THE REAL URBAN EMISSIONS INITIATIVE

Measurement of real-world motor vehicle emissions in Jakarta

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NOVEMBER 2022

ACKNOWLEDGMENTS

The authors* thank Badan Pengatur Jalan Tol/BPJT (Indonesian Toll Road Authority), The Government of DKI Jakarta, KORLANTAS POLRI (Indonesian Traffic Police), TransJakarta Bus Rapid Transit, Institute Technology of Bandung (ITB), and Environmental Technology Consultants (ETC) Hong Kong for their support of the project. The authors also thank internal and external reviewers of this report, including Kaylin Lee, Tenny Kristiana, Adhi Triatmojo, and Francisco Posada (ICCT). Their reviews do not imply any endorsement of the content of this report. Any errors are the authors' own.

This study was funded through the generous support of the Aspen Global Change Institute and ClimateWorks Foundation.

FIA Foundation and the International Council on Clean Transportation (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.

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EXECUTIVE SUMMARY

Motor vehicles contribute significantly to poor air quality in Jakarta, Indonesia, and this pollution has a negative impact on the health of its citizens. There is currently a lack of understanding of the real-world emissions of the Jakarta vehicle fleet and whether existing clean transportation regulations and policies are delivering the expected improvements in emissions performance. To provide insights into these questions, The Real Urban Emissions (TRUE) Initiative, in partnership with Bandung Institute of Technology (ITB) and supported by Badan Pengatur Jalan Tol (BPJT), carried out a first-of-its-kind vehicle emissions testing study in the Greater Jakarta Region to provide up-to-date information on emissions. Analysis of the data collected is intended to provide evidence and support for future actions to address the impacts of motor vehicles on air quality and health.

The study was carried out from January through April 2021. During this time, researchers from ITB used remote sensing technology to measure the tailpipe pollutant emissions of more than 93,000 individual in-use vehicles. The sampled fleet consisted primarily of passenger vehicles, but also included buses, heavy- and light-trucks, motorcycles, and taxis. Data were analyzed following methodologies developed in prior TRUE initiative studies to provide insights into the real-world emissions of the Jakarta fleet. The results of the analysis informs recommendations for policies and actions that could limit emissions from on-road vehicles in Jakarta and Indonesia.

The key findings of the study are:

- Vehicle types where diesel engines are more commonly used—buses, heavy-duty trucks, and light-duty trucks—had the highest median nitrogen oxides (NOx) emissions measured during the study. The median fuel-specific NOx emissions from heavy- and light-duty trucks were 13–14 times the emissions of private passenger vehicles and taxis, where gasoline engines are the most common power source. Less variation was observed in the median carbon monoxide (CO) and hydrocarbon (HC) emissions across vehicle types.
- The median NOx emissions of diesel passenger vehicles and light-duty trucks were 9 and 10 times, respectively, the emissions of comparable vehicles equipped with gasoline engines. For these same vehicle types, median CO and HC emissions were higher for gasoline vehicles compared to diesel vehicles, though the relative magnitude of these emissions differences were smaller than those observed for NOx emissions (1.5–2.5 times for CO emissions and 1.4–1.5 times for HC emissions).
- Natural gas buses showed much better NOx emission performance than diesel buses, with a median fuel-specific emission rate of 3 g/kg compared to 45.5 g/kg for diesel buses. Though the sample size for natural gas buses is relatively small, these findings indicate significant NOx emissions benefits relative to diesel buses. Median HC and CO emissions for natural gas and diesel buses were comparable.
- For gasoline passenger vehicles, the implementation of Euro 2 emission standards in 2007 led to significant reductions in tailpipe emissions. When expressed on a grams-per-kilometer basis, NOx, CO, and HC emissions of Euro 2 certified vehicles measured during this study were 94%, 77%, and 72% lower, respectively, than the emissions from pre-2007 model year vehicles. Further reductions of 58% for median NOx emissions and 49% for median CO emissions were observed for this vehicle group with the introduction of Euro 4 standards in 2018.
- Relative to gasoline models, the implementation of Euro 2 standards for diesel passenger vehicles resulted in more modest emissions decreases—45% for NOx, 25% for CO, and 18% for HC. Median NOx emissions from Euro 2 diesel passenger vehicles were 8–19 times the emissions of gasoline versions produced in the same year. The NOx emissions of Euro 2 diesel passenger vehicles are approximately 7 times higher than those from gasoline models certified to Euro 2 standards.
- The results indicate that only a modest improvement in diesel truck emissions was achieved in the past decade. For diesel heavy- and light-duty trucks certified to Euro2/II standards, the median NOx, CO, and HC emissions were 15%–24%, 18%–21%, and 23% lower, respectively, than those of pre-Euro 2/II vehicles. Although some improvement in median NOx emissions is observed with the introduction of Euro II standards, the magnitude of emissions remains quite high and well above the level that can be achieved with modern diesel exhaust aftertreatment systems.

The findings lead to the following policy recommendations:

- To address elevated NOx emissions from diesel vehicles and to continue to improve the real-world emissions performance across all vehicle types, we recommend that Indonesia develop a plan and timeline for the implementation of Euro 6/VI emission standards. This step will ensure that best-available emissions control technologies, such as diesel particulate filters and selective catalytic reduction systems, are made available for new vehicles and engines. Importantly, fuel quality standards will need to match this ambition and plans for making ultra-low sulfur fuels widely available should also be developed.
- Further development of Jakarta's low emission zone policy would benefit from setting restrictions for those vehicle groups with the highest demonstrated real-world emissions, including pre-Euro 2 gasoline passenger vehicles and all diesel passenger vehicles. If future expansions of Jakarta low emission zones do not restrict goods movement vehicles, as is the case now, we recommend that only Euro 6/VI or zero-emission light- and heavy-duty trucks be allowed into these zones.
- Recommended actions to support the improved emissions performance of buses operating in Jakarta include requiring fleet operators to purchase buses that meet Euro VI emissions standards, tightening inspection and maintenance requirements for these fleets, and accelerating the transition to zero-emission electric buses, especially for urban bus fleets.
- To fully benefit from existing vehicle emission testing programs, Jakarta should implement provisions to encourage greater participation from private vehicle owners. Furthermore, existing thresholds for identifying high-emitting vehicles should be reviewed regularly. Future remote sensing programs could be developed to supplement existing vehicle testing programs in order to more efficiently identify high-emitting vehicles.

TABLE OF CONTENTS

INTRODUCTION

The Government of Indonesia has acknowledged that economic growth has also brought negative impacts to the environment, particularly air pollutant emissions from the transport sector. Road transport in Indonesia dominates the mobility of people and goods, serving approximately 85% of passengers and 90% of freight transport needs.[1] The large number of vehicles, together with a lack of infrastructure, results in major traffic congestion, further contributing to high levels of air pollutant emissions, which have a significant negative effect on public health.[2]

In 2019, Jakarta ranked first as the city with the worst air quality in Southeast Asia[3] and, according to the 2021 World Air Quality Report issued by AQ Air, Jakarta ranks 12th among capital cities worldwide in terms of average annual $PM_{2.5}$ concentration (39.2 μg/m^3), a level that far exceeds the World Health Organization Air Quality Guideline value of 5 μg/m^3.[3, 4] A study conducted by Vital Strategies in 2019 found that vehicle exhaust is the highest major source of $PM_{2.5}$ pollution in both wet and dry seasons in Jakarta.[5]

Reducing emissions from road transport will be critical to achieving clean air goals in Jakarta and protecting the health of its citizens. Current national emission standards for new vehicles sold in Indonesia lag international best practices and it remains unclear if actions taken by the Government of Jakarta, such as mandatory vehicle emission testing programs, are effectively controlling emissions from the highest emitting vehicles in the fleet. A better understanding of the real-world emissions from vehicles currently operating in Jakarta is needed to assess the effectiveness of existing policies and to develop an evidence base to support further measures and actions to address the impacts of transport emissions on the environment and public health.

The Real Urban Emissions (TRUE) Initiative, a partnership of the International Council on Clean Transportation and the FIA Foundation, works to supply cities with information on the real-world emissions of their vehicle fleets to support evidence-based policymaking. TRUE applies innovative real-world vehicle emissions testing technologies to measure the actual on-road emissions of motor vehicles. These data are analyzed to produce an up-to-date picture of the emissions of a city's fleet and provide information to government officials to inform steps to reduce the negative impacts of vehicle emissions on air quality and public health. Since its inception in 2017, TRUE has conducted detailed emission testing studies in London, Paris, Brussels, Warsaw, and Mexico City and has supported additional cities with detailed real-world data analysis projects.

This report details the results of an extensive real-world vehicle emissions survey carried out by TRUE in Jakarta, Indonesia using remote sensing technology. The study was conducted from January to April 2021 in partnership with the Bandung Institute of Technology (ITB) and supported by the Indonesian Toll Road Authority, Badan Pengatur Jalan Tol (BPJT). Researchers measured the emissions of more than 93,000 vehicles at 20 locations throughout the Jakarta metropolitan area. To our knowledge, this represents the first application of remote sensing technology in Indonesia and is among the first such studies to take place in the region. In this report we document the data collection process, present analysis of the real-world emissions data set, and provide policy recommendations.

POLICY BACKGROUND

Tailpipe emission standards for new vehicles and engines. The responsible authority for establishing new vehicle emission standards in Indonesia is the Ministry of Environment and Forestry. Table 1 summarizes the evolution of emission standards for new vehicles and engines in Indonesia. In 2017, the Ministry introduced Euro 4/IV equivalent emission standards for both gasoline and diesel passenger vehicles and heavy-duty vehicles. All new gasoline passenger vehicles and light-duty vehicles sold in Indonesia have been required to

1 Kang Hang Leung, "Indonesia's Summary Transport Assessment," (Asian Development Bank, 2016), https://www.adb.org/publications/indonesia-summary-transport-assessment

2 Budi Haryanto, (2018). Climate Change and Urban Air Pollution Health Impacts in Indonesia, *Climate Change and Air Pollution*, (2017), https://doi.org/10.1007/978-3-319-61346-8_14

3 "Jakarta has most polluted air in Southeast Asia: Study," *The Jakarta Post*, March 8, 2019, https://www.thejakartapost.com/news/2019/03/08/jakarta-has-most-polluted-air-in-southeast-asia-study.html

4 IQAir, "2021 World Air Quality Report: Region & City $PM_{2.5}$ Ranking," (2021), https://www.google.com/url?sa=i&rct =j&q=&esrc=s &source=web&cd=&cad=rja&uact=8&ved= 0CAQQw7AJahcKEwiloou5w5P5AhUAAAAAHQAAAAAQAg&url= https%3A%2F%2Fwww.iqair.com%2F world-most-polluted-cities%2Fworld-air-quality-report-2021-en.pdf&psig=AOvVaw0sBlVjtPWwjNo0DaXfpJjf&ust=1658820470016765

5 Vital Strategies, "Main Sources of Air Pollution in Jakarta," (2019), https://www.vitalstrategies.org/resources/identifying-the-main-sources-of-air-pollution-in-jakarta-a-source-apportionment-study/

Table 1. Emission standards implementation in Indonesia

Emission standard	Adopted year	Vehicle category	Effective year for gasoline engine	Effective year for diesel engine
Euro 2/II	2003	Light-duty vehicles Heavy-duty vehicles	2007	2011
Euro 3	2013	Motorcycles	2015	
Euro 4/IV	2017	Light-duty vehicles Heavy-duty vehicles	2018	2022

comply with Euro 4 standards since September 2018.[6] Prior to this date, new vehicles were required to meet Euro 2-equivalent standards, which were adopted in 2003 and became fully effective in 2007. The planned implementation of Euro 4/IV standards for diesel vehicles was delayed by one year to April 2022 due to the COVID 19 pandemic. By comparison, Euro 4/IV standards were adopted in Europe in 2005 and replaced by Euro 5/V in 2009.[7] The current emission standards in Europe are Euro 6d/VI E, and Euro 7/VII is under development, with expected implementation in 2025.[8]

For motorcycles, the current emission standard is Euro 3, which has been in effect since 2013, although there are discussions regarding the adoption Euro 4 in the near future.[9]

Fuel quality standards. Although Euro 4/IV emission standards have been implemented in Indonesia, there are still challenges regarding the availability of low sulfur fuels. For example, 50 ppm sulfur diesel fuel, which is required to operate Euro IV vehicles, will only be widely available starting in 2026.[10] Indonesia permits the sale of low-quality fuels, largely due to the inability of aging refineries operated by the state-owned oil company, Pertamina, to produce high quality fuels compatible with more stringent emission standards. The highest grade of gasoline distributed by the Pertamina is the 50 ppm sulfur Pertamax Turbo and its highest grade of diesel is the 50 ppm Pertadex high quality, although the vast majority of fuels consumed would not support Euro 3/III gasoline vehicles.[11] There are risks associated with emissions control system malfunction and the potential for higher emissions if low sulfur fuels are not used with Euro 4/IV vehicles.

Local level policies in Jakarta. In addition to national emission standards for new vehicles and engines, the Government of Jakarta has implemented or announced a number of additional policies and measures aimed at controlling emissions from in-use vehicles operating in the city (Table 2). For example, the Government of Jakarta has set a maximum vehicle age limit for public transport vehicles of 10 years. Further, an age limit of 10 years for private vehicles has been introduced through Governor Instruction No 66/2019 on Air Quality Control, which will be fully effective in 2025.[12] However, it is not yet clear whether the age limit for private vehicles can be fully implemented due to a lack of alignment with national regulations (Act No 22/2009 on Traffic and Road Transport). This points to the need

6 The Ministry of Environment and Forestry, "Peraturan Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia Nomor P.20/MENLHK/SETJEN/KUM.1/3/2017 Tentang Baku Mutu Emisi Gas Buang Kendaraan Bermotor Tipe Baru Kategori M, Kategori N, dan Kategori O [Minister of Environment and Forestry Regulation Number P.20/MENLHK/SETJEN/KUM.1/3/2017 on emission limit for new vehicles for M category, N category, and O category]," (2017), https://ditppu.menlhk.go.id/portal/uploads/laporan/1593657998_Peraturan%20Menteri%20LHK%20Nomor%20P%2020%20Tentang%20Baku%20Mutu%20Emisi%20Gas%20Buang%20Kendaraan%20Bermotor%20Tipe%20Baru%20Kategori%20M%20Katagori%20N%20dan%20Katagori%20O.PDF

7 Lingzhi Jin, Caleb Braun, Joshua Miller, Claire Buysee, "Air Quality and Health Impacts of Heavy-Duty Vehicles in G20 Economies," (Washington, DC: ICCT 2021), https://theicct.org/wp-content/uploads/2021/12/g20-hdv-impacts-jul2021_0.pdf

8 Transport & Environment, "Euro 7," accessed October 19, 2022, https://www.transportenvironment.org/challenges/air-quality/the-euro-7/

9 Wawan Priyanto, "AISI Siap Berdiskusi Soal Penerapan Euro 4 Untuk Sepeda Motor [AISI – Association of Indonesia Motorcycle Industry is ready to discuss the implementation of Euro 4 for motorcycle]," *tempo.co*, June 19, 2020, https://otomotif.tempo.co/read/1355450/aisi-siap-berdiskusi-soal-penerapan-euro-4-untuk-sepeda-motor

10 The Ministry of Energy and Mineral Resources Indonesia, "*Keputusan Direktur Jendral Minyak dan Gas Bumi Nomor 146.K/10/DJM/2020 Tentang Standar dan Mutu (Spesifikasi) Bahan Bakar Minyak Jenis Solar Yang Dipasarkan Di Dalam Negeri* [Decree of the Director General of Oil and Gas number 146.K/10/DJM/2020 on standard and quality (specification) of diesel fuel for domestic distribution]," (2020), https ://migas.esdm.go.id/uploads/regulasi/regulasi-kkkl/2020/146.K-10-DJM-2020.pdf

11 Yihao Xie and Marietta Harjono, "The retail fuels market in Indonesia," (Washington, DC: ICCT, 2020), https://theicct.org/wp-content/uploads/2021/06/Retail-fuels-indonesia-oct2020.pdf

12 The Governor of Jakarta Special Region, "Instruksi Gubernur Daerah Khusus Ibukota Jakarta Nomor 66 Tahun 2019 tentang Pengendalian Kualitas Udara [Instruction of the Governor of Jakarta Special Capital Region number 66 year 2019 on air quality management]," (2019), https://jdih.jakarta.go.id/uploads/default/produkhukum/INGUB_NO._66_TAHUN_2019.pdf

Table 2. Jakarta's policies and regulations for air pollution and transport related emissions

Regulation	Responsible agency	Objective or target	Status implementation
Local government regulation No.2/2005	Environment Agency	Prevent, control, monitor and mitigate air pollution in DKI Jakarta	Since its enactment in 2005, the regulation has provided the legal basis for Jakarta to establish ambient air quality standards and other measures to control air pollution, including monitoring of vehicle emissions. The Environmental Management Act (EMA) No. 22/2021, implemented in 2021, sets ambient air quality standards for all regions in Indonesia, but still allows the provincial government to determine their own air pollution control strategies and emission inventories.
Local government regulation No. 5/2014	Transport Agency	Improve the transport system in Jakarta	The regulation allows the extension of bus rapid transit (BRT) corridors to increase its number of passengers. This regulation also sets the age limit of 10 years for public transport fleets.
Governor Regulation No. 155/2018	Transport Agency	Impose traffic restrictions to improve traffic flows in Jakarta's main arteries	The regulation improves traffic flows and reduces air pollution from congestion by restricting vehicles from several arteries based on the license plate number. Odd number plates are allowed to travel only in odd dates, and vice versa, during morning and afternoon rush hours (06.00 – 10.00 am and 16.00 – 21.00 pm) from Monday through Friday. A maximum penalty of IDR 500,000 (~ 33 USD) is assessed for violations. Motorcycles and battery electric vehicles are excluded.
Governor Instruction No. 66/2019	Multi Agencies	Optimize existing air pollution control measures, including from transport sector	For the transport sector, this policy aims to: Assure that maximum vehicle age for public fleets and private vehicles in Jakarta is 10 years and must pass periodic emission test by latest 2025. Encourage broader public participation to support air pollution control through several measures, such as introducing congestion pricing, expanding the "odd-even" access system, and differentiating parking cost based on emission performance.
Governor Regulation No. 66/2020	Environmental Agency Transport Agency	Regulate the implementation of mandatory vehicle emission testing in Jakarta	The regulation provides the basis for imposing mandatory vehicle emission test for private vehicles, including passenger vehicles, motorcycles, and three-wheelers. It also sets a requirement for licensed workshops to perform the emission test, including certification of the instruments used for performing emission tests, and regulates a vehicle emission database for incentives and disincentives based on vehicle emission performance.

for better alignment between national and sub-national regulations for in-use vehicles.[13]

Jakarta introduced emission thresholds for in-use vehicles in 2008. Limits for HC and CO emissions were set for gasoline vehicles, while opacity limits were established for diesel vehicles.[14] Table 3 lists the emission thresholds for motorcycles, passenger vehicles, and commercial vehicles. A further attempt by the Government of Jakarta to address vehicle emissions was incorporated in Governor Regulation No.66/2020

13 Arifin Ridwan, "Pemprov DKI Jadi Batasi Mobil Pribadi Usia 10 Tahun ke Atas? [Government of DKI Jakarta decides to ban private vehicles older than 10 years?]" *Detik Oto*, March 24, 2021, https://oto.detik.com/berita/d-5506543/pemprov-dki-jadi-batasi-mobil-pribadi-usia-10-tahun-ke-atas

14 The Governor of Jakarta Special Capital Region, "Peraturan Gubernur Provinsi Daerah Khusus Ibukota Jakarta Nomor 31 Tahun 2008 Tentang Ambang Batas Emisi Gas Buang Kendaraan Bermotor [Regulation of the Governor of Jakarta Special Capital Region number 31 year 2008 on motorized vehicle exhaust emission limit]," (2008), https://jdih.jakarta.go.id/uploads/default/produkhukum/Jakarta_31_2008.pdf

Table 3. Emission thresholds for in-use vehicles in Jakarta

Vehicle category	Model year	Carbon Monoxide (CO) (%)	Hydrocarbon (HC) (ppm)	Opacity (%HSU)*	Test method
Motorcycle (2 stroke)	before 2010	4,5	12000		idle
Motorcycle (4 stroke)	before 2010	5,5	2400		idle
Motorcycle (2 & 4 stroke)	after 2010	4,5	2000		idle
Gasoline PV and commercial	before 2007	3,0	700		idle
	after 2007	1,5	200		idle
Diesel PV and commercial					
GVW < 3.5 Ton	before 2010			50	Free acceleration
	after 2010			40	Free acceleration
GVW > 3.5 Ton	before 2010			60	Free acceleration
	after 2010			50	Free acceleration

*Hartridge smoke unit

on Exhaust Emission Test for Motor Vehicle.[15] Under this regulation, all private motorized vehicles (two and four wheelers) are required to undergo an exhaust emissions test at least once each year and the test result is integrated with vehicle registration data. Vehicles that do not comply with the testing requirement are subject to sanctions if found to be operating within the city's jurisdiction. Further, vehicles that do not pass the test will be subject to disincentives, such as paying the highest parking rate, and will be banned from entering the low emission zone. The Environmental Agency of Jakarta is responsible for overseeing the implementation of exhaust emission testing. To date, full implementation of the mandatory emissions testing program has been delayed, leading to a lack of participation from vehicle owners, and penalties associated with failures to comply with testing requirement are not yet fully enforced.

Governor Regulation No.66/2020 also specifies the requirements for auto workshops certified to perform vehicle emissions testing. These workshops must have the instruments needed to perform emission tests for both gasoline and diesel vehicles, and these instruments must be certified and calibrated at least once a year.

Test results must be entered into the database system maintained by the government of Jakarta, which is automatically linked into the vehicle registration database.

In early 2021, Jakarta established a low emission zone (LEZ) in Kota Tua, or old town in North Jakarta, with the objective of reducing vehicle emissions and improving air quality in the area. Only vehicles which have passed emissions testing requirements, regardless of their emission standards, are permitted within the LEZ. Jakarta plans to introduce LEZs in several different areas of the city in the near future and, to support this plan, Jakarta has taken steps to revitalize pedestrian areas and build transport hubs to improve access to public transportation.[16]

TRUE JAKARTA REMOTE SENSING STUDY OVERVIEW

The TRUE Initiative conducted a real-world vehicle emissions testing study in Jakarta to provide insights

15 The Governor of Jakarta Special Region, "Peraturan Gubernur Daerah Khusus Ibukota Jakarta Nomor 66 Tahun 2020 Tentang Uji Emisi Gas Buang Kendaraan Bermotor [Regulation of the Governor of Jakarta Special Capital Region number 66 year 2020 on emission testing for motorized vehicles]," (2020), https://jdih.jakarta.go.id/uploads/default/produkhukum/PERGUB_NO._66_TAHUN_2020.pdf

16 Komaruddin Bagja Arjawinangun, "Selain Kota Tua, 3 Lokasi Ini Bakal Jadi Kawasan Zona Rendah Emisi di Jakarta [Besides Kota Tua, these 3 locations will be assigned as low emission zone in Jakarta]," *Sindonews.com*, November 17, 2021, https://metro.sindonews.com/read/602427/171/selain-kota-tua-3-lokasi-ini-bakal-jadi-kawasan-zona-rendah-emisi-di-jakarta-1637154676

Sites	Measurements	Slope
JKT 01	20,744	1.5%
JKT 02	18,668	1.6%
JKT 03	10,055	0.5%
JKT 04	12,682	0.5%
JKT 05	22,342	0.5%
JKT 06	12,677	1%
JKT 07	8,720	2.5%
JKT 08	10,308	0.4%
JKT 09	5,977	1.3%
JKT 10	5,155	1.3%
JKT 11	14,033	1.4%
JKT 12	10,590	0.4%
JKT 13	5,859	0.2%
JKT 14	6,906	0.6%
JKT 15	11,853	2.1%
JKT 16	2,346	0.2%
JKT 17	768	0.1%
JKT 18	735	0.5%

Figure 1. Location of sampling sites in Jakarta. Inset table shows the total number of attempted measurements and the road slope for each site.

into emission levels of common vehicle types operating in the city, and to provide information to government officials to support the further development of vehicle emissions control programs. To our knowledge, this is the first application of remote sensing technology to measure emissions from in-use vehicles in Indonesia. This section provides a description of the data collection activities, details of data post-processing and quality assurance procedures, and an overview of the characteristics of the vehicles whose emissions were measured during the study.

DATA COLLECTION

The TRUE Jakarta vehicle emissions remote sensing study was carried out between January and April 2021. Planning for the field data collection activities, including site selection and coordination with BPJT and related authorities, took place in Q4 2020. Researchers from Bandung Institute of Technology (ITB) under the supervision of Professor Puji Lestari, were contracted by ICCT to conduct data collection field work, coordinate with the related authorities, and obtain vehicle characteristic information for the measured vehicles.

The ITB team deployed remote sensing equipment from Environmental Technology Consultants Limited (ETC). The instrument provided by ETC for this work was the Model M752, which is capable of measuring emissions of a number of common motor vehicle exhaust species, including CO, HC, NO_x and NO_2. The equipment also measures the speed and acceleration of the test vehicle at the time of the emissions measurement and records an image of the vehicle's license plate.

Researchers conducted emissions testing at 18 separate locations in the Jakarta Metropolitan area and 2 additional locations in West Java. Figure 1 shows the 18 locations of the sampling sites used for this study, along with details of the total number of measurements and road slope for each site. The majority of these sites were located at toll gates maintained by the Indonesian Toll Road Authority, BPJT. The toll gate locations are well-suited for the use of remote sensing equipment due to the steady traffic flows, single lane roadways, and positive road slopes. Figure 2 shows an example of the measurement equipment set up at a toll gate sampling site. The sites were selected to provide broad geographic coverage and diversification of the sampled vehicle fleet.

Figure 2. Remote sensing equipment set up at the JKT 01 site (Cempaka putih toll gate). Photo by Aditya Mahalana.

The data collection activities were split into two distinct phases. During the first phase, researchers concentrated on surveying the emissions of the general fleet, and sampled vehicles were predominately passenger vehicles, light trucks, and taxis. The second phase of the study aimed to generate emissions data for heavy-duty trucks and buses, and sampling locations with higher levels of heavy-duty vehicle activity were prioritized. For example, the second phase of the study included seven days of sampling at TransJakarta BRT dedicated bus lanes (see Figure 3).

Following the completion of data collection activities, ITB researchers submitted a list of license plate numbers for the vehicles measured during the study to Korlantas, the Traffic Corps of the Indonesian National Police. Korlantas provided technical information obtained from the vehicle registration database for each test vehicle, including vehicle type, fuel type, build year, make, model, and engine displacement.

A full description of field data collection activities can be found in a companion report prepared by ITB.[17]

Figure 3. Remote sensing equipment set up at TransJakarta BRT dedicated lane.

17 PT. Ganesha Environmental & Energy Services, "Fieldwork and methodology of remote sensing monitoring at Jakarta," (2021), https://theicct.org/wp-content/uploads/2022/11/RSR-01-GEES_Fieldwork-and-methodology-report_final-180821-PL.pdf

DATA PROCESSING AND ANALYSIS

A complete database of Jakarta remote sensing records was provided by ITB at the completion of the data collection phase of this study. The total sample size of raw data was 187,642 measurements, which included the total number of attempted vehicle emissions measurements made during the study. As a first step in processing the dataset, we removed records flagged as invalid by the instrument software and those records for which we could not obtain vehicle technical information. In this step, about 30% of the total measurements were considered invalid data and removed. After data validation and cleaning, 93,188 vehicle emission records were considered for the analysis presented in this report. Further data processing and statistical analysis proceeded following standardized methods described in prior ICCT and TRUE Initiative publications.[18]

This report focuses on the most common vehicle types in the dataset: passenger vehicles, taxis, buses, heavy-duty trucks, light-duty trucks, and motorcycles. Other vehicle types such as garbage trucks, ambulances, and three-wheelers were not well represented in the data set and, as such, these groups are not included in the analysis presented here. Vehicle body type, manufacturer, model, and engine displacement information provided by Korlantas were used to group individual records by vehicle type. Details of the vehicle classification method applied here can be found in Table A1 of the Appendix.

During the data processing and preliminary analysis steps, we found that the software settings of the instrument used in the study resulted in the truncation of raw emissions readings within the following ranges: -1% to 2.5% for CO, -100 ppm to 3,000 ppm for HC, and -150 ppm to 3,500 ppm for NOx.[19] Emissions readings outside of these thresholds were not able to be accurately quantified, impacting the ability to evaluate the mean emissions for individual groupings of vehicles.

18 Yoann Bernard, Uwe Tietge, John German, Rachel Muncrief, "Determination of Real-World Emissions from Passenger Vehicles Using Remote Sensing Data," (TRUE Initiative, 2018), https://www.trueinitiative.org/data/publications/determination-of-real-world-emissions-from-passenger-vehicles-using-remote-sensing-data; Tim Dallmann, Yoann Bernard, Uwe Tietge, and Rachel Muncrief, "Remote sensing of vehicle emissions in London," (TRUE Initiative, 2018), https://www.trueinitiative.org/data/publications/remote-sensing-of-motor-vehicle-emissions-in-london; Uwe Tietge, Yoann Bernard, John German, Rachel Muncrief, "A comparison of light-duty vehicle NOx emissions measured by remote sensing in Zurich and Europe," (ICCT: Washington, DC, June 2019), https://www.theicct.org/sites/default/files/publications/ICCT_LDV_NOx_emissions_Zurich_20190626.pdf

19 The equipment supplier, ETC, indicated these thresholds were set in the instrument software to align with those used in the Hong Kong EPD high-emitter vehicle identification program.

For this reason, we present median values of emission levels for each vehicle group considered here, as the median is not impacted by the data truncation issues to the same extent as the mean.

SAMPLE OVERVIEW

Figure 4 presents a breakdown of valid emission measurements by vehicle type and fuel type collected during the Jakarta remote sensing testing campaign. These data include 93,188 complete records where both valid emissions and vehicle technical information were available. Passenger vehicles (PVs) were the most common vehicle type, accounting for 84% of the total sample.[20] Of the sampled PVs, 88% were powered by gasoline engines and 12% were equipped with diesel engines. Light-duty trucks (LDTs), including pick-up trucks, blind vans, light-duty dump trucks, and light-duty box trucks, accounted for 12% of the total sampled fleet. The sampled LDTs were split almost evenly between diesel and gasoline engines, with slightly more records for diesel vehicles. Although sample sizes for other vehicle types are smaller, a considerable amount of data was also collected for buses (2338 vehicles), heavy-duty vehicles (848 vehicles), motorcycles (297 vehicles), and taxis (512 vehicles). Approximately 98% of the buses in the Jakarta dataset were powered by diesel engines. Virtually all the heavy-duty trucks (HDTs) measured were powered by diesel engines, while all the taxis and motorcycles were powered by gasoline engines.

The relative number of measured motorcycles in the sample is low compared to the actual fleet composition in Jakarta. This is largely attributable to the selection of toll road locations for the majority of sampling activities, where motorcycles are prohibited from entering. Furthermore, the emissions of motorcycles are more difficult to measure using remote sensing technology than other vehicle types. Given these constraints, we mostly focus on emissions from 4-wheeled vehicles in this report. However, given the importance of 2-wheelers to road transport emissions in Jakarta, we recommend future real-world emissions testing studies prioritize testing methods and sampling approaches which are better suited to this vehicle type.

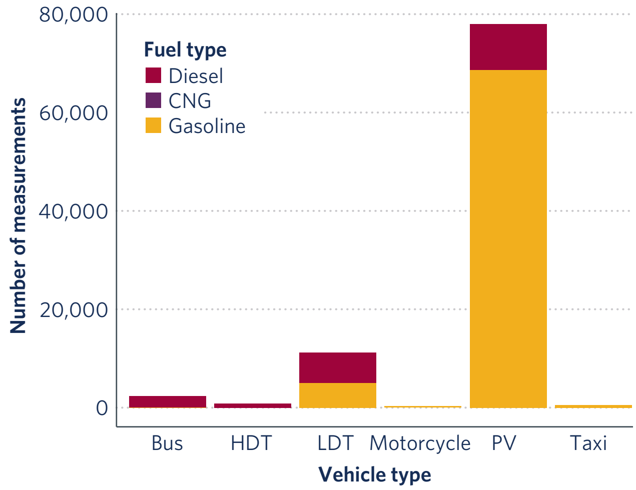

Figure 4. Emissions measurements by vehicle type and fuel type.

Figure 5 shows the model year distribution of the sampled PV fleet in Jakarta. The oldest vehicles observed during the study were produced in the 1940s, though these were very limited in number. The majority of sampled vehicles were produced after 2000, with 90% produced after 2010, 67% after 2015, and 6% after 2020.

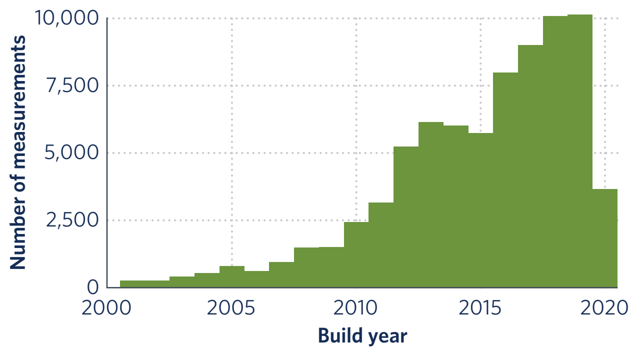

Figure 5. Model year distribution for passenger vehicles measured in Jakarta.

Information on the age of other vehicle types measured in Jakarta is provided in Table 4. The table shows the average age of vehicles for each group, as well as the percentage of vehicles in the sample that were less than 10 years old at the time of sampling. An age of 10 years was selected as it corresponds to the vehicle age limit being considered by the Government of Jakarta as part of their efforts to reduce transport emissions in the city. Across vehicle types, taxis had the lowest average age at 3.5 years, followed by public transit buses. All public transit buses were less than 10 years old, as required under Jakarta law. In contrast, non-public transit buses (e.g., chartered buses and buses operated by companies to transport their employees), which are not subject

20 In this study, private passenger cars and taxis are mutually exclusive.

Table 4. Average age and percentage of vehicles less than 10-years old by vehicle type

Vehicle type	Average age (years)	Vehicles less than 10 years old
Bus – non-public transit	11.3	54%
Bus – public transit	4.4	100%
Heavy-duty truck	9.7	71%
Light-duty truck	7.6	80%
Motorcycle	9	77%
Passenger vehicle	6.6	86%
Taxi	3.5	99%

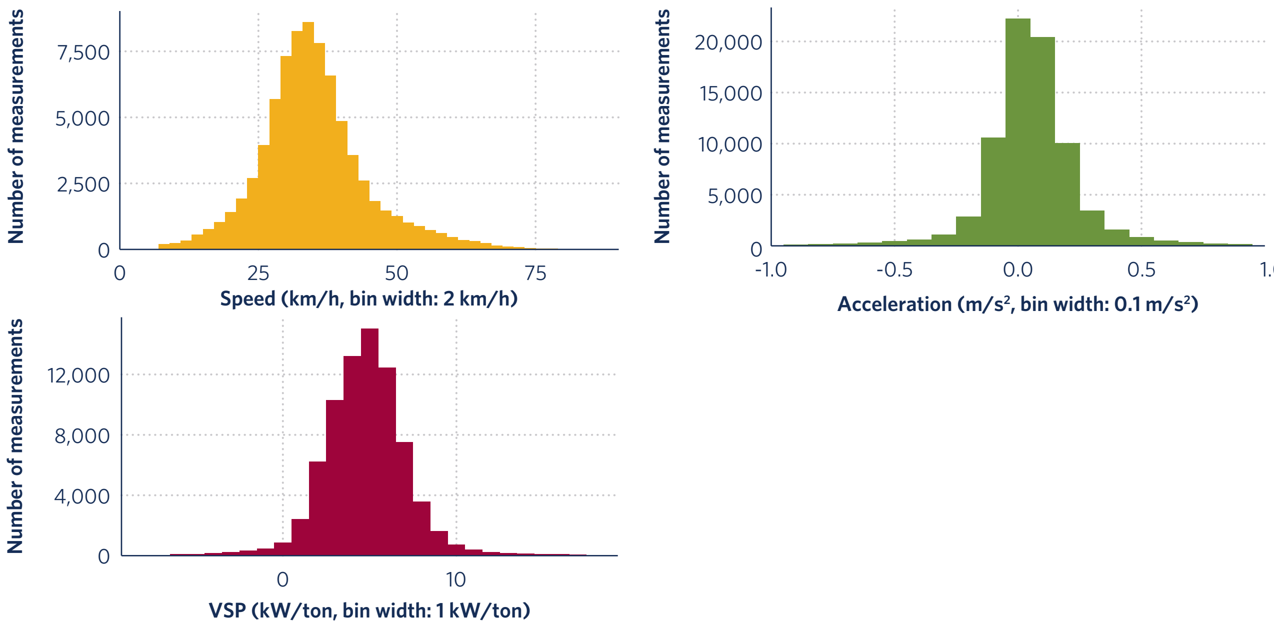

Figure 6. Distribution of testing conditions recorded in the Jakarta remote sensing measurements

to age limits, were the oldest vehicles measured on average, and nearly half were more than 10 years old at the time of measurement. Heavy-duty trucks had the second highest average age (9.7 years) among vehicle groups. If Jakarta were to move forward with a 10-year age limit for private vehicles, approximately 14% of passenger vehicles and 23% of motorcycles measured would be subject to restrictions. Extending a similar age limit for other vehicle types, like HDTs and LDTs, would impact 20%–30% of vehicles in these groups.

Figure 6 summarizes testing conditions for the passenger vehicle measurements in the Jakarta database. The speed, acceleration, and vehicle specific power (VSP) all show a normal distribution around the population mean values. The median speed and acceleration of passenger vehicles at the time of testing were 34.1 km/h and 0.05 m/s^2, respectively. These values are lower than those observed in similar TRUE emissions testing studies carried out in European cities. This led to a lower power demand on vehicles in the Jakarta database, with median VSP of 4.8 kW/ton compared with an average of 5.5 kW/ton in the TRUE Europe database. This means the driving conditions at the Jakarta sampling sites tended to be milder than those observed in the European remote sensing studies.

EMISSION RESULTS

This section presents emissions measurement results by vehicle type, fuel type, and model year.

EMISSIONS BY VEHICLE TYPE

Figure 7 presents the median NOx, CO, and HC emissions of vehicles measured in Jakarta by vehicle type. Data are reported in units of grams of pollutant emitted per kilogram of fuel burned (g/kg fuel). The highest median NOx emissions were observed for the groups with the highest percentage of diesel vehicles in their respective fleets—buses, HDTs, and LDTs. The emissions of the two highest emitting vehicle groups, HDTs and LDTs, are 13.5 and 13.9 times, respectively, the NOx emissions from passenger vehicles. Compared with NOx emissions, less differentiation across vehicle groups is observed in median CO and HC emissions. For buses, CO and HC emissions are relatively low compared to HDTs and LDTs. It should be noted that the differences in emissions levels are heavily influenced by the predominant emissions standard and vehicle age in each group. For example, the average age of public buses is significantly lower than that of HDTs in the sample.

To further illustrate the influence of engine type on emissions, Figure 8 presents the NOx, CO, and HC emissions by vehicle type and fuel type. For diesel vehicles, including diesel buses, HDTs, LDTs, and PVs, NOx emissions are significantly higher than those from gasoline vehicles of the same vehicle type. For LDTs, median NOx emissions from diesel vehicles are 9 times the emissions from their gasoline counterparts. Similarly, median NOx emissions from diesel passenger vehicles are 10 times the emissions from gasoline passenger vehicles. Median CO and HC emissions were higher for gasoline vehicles compared to diesel vehicles, though the relative magnitude of these emissions differences were smaller than those observed for NOx emissions (1.5–2.5 times for CO emissions and 1.4–1.5 times for HC emissions). Median HC and CO emissions for natural gas and diesel buses were comparable. However, natural gas buses showed much better NOx emission performance, with a median emission rate of 3 g/kg compared to 45.5 g/kg for diesel buses. Though the sample size for natural gas buses is relatively small, these findings indicate significant NOx emission benefits relative to diesel buses.

Real-world emissions studies conducted by the TRUE Initiative in the United States and Europe provide points of reference to add context to the Jakarta emissions results. Direct comparisons of the Jakarta results with previous TRUE studies are complicated by a number of factors, such as differences in instrumentation and data quality, so here we focus on the relative level of median emissions observed in Jakarta compared to those of vehicles of different age groups and emission control levels in the United States and Europe. We find that the fleet median NOx, CO, and HC emissions from diesel vehicles in Jakarta are all higher than emission levels of pre-Euro (model year 1992 and older) diesel vehicles in Europe and pre-2000 model year vehicles in the United States. For gasoline vehicles, NOx and CO emissions from gasoline PVs in Jakarta are comparable to model year 2000 gasoline PVs in the United States, while HC emissions are comparable to model year 1993 PVs.

Distance-specific emissions in units of grams per kilometer can be estimated by combining remote

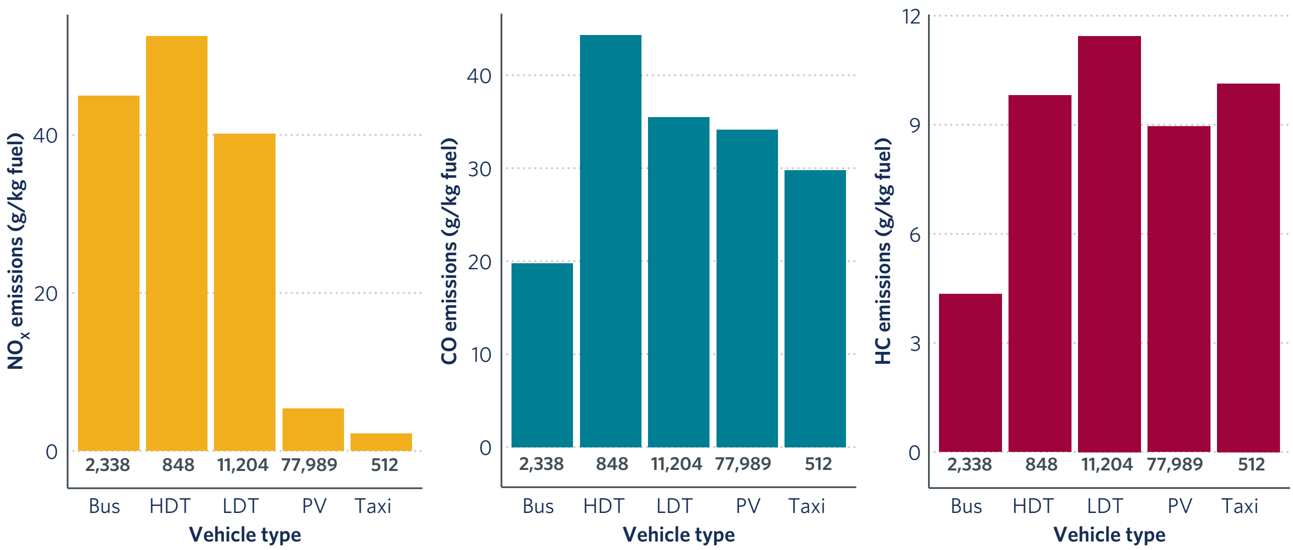

Figure 7. Median NOx, CO, and HC emissions by vehicle type. *Note:* The number of measurements is presented at the bottom of each bar.

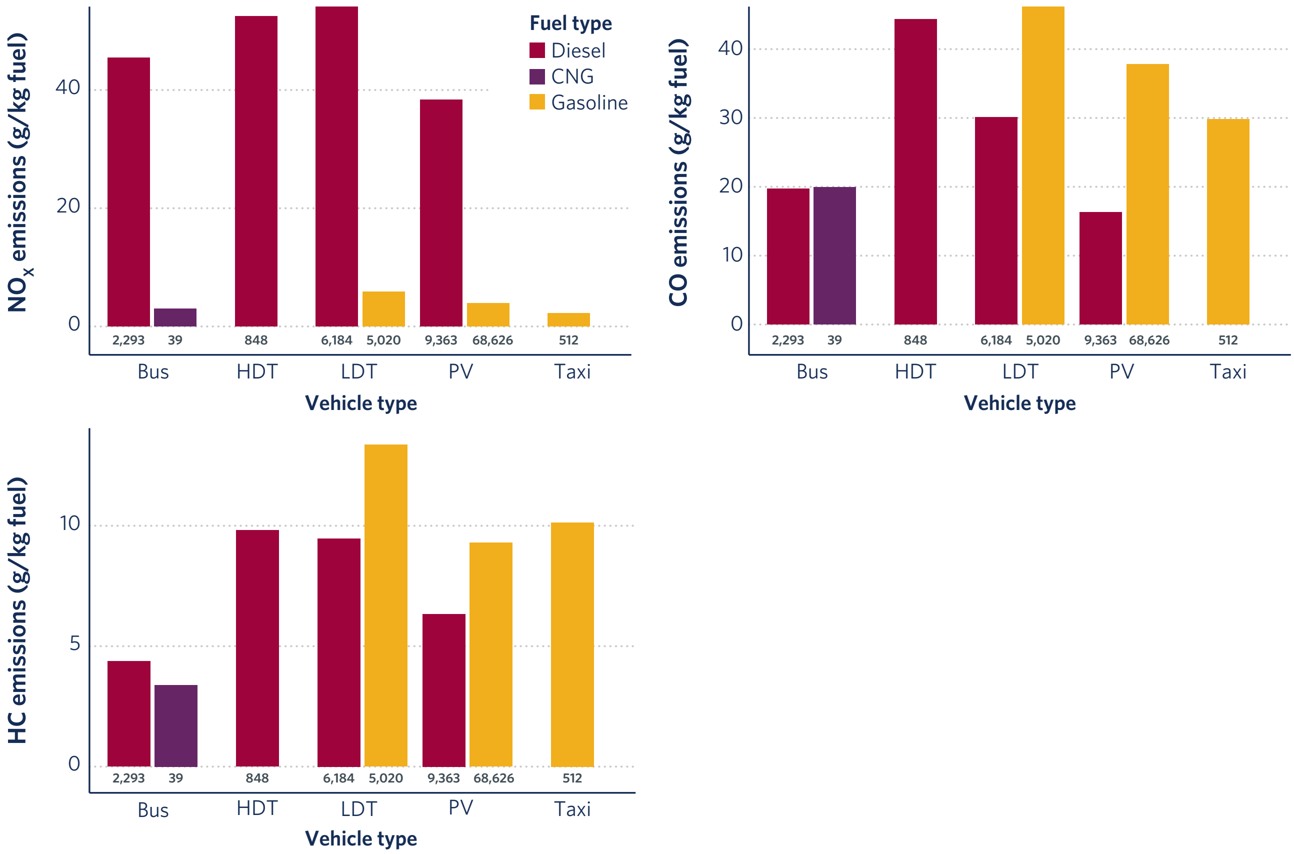

Figure 8. Median fuel-specific NOx, CO, and HC emissions by vehicle type and fuel type.

sensing fuel-specific emission factors with estimates of the average real-world fuel consumption of specific vehicle groups, as detailed in a previous TRUE study.[21] In Indonesia, a real-world fuel consumption database is not available. Therefore, we use the fuel consumption data by vehicle type and model year derived from the ICCT ROADMAP model to estimate the average fuel consumption for Indonesian vehicles.[22] For heavy-duty vehicles, including buses and heavy trucks, the fuel consumption values vary significantly due to different gross vehicle weights. So, only the distance-specific emissions for light-duty vehicles were calculated, including LDTs, passenger vehicles, and taxis.

Figure 9 plots the estimated median distance-specific NOx, CO, and HC emissions of light-duty vehicles by emissions standard and fuel type. As shown, emissions generally decrease for both gasoline and diesel vehicles with the implementation of new emission standards, but the relative magnitude of these emission reductions varies by fuel type and exhaust pollutant. The largest emission benefits of new standards are observed for gasoline vehicles. The real-world distance-specific NOx emissions from the newest Euro 4 gasoline passenger vehicles and LDTs are about 8% of those from uncontrolled pre-Euro gasoline vehicles and are only about 30% higher than the laboratory NOx emission limit for Euro 4 gasoline cars. CO and HC emissions from Euro 4 gasoline PVs and LDTs are reduced 5–15 times compared to pre-Euro vehicles. For Euro 4 gasoline LDVs, real-world CO emissions are about 30% higher than the laboratory limits while real-world HC emissions are 5 times the laboratory limits.

Euro 4 standards had not been implemented for diesel vehicles when the remote sensing measurements were carried out, so only pre-Euro and Euro 2 vehicles are analyzed in this study. Relative to gasoline vehicles of a similar type, we observe smaller emissions benefits for diesel vehicles with the introduction of Euro 2 standards. The NOx emissions from Euro 2 diesel LDVs, including light-duty trucks and passenger vehicles, are about half

21 Yoann Bernard, Uwe Tietge, John German, and Rachel Muncrief, "Determination of real-world emissions from passenger vehicles using remote sensing data."

22 ICCT roadmap model documentation. https://theicct.github.io/roadmap-doc/

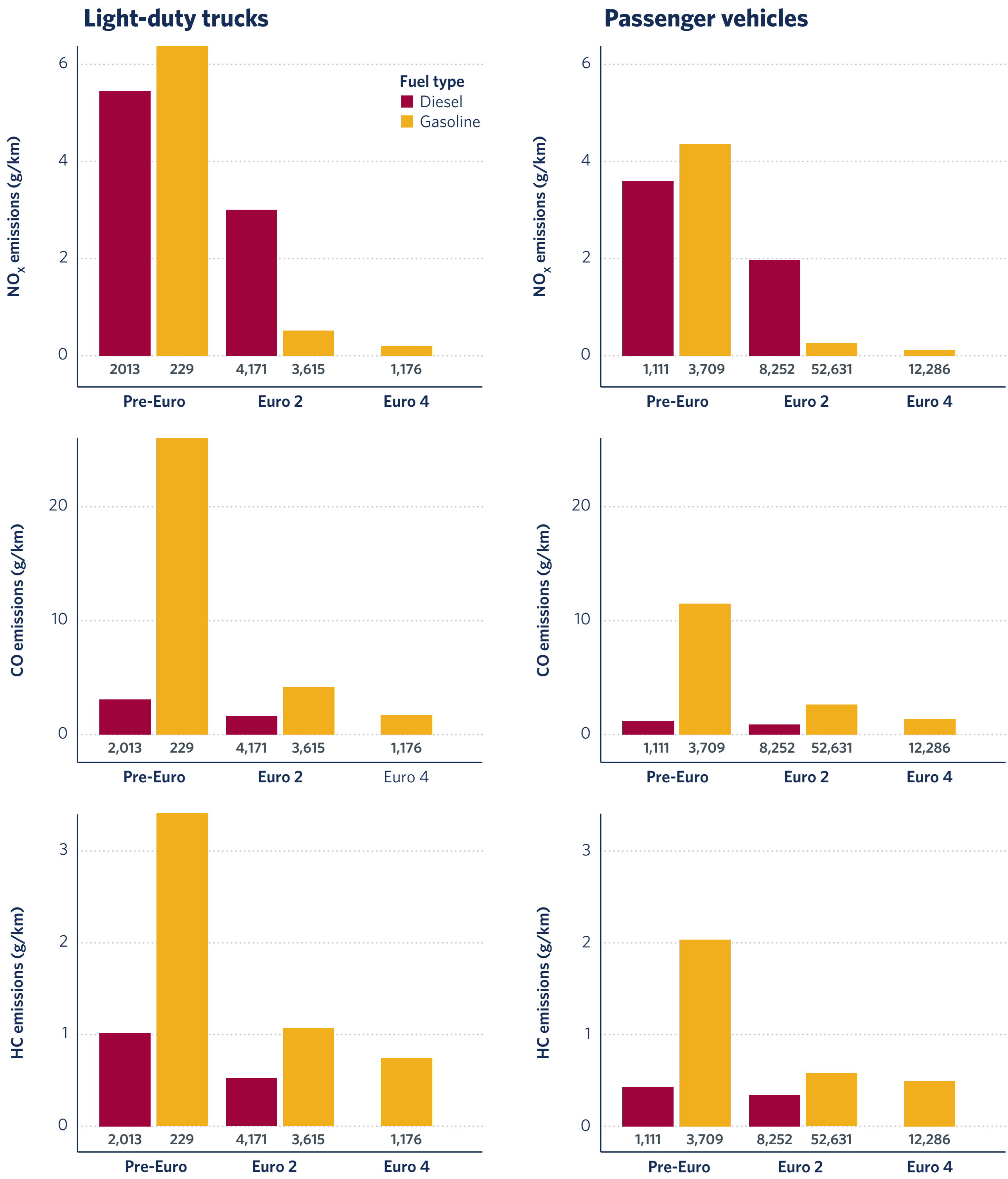

Figure 9. Median distance-specific NOx, CO, and HC emissions of light-duty trucks and passenger vehicles by emission standard and fuel type.

of those from the pre-Euro diesel LDVs, but are still about 5–7 times higher than those from their gasoline counterparts and twice the laboratory type-approval limit. CO emissions from diesel LDVs are generally low; the Euro 2 diesel CO emissions are about one-third of the CO from gasoline LDVs and are even lower than Euro 2 laboratory limits.

PASSENGER VEHICLE EMISSIONS

In this section, we present a more detailed assessment of the emissions of the Jakarta passenger vehicle fleet. Figure 10 shows the median NOx, CO, and HC emissions of passenger vehicles by fuel type and model year. For gasoline passenger vehicles, stepwise reductions in the median emissions of NOx, CO, and HC are observed in 2007, when the first tailpipe emission standards for this vehicle group, Euro 2, were fully implemented in Indonesia. The introduction of these standards followed the full phase-out of leaded gasoline in Indonesia in 2006, which enabled the widespread application of emission control technologies like three-way catalysts. Comparing the emissions of gasoline PVs built in 2007 with those built in 2006 shows the implementation of Euro 2 standards reduced median NOx, CO, and HC emissions by 78%, 40%, and 60%, respectively.

Figure 10. Median NOx, CO, and HC emissions of passenger vehicles by fuel type and build year.

Euro 4 emissions standards for gasoline passenger vehicles were implemented beginning in 2018 and fully phased in by 2019. The Euro 4 gasoline HC and NOx emission limits are about one-third of the Euro 2 limits, and the Euro 4 CO limit is about half of the Euro 2 limit. The results from the Jakarta remote sensing study show the median NOx and CO emissions from gasoline PVs were further reduced when Euro 4 standard was implemented, but no significant reduction in median HC emissions is observed until model year 2021. The NOx emissions level of gasoline PVs produced in 2021 is comparable to Euro 6 gasoline PVs, and CO and HC emissions are comparable to Euro 5 gasoline PVs collected in the TRUE database.[23]

The results presented in Figure 10 show that median real-world NOx emissions of pre-Euro diesel and gasoline passenger vehicles operating in Jakarta are similar. However, while the introduction of Euro 2 standards dramatically decreased NOx emissions from gasoline PVs, similar benefits are not observed with the implementation of Euro 2 standards for diesel passenger vehicles in 2011. Even with the implementation of Euro 2 standards for each PV group, median NOx emissions from diesel PVs remained 8 to 19 times the emissions of gasoline PVs produced in the same year. For the newest diesel PVs, median NOx emissions are still over 30 g/kg fuel and are higher than European pre-Euro diesel PVs and model year 2002 U.S. diesel PVs. This emission level is still very high and likely well above their type-approval limit.

The results indicate that limiting the oldest gasoline vehicles through age or access restrictions could have a significant impact on NOx emissions from this vehicle group. For example, enforcing a 10-year age limit for private vehicles in Jakarta would effectively remove the highest emitting (pre-Euro) gasoline passenger vehicles from the city's fleet. However, similar policies would have less of an impact on NOx emissions from diesel PVs. This finding argues for continued monitoring of the effectiveness of the Euro 4 standard in reducing diesel NOx emissions.

COMPARISON BETWEEN GASOLINE PASSENGER VEHICLES AND TAXIS

Because taxis are driven more each year than private PVs, the age of useful life of taxis is typically less than passenger vehicles. In the Jakarta dataset, 97% of the taxis were produced after 2013. To compare the emissions between gasoline passenger vehicles and taxis of the same vehicle age directly, we selected the PVs and taxis produced after 2013 and plotted the median fuel-specific NOx, CO, and HC emissions of Euro 2 and Euro 4 vehicles (see Figure 11). For Euro 2 vehicles, median NOx, CO, HC emissions from taxis are slightly higher than from private cars. But for newer vehicles, NOx and CO emissions of Euro 4 taxis are

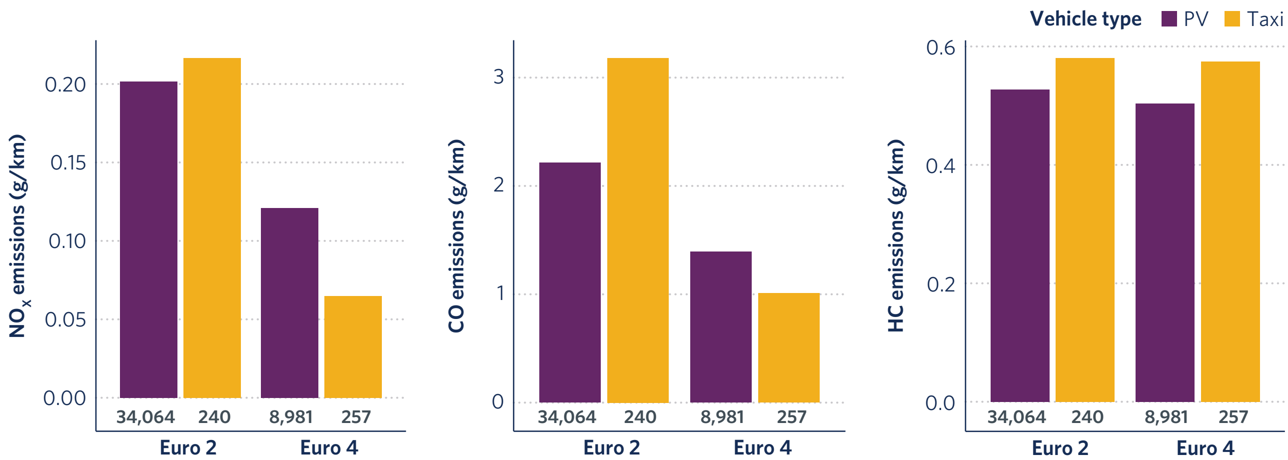

Figure 11. Median NOx, CO, and HC emissions of gasoline passenger vehicles and taxis produced after 2013.

23 Kaylin Lee, Yoann Bernard, Tim Dallmann, Uwe Tietge, Izabela Pniewska,and Isabel Rintanen, "Evaluation of real-world vehicle emissions in Warsaw," (TRUE Initiative, 2022), https://theicct.org/publication/true-warsaw-emissions-apr22/

lower than those from Euro 4 PVs. This might be due to the fact that the participation rate of private PVs in periodical technical inspection is lower than that of the taxis, so newer taxis are well maintained compared to private PVs.[24] Further, taxis are required to pass periodical technical inspections in order to renew their permit.

COMMERCIAL VEHICLE EMISSIONS

For diesel commercial vehicles, including HDTs and LDTs, Euro 2/II emission standards were implemented in March 2011, and Euro 4/IV standards have been in effect since April 2022. The remote sensing measurements in Jakarta were obtained before Euro 4/IV was implemented so there are no Euro 4/IV diesel commercial vehicles in the dataset. Figure 12 presents the median NOx, CO, and HC emissions from diesel HDTs and LDTs in Jakarta. For both diesel HDTs and LDTs, all four pollutants decreased from pre-Euro to Euro 2/II, with NOx reduced by 15%–24%, CO reduced by 18%–21%, and HC reduced by 23%. The results indicate that only a modest improvement in diesel truck emissions was achieved in the past decade. Considering that the implementation of Euro 4/IV was delayed, there are still many high-emitting diesel trucks on the roads. Moreover, even though there was some improvement in median NOx emissions observed with the introduction of Euro 2/II standards, the magnitude remains quite high and well above the level of emissions that can be achieved with modern diesel exhaust aftertreatment systems. For context, the median NOx emission level of diesel trucks in Jakarta, 48–63 g/kg, is considerably greater than the high-emitter threshold NO emissions level established in the Chinese remote-sensing regulation (~32 g/kg).[25] This means that if a similar in-use emissions control program were in place in Jakarta at the time of our study, more than 50% of diesel trucks operating in the city would have been flagged as high-emitters and subject to follow-up enforcement action. While some improvement is expected with the introduction of Euro 4/IV standards in 2022, past experience with the implementation of similar standards in Europe should serve to limit expectations for significant NOx emission benefits.[26] Advanced emission control technologies will not be needed to meet the relatively weak Euro 4/IV NOx emission standards, and emissions are likely to remain high.

Figure 13 shows the emissions results of gasoline and diesel LDTs by emissions standard. For gasoline LDTs in Indonesia, the Euro 2 emissions standard was fully implemented in 2007 and the Euro 4 standard has been fully phased-in since 2019. As shown, CO and HC from gasoline LDTs improved as emission standards improved. Although the implementation of the Euro 2 standard has been very effective in reducing NOx

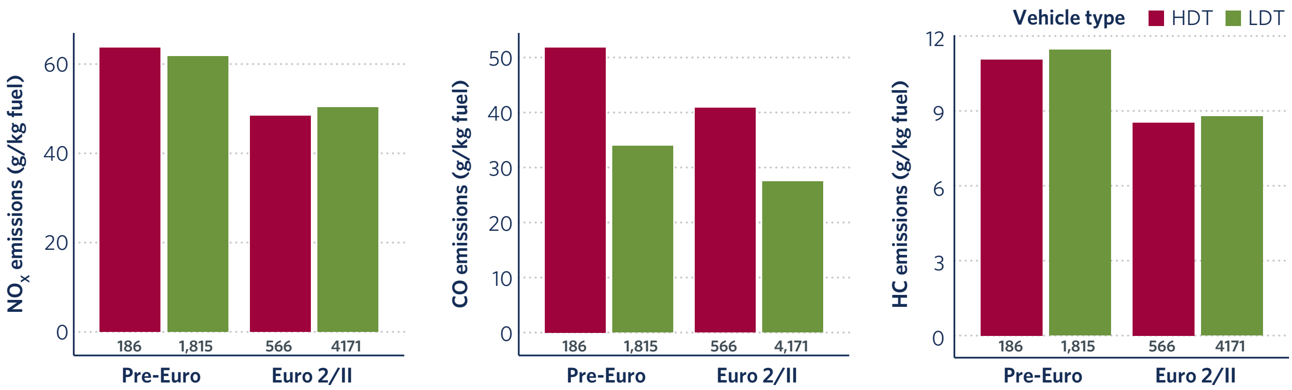

Figure 12. Median NOx, CO, and HC of diesel HDT and LDT by emission standard.

24 "Interest in Jakarta Residents' Emission Test still Low, PSI Blames DKI Provincial Government Policy," Voi.id, March 5, 2022, https://voi.id/en/news/141804/interest-in-jakarta-residents-emission-test-still-low-psi-blames-dki-provincial-government-policy

25 Liuhanzi Yang, Yoann Bernard, and Tim Dallmann, "Technical considerations for choosing a metric for vehicle remote-sensing regulations," (Washington, DC: ICCT, 2019), https://theicct.org/wp-content/uploads/2021/06/China_remotesensing.FINAL_.pdf

26 Kazemi Bakhshmand, Sina, Eamonn Mulholland, Uwe Tietge, and Felipe Rodríguez, "Remote Sensing of Heavy-Duty Vehicle Emissions in Europe," (Washington, D.C.: ICCT, 2022), https://theicct.org/publication/remote-sensing-of-heavy-duty-vehicle-emissions-in-europe/

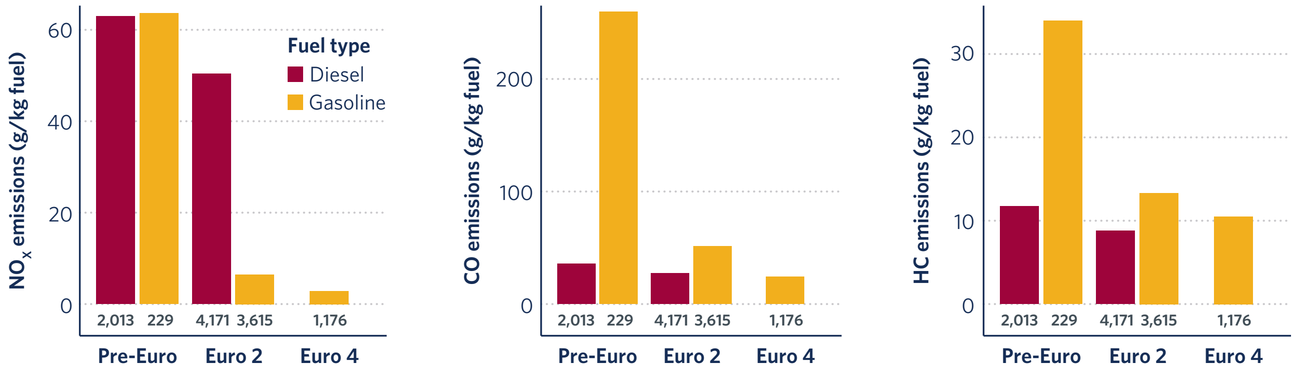

Figure 13. Median fuel-specific NOx, CO, and HC of LDTs by emission standard and fuel type.

emissions from gasoline LDTs, NOx emissions from Euro 2 diesel LDTs were 7.8 times that from Euro 2 gasoline LDTs.

Multiple entities service bus lines In Jakarta. Public transit buses are operated mainly by TransJakarta, and several private bus operators also run fleets to serve commuters from Greater Jakarta region. In the Jakarta dataset, inter-city buses may also be represented. Figure 14 compares the median NOx, CO, and HC emissions from diesel buses operated by different companies. As shown, emissions of each pollutant species from diesel buses have decreased since Euro II was implemented. The TransJakarta bus fleet, in which all buses are certified to the Euro II standard, performed better in real-world driving than buses from other operators. Specifically, NOx, CO, and HC from TransJakarta buses were 50%, 13%, and 41% lower, respectively, than those from other operators.

EMISSIONS FROM MOTORCYCLES

Motorcycles represent the largest component of the traffic stream in Indonesia, accounting for 63% of the total traffic volume.[27] Compared with other vehicle groups, real-world emissions from motorcycles have not been extensively studied. In this study, 297 valid emission records for motorcycles were collected. Since the adoption of Euro 3 emission standard for motorcycle in 2013, manufacturers have gradually phased out their 2 stroke models. Figure 15 presents a comparison of fuel-specific emissions between gasoline motorcycles and passenger vehicles that were produced between 2017 and 2021. In terms of fuel-specific emissions, median NOx, CO, and HC emissions from motorcycles are 20 times, 6 times, and 8 times higher, respectively, than those from gasoline passenger vehicles. The higher fuel-specific emissions from motorcycles were also observed in the TRUE Paris remote sensing

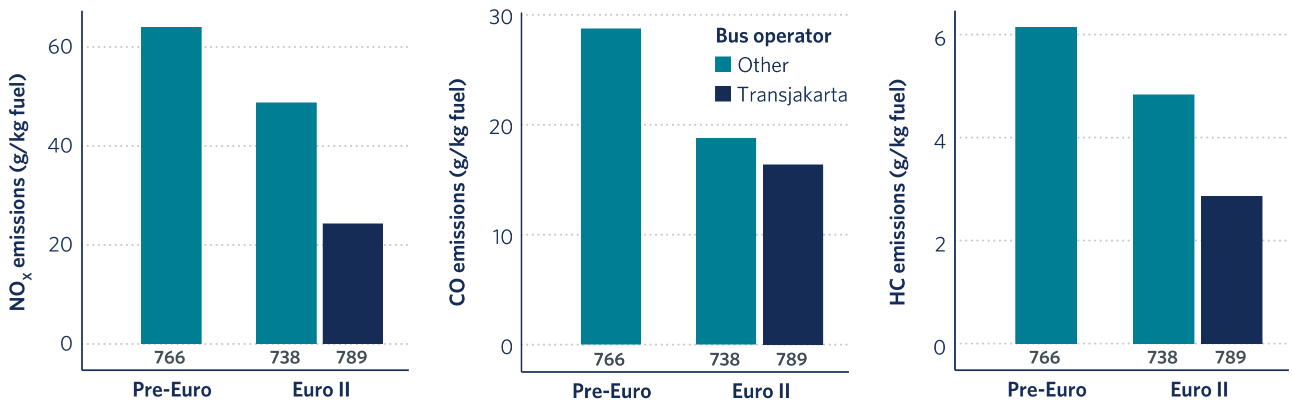

Figure 14. Median NOx, CO, and HC of diesel buses by emission standard and operator

27 Japan International Cooperation Agency (JICA) & ALMEC Corporation, "Urban Transportation Policy Integration Project Phase 2 in the Republic of Indonesia," (2019), https://openjicareport.jica.go.jp/pdf/12356390.pdf

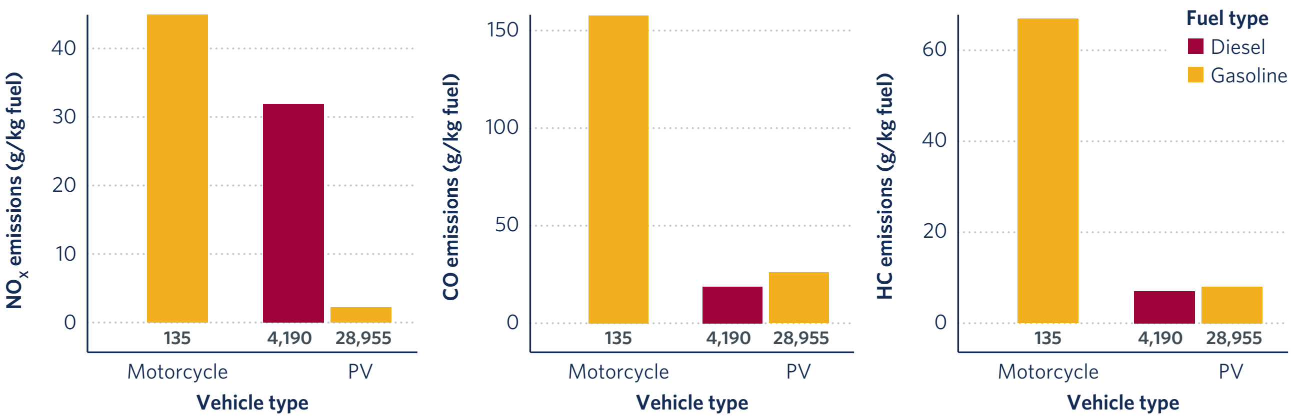

Figure 15. Median fuel-specific NOx, CO, and HC emissions from motorcycles and passenger vehicles produced after 2016.

study.[28] While this gap would be less if emissions were compared on a distance-specific basis—motorcycles consume less fuel per kilometer than passenger vehicles—the higher fuel-specific emissions of these motorcycles indicate that more actions are needed to address motorcycle emissions.

POLICY IMPLICATIONS AND RECOMMENDATIONS

Motor vehicles contribute significantly to the air pollution problems Jakarta has been experiencing for many decades. The data collected during the TRUE Jakarta real-world vehicle emissions testing study provides insights into the effectiveness of policies and measures implemented by the Indonesian Government and the Government of Jakarta aimed at reducing emissions and improving the health and environmental impacts of on-road vehicles. The data also provide important evidence to support new actions to continue to improve the emissions performance of the Jakarta fleet.

EMISSION STANDARDS FOR NEW VEHICLES AND ENGINES

Vehicle emissions data collected during the TRUE Jakarta measurement campaign show the real-world effectiveness of various stages of emission standards for new vehicle and engines and suggest how these standards may be strengthened in the future to promote improved emissions performance. Our findings show that, for gasoline passenger vehicles, the implementation of Euro 2 emission standards in 2007 and Euro 4 standards in 2018 have led to significant reductions in real-world median NOx, CO, and HC emissions. For the newest gasoline PVs in the Jakarta fleet, median emissions performance is on par with levels observed from European PVs certified to Euro 5 and 6 standards. In contrast, our results show relatively small improvements in the emissions of diesel vehicles of all types with the implementation of Euro 2/II emission standards. Across all vehicle types, NOx emissions from diesel vehicles in Jakarta remain much higher than comparable gasoline vehicles. Furthermore, median NOx emissions for even the newest diesel vehicles measured in this study are considerably greater than those of vehicles measured in regions that have implemented more stringent emission standards. Since the time of our study, Indonesia has implemented Euro 4/IV standards for diesel vehicles. These standards can be met without the use of advanced exhaust aftertreatment control strategies and technologies, so any real-world benefits are expected to be modest at best.

To further improve vehicle emissions, we recommend that Indonesia develop a plan and timeline for implementing Euro 6/VI emission standards.[29] A 2020 ICCT study projected that if Euro 6/VI standards are implemented in 2023, the societal costs associated with vehicular emissions outweigh the costs of transitioning to advanced vehicle technology and fuel upgrades by

28 Tim Dallmann, Yoann Bernard, UweTietge, and Rachel Muncrief, "Remote sensing of motor vehicle emissions in Paris," (TRUE Initiative, 2019), https://www.trueinitiative.org/data/publications/remote-sensing-of-motor-vehicle-emissions-in-paris

29 Indonesia remains behind other in terms of emission standards, Indonesia adopted Euro 4/IV standards only in 2017 and there was a significant delay for diesel vehicles. The timeline for Indonesia's implementation of Euro IV standards is slightly behind other countries in the region, e.g., Thailand (2012), the Philippines (2016), and Vietnam (early 2017). As of January 2022, Vietnam has adopted Euro 5/V and Thailand plans to adopt Euro 5/VI in 2024.

a ratio of 9.2:1 between 2020 and 2050.[30] Previous experience in Europe and other countries that have adopted Euro 5/V standards has shown that these standards have not delivered expected real-world emissions benefits, especially for diesel vehicles. This evidence has led other countries, like India, to go from Euro 4/IV directly to Euro 6/VI emission standards. Indonesia would benefit from a similar pathway. Importantly, fuel quality standards would need to match this ambition, and plans for making ultra-low sulfur fuels widely available would also be needed. Finally, we recommend that the Indonesia Ministry of Environment and Forestry consider continued real-world emission testing using remote sensing technology in other cities and regions to continue to build an understanding of the real-world emissions of vehicles throughout the country and track emission changes over time.

JAKARTA LOW EMISSION ZONE

The introduction of a low emission zone (LEZ) in Jakarta was an important step in reducing air pollution in the city. Previous work of the TRUE Initiative has demonstrated how real-world emission measurements can help evaluate the effectiveness of LEZ restriction design in targeting the highest emitting vehicles.[31] Results from the remote sensing campaign provide additional information that can be helpful for Jakarta officials making decisions about the evolution of LEZs in the city. As currently designed, Jakarta LEZs restrict goods transport vehicles, non-TransJakarta public transport vehicles, and private vehicles that have not passed an emissions test. The findings from this study show that goods movement vehicles (HDTs and LDTs) and non-TransJakarta buses had among the highest median real-world emissions of all vehicle types. Restricting access of these vehicles to LEZs effectively targets some of the most polluting vehicles in the Jakarta fleet. Because future expansions of Jakarta LEZs may not be able to restrict these vehicles entirely, as is the case now, we recommend that only Euro 6/VI or zero-emission vehicles be allowed into these zones.

Private passenger vehicles which have passed an emissions test are currently allowed within the Jakarta LEZ. Our findings show that emissions of pre-Euro 2 gasoline passenger vehicles are significantly greater than vehicles certified to Euro 2 and Euro 4 standards. Restrictions could be extended to all vehicles older than model year 2007 to reflect these emission differences. Similarly, median NOx emissions from diesel cars were found to be 8–19 times the emissions of gasoline cars of the same age group, indicating that restrictions could also be extended to this group.

Through the design of the LEZ, the government of Jakarta encourages its citizens to use public transportation when accessing the LEZ area. Currently, TransJakarta buses that travel through the LEZ are powered by diesel and natural gas engines certified to Euro II standards. Remote sensing data show that pollutants emitted by buses have decreased since the introduction of Euro II. Further, NOx, CO, and HC emissions from the TransJakarta bus fleet are lower than other buses. To promote low-emission public transport options, we recommend the city government continue to push for a more ambitious transformation of public transport fleets by aiming for Euro VI or electric mobility. In March 2022, TransJakarta began to operate 30 battery electric buses within its bus rapid transit system as part of their commitment to contribute to air quality improvement. TransJakarta should commit the necessary resources to implement existing plans to electrify 20% of its BRT fleet by 2025 and the whole BRT system by 2030.[32] Furthermore, we encourage the Jakarta government to consider expansions of LEZs to other locations that have good access to public transportation options.

PRIVATE VEHICLE INSPECTION AND EMISSION CHECKS

Jakarta has a policy in place to enforce mandatory annual vehicle emission tests for private vehicles (2- and 4-wheeler) and public fleets. However, the effectiveness of this program in identifying highly polluting vehicles has been limited due to low participation of private vehicle owners. To increase participation, the program could provide disincentives for the highest emitting

30 Zhenying Shao, Josh Miller, and Lingzhi Jin, "Soot-free road transport in Indonesia: A cost-benefit analysis and implications for fuel policy," (Washington, DC: ICCT, 2020), https://theicct.org/sites/default/files/publications/Indonesia-sootfree-CBA-02182020.pdf

31 Kaylin Lee, Yoann Bernard, Tim Dallmann, Caleb Braun, and Josh Miller, "The impact of a low emission zone in Sofia," (TRUE Initiative, 2021), https://www.trueinitiative.org/data/publications/the-impact-of-a-low-emission-zone-in-sofia; Yoann Bernard, Joshua Miller, Sandra Wappelhorst, and Caleb Braun, "Impacts of the Paris low emission zone and implications for other cities," (TRUE Initiative, 2020), https://www.trueinitiative.org/data/publications/impacts-of-the-paris-low-emission-zone-and-implications-for-other-cities

32 The Agency for Communication, Informatics, and Statistic of Jakarta Special Region, "Jakarta E-Mobility Event Day2: Webinar on Global Case Studies and Local Policy Review on Electric Bus Deployment [press release]" March 2, 2022, https://g20sideevents.id/assets/upload/press_release/2022/3d2ab33183dc818863c1de2b764123ba.pdf

vehicles or those that do not pass the annual emission checks. For example, vehicles with high emissions could pay the highest parking fees, be levied higher tolls, or could be banned from entering the low emission zone in Jakarta. In addition, submission of emissions test results and annual mileage should be required for annual registration of all vehicle fleets in Jakarta. Furthermore, existing thresholds for identifying high-emitting vehicles should be reviewed regularly.

As of the end of 2021, there were more than 250 workshops in Jakarta authorized to conduct vehicle emission tests.[33] This number of authorized workshops may not be sufficient to test the entire number of vehicles registered in Jakarta, which surpassed 20 million as of the end 2020. Therefore, remote sensing testing could be considered an alternative solution to measure in-use vehicle emissions and identify the highest emitting vehicles in the fleet, as has been practiced in other countries such as China, the United States, and Europe.[34]

TARGETED ACTIONS FOR FLEETS

BUSES

The median NOx emission from diesel heavy-duty and light-duty vehicles are 13.5 and 13.9 times higher, respectively, compared to gasoline vehicles. However, diesel buses have relatively lower CO and HC emissions compared to other heavy- and light-duty vehicles. As shown in Figure 16, NOx, CO, and HC emissions from diesel buses have decreased following the introduction of Euro II standards, and TransJakarta buses had lower median emissions of all measured pollutants than buses of other operators. The better real-world emission performance of TransJakarta's bus fleet may result from better compliance with inspection and maintenance procedures, as well as the use of cleaner fuels. To improve the real-world emission performance of other bus fleets, the Ministry of Transport could consider providing incentives to all bus operators that perform regular fleet maintenance.

Additional actions to support improved emissions performance of buses operating in Jakarta include requiring TransJakarta and other fleet operators to purchase buses that meet more stringent emissions standards (e.g., Euro VI), tightening inspection and maintenance requirements for these fleets, and accelerating the transition to zero-emission electric buses, especially for urban bus fleets. Lastly, although there is little that the government of Jakarta can do to push compliance for other bus operators, especially long-distance inter-city buses, the government of Jakarta can perform emission tests at inter-city bus stations and only allow buses that pass these tests to enter the city. Further, the city government could offer incentives for urban bus fleet renewal with the condition that the new vehicles comply with Euro VI emission standards or be zero-emission.

MOTORCYCLES

Motorcycles in Indonesia make up most fleets in Indonesian cities. Although we collected only a small amount of emissions data for motorcycles during this study, results indicate that more actions are needed to address motorcycle emissions. One possible cause of high emissions of some pollutants is that motorcycle owners do not pay the same attention to inspection and maintenance compared to passenger vehicles or public buses. Also, the current emissions standard for motorcycles is Euro 3, whereas Euro 5 is now being adopted in Europe and several other countries. Recommendations to address this issue include enforcing mandatory inspection and maintenance and conducting more tests aimed at motorcycles. Further, the government of Jakarta could encourage ride-hailing providers to promote inspection and maintenance and to offer incentives to replace their old motorcycle fleets with electric 2-wheelers. Lastly, Indonesia should plan for the adoption of Euro 5 standards for motorcycles.

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APPENDIX

Table A1. Vehicle classification

Vehicle name	Note	Vehicle type
Blind van	Modified passenger van to transport cargo, e.g., small bullion	LDT
Bus	Bus	BUS
Delivery van	Delivery van	LDT
Jeep	4X4 vehicle hard top	PV
Jeep kanvas	4X4 vehicle soft top	PV
Light truck	Light truck	LDT
Light truck box	Light truck with box	LDT
Light truck dump	Light dump truck	LDT
Light truck tronton	3-axis light truck	LDT
Microbus	Microbus	PV
Minibus	Minibus (passenger vehicle)	PV (Engine displacement<6000 cc) BUS (Engine displacement>6000 cc)
Pick up	Pick up vehicle	LDT
Pick up box	Pick up vehicle with box	LDT
Pick up dbl cabin box	Pick up double cabin with box	LDT
Pick up double cabin	Pick up double cabin	LDT
Sedan	Sedan	PV
Single bus 12 m	Single 12 M bus	BUS
Spd motor solo	Solo motorcycle	Motorcycle
St. Wagon	Station wagon	PV
Taksi	Taxi	TAXI
Tronton bestelwagon	3 axis truck with enclosed box similar with blind van	LDT
Tronton dump truck	3 axis or more dump truck	HDT
Tronton tangki	3 axis or more tanker truck	HDT
Truck	Truck	HDT
Truck box	Truck with box	HDT
Truck car carrier	Car transporter truck	HDT
Truck crane	Crane truck	HDT
Truck delivery van	Delivery van truck	HDT
Truck load bak	Dump truck equivalent	HDT
Truck tangki	Tanker truck	HDT
Truck tractor head	Tractor head truck	HDT
Truck trailer tangki	Trailer tanker truck	HDT

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