISSIONS WITH TYPE-APPROVAL LIMITS

As shown in Figure 10, we found a significant reduction in emissions across NO_X, CO, and HC emissions in the BS VI LGV fleet, but the PM emissions were higher than the BS IV fleet. Additionally, he LGVs were the worst performers in terms of real-world NO_X emissions among all the LDV categories captured in this testing.

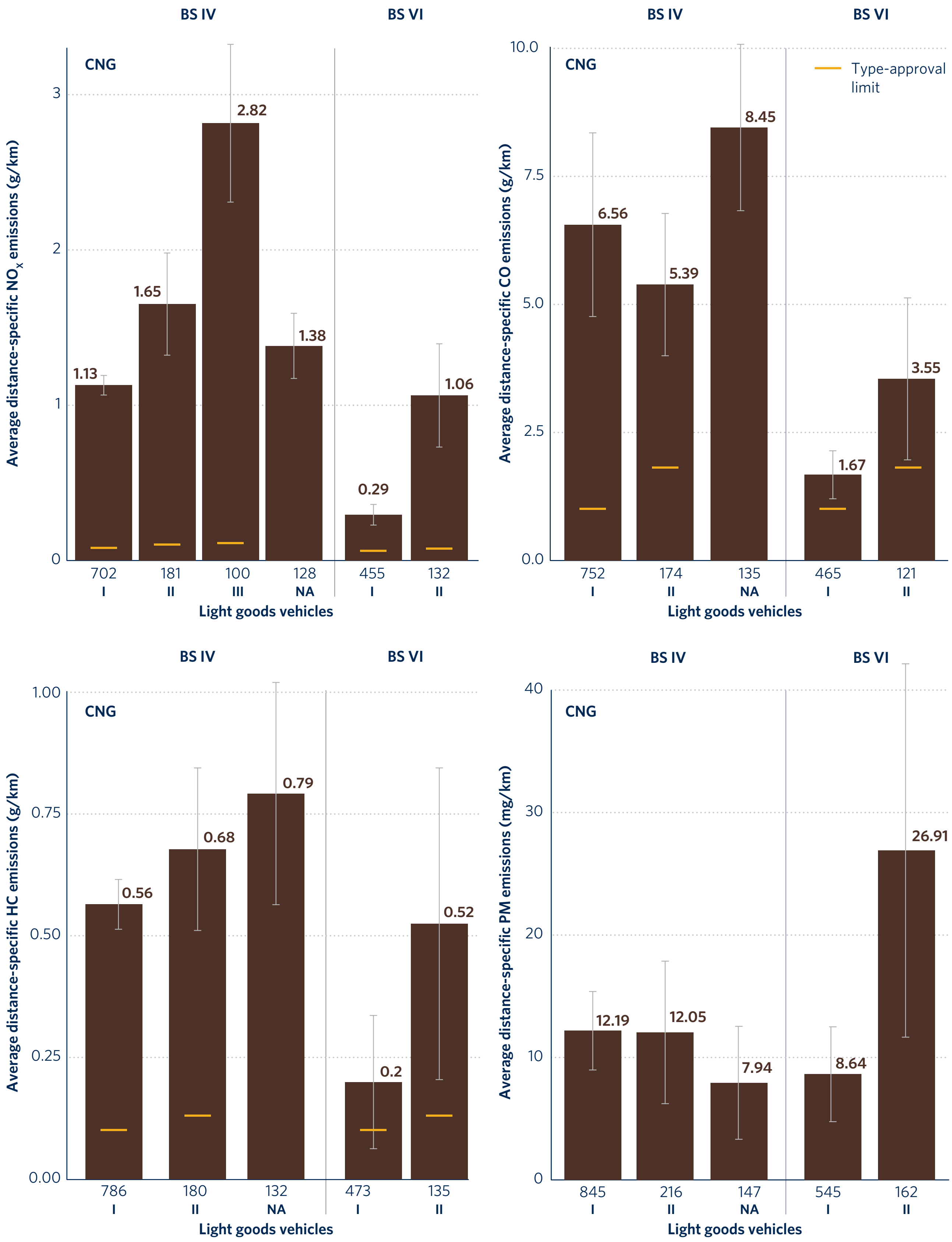

Figure 10. Light goods vehicle fleet's average distance-specific emissions

Note: The number of measurements is presented at the bottom of each bar and whiskers represent the 95% confidence interval of the mean.

Within the BS IV fleet, the heaviest vehicles, Class III vehicles, had the highest NO_x emissions at 25.6 times the type-approval limit; they were followed by Class II vehicles at 16.5 times the limit and Class I vehicles at 14.1 times the limit. The few BS IV LGVs for which weight information was not available (NA in the figure) also had high NO_x emissions. While a NO_x emissions reduction was observed in BS VI LGVs, their emission levels were also multiple times higher than type-approval limits. BS VI Class II average emissions were found to be 14.2 times the type-approval limit, and the Class I emissions were 4.9 times the limit. This study did not capture enough diesel LGVs for emissions analysis. Still, a recent ICCT study that tested a BS VI Class I diesel LGV using a portable emissions measurement system found NO_x emissions 6.2–7.9 times higher than the type-approval limits.[54]

For real-world CO emissions, the weight-unknown BS IV vehicles had the highest emissions, followed by Class I vehicles at 6.6 times the limit and Class II vehicles at 3 times the limit. Of the BS VI fleet measured, Class II vehicles showed CO emissions 2 times the limit and Class I vehicles were found to be 1.7 times higher than the limit.

The trends are similar for real-world HC emissions, with the weight-unknown BS IV fleet having the highest emissions, followed by Class II at 5.2 times the limit and then Class I at 5.6 times the limit. For the BS VI fleet, Class II was found to be 4 times higher than the limit and those were followed by Class I vehicles at 2 times the limit.

For PM emissions, the BS VI Class II fleet was the highest emitter, followed by BS IV Class II and Class I, then Class I of BS VI, and then the BS IV weight-unknown fleet.

COMPARING EMISSIONS FROM BS VI LGV FLEET BY MANUFACTURER

The average emissions from BS VI LGVs by OEM are illustrated in Figure 11. The sub-grouping minimum size of 100 was met only by Class II fleet from LGV_OEM2 and Class I fleets from LGV_OEM1 and LGV_OEM3. As shown, LGV_OEM2's Class II segment is the worst performing across all four pollutants. This fleet had NO_x emissions at 15.6 times the type-approval limit and was followed by LGV_OEM3's Class I fleet at 5.7 times the limit and LGV_OEM1's Class I fleet at 4.7 times the limit.

Similarly, for real-world CO emissions, average emissions from LGV_OEM2's Class II fleet were the highest and were 2.2 times the limit, followed by LGV_OEM3's Class I fleet at 2.7 times the limit and LGV_OEM1's Class I fleet at 1.1 times the limit. Note that as LGV_OEM2 was in the heavier Class II, it had relatively lenient limits. The HC emissions of LGV_OEM2's Class II fleet were 5 times the limit, followed by LGV_OEM1's Class I fleet at 2.5 times the limit and LGV_OEM3's Class I fleet at 1.3 times the limit.

For PM emissions, LGV_OEM2's Class II fleet was the highest emitter at 2.2 times and 8.3 times higher than LGV_OEM1 and LGV_OEM3's Class I fleets, respectively.

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[54] Anirudh Narla et al., *Real-Driving Emissions from Bharat Stage VI (Phase 1) Passenger Cars and a Light Commercial Vehicle in India – PEMS Testing* (International Council on Clean Transportation, 2024), https://theicct.org/publication/real-driving-emissions-from-bharat-stage-vi-ldv-testing-india-pems-testing-jul24/.

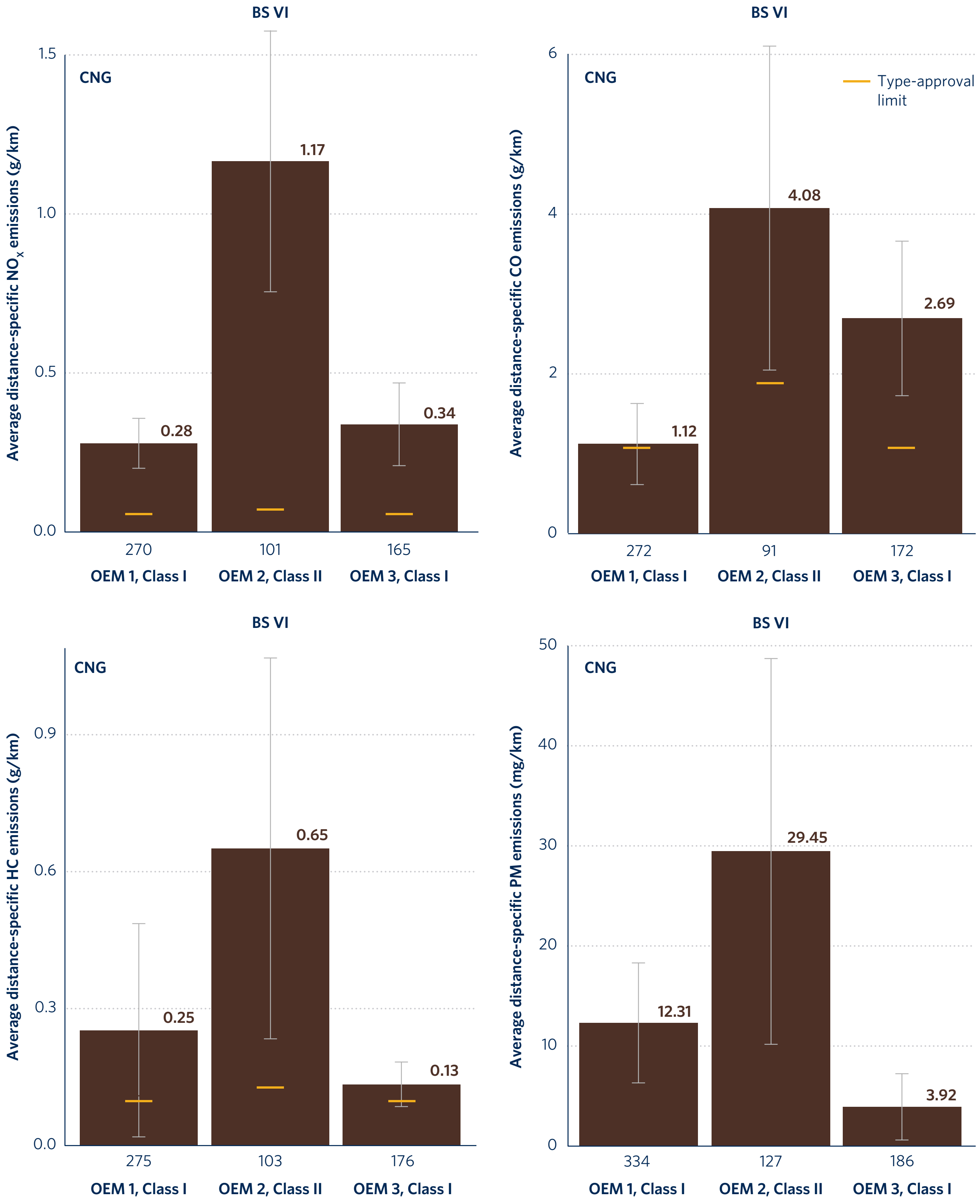

Figure 11. Emissions from light goods vehicle fleets by manufacturer

Note: The number of measurements is presented at the bottom of each bar and whiskers represent the 95% confidence interval of the mean.

TWO-WHEELERS

The captured petrol 2W fleet, akin to the four-wheeler segment, showed reductions in emissions with the progression in emission standards across all four pollutants. This was especially pronounced in the shift from BS III to BS IV and from BS IV to BS VI (recall that full details for all vehicle types are in Appendix D).

COMPARING 2W FLEET EMISSIONS WITH TYPE-APPROVAL LIMITS

Figure 12 presents the average real-world emissions from the 2W fleet captured. The fleet is entirely made up of petrol vehicles, and the data show almost no pre-BS III 2Ws.

We found emission reductions with the progression in emission standards, but the real-world average emissions in few cases were much higher than type-approval limits. Note that, for BS IV 2Ws, different emission limits were defined based on engine displacement (50–150 cc and > 150 cc), and hence the representation on the x-axis in Figure 12.[55] The measured BS VI 2W fleet's real-world average NO_X emissions were 2.8 times higher than the type-approval limit, and the BS IV fleet was within type-approval limit. The average CO emissions were 4.7 times higher than the limit for BS III vehicles, 3 times higher for BS IV vehicles, and 1.8 times higher for BS VI vehicles. BS III and BS IV vehicles had average HC+NO_X limits defined, and the real-world emissions found for these fleets were lower than the type-approval limit. This shifted to comparison with an average HC limit for the BS VI fleet, and this study found average real-world emissions 1.6 times the type-approval limit. Average PM emissions consistently decrease with the progression in emission standards.

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[55] The type-approval limits for BS IV two-wheelers were defined based on maximum speed (V_{maX} in km/h) and engine displacement. Because this model-wise V_{maX} information was not available on the vehicle registration database, the BS IV fleet was compared with type-approval limits based on only engine displacement. The same is true for the BS VI 2W fleet, but the defined type-approval limits did not vary based on either parameter and hence the representation is "All." Additionally, there were not enough > 150 cc 2Ws captured. For BS III and BS VI, "All" represents that all 2Ws, irrespective of engine size or any other grouping, are considered for plotting. Orange dashed lines not being present on few bars of NO_X, HC, and HC+NO_X means that type-approval limits were not defined. For example, there were no defined HC type-approval limits for BS III and BS IV 2Ws.

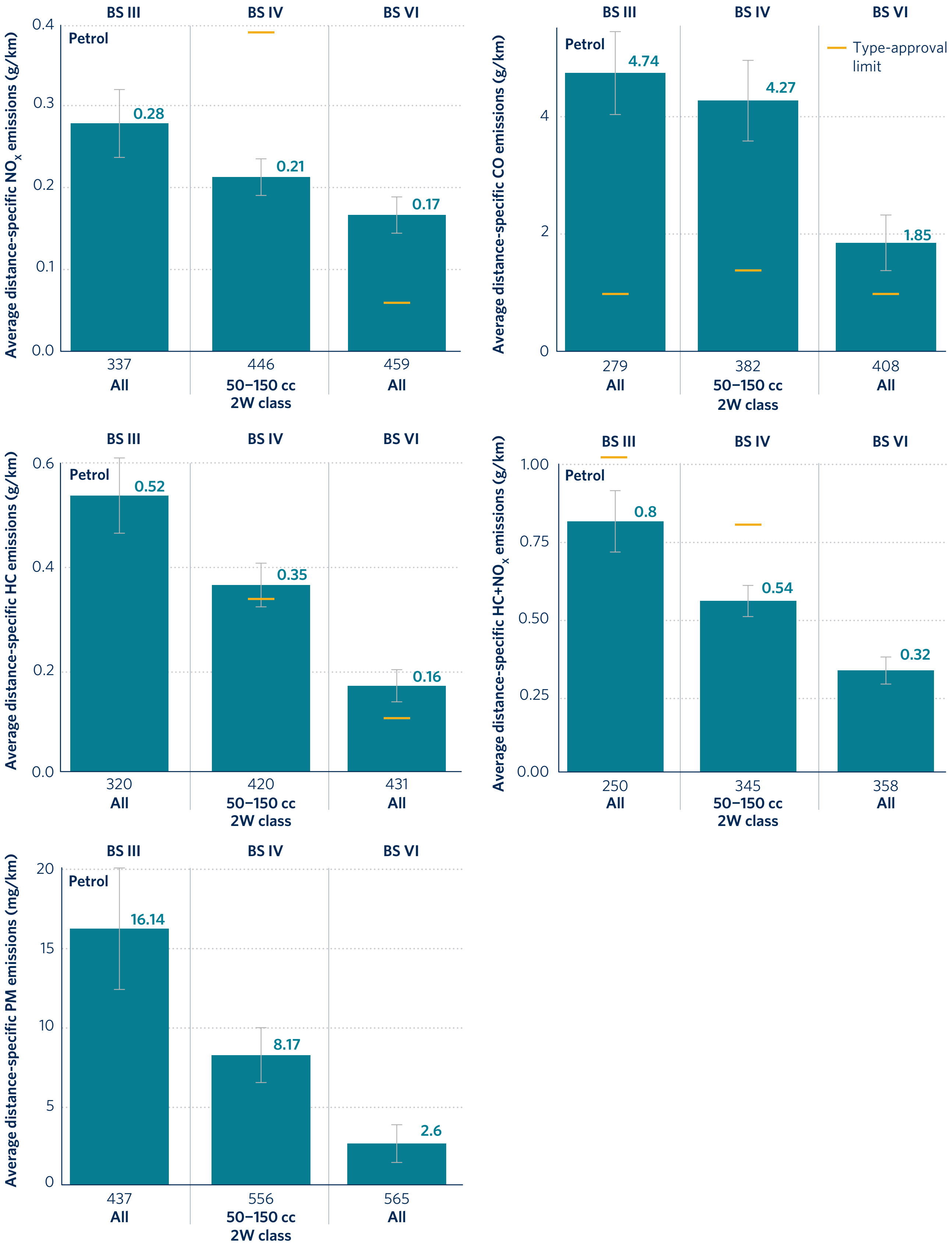

Figure 12. Two-wheeler fleet's average distance-specific emissions

Note: The number of measurements is presented at the bottom of each bar and whiskers represent the 95% confidence interval of the mean.

THREE-WHEELERS

The 3W fleet, comprised of entirely CNG vehicles, showed consistent reductions in emissions with the progression in emission standards.

COMPARING 3W FLEET EMISSIONS WITH TYPE-APPROVAL LIMITS

Figure 13 compares the average real-world emissions from the 3W fleet with the type-approval limits. Unlike 2Ws and four-wheelers, here the type-approval limits remain same for each sub-grouping of emission standard and fuel type.

The average emissions of the fleet decreased from BS III to BS VI, but all were higher than type-approval limits. For NO_X emissions, the BS VI fleet had 3.2 times higher real-world emissions than the type-approval limit. The average real-world CO emissions were 4.1 times higher for BS III vehicles than type-approval limits, 3.9 times higher for BS IV vehicles, and 3.1 times higher for BS VI vehicles. Similarly, the average $HC+NO_X$ emissions were 1.7 times higher than type-approval limits for BS III fleet. A significant reduction in PM emissions was observed with BS VI.

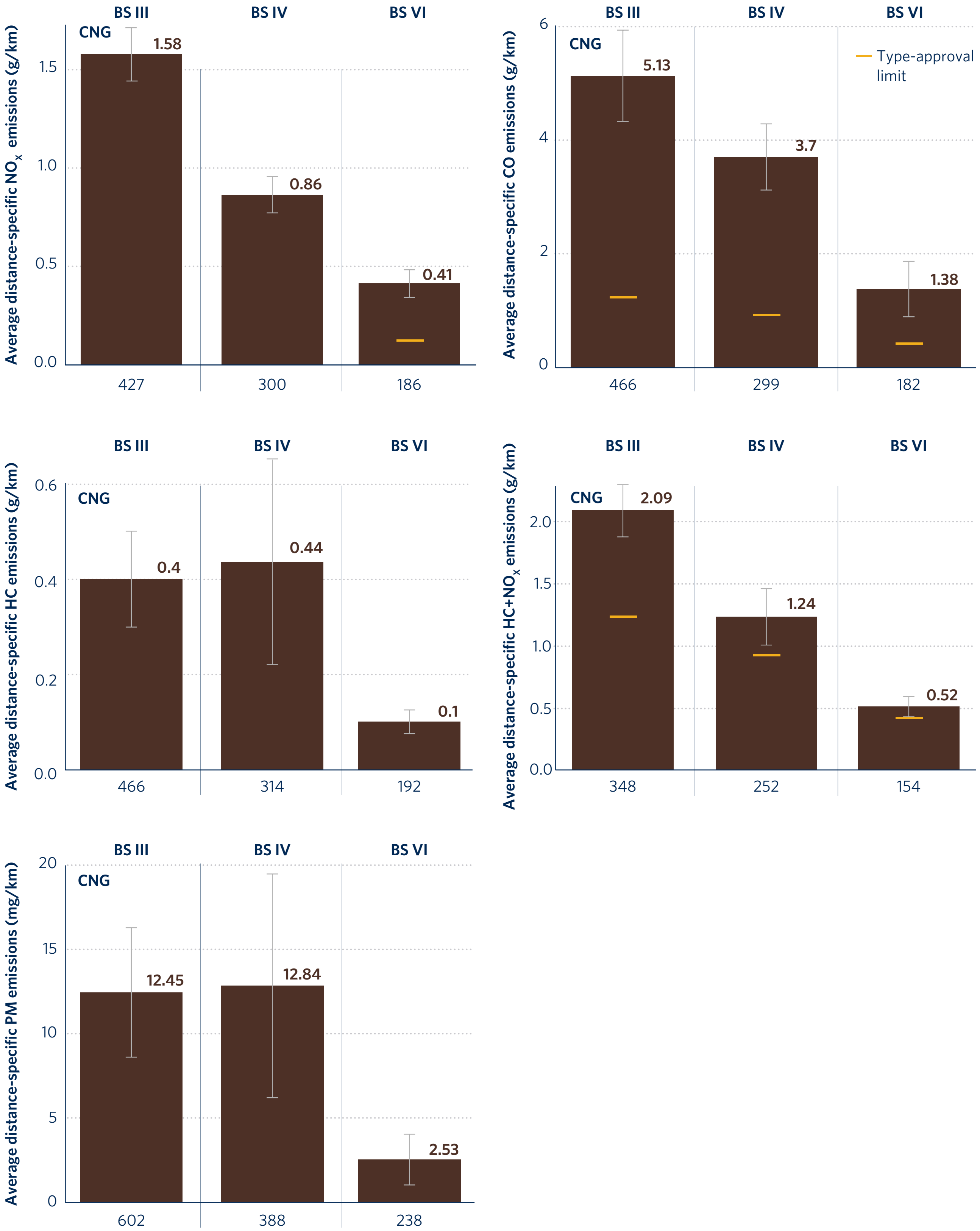

Figure 13. Three-wheeler fleet's average distance-specific emissions

Note: The number of measurements is presented at the bottom of each bar and whiskers represent the 95% confidence interval of the mean. The pollutant HC does have any red dashed lines because HC has not been considered for type-approval compliance testing for 3Ws.

BUSES

The testing for buses was performed at a bus terminal in Delhi. The bus fleet captured is entirely CNG.

COMPARING BUS FLEET EMISSIONS WITH TYPE-APPROVAL LIMITS

In Figure 14, the average real-world emissions from the bus fleet are compared with the transient cycle type-approval limits, which are defined for CNG heavy-duty vehicles. The emissions for this vehicle type vary significantly from the others. Although the BS IV bus fleet had much higher emissions than the BS III fleet, the emissions performance of the BS VI buses was an impressive improvement over both BS IV and BS III. This highlights the effective emissions reduction strategies deployed in BS VI buses.

As mentioned earlier, the average type-approval CO_2 (g/km) of the captured CNG bus fleet doubled from BS III to BS IV and then reduced to slightly higher than BS III for the BS VI fleet. Also, the fleet average engine displacement of the BS IV fleet was almost 3 times and 2 times higher than the BS III and BS VI fleets, respectively. The combination of deployment of better aftertreatment technologies like three-way catalysts and a closed-loop, electronically controlled system could be the reason for the greater reductions of emissions from the CNG BS VI bus fleet.

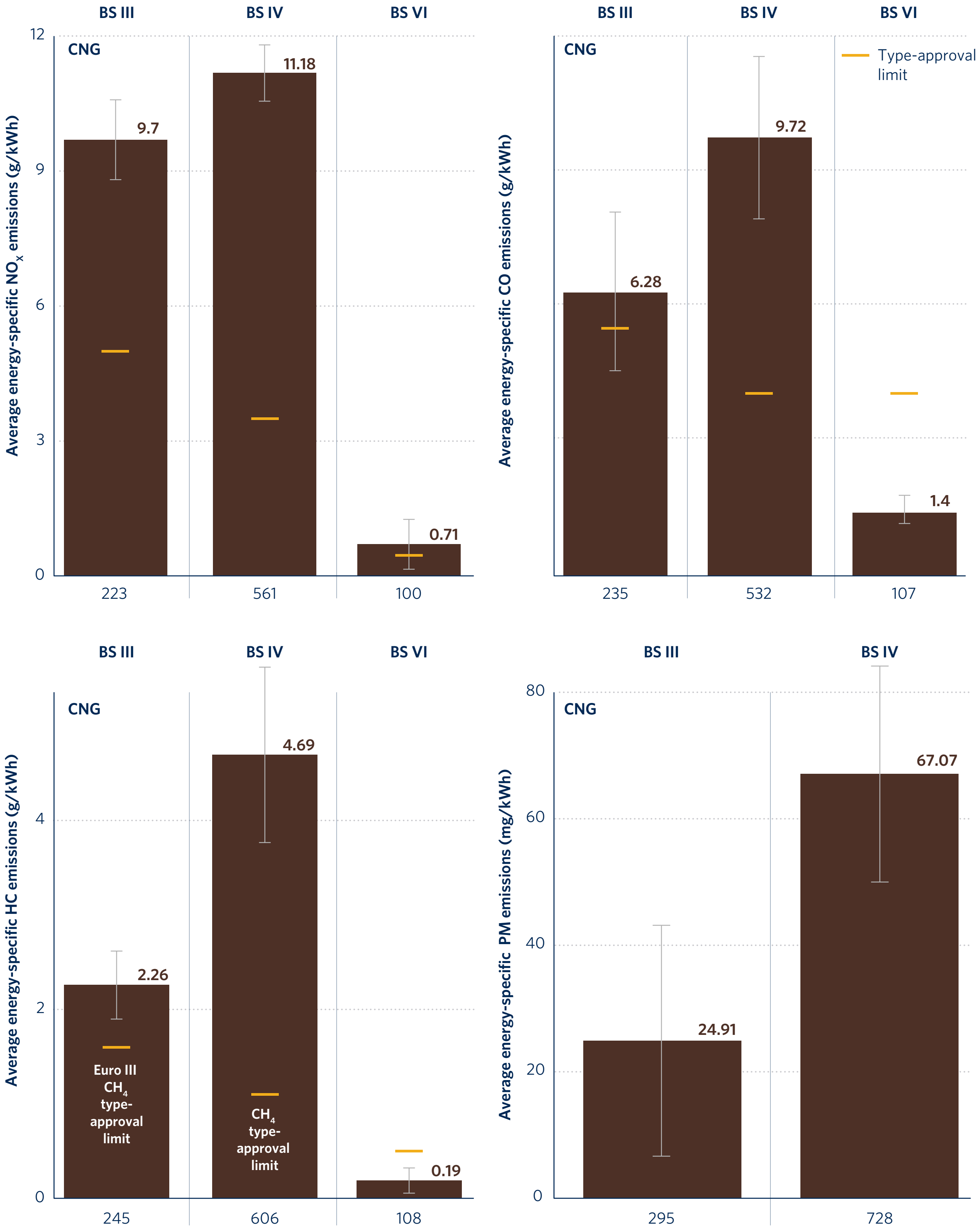

Figure 14. Bus fleet's average distance-specific emissions

Note: The number of measurements is presented at the bottom of each bar and whiskers represent the 95% confidence interval of the mean. The real-world PM emissions from the BS VI bus fleet were below detection levels and are not presented.

For real-world NO_x emissions, the BS III, BS IV, and BS VI vehicles had average real-world NO_x emissions 1.9 times, 3.2 times, and 1.5 times higher than the type-approval limits, respectively. The BS VI fleet's real-world CO and HC emissions were lower than the type-approval limits. For BS III and BS IV vehicles, the real-world CO emissions were 1.2 times and 2.4 times the type-approval limits and the real-world HC emissions were 1.4 times and 4.3 times the type-approval limits, respectively. As there are no total hydrocarbon (THC) limits defined, the available BS IV type-approval limits for methane (CH_4), which generally comprises of majority of HC emissions in CNG vehicles, were used. The CH_4 limit for Euro III, which was not defined for BS III, was used for comparison.

Like the results of other pollutants, the BS IV bus fleet showed higher PM emissions than the BS III fleet. The BS VI fleet's PM emissions were below detectable levels.

COMPARING PETROL AND CNG VEHICLE EMISSIONS WITH PUCC LIMITS

Here we compare the real-world measured HC and CO emissions for the petrol and CNG fleets of all vehicle types with PUCC limits, as these vehicles are tested for these two pollutants during the PUCC test. The comparison also includes the stricter high-idling CO limit for petrol vehicles. In Table 2, the converted tailpipe concentrations from remote sensing data are compared with PUCC limits; note, though, that these test procedures are quite different and high average real-world emissions do not mean that the vehicles are not complying with PUCC limits, which are designed for idle-testing conditions.

As shown in the table, a considerable percentage of vehicles exhibit concentrations above the PUCC limits in real-driving conditions. The PUCC test is not reflective of real-world driving emissions.

SUMMARY OF EMISSIONS THAT EXCEEDED TYPE-APPROVAL LIMITS

Tables 3 through 6 detail that real-world emissions were higher than type-approval limits in multiple cases, including in some BS VI vehicle fleets. The NO_x emissions performance was particularly poor across the vehicles captured, including BS VI vehicles; the exception was private petrol cars. See Appendix E for details of the top six polluting vehicle segments in Delhi and Gurugram, based on the captured data.

Table 2. Share of captured petrol and CNG vehicles exhibiting high HC (ppm) and CO (%) levels compared with PUCC limits

Vehicle type	Emission standard	Fuel type	Exceeding HC (ppm) idling limit		Exceeding CO (%) idling limit		Exceeding CO (%) high idling limit	
			>1.0-2.0 times	>2.0 times	>1.0-2.0 times	>2.0 times	>1.0-2.0 times	>2.0 times
2Ws	**BS IV**	**Petrol**	1.3%	0.5%	4.4%	1.1%		
	BS VI	**Petrol**	3.3%	3.3%	3.8%	6.2%	2.9%	9.0%
3Ws	**BS IV**	**CNG**	0.7%	0.0%	2.1%	0.1%		
	BS VI	**CNG**	6.6%	2.1%	3.5%	2.1%		
Buses	**BS IV**	**CNG**	6.7%	33.5%	4.8%	7.0%		
	BS VI	**CNG**	6.3%	4.2%	0.0%	0.0%		
LGVs	**BS IV**	**CNG**	9.0%	51.4%	10.6%	37.6%		
	BS VI	**CNG**	10.8%	12.9%	2.6%	7.0%		
PCs	**BS IV**	**CNG**	15.6%	31.5%	10.0%	18.1%		
	BS IV	**Petrol**	7.5%	7.3%	5.5%	5.6%	6.7%	8.7%
	BS VI	**CNG**	8.9%	4.7%	2.0%	2.2%		
	BS VI	**Petrol**	4.7%	2.2%	1.4%	0.9%	2.1%	1.6%
Taxis	**BS IV**	**CNG**	12.6%	44.4%	10.9%	28.0%		
	BS IV	**Petrol**	7.0%	47.5%	10.1%	17.5%	12.5%	23.3%
	BS VI	**CNG**	12.0%	4.7%	1.4%	2.2%		
	BS VI	**Petrol**	8.7%	15.6%	4.1%	3.7%	5.5%	6.0%

Notes: Percentages in red are sub-groups with at least 10% of the vehicles showing concentrations at least twice the PUCC limit. Blank cells indicate that no CO (%) high-idling limit is defined for that sub-group.

Table 3. Summary of real-world NO_x emissions that were above type-approval limits, with average emissions greater than or equal to 2.1 times the limit shown in blue and average emissions greater than or equal to 4.0 times the limit shown in red

NO_x	Fuel	Class	BS I	BS II	BS III	BS IV	BS VI
2W	**Petrol**				NA	Below limit	2.8
3W	**CNG**				NA	NA	3.2
PC	**CNG**	0		NA	6.6[a]	6.8[a]	
		All					2.0
	Diesel	0		NA	2.0	3.8	
		III			1.9	3.2	
		All					2.9
	Petrol	0		NA	3.2	2.4	
		All	NA				Close to limit[b]
Taxi	**CNG**	0			7.0[a]	9.4[a]	
		All					4.0
	Diesel	0				4.2	
		All					2.6
	Petrol	0				13.9	
		All					4.8
LGV	**CNG**	I				14.1	4.9
		II				16.5	14.2
		III				25.6	
Bus	**CNG**				1.9	3.2	1.5

Notes: NA represents that fleet has been captured but no type-approval limits are defined. The red and blue thresholds are borrowed from Meyer et al., *Reassessment of Excess NO_x*.

[a] Compared with petrol limits because no CNG limits are defined.

[b] "Close to limit" means that the average real-world emissions, measured using remote sensing, were between 1.0 and 1.1 times higher than the type-approval limit.

Table 4. Summary of real-world CO emissions that were higher than type-approval limits, with average emissions greater than or equal to 2.1 times the limit shown in blue and average emissions greater than or equal to 4.0 times the limit shown in red

CO	Fuel	Class	BS I	BS II	BS III	BS IV	BS VI
2W	**Petrol**				4.7	3.0	1.8
3W	**CNG**				4.1	3.9	3.1
PC	**CNG**	0		1.2	1.2[a]	2.0[a]	
		All					Below limit
	Diesel	0		Below limit	1.5	1.5	
		III			1.4	1.2	
		All					Below limit
	Petrol	0		Below limit	Below limit	1.1	
		All	Below limit				Below limit
Taxi	**CNG**	0			1.7[a]	3.2[a]	
		All					Below limit
	Diesel	0				1.2	
		All					Below limit
	Petrol	0				2.5	
		All					Below limit
LGV	**CNG**	I				6.6	1.7
		II				3.0	2.0
		III					
Bus	**CNG**				1.2	2.4	Below limit

Notes: The red and blue thresholds are borrowed from Meyer et al., *Reassessment of Excess NO_X*.

[a] Compared with petrol limits because no CNG limits are defined.

Table 5. Summary of real-world HC emissions number of times more than type-approval limits, with average emissions greater than or equal to 2.1 times the limit shown in blue and average emissions greater than or equal to 4.0 times the limit shown in red

HC	Fuel	Class	BS I	BS II	BS III	BS IV	BS VI
2W	**Petrol**				NA	NA	1.6 times
3W	**CNG**				NA	NA	NA
PC	**CNG**	0		NA	2.1[a]	2.7[a]	
		All					Below limit
	Diesel	0		NA	NA	NA	
		III			NA	NA	
		All					NA
	Petrol	0		NA	1.6	1.5	
		All	NA				Below limit
Taxi	**CNG**	0			2.4[a]	3.8[a]	
		All					Below limit
	Diesel	0				NA	
		All					NA
	Petrol	0				9.8	
		All					2.9
LGV	**CNG**	I				5.6	2.0
		II				5.2	4.0
		III					
Bus	**CNG**				1.4	4.3	Below limit

Notes: NA represents that fleet has been captured but no TA limits are defined. The red and blue thresholds are borrowed from Meyer et al., *Reassessment of Excess NO_x*.

[a] Compared with petrol limits because no CNG limits are defined.

Table 6. Summary of real-world HC+NO_x emissions number of times more than type-approval limits, with average emissions greater than or equal to 2.1 times the limit shown in blue and average emissions greater than or equal to 4.0 times the limit shown in red

HC+NO_x	Fuel	Class	BS I	BS II	BS III	BS IV	BS VI
PC	**CNG**	0		2.6[a]	NA	NA	NA
	Diesel	0		1.5	2.0	3.5	
		III			1.8	3.0	
		All					1.4
	Petrol	0		1.2	NA	NA	
		All	Below limit				NA
Taxi	**CNG**	0			NA	NA	
		All					NA
	Diesel	0				3.7	
		All					1.1
	Petrol	0				NA	
		All					NA
2W	**Petrol**				Below limit	Below limit	NA
3W	**CNG**				1.7	1.3	1.2

Notes: NA represents that fleet has been captured but no TA limits are defined. The red and blue thresholds are borrowed from Meyer et al., *Reassessment of Excess NO_X.*

[a] Compared with petrol limits because no CNG limits are defined.

DEVELOPMENT OF REMOTE SENSING EMISSION LIMITS FOR INDIAN VEHICLES

Remote sensing measurements of petrol and CNG vehicles, which use a spark-ignition (SI) engine, can be compared against tailpipe concentration limits gathered during the PUCC inspection test, as currently proposed in AIS 170, but this comparison is not possible for diesel vehicles. Instead, remote sensing data from all internal combustion engine technologies could be used to develop pollutant thresholds in terms of fuel-specific emissions (g/kg) or distance-specific emissions (g/km) for LDVs and energy-specific emissions for heavy-duty vehicles (g/kWh).[56] Furthermore, the distance-specific emission factors (g/km) derived from g/kg could also allow direct comparison with India's existing type-approval limits.

The proposed monitoring phase in the draft AIS 170 would ideally cover all internal combustion engine vehicle types, emission standards (including pre-BS IV), and fuel types. This will require multiple pilots at different geographies within India, as the experience from this current study reveals all vehicle types with all varieties of emission standards and fuel types are not likely to be available in every region because of movement restrictions and because fleet mixes vary across regions. The 95th percentile values for such sub-groupings could be used to identify the top-emitting 5%, whether in g/kg or g/km. These values for the captured fleet in this study, listed as reference in Appendix F, could be a starting point.

SUMMARY AND IMPLICATIONS FOR POLICY

Gaining insights into a city's real-world vehicle emissions can uncover important patterns that can guide development of targeted and effective policies to combat traffic-related pollution. The findings above show that India's strategy of leapfrogging from BS IV to BS VI emission standards had distinctly positive effects. At the same time, the data highlights that there are still substantial emissions from commercial vehicles, and they surpass those of private vehicles. Furthermore, we found high emissions associated with CNG vehicles, particularly high NO_X emissions; this aligns with findings from other studies in Europe and Abu Dhabi and challenges the thinking that CNG is a "clean" fuel option. Our real-world emissions analysis supports the following takeaways and policy suggestions:

The findings show that the average emissions from commercial vehicles are much higher than private vehicles. In the four-wheeler segment, where direct comparison with private cars was possible, the LGV segment was found to be the worst performing vehicle type, followed by commercial taxis. That these findings are also true for vehicles certified to BS VI standards highlights the potential of an **accelerated shift to zero-emission vehicles (ZEVs) in commercial vehicle segments in the NCR**. This could be done through measures like implementing a ZEV sales mandate and establishing low-emission zones to complement existing policies. The CAQM is best placed to roll out a ZEV sales mandate in the NCR, and other agencies such as DPCC and the Departments of Transport and Environment could enable such policies in Delhi.[57] In addition, developing a phaseout program for grossly emitting vehicle segments could also be considered.

CNG vehicles were found to have high emissions, particularly for NO_X, a pollutant that contributes to the formation of secondary PM and ozone. As shown in Appendix E, the top five highest NO_X emitting segments in both the test cities are CNG vehicles. Note, also, that the high HC emissions from CNG vehicles could be methane slip, and methane has significant climate impact due to its high global warming potential. **Considering CNG vehicles as a viable alternative or transitional step to ZEVs, especially in regions suffering from poor air quality like Delhi and Gurugram, may not be the right approach**. Consider restricting the retrofitting of vehicles to CNG and allowing only retrofitting to EVs within the NCR.

Even for BS VI vehicles, real-world emissions are multiple times higher than the type-approval limits, particularly for NO_X. To effectively reduce emissions from combustion engine vehicles, a phased regulatory strategy at the national level is advised. **Initially, introducing updated BS VI phases akin to the Euro 6/VI-e/E standards in Europe**

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[56] Setting thresholds for remote-sensing emissions measurements in terms of fuel-specific emission factors instead of concentration limits is more appropriate since the assumption in deriving tailpipe concentration using remote sensing is that all oxygen has been used to burn the fuel; consequently, there is no oxygen left in the exhaust and the CO_2 concentration is approximatively 15%. This condition is generally valid for spark-ignition engines (e.g., petrol), but not at all for compression-ignition engines (diesel). *See*: Yang, Bernard, and Dallmann, *Technical Considerations for Choosing a Metric*.

[57] Sunitha Anup and Shikha Rokadiya, *Developing a Mandate Mechanism for the Adoption of Electric Two-Wheelers in the State of Delhi, India* (International Council on Clean Transportation, 2024), https://theicct.org/wp-content/uploads/2024/03/ID-115-%E2%80%93-ZEV-mandate-Delhi_fact-sheet_final.pdf.

can reduce the gap between real-world emissions and type-approval limits. This can be achieved by measures such as lowering the conformity factors that set the on-road limits and widening the testing conditions, and implementation is feasible within 1-2 years. **Subsequently, a longer-term objective would be to advance to BS VII standards**, which would entail stricter type-approval limits and the incorporation of on-board emissions monitoring; this is potentially achievable by 2028.

While the AIS 170 document is being finalized and published, concurrent plans could be made for remote sensing pilots for monitoring. The document will be crucial for the multiple agencies interested in deploying this technology within their jurisdictions, as it will set the required technical parameters for remote sensing devices and provide a legal standing for agencies to take action on high-emitting vehicles identified by remote sensing. Similar to the European Commission's regulation, MoRTH could also look at including remote sensing for priority selection of high-emitting vehicles for ISC tests and market surveillance.

The currently proposed tailpipe concentration limits for remote sensing, which are only mandatory for HC and CO, will not cover fuel types such diesel or key transport pollutants like NO_X and PM. The draft AIS 170 proposed initial remote sensing pilots, and the data from these, will aid in development of remote sensing thresholds.

Additionally, defining pollutants in terms of **g/kg_{CO2} or g/kg_{fuel} or g/km would be preferrable for defining real-world vehicular emissions thresholds** as that would not only ensure coverage of all fuel types, but the g/km metric also allows for direct comparison with India's existing type-approval limits.

Remote sensing could be used in the short term to complement the PUCC inspection procedure. For example, the highest emitting vehicles measured on-road (those over the 95th percentile emissions thresholds shown in Appendix F) could be subject to a PUCC retest. Due to the limitations of the PUCC procedure, such as the low-engine-load idle testing and the absence of NO_X measurements, **infrastructure to retest the high-emitters identified by remote sensing over a broader range of conditions, such as a short chassis dynamometer test, could be established in the long term**.

Multiple funding sources could be leveraged to deploy remote sensing pilots to test the use of different technologies such as cross-road systems, overhead systems, and plume chasers. These sources include unutilized National Clean Air Programme funds by Delhi and other NCR cities, the 15th Finance Air Quality Performance Grant, and unused "green funds" from CPCB or Delhi's Air Ambience Fund. The same funds could also be used to set up chassis dynamometer facilities for more in-depth investigation of identified high emitters.

APPENDIX A. SUGGESTIONS FOR THE DRAFT AIS 170

Once a vehicle is identified as a high-emitter with remote sensing, there could be provisions for a certain rectification or repair period. In the short term, high-emitting vehicles identified by remote sensing can be subjected to PUCC retesting, as mentioned in the draft AIS 170. However, after the provision period for rectification, light-duty vehicles could alternatively be subjected to chassis dynamometer emissions testing using a short-duration cycle like the IM240 used in the United States or the TÜV cycle used in Hong Kong. The shift from PUCC retesting to chassis dynamometer testing would allow for more in-depth and accurate investigation before the identified high emitters are penalized or taken off the roads. Heavy-duty vehicles are different and could be subjected to a loaded chassis dynamometer test similar to the DT80 test in Australia.[58] In cases where vehicles fail the chassis dynamometer test, a provision for subsequent deregistration could be in place. This is especially important in highly polluted cities like Delhi and Gurugram.

Measurement of CO_2 absorption is optional in the current draft AIS 170 but needs to be made mandatory because remote sensing devices measure pollutant-to-CO_2 ratios. It is not possible to calculate the emissions without this information. In addition, other key transport pollutants like NO, NO_2, and PM need to be captured for research and monitoring purposes.

Recording pollutants in terms of measured values, that is, moles of pollutant per moles of CO_2, would allow the conversion into any preferable unit like ppm, g/kg, or g/km, based on the fuel type of the vehicle. The proposed threshold metric of ppm will work only for SI engines. As detailed earlier, either g/kg or g/km is preferable for defining thresholds for every fuel type. If g/km is chosen as the threshold metric, the information on the gross vehicle weight and empty weight (for cars and LGVs), engine displacement (for two-wheelers, 2Ws) and the type-approval CO_2 could also be made available to the relevant reporting or testing agency.

To finalize the draft document, a task force could be created that includes providers of remote sensing devices to help define the minimum technical specifications.

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[58] Francisco Posada, Zifei Yang, and Rachel Muncrief, *Review of Current Practices and New Developments in Heavy-Duty Vehicle Inspection and Maintenance Programs* (International Council on Clean Transportation, 2015), https://theicct.org/publication/review-of-current-practices-and-new-developments-in-heavy-duty-vehicle-inspection-and-maintenance-programs/.

APPENDIX B. FLEET COMPOSITION BY STATE

Figure B1 shows the data on captured vehicle fleets from different states. In terms of Bharat Stage (BS) standards, Delhi (DL) and Haryana (HR) appear to have relatively newer fleets, whereas the captured fleet registered in Uttar Pradesh (UP) has a higher share (about 26%) of pre-BS IV vehicles.

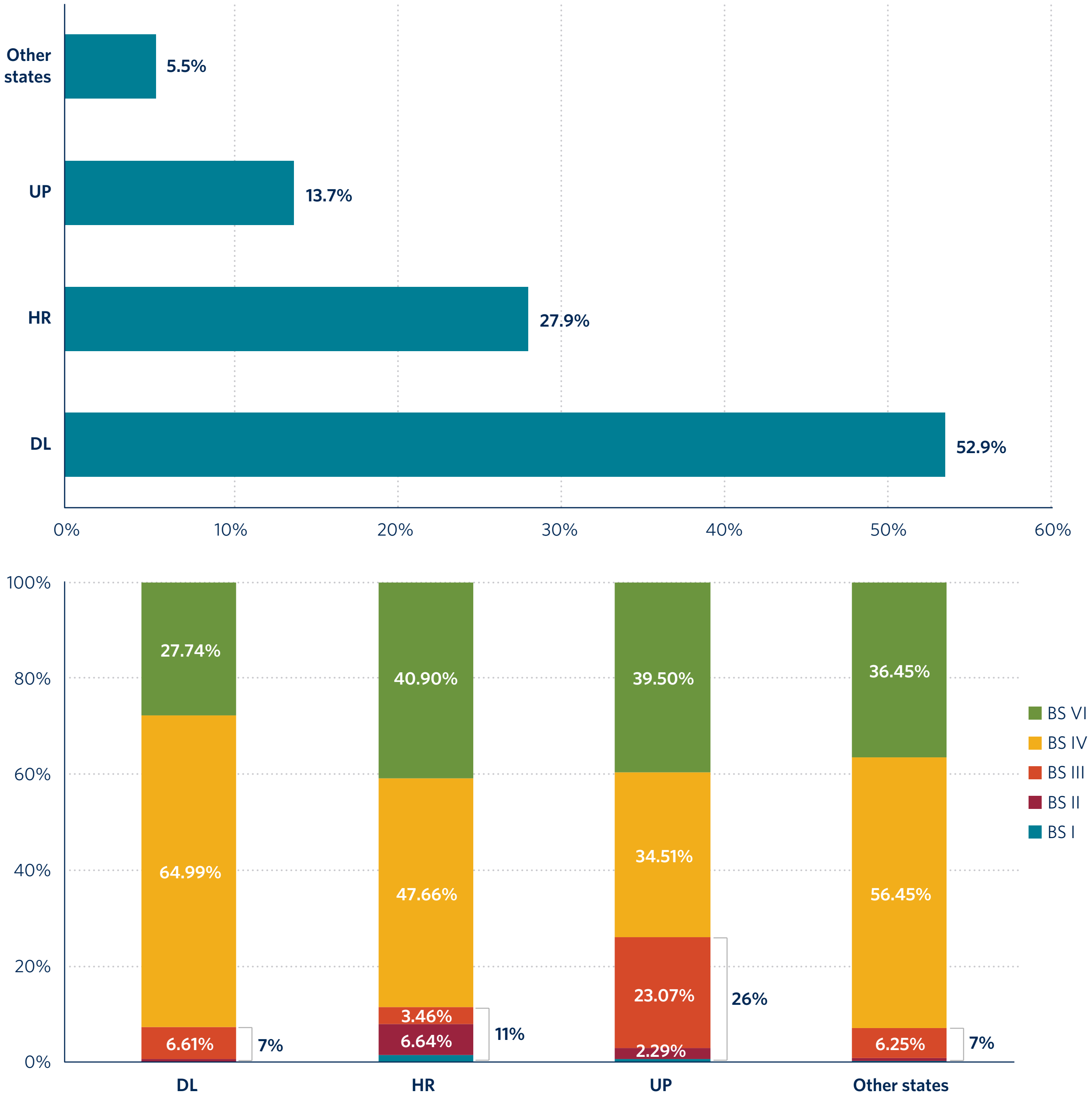

Figure B1. Share of measured vehicles and breakdown of emission standards by state

APPENDIX C. FUEL-SPECIFIC EMISSIONS (G/KG) BY VEHICLE TYPE

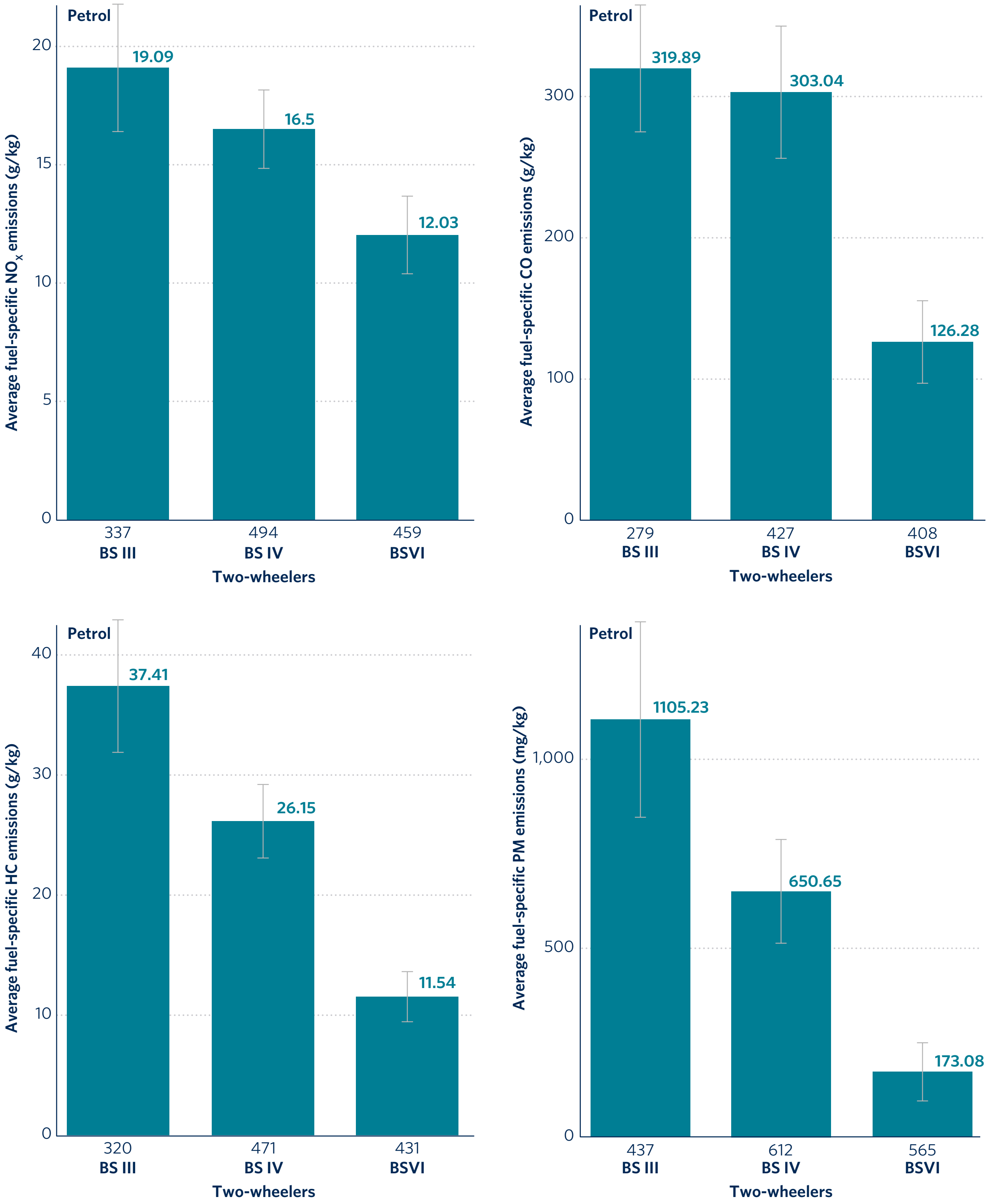

Figure C1. Two-wheeler fleet's average fuel-specific emissions

Notes: The number of measurements is presented at the bottom of each bar. Whiskers represent the 95% confidence interval of the mean.

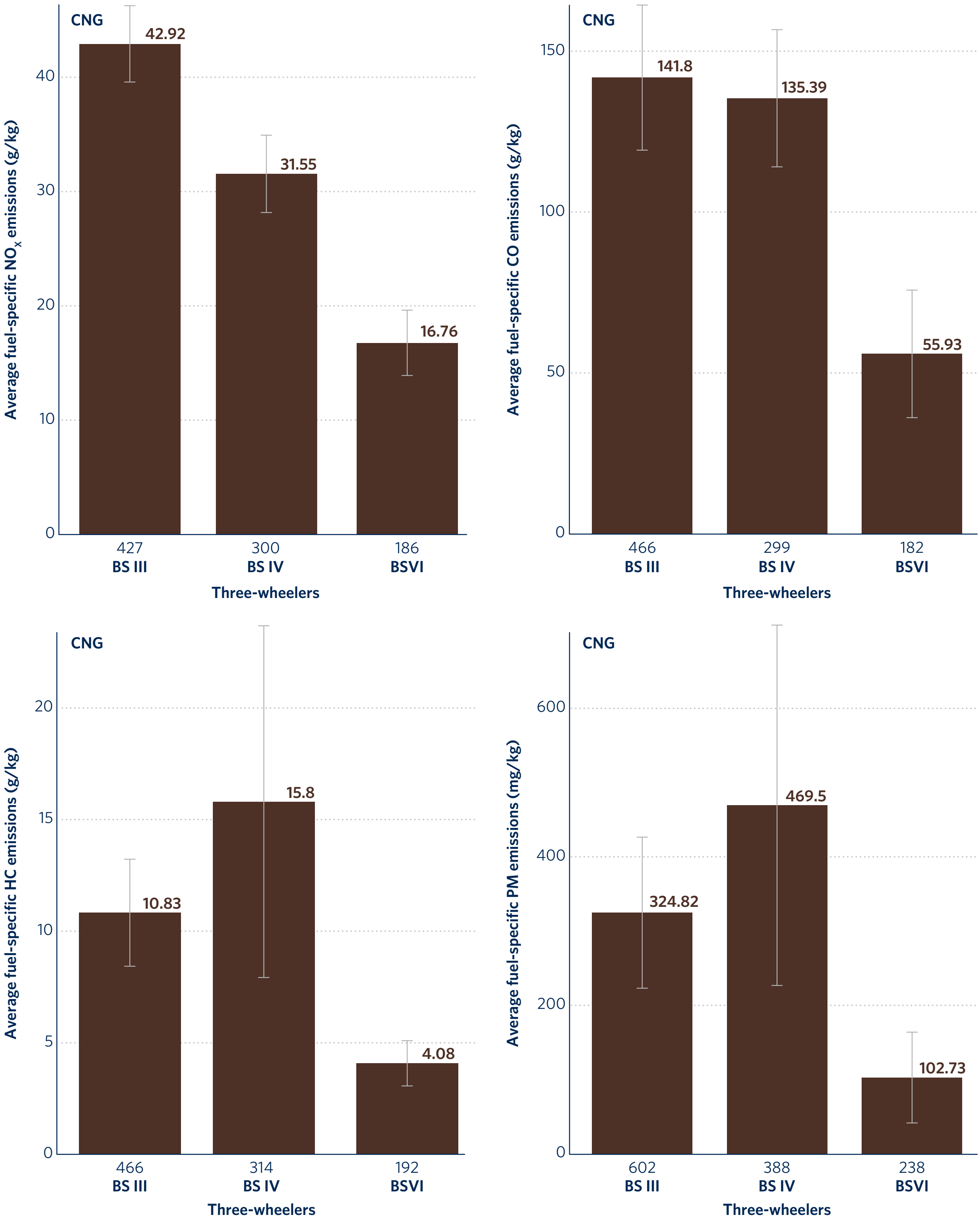

Figure C2. Three-wheeler fleet's average fuel-specific emissions

Notes: The number of measurements is presented at the bottom of each bar. Whiskers represent the 95% confidence interval of the mean.

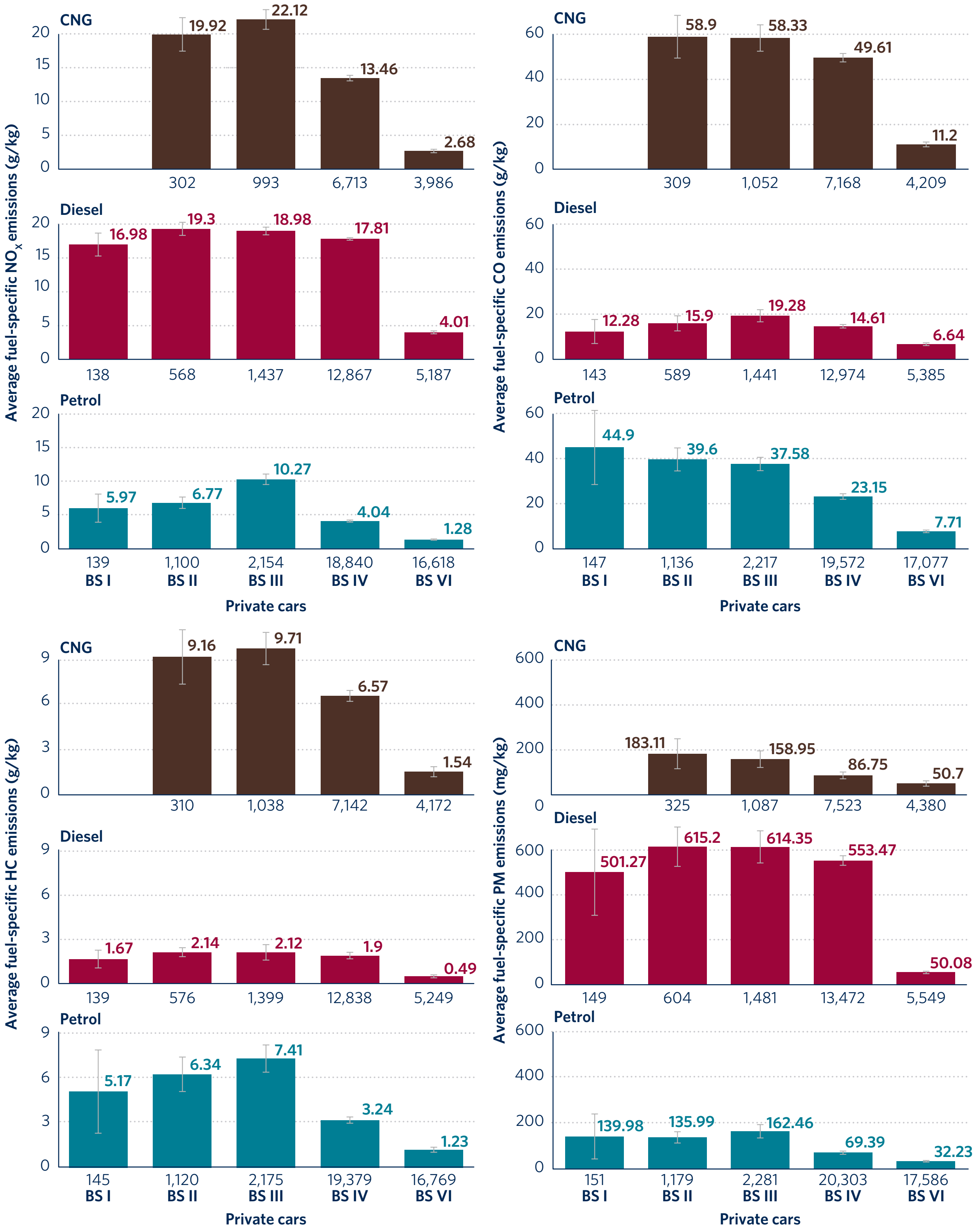

Figure C3. Private car fleet's average fuel-specific emissions

Notes: The number of measurements is presented at the bottom of each bar. Whiskers represent the 95% confidence interval of the mean.

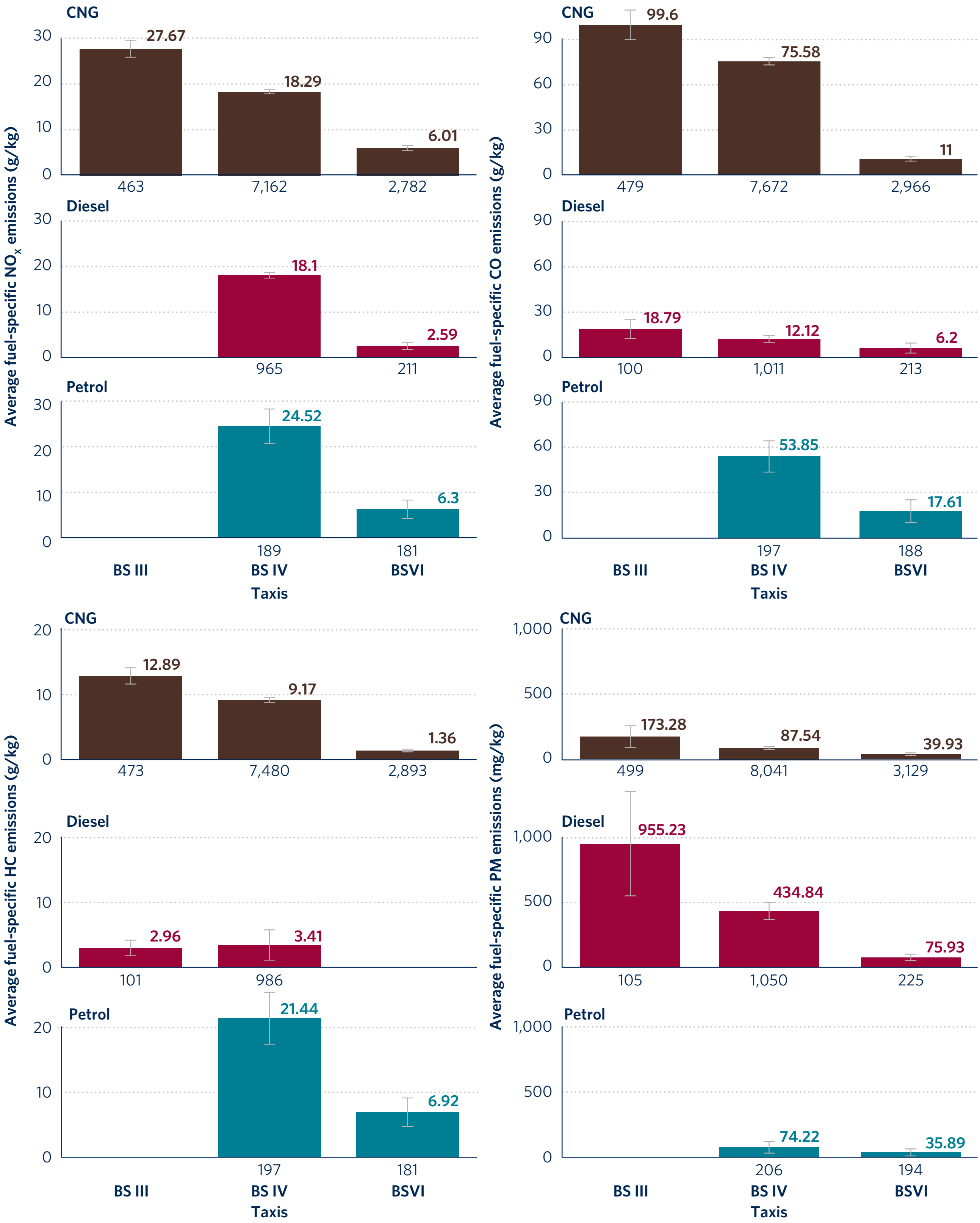

Figure C4. Taxi fleet's average fuel-specific emissions

Notes: The number of measurements is presented at the bottom of each bar. Whiskers represent the 95% confidence interval of the mean.

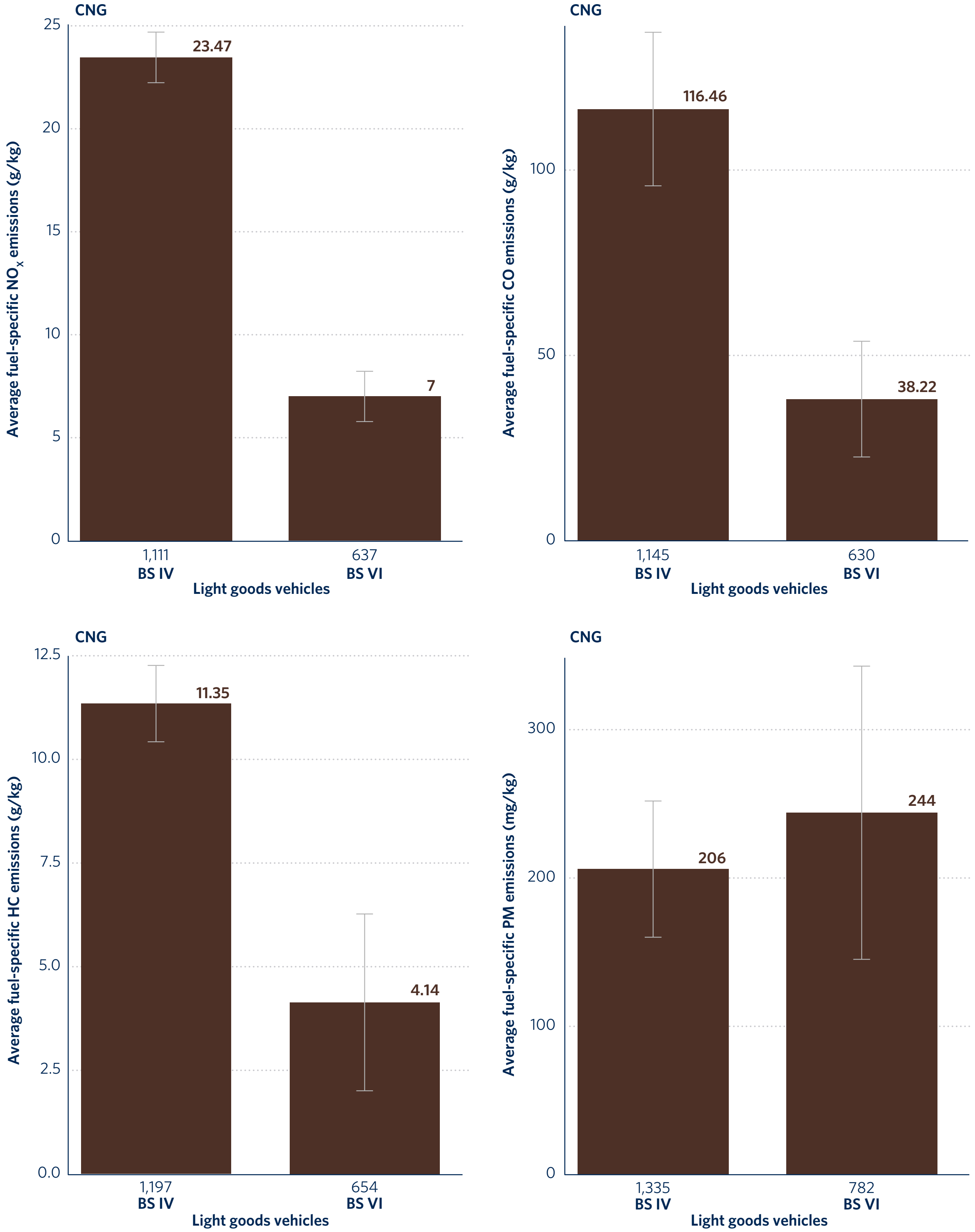

Figure C5. Light goods vehicle fleet's average fuel-specific emissions

Notes: The number of measurements is presented at the bottom of each bar. Whiskers represent the 95% confidence interval of the mean

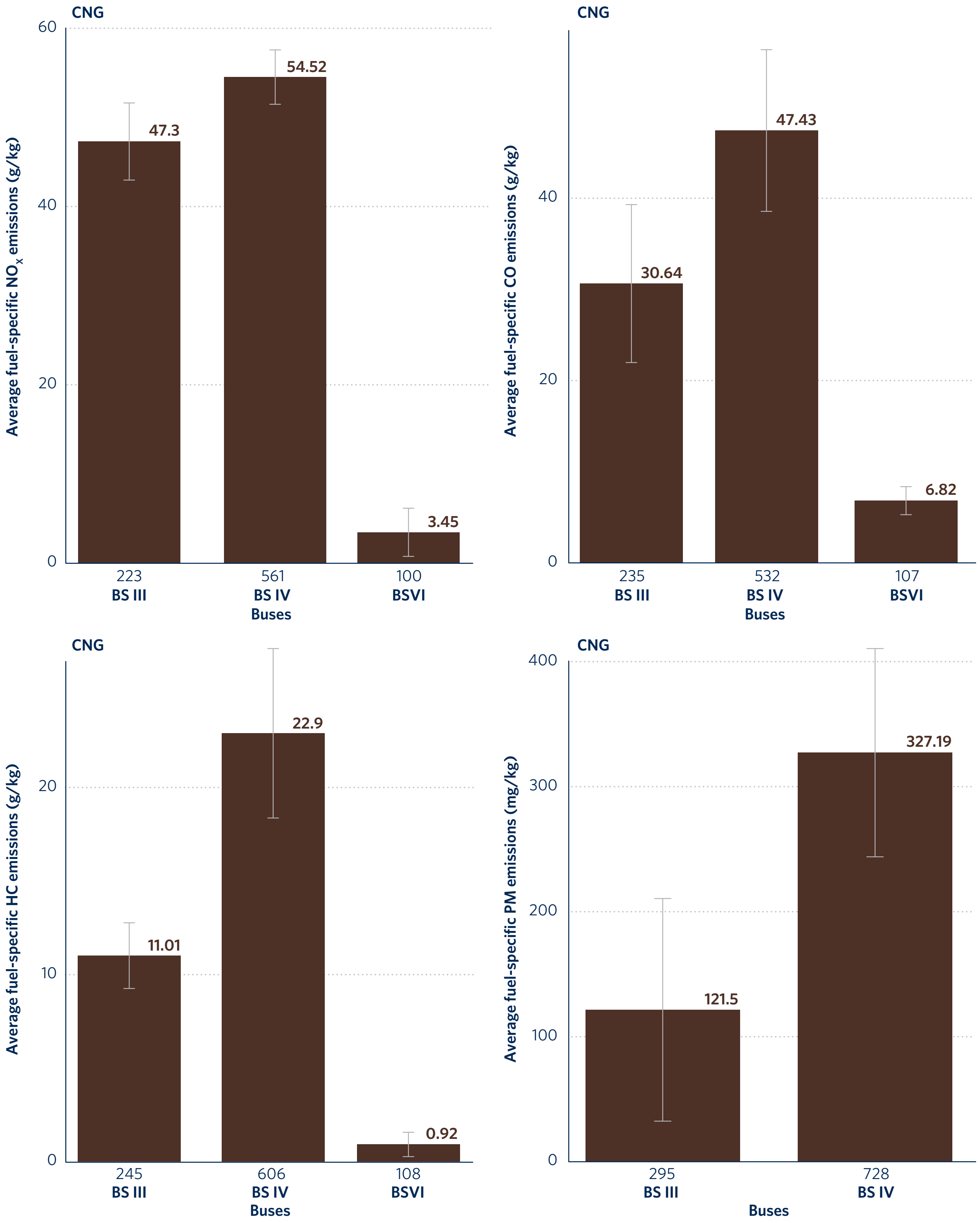

Figure C6. Bus fleet's average fuel-specific emissions

Notes: The number of measurements is presented at the bottom of each bar. Whiskers represent the 95% confidence interval of the mean.

APPENDIX D. EMISSIONS PERFORMANCE WITH PROGRESSION IN EMISSION STANDARDS

Table D1. Emissions performance (g/km) in the captured private car fleet with progression in emission standards

Average real-world emissions	Fuel type	BS I fleet to BS II fleet	BS II fleet to BS III fleet*	BS III fleet to BS IV fleet*	BS IV fleet to BS VI fleet*
Change in NO_x	**Petrol**	+14.8%	+62.2%	-61.1%	-69.3%
	CNG	—	+8.5%	-45.2%	-78.1%
	Diesel	—	+10.9%	-7.8%	-77.1%
Change in CO	**Petrol**	-22.5%	+8.5%	-38.8%	-67%
	CNG	—	+5.9%	-26.5%	-75%
	Diesel	—	+38.6%	-25.3%	-49.1%
Change in HC	**Petrol**	+20.8%	+25.2%	-58.1%	-60.5%
	CNG	—	+5.1%	-38.5%	-74.2%
	Diesel	—	-4.1%	+0.6%	-71.7%
Change in HC+NO_x	**Petrol**	+36.4%	+40.6%	-61.1%	-66.5%
	CNG	—	+5.3%	-42.8%	-78.5%
	Diesel	—	+8.6%	-7.2%	-78.9%
Change in PM	**Petrol**	-10.4%	+33.6%	-59.2%	-50.9%
	CNG	—	-10.0%	-52.5%	-36.3%
	Diesel	—	+4.0%	-10.0%	-89.0%

*Weighted averages considered, including the NAs (Figure 7), wherever applicable.

Table D2. Emissions performance (g/km) in the captured taxi fleet with progression in emission standards

Average real-world emissions	Fuel type	BS III fleet to BS IV fleet	BS IV fleet to BS VI fleet*
Change in NO_x	**Petrol**	—	-73.9%
	CNG	-28.1%	-68.2%
	Diesel	—	-79.8%
Change in CO	**Petrol**	—	-68.3%
	CNG	-16.2%	-86.5%
	Diesel	—	-19.7%
Change in HC	**Petrol**	—	-70.4%
	CNG	-20.1%	-87%
	Diesel	—	—[a]
Change in HC+NO_x	**Petrol**	—	-73.2%
	CNG	-26.5%	-75.7%
	Diesel	—	-83.8%
Change in PM	**Petrol**	—	-35.6%
	CNG	-37.0%	-55.0%
	Diesel	—	-71.8%

* Weighted averages considered, including the NAs ((Figure 9), when applicable.

[a] The diesel BS VI taxi fleet had average HC real-world emissions below detection levels.

Table D3. Emissions performance (g/km) in the captured light goods vehicle fleet with progression in emission standards

Average real-world emissions	Fuel type	BS IV fleet to BS VI fleet*
Change in NO_x	CNG	-66.8%
Change in CO	CNG	-68.9%
Change in HC	CNG	-55.4%
Change in PM	CNG	+10.1%

*Weighted averages considered, including the NAs (Figure 10), wherever applicable.

Table D4. Emissions performance (g/km) in the captured two-wheeler fleet with progression in emission standards

Average real-world emissions	Fuel type	BS III fleet to BS IV fleet	BS IV fleet to BS VI fleet
Change in NO_x	Petrol	-25%	-19%
Change in CO	Petrol	-9.9%	-56.7%
Change in HC	Petrol	-32.7%	-54.3%
Change in $HC+NO_x$	Petrol	-32.5%	-40.7%
Change in PM	Petrol	-49.4%	-68.2%

Table D5. Emissions performance (g/km) in the captured three-wheeler fleet with progression in emission standards

Average real-world emissions	Fuel type	BS III fleet to BS IV fleet	BS IV fleet to BS VI fleet
Change in NO_x	CNG	-45.6%	-52.3%
Change in CO	CNG	-27.9%	-62.7%
Change in $HC+NO_x$	CNG	-40.7%	-58.1%
Change in PM	CNG	+3.1%	-80.3%

Table D6. Emissions performance (g/kWh) in the captured bus fleet with progression in emission standards

Average real-world emissions	Fuel type	BS III fleet to BS IV fleet	BS IV fleet to BS VI fleet
Change in NO_x	CNG	+15.3%	-93.7%
Change in CO	CNG	+54.8%	-85.6%
Change in HC	CNG	+107.5%	-96.0%
Change in PM	CNG	+169.3%	—[a]

[a] PM levels in BS VI fleet below detection levels, indicating a very significant reduction as compared with the BS IV fleet.

APPENDIX E. TOP POLLUTING SEGMENTS

While individual vehicle segments contribute differently to the emissions load, the top six highest emitting vehicle groups by type, fuel, and emissions standard are summarized in Table E1 for the different pollutants. The captured fleet sample size is different for each sub-group, but a minimum sample of 100 is ensured for the comparison.

Table E1. Top six emitting vehicle segments by pollutant per distance driven, according to remote sensing data

NO_x emissions (g/km)	1. BS IV CNG buses 2. BS III CNG buses 3. BS IV CNG light goods vehicles (Class III) 4. BS IV CNG light goods vehicles (Class II) 5. BS III CNG three-wheelers 6. BS III diesel private cars (Class III) *Within BS VI fleet, it is CNG light goods vehicles (Class II)*
CO emissions (g/km)	1. BS IV CNG buses 2. BS IV CNG light goods vehicles (Class NA) 3. BS IV CNG light goods vehicles (Class I) 4. BS IV CNG light goods vehicles (Class II) 5. BS III CNG three-wheelers 6. BS III petrol two-wheelers *Within BS VI fleet, it is CNG light goods vehicles (Class II)*
HC emissions (g/km)	1. BS IV CNG buses 2. BS III CNG buses 3. BS IV petrol taxis (Class 0) 4. BS IV CNG light goods vehicles (Class NA) 5. BS III petrol private cars (Class NA) 6. BS III petrol taxis (Class NA) *Within BS VI fleet, it is CNG light goods vehicles (Class II)*
PM emissions (mg/km)	1. BS IV CNG buses 2. BS IV diesel private cars (Class NA) 3. BS III diesel private cars (Class 0) 4. BS II diesel private cars (Class 0) 5. BS III diesel private cars (Class III) 6. BS IV diesel private cars (Class 0) *Within BS VI fleet, it is CNG light goods vehicles (Class II)*

APPENDIX F. 95TH PERCENTILE VALUES OF FLEET EMISSIONS

Table F1. 95th percentile NO_x values for the captured fleet

Vehicle type	Fuel type	BS	95th percentile NO_x (g/km)	95th percentile NO_x (g/kg)
2W	**Petrol**	III	1.03	67.6
2W	**Petrol**	IV	0.801	50.4
2W	**Petrol**	VI	0.613	41.6
3W	**CNG**	III	3.99	114
3W	**CNG**	IV	2.45	89.6
3W	**CNG**	VI	1.46	59.2
Bus	**CNG**	III	13	108
Bus	**CNG**	IV	31.6	126
Bus	**CNG**	VI	5.25	37.6
LGV	**CNG**	IV	4.32	60.3
LGV	**CNG**	VI	2.26	29.7
PC	**CNG**	II	2.74	60.8
PC	**CNG**	III	3	66.6
PC	**CNG**	IV	1.94	47.1
PC	**CNG**	VI	0.561	12.5
PC	**Diesel**	I	2.35	33.2
PC	**Diesel**	II	2.29	38.1
PC	**Diesel**	III	2.32	36.9
PC	**Diesel**	IV	2.2	36.1
PC	**Diesel**	VI	0.94	17.4
PC	**Petrol**	I	1.73	40
PC	**Petrol**	II	2.01	41.5
PC	**Petrol**	III	2.6	53.1
PC	**Petrol**	IV	1.18	24.8
PC	**Petrol**	VI	0.342	7.06
Taxi	**CNG**	III	2.28	61
Taxi	**CNG**	IV	2.28	55.9
Taxi	**CNG**	VI	1.51	38
Taxi	**Diesel**	IV	2.22	35.5
Taxi	**Diesel**	VI	0.96	12.1
Taxi	**Petrol**	IV	3.5	75.8
Taxi	**Petrol**	VI	1.58	37.1

Vehicle type	Fuel type	BS	95th percentile NO_x (g/kWh)	95th percentile NO_x (g/kg)
Bus	**CNG**	III	22.1	108
Bus	**CNG**	IV	25.8	126
Bus	**CNG**	VI	7.71	37.6

Table F2. 95th percentile CO values for the captured fleet

Vehicle type	Fuel type	BS	95th percentile CO (g/km)	95th percentile CO (g/kg)
2W	Petrol	III	15.9	984
2W	Petrol	IV	12.8	936
2W	Petrol	VI	6.86	461
3W	CNG	III	18.9	562
3W	CNG	IV	13.6	498
3W	CNG	VI	3.93	160
Bus	CNG	III	14.8	136
Bus	CNG	IV	55.5	222
Bus	CNG	VI	2.68	18.7
LGV	CNG	IV	18.5	330
LGV	CNG	VI	10.4	149
PC	CNG	II	10.3	239
PC	CNG	III	11.8	264
PC	CNG	IV	8.17	205
PC	CNG	VI	1.71	39.3
PC	Diesel	I	2.87	63.7
PC	Diesel	II	3.95	75.1
PC	Diesel	III	5.18	102
PC	Diesel	IV	3.71	74.2
PC	Diesel	VI	1.16	19
PC	Petrol	I	9.28	168
PC	Petrol	II	7.77	156
PC	Petrol	III	7.72	154
PC	Petrol	IV	4.69	98.3
PC	Petrol	VI	1.23	25.9
Taxi	CNG	III	10.9	299
Taxi	CNG	IV	11.6	261
Taxi	CNG	VI	1.52	36.2
Taxi	Diesel	III	4.64	60.3
Taxi	Diesel	IV	2.19	43.7
Taxi	Diesel	VI	1.12	15.2
Taxi	Petrol	IV	9.56	207
Taxi	Petrol	VI	3.21	71

Vehicle type	Fuel type	BS	95th percentile CO (g/kWh)	95th percentile CO (g/kg)
Bus	CNG	III	27.8	136
Bus	CNG	IV	45.5	222
Bus	CNG	VI	3.84	18.7

Table F3 95th percentile HC values for the captured fleet

Vehicle type	Fuel type	BS	95th percentile HC (g/km)	95th percentile HC (g/kg)
2W	**Petrol**	III	1.75	127
2W	**Petrol**	IV	1.12	80.3
2W	**Petrol**	VI	0.792	59.5
3W	**CNG**	III	0.943	27
3W	**CNG**	IV	0.939	32.7
3W	**CNG**	VI	0.318	12.9
Bus	**CNG**	III	3.83	33.4
Bus	**CNG**	IV	17.5	71.4
Bus	**CNG**	VI	0.719	5.15
LGV	**CNG**	IV	1.96	34
LGV	**CNG**	VI	0.997	13.2
PC	**CNG**	II	1.47	34.9
PC	**CNG**	III	1.41	31.6
PC	**CNG**	IV	0.97	23.7
PC	**CNG**	VI	0.233	5.12
PC	**Diesel**	I	0.377	7.28
PC	**Diesel**	II	0.453	8.17
PC	**Diesel**	III	0.462	8.89
PC	**Diesel**	IV	0.418	7.63
PC	**Diesel**	VI	0.304	4.83
PC	**Petrol**	I	1.25	27.2
PC	**Petrol**	II	1.24	26.6
PC	**Petrol**	III	1.67	33.5
PC	**Petrol**	IV	0.813	17.4
PC	**Petrol**	VI	0.314	6.48
Taxi	**CNG**	III	1.45	37.6
Taxi	**CNG**	IV	1.27	29.7
Taxi	**CNG**	VI	0.209	5.26
Taxi	**Diesel**	III	0.714	11.4
Taxi	**Diesel**	IV	0.448	7.91
Taxi	**Diesel**	VI	0.283	3.5
Taxi	**Petrol**	IV	2.96	68.5
Taxi	**Petrol**	VI	1.58	37.9

Vehicle type	Fuel type	BS	95th percentile HC (g/kWh)	95th percentile HC (g/kg)
Bus	**CNG**	III	6.85	33.4
Bus	**CNG**	IV	14.6	71.4
Bus	**CNG**	VI	1.06	5.15

Table F4. 95th percentile PM values for the captured fleet

Vehicle type	Fuel type	BS	95th percentile PM (mg/km)	95th percentile PM (mg/kg)
2W	PETROL	III	64.07	4,347.41
2W	PETROL	IV	39.18	3,002.13
2W	PETROL	VI	18.55	1,184.98
3W	CNG	III	65.23	1,820.44
3W	CNG	IV	51.77	1,893.16
3W	CNG	VI	19.4	788.25
Bus	CNG	III	144.54	1,178.85
Bus	CNG	IV	512.91	2,029.67
Bus	CNG	VI	53.31	406.31
LGV	CNG	IV	67.89	1,104.21
LGV	CNG	VI	93.01	1,361.8
PC	CNG	II	31.46	704.15
PC	CNG	III	38.23	834.37
PC	CNG	IV	21.28	525.13
PC	CNG	VI	16.58	374.32
PC	DIESEL	I	77.09	1,509.98
PC	DIESEL	II	109.96	2,216.21
PC	DIESEL	III	117.11	2,196.81
PC	DIESEL	IV	101.44	1,964.04
PC	DIESEL	VI	18.27	307.49
PC	PETROL	I	57.34	974.84
PC	PETROL	II	40.77	872.43
PC	PETROL	III	45.98	1,003.6
PC	PETROL	IV	22.03	456.49
PC	PETROL	VI	13.33	270.71
Taxi	CNG	III	28.19	705.52
Taxi	CNG	IV	21.97	514.33
Taxi	CNG	VI	15.11	375.37
Taxi	DIESEL	III	300.36	4,798.66
Taxi	DIESEL	IV	72.6	1,409.92
Taxi	DIESEL	VI	35.55	425.52
Taxi	PETROL	IV	29.35	671.45
Taxi	PETROL	VI	13.27	297.14

Vehicle type	Fuel type	BS	95th percentile PM (mg/kWh)	95th percentile PM (mg/kg)
Bus	CNG	III	241.66	1178.85
Bus	CNG	IV	416.08	2029.67
Bus	CNG	VI	83.29	406.31

APPENDIX G. DISTANCE-SPECIFIC EMISSIONS (G/KM) BY VEHICLE TYPE AND AGE GROUP

The age of each vehicle considered is the amount of time between the registration date and the date of emissions measurement in this study. These are in groups of 0-3 years, 3–6 years, 6–10 years, and 10–15 years for the figure below.

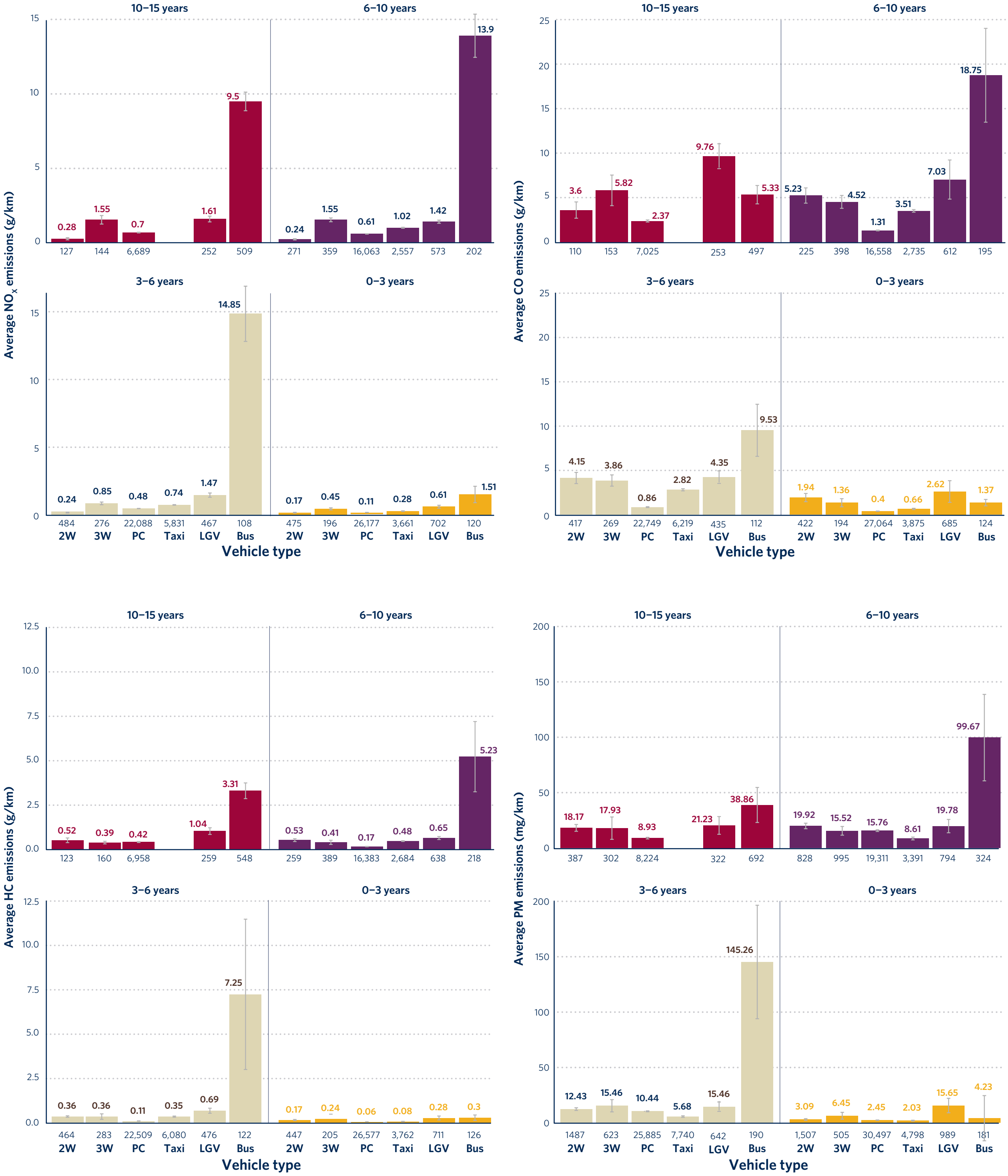

Figure G1. Fleet-average real-world tailpipe emissions by vehicle type and age group for NO_X, CO, HC, and PM

Note: The number of measurements is presented at the bottom of each bar and the whiskers represent the 95% confidence interval of the mean.

APPENDIX H. FOUR-WHEELER CLASSES FOR TYPE-APPROVAL EMISSIONS TESTING IN INDIA

For ease of representation, the segment with gross vehicle weight (GVW) ≤ 2,500 kg is termed as Class 0 and the segments where there is no division (for defining type-approval limits) based on weight is termed as 'All'.

Table H1. Four-wheeler classes for type-approval emissions testing, based on GVW and reference mass (RM)

	BS I	BS II	BS III and BS IV	BS VI
Cars (petrol, CNG)	All	Class 0: GVW ≤ 2,500 kg Class I: GVW > 2,500 kg and RM ≤ 1,250 kg Class II: GVW > 2,500 kg and 1,250 kg < RM ≤ 1,700 kg Class III: GVW > 2,500 kg and 1,700 kg < RM	Class 0: GVW ≤ 2,500 kg Class I: GVW > 2,500 kg and RM ≤ 1,305 kg Class II: GVW > 2,500 kg and 1,305 kg < RM ≤ 1,760 kg Class III: GVW > 2,500 kg and 1,760 kg < RM	All
Cars (diesel)	Class I: RM ≤ 1,250 kg Class II: 1,250 kg < RM ≤ 1,700 kg Class III: RM > 1,700 kg			
LGVs (petrol, CNG, and diesel)				Class I: RM ≤ 1,305 kg Class II: 1,305 kg < RM ≤ 1,760 kg Class III: 1,760 kg < RM

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