Assessment of real-world passenger vehicle and taxi emissions in Mexico City

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ACKNOWLEDGMENTS

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. TRUE will use a combination of measurement techniques to produce a granular picture of the on-road emissions of the entire vehicle fleet by make, model, and model year.

EXECUTIVE SUMMARY

Vehicle emissions contribute significantly to air pollution in Mexico City. Ozone and fine particulate matter concentrations regularly exceed national and World Health Organization guidelines, adversely impacting the health of Mexico City residents. Air quality management policies are particularly important given Mexico City's specific geographic conditions, including its high elevation, basin shape that limits air flow and pollutant dispersion, and high solar radiation that contribute to elevated ozone levels.

Light-duty vehicles (LDVs), such as passenger vehicles and taxis, are a key source of transport emissions in Mexico City. The policies governing LDV emissions in Mexico continue to lag those of other countries, however. The country's LDV emission standard was last updated in 2005; while an update is currently being drafted, it is not expected to be rolled out until 2025. A locally periodic inspection program—the Mandatory Vehicle Verification Program (PVVO)—tests exhaust emissions of cars in Mexico City and restricts the highest-emitting vehicles from driving on select days. The Mexico City government also has announced plans to implement additional policies to reduce 30% of criteria pollutants from transportation by 2024.

This analysis, conducted under The Real Urban Emissions (TRUE) Initiative, provides insights on real-world vehicle emissions in Mexico City to inform the implementation and oversight of policies to reduce air pollution. It analyzes real-world vehicle emissions data collected from passenger vehicles (PVs), taxis, and light-duty trucks in Mexico City and the surrounding region, 98.6% of which were fueled by gasoline. Testing ran from February to April 2022 and measured tailpipe carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_X), and ultraviolet (UV) smoke, a proxy for particulate matter. In a first for the TRUE Initiative, this study also considers evaporative emissions—HC emissions from sources other than the tailpipe—to offer a comprehensive view of vehicle emissions in Mexico City. Key findings of our analysis include:

Limiting the operation of the small percentage of high-emitting, older passenger vehicles that have an outsized emissions impact can result in large emission reductions. Although older vehicles make up a small portion of the sampled fleet, they contribute significantly to total emissions: 50% of gasoline passenger vehicle CO, HC, NO_X, and UV smoke emissions were from vehicles 14–17 years old and older, which account for under 20% of the sampled fleet. Adopting a low-emission zone in Mexico City's downtown area by 2024 would help greatly reduce emissions from older vehicles and improve air quality.

Prioritizing incentives to phase out the highest-emitting taxis would help to improve the average real-world emissions performance of taxis. Despite being comparatively newer than PVs, average taxi emissions were approximately 2.2–3.1 times higher than PVs across all pollutants. High NO_X averages among taxis can be partially attributed to the prevalence of the Nissan Tsurus, which accounted for 46% of pre-2016 taxis and emitted up to 2.6 times higher NO_X emissions than other taxis and up to 10 times higher than other PVs of the same model year. Accelerating the replacement of Nissan Tsurus and other high-emitting vehicles through collaboration with manufacturers, taxi fleets, and ride-hailing companies would reduce taxi emissions. For instance, Mexico City's current rebate program, which provides incentives for replacing higher-emitting vehicles with lower- and zero-emitting alternatives, could be expanded to support replacement of a larger portion of the high-emitting taxi fleet.

Assessing PVVO administration across states to fully harmonize inspection and maintenance programs could help close the gap in real-world emissions between registration locations. Older passenger vehicles registered in the State of Mexico, which neighbors Mexico City, show higher emissions compared to those registered in Mexico City. For instance, 1994–2005 model year PVs registered in the State of Mexico accounted for only 7% of the sampled fleet but made up 25%–42% of total emissions. As Mexico City and the State of Mexico have the same PVVO requirements, these results indicate that Mexican authorities might consider assessing whether verification programs are being similarly administered across both areas. Greater data transparency on vehicle test results could also help to harmonize the PVVO across all states. In all jurisdictions, building robust and updated data storage and collaboration mechanisms could support implementation of local policies.

Local regulations, incentives, and awareness campaigns could accelerate the transition to lower-emitting and zero-emission new vehicles. In addition to transitioning away from older, high-emitting vehicles, ensuring that new vehicles have low real-world emissions is also a priority. With Mexico's national

emission standards lagging those of many major markets, currently equivalent to U.S. Tier 1 and Euro 3 standards, it is important for local governments to consider implementing more stringent regulations. The Environmental Commission of the Megalopolis, which coordinates among the central government, Mexico City, and six surrounding states, could play a key role in achieving greater reductions by coordinating the adoption of more stringent regulations across several regions. Additionally, Mexico City could dramatically reduce transport emissions by leapfrogging to zero-emission vehicles. To this end, local governments could offer financial and non-financial incentives, support the planning and deployment of charging infrastructure, and increase consumer awareness to support the transition to zero-emission vehicles.

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INTRODUCTION

Several studies have sought to evaluate real-world emissions in Mexico City using remote sensing. In 1997 and 2008, for instance, researchers examined the impact of light-duty vehicle (LDV) emission standards on real-world emissions over time.[1] More recently, remote sensing studies have evaluated the real-world emissions of vehicles by registration location and assessed the effectiveness of inspection and maintenance programs.[2]

This report builds on past remote sensing work and analyzes real-world emissions data collected in Mexico City from February to April 2022 under The Real Urban Emissions (TRUE) Initiative, the first TRUE Initiative campaign in Latin America. TRUE works to provide cities with information about the real-world emissions of their vehicle fleets and offer evidence-based policy recommendations to limit on-road transport emissions. Past TRUE remote sensing studies have been conducted in several European cities, Seoul, and Jakarta.

This emissions testing campaign seeks to provide an up-to-date picture of emissions from passenger vehicle and taxi fleets operating in Mexico City and the surrounding region. Results of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x), and ultraviolet (UV) smoke (a proxy for particulate matter) emissions are analyzed in detail by model year (MY), registration location, and make and model. Additionally, this study introduces an analysis of evaporative emissions, a first for the TRUE Initiative. We conclude with policy recommendations to reduce air pollution and health impacts of vehicle emissions in Mexico City.

BACKGROUND

Mexico City is one of the most populous cities in the world. According to Mexico City's Secretariat of the Environment, the Metropolitan Area of the Valley of Mexico (Zona Metropolitana del Valle de México, ZMVM)—which encompasses Mexico City and portions of the surrounding States of Mexico and Hidalgo—had an estimated 21.7 million people as of 2020, making it the largest metropolitan area in the country.[3]

According to government estimates, Mexico City registers roughly 19 million daily trips between the city and its surroundings in the ZMVM.[4] Real-world vehicle emissions within Mexico City are influenced by not only vehicles registered in Mexico City but also vehicles registered in surrounding states. Within the ZMVM, there are approximately 6.2 million registered vehicles; 76% are private cars, 16% are motorcycles, 4% are taxis, 3% are freight vehicles, and less than 1% are public transportation. Most vehicles (97%) use gasoline exclusively, while 2% use diesel and 1% are hybrid.[5]

AIR QUALITY

Fine particulate matter ($PM_{2.5}$) and ozone (O_3) are major health concerns in Mexico City. In 2018, the annual average of $PM_{2.5}$ there was 23.2 μg/m^3, well above the national regulation of 12 μg/m^3 and the current World Health Organization (WHO) guideline of 5 μg/m^3.[6] The same year, the 8-hour average O_3 concentration in Mexico City was 120 ppb, exceeding the national regulation of 70 ppb.[7] The effects of air pollution are inequitable across the city. A 2022 study found that lower-income, informal workers experience more severe health impacts and lose more income due to air pollution

1   Gary Bishop et al., "On-Road Remote Sensing of Vehicle Emissions in Mexico," *Environmental Science & Technology* 31 no. 12 (1997): https://doi.org/10.1021/es9702475; I. Schifter et al., "Trends in Exhaust Emissions from In-Use Mexico City Vehicles, 2000–2006. A Remote Sensing Study," *Environmental Monitoring and Assessment* 137 (2008): 459–70, https://doi.org/10.1007/s10661-007-9781-4.

2   Instituto Nacional de Ecología y Cambio Climático (INECC), "Fase Introductoria de La Campaña de Identificación de Altos Emisores Vía Sensor Remoto (Contaminómetros) [Introductory Phase of the Campaign to Identify High Emitters via Remote Sensor (Pollution Meters)]," 2018, https://www.gob.mx/cms/uploads/attachment/file/756662/9._Informe_gral_CAMe_sensor_remoto_contaminometro.pdf; Secretaría del Medio Ambiente de la Ciudad de México, "Campaña Metropolitana con Sensor Remoto [Metropolitan Campaign with Remote Sensor]," 2015.

3   Secretaría del Medio Ambiente de la Ciudad de México, "Inventario de Emisiones de la Zona Metropolitana del Valle de México 2020 [Emissions Inventory of the Metropolitan Zone of the Valley of Mexicio 2020]," 2023, http://www.aire.cdmx.gob.mx/descargas/publicaciones/flippingbook/inventario-emisiones-cdmx-2020/inventario-emisiones-cdmx-2020.pdf.

4   Secretaría de Movilidad de la Ciudad de México, "Programa Integral de Movilidad de la Ciudad de México 2020-2024: Diagnóstico Técnico [Comprehensive Mobility Program of Mexico City 2020-2024: Technical Diagnostic]," 2020, https://semovi.cdmx.gob.mx/storage/app/media/diagnostico-tecnico-de-movilidad-pim.pdf.

5   Secretaría del Medio Ambiente de la Ciudad de México, "Inventario de Emisiones."

6   Secretaría del Medio Ambiente de la Ciudad de México, "Informe Anual Calidad del Aire 2018 [Annual Air Quality Report 2018]," 2020, http://www.aire.cdmx.gob.mx/descargas/publicaciones/informe-anual-calidad-del-aire-2018.pdf; "What Are the WHO Air Quality Guidelines?," accessed September 29, 2023, https://www.who.int/news-room/feature-stories/detail/what-are-the-who-air-quality-guidelines.

7   Secretaría del Medio Ambiente de la Ciudad de México, "Informe Anual Calidad del Aire 2018."

than higher-income, formal workers.[8] Another study found that populations with a higher marginalization index, which measures deprivation in education, healthcare, housing, and other factors, are exposed to higher O_3 levels in Mexico City.[9]

The transportation sector is one of the main sources of criteria pollutants that contribute to air pollution and adverse health impacts in Mexico City and the ZMVM more broadly. Research from the International Council on Clean Transportation (ICCT) estimated that in 2015, 34.8% of premature deaths due to $PM_{2.5}$ and O_3 in Mexico City were attributable to transportation, the highest rate in Latin America and one of the highest globally.[10] According to Mexico City's Secretariat of the Environment, in the ZMVM, as of 2020, transportation accounted for 95% of CO, 84% of NO_x, 42% of $PM_{2.5}$, and 26% of volatile organic compound (VOC) emissions.[11] Within the sector, passenger vehicles and taxis accounted for 45% of CO emissions, 59% of NO_X emissions, 25% of $PM_{2.5}$ emissions, 50% of VOC emissions, and 63% of CO_2-equivalent emissions.[12]

NO_X and VOC emissions are of particular concern in Mexico City, as they are the major precursors to O_3. The ZMVM has distinct geographical features that contribute to high ozone levels, including high elevation, high solar radiation, surrounding mountain ranges, and a basin shape of the city that limits air flow and pollutant dispersion. In 2020, during COVID-19 related lockdowns, NO_X and VOC from vehicle tailpipe emissions declined due to travel restrictions; however, continued VOC emission from other sources—including evaporative emissions from vehicles not in operation—resulted in an increase in ozone levels.[13]

The Environmental Commission of the Megalopolis (Comisión Ambiental de la Megalópolis, CAMe)—a government body that coordinates environmental actions between the central government, Mexico City, and six surrounding states—monitors the local air quality index and issues alerts of bad air quality days.[14] During high-risk air quality conditions (O_3 > 154 ppb, $PM_{2.5}$ > 97.4 μg/m^3 [24hr]), the environmental authorities of each state impose temporary restrictions on certain older, higher-emitting vehicle groups to reduce the population's exposure.[15] Though the program has helped to promote fleet renewal, ambient air quality data shows little improvement due to these vehicle restrictions.[16]

Local and national governments work together to address air quality problems. Coordinated actions include the National Air Quality and Health Index (Índice AIRE y SALUD), a 5-color band indicator used to communicate air quality conditions and potential health risk effects on sensitive and general population groups; air quality management programs (ProAire) to coordinate local, regional, and national efforts to reduce air pollution; and the National Air Quality Monitoring System (SINAICA), which provides information about the state of the air in main metropolitan areas throughout Mexico.[17] CAMe and the Secretariat of Environment also carry out public outreach campaigns

8   Bridget Hoffmann and Juan Pablo Rud, "Exposure or Income? The Unequal Effects of Pollution on Daily Labor Supply" (working paper, Inter-American Development Bank, 2022), https://publications.iadb.org/publications/english/document/Exposure-or-income-the-unequal-effects-of-pollution-on-daily-labor-supply.pdf.

9   Jimena García-Burgos et al., "Exploring the Spatial Distribution of Air Pollution and Its Association with Socioeconomic Status Indicators in Mexico City," *Sustainability* 14, no. 22 (November 18, 2022): 15320, https://doi.org/10.3390/su142215320.

10 Susan Anenberg et al., *A Global Snapshot of the Air Pollution-Related Health Impacts of Transportation Sector Emissions in 2010 and 2015,* (Washington, D.C.: International Council on Clean Transportation, 2019), https://theicct.org/publication/a-global-snapshot-of-the-air-pollution-related-health-impacts-of-transportation-sector-emissions-in-2010-and-2015/.

11 Secretaría del Medio Ambiente de la Ciudad de México, "Inventario de Emisiones."

12 Motorcycles contributed 41% of CO emissions and 36% of VOC emissions; trucks, buses, and other heavy-duty vehicles accounted for 65% of $PM_{2.5}$ and 32% of NO_x emissions. Secretaría del Medio Ambiente de la Ciudad de México, "Inventario de Emisiones."

13 Secretaría del Medio Ambiente de la Ciudad de México, "Informe anual: Calidad Del Aire 2020 Ciudad De México [Annual Report: Air Quality 2020 Mexico City]," 2023, https://www.aire.cdmx.gob.mx/descargas/publicaciones/informe-anual-calidad-del-aire-2020.pdf.

14 As of January 2024, the Government of Mexico defined the Megalopolis of the ZMVM to include Mexico City and the states of Hidalgo, Mexico, Morelos, Puebla, Querétaro, and Tlaxcala. Government of Mexico, "La megalópolis de la ZMVM [The Megalopolis of the ZMVM]," https://www.gob.mx/comisionambiental/articulos/la-megalopolis-de-la-zmvm?idiom=es.

15 Secretaría del Medio Ambiente de la Ciudad de México, "Activación de las Contingencias Ambientales Atmosféricas (PCAA) en la ZMVM [Activation of Atmospheric Environmental Contingencies (PCAA) in the ZMVM]," 2023, http://www.aire.cdmx.gob.mx/descargas/ultima-hora/calidad-aire/pcaa/pcaa-historico-contingencias.pdf; Comisión Ambiental de la Megalópolis, "Índice Aire y Salud: Características y Aplicación [Air and Health index: Characteristics and Application]," 2020, https://www.gob.mx/cms/uploads/attachment/file/554425/comunicado_indice_calidad_aire_05_2020_FINAL_v3.pdf.

16 Lucas W. Davis, "Saturday Driving Restrictions Fail to Improve Air Quality in Mexico City," *Scientific Reports* 7, no. 1 (February 2, 2017): 41652, https://doi.org/10.1038/srep41652.

17 Secretaría de Medio Ambiente y Recursos Naturales, "Programas de Gestión para Mejorar la Calidad del Aire ProAire [Management Programs to Improve Air Quality ProAire]," March 17, 2023, https://www.gob.mx/semarnat/acciones-y-programas/programas-de-gestion-para-mejorar-la-calidad-del-aire; INECC, "Sistema Nacional de Información de la Calidad del Aire, SINAICA," accessed Februrary 22, 2024, https://sinaica.inecc.gob.mx/index.php; Secretaría del Medio Ambiente de la Ciudad de México, "Índice Aire Y Salud [Air and Health Index]," Accessed February 22, 2024, http://186.96.0.232/aire/default.php?opc=%27ZaBhnml=&dc=%27Zw==.

NATIONAL EMISSION STANDARDS

NOM-042-SEMARNAT-2003 (NOM-042) is the national emission standard for new LDVs.[18] It has not been updated since 2005 and is equivalent to the U.S. Tier 1 and Euro 3 standards. The Secretariat of Environment and Natural Resources (Secretaría de Medio Ambiente y Recursos Naturales, SEMARNAT) started updating the standard in 2023; the updated standard is expected to be finalized in 2024 and will apply to LDVs from model year 2025 and later. For Mexico to adopt U.S. Tier 3 standards, the country would need to transition to ultra-low sulfur gasoline, a step that seems unlikely based on current policy discussions. As a result, the revision of NOM-042 will most likely entail the adoption of U.S. Tier 2 standards.

NOM-167-SEMARNAT-2017 (NOM-167) is the national standard that limits in-use vehicle emissions in the Megalopolis. Among other provisions, it establishes the specifications of the Mandatory Vehicle Verification Program (Programa de Verificación Vehicular Obligatorio, PVVO), including the use of remote sensing equipment to identify in-use high-emitting vehicles (on the PVVO, see below). In July 2023, SEMARNAT published a proposal to modify the standard; the main changes included relaxing NO_x limits and classifying the On-Board Diagnostic test as optional.[19]

Table 1 summarizes the LDV pollutant limits set forth in these standards.

In the absence of updated national emission standards, states in Mexico can adopt more stringent regulations, although this is difficult to do on a small scale. Having a small fraction of the country's vehicle sales meet lowered emission limits requiring improved emission control systems can result in prohibitive cost increases for automakers and consumers. Instead, coordinated action to adopt improved standards across the Megalopolis would help spread out increased manufacturing costs and achieve greater emission reductions. This approach is like one taken in the United States, where several states have adopted California's vehicle regulations.[20]

Table 1. Summary of LDV criteria pollutant national standards and limits with implications in Mexico City.

Standard	Pollutants	Unit	Current standard limit	Equivalent standard	Standard proposal update	Implications
NOM-042: Emission limits for new sales	CO	g/km	2.11	Tier 1+/ Euro 3	TBD	This standard has not been updated since 2005. It is not fully harmonized with any European or U.S. regulation, as it has different values for each pollutant and weaker evaporative emission controls and useful life requirements.*
	NMHC	mg/km	99			
	NO_x	mg/km	249			
	PM	g/km	0.05			
	Evap	g/test	2.0			
NOM-167: Emission limits for on-road fleet	HC	ppmh	80	NA	80	Limits for the on-road fleet in the Megalopolis. The limits established in the standard are used for the CDMX PVVO.
	CO	%	0.4		0.4	
	NO_x	ppm	250		700	
	O_2	%	0.4		0.4	
	$CO+O_2$	%	13–16.5		13–16.5	

* Leticia Pineda et al., *Air Quality and Health Benefits of Improved Fuel and Vehicle Emission Standards in Mexico*, (Washington, D.C.: International Council on Clean Transportation, 2018), https://theicct.org/wp-content/uploads/2021/06/Mexico-emissions-review_ICCT-Working-Paper_03012018_vF_0.pdf.

18 Norma Oficial Mexicana NOM-042-SEMARNAT-2003, Secretaría de Medio Ambiente y Recursos Naturales, September 7, 2005, https://dof.gob.mx/nota_detalle.php?codigo=2091196&fecha=07/09/2005#gsc.tab=0.

19 Proyecto de Modificación de la Norma Oficial Mexicana NOM-167-SEMARNAT-2017, Secretaría de Medio Ambiente y Recursos Naturales, July 4, 2023, https://dof.gob.mx/nota_detalle.php?codigo=5694213&fecha=04/07/2023#gsc.tab=0.

20 "States that Have Adopted California's Clean Vehicle Regulations," California Air Resources Board, 2024, https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/states-have-adopted-californias-vehicle-regulations.

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CURRENT POLICIES AND PROGRAMS

In 2019, the Mexico City government adopted an emissions reduction plan for the transportation sector (Plan de Reducción de Emisiones del Sector Movilidad en la Ciudad de México), which aims to reduce criteria pollutant emissions from transport by 30% by 2024.[21] The plan proposes implementing a low-emission zone in the downtown area; transitioning 20% of taxis and 10% of private cars to be hybrid vehicles (HEV) or battery-electric vehicles (BEV); expanding soot-free and electrified transit; electrifying one of the lines of the Metrobus bus rapid transit system;[22] and implementing vehicle restrictions for freight vehicles.[23] Mexico City also adopted a local Climate Action Strategy and Plan committing to a 10% reduction in emissions by 2030 and net-zero emissions by 2050 (Estrategia Local [2021-2050] y Programa de Acción Climática [2021-2030])[24]. Additionally, the ZMVM's Air Quality Management Program (ProAire 2021-2030) aims to reduce air pollutants by 25% by 2030 across 19 sectors, including transportation.[25]

MANDATORY VEHICLE VERIFICATION PROGRAM (PVVO)

The PVVO is an exhaust emission test required every 6 months for most vehicle categories registered in the ZMVM. All vehicles registered within the Megalopolis are subject to compliance with the PVVO, though they may obtain certification in their own state's verification program. Battery electric vehicles, plug-in hybrids, and full hybrids are exempted from the PVVO in Mexico City. Vehicles outside the Megalopolis, or from other states, can request exemption from PVVO requirements but are still subject to some restrictions on bad air quality days.

Based on their PVVO certification, vehicles are subject to different restrictions under the "Hoy No Circula" (No Driving Day) initiative, an air quality management program run by Mexico City's Secretariat of the Environment (Secretaría del Medio Ambiente, SEDEMA).[26] Vehicles can obtain one of four types of certificates based on their emission standards and test results:[27]

i. "00" (double zero): This certification is for new vehicles that comply with the strictest greenhouse gas emission limits, the U.S. Tier 2, Bin 5 standard, and have a minimum fuel efficiency of 13.5 km/L. Vehicles that receive a "00" certification are exempted from "Hoy No Circula." These vehicles are also exempted from the PVVO for 2 years if their fuel economy is between 13.5 and 16.0 km/L and 4 years if their fuel economy is higher than 16.0 km/L.

ii. "0" (zero): A "0" certification also exempts vehicles from "Hoy No Circula," as they meet the same criteria pollutant emission limits as "00". However, these vehicles must be verified once every 6 months.

iii. "1" (one): Vehicles with a "1" certification comply with less strict emission levels than "00" and "0" counterparts; under "Hoy No Circula," they are restricted from operating on one weekday each week and two Saturdays each month.

iv. "2" (two): Vehicles with a "2" certification are certified to the least stringent emission standards and are prohibited from operating on one weekday each week and every Saturday.

Vehicles that have not applied to the PVVO are restricted from operating on one weekday each week and every Saturday if registered in Mexico City, and one weekday, every Saturday, and daily between 5:00–11:00 am if registered outside of Mexico City. Local police

21 Gobierno de la Ciudad de México, "Plan de Reducción de Emisiones del Sector Movilidad en la Ciudad de México," 2019, https://www.jefaturadegobierno.cdmx.gob.mx/storage/app/media/plan-reduccion-de-emisiones.pdf.

22 In February 2023, Metrobus inaugurated its first electrified line; a second line was electrified in December of the same year.

23 Leticia Pineda, Carlos Jimenez, and Oscar Delgado, *Estrategia Para el Despliegue de Flota Eléctrica en el Sistema de Corredores de Transporte Público de Pasajeros de la Ciudad de México "Metrobús": Líneas 3 y 4* [Strategy for the Deployment of the Electric Fleet in the Routes of the "Metrobus" Public Passenger Transport System of Mexico City: Lines 3 and 4], (Washington, D.C.: International Council on Clean Transportation, 2022), https://theicct.org/wp-content/uploads/2022/03/MexCity-ZEBRA-A4-v4-may22.pdf.

24 Secretaría del Medio Ambiente de la Ciudad de México. Estrategia Local de Acción Climática 2021 - 2050 y el Programa de Acción Climática de la Ciudad de México 2021 – 2030, accessed September 29, 2023. http://www.data.sedema.cdmx.gob.mx/cambioclimaticocdmx/images/biblioteca_cc/PACCM-y-ELAC_uv.pdf.

25 Secretaría del Medio Ambiente de la Ciudad de México. "Programa de gestión para mejorar la Calidad del Aire de la Zona Metropolitana del Valle de México," accessed August 30, 2023, http://www.aire.cdmx.gob.mx/descargas/publicaciones/flippingbook/proaire2021-2030/pdf/ProAireZMVM2021-2030-VersionCompleta.pdf.

26 "Hoy No Circula," Secretaría del Medio Ambiente de la Ciudad de México, accessed September 29, 2023, https://sedema.cdmx.gob.mx/programas/programa/hoy-no-circula.

27 "Programa de Verificación Obligatoria," Secretaría del Medio Ambiente de la Ciudad de México, accessed August 30, 2023, http://www.sadsma.cdmx.gob.mx:9000/datos/storage/app/media/gacetas/GOCDMX_23-07-03_DGCA.pdf.

enforce compliance based on emissions certificate stickers, which are required to be visible in the vehicle. Vehicles that do not comply with the restrictions can be fined between US$120–241.[28]

As of 2021, most vehicles enrolled in the PVVO received a "0" certificate (81%).[29] Table 2 presents the number of vehicles per certificate and associated pollutant limits. In total, 86% of enrolled vehicles received a "0" or "00" certification and, therefore, were exempt from "Hoy No

Table 2. PVVO enrollment by certificate level as of the 2nd semester 2021.

Certificate	Vehicles verified		Pollutant emission limits					
	#	%	HC (ppmh)	CO (%)	NOₓ (ppm)	O₂ (%)	CO+O₂ (%)	Lambda
Cert 00	77,388	4.9	80	0.4	250	0.4		1.03
Cert 0	1,298,130	81.4	80	0.4	250	0.4	13 min 16.5 max	1.03
Cert 1	206,849	13.0	100	0.7	700	2.0		1.03
Cert 2	13,013	0.8	350	2.5	2000	2.0		1.05
Total	**1,595,380**	**100**						

Figure 1. PVVO certificates by model year as of the 2nd semester 2021.
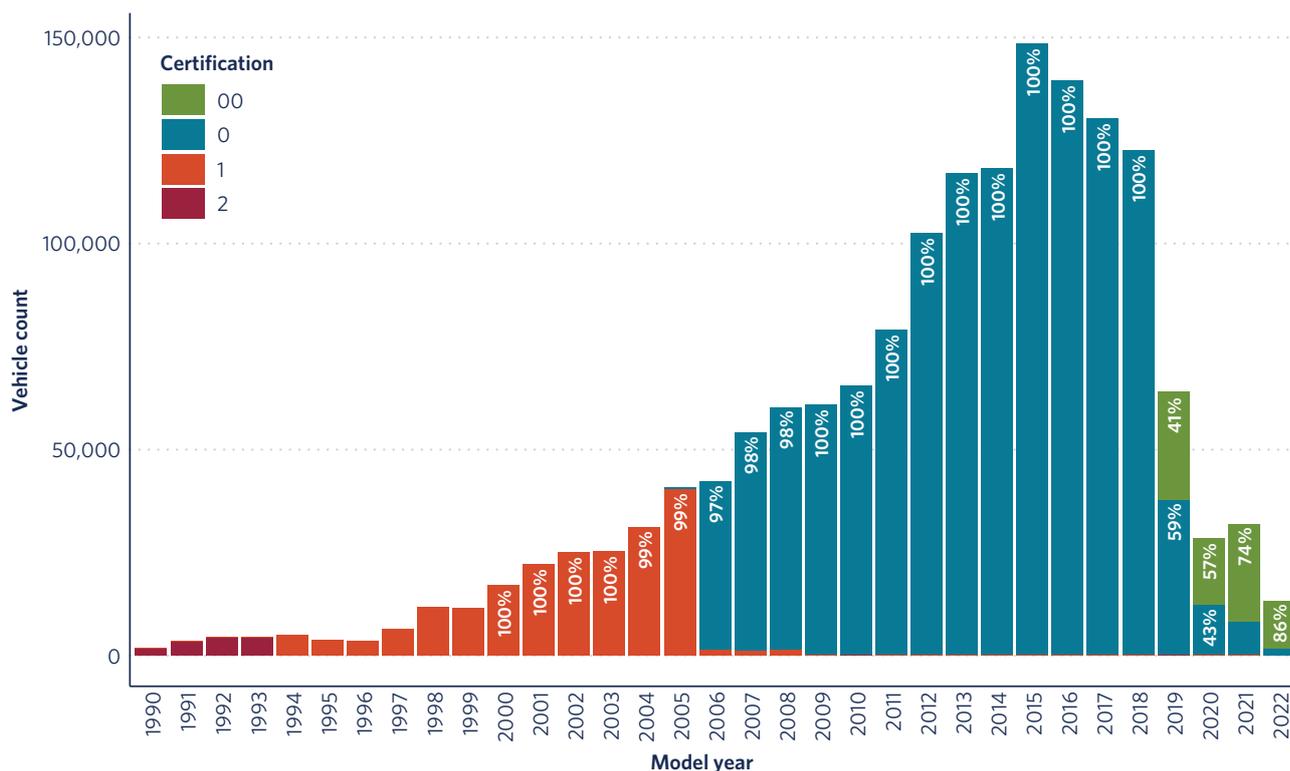
28 Amounts calculated for June 2023, using the monthly average interbank exchange rate MX$17.25 = US$1.00. Banco de México, "Tipo de cambio promedio del periodo - (CF86)," accessed June 30, 2023, https://www.banxico.org.mx/SieInternet/consultarDirectorioInternetAction.do?sector=6&accion=consultarCuadro&idCuadro=CF86&locale=es.

29 El Poder del Consumidor, 2022. Information request on PVVO results in 2021, privately shared with the ICCT.

Circula." Additional detail on the breakdown by vehicle model year is shown in Figure 1.

VEHICLE PROPERTY TAX

In Mexico, vehicle property taxes (tenencia vehicular) vary by jurisdiction. In Mexico City, most vehicles are subject to property taxes based on their depreciated purchase value, except for BEVs, HEVs, plug-in hybrids, and vehicles with a depreciated purchase value below roughly US$14,493 (at the June 2023 exchange rate). Other jurisdictions, such as neighboring Morelos State, do not charge taxes for any vehicles, creating an economic incentive for Mexico City residents to register their vehicles in Morelos. The temporary suspension of the PVVO in Morelos due to the COVID-19 pandemic created further incentives for registering vehicles in Morelos.
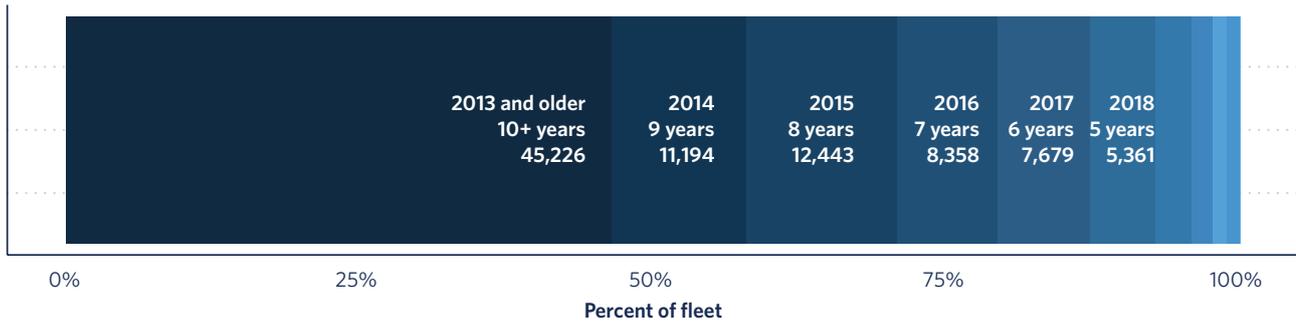
TAXI RENEWAL PROGRAM

Taxis in Mexico City are limited to 10 years of operation, but there are no registration requirements related to model year or age. According to the Secretariat of Mobility of Mexico City (Secretaría de Movilidad, SEMOVI), as of 2023, 45,226 taxis (47% of the fleet) were 10 or more years old.[30] Figure 2 shows the distribution of taxis by model year.[31]

The Mexico City government provides a short list of vehicles that meet current taxi concession specifications in an annual "Feria del Taxi" event. Among these options, certain makes and models—historically led by the Nissan Tsuru—have comprised a large share of the taxi fleet, in part due to advantageous financial terms offered by manufacturers to fleets and owners.

Since 2002, Mexico City has implemented several renewal programs to replace taxis that are 10 or more years old with newer vehicles that meet safety standards, accessibility features, and lower emissions limits. Through these initiatives, taxi owners can scrap their existing vehicles and receive a rebate to purchase new vehicles. Criteria for new vehicles are outlined in Table 3. Two active programs provide rebates and financing options to purchase highly efficient vehicles or HEVs and BEVs.[32] Priority is given to renewing 10-year-old (or older) taxis, and particularly for replacing Nissan Tsurus—which have particularly high emissions.

Table 4 shows participation in renewal programs by year. From 2019–2020, 1,232 taxis were renewed under the program; 83% of vehicles purchased were highly efficient, while 17% were HEVs or BEVs. Participation in the program was highest in its first year, 2019, and has since dropped off. In total, vehicles purchased through this program account for approximately 1.3% of the Mexico City taxi fleet.

Figure 2. Mexico City taxi distribution by age.

2013 and older 10+ years 45,226	2014 9 years 11,194	2015 8 years 12,443	2016 7 years 8,358	2017 6 years 7,679	2018 5 years 5,361

Percent of fleet

30 Secretaría de Movilidad de la Ciudad de México, "Aviso por el que se dan a Conocer los Lineamientos de Operacion de la Accion Social 'Programa de sustitucion de Taxi, 2023' [Notice Announcing the Operational Guidelines of the "Taxi Substition Program, 2023" Social Action]," 2023, https://www.semovi.cdmx.gob.mx/storage/app/media/FIFINTRA/5.%20Publicaciones/2023/LOP%20-%20TAXI%20AE%202023_VF.pdf.

31 Secretaría de Movilidad de la Ciudad de México, "Aviso."

32 Secretario de Movilidad de la Ciudad de México, "Aviso."

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Table 3. Summary of taxi renewal program in Mexico City.

Vehicle type	Minimum requirements	Rebates	Financing
Highly efficient vehicles	15 km/L in city driving CO_2 max: 155 g/km NO_X max: 167 g/1000 km (NOM-042 C standard) Other safety and accessibility requirements	MX$75,000 + MX$20,000 (swivel front seat for limited mobility users) Issued at the point of sale	Low interest rate loans through NAFIN (the national development bank) and other financing institutions
HEV		MX$135,000 + MX$20,000 (swivel front seat for limited mobility users) Issued at the point of sale	
BEV	N/A	MX$180,000 + MX$20,000 (swivel front seat for limited mobility users) Issued at the point of sale	

Table 4. Number of taxis renewed in Mexico City under programs.

Year	HEV & BEV	Highly efficient vehicles	Total
2019	172	438	610
2020	19	97	116
2021	10	211	221
2022	11	274	285
Total	212	1,020	1,232

REMOTE SENSING STUDY OVERVIEW

DATA COLLECTION

The TRUE Initiative conducted a remote sensing testing campaign to measure real-world emissions from vehicles in Mexico City and the surrounding region over 22 days from February to April 2022. In total, 74,490 measurements with valid pollutant readings were collected at 21 different locations in Mexico City and the States of Mexico and Puebla. The sampled fleet included passenger vehicles, taxis, and light-duty commercial vehicles.[33] Testing of heavy-duty vehicles at toll booths was planned but ultimately was not conducted due to permitting and scheduling issues.

Emissions testing was conducted by Opus Inspection in coordination with SEDEMA, CAMe, and the National Institute for Ecology and Climate Change (Instituto Nacional de Ecología y Cambio Climático, INECC). Sites

were selected and permits were obtained by SEDEMA and CAMe based on past testing experience. While most sites selected were multi-lane arterials, local traffic police used traffic cones to narrow the roadways to single lanes to prevent interference from non-target vehicle exhaust plumes. After testing was conducted, vehicle specifications from license plate records were obtained from Mexico City and the States of Mexico and Morelos. The sampled fleet registered in Puebla was not included in the analysis because it was not possible to obtain vehicle specification data.

Figure 3 shows a map of the sites and the number of valid measurements from each site. Approximately 70% of measurements were taken in Mexico City, while roughly 30% were taken in the State of Mexico (most near the state's border with Mexico City). Data collection also occurred at three sites in Puebla; however, only a small number of measurements (<150) were included in this analysis due to missing vehicle specifications of cars registered in Puebla.

The Opus AccuScan RSD 5300 model was used to measure emissions as vehicles drove past the device (Figure 4). The instrument measured tailpipe emissions of CO, HC, NO, NO_2, and UV smoke (a proxy for PM).[34] Additionally, for the first time in a TRUE study, it examined evaporative emissions—HC emissions from sources other than the tailpipe—to present a comprehensive view of real-world emissions from vehicles in Mexico City.

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33 Buses, heavy-duty trucks, and two-wheelers were also measured, but due to the small number of measurements (<30 measurements), these vehicles were not included in this analysis.

34 UV smoke is measured by the ratio of opacity to fuel burned. The measurement is dependent on various physical and chemical characteristics of the exhaust particulate matter and therefore is used primarily for comparative analyses. See Michelle Meyer et al., *Particulate Matter Emissions from U.S. Gasoline Light-Duty Vehicles and Trucks* (Washington, D.C.: International Council on Clean Transportation, 2023), https://theicct.org/publication/true-pm-emissions-jun23/.

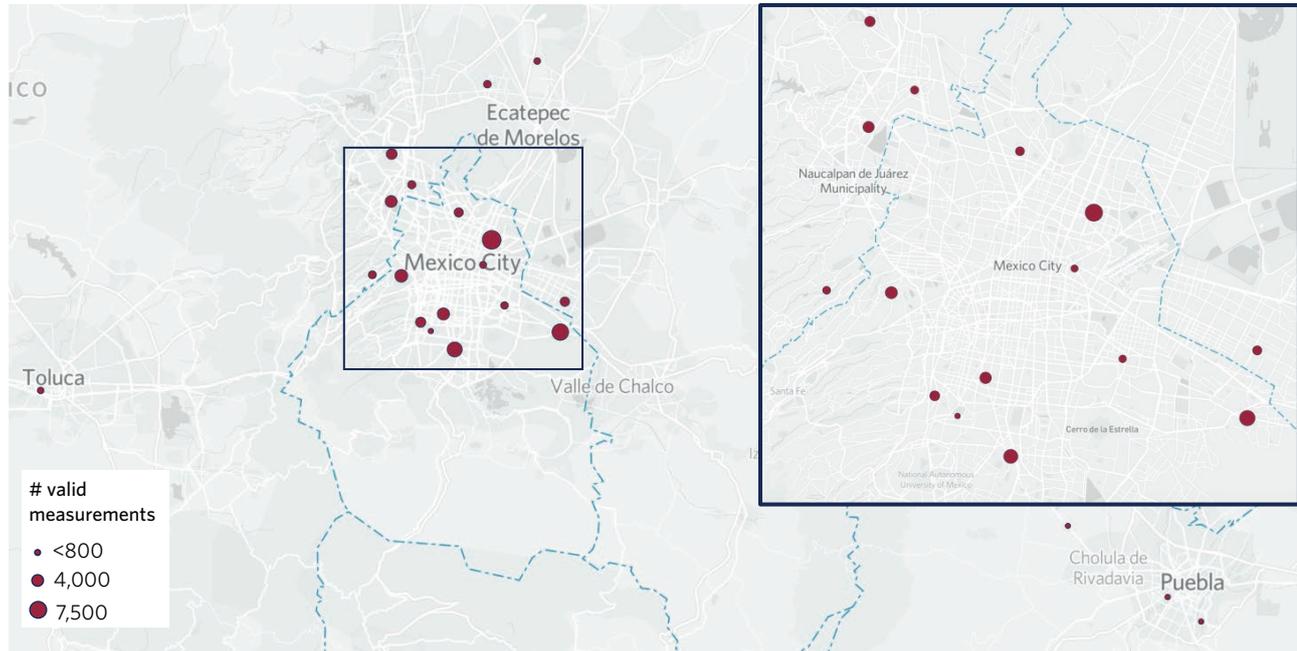**Figure 3**. Map of sites and number of valid measurements.

Figure 4. Remote sensing device setup on Blvd de los Virreyes in Mexico City.

DATA PROCESSING

In total, 106,169 raw measurements were collected in this remote sensing campaign. To filter for valid data, we applied the following criteria:

- The pollutant measurement was determined to be valid by instrument software and remote sensing device operators.
- Vehicle speed and acceleration were recorded.

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Table 5. Summary of measurement counts by validity.

		License plate reading is valid; successful match with vehicle information		
		Yes	**No**	**Total**
Speed, acceleration VSP, and pollutant reading are valid	**Yes**	44,731	27,840	**72,571**
	No	19,824	13,774	**33,598**
	Total	**64,555**	**41,614**	**106,169**

- Vehicle Specific Power (VSP) was greater than -5 kW/t.[35]
- Vehicle information was available.

Table 5 summarizes the results of this data filtering. Of the full data set, 69% of measurements had valid speed, acceleration, VSP, and pollutant readings, and 61% had valid license plate readings and were successfully matched with vehicle information. This resulted in 44,731 valid measurements for use in our emissions analysis.

SAMPLE OVERVIEW

Table 6 shows the three main vehicle classes and corresponding vehicle types used in this analysis. As noted, vehicle types with fewer than 30 measurements—including some buses, heavy-duty trucks, and two- and three-wheel motorcycles—were not analyzed.

Table 6. Description of vehicle classes.

Vehicle class	Vehicle types
Passenger vehicle	Compact car, subcompact car, SUV
Taxi	Taxi (predominantly compact and subcompact cars)
Light-duty truck	Pickup truck, delivery van, passenger van, light truck, medium truck

Figure 5 shows the distribution of measurements by vehicle class and fuel type, considering all 64,555 measurements for which vehicle specifications were available. Passenger vehicles (PVs) were the most common vehicle type, with 53,060 measurements (82% of the sample), more than 99% of which were fueled by gasoline. Taxis made up approximately 9% of the sample, closely followed by light-duty trucks

(LDTs), which accounted for 8%. The sampled fleet was predominantly gasoline vehicles; 98.6% of measured vehicles were fueled by gasoline.

Figure 5. Number of measurements by fuel type and vehicle classification. The percent of gasoline vehicles is displayed in each bar.
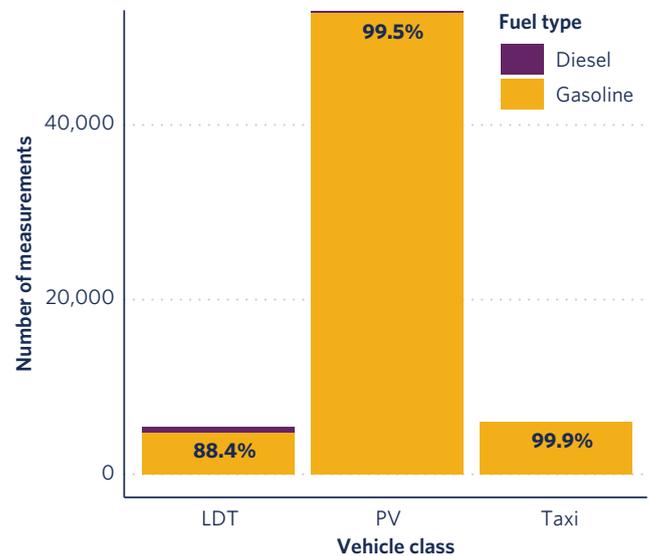
Figure 6 summarizes data collected across the sample on four driving and ambient conditions that impact emissions: speed, acceleration, VSP, and recorded ambient temperature. Each are approximately normally distributed, with median values of 22.7 km/h (for speed), 0.47 m/s^2 (acceleration), 5.9 kW/ton (VSP) and 31 °C (recorded ambient temperature). The median VSP of this sample is relatively similar to the median of the TRUE Europe database (8.2 kW/t), indicating that driving conditions are relatively similar to past remote sensing campaigns. Recorded ambient temperature values were higher than expected, with values around 5–10 °C hotter than ambient temperatures recorded by weather stations.[36] This may be attributed to elevated

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35   We selected this threshold because fuel injection is typically disabled below -5 kW/ton, as outlined in Yoann Bernard, Uwe Tietge, John German, and Rachel Muncrief, *Determination of Real-World Emissions from Passenger Vehicles Using Remote Sensing Data* (Washington, D.C.: International Council on Clean Transportation, 2018), https://theicct.org/wp-content/uploads/2021/06/TRUE_Remote_sensing_data_20180606.pdf.

36   "Mexico City, Mexico Weather Conditions," Weather Underground, accessed September 29, 2023, https://www.wunderground.com/weather/mx/mexico-city/IMEXIC159.

Figure 6. Summary of testing conditions.
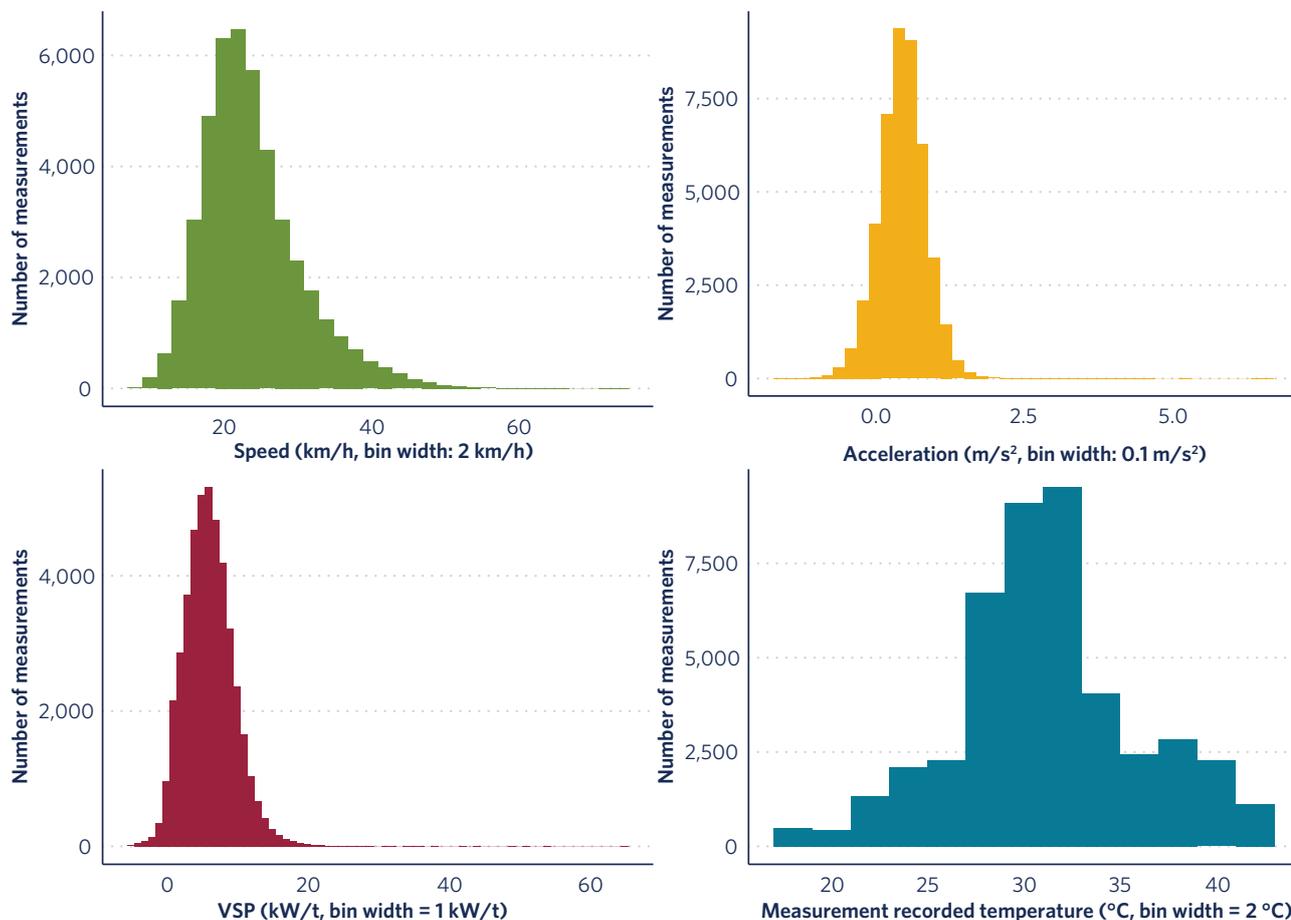
temperatures near roadways due to higher asphalt temperatures and vehicle activity.[37] As Figure 6 shows, the measurements in our study captured a wide range of driving conditions, providing an accurate representation of real-world driving for our analysis.

EMISSIONS ANALYSIS

FLEET CHARACTERISTICS

Vehicles measured in this campaign were registered in two main locations, the State of Mexico and Mexico City, with a small portion registered in the State of Morelos. Table 7 shows the percentage of measurements in each registration location. Figure 7 shows the distribution of measurements by model year and registration location, showing all groups for which there were at least 30 measurements. There were a greater number of older,

pre-MY 2010 cars registered in the State of Mexico compared to Mexico City. Vehicles registered in Morelos tended to be newer; the median model year for Morelos cars was 2018 compared to the overall median of 2015.

Table 7. Percentage of measurements in each registration location.

Registration location	% of measurements
State of Mexico	49
Mexico City	46
Morelos	5

EMISSIONS BY VEHICLE TYPE

Figure 8 shows the average fuel-specific CO, HC, NO_x, and UV smoke measurements from the three most common vehicle types (LDTs, PVs, and taxis). CO and HC emissions were higher among gasoline vehicles than diesel vehicles, by up to 3.7 times for LDTs and 4.6 times for PVs. CO emissions from gasoline vehicles were particularly high, with LDTs and taxis exhibiting average

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37 This study does not analyze emission trends by ambient temperature, so higher ambient temperatures do not have any tangible impacts on the study's findings.

Figure 7. Vehicle age distribution by registration location.
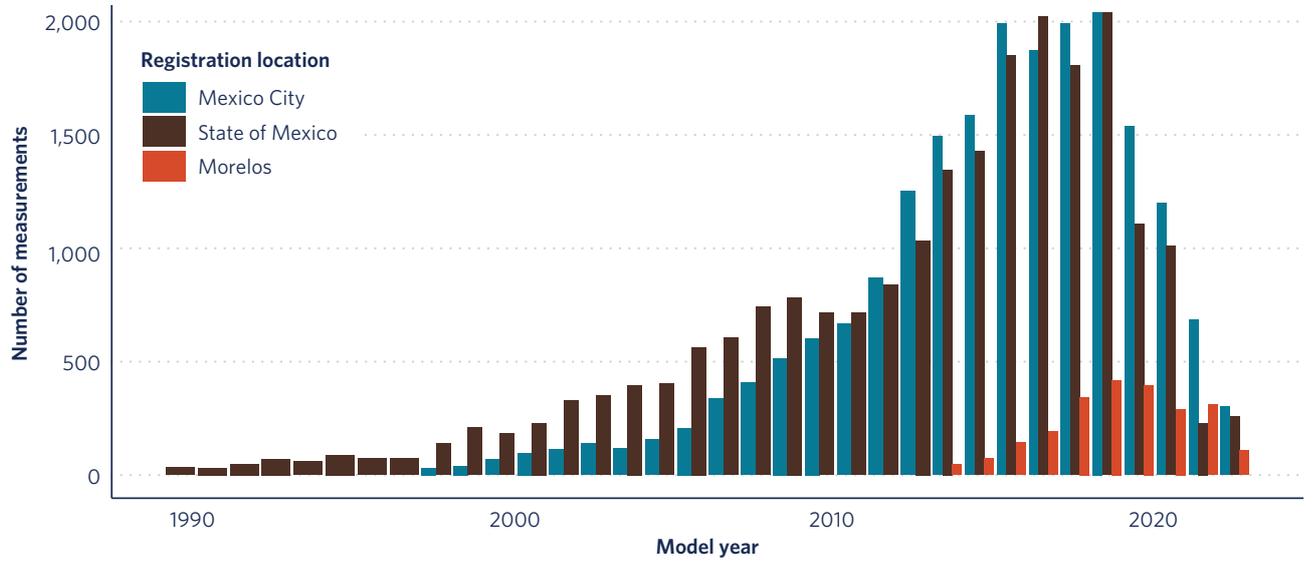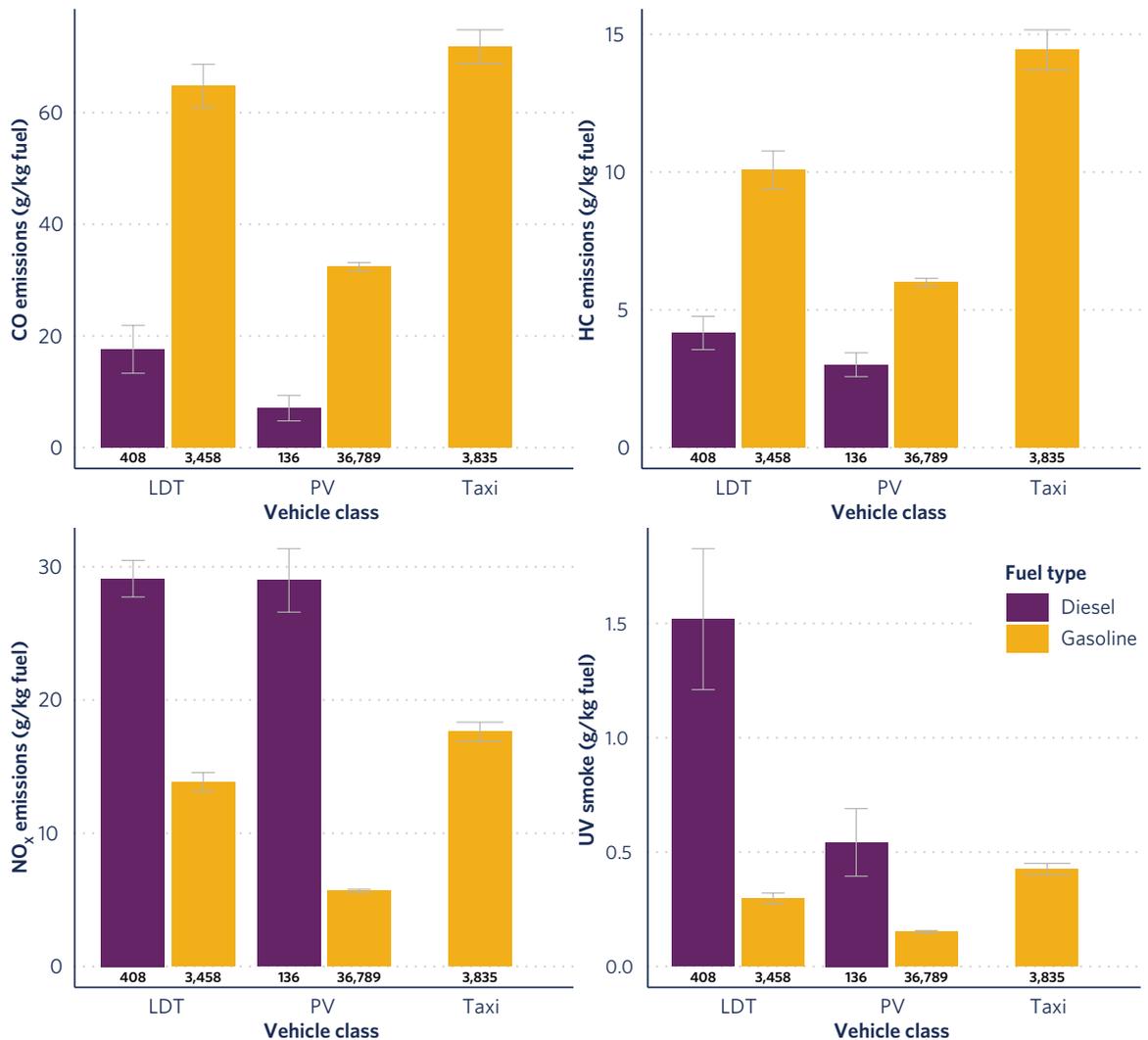

Figure 8. Average CO, HC, NOₓ, and UV smoke for each vehicle type. Error bars represent the 95% confidence interval.

emissions above 60 g/kg—much higher than average CO levels recorded in most past TRUE campaigns.[38] Meanwhile, diesel vehicles of all classes showed higher average levels of NO_x than gasoline vehicles. Diesel LDTs had approximately double the NO_x levels of their gasoline counterparts, for instance, while diesel PVs had average NO_x levels over 5 times those of gasoline PVs.

Comparing across vehicle classes, taxis exhibited substantially higher emissions compared with PVs across all pollutants, with 2.2 times higher CO, 2.4 times higher HC, 3.1 times higher NO_x, and 2.8 times higher UV smoke than gasoline PVs. Indeed, across pollutants,

taxis showed emissions close to or even exceeding those of gasoline-fueled LDTs. These results are consistent with past studies indicating high levels of taxi emissions and help illustrate the extent of excess emissions from taxis (discussed in greater detail below).

PASSENGER VEHICLE EMISSION TRENDS

Figure 9 shows the cumulative share of emissions for each pollutant for gasoline PVs.[39] The dots are ordered by model year, proceeding from older PVs (darker-gradient dots) to newer PVs (lighter-gradient dots). The black lines indicate the share of measurements

Figure 9. Cumulative share of gasoline passenger vehicle CO, HC, NO_x, and UV smoke emissions by vehicle age.
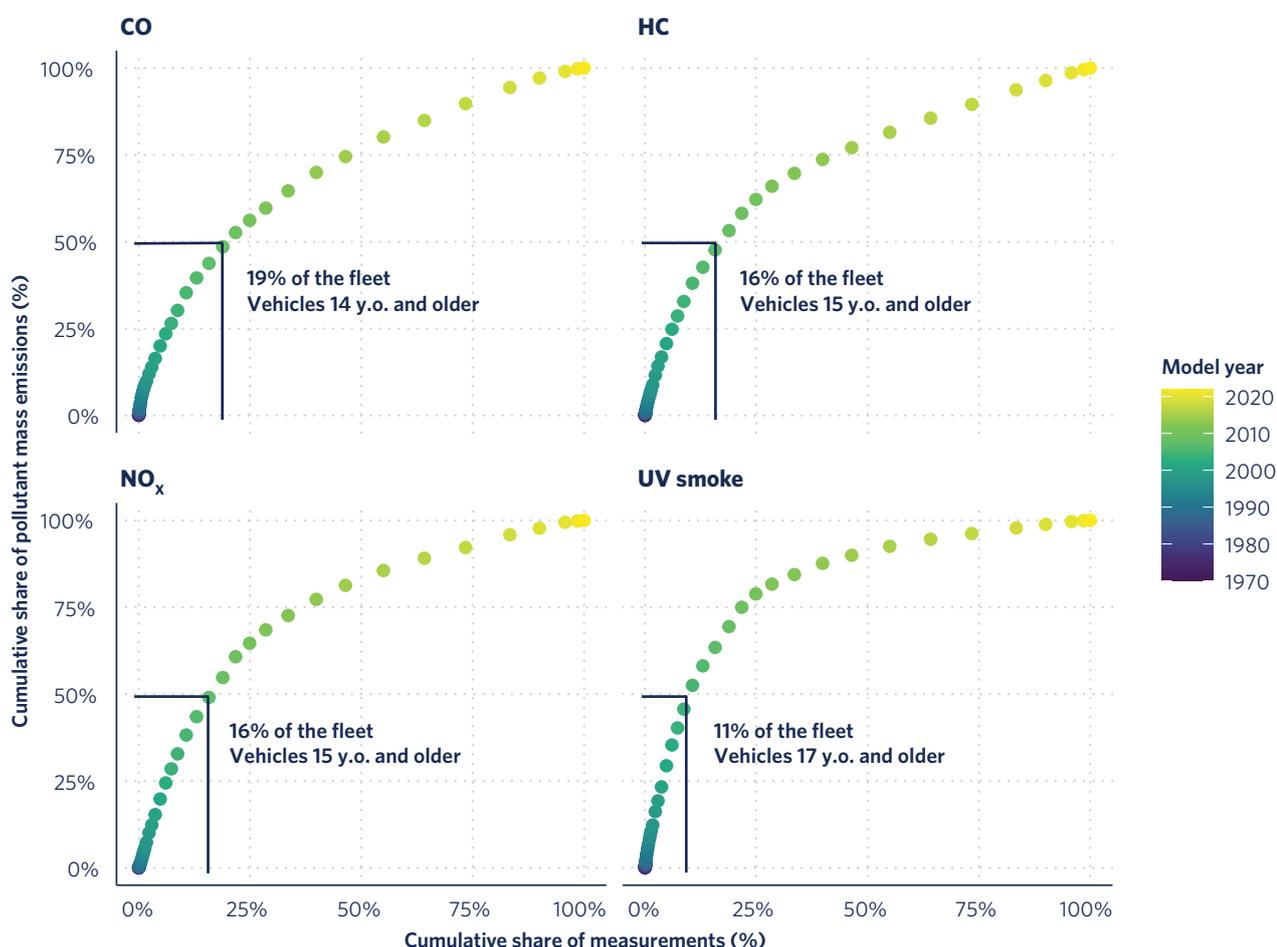
38 Yoann Bernard et al., *Evaluation of Real-World Vehicle Emissions in Brussels*, (Washington, D.C.: International Council on Clean Transportation, 2021), https://www.trueinitiative.org/media/792040/true-brussels-report.pdf; Kaylin Lee, Yoann Bernard, and Jonathan Cooper, *Assessment of Real-World Vehicle Emissions in Scotland in 2021*, (Washington, D.C.: International Council on Clean Transportation, 2023), https://www.trueinitiative.org/media/792423/true-scotland-remote-sensing.pdf; Liuhanzi Yang et al., *Remote Sensing of Motor Vehicle Emissions in Seoul*, (Washington, D.C.: International Council on Clean Transportation, 2022), https://www.trueinitiative.org/media/792173/remote-sensing-seoul-true-paper.pdf.

39 While other plots use fuel-specific emission factors, the results from this plot reflect the trends of distance-specific emission factors, converted using Global Fuel Economy Initiative data. IEA (Fuel Economy in Mexico, updated December 2021), https://www.iea.org/articles/fuel-economy-in-mexico.

that are at least 14 years old, which make up 19% of the sampled fleet, are responsible for half of pollutant mass emissions. Our analysis revealed similar trends for other pollutants: 50% of HC and NO_x emissions were from vehicles that were at least 15 years old and 50% of UV smoke emissions were from vehicles that were at least 17 years old, despite these vehicles making up a small share of the overall gasoline-powered PV fleet (16% and 11%, respectively).

These results indicate that as the fleet shifts to newer, lower-emitting vehicles, older vehicles make up an increasing portion of total fleet emissions. This finding highlights the importance of targeting the oldest, highest-emitting portion of the fleet for maintenance or replacement. Based on these results, PV emissions in Mexico City could be substantially reduced by targeting a small portion (less than 20%) of the fleet.

Figure 10 shows the average fuel-specific emissions for each pollutant by model year and registration location.[40] A clear downward trend is visible for all pollutants, with newer vehicles exhibiting up to 99% lower emissions than the oldest vehicles in the fleet. For MY 2013 and more recent, vehicles registered in Mexico City, the State of Mexico, and the State of Morelos all exhibited relatively similar emission patterns, though cars registered in Morelos had the lowest emissions for all pollutants. This trend of lower emissions for cars registered in Morelos is primarily due to the difference in makes and models; generally, cars registered in Morelos are more expensive and likely have better emission control technologies.

Older vehicles, however, showed different emission patterns based on registration location. Although cars in Mexico City and the State of Mexico are certified to the same national emission standard and subject to the same inspection and maintenance requirements, older cars registered in the State of Mexico exhibited higher emissions than cars of the same model year registered in Mexico City. This gap is greatest for pre-MY 2005 vehicles, then narrows but is still present for MYs 2005–2012. For MY 2004, as an example, vehicles registered in the State of Mexico showed 2.1 times higher CO, 2.4 times higher HC, 2.8 times higher NO_x, and 5.1 times

higher UV smoke compared to vehicles of the same model year registered in Mexico City.[41]

As a result, the oldest vehicles registered in the State of Mexico contribute a large share of total emissions. As Figure 11 shows, cars of MYs 1994–2005 registered in the State of Mexico made up 7% of the sampled fleet but accounted for a disproportionately high share of total emissions (between 26% and 43%, depending on the pollutant).[42] By comparison, cars of the same model year registered in Mexico City, which made up 3% of the sampled fleet, accounted for roughly 4%–5% of emissions. These findings indicate the potential for large emission reductions by focusing policy action on pre-2005 MY cars registered in the State of Mexico. Ensuring that vehicle inspection procedures and enforcement practices in the State of Mexico are as rigorous as those in Mexico City would likely help improve the effectiveness of the PVVO in addressing high-emitting vehicles and close the real-world emissions gap between the two jurisdictions.

Moreover, while not as pronounced, Figure 11 also shows that newer (post-MY 2006) cars registered in the State of Mexico account for comparatively higher shares of emissions than those registered in Mexico City across all pollutants, despite accounting for similar shares of the sampled fleet (43% and 40%, respectively). This is particularly true of UV smoke, for which vehicles of model years 2006–2022 registered in the State of Mexico emitted 35% of total PV emissions, while those registered in Mexico City emitted 11%. Although these newer cars registered in the State of Mexico emit a slightly lower share of total emissions compared to their share of the fleet, they still account for a substantial share (35%–40%) of total emissions.

In total, gasoline PVs registered in the State of Mexico accounted for 50% of the sampled fleet and 64%–77% of total emissions, compared to gasoline PVs registered in Mexico City, which accounted for 43% of the sampled fleet and 16%–28% of total emissions. These results highlight the importance of policies to address higher emissions from cars registered in the State of Mexico. Although Mexico City and the State of Mexico have

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40 More than 30 measurements were collected for 1991–1994 MY cars registered in the State of Mexico; however, these are excluded from the plot to improve the visualization of more recent model years.

41 Model year groupings were based on PVVO certificates, shown in Figure 1. Vehicles of model years 1994–2005 are typically "1" and "2" certificate, and vehicles of model years 2006–2022 are typically "00" and "0 certificates.

42 Like Figure 9, this plot uses distance-specific emission factors, converted using Global Fuel Economy Initiative data. IEA (Fuel Economy in Mexico, updated December 2021), https://www.iea.org/articles/fuel-economy-in-mexico.

Figure 10. Average emissions from gasoline passenger vehicles by model year for each registration location. Shaded region represents the 95% confidence interval.
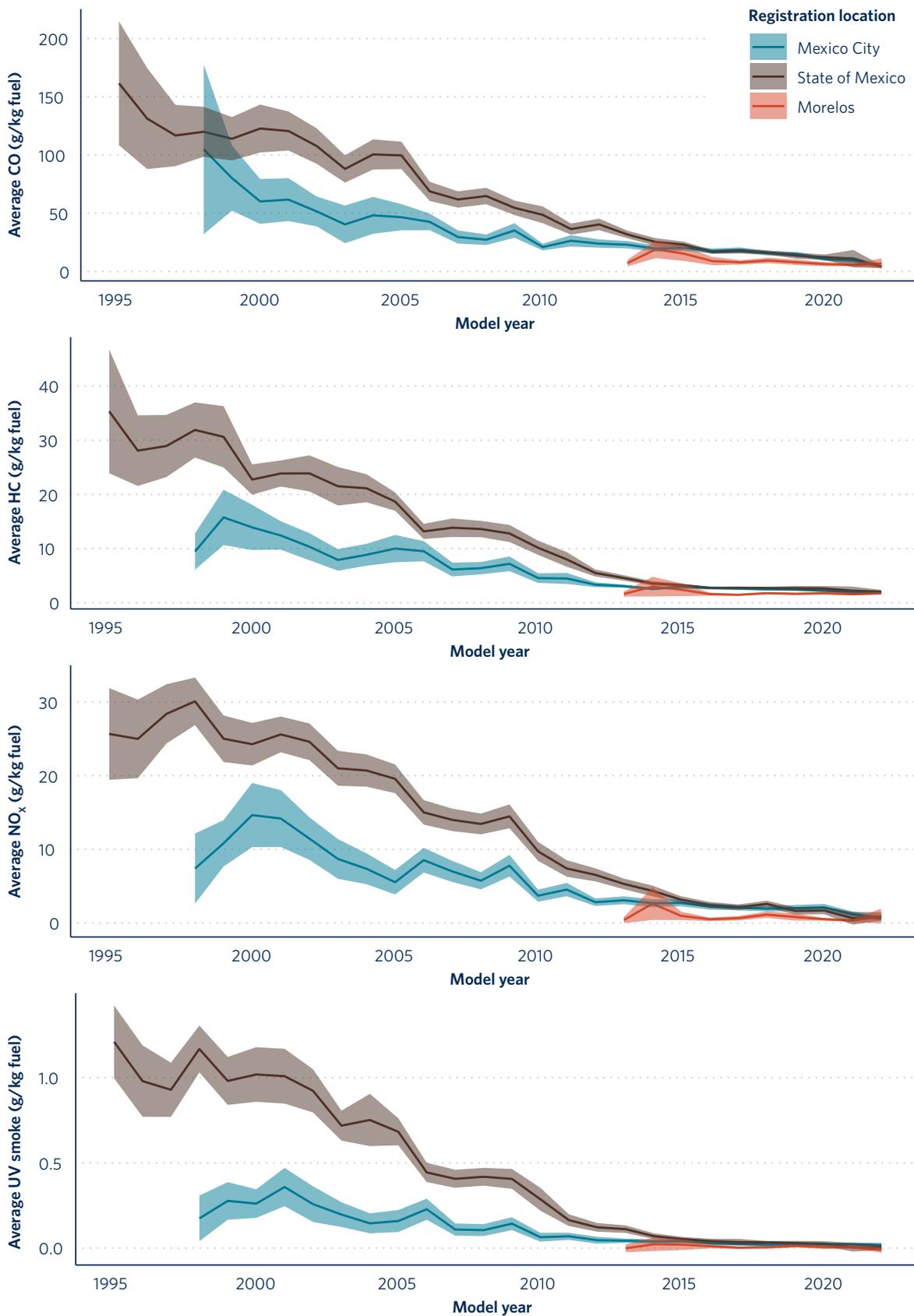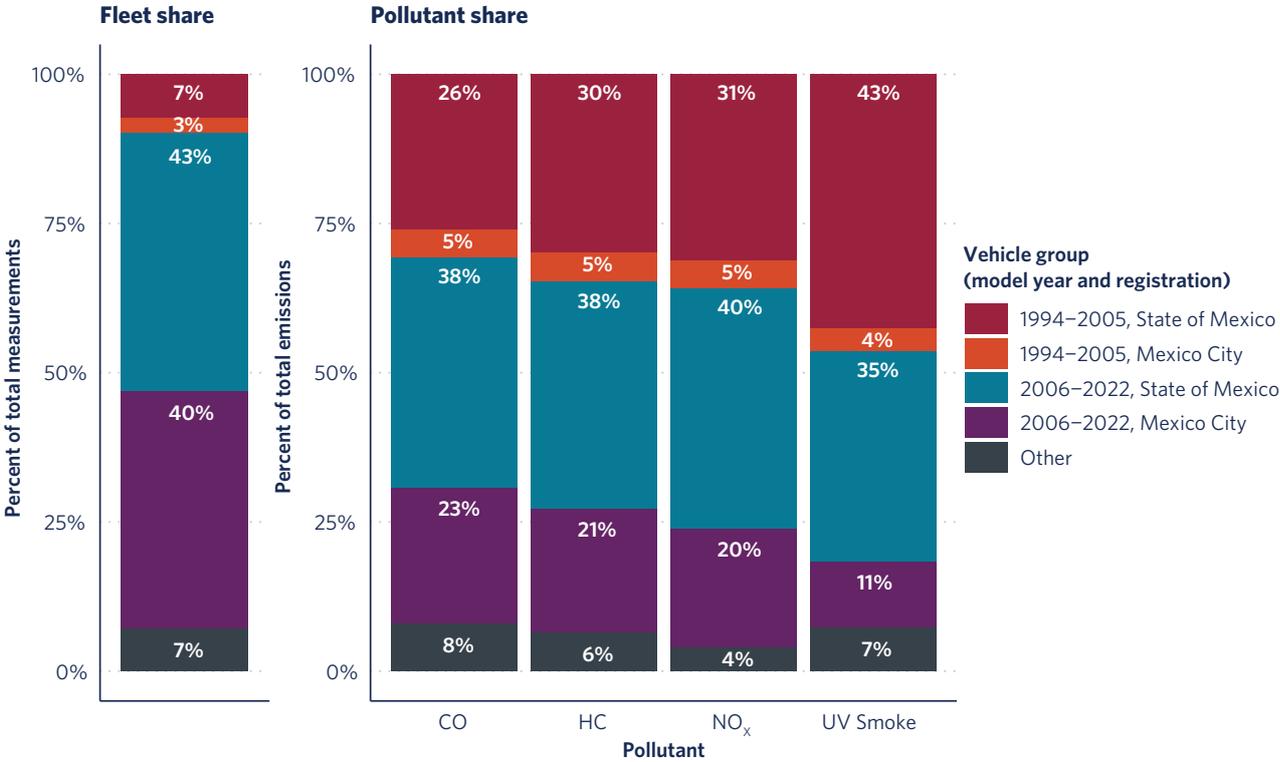
Figure 11. Gasoline passenger car share of the sampled fleet versus share of total pollutants by model year group and registration location. "Other" refers to vehicles registered in Morelos or pre-1994 MY cars, which make up a small portion of the fleet.

the same PVVO programs, the higher emissions in the State of Mexico indicate that the program should be further investigated by the local authorities. Ensuring true harmonization of vehicle inspection procedures and enforcement practices in both jurisdictions would

likely help improve the effectiveness of the PVVO in addressing high-emitting vehicles.

Figure 12 presents a more detailed breakdown of emissions from gasoline passenger vehicles by PVVO certificate.[43] For all pollutants, cars with 0 and 00

Figure 12. Average emissions of gasoline passenger vehicles registered in Mexico City and the State of Mexico by PVVO certificate.

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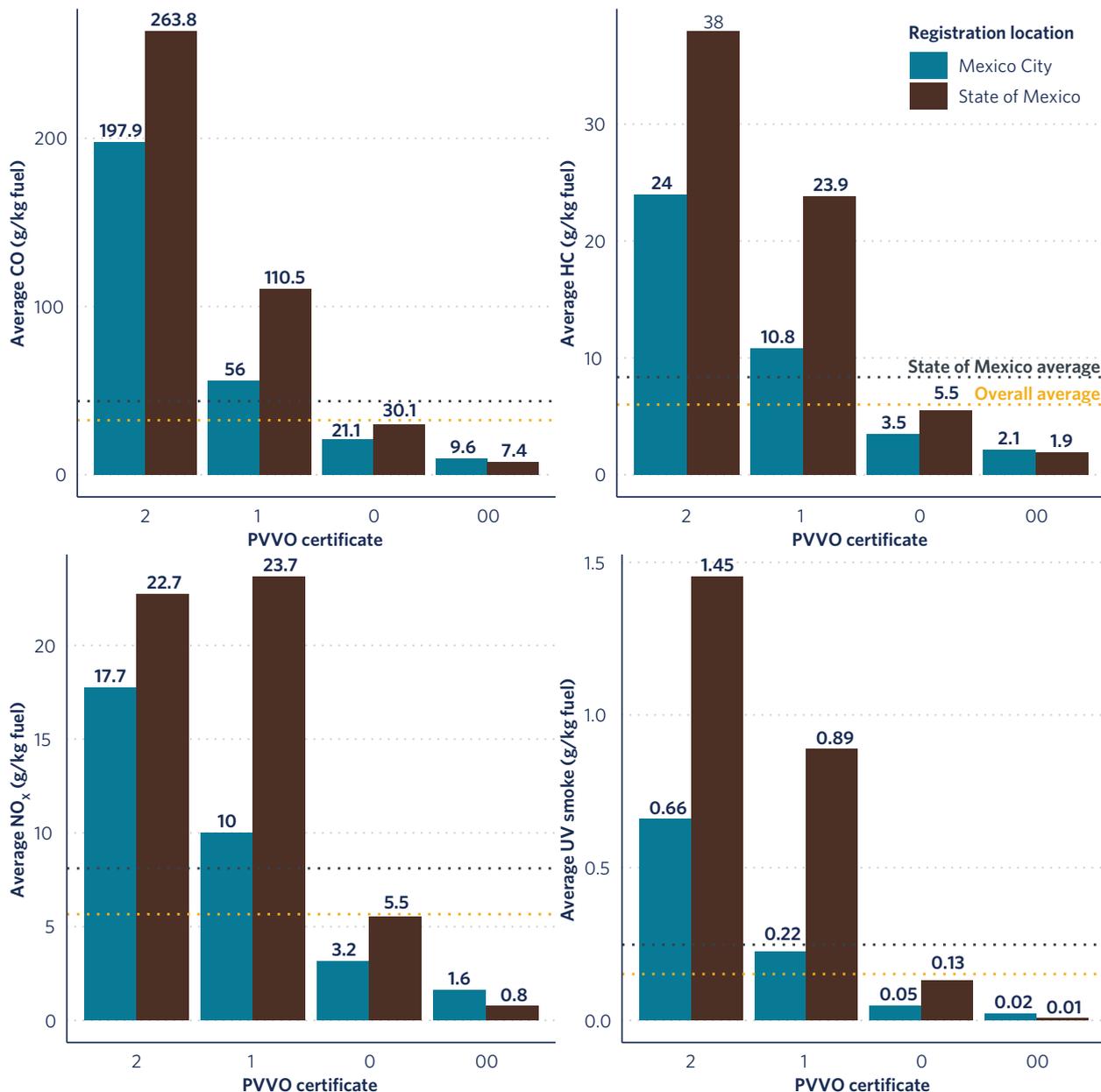
43 For the State of Mexico, vehicles are categorized by the PVVO certificates reported with the vehicle specifications. This information was not included for cars registered in Mexico City, so these vehicles were categorized by model year based on the information in Figure 1; MY 1993 and earlier are classified as "2," MY 1994–2005 are classified as "1," MY 2006–2019 are classified as "0," and MY 2020 and later are classified as "00."

certificates from both Mexico City and the State of Mexico showed emissions below the overall average. At PVVO certification 1, trends between Mexico City and the State of Mexico diverge, with cars registered in the State of Mexico exhibiting roughly double (or greater) the average emissions of those registered in Mexico City. Indeed, except in the case of CO, cars registered in the State of Mexico certified to PVVO level 1 exhibited emissions similar to or even higher than Mexico City-registered cars certified to level 2. Overall, these results highlight that real-world emissions performance is generally well-aligned with government driving restrictions based on the PVVO scheme, but that additional policy action is needed to better address high emissions from 1-certified cars registered in the State of Mexico.

Figure 13 shows the highest-emitting gasoline passenger vehicles of MY 2004 and newer—specifically, those with average emissions at least 50% higher than the fleet average across all pollutants. The Nissan Tsuru 1.6L had the highest emissions levels, followed by the VW Pointer 1.8L, Chevrolet Chevy 1.6L, and the Nissan Platina 1.6L. All four models had at least 2.5 times greater average emissions for all pollutants compared to fleet averages. Full results of all vehicle models with least 100 measurements are included in Appendix A.

TAXI EMISSION TRENDS

As Mexico City authorities prohibit taxis from operating for more than 10 years, there are fewer older taxis compared to PVs. Figure 14 presents the distribution of taxis by model year, showing that a large majority (77%) are of MY 2012–2018, meaning they were between 4 and 10 years old at the time of measurement. There are almost no taxis older than MY 2006; by contrast, 10% of passenger vehicles in our sample were older than MY 2006.

On average, across all pollutants, taxis generally emit much higher emissions than PVs of the same model year—up to 10 times higher, in some instances (Figure 15). For example, on average, MY 2015 taxis emitted 3.5 times more CO, 4.6 times more HC, 6.9 times more NO_x, and 8.2 times more UV smoke than their MY 2015 PV counterparts. Indeed, the oldest taxis (MY 2009) showed average emission levels similar to or higher than PVs approximately 10 years older, with substantially higher HC emissions than 2000 MY PVs and NO_x and UV smoke levels exceeding those of 1999 MY PVs. Though average taxi emissions decrease for newer model years, only MY 2020 and MY 2021 taxis showed similar emissions to PVs.

Figure 13. Highest-emitting gasoline passenger vehicles of MY 2004 and newer. Error bars represent 95% confidence intervals.
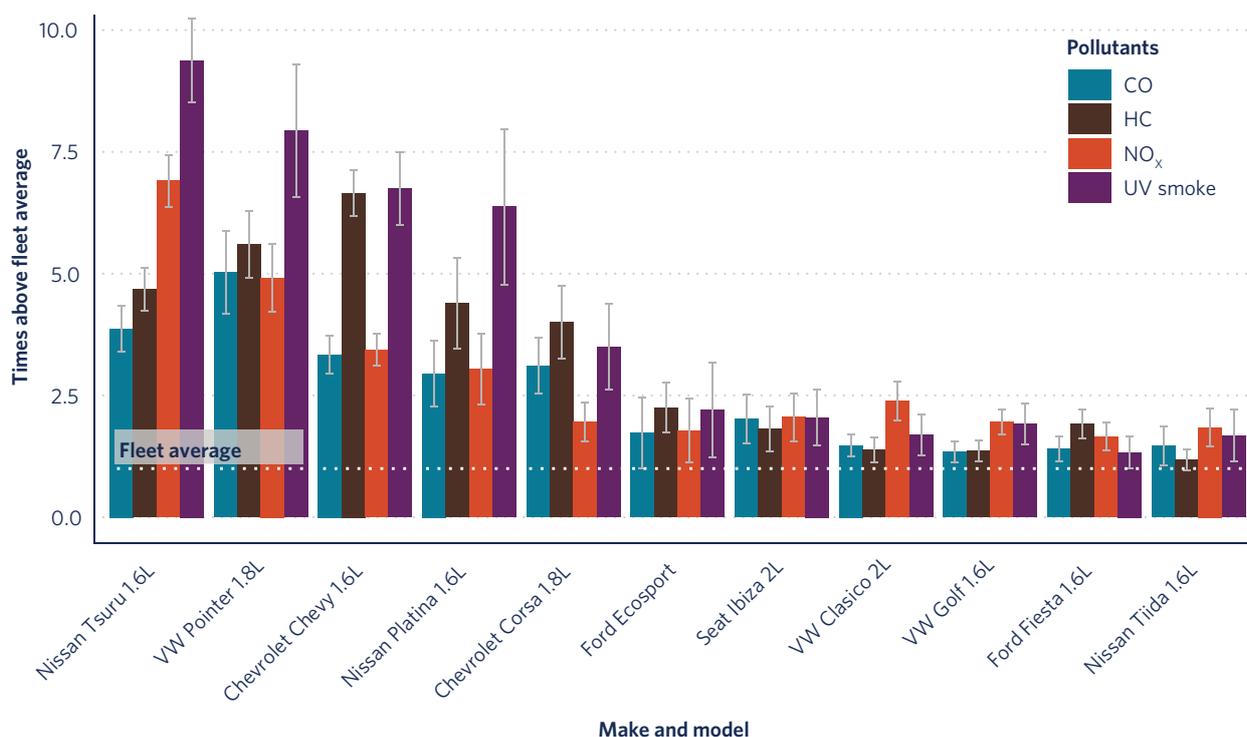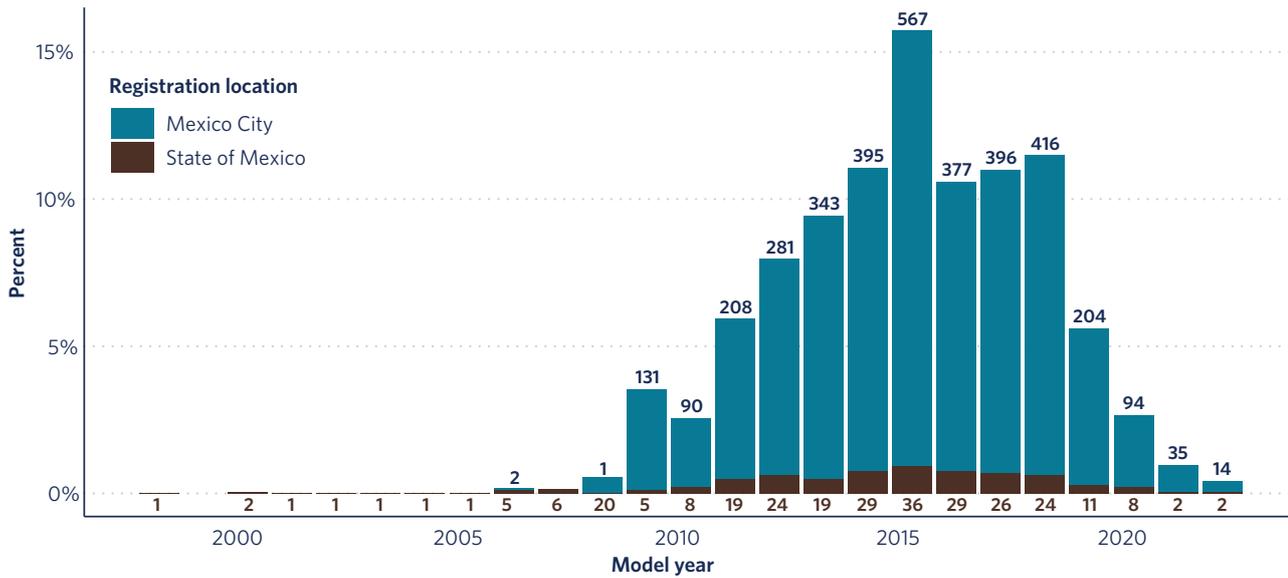
Figure 14. Taxi model year distribution.

Elevated taxi emissions can be partially attributed to faster deterioration among taxis than PVs due to higher mileage accumulation. A previous study showed taxi deterioration, with average HC emissions approximately doubling over the span of 3 years between two measurement campaigns.[44] The present study does not examine deterioration, as the measurements were all taken within the same year; however, based on our results that indicate high emissions from taxis, further investigation into taxi deterioration may be warranted. Currently, taxis are required to pass an annual inspection and maintenance test in addition to the PVVO. High taxi emissions suggest that modifications to the inspection and maintenance procedure may help reduce the negative effects of deterioration.

Higher usage and deterioration alone do not explain the observed disparity between taxi and PV emissions, however. Compared to past TRUE remote sensing campaigns in other cities, the gap between taxi and PV emissions is much higher in Mexico City. In Scotland, for instance, diesel taxis showed up to two times greater NO_X emissions compared to diesel PVs of the same model year, while taxis in London exhibited 2.7

times higher emissions than diesel PVs—far narrower disparities than those found in the present study.[45]

The prominence of one specific vehicle model, the Nissan Tsuru, among Mexico City taxis helps explain this trend. As shown in Figure 13, the Nissan Tsuru was one of the highest-emitting PV models in this study. The model also made up over 50% of the sampled taxi fleet, having been especially dominant up to MY 2012 before gradually declining until MY 2017 (Figure 16), when their production ended amid safety concerns.[46] The trends shown in Figure 15 indicate that emissions dropped substantially by MY 2017, which aligns with a decrease in the share of Nissan Tsurus and an increase in popularity of other models, such as the Chevrolet Aveo and Nissan Versa (Figure 16).

NO_X emissions from Nissan Tsurus are particularly high compared with other taxis and PVs. Figure 17 shows that across all model years through 2017, Nissan Tsuru taxis show substantially higher levels of NO_X than other taxi models and PVs. For example, among MY 2014 vehicles, Nissan Tsurus showed 2.6 times higher NO_X emissions than other taxis and 10.4 times higher NO_X emissions than PVs. These disparities indicate that although other taxis do

44 John Koupal and Cindy Palacios, *Analysis of 2019 Mexico City RSD HC levels*, (2021), https://theicct.org/wp-content/uploads/2022/04/ERG_Mexico-City-2019-RSD-Analysis_Updated-March-1_Clean.pdf.

45 Kaylin Lee, Yoann Bernard, and Jonathan Cooper, *Assessment of Real-World Vehicle Emissions in Scotland in 2021;* Tim Dallmann, Yoann Bernard, Uwe Tietge, Rachel Muncrief, *"NO_X and Particulate Emissions from London's Taxis,"* (Washington, D.C.: International Council on Clean Transportation, 2018), https://www.trueinitiative.org/media/597546/true-london-taxi-fact-sheet.pdf.

46 Luis Rojas, "Nissan to stop making Mexican Tsuru amid safety criticism," *Reuters,* October 26, 2016, https://www.reuters.com/article/us-nissan-tsuru/nissan-to-stop-making-mexican-tsuru-amid-safety-criticism-idUSKCN12Q22M.

Figure 15. Comparison between gasoline passenger vehicle and taxi emissions. Error bars represent the 95% confidence intervals.
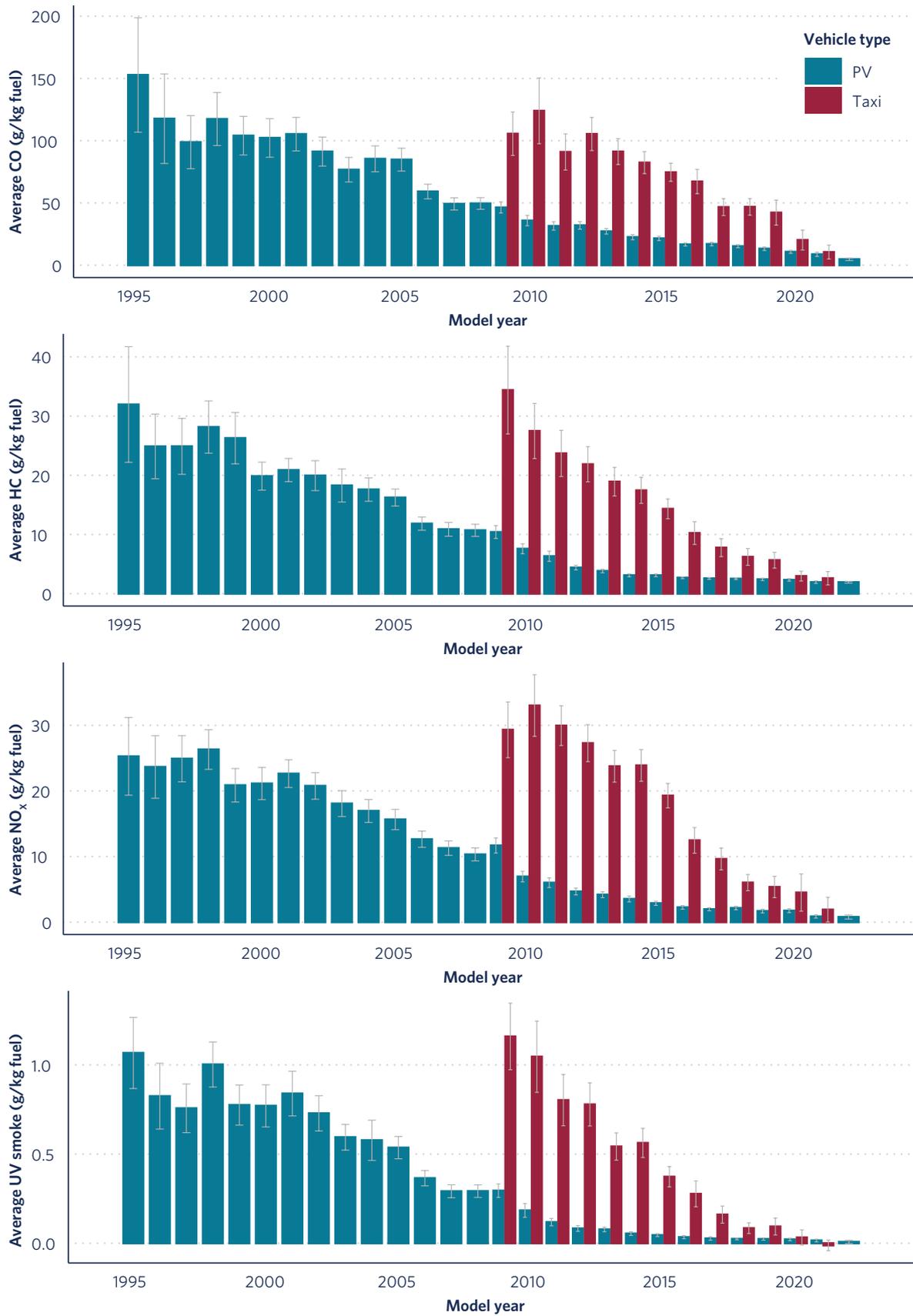
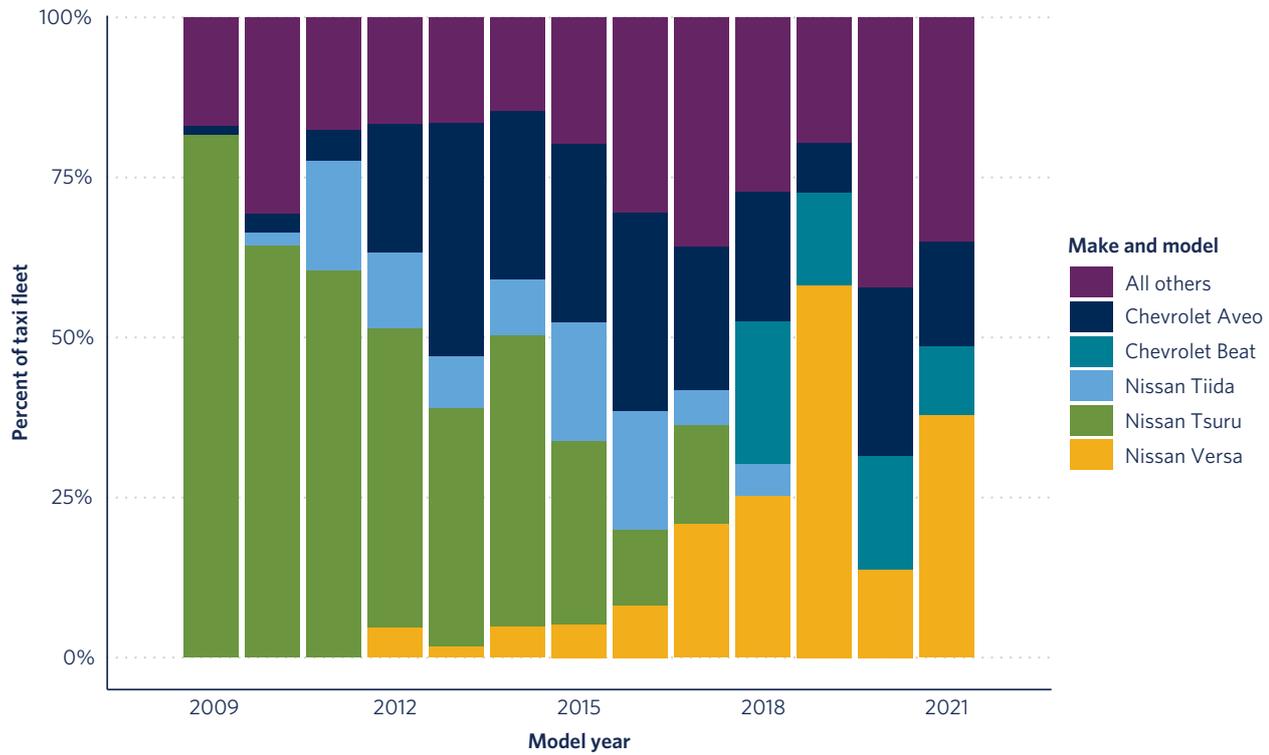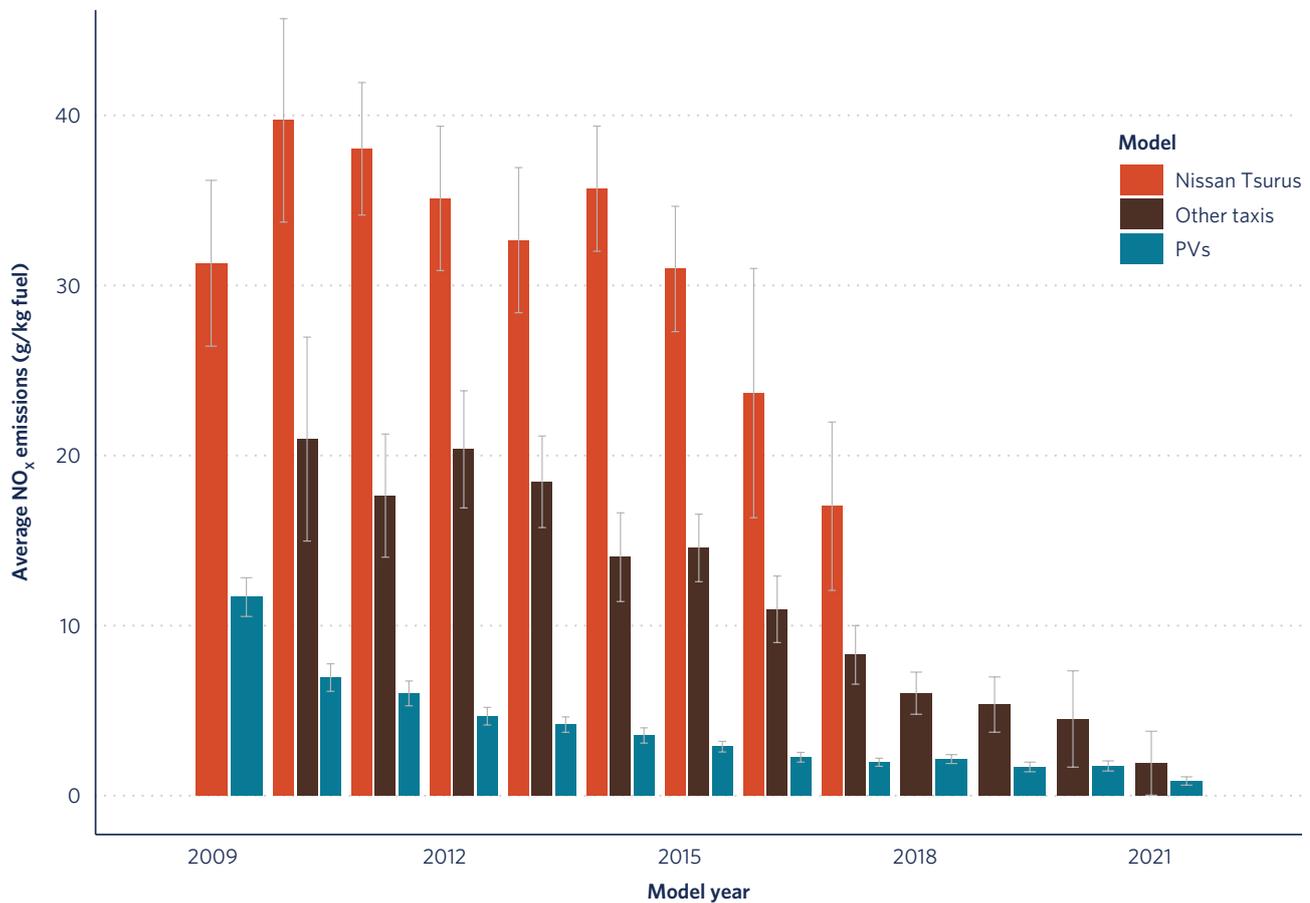**Figure 16.** Share of taxi models by model year.

Figure 17. NO$_x$ emissions from Nissan Tsurus, all other taxi models, and PVs by model year. Error bars represent the 95% confidence intervals.

show high emissions compared to PVs, a large part of the high average NO$_X$ emissions from taxis can be attributed to Nissan Tsurus, especially for older model years.

Though Nissan Tsurus are not solely responsible for high average emissions from taxis, these results highlight the impact that one single vehicle model can have on average fleet emissions. Mexico City already prioritizes renewal programs to replace Nissan Tsurus due to poor safety conditions, and this study shows that there are important air quality implications as well. Other common taxi models identified as high emitters should be investigated by the city governments and automakers. Government incentives should be examined carefully to avoid incentivizing high-emitting models.
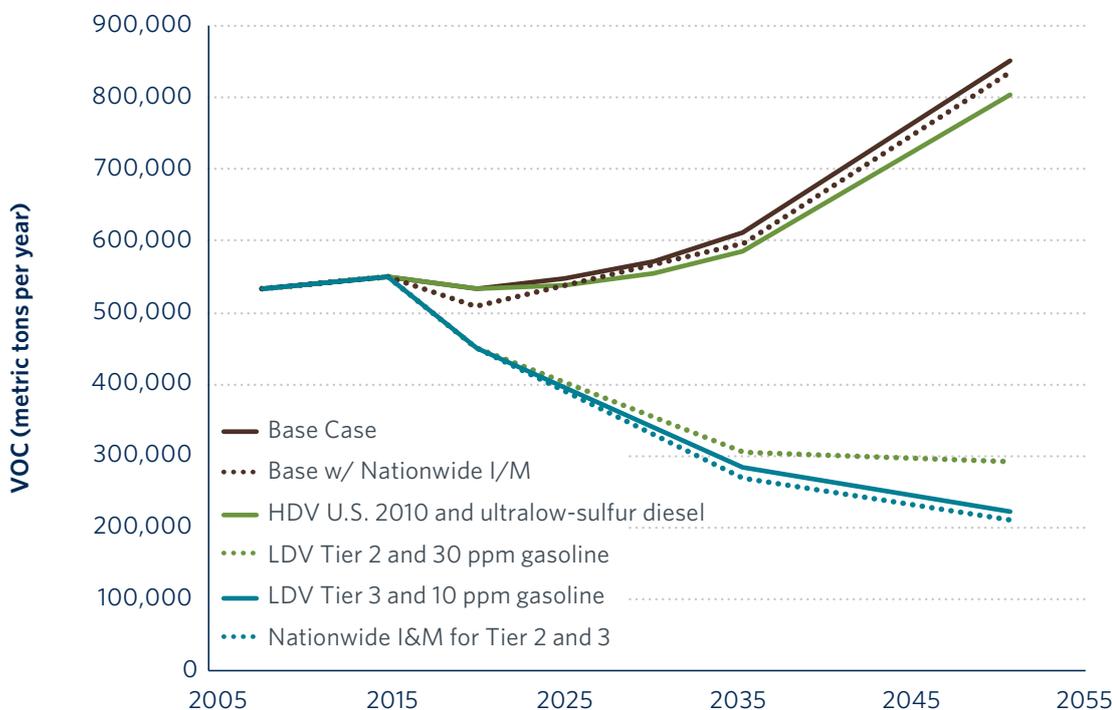
EVAPORATIVE EMISSIONS

As noted above, this study incorporated an assessment of evaporative emissions, a first for the TRUE initiative. NOM-042 established a 2g HC evaporative emission limit for a 24-hour diurnal and hot soak test, which does not include onboard refueling vapor recovery (ORVR) requirements like the use of a carbon canister or other advanced provisions included in U.S. Tier 3 regulations. Gaining insight on evaporative emissions and ozone formation dynamics can help accelerate the national vehicle emission standard (NOM-042) update and support strong, harmonized inspection and maintenance programs.

The ICCT has long pointed out the impact of poor evaporative emission limits and importance of using cleaner fuels. In 2018, the ICCT published an air quality and health study assessing the impact of improved LDV and HDV emission regulations and low sulfur fuels (Figure 18). The results show compelling short-term benefits of adopting Tier 2 bin 5 and ORVR standards.[47]

Studies to measure the precision of remote sensing-based evaporative emissions measurements are limited, and the results currently available indicate that accuracy is not sufficient to perform quantitative analyses.[48] Thus,

Figure 18. VOC emissions under different regulatory scenarios. Note: "I/M" stands for Inspection and Maintenance. I/M programs are regulatory strategies aimed at ensuring that vehicles on the road are maintained to meet specific emissions standards.

47 Pineda et al., *Air Quality and Health Benefits of Improved Fuel*.

48 Charles L. Blanchard, "CRC Report No. E-119-3a" (CRC: Alpharetta, GA, 2023), https://crcao.org/wp-content/uploads/2023/04/E-119-3a-Final-Report.pdf.

our analysis focused on comparative analyses of the presence of detectable evaporative emissions.

To evaluate evaporative emissions, we analyzed the index calculated and reported by Opus, which indicates whether evaporative emissions are detected. Opus also reported an index ranging from 0–4, with 4 indicating the highest level of evaporative emissions.[49] The algorithm uses HC and CO_2 measurements from each of the 100 plume points captured in the 1 second of data collection, and then utilizes two regressions to determine the evaporative index.[50] Opus also reported another index, the Eastern Research Group (ERG) index, which utilizes a different algorithm; however, this was not analyzed in this study due to evidence of the prevalence of potential false positives.[51]

Figure 19 presents evaporative emissions index scores across the sampled fleet, by vehicle class. Of light-duty trucks, 3.7% showed detectable evaporative emissions while driving, and 1.6% of the sampled fleet had an evaporative emissions index of 4, the highest of the scale. Taxi trends closely resemble those of LDVs: 3.5% of the sampled fleet showed detectable evaporative emissions and 1.7% of the sampled fleet had an evaporative emissions index of 4. Approximately 1.7% of the sampled PV fleet showed detectable evaporative emissions, lower than the other two vehicle classes.

Though these percentages are relatively low, vehicles showing detectable evaporative emissions had high levels of HC emissions. LDTs with detectable evaporative emissions averaged 49 g HC/kg fuel (nearly 5 times

Figure 19. Share of gasoline vehicles that showed detectable evaporative emissions and associated evaporative emissions index by vehicle class. The number of measurements is shown in each bar.
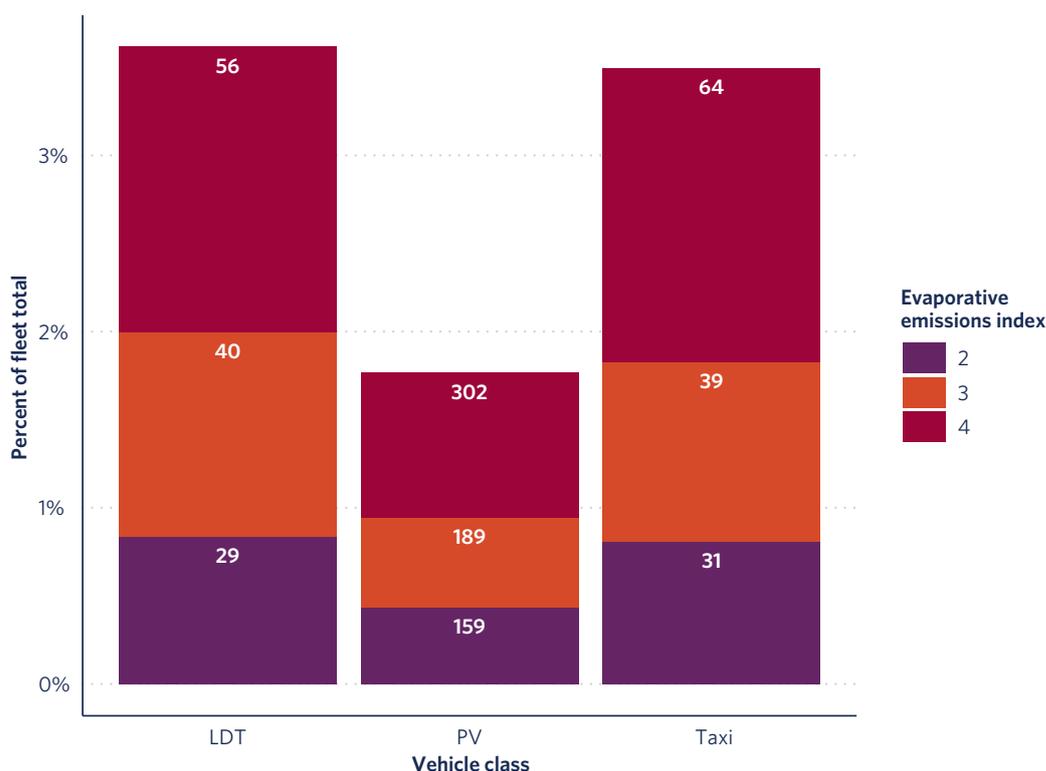
49 Blanchard, "CRC Report No. E-119-3a."

50 The first regression performed is a linear regression between CO_2 and HC. If HC is present and the correlation is weak, this can be a sign of evaporative emissions (HC) from a source other than the tailpipe. Secondly, a LOESS regression is evaluated against the linear regression, and if the slopes are quite different from one another, this further indicates evaporative emissions.

51 Another study did find that the ERG index correlated better with simulated evaporative emissions. However, given that this analysis looks at detection rates and does not aim to estimate emissions amounts, we use the Opus algorithm. Blanchard, "CRC Report No. E-119-3a"; Michael J. St. Denis and Gerard Glinsky, "CRC Report No. RW-105," (CRC: Alpharetta, GA, 2023), https://crcao.org/wp-content/uploads/2023/04/CRC-RW-105-Final-Report-Revecorp-20230405.pdf.

higher than the fleet average), PVs with detectable evaporative emissions averaged 50 g HC/kg fuel (approximately 8 times higher than the fleet average), and taxis with detectable evaporative emissions averaged 67 g HC/kg fuel (nearly 5 times higher than the fleet average). Targeting these vehicles with the highest levels of HC emissions due to evaporative emissions for maintenance or replacement would help address Mexico City's issue of ozone pollution.

Examining the data more closely, among PVs and LDTs, a higher share of older vehicles showed detectable evaporative emissions. As shown in Figure 20, nearly 12% of MY 2004 and older LDTs showed detectable evaporative emissions, compared to just 2.5% of MY 2005 and newer LDTs. Similarly, approximately 8% of MY 2004 and older PVs showed detectable evaporative emissions compared to just 1% of MY 2005 and newer PVs. These results indicate that thoroughly inspecting older vehicles for evaporative emission leaks may be important for reducing O_3 pollution.

Figure 20. Share of gasoline vehicles that showed detectable evaporative emissions split by model year group. The number of measurements is shown in each bar.

Although the technique of measuring evaporative emissions is relatively new and its accuracy is still being studied, these results provide useful information on portions of the fleet to focus on for reducing evaporative emissions. As average tailpipe HC emissions decline due to fleet turnover, it will be increasingly important to address evaporative emissions to limit HC emissions and associated O_3 air quality impacts.

CONCLUSIONS AND POLICY IMPLICATIONS

This study provides insight on how Mexico City can better address the negative air quality and health impacts of vehicle emissions in Mexico City through targeted policy action. Through an analysis of CO, HC, NO_x, UV smoke, and evaporative emissions from approximately 45,000 remote sensing measurements, we present four conclusions:

1. **Limiting the operation of the small percentage of high-emitting, older passenger vehicles that have an outsized emissions impact can result in large emission reductions.** Older vehicles make up a small portion of the sampled fleet but contribute substantially to total emissions. Specifically, 50% of gasoline passenger vehicle CO, HC, NO_x, and UV smoke emissions were from vehicles 14–17 years old and older, which make up less than 20% of the sampled fleet. Prioritizing the adoption of a low-emission zone (LEZ) in Mexico City's downtown area by 2024 as proposed by the Mexico City government would help greatly reduce emissions from older vehicles and improve air quality. As of January 2024, the Mexico City government had converted the streets surrounding the main Zócalo square to a pedestrian area to recuperate public space, increase transit safety, and allow for more sustainable mobility options.[52] The design of potential LEZ phases can be informed by the results from our analysis to maximize real-world emission reductions. Collaboration between government authorities to share vehicle registration data across states will be necessary to support the implementation of a LEZ.

2. **Prioritizing incentives to phase out the highest-emitting taxis would help to greatly improve the average real-world emissions performance of taxis.** Despite their comparatively newer vehicle fleet, taxis emissions were much higher compared to PVs, approximately 2.2–3.1 times higher across

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52 "Conquistamos el principal Espacio Público de México con la Peatonalización del Zócalo Capitalino: Martí Batres," Secretaría de Obras y Servicios, 2024, https://www.obras.cdmx.gob.mx/comunicacion/nota/conquistamos-el-principal-espacio-publico-de-mexico-con-la-peatonalizacion-del-zocalo-capitalino-marti-batres.

all pollutants. For cars of the same model year, taxis showed up to 4 times higher CO, 5.6 times higher HC, 6.9 times higher NO_X, and 10.4 times higher UV smoke levels compared to PVs. A large part of the extreme NO_X averages from taxis can be attributed to Nissan Tsurus, which emitted up to 2.6 times higher NO_X emissions compared to other taxis of the same model year. Informing taxi fleets and ride-hailing companies about the results of high-emitting vehicle models can help them transition toward cleaner models. Additionally, Mexico City can consider expanding its rebate programs to further accelerate the replacement of Nissan Tsurus with lower-emitting and zero-emission alternatives. Accelerating the replacement of high-emitting vehicles requires the collaboration of the government agencies with OEMs, taxi fleets, and ride-hailing companies and ensuring incentives and financing options are destined to the cleanest and most efficient vehicles.

3. **Investigating the PVVO across states to fully harmonize inspection and maintenance programs can help close the gap in real-world emissions between registration locations.** PVs registered in the State of Mexico showed higher emissions compared to those registered in Mexico City, particularly for older vehicles. Specifically, despite accounting for only 7% of the sampled fleet, 1994–2005 model-year PVs registered in the State of Mexico made up 25%–42% of total emissions across pollutants. In comparison, Mexico City cars of the same age group accounted for 3% of the sampled fleet and contributed a roughly proportionate share of emissions (4%–5%). As Mexico City and the State of Mexico currently have the same PVVO requirements, Mexican authorities may examine whether inspection and enforcement mechanisms are being evenly applied across jurisdictions. Ensuring programs in all states across the Megalopolis region are harmonized can help improve emissions performance of the full fleet of vehicles operating in the ZMVM. Programs can also benefit from more data transparency to support compliance and enforcement by identifying high-emitting vehicles or other unintended results. In Costa Rica, for instance, a mandatory inspection and maintenance program known as RITEVE includes reports of detailed test results by vehicle category so that policymakers across agencies various to have a clear view of high-emitting portions of the fleet.[53]

Further, authorities could consider undertaking a detailed analysis of the efficacy of the PVVO design to ensure all jurisdiction programs are working properly and delivering the same benefits. This can be supported by building a robust, updated database of registration information and collaboration mechanisms to support implementation of local policies.

4. **Local regulations, incentives, and awareness campaigns can help accelerate the transition to lower-emitting and zero-emission new vehicles.** In addition to transitioning away from older, high-emitting vehicles, ensuring that new vehicles have low real-world emissions is also an important priority. National emission standards for LDVs have not been updated in 20 years, resulting in higher-polluting new and in-use vehicles than those meeting world class standards like Tier 3. Additionally, a recent proposal to relax NO_X limits would further weaken the regulations on new vehicles if adopted. Although local governments can implement more stringent regulations, it is more challenging and requires harmonization among several states. CAMe's role as a coordinating body is, therefore, critical to achieving greater emissions reductions pending national-level regulatory updates. Leapfrogging to zero-emission vehicles is another strategy to dramatically improve transport emissions in the context of weak national regulations. The LEZ can be designed to accelerate transport decarbonization by establishing a timeline to allow only zero-emission vehicles into the area. Local governments also can implement policies to support the transition to zero-emission vehicles by offering financial and non-financial incentives, supporting the planning and installment of charging infrastructure, and increasing consumer awareness.

Our analysis also highlights opportunities for additional study in several areas. For instance, analyzing the measurements from this campaign alongside CAMe's remote sensing campaign from March and June 2022 could provide a fuller picture of fleet emissions. Meanwhile, while this study provided some information on evaporative emissions from vehicles, further study using higher accuracy testing methods could help inform policies to reduce evaporative emissions and resulting O_3 air pollution. Finally, national and local governmental authorities could further investigate the high-emitting vehicle models identified in this report.

53 "Report of RTV of the I Semester 2019", RITEVE, accessed September 30, 2023, https://www.rtv.co.cr/en/report-of-rtv-of-the-i-semester-2019/.

APPENDIX A: DETAILED PASSENGER VEHICLE EMISSIONS BY VEHICLE MODEL

The results below show the results for CO, HC, NO$_x$, and UV smoke averages by vehicle make and model. Results are only shown for vehicles certified to the most recent emission standard (MY 2004 and later vehicles). Vehicles are grouped by engine size where possible; however, this information was missing for some vehicles. Only vehicle models with at least 100 measurements are included.

Figure A1. CO emissions by vehicle make and model for passenger vehicles of MY 2004 and newer. Error bars represent the 95% confidence intervals.
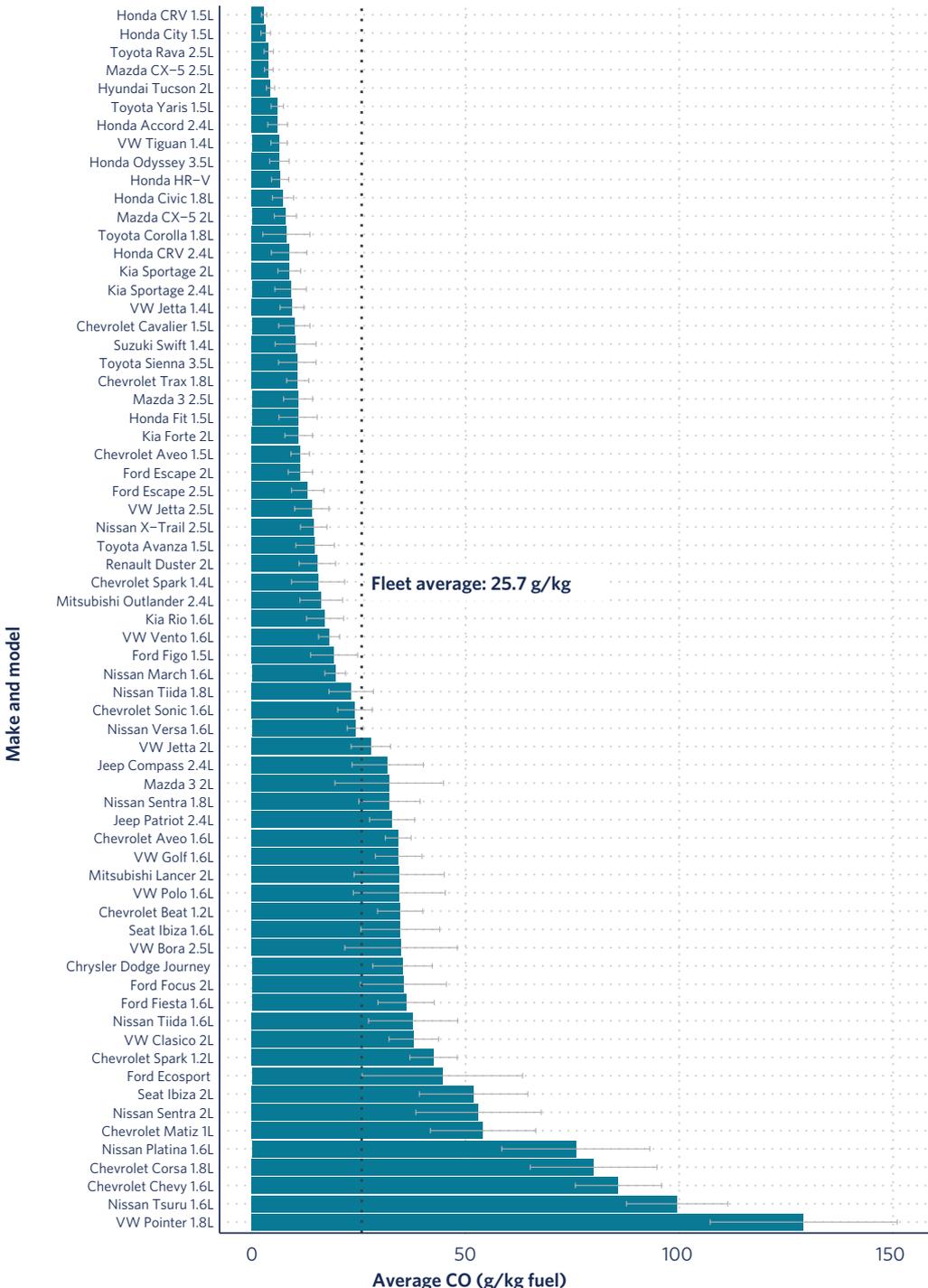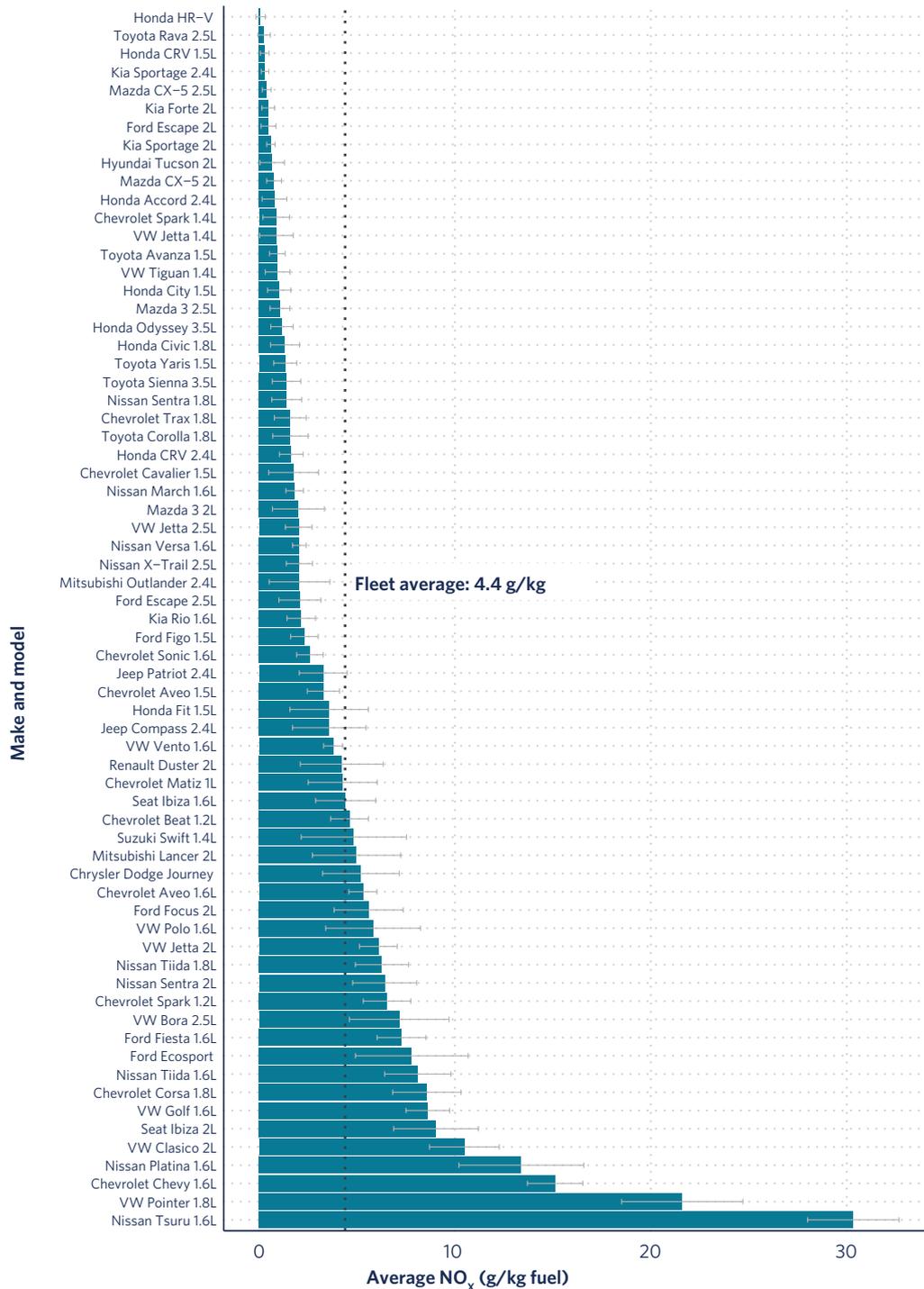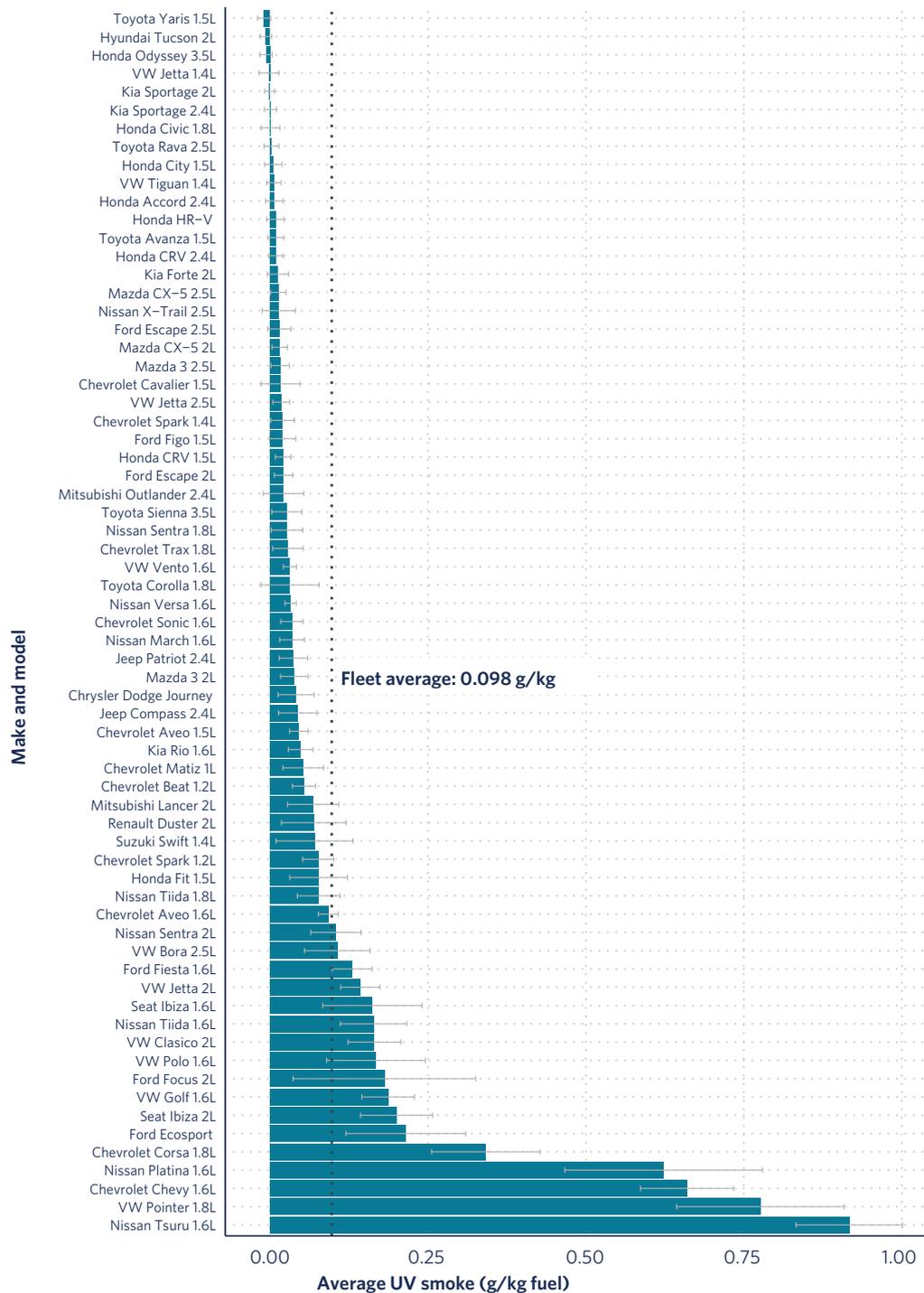
Figure A2. HC emissions by vehicle make and model for passenger vehicles of MY 2004 and newer. Error bars represent the 95% confidence intervals.
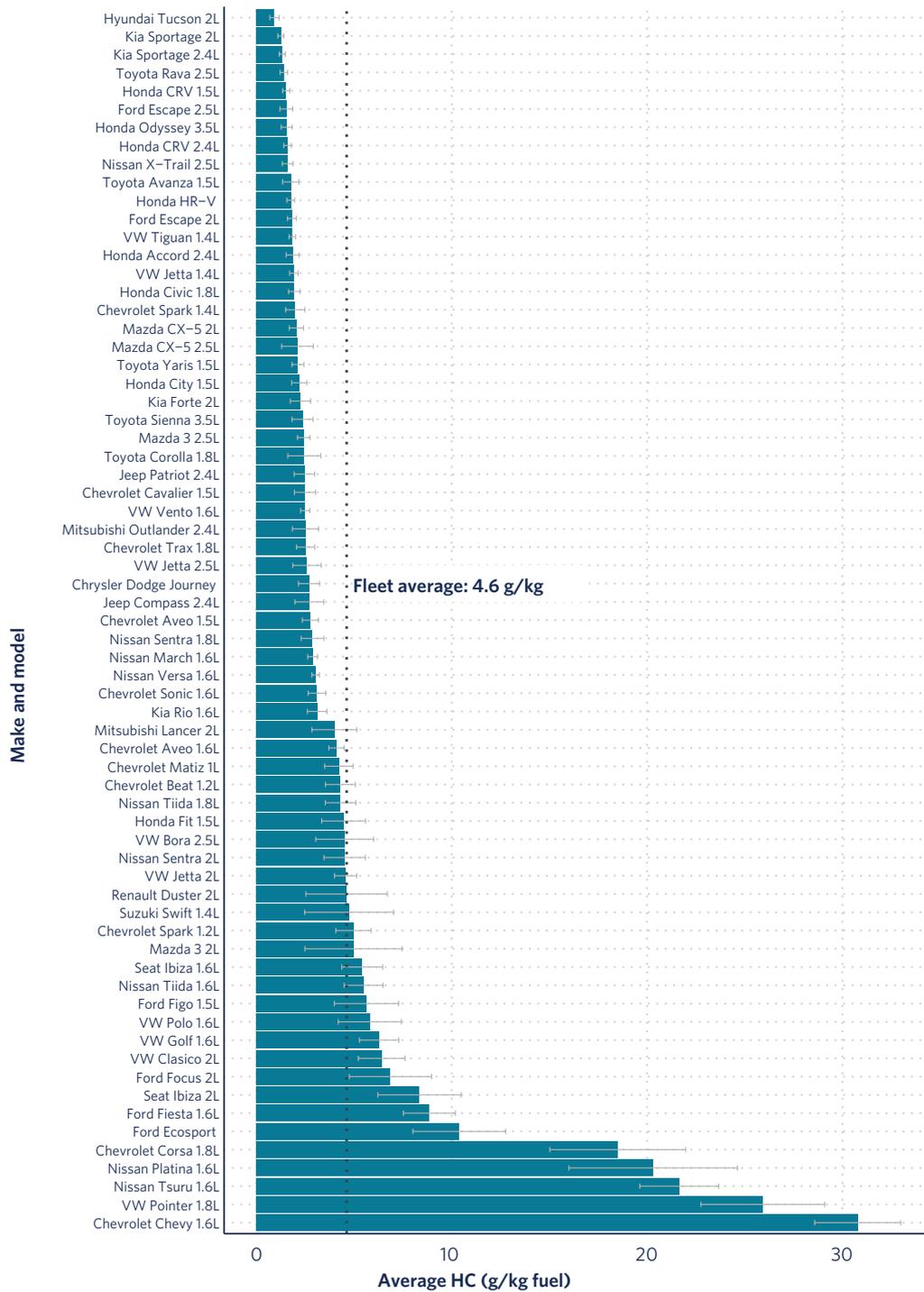
Figure A3. NO$_X$ emissions by vehicle make and model for passenger vehicles of MY 2004 and newer. Error bars represent the 95% confidence intervals.

Figure A4. UV smoke emissions by vehicle make and model for passenger vehicles of MY 2004 and newer. Error bars represent the 95% confidence intervals.

Fleet average: 0.098 g/kg

true
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APPENDIX B: DETAILED TAXI EMISSIONS BY VEHICLE MODEL

The results below show the results for CO, HC, NO$_x$, and UV smoke averages by taxi vehicle make and model. The results are split by model year groups 2017 and earlier and 2018 to better visualize the differences by vehicle model. This cutoff year was chosen as it is the last year that the Nissan Tsuru, the most common taxi model, was produced. Only vehicle models with at least 100 measurements are included.

Figure B1. CO emissions by taxi make and model. Error bars represent the 95% confidence intervals.
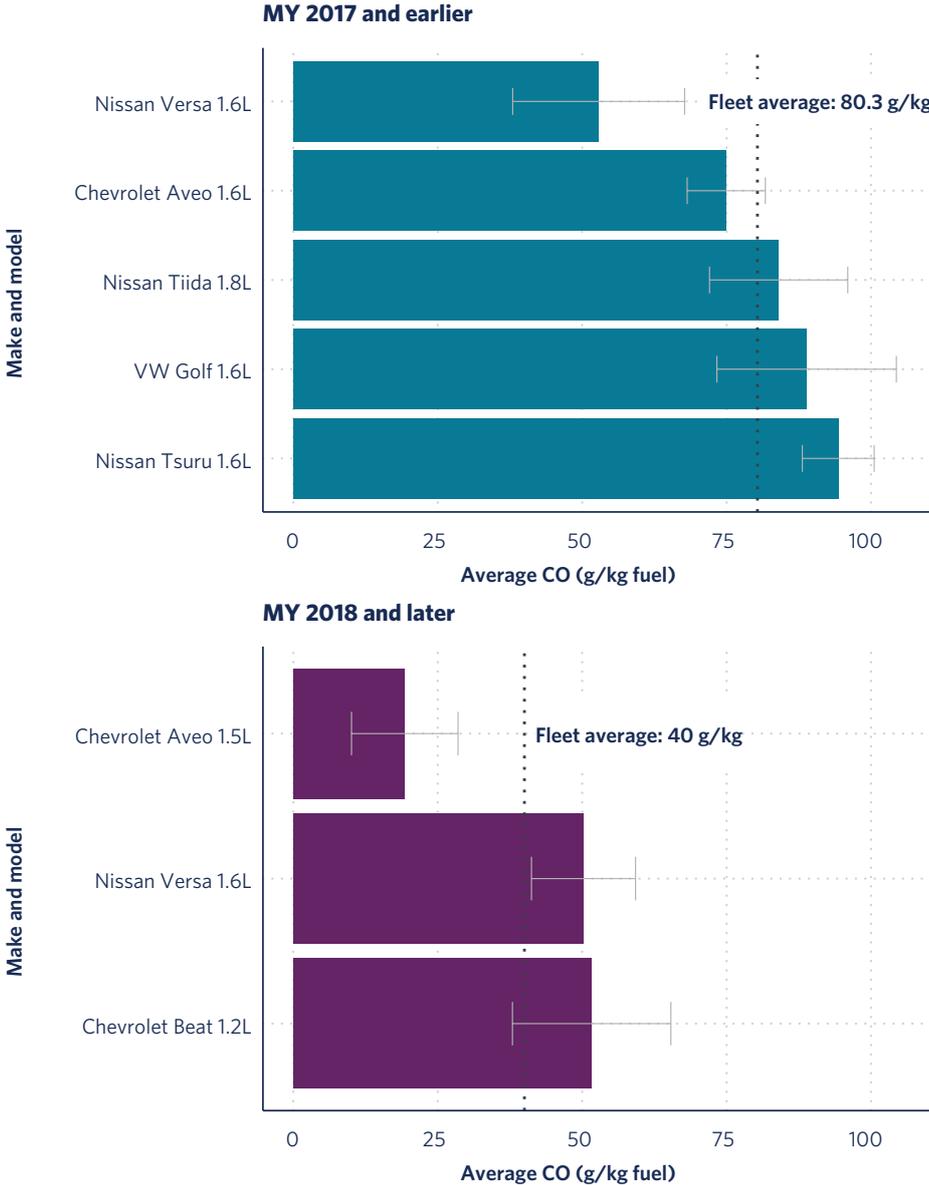
MY 2017 and earlier

Fleet average: 80.3 g/kg

MY 2018 and later

Fleet average: 40 g/kg

Figure B2. HC emissions by taxi make and model. Error bars represent the 95% confidence intervals.

MY 2017 and earlier

Fleet average: 16.8 g/kg

MY 2018 and later

Fleet average: 5.5 g/kg
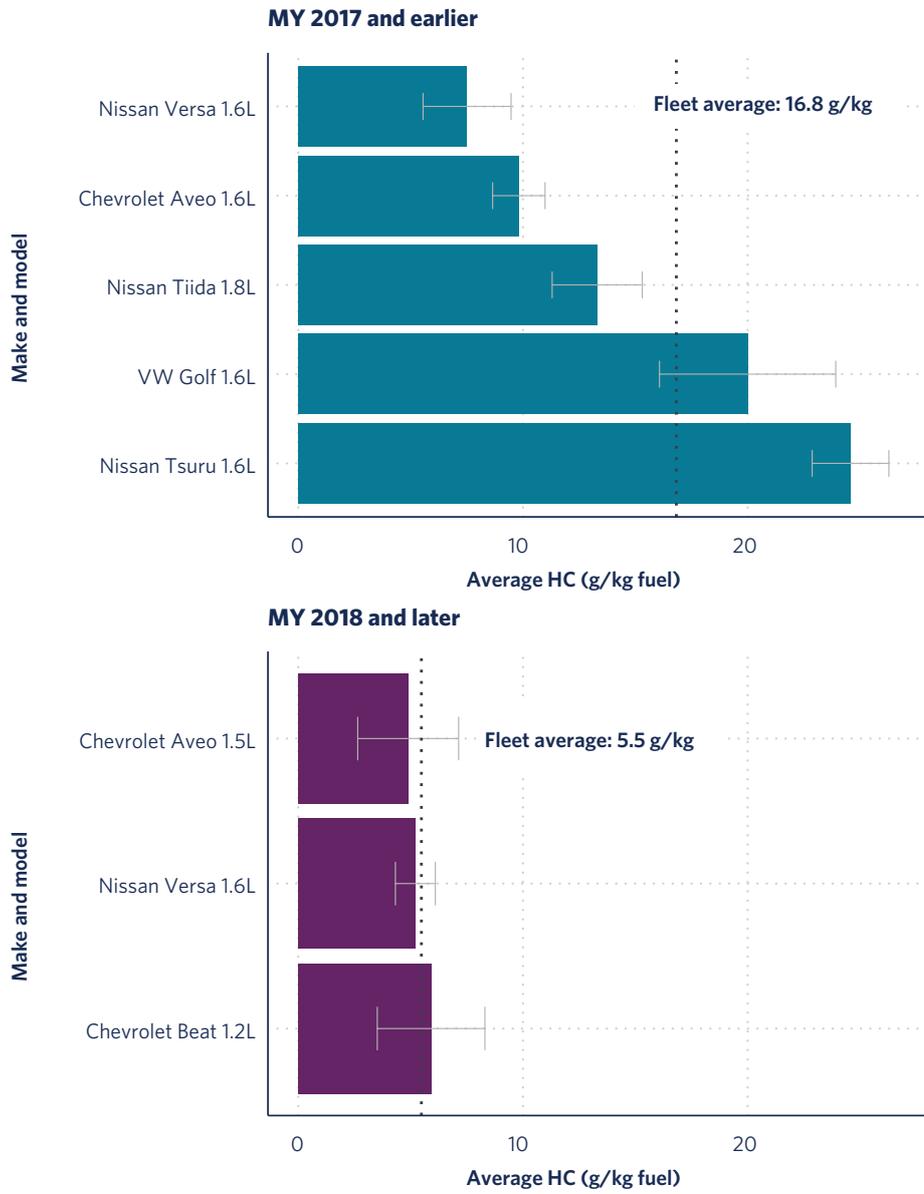
Figure B3. NO$_x$ emissions by taxi make and model. Error bars represent the 95% confidence intervals.

MY 2017 and earlier

Fleet average: 20.9 g/kg

MY 2018 and later

Fleet average: 5.5 g/kg
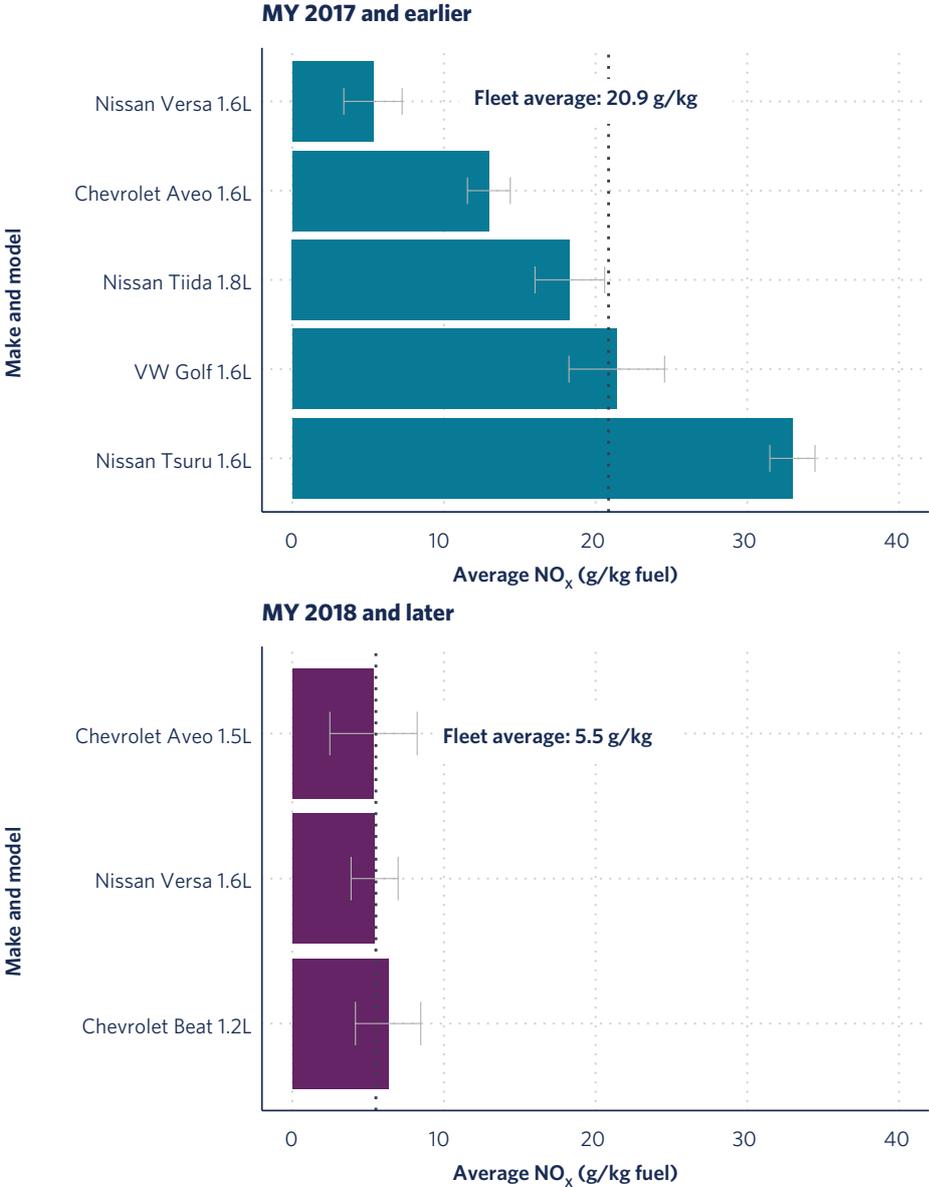
Figure B4. UV smoke emissions by taxi make and model. Error bars represent the 95% confidence intervals.

MY 2017 and earlier

Fleet average: 0.5 g/kg

MY 2018 and later

Fleet average: 0.1 g/kg

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