Assessment of real-world vehicle emissions in São Paulo

Kaylin Lee, Mallery Crowe, Yoann Bernard, Guido Giovanelli Haytzmann,
and Ana Beatriz Rebouças

NOVEMBER 2025

ACKNOWLEDGMENTS

This study was funded through the generous support of the FIA Foundation. The authors thank the team of the Department of Mobile Emission Sources at the Environmental Company of the State of São Paulo (CETESB) for the collaboration and support throughout the project. The authors extend the thank you to OPUS RSE and Tecsidel Brasil for the successful implementation of emission testing, Traffic Engineering Company (CET), São Paulo State Transportation Agency (ARTESP), Executive Secretariat for Climate Change (SECLIMA), Municipal Government of Santo André, Federal Highway Police (PRF), São Paulo Transport Company (SPTrans) and Motiva for their operational support in the remote sensing campaign, DETRAN/SP for their contribution to data collection, and Anirudh Narla (ICCT) and Marcelo Bales (CETESB) for their reviews and constructive feedback.

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

Vehicular emissions are the largest contributor to air pollution in the São Paulo Metropolitan Area (SPMA). Although the national Program for the Control of Air Pollution Emissions for Motor Vehicles (PROCONVE) drove down vehicle emissions and promoted cleaner vehicle technologies by setting emission limits, the SPMA's annual average concentrations of nitrogen dioxide (NO_2) and fine particulate matter ($PM_{2.5}$) frequently exceed the 2021 World Health Organization guidelines. The SPMA also suffers from high levels of ground-level ozone (O_3), a secondary air pollutant with serious health implications, which is exacerbated by strong sunlight and frequent high temperatures.

Light-duty vehicles (LDVs) in Brazil are predominantly flex-fuel vehicles (FFVs), which emerged in 2003 and are fueled by any mixture of ethanol and gasoline. For heavy-duty vehicles (HDVs), which are typically fueled by diesel, biodiesel blend is mandatory. These biofuels—ethanol and biodiesel—are produced mainly from domestic sugarcane and soybeans and their use has been widely promoted in Brazil to reduce reliance on imported fossil fuels. Currently, new LDVs and HDVs are required to meet emission limits outlined in the L8 phase (from 2025 onwards) and the P8 phase (from 2023 onwards), respectively, under the PROCONVE program.

This study, conducted under The Real Urban Emissions (TRUE) Initiative, provides insights into the real-world pollutant emissions from vehicles in the SPMA. Over 323,000 vehicle emissions measurements were collected from nine sites across the SPMA from May to July 2024. Remote sensing technology was used to measure emissions of carbon monoxide (CO), hydrocarbons (HC), ammonia (NH_3), nitrogen oxides (NO_X), and ultraviolet smoke (a proxy for particulate matter), in addition to evaporative emissions. This study offers a comprehensive analysis of passenger cars and trucks, which are responsible for a large share of pollutant emissions in the SPMA. The analysis supports the following conclusions and policy recommendations:

Phasing out vehicle groups certified to the L3 and P3 or older emission standards would have an outsized effect on fleetwide emission reductions. Among passenger cars, flex-fuel and gasoline C cars of the L3 standard exhibited the highest real-world NO_X, CO, HC, and NH3 emissions exceeding emissions limits by multiple times while making up only 5.5% of the passenger car sample. These vehicle groups also had the highest share of detectable evaporative emissions, an important precursor to O_3. Diesel trucks introduced before the P3 standard, which are unlikely to be equipped with modern emissions control systems, made up nearly 10% of the truck sample and exhibited real-world NO_X and PM emissions 5 times and 12 times higher, respectively, than the most recent P8 trucks. Scrappage and tax programs that provide financial incentives to replace old internal combustion engine vehicles with battery electric vehicles could effectively reduce emissions.

Updating the PROCONVE program based on the real-world emission performance of the in-use fleet would help ensure emission reductions from newer vehicles. Despite the notable emission reductions from vehicles in the most recent PROCONVE phases at the time of measurement—L7 for passenger cars and P8 for HDVs—real-world emissions still exceeded emission limits, particularly for NO_X and HC (passenger cars) and NO_X and PM (trucks). Closing a loophole that allows some vehicle types used for passenger transport, such as sport utility vehicles and pick-up trucks, to be certified as light commercial vehicles could ensure that the succeeding L8 phase achieves the expected reduction in passenger car emissions. For trucks, updating the P8 phase to require in-service conformity testing for lower power thresholds and cold starts would reduce emissions in urban settings.

Electrification of taxis, ride-hailing vehicles, and urban cargo trucks, which contribute a considerable share of emissions in urban areas, could have disproportionate benefits. Taxis and ride-hailing vehicles, which accounted for nearly 30% of total observed passenger car activity, showed significant emission deterioration from extensive use. L6 flex-fuel taxis and ride-hailing vehicles had real-world NO_X, CO, and HC emissions over 2 times higher than their private counterparts. Urban cargo trucks, largely responsible for last-mile deliveries, also showed real-world NO_X and PM emissions nearly 30% higher than long-haul trucks, likely due to the prevalence of cold starts, which are common in urban driving conditions. Electrification of these specialized vehicle groups with high emission contributions could have an outsized effect on fleetwide emissions.

Implementing a routine inspection at the national or regional level and ensuring vehicle maintenance would address persistent emissions from vehicles. The remote sensing measurements showed that vehicles coming from outside the city account for 50% of the vehicle activity in the city of São Paulo and around 35% of the vehicle activity in the SPMA may be attributable to vehicles registered out-of-state, highlighting that local inspection and maintenance (I/M) programs may not be effective for reducing vehicle emissions in the region. Our findings suggest that I/M programs covering a large geographic area, multiple pollutants (including particulate number and evaporative emissions), and a range of vehicle classes (including both private and commercial vehicles) would be effective in Brazil. Remote sensing can further support the development of I/M programs by informing thresholds based on real-world emissions data to flag vehicles for updates or repairs, in addition to identifying pollutants and vehicle groups to target.

TABLE OF CONTENTS

INTRODUCTION

Despite the considerable improvement in air quality achieved through various government programs targeting industrial and vehicular emissions, the São Paulo Metropolitan Area (SPMA) frequently shows levels of fine particulate matter ($PM_{2.5}$), nitrogen dioxide (NO_2), and ozone (O_3) exceeding the 2021 World Health Organization guidelines.[1] The transport sector contributes over 40% of $PM_{2.5}$ emissions in the city of São Paulo, making it a major source of air pollution alongside industrial sources, such as the burning of sugarcane, wood, and charcoal.[2] The Program for the Control of Air Pollution Emissions by Motor Vehicles (PROCONVE), which established emission limits for vehicles and reduced sulfur content in diesel fuel, has helped to significantly reduce emissions of primary pollutants, such as nitrogen oxide (NO_X) and carbon monoxide (CO). However, PROCONVE has had limited effects on secondary pollutants, such as $PM_{2.5}$ and O_3.[3] Understanding real-world vehicle emissions in São Paulo is important to inform evidence-based policy decisions to reduce persistent vehicle-related pollution.

The Real Urban Emissions (TRUE) Initiative conducted an emissions testing campaign in São Paulo from May to July 2024 in partnership with the State Environmental Agency of São Paulo (Companhia Ambiental do Estado de São Paulo; CETESB) and Traffic Engineering Company (Companhia de Engenharia de Tráfego; CET). Using remote sensing technology, the testing campaign collected over 320,000 measurements of real-world vehicular emissions of CO, hydrocarbons (HC), NO_X, ammonia (NH_3), and PM. The TRUE Initiative seeks to provide cities with a better understanding of their vehicle fleets and associated emissions to support evidence-based policy measures to curb emissions from on-road transportation.

This study builds on the TRUE Initiative's previous work in Latin America and examines the real-world emissions from in-use vehicles in São Paulo and surrounding regions.[4] Specifically, we analyze real-world emissions from passenger cars and trucks, including taxis, ride-hailing vehicles, and urban cargo trucks, and suggest tailored policies to effectively reduce emissions from these segments. The findings and policy recommendations from this study will be particularly important as policymakers discuss plans to improve vehicle emissions reduction programs, such as the vehicle inspection and maintenance program.

BACKGROUND

AIR QUALITY AND ITS HEALTH IMPACTS IN SÃO PAULO

The SPMA includes the city of São Paulo and 38 surrounding municipalities, making it a large urban region with a population of over 20 million inhabitants and 7.1 million cars.[5] A large share of the population relies on private cars, leading to traffic congestion and long travel times along urban roadways.[6] The cost of traffic congestion in the city resulting from factors such as wasted time, fuel consumption, and accidents was estimated to be over US$2 billion in 2019, equivalent to 1.1% of the city's gross domestic product.[7]

Although industrial sources were the primary source of emissions in the 1970s, pollutant emissions in the SPMA have increasingly come from mobile sources, which were responsible for 80% of NO_X emissions in 2012.[8] The PROCONVE program and fuel standards drove a significant decline in ambient concentrations of CO, PM, and SO_2 and a steady decrease in HC and NO_X between

1 Vanessa Silveira Barreto Carvalho et al., "Air Quality Status and Trends over the Metropolitan Area of São Paulo, Brazil as a Result of Emission Control Policies," *Environmental Science & Policy* 47 (March 2015): 68–79, https://doi.org/10.1016/j.envsci.2014.11.001; David Shiling Tsai and Helen Sousa, *Qualidade Do Ar No Município de São Paulo* [Air in the municipality of São Paulo] (Instituto de Energia e Meio Ambiente, 2022), https://energiaeambiente.org.br/wp-content/uploads/2022/05/IEMA_notatecnica_aremSP.pdf.

2 Guilherme Martins Pereira et al., "Source Apportionment and Ecotoxicity of $PM_{2.5}$ Pollution Events in a Major Southern Hemisphere Megacity: Influence of a Biofuel-Impacted Fleet and Biomass Burning," *Atmospheric Chemistry and Physics* 25, no. 8 (2025): 4587–616, https://doi.org/10.5194/acp-25-4587-2025.

3 Maria de Fatima Andrade et al., "Air Quality in the Megacity of São Paulo: Evolution over the Last 30 Years and Future Perspectives," *Atmospheric Environment* 159 (June 2017): 66–82, https://doi.org/10.1016/j.atmosenv.2017.03.051; Carvalho et al., "Air Quality Status and Trends."

4 Michelle Meyer et al., *Assessment of Real-World Passenger Vehicle and Taxi Emissions in Mexico City* (TRUE Initiative, 2024), https://trueinitiative.org/research/assessment-of-real-world-passenger-vehicle-and-taxi-emissions-in-mexico-city/.

5 Companhia Ambiental do Estado de São Paulo (CETESB), *Emissões Veiculares No Estado de São Paulo 2023* [Vehicle emissions in the State of São Paulo 2023] (2024), https://cetesb.sp.gov.br/veicular/wp-content/uploads/sites/6/2024/11/Relatorio-Emissoes-Veiculares-no-Estado-de-Sao-Paulo-2023.pdf.

6 Celio Daroncho and Pedro José Perez Martinez, *Traffic Behavior on São Paulo's Streets: A Post-Pandemic Study* (Universidad Politécnica de Cartagena, 2024), http://hdl.handle.net/10317/13593.

7 Agustina Calatayud et al., *Urban Road Congestion in Latin America and the Caribbean: Characteristics, Costs, and Mitigation* (Inter-American Development Bank Transportation Division, 2021), https://publications.iadb.org/publications/english/document/Urban-Road-Congestion-in-Latin-America-and-the-Caribbean-Characteristics-Costs-and-Mitigation.pdf.

8 Carvalho et al., "Air Quality Status and Trends."

1990 and 2010.[9] Despite these advances, annual average concentrations of NO_2 and $PM_{2.5}$ in the SPMA still frequently exceed the 2021 World Health Organization guidelines—for example, by nearly 4 and 3 times for NO_2 and $PM_{2.5}$, respectively, in 2023.[10] On-road vehicles also contribute to high O_3 concentrations; in 2023, the SPMA recorded very poor O_3 levels (of 160 – 200 µg/m^3) 4.5 times more frequently than in interior and coastal areas of Brazil.[11]

The SPMA's poor air quality is further exacerbated by its meteorological and geographical conditions. Surrounded by mountains in the north and northwest and impacted by winds from the ocean in the southeast, the region experiences frequent occurrence of subsidence layers and low-altitude thermal inversions in winter, which are unfavorable to pollutant dispersion.[12] Strong solar radiation in other seasons is particularly conducive to the formation of ground O_3, which results from the reaction between NO_X and volatile organic compounds (VOCs) from vehicle emissions in the presence of sunlight. The SPMA has a chemical regime in which O_3 formation is VOC-limited, meaning limiting NO_X alone encourages O_3 formation, and reducing VOCs is crucial for O_3 control.[13]

Air pollution in São Paulo has significant effects on the health of its inhabitants. In the city of São Paulo, PM_{10}, $PM_{2.5}$, NO_2, SO_2, and CO emissions are associated with increased risks of cardiovascular and respiratory mortality.[14] Other evidence has linked an increase in hospital admissions for respiratory diseases in children and exposure to pollutants, such as O_3, SO_2, CO, and PM_{10}, in the SPMA.[15] Socioeconomically disadvantaged populations are at higher risk of these impacts. Several studies have found positive correlations between incidences of respiratory cancer and NO_2 levels and between cardiovascular diseases and $PM_{2.5}$ levels in high traffic areas with poorer living conditions within the city.[16]

DEVELOPMENT OF PROCONVE AND FUEL STANDARDS

Numerous efforts have been made to improve the air quality in Brazil over the past few decades. Most notably, PROCONVE, established in 1986 and based on CONAMA (National Environmental Council) Resolution 18/1986, has played an important role in reducing transport-related emissions by setting limits on vehicle emissions for the type-approval and conformity of production stages.[17] In addition to emission limits, PROCONVE also established other fuel and technology requirements. The PROCONVE standards and their requirements are summarized in Table 1 for passenger cars and Table 2 for heavy-duty vehicles (HDVs). A vehicle is required to meet the standards for a given phase based on the date it was built, and is not subject to standards of phases subsequently implemented throughout its lifetime.

The PROCONVE program is loosely based on the European emission standards, and its restrictions tighten progressively with each phase. Most notably, with the implementation of L2 in 1992, passenger cars adopted catalytic converters to meet emission limits; by 2003, all flex-fuel vehicles (FFVs) available in Brazil were equipped with three-way catalytic converters.[18] L4 mandated on-board diagnostic systems, a built-in system that monitors the vehicle's emissions performance, and introduced emission limits for diesel vehicles. L7 introduced a single limit for NO_X and non-methane organic gases (NMOGs) to address O_3 by targeting its precursors, which was further tightened with L8. L8, the most recent phase implemented in 2025, introduced real-driving emissions testing, which

9 Carvalho et al., "Air Quality Status and Trends"; M.H.R.B. Martins et al., "Evolution of Air Quality in the Sao Paulo Metropolitan Area and Its Relation with Public Policies," *International Journal of Environment and Pollution* 22, no. 4 (2004): 430, https://doi.org/10.1504/IJEP.2004.005679.

10 Valeria Mardoñez-Balderrama et al., "Health Impacts of Air Pollution in South America: Recent Advances and Research Gaps," *Current Opinion in Environmental Science & Health* 45 (June 2025): 100627, https://doi.org/10.1016/j.coesh.2025.100627.

11 CETESB, *Emissões Veiculares No Estado*.

12 H Ribeiro and J.V. de Assuncao, "Historical Overview of Air Pollution in Sao Paulo Metropolitan Area, Brazil: Influence of Mobile Sources and Related Health Effects," *Transactions on the Built Environment* 52, accessed August 11, 2025, https://www.witpress.com/elibrary/wit-transactions-on-the-built-environment/52/3229.

13 Carvalho et al., "Air Quality Status and Trends."

14 Maria de Fatima Andrade et al., "Vehicle Emissions and $PM_{2.5}$ Mass Concentrations in Six Brazilian Cities," *Air Quality, Atmosphere, & Health* 5, no. 1 (2012): 79–88, https://doi.org/10.1007/s11869-010-0104-5; Mercedes A. Bravo et al., "Air Pollution and Mortality in São Paulo, Brazil: Effects of Multiple Pollutants and Analysis of Susceptible Populations," *Journal of Exposure Science & Environmental Epidemiology* 26, no. 2 (2016): 150–61, https://doi.org/10.1038/jes.2014.90; Karina Camasmie Abe and Simone Georges El Khouri Miraglia, "Health Impact Assessment of Air Pollution in São Paulo, Brazil," *International Journal of Environmental Research and Public Health* 13, no. 7 (2016): 694, https://doi.org/10.3390/ijerph13070694.

15 Andrade et al., "Air Quality in the Megacity of São Paulo."

16 Adeylson Guimarães Ribeiro et al., "Incidence and Mortality for Respiratory Cancer and Traffic-Related Air Pollution in São Paulo, Brazil," *Environmental Research* 170 (March 2019): 243–51, https://doi.org/10.1016/j.envres.2018.12.034; Mardoñez-Balderrama et al., "Health Impacts of Air Pollution in South America."

17 Resoluçao No. 18, de 6 de Maio de 1986, Official Gazette of June 17, 1986, Section 1, 8792, https://conama.mma.gov.br/?option=com_sisconama&task=arquivo.download&id=41.

18 Andrade et al., "Air Quality in the Megacity of São Paulo."

Table 1. PROCONVE emission standard phases for passenger cars

PROCONVE phase	Date of implementation	CO (g/km)	PM (g/km)	NO_x (g/km)	NMHC (g/km)	HCO (g/km)
L1	Jan 1, 1988	24.0	-	2.0	-	-
L2	Jan 1, 1992	12.0	-	1.4	-	0.15
L3	Jan 1, 1997	2.0	0.05	0.6	-	0.03
L4	Jan 1, 2007	2.0	0.05	0.25	0.16	0.03
L5	Jan 1, 2009	2.0	0.05	0.12	0.05	0.02
L6	Jan 1, 2013	1.3	0.025	0.08	0.05	0.02
L7	Jan 1, 2022	1.0	0.006	0.08[a]		0.015
L8	Jan 1, 2025[b]	1.0[c]	0.006	0.08[c]		0.015

Note: Date of implementation refers to the date each standard became mandatory for all new vehicles.

[a] NO_x and non-methane hydrocarbon (NMHC) limits were replaced by a single NO_x + non-methane organic gas (NMOG) limit from L7.

[b] L8 introduced a corporate limit of 0.05 g/km for NO_x + NMOG emissions, which are compared against the average individual vehicle model emission levels weighted by the annual sales of each model. This limit decreases to 0.04 g/km in 2027 and 0.03 g/km in 2029.

[c] L8 introduced real-driving limits for CO and NO_x + NMOG set at 2 times type-approval limits starting 2025 and 1.5 times type-approval limits from 2027 onward.

Table 2. PROCONVE emission standard phases for heavy-duty vehicles

PROCONVE phase	Date of implementation	CO (g/kWh)	PM (g/kWh)	NO_x (g/kWh)	NMHC (g/kWh)	THC (g/kWh)	NH_3 (ppm)
P1	Jan 1, 1989	Only smoke opacity limit of 2.5					
P2	Jan 1, 1996	11.20	–	14.40	–	2.45	–
P3	Jan 1, 2000	4.9	0.7	9.0	–	1.23	–
P4	Jan 1, 2002	4.0	0.15	7.0	–	1.1	–
P5[a]	Jan 1, 2006	5.45	0.21	5.0	0.78	–	–
P7[a]	Jan 1, 2012	4.0	0.03	2.0	0.55	–	25
P8[b]	Jan 1, 2023	4.0	0.01	0.46		0.16	10

Note: P6 was never implemented due to the unavailability of ultra-low-sulfur diesel fuel at the time required to meet the emission limits. Date of implementation refers to the date each standard became mandatory for all new vehicles.

[a] P5 and P7 limits are based on the European Transient Cycle, which involves testing in urban, rural, and motorway conditions.

[b] P8 limits are based on the World Harmonized Transient Cycle, which replaced the European Transient Cycle.

has been shown to be effective in reducing the gap between real-world and laboratory emissions in Europe.[19]

For HDVs, although PROCONVE standards were established in 1990, legally binding limits were only introduced with P3 in 2000.[20] Sulfur content in diesel fuel has also decreased over time to meet the more stringent emission limits imposed by successive phases of the standards. The lack of diesel fuel with sulfur content below 50 ppm (S50), which was necessary to achieve the P6 emission limits planned for implementation in 2009, resulted in the P5 phase being extended until 2011. However, diesel with sulfur

19 Joshua Miller and Vicente Franco, *Impact of Improved Regulation of Real-World NO_x Emissions from Diesel Passenger Cars in the EU, 2015–2030* (International Council on Clean Transportation, 2017), https://theicct.org/publication/impact-of-improved-regulation-of-real-world-nox-emissions-from-diesel-passenger-cars-in-the-eu-2015%e2%88%922030/.

20 Thiago Nogueira et al., "Evolution of Vehicle Emission Factors in a Megacity Affected by Extensive Biofuel Use: Results of Tunnel Measurements in São Paulo, Brazil," *Environmental Science & Technology* 55, no. 10 (2021): 6677–87, https://doi.org/10.1021/acs.est.1c01006.

content below 10 ppm (S10) was made available in time for implementation of the P7 standards, which enabled the requirement of selective catalytic reduction and diesel particulate filters in HDVs. P8 further lowered emission limits for NO_X, PM, and NH_3, and introduced a particle number (PN) limit of 6 x 10^{11}/kWh.

The development of PROCONVE has been accompanied by various policies to promote the use of biofuels—ethanol and biodiesel—which are mostly domestically produced from sugarcane and soybeans. Proálcool, the national ethanol program implemented in 1975, mandated the mixture of ethanol and gasoline, with varied ratios over the years.[21] The emergence of FFVs in 2003 allowed drivers to choose any mix of ethanol (E100) and gasoline C (gasoline mixed with 20%–25% anhydrous ethanol). Since 2008, the addition of biodiesel to diesel fuel has been mandatory and the biodiesel blending requirement has gradually increased from 2% to 15%. At the time of this study, the mandatory minimum blend of ethanol in gasoline was 27% (E27, or gasoline C) and biodiesel in diesel fuel was 14% (B14).[22] Due to the flex-fuel technology, drivers of FFVs can refuel their vehicles with any mix of E27 and E100.

VEHICLE PROGRAMS IN THE CITY OF SÃO PAULO

São Paulo has implemented various local policies and programs to curb traffic emissions. The Rodízio Veicular program was introduced in 1995 in the SPMA to restrict passenger cars and commercial vehicles from being driven in the central area of São Paulo from 7:00 am to 8:00 pm, Monday through Friday, based on the last digit of the vehicle's number plate.[23] The initiative, which had a compliance rate of over 90%, was associated with a reduction in CO and PM_{10} levels despite its short duration.[24] The program was made permanent in 1997 in a 152 km^2 area in São Paulo city during peak hours from 7:00 to 10:00 am and from 5:00 to 8:00 pm, Monday through Friday.[25] The Rodízio program in the reduced geographic area was associated with minor air pollution alleviation during its implementation, but the net effects on air pollution merit further investigation.[26]

In an effort to identify vehicle tampering and encourage corrective and preventive maintenance, the São Paulo city council introduced a mandatory environmental vehicle inspection program in 2009.[27] However, this program was suspended after 5 years, showing limited effects on atmospheric $PM_{2.5}$ and CO levels and no measurable health benefits.[28] Currently, the development of a new federal inspection program is under discussion in Brazil.[29]

REMOTE SENSING STUDY OVERVIEW

DATA COLLECTION AND PROCESSING

The TRUE Initiative conducted remote sensing emissions testing to measure real-world emissions from vehicles in the SPMA over 40 days from May 8 to July 5, 2024. The dry winter period between May and July in São Paulo is important for air pollution because the stable atmosphere and frequent thermal inversions worsen $PM_{2.5}$ and O_3 levels. A total of 323,934 measurements were collected from nine sites across the SPMA.

21 Manfred Nitsch, "The Proálcool Biofuels Program in the Context of the Brazilian Energy Strategy," *Brazilian Journal of Political Economy* 11, no. 2 (1991): 274–99, https://doi.org/10.1590/0101-31571991-0712.

22 The mandatory blend of ethanol in gasoline was increased to 30% from August 1, 2025. See: Brazilian Government, "Governo aprova aumento de etanol na gasolina de 27% para 30% e de 14% para 15% no biodiesel [Government approves increase in ethanol in gasoline from 27% to 30% and in biodiesel from 14% to 15%], June 25, 2025, https://www.gov.br/planalto/pt-br/acompanhe-o-planalto/noticias/2025/06/governo-aprova-aumento-de-etanol-na-gasolina-de-27-para-30-e-de-14-para-15-no-biodiesel.

23 Government of State of São Paulo, *Decreto nº 41.858, de 12 de junho de 1997* [Decree No. 41.858, of June 12, 1997], accessed August 18, 2025, https://governo-sp.jusbrasil.com.br/legislacao/171386/decreto-41858-97.

24 C.-Y. Cynthia Lin et al., *The Effects of Driving Restrictions on Air Quality: São Paulo, Bogotá, Beijing, and Tianjin*, paper presented at the Agricultural & Applied Economics Association's 2011 AAEA & NAREA Joint Annual Meeting, Pittsburgh, Pennsylvania, July 24–26, 2011), https://www.researchgate.net/publication/254384191_The_Effects_of_Driving_Restrictions_on_Air_Quality_Sao_Paulo_Bogota_Beijing_and_Tianjin; Pedro Jacobi et al., "Governmental Responses to Air Pollution: Summary of a Study of the Implementation Ofrodízio in São Paulo," *Environment & Urbanization* 11, no. 1 (1999): 79–88, https://doi.org/10.1177/095624789901100117.

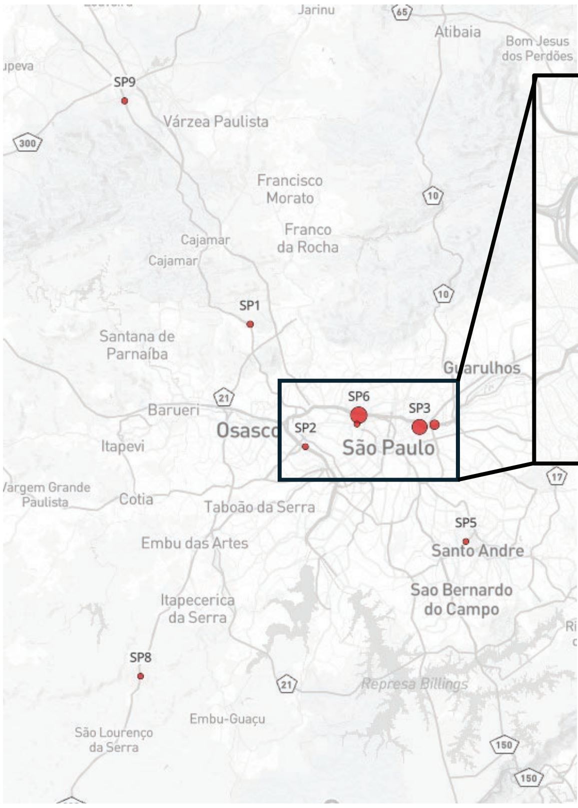
25 Lin et al., *The Effects of Driving Restrictions on Air Quality*.

26 Lin et al., *The Effects of Driving Restrictions on Air Quality*.

27 Municipality of São Paulo, *Decreto Nº 50.232 de 17 de novembro de 2008 [Decree No. 50.232, of November 17, 2008]* accessed August 18, 2025, http://legislacao.prefeitura.sp.gov.br/leis/decreto-50232-de-17-de-novembro-de-2008.

28 Orlei Ribeiro de Araujo and Milena Corrêa Araujo, "O Impacto Nulo do Programa de Inspeção Veicular na Saúde Pública em São Paulo, SP" [The null impact of the vehicle inspection program on public health in São Paulo, SP], *Journal of Public Health* 54 (August 2020): 84, https://doi.org/10.11606/s1518-8787.2020054001856.

29 Brazilian government, "MMA Formaliza Cooperações Estratégicas para Aprimoramento da Gestão da Qualidade do Ar" [MMA formalizes strategic cooperation to improve air quality management], September 18, 2025, https://www.gov.br/mma/pt-br/assuntos/noticias/mma-formaliza-cooperacoes-estrategicas-para-aprimoramento-da-gestao-da-qualidade-do-ar-1.



Site	Slope	Number of measurement
SP1	0.5	8,865
SP2	2	4,085
SP3	0.2	118,156
SP4	0.7	46,104
SP5	2	3,197
SP6	2.6	134,976
SP7	0.1	1,814
SP8	0.4	600
SP9	2.2	5,565

Figure 1. Emission testing campaign (top) and map of emission testing sites and number of measurements from each site (bottom)

Testing sites were pre-selected in conjunction with CETESB, OPUS RSE, and Tecsidel Brasil to ensure that the data sample was representative of the typical traffic in the SPMA and included diverse vehicle types. As shown in Figure 1, four sites were located outside the city to capture traffic coming in and out of the city, and five sites were within the city boundary to measure urban traffic emissions.

The testing was led by Tecsidel Brasil, under the supervision of OPUS RSE. The Opus portable RSD5700 system was used to measure tailpipe emissions of CO, HC, NO_X, NO_2, NH_3, and UV smoke (a proxy for PM) of vehicles as they drove past the testing sites. The OPUS system provides pollutant concentrations as a ratio to carbon dioxide (CO_2). Evaporative emissions—HC emissions from sources other than the tailpipe, like permeation, fuel venting through the canister, and fuel leaks—were also estimated. A camera was set up in parallel to capture images of passing vehicles and their license plate information, which were used to retrieve vehicle specification data from the State's vehicle registry database (Detran). Given the sensitive nature of some data in the registry database, this process was conducted by CETESB. Using the fuel type data, the ratio of pollutant emissions concentration in the exhaust plume was converted to fuel-specific emissions (g pollutant/kg fuel) for each measurement. Each record consists of vehicle technical data; kinetic conditions like speed, acceleration, and vehicle specific power (VSP); emissions data; and environmental conditions, such as ambient temperature, pressure, and humidity.

SAMPLE OVERVIEW

The sample included a total of 323,934 raw measurements from 150,605 unique vehicles, as some vehicles were measured more than once. After data collection, the measurements were audited to ensure data quality. To characterize the driving conditions of vehicles measured, all records that were audited and checked for valid speed, acceleration, and VSP were considered. Some of the emission measurements included in the sample may not be valid. Table 3 summarizes the testing conditions of all measured vehicles, including those measured in the city of São Paulo and those measured in other municipalities surrounding the city. The ambient temperature measured in São Paulo city was higher than that measured in other municipalities, consistent with the heat island effect commonly found in highly urbanized areas.[30] Vehicles measured in São Paulo city had lower median speed, higher median acceleration, and higher median VSP than those measured in other municipalities.

Vehicle technical data were available for around 65% of the records (207,729 raw records from 127,864 unique vehicles) from the Detran database. The remaining 35% of the records (116,205 raw records from 22,741 unique vehicles) with vehicle information that was not retrievable from the database are likely from vehicles registered outside of the state. Due to the lack of available technical data, these records were not included in the study. This highlights that a large share of vehicle activity in the SPMA is likely from out-of-state vehicles. Additionally, out of 305,135 measurements taken from the sites located in the city, only 144,313 measurements (47%) are from vehicles registered in the city.

After excluding records with no vehicle technical data, those that were not audited, and those with invalid speed and VSP measurements, the usable dataset comprised 165,868 records from 106,506 unique vehicles. OPUS RSD systems review and validate emissions measurements, providing a validity flag for each pollutant. Out of the 165,868 records, the share of valid emission measurements varied from 48% (NH_3) to 97% (smoke UV, or PM). The number of valid emissions measurements and share for each pollutant is given in Table 4. These filters are only applied in the emissions analysis.

Table 3. Summary of driving conditions of the vehicles measured during the testing campaign

Median	All measurements	São Paulo city (SP2, SP3, SP4, SP6, SP7)	Other municipalities (SP1, SP5, SP8, SP9)
Number of raw measurements	323,934	305,135	18,799
Ambient temperature (°C)	26.5	26.7	23.2
Speed (km/h)	16.7	16.6	18.1
Acceleration (km/h/s)	1.8	1.9	0.2
Vehicle specific power (kW/t)	9.5	9.8	4.1

Table 4. Number of valid emission measurements and share for each pollutant

Usable data	Total measurements with available vehicle technical data, valid speed, and VSP	Validity flag				
		NO_x	PM (smoke UV)	CO	HC	NH_3
Number of measurements	165,868	114,831	160,681	128,714	136,116	80,272
Share	100%	69%	97%	78%	82%	48%

30 Augusto Cezar Lima do Nascimento et al., "Comparison between Air Temperature and Land Surface Temperature for the City of São Paulo, Brazil," *Atmosphere* 13, no. 3 (2022): 491, https://doi.org/10.3390/atmos13030491.

FLEET COMPOSITION

The vehicles measured during the testing campaign were mainly passenger cars, which accounted for 61% of the sample. Light commercial vehicles (LCVs) made up the second largest vehicle class at 27%, followed by 2-wheelers (7%), trucks (4%), and buses (1%). Around 6% of the measured vehicles in the passenger car and LCV segments were imported vehicles.

Passenger cars in Brazil are predominantly FFVs, which can use commercial fuels such as gasoline C (E27), hydrous ethanol (E100), or any blend of these fuels.[31] As shown in Figure 2, in the passenger car segment, flex-fuel vehicles made up 88% of the sample and gasoline C (originally built as gasoline vehicles) made up 11%. Passenger cars built to use only 100% ethanol (E100), compressed natural gas (CNG), or electricity each accounted for less than 0.5% of the measured fleet. In Brazil, CNG systems can easily be installed in vehicles as a retrofit, allowing drivers to choose between CNG, gasoline C, and ethanol, depending on the original vehicle.[32]

Flex-fuel vehicles also made up 60% of LCVs and 47% of 2-wheelers in the sample. The remaining 2-wheelers (53%) used gasoline C. Some diesel sport utility vehicles (SUVs) or pick-up trucks may be found in the LCV segment, as these vehicles are allowed to be certified as LCVs in Brazil although they are primarily for passenger transport. Gasoline C was the primary fuel type for 16% of LCVs in the sample, and 63% of these LCVs were imported vehicles. Diesel vehicles accounted for 23% of measured LCVs, and CNG and hydrous ethanol (E100) vehicles accounted for less than 1%. Among HDV segments, such as trucks and buses, diesel vehicles made up over 99% of the measurements.

The average age of flex-fuel passenger cars in the sample was 8 years, whereas that of gasoline C cars was 20 years. FFVs were also younger, on average, than gasoline C vehicles in the LCV and 2-wheeler segments, which highlights the high market share of FFVs in recent years. The average ages of the truck and bus fleets in the dataset were 14 and 8 years, respectively. The younger average age of buses can be attributed to the city of São Paulo's age limits on transit buses, which set a maximum age of 10 years for diesel buses and 15 years for electric buses.[33]

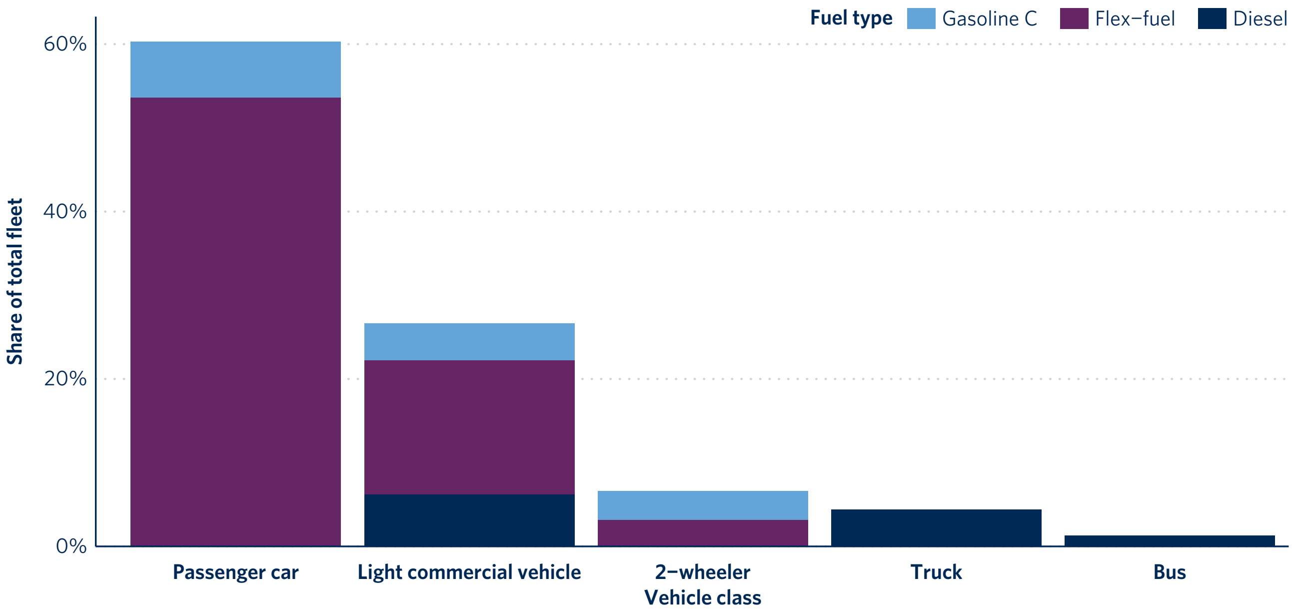


Figure 2. Share of measurements by vehicle class and fuel type

31 At the time of the study, the mandated blend of anhydrous ethanol in gasoline fuel was 27 vol.% and E27 was commercially available as gasoline C.

32 Ithamar Ribeiro Rangel et al., "A Comparison of the Emissions of Gasoline–Ethanol Fuel and Compressed Natural Gas Fuel Used in Vehicles with Spark Ignition Engine in Rio de Janeiro: Brazil," *Clean Technologies and Environmental Policy* 23 (September 2021): 2895–907, https://doi.org/10.1007/s10098-021-02208-7.

33 Secretaria Municipal de Mobilidade Urbana e Transporte, "Contratos de Concessão" [Concession contracts], Prefeitura de São Paulo, August 15, 2025, https://prefeitura.sp.gov.br/web/mobilidade/w/institucional/sptrans/acesso_a_informacao/284142.

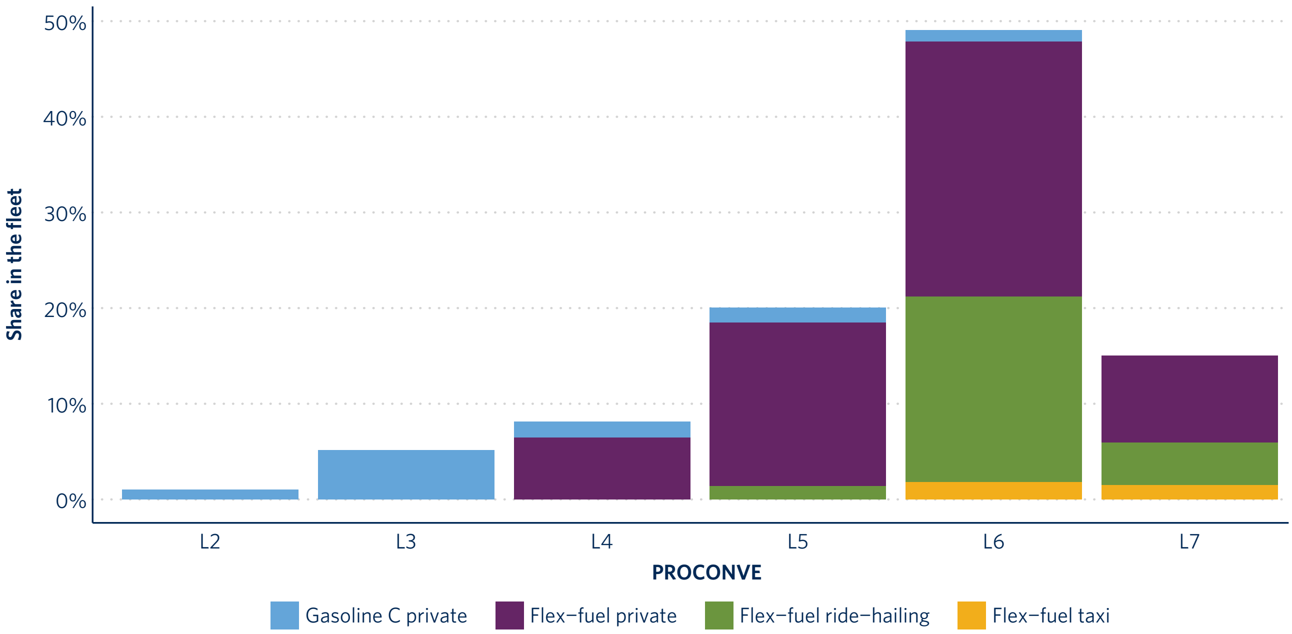


Figure 3. Distribution of PROCONVE, fuel type, and service type for passenger cars

Note: Only shares above 1% are presented.

Vehicles from the municipalities surrounding São Paulo city made up 28% of the sample, indicating a fair share of traffic coming into the city. The shares of vehicle measurements from other municipalities were similar for passenger cars, LCVs, and 2-wheelers, at between 26% and 30%. For the truck segment, however, 63% of vehicle measurements were from outside the city, and the share for the bus segment was lower, at 18%.

EMISSIONS ANALYSIS

PASSENGER CAR EMISSIONS

To compare passenger car emissions and PROCONVE emission limits, we first converted passenger car emissions from fuel-specific values (g/kg) to distance-specific values (g/km), a unit consistent with the limits, using real-world fuel economy data. Emissions on a distance-traveled basis, accounting for differential energy intensity of fuels, also allow for a more accurate comparison of emissions from vehicles using different fuel types. We used fuel economy data from two sources. The first was Brazil's labeling program (Programa Brasileiro de Etiquetagem Veicular, PBEV), coordinated by the National Institute of Metrology, Standardization, and Industrial Quality (INMETRO), which reports real-world energy and fuel usage in urban driving cycle. The second was type-approved energy and fuel consumption of production samples reported by manufacturers as part of the conformity of production program.[34] For FFVs, we assumed an average fuel blend of E52 based on CETESB's estimate from 2024.[35] We further assumed that gasoline C vehicles use the fuel blend of E27 and ethanol vehicles use E100.

Figure 3 shows the distribution of passenger car measurements by PROCONVE phase, fuel type, and service type. Ride-hailing vehicles and taxis are treated separately as they are subject to different regulations in the city of São Paulo. Vehicles that meet the PROCONVE phases L6 and L5 standards were the most common, accounting for 47% and 20% of the passenger car measurements, respectively. The figure also depicts the

34 For FFVs, the average gap between real-world and type-approval energy consumption values, estimated by comparing the PBEV data (available from 2009 to 2023) with the conformity of production data from 2023, was applied to the available conformity of production data from 1983 to derive real-world energy consumption values for FFVs of all model years from 2003, when FFVs were introduced in Brazil. For mono-fuel ethanol (E100) and gasoline C (E27) vehicles, type-approval fuel consumption values were corrected for urban driving conditions, using the methodology from the U.S. Environmental Protection Agency Federal Test Procedure (FTP75), which uses the same testing method as the Brazilian norm ABNT NBR 6601 for the urban driving cycle. The average fuel economy values of flex-fuel and gasoline C passenger cars used in the study were 7.8 kg/100km and 8.6 kg/100km, respectively. See INMETRO, *Decreto No. 169 de 3 de maio de 2023* [Decree No. 169 of May 3, 2023], accessed October 27, 2025, http://www.inmetro.gov.br/legislacao/detalhe.asp?seq_classe=1&seq_ato=3000; CETESB, "Emissão Veicular: Relatórios e Publicações" [Vehicle emissions: Reports and publications], accessed October 23, 2025, https://cetesb.sp.gov.br/veicular/relatorios-e-publicacoes/.

35 Ministério de Minas e Energia, "Painel Dinâmico do Mercado Brasileiro de Combustíveis Líquidos" [Dynamic panel of the Brazilian liquid fuel market], October 1, 2020, https://www.gov.br/anp/pt-br/centrais-de-conteudo/paineis-dinamicos-da-anp/paineis-dinamicos-do-abastecimento/painel-dinamico-do-mercado-brasileiro-de-combustiveis-liquidos.

growth of flex-fuel passenger cars since their introduction in 2003—the share of flex-fuel within L3 passenger cars was 6%, increasing to 79% for L4 passenger cars and 99% for L7 passenger cars. Among FFVs, a large share were ride-hailing vehicles, which made up nearly 40% and 30% of the L6 and L7 passenger car samples, respectively. Ride-hailing vehicles accounted for about 25% of the total passenger car sample, whereas taxis accounted for 3%. Gasoline C was the predominant fuel type for L2 and L3 passenger cars, accounting for around 90%, but this share fell to 2% by L6 and to less than 1% by L7.

We present the real-world emissions of NO_X, CO, total HC, and NH_3 for passenger cars against the PROCONVE limits, because these pollutants are the primary emissions of concern for flex-fuel, gasoline C, and ethanol vehicles, whereas PM emissions are more significant for diesel vehicles.[36] In particular, NH_3 plays an important role in the formation of secondary $PM_{2.5}$, which, along with O_3, remains a large problem for the SPMA. We present the results for private vehicles, ride-hailing vehicles, and taxis separately due to the larger emission impact of high-usage fleets.

Figure 4 shows the mean distance-specific emissions of NO_X, CO, HC, and NH_3 from passenger cars by PROCONVE standards, fuel type, and service type.[37] Emission limits for non-methane hydrocarbons (NMHC) and NO_X were replaced by the NO_X + NMOG measure in PROCONVE L7. L1 and L2 cars made up less than 1.5% of the measured fleet and are not shown due to insufficient measurements. Despite a notable downward trend in real-world emissions of all pollutants examined with the advancement of PROCONVE standards, most vehicle groups in the sample showed real-world emissions exceeding the respective PROCONVE limits, except for L7 in the case of CO emissions. There is currently no NH_3 limit for passenger cars in the PROCONVE standards.

The highest levels of emissions were seen in L3 and L4 cars, with real-world NO_X, CO, and HC levels exceeding the respective limits by multiple times.[38] Emissions of all four pollutants from these vehicles were also multiple times higher than those from more modern vehicles certified to L6 and L7. However, more stringent limits nearly halved NO_X, CO, and HC emissions of private gasoline C cars and FFVs in L5 and again in L6.

As noted above, L7 introduced a single limit for NO_X and NMOG, made up of both nonoxygenated and oxygenated HC, a combination of which contributes to ground-level O_3 in the presence of sunlight. This step further reduced NO_X emissions among private flex-fuel passenger cars by approximately 60%, CO emissions by 75%, HC emissions by 50%, and NH_3 emissions by 40%. However, their real-world NO_X and HC emissions were still significantly above the 0.08 g/km combined limit for NO_X and NMOG, even as remote sensing technology likely underestimates oxygenated emissions, including aldehydes.[39]

Despite the substantial emissions improvement among private flex-fuel cars, emissions from flex-fuel ride-hailing vehicles and taxis vary significantly in the dataset. In particular, L6 ride-hailing vehicles, which accounted for over 20% of all passenger car measurements, showed real-world NO_X, CO, and HC emissions up to 2.5 times higher than those from private flex-fuel cars. The elevated emissions are likely due to the extensive usage of ride-hailing vehicles in the city and low maintenance rate. L6 required manufacturers to ensure that the emission limits are met within the durability period of 5 years or 80,000 km. With an average age of 6 years, the L6 ride-hailing vehicles are likely operating beyond their durability period. The newer L7 ride-hailing vehicles also showed NO_X, CO, and HC emissions up to 2.2 times higher than those from private flex-fuel cars, despite their average age of 1 year. L7 increased the durability period to 10 years or 160,000 km, but the results demonstrate that these high-mileage vehicles already show significant emissions deterioration.

Flex-fuel taxis accounted for 3% of passenger car measurements, much lower than flex-fuel ride-hailing vehicles, which made up 25%. The flex-fuel taxis in the dataset, which are mostly certified to the L6 and L7 standards, had an average age of 4 years, around 2 years younger than flex-fuel ride-hailing vehicles. This is likely because São Paulo city has an age limit of 5 years for taxis

36 The more precise air to fuel ratio required in spark ignition engines used in these vehicles leads to minor PM emissions compared to compression ignition engines used in diesel vehicles.

37 Hydrocarbon emissions measured by infrared (IR) censors and calibrated with propane are underestimated due to many hydrocarbon compounds absorb less IR than propane. Therefore, we used scaling factors of 2.64 (for E27), 2.38 (E52), and 2 (E100).

38 Although RSD systems measure total HC, NMHC limits are used for HC, as we assume most of HC emissions from FFVs and gasoline C vehicles are non-methane HC. It is also important to note that results may underestimate total HC of vehicles using ethanol blends as remote sensing does not measure oxygenated HC, such as aldehydes (HCO).

39 L7 introduced a specific limit for aldehyde emissions, which are mainly emitted by vehicles using ethanol fuel mixture and have a high ozone formation potential. However, further research is needed to examine aldehyde emissions from in-use vehicles in the SPMA due to the limitations of remote sensing.

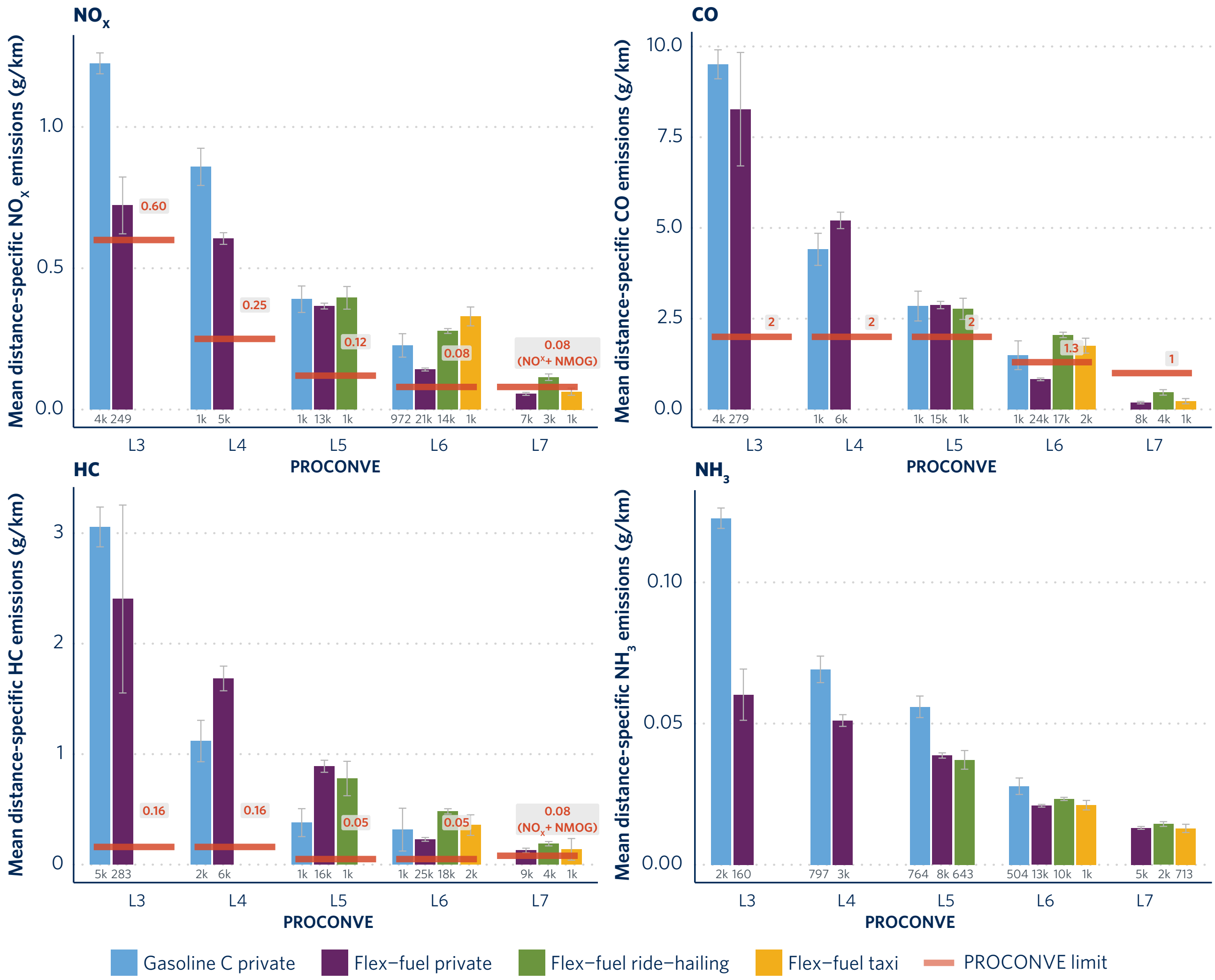


Figure 4. Mean distance-specific NO_x, CO, HC and NH_3 emissions from passenger cars

Note: Whiskers represent the 95% confidence interval of the mean. Numbers below bars indicate number of measurements. Only results with over 100 measurements are presented.

but 10 years for ride-hailing vehicles.[40] Despite this, their real-world emissions levels were similar to those of flex-fuel ride-hailing vehicles, with some variance due to the small sample sizes.

Private gasoline C passenger cars showed higher NO_x, CO, and NH_3 emissions across nearly all PROCONVE standards compared with private flex-fuel passenger cars. This is partially attributed to the difference in engine sizes—the average engine size of gasoline C passenger cars was 1.5 L, while that of flex-fuel passenger cars was smaller, at 1.3 L. Despite the small sample of gasoline C cars, the NO_x and CO emission gap between the gasoline C and flex-fuel cars is notable for L6: Private gasoline C cars exhibited 1.6–1.9 times higher mean NO_x and CO emissions than private flex-fuel cars. For NH_3, L3 gasoline C cars had over double the emissions of their flex-fuel counterparts.

A closer look into the L6 passenger cars reveals that 75% of L6 gasoline C cars were imported, whereas the share of imported L6 flex-fuel cars was lower, at only 5%. Although the share of gasoline C cars has declined drastically over the years with the emergence of flex-fuel vehicles in 2003, Brazil has seen an increase in the import of new gasoline C passenger cars. Imported gasoline C passenger cars are subject to the same homologation process as domestic

40 Prefeitura de São Paulo, *Decreto Nº 8.439 de 10 de outubro de 1969* [Decree No. 8.439 of October 10, 1969], accessed October 15, 2025, https://legislacao.prefeitura.sp.gov.br/leis/decreto-8439-de-10-de-outubro-de-1969; Prefeitura de São Paulo, Decreto No 62.040 de 12 de dezembro de 2022 [Decree No. 62.040 of December 12, 2022], accessed September 16, 2025, https://legislacao.prefeitura.sp.gov.br/leis/decreto-62040-de-12-de-dezembro-de-2022/consolidado.

gasoline C passenger cars once they enter Brazil, but imported gasoline C cars showed real-world NO_X, CO, and HC emissions 2–4.2 times higher than their domestic counterparts. The elevated emissions can be partially attributed to the larger size and heavier weight of imported cars compared with domestic ones.[41] Additionally, gasoline direct injection (GDI), a technology that improves thermal efficiency and fuel economy, is found mostly in imported vehicles, and more specifically imported sports vehicles.[42] Numerous studies have documented that vehicles with GDI technology contribute higher levels of NO_X, particulate number (PN), and HC or nonoxygenated VOCs than conventional internal combustion engine vehicles, and that the emission contributions are several times higher during cold start conditions.[43]

EVAPORATIVE EMISSIONS FROM PASSENGER CARS

Vehicular evaporative emissions are HC emissions that escape from the fuel system into the atmosphere and contribute to atmospheric VOCs with harmful health effects. Evaporative emissions occur when fuel permeates through different fuel system components or there is a leak in one of the components, allowing fuel vapor, or even liquid, to escape. Modern vehicles are equipped with an evaporative emission control system, which captures and stores fuel vapors in a charcoal canister and purges them to the engine for combustion.

Evaporative emissions are particularly noteworthy in the SPMA due to the frequent high temperatures and humidity in the region, conditions in which evaporative emissions are more likely to occur. Over the years, Brazil has introduced and enhanced evaporative control measures, with the most recent development being updated testing methods and tightened limits for passenger cars in L8.[44]

Given the significance of evaporative emissions, an assessment of them is incorporated into this study.

Currently, studies of evaporative emissions based on remote sensing measurements are limited and their accuracy is not sufficient to conduct quantitative analysis.[45] However, OPUS RSD systems report whether evaporative emissions are detected as an index ranging from 0 to 4, with 4 indicating the highest level of evaporative emissions, which allowed us to analyze the evaporative emission trends.[46] We only present the evaporative emission trends for flex-fuel and gasoline C passenger cars as these vehicle groups had more than 300 evaporative emission indices in the dataset.

Overall, the share of passenger cars showing detectable evaporation emissions was minor, at 1%, for flex-fuel vehicles. The share of gasoline C passenger cars was more substantial at 6%. Both gasoline C and flex-fuel passenger cars showed declining shares of vehicles with evaporative emissions with newer standards, as shown in Figure 5. For measured gasoline C cars, the rate was highest at 16% for L2 and 8% for L3, but significantly lower for the successive PROCONVE phases, recording less than 1% by L5 and L6. Flex-fuel passenger cars showed a similar trend in the dataset: Evaporative emissions were detected for 6% of L3, 4% of L4, 3% of L5, and below 1% of L6 and L7. The notable improvement in evaporative emissions for L6 flex-fuel passenger cars can likely be attributed to the adoption of the 1-hour diurnal test and 1-hour hot soak test requirements, with a limit of 1.5 g per test in L6. The update to the 48-hour test, aligning with the testing method used in the U.S. light-duty vehicle emission control program, and the lowering of the limit to 0.5 g per test in L7 likely led to further improvement shown for L7 flex-fuel passenger cars.[47]

Although newer cars fueled by gasoline C and flex-fuel, particularly those above L6, showed substantially reduced on-road evaporative emissions, older vehicles with persistent evaporative emissions are still widespread. L2 and L3 gasoline C cars with the highest shares of vehicles with detectable evaporative emissions, of 16%

41 The median engine size of L6 imported gasoline C vehicles (1,798 cc) was around 20% higher than that of L6 domestic gasoline C vehicles (1,496 cc).

42 Francisco Posada and Cristiano Façanha, *Brazil Passenger Vehicle Market Statistics* (International Council on Clean Transportation, 2015), https://theicct.org/publication/brazil-passenger-vehicle-market-statistics/.

43 Zhuoyao He et al., "Impacts of Gasoline Fuel Components on GDI Engine Performances: Part 1, Influence on Gaseous Toxic Pollutants," *Fuel 310* (February 2022): 122423, https://doi.org/10.1016/j.fuel.2021.122423; Xian Wu et al., "Impacts on Real-World Extra Cold Start Emissions: Fuel Injection, Powertrain, Aftertreatment and Ambient Temperature," *Environmental Pollution* 324 (May 2023): 121339, https://doi.org/10.1016/j.envpol.2023.121339.

44 Tim Dallmann, *Brazil PROCONVE L-7 and L-8 Emission Standards for Light-Duty Vehicles* (International Council on Clean Transportation, 2020), https://theicct.org/publication/brazil-proconve-l-7-and-l-8-emission-standards-for-light-duty-vehicles/.

45 Charles L. Blanchard, *Remote Sensing Device (RSD) Statistical Analysis*, CRC Report No. E-119-3a (Coordinating Research Council, 2023), https://crcao.org/wp-content/uploads/2023/04/E-119-3a-Final-Report.pdf.

46 OPUS's algorithm to estimate evaporative emissions uses HC and CO_2 measurements from each of the 100 plume points in the 1 second of data collection and two regressions. When the first linear regression between HC and CO_2 shows weak correlation, this is considered a sign of evaporative (HC) emissions from sources other than tailpipe. The slopes of the linear regression and a LOESS regression are further compared to identify indication of evaporative (HC) emissions.

47 Dallmann, *Brazil PROCONVE L-7 and L-8 Emission Standards.*

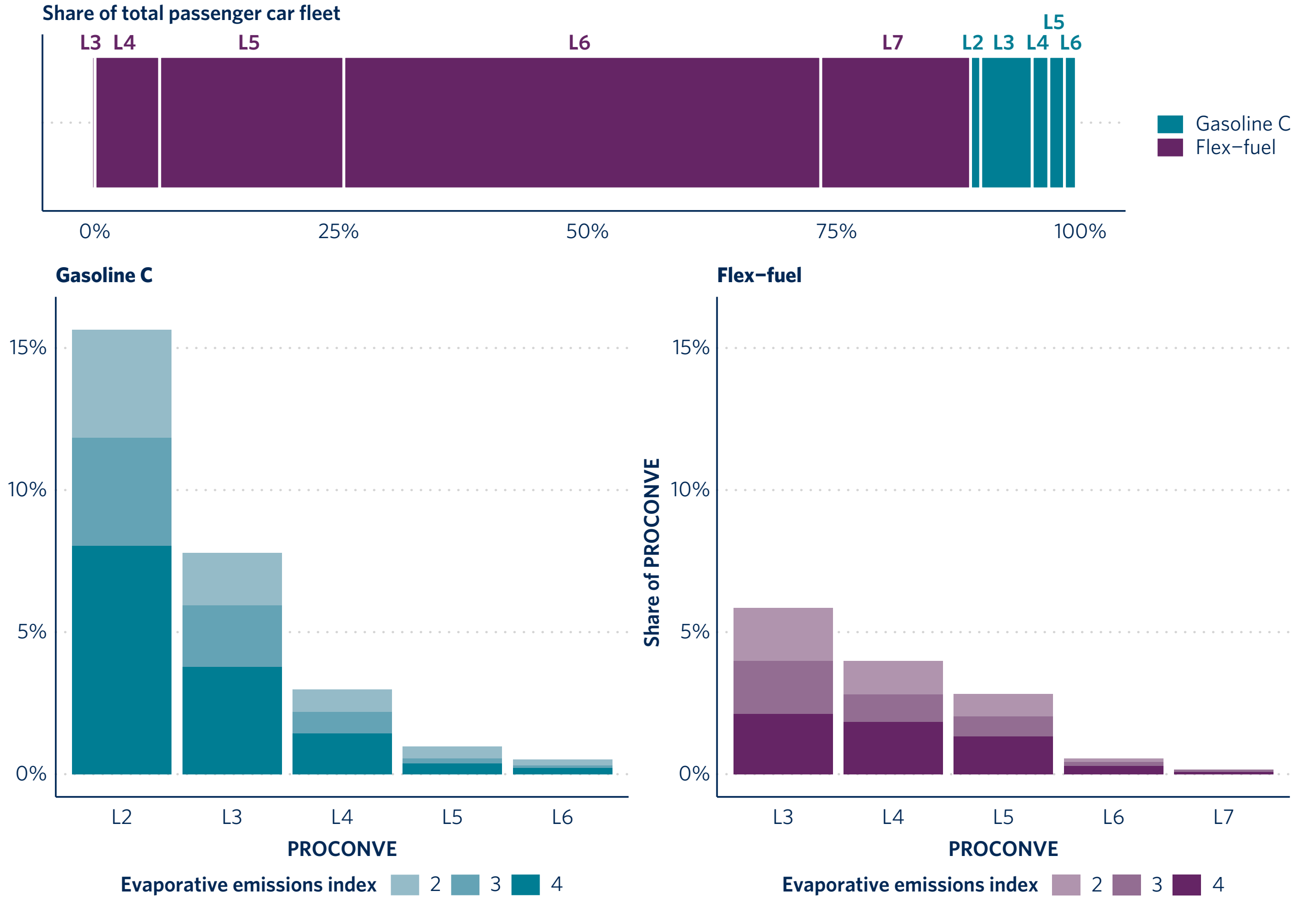


Figure 5. Share of flex-fuel and gasoline C vehicles in the total measured passenger car fleet (top) and share of vehicles with detectable evaporative emissions and their associated emission index by PROCONVE for gasoline C (bottom left) and flex-fuel (bottom right) passenger cars

Note: Only the PROCONVE standards with valid evaporative emission measurements of at least 300 are presented.

and 8%, respectively, made up 6% of the passenger car measurements. Furthermore, vehicle maintenance, such as checking vehicles for leaks and canister saturation, would be key to preventing any additional evaporative emissions from vehicles certified to more recent standards.

HIGH-EMITTING FLEX-FUEL PASSENGER CAR FAMILIES

A large sample of L6 flex-fuel passenger cars allowed us to investigate emissions from these vehicles at the vehicle family level, which is defined by engine manufacturer and size, and to identify vehicle families with conspicuously high real-world emissions. There are nearly 50,000 measurements of L6 flex-fuel passenger cars in the dataset, accounting for nearly half of the measured passenger car fleet. To account for the difference in fuel economy across different vehicle brands, model years, and engine sizes, distance-specific emission values were recalculated using average fuel economy values further disaggregated at the brand, model year, and engine size levels from the national labeling program.[48] We present the emissions results only for NO_X, CO, and HC due to the insufficient emissions sample of NH_3.

Figure 6 presents the mean distance-specific NO_X, CO, and HC emissions from the top 10 highest-emitting L6 vehicle families. Almost all vehicle families shown had real-world NO_X and CO emissions exceeding PROCONVE emission limits and all vehicle families had real-world HC emissions multiple times higher than the limit they had to meet during type approval. Eight vehicle families, namely, FIA (Fiat) 1L, REN (Renault) 1L, VWG (Volkswagen) 1L, CHV (Chevrolet) 1.8L, HYU (Hyundai) 1L, CHV 1L, CHV 1.4L, and FRD (Ford) 1L, belong to the top 10 highest-emitting vehicle families for all pollutants studied. These vehicle families are also the most commonly found vehicle families in the sample, accounting for over 20% of the passenger

48 INMETRO, *Decreto No. 169 de 3 de de 2023*.

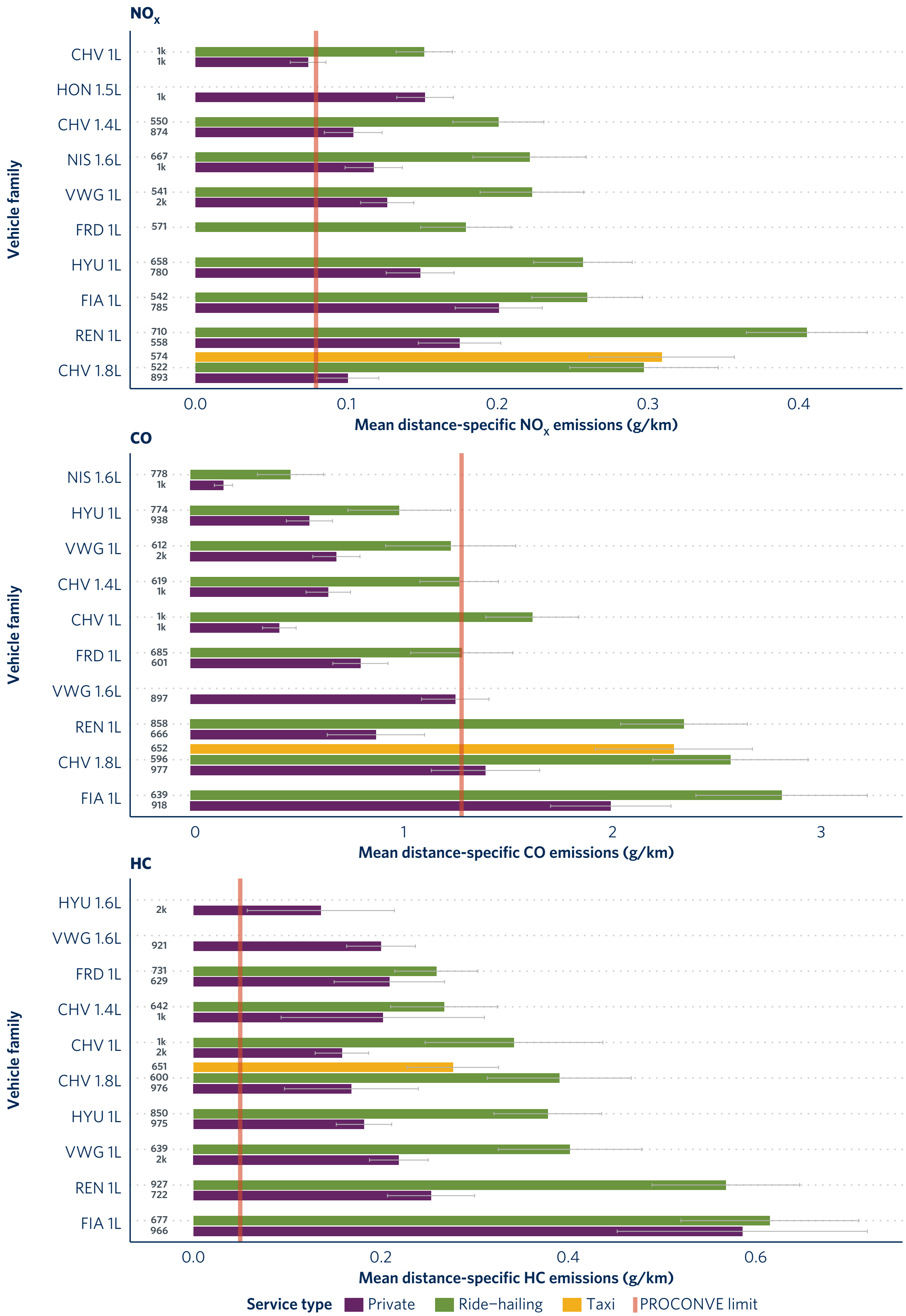


Figure 6. Top 10 highest-emitting L6 flex-fuel passenger car vehicle families for NO_x, CO, and HC

Note: Whiskers represent the 95% confidence interval of the mean. Numbers next to the bars indicate number of measurements. Only results with over 500 measurements are presented.

car measurements, highlighting their potentially high contributions to NO_X, CO, and HC emissions.

Figure 6 also highlights the large emissions gap between private vehicles and high-usage vehicles, such as ride-hailing vehicles and taxis. For all vehicle families, ride-hailing vehicles showed real-world emissions up to 2.2–3.8 times higher than their private counterparts. CHV 1.8L, which accounted for 20% of the measured taxi fleet, exhibited mean NO_X emissions 3 times higher and CO and HC emissions 1.6 times higher than those from their private counterparts. This gap can likely be attributed to emissions deterioration resulting from the high mileages these fleets accumulate.

Across all service types, FIA 1L and CHV 1.8L showed real-world emissions of all pollutants exceeding respective limits. Most of the vehicles belonging to these vehicle families have surpassed the durability period of 80,000 km or 5 years, during which manufacturers must ensure emission limit compliance. However, these groups merit further investigation as the highly elevated emissions from private fleets may indicate non-compliance at type approval or faster deterioration of emission control systems.

TRUCK EMISSIONS

Although trucks only accounted for around 4% of the total measurements (9,150), they have notable contributions to NO_X and PM emissions.[49] HDVs, including trucks, were also the largest contributors to fine particulate matter ($PM_{2.5}$) in the SPMA, with secondary aerosols resulting from SO_2, NO_X, NH_3, and black carbon emissions making up a large portion.[50] Given their significance, we assess real-world emissions of trucks against PROCONVE emission limits and real-world emissions of trucks in European cities that are subject to equivalent regulations. Because trucks measured in the SPMA predominantly used diesel (99.6%), this assessment focused only on diesel trucks.

As shown in Figure 7, the use of old trucks was still persistent in the SPMA. Trucks homologated to below

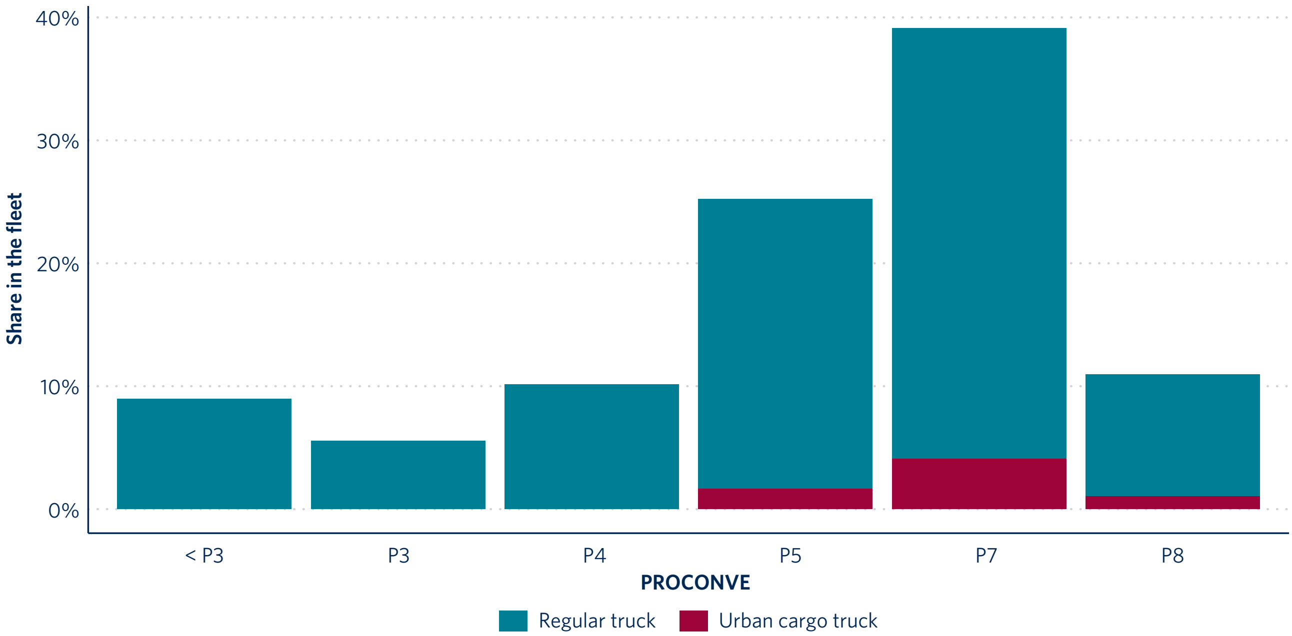


Figure 7. PROCONVE distribution of diesel trucks by truck type

Note: Only shares of above 1% are presented.

49 Trucks are defined as passenger and freight vehicles with gross vehicle weight over 3,856 kg or vehicle in running weight over 2,720 kg in Brazil. See "Brazil Heavy Duty Emissions," TransportPolicy.net, accessed September 18, 2025, https://www.transportpolicy.net/standard/brazil-heavy-duty-emissions/.

50 Erick Vinicius Ramos Vieira et al., "Chemical Characterization and Optical Properties of the Aerosol in São Paulo, Brazil," *Atmosphere* 14, no. 9 (2023): 1460, https://doi.org/10.3390/atmos14091460; Regina Maura de Miranda et al., "Source Apportionment of Fine Particulate Matter by Positive Matrix Factorization in the Metropolitan Area of São Paulo, Brazil," *Journal of Cleaner Production* 202 (November 2018): 253–63, https://doi.org/10.1016/j.jclepro.2018.08.100.

P3 with an average age of 40 years, including those from before the introduction of the PROCONVE standards, made up nearly 10% of the measurements. P7 trucks were the most prevalent, making up nearly 40% of the sample, followed by P5 (24%), P8 (11%), and P4 (10%). Urban cargo trucks, or VUC (Veículo Urbano de Carga) in Brazil, which are small trucks designed for last-mile delivery in urban areas, made up around 7% of the truck measurements and were distributed across the P5, P7, and P8 standards. The P6 standards were never implemented as the low-sulfur fuel needed to meet emission limits was not made available at the time.[51]

To investigate emissions from trucks in a unit consistent with PROCONVE limits, we converted fuel-specific emission values (g/kg) to energy-specific emission values (g/kWh), using a methodology based on a previous ICCT study by Bakhshmand et al.[52] Emissions from NO_x and PM were studied as they are mainly emitted by diesel vehicles.

Real-world NO_x and PM emissions from trucks in the dataset showed a steady decrease over time with more stringent emission limits but mean real-world emissions of vehicles of more stringent standards remained above the emission limits, as shown in Figure 8. Notably, P7 trucks, the most common in the sample, had mean NO_x emissions 1.8–2.3 times higher than the type-approval limits. Highly elevated emissions from P7 trucks, the standard generally equivalent to Euro V, are consistent with high real-world emissions from Euro V trucks seen in European cities. It is well documented that in typical urban conditions characterized by light loads and low speeds, selective catalytic reduction systems are found to be ineffective, leading to excess NO_x emissions.[53] Prior studies also attributed high real-world NO_x emissions from Euro V trucks to the presence of trucks with tampered or malfunctioning emission control systems.[54]

Trucks in the dataset homologated to the P8 standard, largely equivalent to Euro VI, exhibited real-world NO_x emissions over 55% lower than those from P7 trucks. Euro VI regulations not only tightened the limit by 80% compared with the P7 limit but also introduced off-cycle laboratory testing and on-road testing with portable emissions measurement systems to amend the gap shown by Euro V vehicles. Additionally, Euro VI vehicles are subject to an in-service conformity limit of 0.69 g/kWh, which in-use vehicles are required to meet. The P8 standards, which reflect these updates, likely contributed to the reduction in emissions. However, mean NO_x emissions from P8 trucks were still over 3 times the type-approval limits and 2 times above the in-service conformity (ISC) limits, respectively. This is likely because the ISC requirements of P8 do not include low load or cold start, common conditions of trucks in urban areas. The mean NO_x emissions of the P8 trucks in the sample are similar to those of the European equivalents (Euro VI) with urban driving conditions in the TRUE database.

Despite their mean emissions exceeding the emission limits, real-world PM emissions from trucks decreased substantially from P4 to P5 and P5 to P7. In P5, a transient testing limit that is higher but reflects more dynamic vehicle behaviors was introduced to reduce the gap between laboratory and real-world emissions, achieving a reduction of over 50% in PM emissions. Diesel trucks certified prior to P7 (i.e., those manufactured before 2012) may still use diesel fuel with higher sulfur content (500 ppm) than those certified to P7 and P8 (10 ppm) in São Paulo, which likely contributed to their elevated emissions.[55] In P7, diesel fuel with a lower sulfur content (10 ppm) became necessary, achieving a further reduction of 77%–88% from P5. However, the mean real-world PM emissions from P7 trucks were still 1.7 times the limit. Furthermore, the mean real-world PM emissions from P8 trucks were 4.4 times the limit and double the mean PM emissions from European equivalents (Euro VI). However, further data are necessary

51 TransportPolicy.net, "Brazil Heavy Duty Emissions."

52 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/.

53 Ruud Verbeek et al., *Real-World NO_x Emissions of Euro V Vehicles*, MON-RPT-2010-02777 (TNO Science and Industry, 2010), https://circabc.europa.eu/sd/a/d772193a-6646-46dd-bdf1-cd775fcdd925/TNO_report_MON-RPT-2010-02777_Euro_V%20(2).pdf; Rachel Muncrief, *Comparison of Real-World off-Cycle NO_x Emissions Control in Euro IV, V, and VI* (International Council on Clean Transportation, 2015), https://www.theicct.org/publications/comparing-real-world-cycle-nox-emissions-control-euro-iv-v-and-vi; Michal Vojtisek-Lom et al., "On-Road Detection of Trucks with High NO_x Emissions from a Patrol Vehicle with on-Board FTIR Analyzer," *Science of The Total Environment* 738 (October 2020): 139753, https://doi.org/10.1016/j.scitotenv.2020.139753.

54 Nils Hooftman et al., *Analysis of the 2019 Flemish Remote*; Kaylin Lee et al., *Assessment of Real-World Vehicle Emissions from Four Scottish Cities in 2022* (TRUE Initiative, 2024), https://trueinitiative.org/research/real-world-vehicle-emissions-in-four-major-scottish-cities/.

55 "Brazil: Fuels: Diesel and Gasoline," TransportPolicy.net, accessed October 8, 2025, https://www.transportpolicy.net/standard/brazil-fuels-diesel-and-gasoline/; Brazilian Government, "Descontinuidade Óleo Diesel S500" [Discontinuation of S500 diesel oil], May, 2025, https://www.gov.br/anp/pt-br/canais_atendimento/imprensa/infograficodiesels500.pdf.

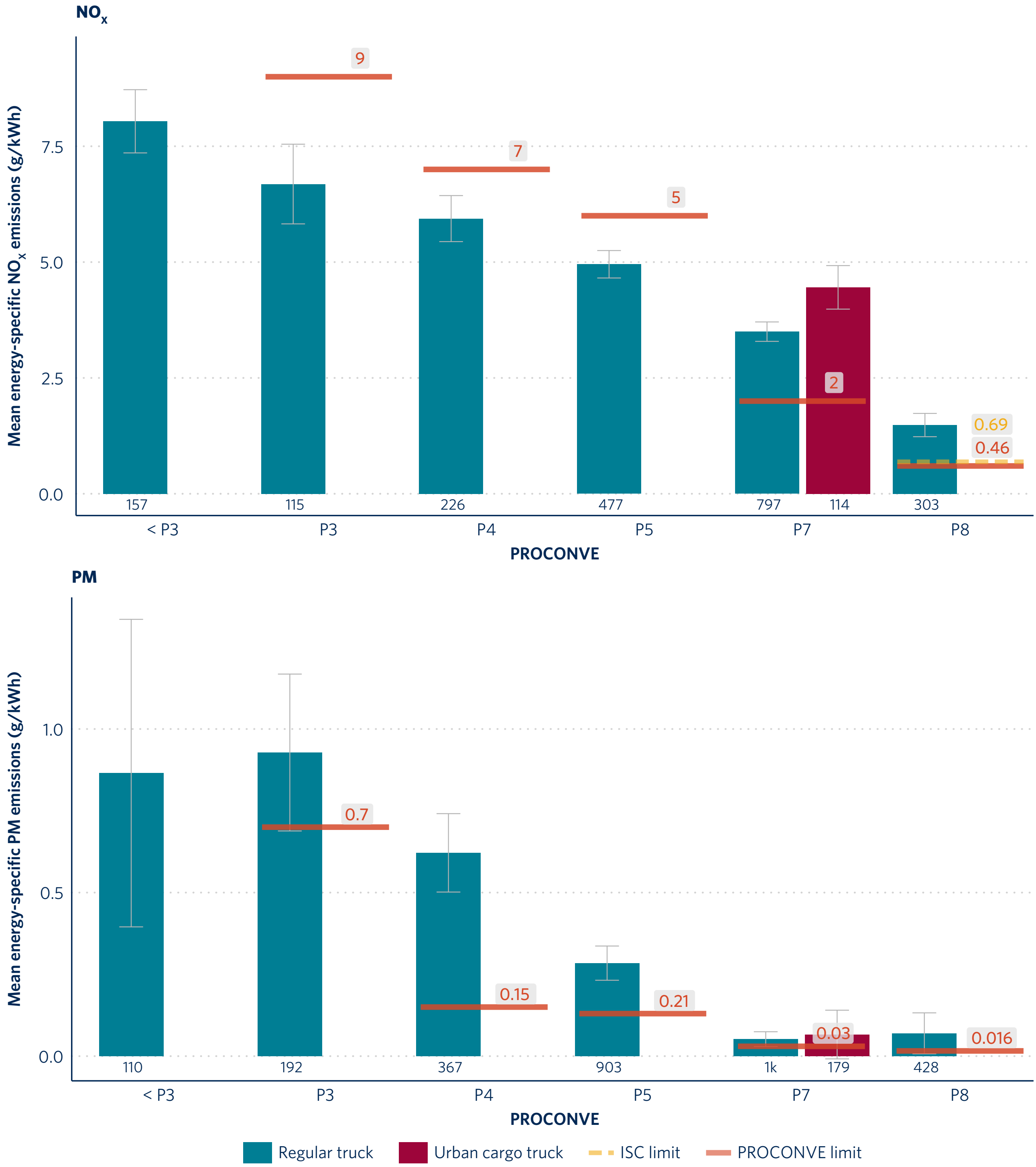


Figure 8. Mean energy-specific NO_x and PM emissions from diesel trucks

Note: Whiskers represent the 95% confidence interval of the mean. Numbers below bars indicate number of measurements. Only results with over 100 measurements are presented.

to assess this improvement in emission performance due to the wide 95% confidence intervals.

Urban cargo trucks in the sample showed real-world NO_X and PM emissions around 30% higher—27% and 29%, respectively—than regular trucks. This is likely because of the prevalence of cold starts among urban cargo trucks, as they drive shorter distances than regular trucks. A cold start is a condition where a vehicle's engine and exhaust aftertreatment system are not at an optimal temperature, leading to high emissions. Additionally, urban cargo trucks certified to the P7 standard were 2 years older than regular trucks in the sample, which may explain the higher emissions.

CONCLUSIONS AND POLICY RECOMMENDATIONS

Understanding real-world vehicle emissions is important to inform evidence-based policy decisions that can reduce vehicle-related pollution and improve the health of a city's inhabitants. This report presented the results of a remote sensing study that measured real-world pollutant emissions from vehicles in São Paulo, where the TRUE Initiative partnered with CETESB, OPUS RSE, and Tecsidel Brasil to collect over 323,000 vehicle measurements from nine sites across the SPMA from May to July 2024. This analysis supports the following conclusions and policy recommendations:

PHASE-OUT OF THE OLDEST VEHICLES IN THE FLEET AND PROMOTION OF CLEANER VEHICLE TECHNOLOGIES

Our study results show that the oldest vehicles are the highest-emitting vehicles in the SPMA. These vehicles also do not make up a large share of the measured fleet, which makes them a relatively easy target for phase-out efforts. L3 flex-fuel and gasoline C fuel passenger cars had the highest emissions for all four pollutants studied (NO_X, CO, HC, and NH_3) and accounted for 5.5% of the passenger car fleet. In particular, L3 gasoline C cars had the highest NO_X and NH_3 emissions. An immediate phase-out of gasoline C vehicles certified to L3 and below, the oldest vehicle groups in the passenger car fleet, would be beneficial for controlling secondary pollutants, as NO_X and NH_3 play an important role in the formation of O_3 and secondary $PM_{2.5,}$ respectively. These gasoline C vehicles also showed the highest shares of detectable evaporative emissions, which lead to the formation of O_3.

Our results also show that older trucks with an average age of 40 years and the highest NO_X and PM emissions are still persistently used in the SPMA, making up nearly 10% of the truck sample. This group includes trucks manufactured before the introduction of PROCONVE and those homologated to P1 and P2 standards that had no limits on NO_X and PM. It is important that these trucks with the highest emissions are prioritized for phase-out. Real-world NO_X and PM emissions from trucks were not effectively reduced until the P7 and P8 phases, when aftertreatment systems were required to meet stricter emission limits. Given the large share of trucks below the P7 standards in the fleet, a retrofit mandate for trucks over a certain age or those that frequently circulate in the city could also be considered for emission reduction.

The phase-out of the oldest and highest-emitting vehicles can be facilitated by policy measures, such as scrappage programs or financial incentives for cleaner vehicle technologies. Within the current policy framework, car owners in Brazil are disincentivized from replacing their old cars and are discouraged from purchasing zero-emission battery electric vehicles. Brazil's annual vehicle ownership tax, the Imposto sobre a Propriedade de Veículos Automotores, is structured more favorably towards owners of older cars, as it is based on the vehicle's market value, which depreciates with age.[56] Brazil's Green Mobility and Innovation (MOVER) Program, launched in 2024, provides uniform tax incentives for both battery electric vehicles (BEVs) and flex-fuel plug-in hybrids (PHEVs), despite the limited emission reduction potential of PHEVs in Brazil compared with BEVs.[57] This approach risks locking in higher pollutant emissions, since the limited electric driving range of PHEVs in Brazil could lead to greater use of their combustion engines.[58] A forward-looking policy measure would provide incentives for the replacement of old internal combustion engine vehicles with battery electric vehicles, rather than HEVs or PHEVs, while

56 Legislative Assembly of the State of São Paulo, *Lei Nº 13.296, de 23 de dezembro de 2008* [Law No. 13.296, of December 23, 2008], accessed October 27, 2025, https://www.al.sp.gov.br/repositorio/legislacao/lei/2008/lei-13296-23.12.2008.html.

57 André Cieplinski et al., *The Regulation of Brazil's Green Mobility and Innovation (MOVER) Vehicle Emissions Program* (International Council on Clean Transportation, 2025), https://theicct.org/publication/regulation-of-brazil-green-mobility-and-innovation-mover-vehicle-emissions-program-oct25/; Zamir Mera et al., *Comparison of the Life-Cycle Greenhouse Gas Emissions of Combustion Engine and Electric Passenger Cars in Brazil* (International Council on Clean Transportation, 2023), https://theicct.org/publication/comparison-of-life-cycle-ghg-emissions-of-combustion-engines-and-electric-pv-brazil-oct23/.

58 André Cieplinski, *Risks of Betting on Biofuels with Flex-Fuel Plug-In Hybrid Cars in Brazil* (International Council on Clean Transportation, 2024), https://theicct.org/risks-of-betting-on-biofuels-flex-fuel-plug-in-hybrid-cars-brazil-jan24/.

fostering the expansion of a domestic market for electric vehicles. This would also generate other benefits, such as job creation.[59]

REVIEW AND UPDATE OF THE PROCONVE STANDARDS

The mean real-world emissions of the newest L7 cars in our study are shown to significantly exceed PROCONVE limits, demonstrating the need for real-driving emission limits. The successive L8 standard introduces real-driving emission limits for NO_X, NMHC, and CO equal to 2 times the laboratory limit in 2025 and tightens it to 1.5 times the laboratory limit in 2027. However, the L8 standards will not be fully implemented for LCVs until 2031, leaving room for SUVs and pick-up trucks certified as LCVs to emit more than passenger cars. Consequently, this could incentivize further sales of these vehicles. Closing this loophole by applying uniform regulations for vehicles used for passenger transport could ensure an emissions reduction in one segment does not increase emissions in other segments.

Vehicles imported into Brazil are subject to the same PROCONVE homologation process as domestic vehicles. Our findings, however, reveal that imported gasoline C vehicles have 2–4.2 times higher real-world emissions of controlled pollutants, like NO_X, CO, and HC, than their domestic counterparts. This is likely attributable to their larger size, heavier weight, and the use of GDI technology. Contributions of vehicles equipped with GDI technology to fleetwide NO_X, PN, and HC emissions are especially substantial during cold start, which are typical of urban driving conditions. Although L7 established a PM emission limit, PN limits are not included in L7 or L8 for GDI vehicles and a PM mass limit does not ensure that PN is also capped. Under the Euro 6 regulations, GDI vehicles are subject to a PN limit. Similar PN requirements for GDI vehicles under the PROCONVE program could safeguard against excess emissions from imported vehicles.

59 André Cieplinski et al., *The Transition to Electric Vehicles in Brazil's Automotive Industry and Its Effects on Jobs and Income* (International Council on Clean Transportation, 2025), https://theicct.org/publication/the-transition-to-electric-vehicles-in-brazils-automotive-industry-and-its-effects-on-jobs-and-income-june25/.

IMPLEMENTATION OF A NATIONAL- OR REGIONAL-LEVEL INSPECTION AND MAINTENANCE PROGRAM

At present, there is no mandatory inspection and maintenance (I/M) program in the State of São Paulo or in Brazil. A mandatory environmental vehicle inspection program was established in São Paulo city in 2009, only to be suspended in 2013. Currently, the planning of an inspection and maintenance program at the federal level is underway.

Our findings provide a timely assessment of what an effective I/M program could look like. The remote sensing measurements collected from the testing indicate that vehicles coming from outside the city account for 50% of the vehicle activity in the city of São Paulo and around 35% of the vehicle activity in the SPMA may be attributable to vehicles registered out-of-state. This demonstrates that local I/M programs may not be able to effectively reduce emissions from vehicles operating in their jurisdiction. As demonstrated by the role of the national PROCONVE regulations in driving emissions reduction, I/M programs implemented at the national or regional level would be critical to reducing emissions and generate health benefits.

Our findings show that older vehicles (L3 and L4 passenger cars and trucks of P3 and earlier) or vehicles with extensive use (ride-hailing vehicles or taxis) have highly elevated real-world emissions—some at levels consistent with vehicles with malfunctioning or no emission control systems—resulting not only from emissions deterioration with time and use but also from improper maintenance. This underscores the need for mandating regular inspection and immediate repair in case of failure. An effective I/M program in Brazil would ideally have comprehensive coverage of vehicle classes and pollutants, such as NO_X, PM, CO, HC, and evaporative emissions, that are mainly emitted by its fleet. Emissions can be checked using on-board diagnostics or tailpipe exhaust tests for CO, HC, and NO_X, opacity tests for PM, and gas cap tests for evaporative emissions. Recently, some European countries, such as Belgium, the Netherlands, Switzerland, and Germany, have also introduced particle number tests.[60]

Remote emissions sensing can also play an important role in I/M programs. Remote sensing has been used to assist road-side inspection campaigns in Europe, increasing

60 Robin Smith et al., "Excess Pollution from Vehicles—A Review and Outlook on Emission Controls, Testing, Malfunctions, Tampering, and Cheating," *Sustainability* 17, no. 12 (2025): 12, https://doi.org/10.3390/su17125362.

the rate at which tampered or malfunctioning vehicles are identified and facilitating more effective and efficient enforcement.[61] When used for I/M programs, remote sensing can flag vehicles suspected of high emissions in conditions reflecting actual driving conditions and where fraud is unlikely.[62] The potential application of remote sensing can be further examined and considered for I/M programs in Brazil.

MEASURES TO LIMIT EMISSIONS FROM TAXIS AND RIDE-HAILING VEHICLES

The results show that emission deterioration is evident in high-usage vehicles like taxis and ride-hailing vehicles in the SPMA. Real-world NO_X, CO, and HC emissions from flex-fuel taxis and ride-hailing passenger cars were over 2 times higher than those from private flex-fuel cars for vehicles certified to the L6 standards. São Paulo city's 5-year age limit on taxis has helped to limit the circulation of older taxis with likely higher emissions, as demonstrated by the fleet's average age of 4 years, compared with ride-hailing cars, whose average age was 6 years. However, both fleets, which accounted for nearly 30% of the total passenger car measurements, exhibited significant emission deterioration, which is a large setback to the emission reduction the PROCONVE regulations have achieved over time.

As these fleets have larger emission contributions and can be more easily targeted for regulations than private vehicles, encouraging electrification in this sector—for instance, through tax incentives for battery electric taxis and ride-hailing vehicles—could be impactful. As an intermediate step, providing information on high-emitting models to prevent drivers from choosing these models could also be helpful. Our findings show that certain brands and engine sizes, like Chevrolet 1.8 L vehicles, dominate the taxi market but have real-world emissions exceeding limits, even for private vehicles with likely lower emission deterioration. Additionally, it is important to examine the reasons for elevated emissions, such as through inspection and maintenance programs and required repairs. Mandatory inspection of taxis and ride-hailing vehicles in parallel with age limits can help to limit the circulation of a vehicle fleet showing major emission deterioration.

MEASURES TO LIMIT EMISSIONS FROM TRUCKS

P7 and P8 trucks, accounting for over half of the truck measurements, had real-world emissions 1.8–3.3 times the PROCONVE limits. Trucks certified to P8, which is based on the Euro VI standard, still showed real-world emissions above the limits for both NO_X and PM, despite P8's reduction in NO_X emissions compared with P7 trucks. In Europe, a substantial reduction in emissions was only achieved through subsequent standards, such as Euro VI-D and Euro VI-E, which required the inclusion of a lower power threshold (Euro VI-D) and cold start (Euro VI-E) in the in-service conformity testing.[63] The Euro VI-E standard was implemented in 2021 and compliance was required for all new vehicles in 2022 in Europe, one year earlier than the implementation year of the P8 standard in Brazil. Updates to the P8 standard to include these additional requirements aligning it with Euro VI-E would help to lower real-world emissions further.

The elevated emissions from urban cargo trucks can pose additional health risk as these trucks are used in the city of São Paulo for last-mile delivery. Our results show that urban cargo trucks emit nearly 30% higher NO_X and PM emissions, on average, than the regular truck homologated to the same PROCONVE standard (P7). Urban cargo trucks are more likely to drive with cold engines for a larger share of the time than long-haul trucks due to shorter trips and frequent stops, which prevent emission control systems from reaching optimal conditions. As no phase in the current HDV PROCONVE regulations covers cold start, electrification of this vehicle group would reduce air pollution in the city of São Paulo. Purchase incentives or tax exemptions for fully electric vehicles geared towards companies, and an eventual restriction of diesel trucks in the city through the establishment of a low-emission zone, would help limit the exposure of the city populations to high levels of NO_X and PM emissions.

61 N. Hooftman et al., *Analysis of the 2019 Flemish Remote Sensing Campaign* (Flemish Environmental Planning Agency, 2020), https://resolver.tno.nl/uuid:7e96bc14-46e3-4e5a-8f06-e436c85160f7; Yuhan Huang, *Remote Sensing of On-Road Vehicle Emissions: Mechanism, Applications and a Case Study from Hong Kong*, n.d., https://doi.org/10.1016/j.atmosenv.2018.03.035.

62 Smith et al., "Excess Pollution from Vehicles."

63 Lee et al., *Real-World Vehicle Emissions.*

THE REAL URBAN EMISSIONS INITIATIVE

FIA FOUNDATION

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION