THE REAL URBAN EMISSIONS INITIATIVE

Evaluation of real-world vehicle emissions in Kampala, Uganda

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FIA Foundation and the International Council on Clean Transportation 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

Vehicle-related air pollution is a major challenge in Kampala, Uganda, where annual average ambient fine particulate matter ($PM_{2.5}$) pollution exceeds World Health Organization guidelines by at least 8 times. The heavy reliance on private cars, motorcycles, and informal minibus transport systems presents a challenge for addressing traffic-related air pollution in the city, and comprehensive policies are needed to reduce vehicle emissions.

Currently, Uganda enforces a 15-year age limit on imported light-duty vehicles and no age limit on imported heavy-duty vehicles. The National Environment (Air Quality Standards) Regulations, 2024 adopted Euro 4 emission limits on all vehicle imports, both new and used, but the extent to which these standards are currently enforced is uncertain. The same uncertainty surrounds enforcement of the routine vehicle inspection program described in Uganda's Traffic and Road Safety (Motor Vehicle Inspection) Regulations, 2016. In this context, real-world vehicle emissions data from Kampala are critical to understanding the transport sector's contribution to air pollution in the city.

In July 2024, The Real Urban Emissions (TRUE) Initiative partnered with the United Nations Environment Programme and local researchers and authorities to employ a plume chasing remote sensing technique in Kampala. Vehicles were followed to measure their real-world emissions and nearly 6,000 measurements of nitrogen oxides (NO_X), nitrogen dioxide (NO_2), black carbon (BC), and particle number (PN) were collected across multiple vehicle types, including passenger cars, motorcycles, minibuses, large buses, light commercial vehicles (LCVs), and heavy commercial vehicles (HCVs). This report examines the distribution, characteristics, and emissions of vehicles measured in Kampala and then identifies ways that policy can help reduce vehicle-related pollution.

The findings of the TRUE Kampala real-world vehicle emissions analysis highlight that an age limit alone cannot guarantee lower-emitting vehicles in Uganda. They support the following conclusions and policy recommendations:

Strengthening vehicle import requirements would promote a lower-emitting fleet in Kampala. The newer imports measured in this study did not consistently demonstrate lower real-world emissions than older vehicles, and average real-world emissions across all vehicle classes were above Euro 4 emission limits. This highlights the emissions reduction possible from implementing Euro 4 vehicle emission limits on all imported vehicles. Furthermore, as emission standards continue to progress in exporting countries, including to Euro 6 and beyond, it will become increasingly feasible for Uganda to align its import requirements accordingly. Transitioning to Euro 6 standards in Uganda by 2030 would be facilitated by maintaining the current age limits. Uganda would also need to maintain its commitment to achieve 10 ppm sulfur fuel content in the near term and not later than 2030, as this is necessary for Euro 5 and later emission standards.

Implementing routine vehicle inspection and improving vehicle maintenance would reduce emissions from vehicles already on the roads. More than 50% of gasoline passenger cars measured exhibited average NO_X emissions above 1,000 mg/km, levels suggestive of potential malfunctions or the removal of catalytic converters. The especially elevated BC emissions among diesel vehicles over 15 years old also suggests inefficient fuel combustion or emission control systems. Diesel passenger cars, LCVs, and HCVs over 15 years old emitted 3 times more BC than those aged 8–15 years. Fully implementing the routine vehicle inspection program as laid out in the Traffic and Road Safety Regulation, 2016 could help to identify the reasons for elevated emissions among the in-use fleet. Quality vehicle maintenance is important for keeping emissions down and could be made more accessible through capacity-building initiatives for vehicle mechanics and licensing vehicle garages that meet certain standards for service.

Prioritizing policies that promote cleaner public transportation would curb emissions from minibus taxis. The diesel minibus taxi fleet was one of the oldest segments measured, with an average age of 25. This fleet exhibited elevated real-world vehicle emissions indicative of deteriorating vehicles with likely missing or malfunctioning emission control systems. Over half of the diesel minibuses in Kampala exhibited real-world BC emissions above 1,000 mg/km and NO_X emissions above 3,000 mg/km. Diesel minibuses over 15 years of age exhibited particularly elevated average BC emissions, 6 times higher than those of diesel minibuses between 8 and 15 years old. With old age and high mileage likely contributing to fleet deterioration, progressive modernization of this fleet could be achieved by limiting the age of newly registered minibus taxis to under 15 and reducing the age limit to 8 by 2030. Longer-term reductions in emissions could be achieved through rebate programs for the scrappage of older minibus models and supporting taxi minibus owners in transitioning to newer, cleaner models or electric alternatives. Requiring that vehicles in this fleet be inspected at least once per year is important for ensuring that necessary maintenance is undertaken.

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INTRODUCTION

Air pollution is a significant challenge for Kampala, the capital of Uganda and its largest city. Studies have found that the city's ambient concentrations of fine particulate matter ($PM_{2.5}$), at levels of 39–59 μg/m^3, exceed the World Health Organization's recommended annual average of 5 μg/m^3 by 8–12 times.[1] Such elevated air pollution levels pose significant health risks. Approximately 19% of all non-accidental premature adult deaths in Kampala between 2018 and 2021 were attributable to long-term $PM_{2.5}$ exposure.[2] Elevated monthly $PM_{2.5}$ concentrations in Kampala city have been associated with increased respiratory-related healthcare facility visits, including for infant asthma and pneumonia.[3] Although there is no safe level of air pollution, substantial health benefits can be achieved with even incremental reductions in pollution.[4]

The transportation sector is a major contributor to elevated pollution levels in Kampala. The city has a population of over 1.7 million residents and is home to the largest number of registered vehicles in Uganda.[5] In addition to the residents, the commuter-adjusted population rises to 2.5 million during the day as people travel to the city for work and other needs.[6] Due to a lack of formalized public transportation in Kampala, these commuters primarily rely on private cars and low-capacity transport systems such as minibus taxis and commercial motorcycles.[7] Adding to the air pollution challenge, the broader Kampala Metropolitan Area experiences an influx of heavy commercial vehicles (HCVs) as a result of the Jinja–Kampala–Mpigi corridor, a major 120 km transport corridor that links Uganda with key trade partners and passes through Kampala city. Studies investigating the contribution of road transport to ambient air pollution in Kampala estimate that 60% of nitrogen dioxide (NO_2) pollution and up to 24% of $PM_{2.5}$ pollution can be attributed to the sector.[8] Understanding the real-world vehicle emissions on the roads in Kampala is a critical step in understanding road transport's contribution to air pollution. Real-world emissions data are also valuable for understanding how well prevailing emission regulations are being enforced.

The Real Urban Emissions (TRUE) Initiative, in partnership with the United Nations Environment Programme (UNEP) and local researchers and authorities, conducted a plume chasing study in Kampala in July 2024. The first of its kind in Africa, the study sheds light on the real-world emissions of vehicles and offers evidence-based policy recommendations to mitigate air pollution from on-road transportation in Uganda. While the TRUE Initiative has conducted similar remote sensing studies around the world, this is the first TRUE project in Africa.

POLICY BACKGROUND

Most of the vehicles on Uganda's roads are used and imported. In 2023, Uganda imported vehicles worth US$291 million and vehicles ranked fifth among the most imported products in the country by number of units.[9] Between 2015 and 2023, over 1.4 million private passenger cars and motorcycles were registered in Uganda, an average of 163,000 registrations per year.[10] Annual vehicle registrations grew significantly between 2000 and 2014, and during this time only 34% of diesel vehicles and 6% of gasoline vehicles were under 8 years old at the time of registration. Between 2005 and 2014, the average age at import increased from 8 years to 16 years for diesel vehicles and from 10 years to 15 years for

1 Lynn M. Atuyambe et al., "Air Quality and Attributable Mortality Among City Dwellers in Kampala, Uganda: Results from 4 Years of Continuous $PM_{2.5}$ Concentration Monitoring Using BAM 1022 Reference Instrument," *Journal of Exposure Science & Environmental Epidemiology* 35, (April 2025): 288–293, https://doi.org/10.1038/s41370-024-00684-9; Gabriel Okello et al., "Association between Ambient Air Pollution and Respiratory Health in Kampala, Uganda: Implications for Policy and Practice," *Urban Climate 58* (November, 2024): 102128, https://doi.org/10.1016/j.uclim.2024.102128.

2 Atuyambe et al., "Air Quality and Attributable Mortality."

3 Okello et al., "Association between Ambient Air Pollution."

4 World Health Organization, *WHO Global Air Quality Guidelines: Particulate Matter ($PM_{2.5}$ and PM_{10}), Ozone, Nitrogen Dioxide, Sulfur Dioxide and Carbon Monoxide* (2021), https://apps.who.int/iris/handle/10665/345329.

5 Kampala Capital City Authority, "Kampala Road Safety Strategy 2021 - 2030" (2021), https://kcca.go.ug/media/docs/Kampala%20Road%20Safety%20Strategy%202021-2030.pdf.

6 Government of Uganda, "National Population and Housing Census 2024 – Final Report – Volume I (Main)" (2024), https://www.ubos.org/uganda-bureau-of-statistics-2024-the-national-population-and-housing-census-2024-final-report-volume-i-main/.

7 Ministry of Lands, Housing and Urban Development, "The Jinja-Kampala-Mpigi Corridor Physical Development Plan Chapter 6: Mobility and Connectivity Strategy" (2023), https://www.kcca.go.ug/media/docs/Chapter%206%20FINAL%20Transport%20Mobility%20and%20Connectivity%20Strategy.pdf.

8 National Environment Management Authority, "Stakeholders Call for Multi-Sectoral Approach to Reduce Air Pollution," press release, May 3, 2021, https://nema.go.ug/sites/default/files/Air%20Quality%20Awareness%20Week%20Statement.pdf; Omid Ghaffarpasand et al., "The Impact of Urban Mobility on Air Pollution in Kampala, an Exemplar Sub-Saharan African City," *Atmospheric Pollution Research 15*, no. 4 (April, 2024): 102057, https://doi.org/10.1016/j.apr.2024.102057; Deo Okure et al., "Integrated Air Quality Information for Kampala: Analysis of $PM_{2.5}$, Emission Sources, Modelled Contributions, and Institutional framework," *Environmental Science: Atmospheres 5*, no. 4 (March, 2025): 471–84, https://doi.org/10.1039/d4ea00081a.

9 Observatory of Economic Complexity, "Cars in Uganda," January 2025, https://oec.world/en/profile/bilateral-product/cars/reporter/uga.

10 Ugandan Bureau of Statistics, "Private Newly Registered Motor Vehicles _ Motorcycles from 2015 to 2023" (2025), https://www.ubos.org/explore-statistics/29/.

gasoline vehicles.[11] Japan is currently the largest source of new and used light and heavy vehicles imported into Uganda, followed by the United Kingdom, Germany, and Tanzania.[12] Over the last 5 years, vehicle import trade with China, India, and Indonesia has grown rapidly and these countries now rank among Uganda's top 10 vehicle trading partners.[13]

A 2016 Ugandan regulation specified that upon first registration in the country, vehicles would be subject to a certificate of fitness test.[14] According to this regulation, all motor vehicles are subject to an emissions test that measures the exhaust for carbon monoxide (CO), hydrocarbon (HC) content, and Lambda value (a measure of air-fuel ratio) in accordance with either the manufacturer's recommendation (when that is available) or the defined limits shown in Table 1. However, this program faced criticism, including for reportedly high inspection fees, and the parliament suspended it in 2017.[15] Recent news reports suggest that the mandatory emissions test will recommence in July 2025 with a grace period of about 1 month for vehicles that fail the test before strict enforcement of the limits and penalties for non-compliance begin.[16]

An environmental tax was first introduced in Uganda in 2006 and it required all vehicles over the age of 8 years old at import to pay a 10% tax.[17] In 2018, the environmental tax was increased to between 20% and 50%.[18] Evidence suggests that the environmental tax has not discouraged the import of vehicles more than 8 years old, likely as these vehicles remain cheaper than most newer counterparts, even with the environmental tax.[19] In 2018, Uganda also imposed an age limit of 15 years on all imported light-duty vehicles (under 4 tons); currently there is no age limit on imported vehicles over 4 tons. The emission standards in Japan, the leading vehicle importer, have been approximately equivalent to Euro 4 standards since 2005 and Euro 6 standards since 2009.[20]

Vehicle maintenance in the Kampala Metropolitan Area is a challenge. A 2024 focus group study of vehicle mechanics found that 85% of mechanics in Kampala lack formal training and have limited knowledge of modern vehicle technologies. This leads to substandard maintenance practices and is exacerbated by the widespread use of counterfeit or low-quality spare parts.[21] Additionally, emission control systems—particularly catalytic converters—are frequently removed or stolen.[22] Qualified mechanics are often affiliated with expensive car dealerships or original equipment manufacturers and such maintenance is often inaccessible to the average vehicle owner; many vehicle owners therefore seek repairs only when breakdowns occur, rather than as a preventative measure.[23]

Seeking to address the emissions from vehicles, Uganda has introduced numerous policies over the last few years. In November 2023, the Technology and Innovation Secretariat of Uganda launched a national e-mobility strategy that set ambitious targets to electrify the public transportation network and motorcycles by 2030, and transition all passenger vehicle sales to electric by 2040.[24] As part of this, the Ugandan government is collaborating with the private sector to establish a network of at least 3,500 public vehicle charging stations and over 10,000 fast chargers by 2040; the aim is to establish fast charging availability in every 50 km radius. As part of the transition, Uganda has already deployed 24 electric buses and 1,500 electric motorcycles in the Greater Kampala Metropolitan

11 John Mutenyo et al., "Baseline Survey on Uganda's National Average Automotive Fuel Economy" (Global Fuel Economy Initiative, 2015), https://www.streetsforlife.org/media/461028/africa_vehicle-fuel-economy-baseline-for-uganda.pdf.

12 United Nations Environment Programme, "Used Vehicles And The Environment: A Global Overview of Used Light Duty Vehicles: Flow, Scale and Regulation" (2020), https://www.unep.org/resources/report/global-trade-used-vehicles-report; Observatory of Economic Complexity, "Cars in Uganda."

13 Observatory of Economic Complexity, "Cars in Uganda."

14 Ministry of Works and Transport, "Traffic and Road Safety (Motor Vehicle Inspection) Regulations 2016" (July 15, 2016), https://works.go.ug/policies-regulations/traffic-and-road-safety-laws-regulations/11-policies-regulations/14-traffic-and-road-safety-laws-regulations/4-traffic-and-road-safety-motor-vehicle-inspection-regulations-2016.

15 Jackson Rugunda, "Uganda to Begin Mandatory Vehicle Inspections July 1, Government Says," *UG Standard*, May 20, 2025, https://www.ugstandard.com/uganda-to-begin-mandatory-vehicle-inspections-july-1-government-says/.

16 Rugunda, "Uganda to Begin."

17 Finance Act, 2006, No. 32, Uganda Gazette No. 71, Supplement No. 11, Volume XCVIX December 8, 2006, https://ulii.org/akn/ug/act/2006/32/eng@2006-12-08#page-1.

18 Traffic and Road Safety Act, 1998 (Amendment) Act, 2018, No. 5, Uganda Gazette No. 33, Supplement No. 2 , Volume CXI, June, 29, 2018, https://ulii.org/akn/ug/act/2018/5/eng@2018-06-29.

19 Mutenyo et al., "Baseline Survey on Uganda's National Average Automotive Fuel Economy."

20 "Japan: Light-duty: Emissions," TransportPolicy.net, accessed May 30, 2025; "Japan: Heavy-duty: Emissions," TransportPolicy,net, accessed May 30, 2025, https://www.transportpolicy.net/standard/japan-heavy-duty-emissions/.

21 Michael Wanyama, "Africa's Automobile Maintenance Structure: A Policy Brief Highlighting the Safety and Emission Risks of Automobile Maintenance in Kampala" (Autosafety Uganda, 2024), https://transport-links.com/wp-content/uploads/2025/01/Autosafety-Policy-Brief.pdf.

22 Wanyama, "Africa's Automobile Maintenance."

23 Wanyama, "Africa's Automobile Maintenance."

24 Technology and Innovation Secretariat of Uganda, "National E-Mobility Strategy: Strategy, Positioning Uganda as a Net Source of E-Mobility Tools & Solution to Reduce Dependence on Imports and Improve the Wellbeing of Ugandans" (November 2023), https://www.gcic.go.ug/national-e-mobility-strategy/.

Table 1. Emissions inspection limits in Uganda's Traffic and Road Safety (Motor Vehicle Inspection) Regulations, 2016

Manufacture date	Engine type	CO volume (%)[a]	HC (ppm)	Lamda (λ)	Exhaust emission color[b]	Smoke meter reading limit (ml)[b]	Other conditions for failure
Before 1/10/1986	Positive ignition	4.5	1,000[a]	—	—	—	The emission control system is leaking, incomplete, incorrectly assembled, or unsafely repaired or modified. Idle speed is outside vehicle manufacturer's recommendations. Engine exhaust system is leaking. Excess exhaust smoke likely to affect other road users.
01/10/1986 to 31/12/1993		3.5	750[a]	—	—	—	
01/01/1994 to 01/07/2002		0.5	200[c]	1+/- 0.03[c]	—	—	
After 1/07/2002		0.3			—	—	
Before 1/01/1980	Compression ignition	—	—	—	Black haze or darker		Engine oil level too high or low, coolant too low. Obvious engine defects. Engine idle speed is incorrect. The emission control system is leaking, incomplete, or incorrectly assembled.
1/01/1980 to 01/07/2008	Turbo charged compression ignition	—	—	—	—	3.0	
	Naturally aspirated compression ignition	—	—	—	—	2.5	
After 01/07/2008	Compression ignition	—	—	—	—	1.5	In addition to the above, the maximum attainable engine speed is less than 90% of the maximum speed specified by the manufacturer of the vehicle.

[a] Limit defined at idling speed
[b] These limits are in the case of vehicles for which the manufacturer's specified standard for exhaust smoke emissions is not available
[c] Limit defined as 2,500 rpm or at the speed specified by the manufacturer

Area, alongside 16 fast chargers and more than 100 battery-swapping stations.

Uganda transitioned to low-sulfur fuels in 2015 in accordance with standards set by the East African Community, an intergovernmental organization consisting of eight member states.[25] These standards apply to all East African Community member states and allow a maximum sulfur content of 50 ppm in diesel and 150 ppm in gasoline.[26] The standards were revised in 2019 with the regional commitment to reduce sulfur content of both diesel and gasoline to 10 ppm, and Uganda is set to transition 10 ppm sulfur fuels, which enables the adoption of Euro 5 and higher emission limits.[27]

In 2022, the East African Community adopted regionally harmonized Euro 4 vehicle exhaust emission standards for

25 "About EAC," East African Community, accessed May 30, 2025, https://www.eac.int/about-eac.

26 United Nations Environment Programme, "The Global Sulphur Progress Tracker" (2019), https://www.unep.org/resources/toolkits-manuals-and-guides/global-sulphur-progress-tracker.

27 United Nations Environment Programme, "The Five East African Community Countries Discuss Ultra-Low Sulphur Fuels," United Nations Environment Programme, January 29, 2019, https://www.unep.org/events/un-environment-event/five-east-african-community-countries-discuss-ultra-low-sulphur-fuels.

Table 2. Uganda's vehicle emission limits according to the National Environment (Air Quality Standards) Regulations, 2024

Fuel	Vehicle group	Pollutant (g/km)				
		CO	THC	HC + NO_x	NO_x	PM
Diesel	**Passenger cars**	0.5	—	0.3	0.25	0.025
Gasoline		1	0.1	—	0.08	—
Diesel	**Buses**	0.5	—	0.3	0.25	0.025
	Large buses	0.63	—	0.39	0.33	0.04
	Light trucks	0.74	—	0.46	0.39	0.06
Gasoline	**Bus**	1	0.1	—	0.08	—
	Large buses	1.81	0.13	—	0.1	—
	Light trucks	2.27	0.16	—	0.11	—
Gasoline	**Motorcycles with power > 11 kW**	1.14	0.38	—	0.07	—
	Motorcycles with power ≤ 11 kW	1.14	0.17	—	0.09	—
	Tricycle positive ignition	2	0.55	—	0.25	—
	Tricycle compression ignition	1	0.1	—	0.55	—
Fuel	**Vehicle group**	**Pollutant (kg/kWh)**				
		CO	**HC**	**NO_x**	**PM[a]**	**Smoke limits/m^{-1}**
Diesel	**Heavy trucks**	1.5	0.46	3.5	0.02	0.5

[a] The units for the HDV PM emission limits are not in line with Euro 4, which stipulates 0.02 g/kWh rather than kg/kWh. We advise that the HDV PM emission limit be revised accordingly.

new and used light- and heavy-duty vehicles.[28] Following this, Uganda's National Environment Management Authority (NEMA) released the National Environment (Air Quality Standards) Regulations, 2024.[29] The vehicle emission limits included in this regulation are equivalent to Euro 4 standards and are outlined in Table 2; while the regulations stipulate that vehicle emission standards apply to all new and used vehicles imported into Uganda, it is unclear if vehicles are yet required to meet them due to operational challenges.[30] The 2024 regulations also outline a routine vehicle inspection schedule that subjects all vehicles to an initial inspection upon import and then every 12 months thereafter, except for private passenger cars, which are to be inspected every 2 years. The routine emissions inspection test is the same as that outlined in the 2016 regulation (Table 1) and measures exhaust CO, HC, and Lambda value.[31]

PLUME CHASING STUDY OVERVIEW

DATA COLLECTION

Plume chasing is a remote sensing technique whereby a vehicle equipped with measurement instrumentation follows a target vehicle on the road while sampling its exhaust plume directly from the ambient air. Figure 1 is an illustration of the technique and Figure 2 is images from the measurement work done for this study in Kampala. Research suggests that plume chasing and roadside remote sensing have similar margins of error, and

28 "The East Africa Sub Region Becomes the Second Sub-Region in Africa to Adopt Euro 4/IV Equivalent Vehicle Emission Standards," United Nations Environment Programme, September 2022, https://www.unep.org/events/workshop/east-africa-sub-region-becomes-second-sub-region-africa-adopt-euro-4iv-equivalent.

29 National Environment Management Authority, "The National Environment (Air Quality Standards) Regulations, 2024" (April 26, 2024), https://ulii.org/akn/ug/act/si/2024/22/eng@2024-04-26.

30 "Uganda to Enforce Euro 4 Emissions Standards Amid Budget Cuts," *AGC News*, April 9, 2025, https://www.agcnewsnet.com/article/3947.

31 Ministry of Works and Transport, "Traffic and Road Safety (Motor Vehicle Inspection) Regulations 2016."

Figure 1. Plume chasing data collection technique

Figure 2. Plume chasing vehicle setup in Kampala

accuracy improves when measurements are aggregated into averages.[32]

The TRUE Initiative conducted a plume chasing measurement study of real-world emissions from vehicles on the roads in Kampala and the surrounding region over 26 days between July 3 and July 29, 2024. The measurement vehicle used, a passenger car (Figure 2), was retrofitted with an ICAD-NO_X-200DE monitor, a TuGraz black carbon tracker, and a modified AVL DiTEST particulate number counter fitted with a catalytic stripper to measure NO_X, NO_2, non-volatile PN, and BC (see Table 3).[33]

The plume chasing was conducted by Airyx GmbH and a team in Kampala coordinated by members of the Ugandan Ministry of Works and Transport (MoWT) and Ministry of Energy and Mineral Development. The team was comprised of researchers from Makerere University, Kampala Capital City Authority (KCCA), Clean Air Initiative Africa, Environment Compliance Institute, the Kampala traffic police, and Autosafety Uganda. During the study, the measurement of a given vehicle could be started and stopped via an e-tablet interface in the front of the vehicle. During each vehicle measurement, a researcher logged details of the target vehicle, including the license plate number, vehicle type, brand, model, and relevant notes.

32 Yuhan Huang et al., "Remote Sensing of On-Road Vehicle Emissions: Mechanism, Applications and a Case Study from Hong Kong," *Atmospheric Environment 182* (June 1, 2018): 58–74, https://doi.org/10.1016/j.atmosenv.2018.03.035; Hui Wang et al., "Evaluating Mobile Monitoring of On-Road Emission Factors by Comparing Concurrent PEMS Measurements," *Science of The Total Environment 736* (September 20, 2020): 139507, https://doi.org/10.1016/j.scitotenv.2020.139507.

33 Airyx, "ICAD NO2-NOx-NO Analyzer SERIES 210," Airyx, n.d., https://airyx.de/item/icad/; Knoll Markus Franz, "Point Sampling as Remote Emission Sensing Method to Screen Particulate Matter Emissions" (Dissertation, Graz, Austria, Technischen Universität Graz, 2024), https://repository.tugraz.at/publications/esedq-gx203.

Table 3. Pollutant measurement instruments used in the Kampala plume chasing study

Instrument	Measured pollutant
ICAD-NO$_x$-200DE	Nitrogen dioxide (NO_2)
	Nitrogen oxides (NO_x)
	Carbon dioxide (CO_2)
Black carbon tracker[a]	Black carbon (BC) within range 0–320 µg/m³ / 2,000 ppm
AVL DiTEST PN counter[b]	Particle number (PN) within range 0–10 × 10^6 /cm³

[a] Custom black carbon tracker by Graz University of Technology Austria (TUGraz)
[b] Customized by TUGraz and fitted with a catalytic stripper to remove volatile PN during study

Figure 3 is a map of the start and stop locations of all the plume chasing routes traveled during data collection in July 2024. Vehicles were measured at random in an effort to obtain a representative sample of the fleet on the road in Kampala. Nevertheless, data collection in the center of Kampala was challenging due to heavy traffic congestion. This hindered plume chasing because the method requires vehicles to travel for a period of at least 30 seconds without stopping to isolate individual plumes. Measurement of motorcycles was particularly difficult, as their maneuverability and dense presence complicated efforts to isolate individual vehicles and follow them in the passenger car. The share of motorcycles among the vehicles measured in this study is almost certainly smaller than the share of motorcycles in Kampala's on-road vehicle fleet

Figure 3. Geospatial maps showing distribution of routes taken by the plume chasing vehicle

SAMPLE OVERVIEW

A total of 5,994 "vehicle chases" were measured during the study, at an average chasing vehicle speed of 38 km/h (Figure 4); the average speeds by vehicle segment ranged from 22 km/h for motorcycles to 46 km/h for heavy vehicles. The average speed of measurement is consistent with urban driving conditions and that of other TRUE remote-sensing studies conducted using roadside measurements.[34] Weather conditions were reported to be predominantly sunny during 41% of the testing and predominantly cloudy 27% of the time (no information was provided for the remaining time).

On average, each vehicle chase recorded 22 measurements while sampling at a rate of 0.5 Hz. The number of measurements per vehicle chase varied from 0 to 133 (see Table A1 in the appendix) and a vehicle chase was considered valid for further analysis if at least 15 measurements were collected per chase (approximately 30 seconds at a 0.5 Hz sampling rate). The plume chasing data underwent post-processing by Airyx to correct for asynchronies between pollutant measurements recorded by different instruments. This process involved aligning measurement timestamps, adjusting response functions, and applying time shifts to compensate for instrument response delays to ensure more accurate pollutant data for analysis.

The plume chasing measurements were provided in pollutant-to-CO_2 ratio and were converted to pollutant per kilogram of fuel burned by approximating the fuel's chemical composition with an average molecular ratio of hydrogen to carbon of 1.92 for diesel and 1.87 for gasoline. The International Energy Agency's Mobility Model was used to estimate real-world fuel economy in Uganda and calculate the pollutant emissions per kilometer traveled (mg/km).

The final dataset delivered contained all 5,994 measurements from 5,781 unique vehicles, including both valid and invalid pollutant data. Of all measurements, 95% (5,679) had valid pollutant data that were used in our analysis (Table 4). We also sourced vehicle characteristic data from the Ugandan MoWT, and 5,195 of the chases (about 87%) had both MoWT data and valid pollutant measurements for analysis. The analysis below was done on the entirety of the 5,195 chases with sufficient data.

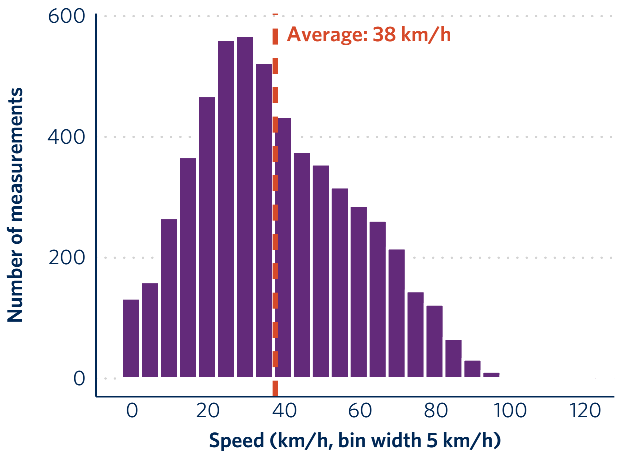

Figure 4. Distribution of average plume chasing vehicle speed in km/h

Table 4. Data with valid pollutant and vehicle characteristic data from the plume chasing and the Ugandan Ministry of Works and Transport (MoWT)

Valid pollutant data from plume chasing	MoWT data	Count	Percent of total (%)
False	False	96	1.6
	True	219	3.7
True	False	484	8.1
	True	5,195	86.7

FLEET CHARACTERISTICS

Gasoline passenger cars were the most commonly measured vehicle segment and made up 52% of the sample. They were followed by diesel heavy commercial vehicles (HCVs; 14%), diesel minibuses (7%), and diesel light commercial vehicles (LCVs; 7%). Motorcyles were only 2% of the measured vehicles but are likely underrepresented in the sample due to the aforementioned measurement challenges they pose. There were also 2 special purpose vehicles, 3 gasoline buses, 3 heavy machinery vehicles, 6 gasoline HCVs, 14 tricycles, and 17 gasoline minibuses measured; together these made up less than 1% of the sample and they are not shown in Figure 5.

34 Michelle Meyer et al., *Assessment of Real-World Passenger Vehicle and Taxi Emissions in Mexico City* (TRUE Initiative, 2024), https://www.trueinitiative.org/publications/reports/assessment-of-real-world-passenger-vehicle-and-taxi-emissions-in-mexico-city; Kaylin Lee, Yoann Bernard, and Richard Riley, *Assessment of Real-World Vehicle Emissions from Four Scottish Cities in 2022* (TRUE Initiative, 2024), https://www.trueinitiative.org/publications/reports/assessment-of-real-world-vehicle-emissions-from-four-scottish-cities-in-2022; Peter Mock, *Real-Driving Emissions Test Procedure for Exhaust Gas Pollutant Emissions of Cars and Light Commercial Vehicles in Europe* (International Council on Clean Transportation, 2017), https://theicct.org/publication/real-driving-emissions-test-procedure-for-exhaust-gas-pollutant-emissions-of-cars-and-light-commercial-vehicles-in-europe/.

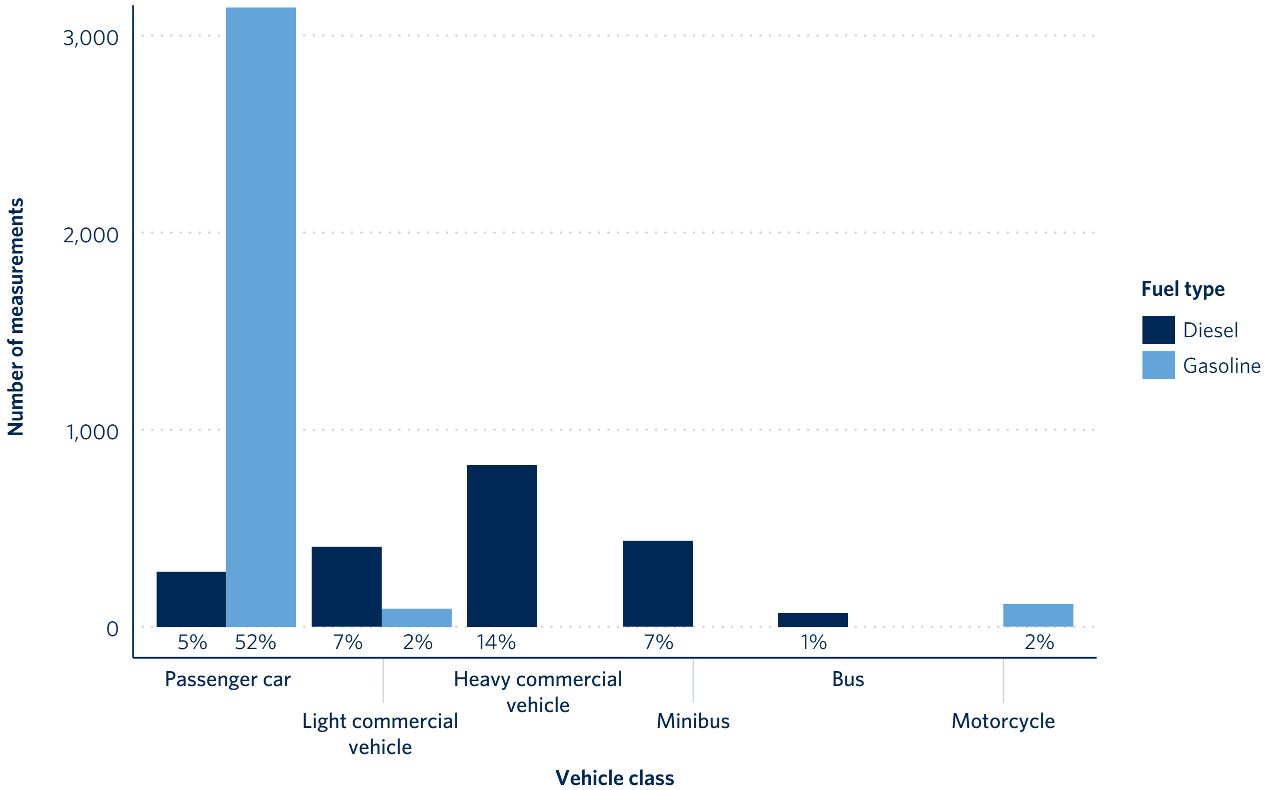

Figure 5. Number of measurements by fuel type and vehicle classification, with the share of the total displayed under each bar

The oldest vehicle class on average was HCVs, which had an average age of 26 years; 77% of the HCVs measured were more than 15 years old. Minibuses measured had an average age of 25 years and 91% of the measurements were over 15 years of age. Passenger cars, LCVs, and buses all had an average age of 19 years. Motorcycles were the youngest vehicle category, with an average age of 4 years.

Figure 6 shows the number of vehicles measured across each vehicle build year and country of origin by vehicle class. Country of origin refers to the country from which the vehicle was imported into Uganda and this is not necessarily the country of manufacture or where emissions type-approval certification was done. Nevertheless, it is likely that used imported vehicles were once operating in their country of origin and hence would have met the type-approval requirements of that country.

While 77% of all vehicles originated from Japan, in more recent registration years, the sample showed an increase in the number of vehicles from other markets, including China, India, South Africa, and Thailand. This trend was most pronounced among LCVs and HCVs, and is consistent with the reported growth in the market.[35] Most of the HCVs and LCVs from Japan were from model years before 1998, which correspond to Japan's least-stringent emission standards, approximately equivalent to Euro 1 and pre-Euro standards.[36] The vast majority of minibuses (98%) and passenger cars (95%) originated from Japan and 95% of motorcycles were from India. Still, the data revealed that the share of diesel LCVs and HCVs from Japan decreased to 30% and 54%, respectively, in 2024. This was due to an increasing share of diesel LCVs from South Africa and Thailand and diesel HCVs from China and India since 2008.

Figure 7 presents the average age of vehicles at the time of first registration in Uganda for each vehicle class.[37] The data reveal a marked decline in the average age at registration for LCVs and minibuses, particularly from 2018 onward. The average age among motorcycles was consistently under 5 years across registration years

35 Observatory of Economic Complexity, "Cars in Uganda."

36 "Japan: Light duty: Emissions"; "Japan: Heavy duty: Emissions."

37 Vehicle age at domestic registration was calculated as the difference between the vehicle's build year and the date of first registration in Uganda. Note, though, that in Uganda, vehicles can remain in a warehouse or showroom for up to 9 months before being registered, and this may affect the estimated vehicle age by up to 1 year.

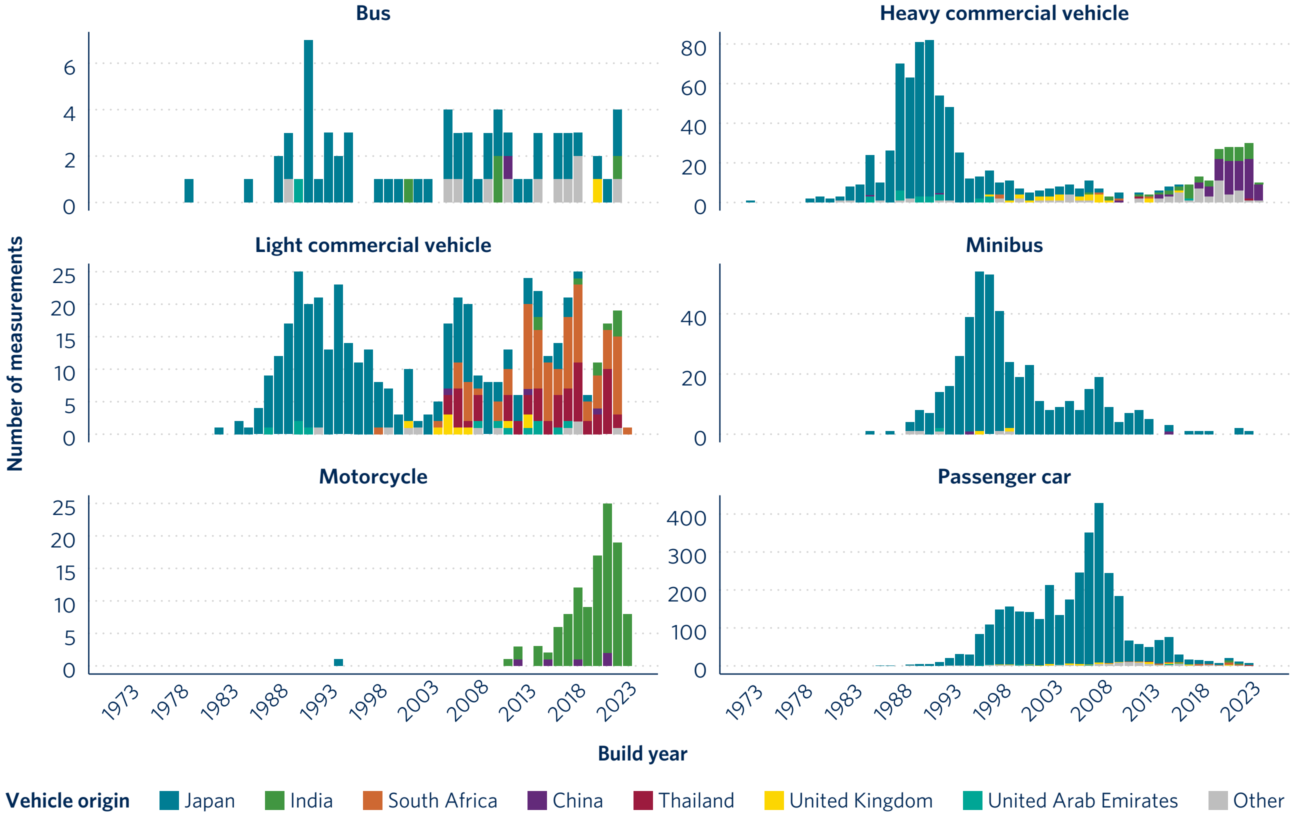

Figure 6. Number of measurements by vehicle build year and vehicle origin by vehicle class

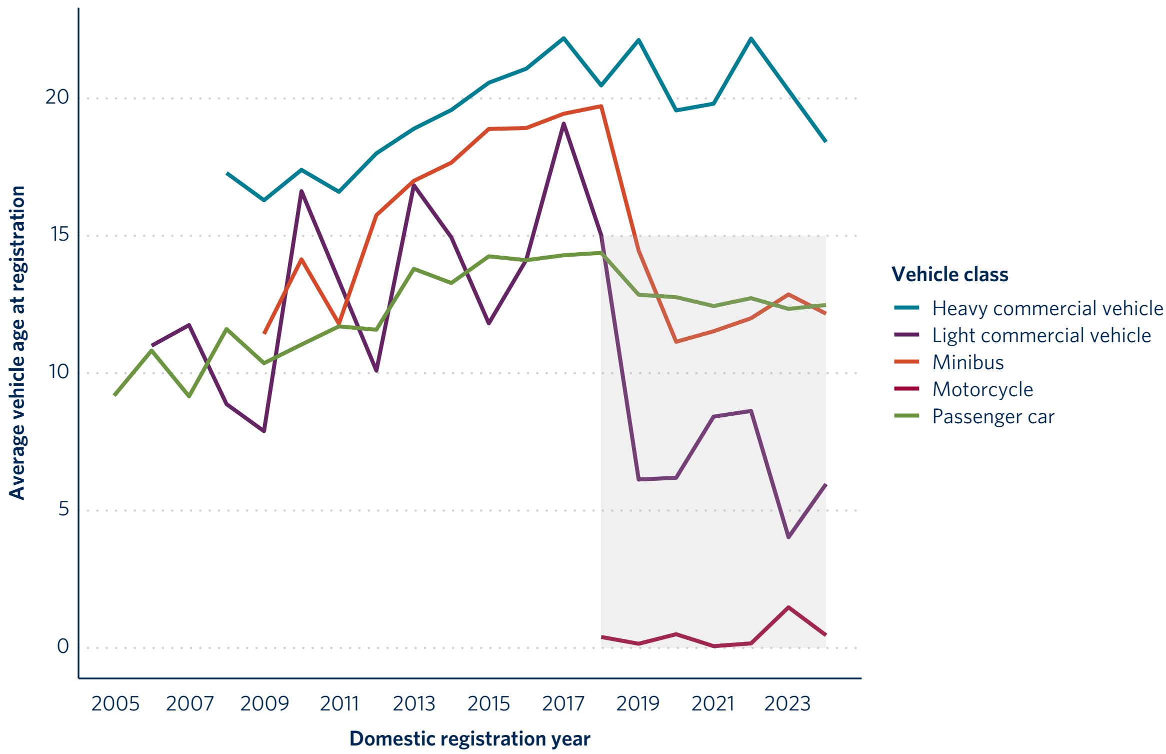

Figure 7. Vehicle age at first registration in Uganda by registration year and vehicle class

Note: The shaded box indicates vehicles aged 15 years and under at first registration in Uganda, the age limit for imported light-duty vehicles since 2018.

2018–2024, and HCVs and passenger cars have remained relatively consistent in average age at first domestic registration since 2018. The share of passenger cars more than 8 years old at first domestic registration decreased by only 1% (from 91% to 90%) after the environmental levy tax was introduced in 2018, and thus older passenger cars clearly remain in demand. Recall that HCVs are not subject to the 15-year age limit; the average age of HCVs at import was above 15 years between 2008 and 2024.

The average age at import to Uganda of HCVs and LCVs by registration year for each country of origin is presented in Figure 8. In recent years, both LCVs and HCVs have increasingly come from markets other than Japan, particularly from China, India, South Africa, and Thailand, and the average age of these vehicles ranged between 1 and 4 years at import. Despite this trend toward younger vehicles from these markets, older vehicles were also imported across registration years in the sample. Notably, Figure 8 shows an increasing average age of HCVs imported from Japan from 17 in 2009 to 35 in 2024. In contrast, the average age of LCVs from Japan has fallen since 2018, around the time the 15-year age limit for light-duty vehicles was introduced.

VEHICLE EMISSIONS ANALYSIS

The real-world vehicle emissions in Kampala are presented below. First, we provide an overview of the real-world average distance-specific emissions across all vehicle fuel groups. Following that, we present detailed vehicle emission trends for the four most common vehicle classes measured in this study—passenger cars, minibuses, LCVs, and HCVs.

EMISSIONS BY VEHICLE CLASS

This section presents the average distance-specific NO_x, NO_2, BC, and particle number (PN) emissions for each major vehicle class and fuel type, and their respective contribution to the total pollution measured per kilometer traveled.[38] The six vehicle groups with sufficient

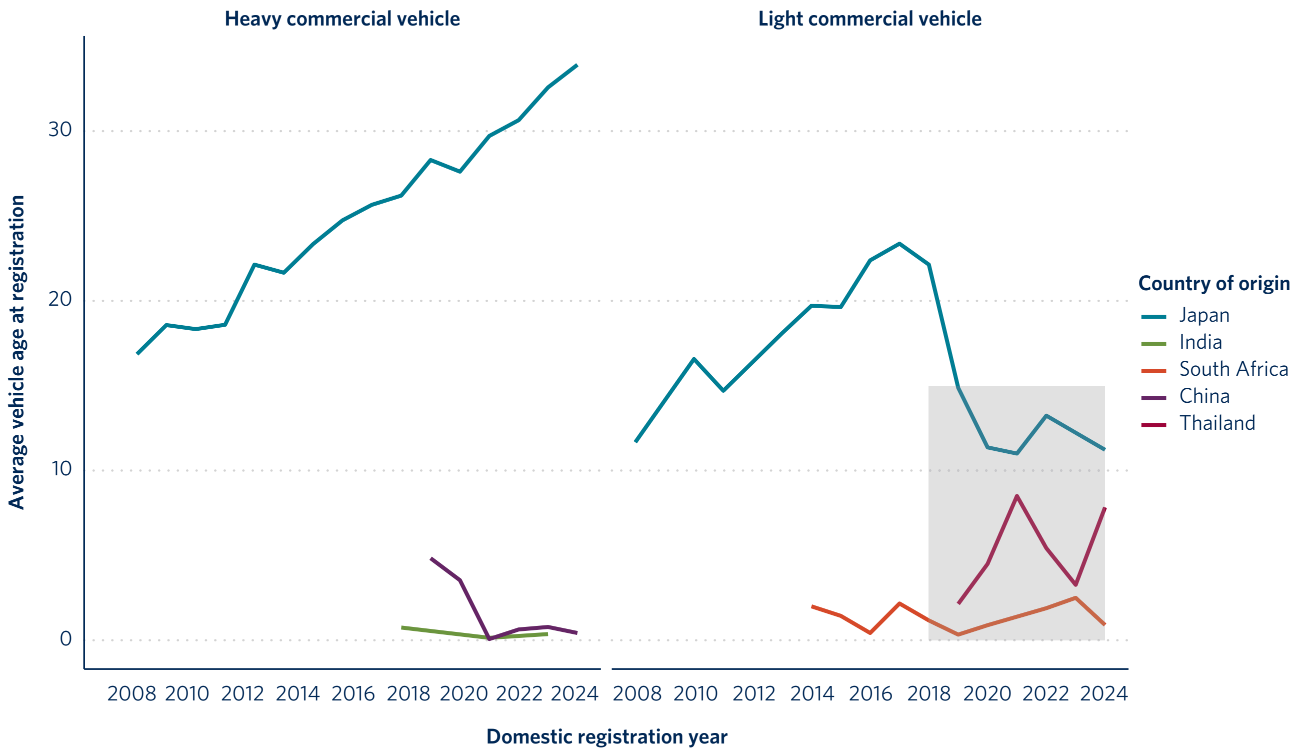

Figure 8. Light and heavy commercial vehicle age at first registration in Uganda by registration year and country of origin

Note: The shaded box indicates the 15-year age limit applicable to imported light-duty vehicles in Uganda since 2018.

38 Vehicle classes were assigned to align as closely as possible with those classes outlined in the National Environment (Air Quality Standards) Regulations, 2024. We used the vehicle classes, gross vehicle weights, body types, and seating capacities from the Ministry of Works and Transport.

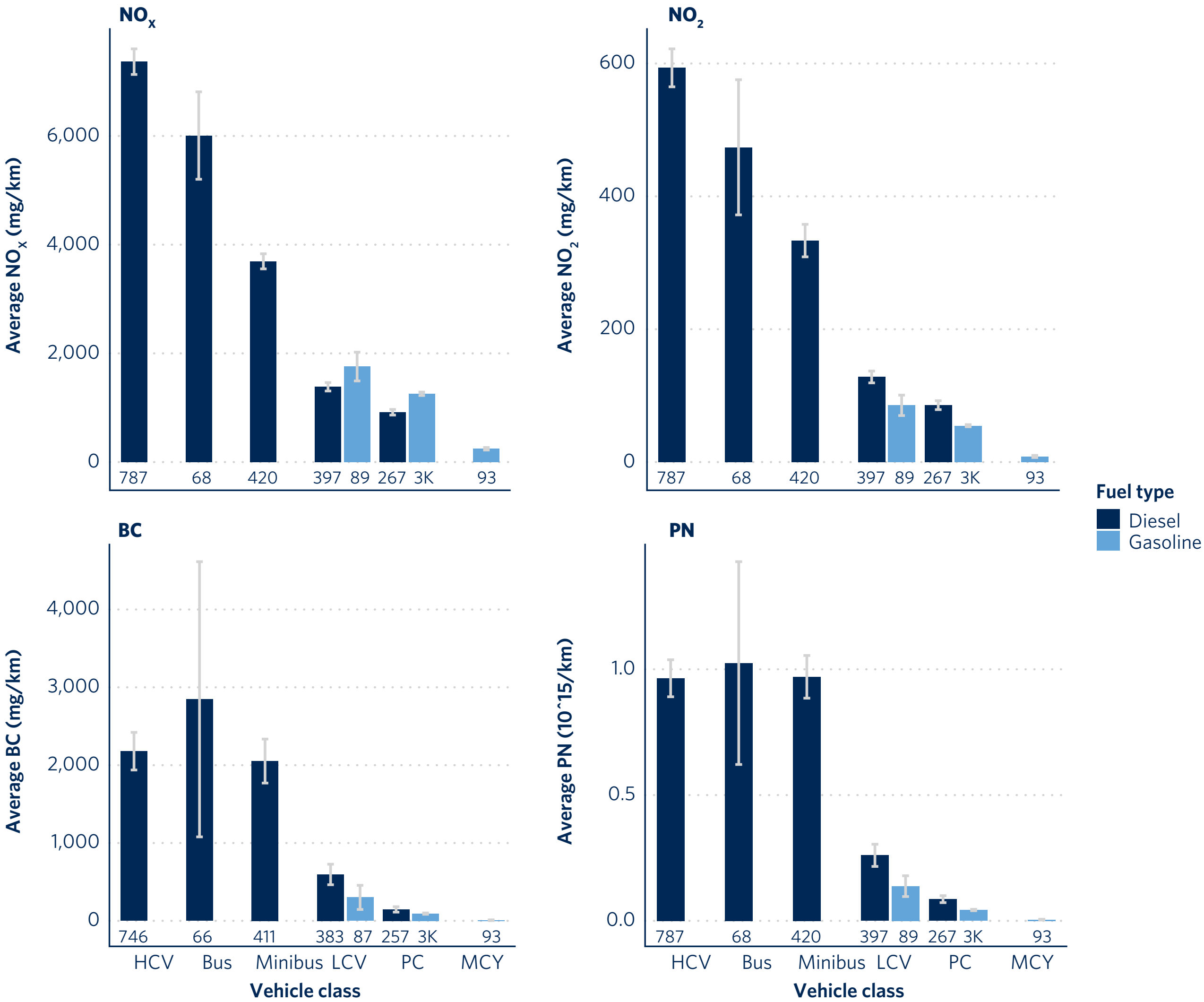

Figure 9. Average distance-specific NO_x, NO_2, BC, and PN emissions for each vehicle type

Note: Error bars represent the 95% confidence interval and the number at the bottom of the bar indicates the sample size.

measurement data for analysis were passenger cars (PCs), HCVs, LCVs, motorcycles (MCYs), minibuses, and buses. The minimum number of vehicle chases considered for subgroup analysis was generally 20; one exception was trends by build year, for which a minimum sample size of five was used.

Among all vehicle classes, diesel HCVs, diesel buses, and minibuses exhibited the highest average distance-specific NO_x, NO_2, BC, and PN emissions, as shown in Figure 9. These vehicle groups also exhibited the highest average fuel-specific emissions (Figure A1 in the appendix). Diesel HCVs were the oldest vehicle-fuel group on average at 26 years of age, and diesel minibuses showed higher average emissions than diesel LCVs despite belonging to similar vehicle classes. Minibuses averaged 25 years of age and this age likely contributed to their elevated emissions.

Notably, gasoline passenger cars showed higher average distance-specific NO_x emissions than their diesel counterparts, a trend not commonly observed in other TRUE studies.[39] Gasoline spark ignition engines generally emit less NO_x than diesel vehicles due to their lower combustion temperatures and because the air-fuel mixture is closer to the stoichiometric ratio. Moreover, three-way catalytic converters have effectively reduced NO_x emissions in gasoline engines since the 1980s. The higher average NO_x emissions among gasoline

39 Meyer et al., "Assessment of Real-World Passenger Vehicle and Taxi Emissions in Mexico City."

passenger cars observed in this study is consistent with issues including potential vehicle malfunction or the removal of the catalytic converter. Recall that both poor vehicle maintenance and theft of catalytic converters have been highlighted in previous studies of the Kampala Metropolitan Area.[40]

Vehicles' BC and PN emissions exhibited similar patterns that highlight their role in contributing to particulate matter pollution. A strong correlation between PN and BC (correlation coefficient greater than 0.9) was observed across all vehicle classes (see Table A2 in the appendix). We also identified outliers in BC and PN emissions, particularly among diesel HCVs, buses, and minibuses. The highest 10% of BC measurements for diesel HCVs, buses, and minibuses emitted over 5 times the respective group medians, with maximum values reaching over 20 times the group medians. Similarly, the top 10% of PN measurements among diesel HCVs, buses, and minibuses emitted over 3 times the group medians, with maximum values reaching over 8 times the group medians. These elevated levels of PN and BC may be the result of incomplete fuel combustion or missing or malfunctioning emission control systems such as defective fuel injection or missing aftertreatment systems. These findings align with prior research which suggested that poor vehicle maintenance practices further exacerbate emissions from the aging fleet in Kampala.[41]

DETAILED EMISSION TRENDS BY VEHICLE CLASS

This section presents an analysis of emissions from four key vehicle categories measured in Kampala: passenger cars, diesel minibuses, LCVs, and HCVs. Results are presented by vehicle age group, which represents the age of the vehicle at the time of measurement.[42] The age groups—under 8 years, 8 to 15 years, and over 15 years—were selected based on Uganda's import age limit and environmental tax policies. The analysis presents the average distance-specific NO_x and BC emissions and compares them with Euro 4 NO_x and PM emission limits, which are equivalent to those adopted in Uganda under the National Environment (Air Quality Standards) Regulations, 2024. While the comparison with Euro 4 emission limits contextualizes the real-world vehicle emissions in Kampala, vehicles measured during the study were not required to meet Euro 4 standards before import, since the regulation was not enforced at the time of data collection.

Importantly, BC constitutes only a portion of total PM emissions, meaning total real-world PM emissions from these vehicles are likely higher than the BC levels with which they are compared in this report. Research suggests that BC accounts for up to 50% of total $PM_{2.5}$ emissions from the transportation sector, and even higher BC-to-PM ratios have been reported for heavy-duty vehicles observed under high-load conditions such as highway operation.[43]

PASSENGER CAR EMISSION TRENDS

Passenger cars were the most common vehicle segment measured in this study —57% of the measurements—and over 90% of the passenger cars measured were powered by gasoline fuel. Figure 10 presents average distance-specific NO_x and BC emissions for gasoline and diesel passenger cars in Kampala by age group and compares them with Euro 4 emission limits. We found markedly lower average NO_x emissions among gasoline passenger cars under 8 years old (439 mg/km) than those over 15 years old (1,417 mg/km). Despite this, average real-world NO_x emissions from gasoline passenger cars under 8 years old were 5.5 times higher than the Euro 4 regulatory limit of 80 mg/km, and only 7% of this age group showed emissions below the limit (see Appendix Figure A3).

Nearly all gasoline passenger cars in the sample originated from Japan (96%), where NO_x emission limits have been 80 mg/km for gasoline passenger cars manufactured since 2005.[44] Recall, though, that country of origin does not guarantee location of manufacture nor location of type-approval certification. Over 50% of the measured gasoline passenger cars showed NO_x emissions exceeding 1,000 mg/km (see Figure A4 in the appendix), emissions consistent with those of pre-Euro certified vehicles and

40 Wanyama, "Africa's Automobile Maintenance."

41 Wanyama, "Africa's Automobile Maintenance."

42 While the import age limits apply to vehicles at the time of import, the age groups shown reflect the age of vehicles at the time of measurement. Vehicles that met the 15-year age limit in 2018 may have been up to 21 years of age in July 2024.

43 T. R. Dallmann et al., "Characterization of Particulate Matter Emissions from On-Road Gasoline and Diesel Vehicles Using a Soot Particle Aerosol Mass Spectrometer," *Atmos. Chem. Phys. 14*, no. 14 (July 29, 2014): 7585–99, https://doi.org/10.5194/acp-14-7585-2014; Zbigniew Kilmont et al., "Global Anthropogenic Emissions of Particulate Matter Including Black Carbon," *Atmos. Chem. Phys.* 17 (n.d.): 8681–8723, https://doi.org/10.5194/acp-17-8681-2017.

44 Emission limits were estimated based on the vehicles' build year and the emission standard timeline for Japan as outlined in "Japan, Light duty: Emissions."

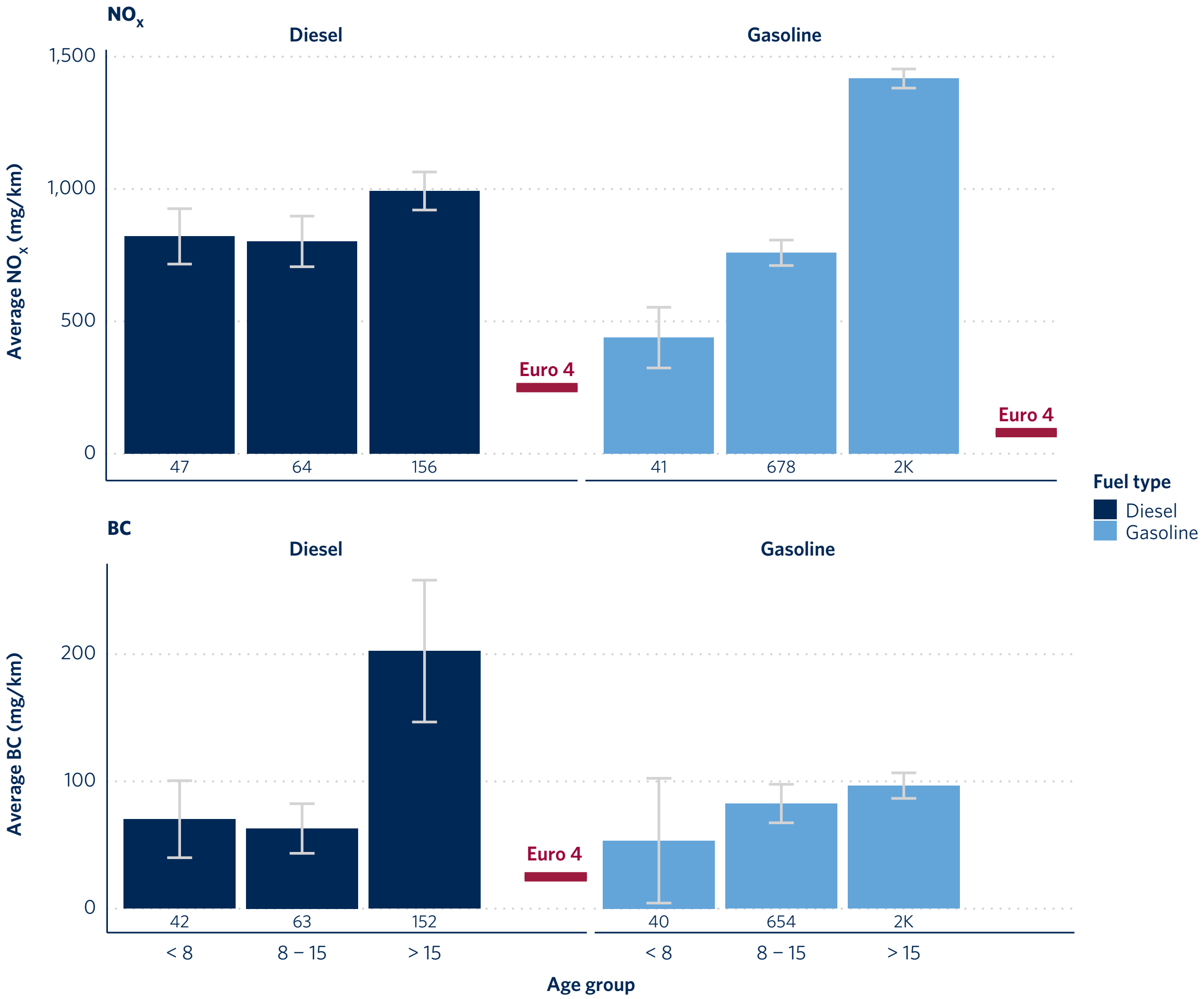

Figure 10. Passenger car NO_x (top) and BC (bottom) emissions by age group for diesel (left) and gasoline (right) vehicles compared with Euro 4 NO_x and PM emission limits

Note: Error bars represent the 95% confidence interval and the number at the bottom of the bar indicates the sample size.

suggestive of potential malfunctions or the removal of catalytic converters.[45]

Moreover, diesel passenger cars under 8 years of age in Uganda showed emissions 3.3 times above the Euro 4 NO_X regulatory limit of 250 mg/km. Minimal changes in NO_X emissions were observed across diesel passenger car age groups, a trend consistent with other TRUE studies, which found that significant NO_X reductions only occur with the introduction of Euro 6 and later emission standards, which mandate stricter NO_X limits and on-road testing that lead to implementation of more effective aftertreatment systems such as selective catalytic reduction.[46] Most diesel passenger cars in the Kampala sample (80%) came from Japan, where the NO_X emissions limit has been set at 80 mg/km since 2009.[47]

Average BC emissions among diesel passenger cars over the age of 15 were particularly elevated at 202 mg/km, 3 times higher than those of diesel passenger cars aged between 8 and 15 years. Such elevated BC emissions are indicative of possible inefficient fuel combustion and could be due to malfunctioning emission control systems. Indeed, the vehicle log notes taken during plume chasing data collection indicated that at least 7% of measured

45 Liuhanzi Yang, *Real-World Emissions in China: A Meta-Study of PEMS Data* (International Council on Clean Transportation, 2018), https://theicct.org/publication/real-world-emissions-in-china-a-meta-study-of-pems-data/.

46 Kaylin Lee et al., *Evaluation of Real-World Vehicle Emissions in Warsaw*.

47 "Japan, Light duty: Emissions."

diesel passenger cars over the age of 15 were emitting visible black smoke from the exhaust during measurement. Black smoke would not be expected if the vehicle engine and emission control systems were operating well. Although PM limits for gasoline passenger cars are not regulated under Euro 4 emission standards, the PM emissions limit in Japan has been set at 7 mg/km since 2009; the gasoline passenger cars imported from Japan and manufactured after 2009 that we measured showed average real-world BC emissions 12 times higher than this limit. Similarly, the diesel passenger cars from Japan manufactured after 2009 exhibited average BC emissions 12 times higher than the 5 mg/km limit in place in Japan since 2009.

MINIBUS EMISSION TRENDS

Minibuses accounted for 8% of the total fleet measured in Kampala. Since the early 1990's, privately owned paratransit minibuses have been widely used as passenger transport taxis in Uganda.[48] Although limited public data is available detailing the real-world share of minibuses in Kampala, vehicle registration data suggests that between 2015 and 2022, public service vehicles were 9% of vehicle registrations in Uganda.[49] Additionally, there were 15,000 minibus taxis operating in 2016 which accounted for 21% of the region's vehicle movement while transporting 82% of commuters in the Greater Kampala Metropolitan Region.[50]

Of the minibuses measured during this study, 96% were powered by diesel and 95% were the Toyota HiAce model. Therefore, this section examines the average distance-specific NO_x and BC emissions from diesel minibuses and compares them with Euro 4 NO_x and PM emission limits. Under Uganda's National Environment Regulations, 2024, all imported diesel minibuses would be required to meet a NO_x emissions limit of 390 mg/km and a PM emissions limit of 60 mg/km.

Figure 11 shows that average real-world NO_x emissions among diesel minibuses in Kampala were similar among those aged 8–15 years and over 15 years, with both groups exhibiting emissions more than 9 times above the Euro 4 NO_x limit of 390 mg/km. None of the measured diesel minibuses over the age of 8 years showed emissions below

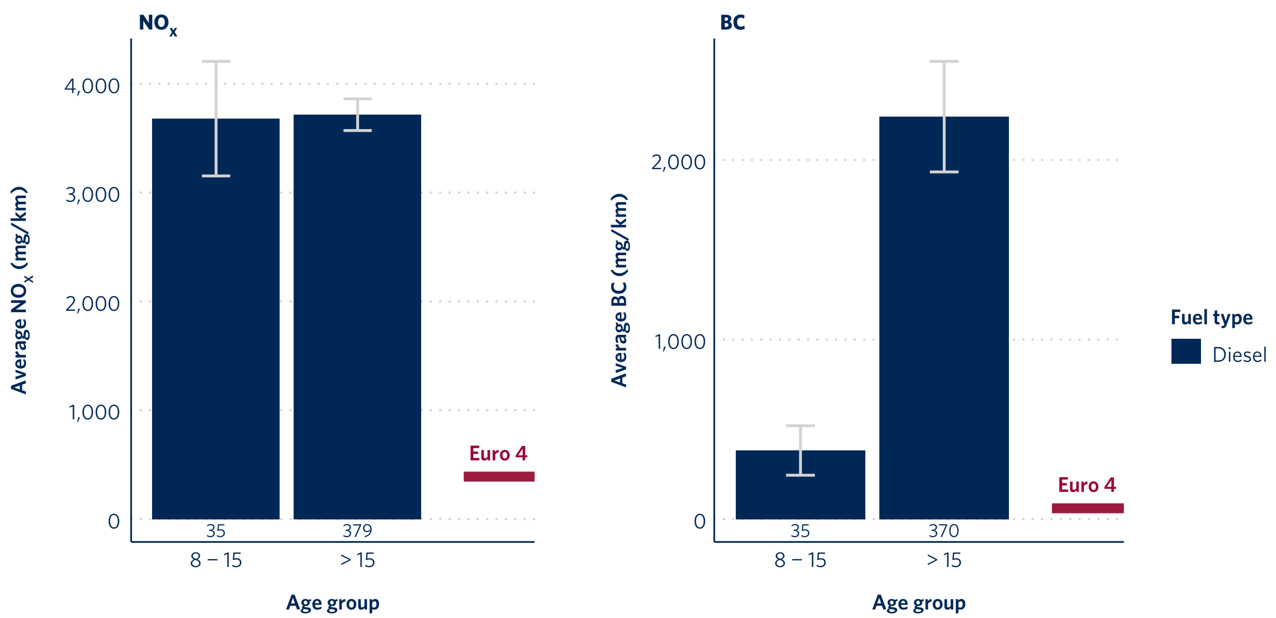

Figure 11. Diesel minibus NO_x (left) and BC (right) emissions by age group compared with Euro 4 NO_x and PM emission limits of 390 mg/km and 60 mg/km, respectively

Note: Error bars represent the 95% confidence interval and the number at the bottom of the bar indicates the sample size.

48 Innocent Ndibatya and M.J. Booysen, "Minibus Taxis in Kampala's Paratransit System: Operations, Economics and Efficiency," *Journal of Transport Geography 88* (October 1, 2020): 102853, https://doi.org/10.1016/j.jtrangeo.2020.102853.

49 Ugandan Bureau of Statistics, "Number of Licensed Public Vehicles 2013 to 2023" (2025), https://www.ubos.org/explore-statistics/29/; Ugandan Bureau of Statistics.

50 Jennifer Semakula Musisi, "Policy Challenges in Urban Transport and Infrastructure: The Case of Kampala." (Presentation, 2nd Annual IGC Cities Research Conference, London, January 2016), https://www.theigc.org/sites/default/files/2015/10/EDs-Presentation-Transport-Infrastructure-333.pdf.

390 mg/km and half of all the diesel minibuses recorded real-world NO_x emissions above 3,636 mg/km (see Figure A6 in the appendix). Diesel minibuses under the age of 15 from Japan (manufactured after 2009) exhibited average real-world NO_x emissions above Japan's emission limit (150 mg/km since 2009).[51]

Additionally, Figure 11 shows that the real-world average BC emissions from diesel minibuses more than 15 years old were particularly elevated (2,241 mg/km) at 6 times higher than those of diesel minibuses between 8 and 15 years old (382 mg/km). Diesel minibuses under the age of 15 from Japan (manufactured after 2009) exhibited average BC emissions above Japan's PM emissions limit, which has been set at 7 mg/km since 2009.[52] Such elevated emissions may indicate inefficient fuel combustion and poorly functioning emission control systems.

Moreover, Figure 12 shows that half the diesel minibuses recorded real-world BC emissions above 1,044 mg/km, and 10% recorded emissions above 5,000 mg/km; all in the 10% with emissions above 5,000 mg/km were over 15 years old. For measured diesel minibuses over 15 years old, 16% had vehicle log notes indicating visible black exhaust smoke during measurement.

Even considering that most minibuses measured in Kampala had a seating capacity of 14 people, the average NO_x and BC emissions of diesel minibuses per passenger was higher than that of passenger cars in Kampala. Elevated BC emissions are of concern because BC has significant impacts on both the climate and human health. It makes up a portion of particulate matter pollution, which is now considered one of the greatest risk factors for premature death globally.[53] According to the Intergovernmental Panel on Climate Change, the global warming potential of BC emissions are

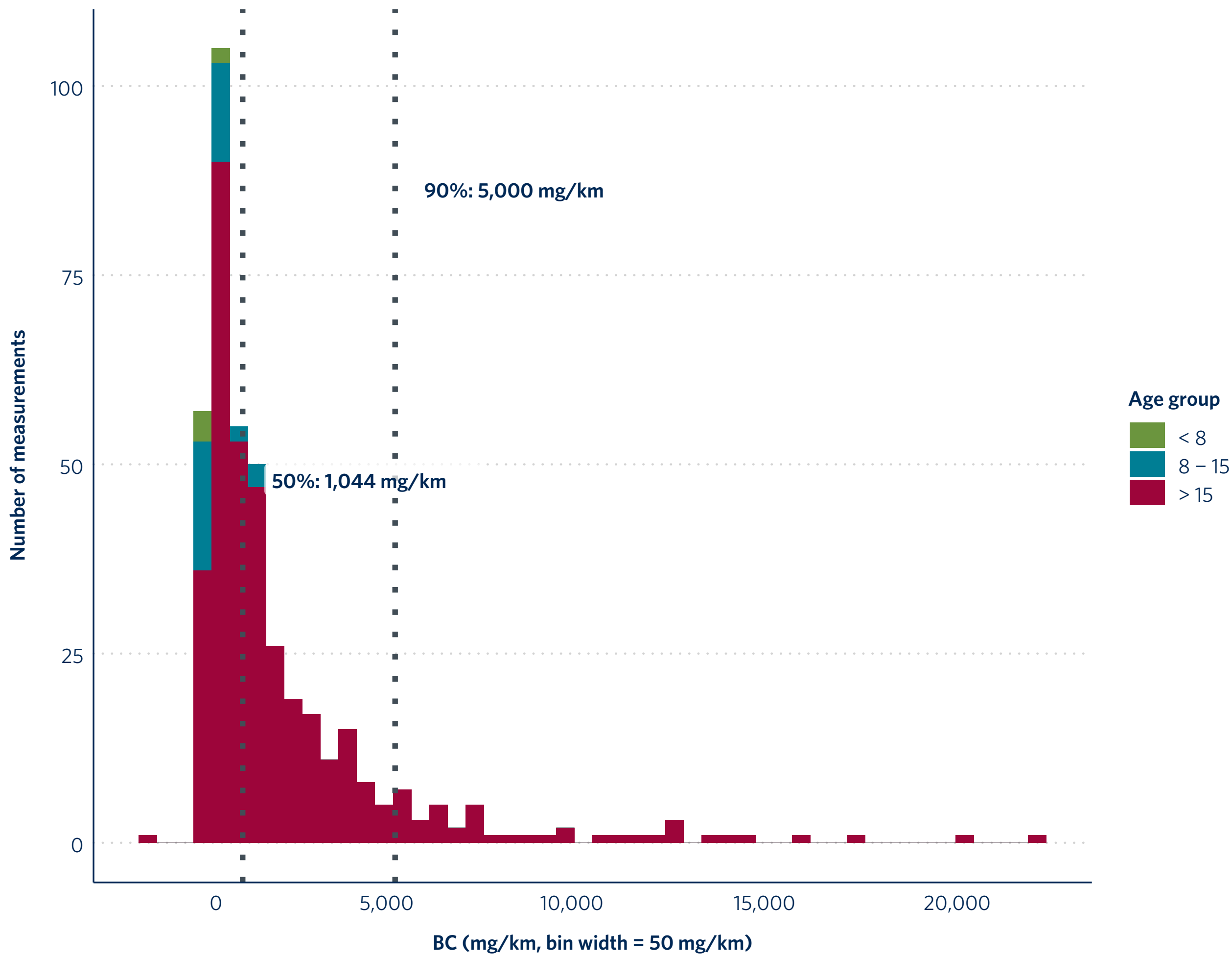

Figure 12. Diesel minibus BC emissions distributions by 50 and 90 quantiles

51 "Japan: Heavy duty: Emissions."

52 "Japan: Heavy duty: Emissions."

53 Health Effects Institute, "State of Global Air 2024" (2024), https://www.stateofglobalair.org/resources/report/state-global-air-report-2024.

estimated to be up to 2,420 times higher than CO_2 over a 20-year period after the pollutant is released into the atmosphere.[54] We estimate that the average BC emissions of diesel minibuses over 15 years of age (2,241 mg/km) corresponds to over 5,400 g CO_2 equivalent emissions per kilometer traveled. This is more than 7 times the estimated average CO_2 tailpipe emissions from diesel minibuses over 15 years of age in Kampala.[55]

LIGHT COMMERCIAL VEHICLE EMISSION TRENDS

Light commercial vehicles accounted for 8% of the total fleet measured in Kampala. Of the LCVs measured, 96% were powered by diesel, and thus the analysis in this section focuses on diesel LCVs. We compare the real-world vehicle emissions with the Euro 4 emission limits adopted by Uganda for diesel LCVs in 2024: 390 mg/km for NO_x and 60 mg/km for PM.

Figure 13 presents the average real-world NO_x emissions across all diesel LCV age groups. Average NO_x emissions for all age groups were above the Euro 4 limit, and fewer than 5% of measured diesel LCVs emitted below the limit (see Figure A8 in the appendix). Nevertheless, on average, diesel LCVs emitted less NO_x than diesel minibuses.

Figure 13 shows substantially higher average BC emissions among diesel LCVs over 15 years old (996 mg/km), 3 times higher than those of diesel LCVs 8–15 years old. This aligns with trends observed above with diesel minibuses and passenger cars, which showed much higher BC emissions for vehicles over 15 years old. The vehicle log notes taken during plume chasing data collection indicated at least 20% of measured diesel LCVs over the age of 15 were emitting visible black smoke from their exhaust.

The average NO_x emissions among LCVs varied depending on the country from which the vehicle was imported. As shown in Figure 14, LCVs under 8 years of age imported from South Africa and Thailand—which accounted for 25% and 16% of all diesel LCVs in the sample, respectively—did not demonstrate significantly lower emissions than their older counterparts. Diesel LCVs under 8 years of age from South Africa exhibited average NO_x emissions of 1,239 mg/km, while those over 15 years of age from South Africa exhibited lower average emissions of 903 mg/km. Although Thailand has enforced a NO_x type-approval emissions limit of 390 mg/km on diesel LCVs since 2012, vehicles in South Africa are currently required to comply with Euro 2 standards that do not contain a NO_x emissions limit, only a combined HC and NO_x limit of below 900 mg/km.[56]

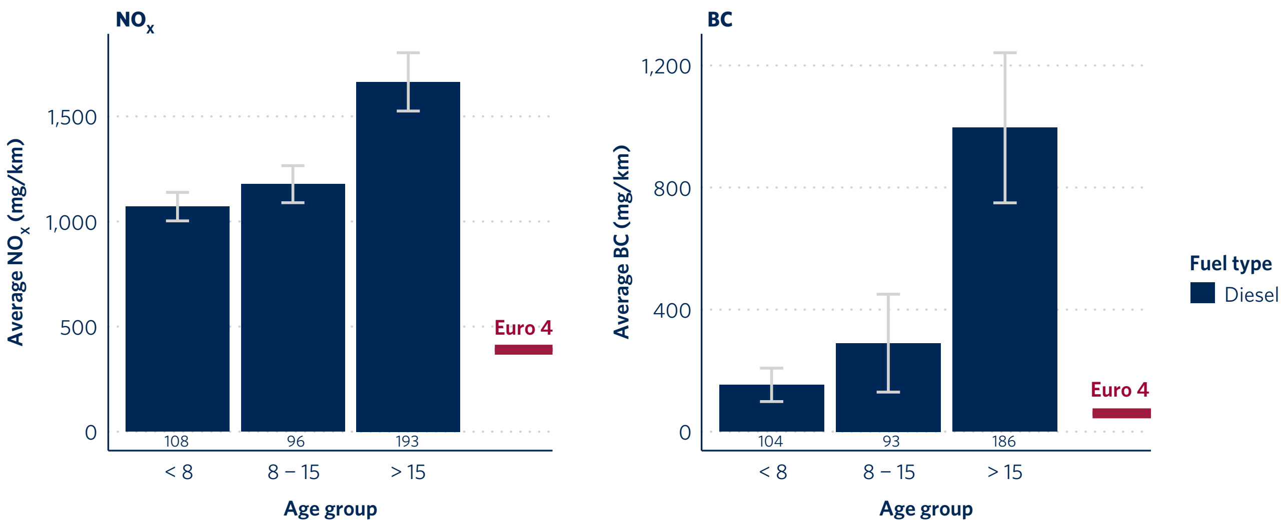

Figure 13. Diesel light commercial vehicle NO_x (left) and BC (right) emissions by age group relative to the Euro 4 NO_x and PM emission limits of 390 mg/km and 60 mg/km, respectively

Note: Error bars represent the 95% confidence interval and the number at the bottom of the bar indicates the sample size.

54 Gunnar Myhre et al., "Anthropogenic and Natural Radiative Forcing - Supplementary Material" (Intergovernmental Panel on Climate Change, 2013), https://www.ipcc.ch/site/assets/uploads/2018/07/WGI_AR5.Chap_.8_SM.pdf.

55 We estimate average CO_2 tailpipe emissions of over 15-year-old buses to be 696 g/km using average modeled fuel economy value of 29 L of gasoline equivalent per 100 km from the International Energy Agency's Mobility Model.

56 " Thailand: Light-duty: Emissions," TransportPolicy.net, accessed May 30, 2025, https://www.transportpolicy.net/standard/thailand-light-duty-emissions/.

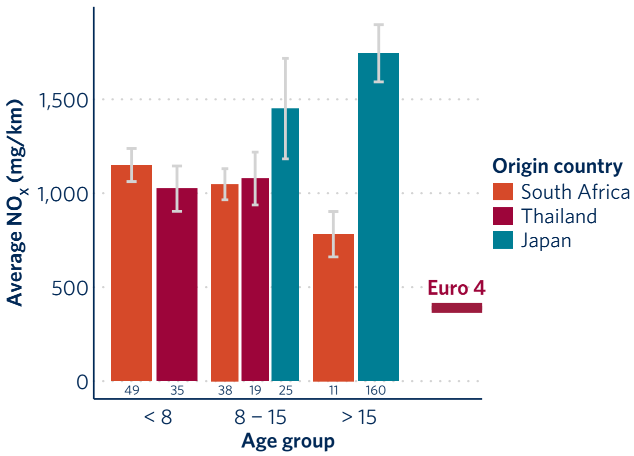

Figure 14. Diesel light commercial vehicle NO_x emissions by age group and country of origin compared with the Euro 4 NO_x emissions limit of 390 mg/km

Note: Error bars represent the 95% confidence interval and the number at the bottom of the bar indicates the sample size. A minimum sample size of 10 was considered for analysis.

HEAVY-DUTY VEHICLE EMISSION TRENDS

Heavy commercial vehicles were 14% of the vehicle fleet measured in Kampala and 98% of them were powered by diesel. This analysis therefore compares real-world emissions of diesel HCVs in Kampala in g/kWh with the Euro 4 limits that Uganda has adopted of 3.5 g/kWh and 0.02 g/kWh for NO_x and PM, respectively.[57]

As illustrated in Figure 15, NO_x emissions from younger diesel HCVs were higher than older ones. Vehicles under 8 years old exhibited average NO_x emissions of 6.4 g/kWh, while those over 15 years old had a slightly lower average of 5.6 g/kWh. Only 5% of diesel HCVs under 8 years of age met the 3.5 g/kWh Euro 4 NO_x limit in real-world conditions while 14% of those over the age of 15 years met the limit (see Figure A10 in the appendix).

Elevated average BC emissions were observed across all age groups of diesel HCVs. Only 2% of measured diesel HCVs under 8 years old showed emissions below the 0.02 g/kWh PM limit (see Figure A10 in the appendix). Figure 15 shows that, on average, BC emissions were particularly elevated among diesel HCVs over 15 years old, at 1.98 g/kWh, 3 times higher than those of diesel HCVs aged between 8 and 15 years. Such BC emissions are consistent with potentially malfunctioning or missing emission control systems. Vehicle log notes taken during plume chasing data collection indicated at least 21% of measured diesel HCVs over the age of 15 were emitting visible black smoke from their exhaust.

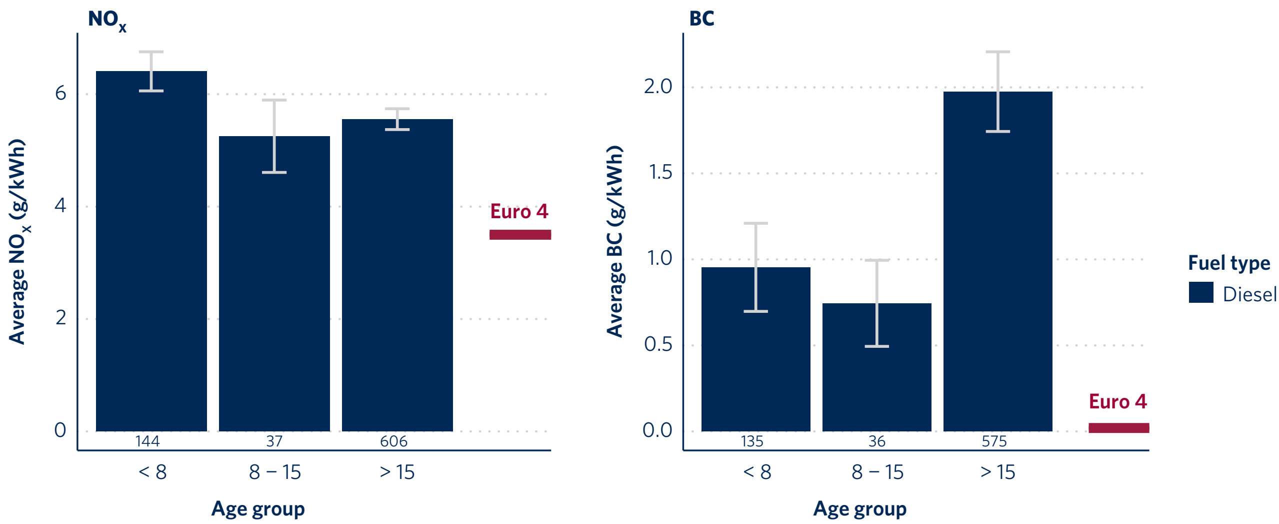

Figure 15. Diesel heavy commercial vehicle NO_x (left) and BC (right) emissions by age group compared with the Euro 4 NO_x and PM emissions limits of 3.5 g/kWh and 0.02 g/kWh, respectively

Note: Error bars represent the 95% confidence interval and the number at the bottom of the bar indicates the sample size.

57 The regulatory emission limits for HDVs are established on an energy-specific basis (g/kWh), and the distance specific emissions were converted to energy specific emissions using brake specific fuel consumption of the vehicle in g/kWh by using methodology previously outlined in the following publication: 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/.

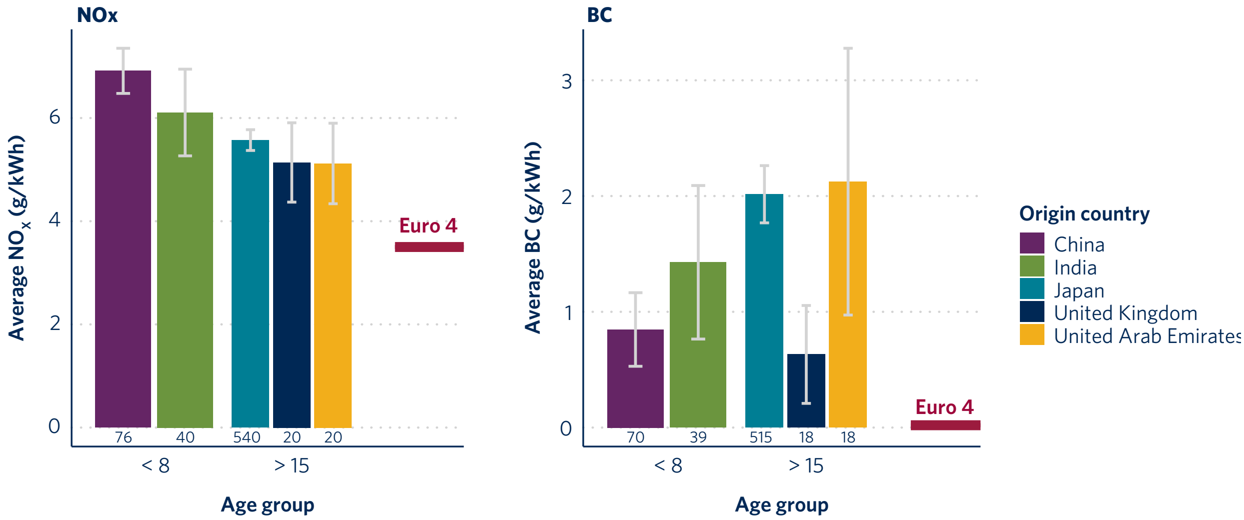

Figure 16. Diesel heavy commercial vehicle NO_x (left) and BC (right) emissions by age group and country of origin compared with the Euro 4 NO_x and PM emission limits of 3.5 g/kWh and 0.02 g/kWh, respectively

Note: Error bars represent the 95% confidence interval and the number at the bottom of the bar indicates the sample size. A minimum sample size of 10 was considered for analysis.

Diesel HCVs under 8 years old imported from China and India showed higher real-world average NO_x emissions than older HCVs from Japan, the United Arab Emirates, and the United Kingdom, as shown in Figure 16. Among the diesel HCVs measured, 10% originated from China and 6% from India, and both China and India have had a NO_x emissions limit of 3.5 g/kWh for diesel heavy-duty vehicles since 2010.[58] Nonetheless, this comports with previous TRUE findings that that meaningful real-world NO_x reductions are typically not observed until compliance with Euro 6 and later standards.

POLICY RECOMMENDATIONS AND CONCLUSIONS

Understanding the real-world emissions of vehicles in a city provides important insights into local trends and helps shape targeted policies to address pollution from on-road vehicles. This report presented the results of a plume chasing study that measured real-world vehicle emissions in Kampala, where the TRUE Initiative partnered with UNEP and local researchers and authorities to collect nearly 6,000 measurements between July 3 and July 29, 2024.

This section summarizes key findings and highlights policy recommendations supported by the results, grouped under three broader themes: **(1) strengthening vehicle import requirements**; **(2) addressing the emissions of in-use vehicles through regular inspection and maintenance**; and **(3) prioritizing public transportation**.

Real-world NO_x emission trends varied among diesel LCVs and HCVs, and registration data showed a recent shift in Uganda's vehicle imports, with younger LCVs and HCVs increasingly coming from countries other than Japan. That newer imports did not consistently demonstrate lower real-world NO_x emissions highlights how the import age limit alone cannot guarantee lower-emitting vehicles in Uganda. For example, some diesel LCVs under 8 years old showed higher average NO_x emissions than others over 15 years old. Similarly, some diesel HCVs under 8 years old exhibited higher average NO_x emissions than others that were more than 15 years old.

Analysis also found that average real-world emissions across all vehicle classes were above Euro 4 emission limits. This highlights the potential for emissions reduction with full implementation of Euro 4 vehicle emission limits on all imported vehicles. Nevertheless, little differences in average real-world NO_x emissions were observed among older and newer diesel vehicles across all groups—passenger cars, minibuses, LCVs, and HCVs. This is aligned with existing TRUE evidence that meaningful real-world NO_x reductions are typically not observed until compliance with Euro 6 and later standards. Progressive strengthening of emission standards is especially important for reducing NO_x emissions from diesel vehicles.

58 " China: Heavy-duty: Emissions," TransportPolicy.net, accessed May 30, 2025, https://www.transportpolicy.net/standard/china-heavy-duty-emissions/; "India: Heavy-duty: Emissions," TransportPolicy.net, accessed May 30, 2025, https://www.transportpolicy.net/standard/india-heavy-duty-emissions/.

1. Strengthening vehicle import requirements

Substantial vehicle emission reductions could be achieved if all imported vehicles were required to demonstrate compliance with Euro 4 emission standards upon import to Uganda. Indeed, requiring Euro 4 compliance for all vehicle imports, as laid out in the Ugandan National Environment Regulations, 2024, and combining it with a roadmap towards Euro 6 emission standards by 2030 would be expected to significantly reduce vehicle emissions in Kampala.

As emission standards continue to progress in exporting countries, so too could the emission requirements for vehicles imported by Uganda. This could be facilitated by maintaining the existing import age limit for light-duty vehicles and expanding it to cover all vehicles. For example, a 15-year-old vehicle imported from Germany in 2025 may be certified to Euro 5, but in 5 years, a vehicle of the same age from the same country would likely meet the Euro 6 standards that are associated with meaningful reductions in real-world NO_X.

To achieve progressively stringent emission standards (including Euro 5 and later) by 2030, it is also important for Uganda to maintain its commitment to ultra-low sulfur fuels of 10 ppm or less.

2. Addressing the emissions of in-use vehicles through regular inspection and maintenance

In parallel with import requirements, requiring regular vehicle inspection, as laid out in the National Environment Regulations, 2024 and the Traffic and Road Safety Regulation, 2016, and mandating prompt maintenance would help mitigate elevated emissions among vehicles on the roads in Kampala. Of the measured gasoline passenger cars, 50% showed NO_X emissions that exceeded 1,000 mg/km; such emissions are consistent with those of pre-Euro certified vehicles and indicative of potential malfunctions or the removal of catalytic converters.[59]

Additionally, results showed diesel passenger cars, LCVs, and HCVs over 15 years old emitted 3 times more BC than those aged between 8 and 15 years. This, too, underscores the importance of effective vehicle maintenance, as such emissions are associated with potentially inefficient fuel combustion or malfunctioning emission control systems.

While the introduction of mandatory annual vehicle inspections in Uganda is scheduled to commence in July 2025, it remains unclear how soon mandatory maintenance will be required. Prioritizing and mandating quick repair of vehicles that exhibit visible black smoke from exhaust or visibly missing emission control systems during inspection, without any leniency period, would help reduce emissions. Furthermore, establishing a digital platform to support citizens in reporting vehicles emitting black smoke from their exhaust could help target the highest-emitting vehicles for vehicle inspections.

Better quality vehicle maintenance could be promoted through capacity-building initiatives that equip local automotive technicians with best practices in automobile maintenance.[60] Furthermore, licensing vehicle garages that meet minimum standards would help vehicle owners identify locations to get quality maintenance service.

3. Prioritizing public transportation

The fleets of diesel minibuses that are used primarily as paratransit taxis in Kampala exhibited markedly higher average real-world vehicle emissions than diesel LCVs, despite being in a similar vehicle group. Over half of the diesel minibuses in Kampala showed real-world BC emissions above 1,000 mg/km and NO_X emissions above 3,000 mg/km, and 16% of diesel minibuses exhibited visible black smoke during measurement. As diesel minibuses over 15 years of age exhibited particularly elevated average BC emissions, 6 times higher than those of diesel minibuses aged between 8 and 15 years, high mileage is likely contributing to fleet deterioration. Therefore, ensuring this fleet is routinely inspected at least once a year could reduce emissions due to malfunctions and deterioration. Furthermore, mandating prompt vehicle maintenance on minibuses that exceed the routine inspection emission limits could help to quickly mitigate the elevated emissions from this segment of the fleet.

A focus on public transport could also include progressive modernization of the minibus fleet. Supporting minibus taxi owners to transition to newer and lower-emitting models certified to more stringent emission standards through rebate programs for the scrappage of older models would reduce vehicle related pollution in Kampala city. The fleet could be progressively modernized by introducing a 15-year age limit on newly registered minibus taxis and dropping it to an 8-year age limit by 2030.

Supporting minibus taxi owners to transition to electric alternatives could not only reduce emissions from this sector in Kampala but also align with Uganda's e-mobility strategy, which aims to electrify the whole public transport system in Kampala by 2030.

59 Yang, "Real-World Emissions in China: A Meta-Study of PEMS Data."

60 Wanyama, "Africa's Automobile Maintenance."

APPENDIX

Table A1. The number of vehicle chases and minimum, average, and maximum measurements per vehicle chase for each vehicle class measured

Vehicle class	Count	Minimum	Average	Maximum
Tricycle	14	0	18	27
Heavy machinery	4	17	20	21
Heavy commercial vehicle	836	0	22	129
Light commercial vehicle	498	0	22	56
Minibus	453	0	22	127
Motorcycle	114	0	22	74
Passenger car	3,421	0	22	133
Special purpose vehicle	2	21	22	22
Bus	72	10	23	53
Not available	580	0	20	70

Note: The minimum number of measurements considered for a valid chase was 15.

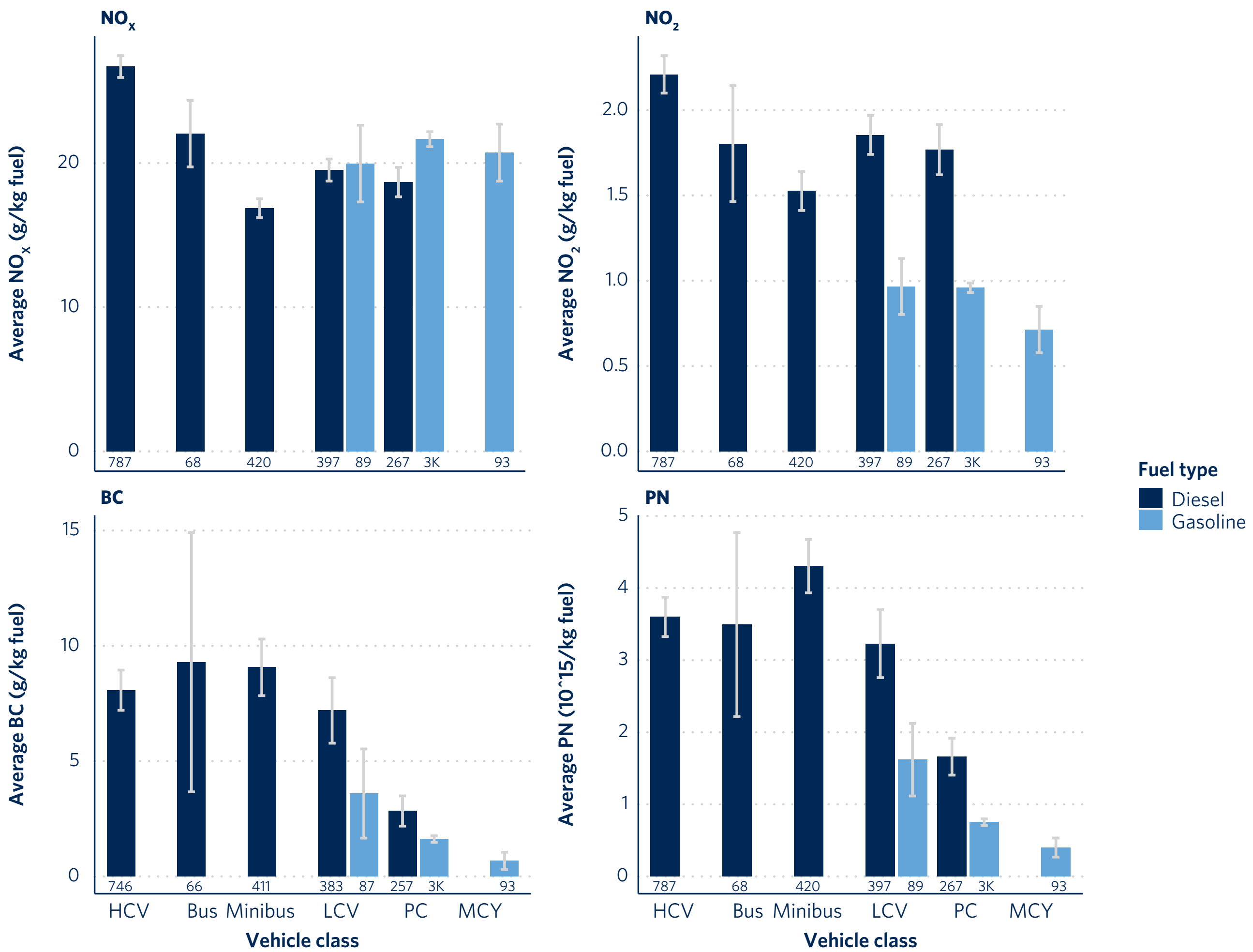

Figure A1. Average fuel-specific NO_x, NO_2, BC, and PN emissions for each vehicle type

Note: Error bars represent the 95% confidence interval and the number at the bottom of the bar indicates the sample size.

Table A2. Correlation coefficient of a linear regression model between distance-specific PN (particles/km) and BC (mg/km) emissions by vehicle class

Vehicle class	Correlation coefficient (R^2)	Intercept (x 10^{14})	Slope (x 10^{11})
Bus	0.94	3.45	2.28
Heavy commercial vehicle	0.84	3.35	2.88
Light commercial vehicle	0.91	0.67	3.12
Minibus	0.87	3.94	2.80
Passenger car	0.82	0.16	3.15

Note: All p values were < 0.001

PASSENGER CARS

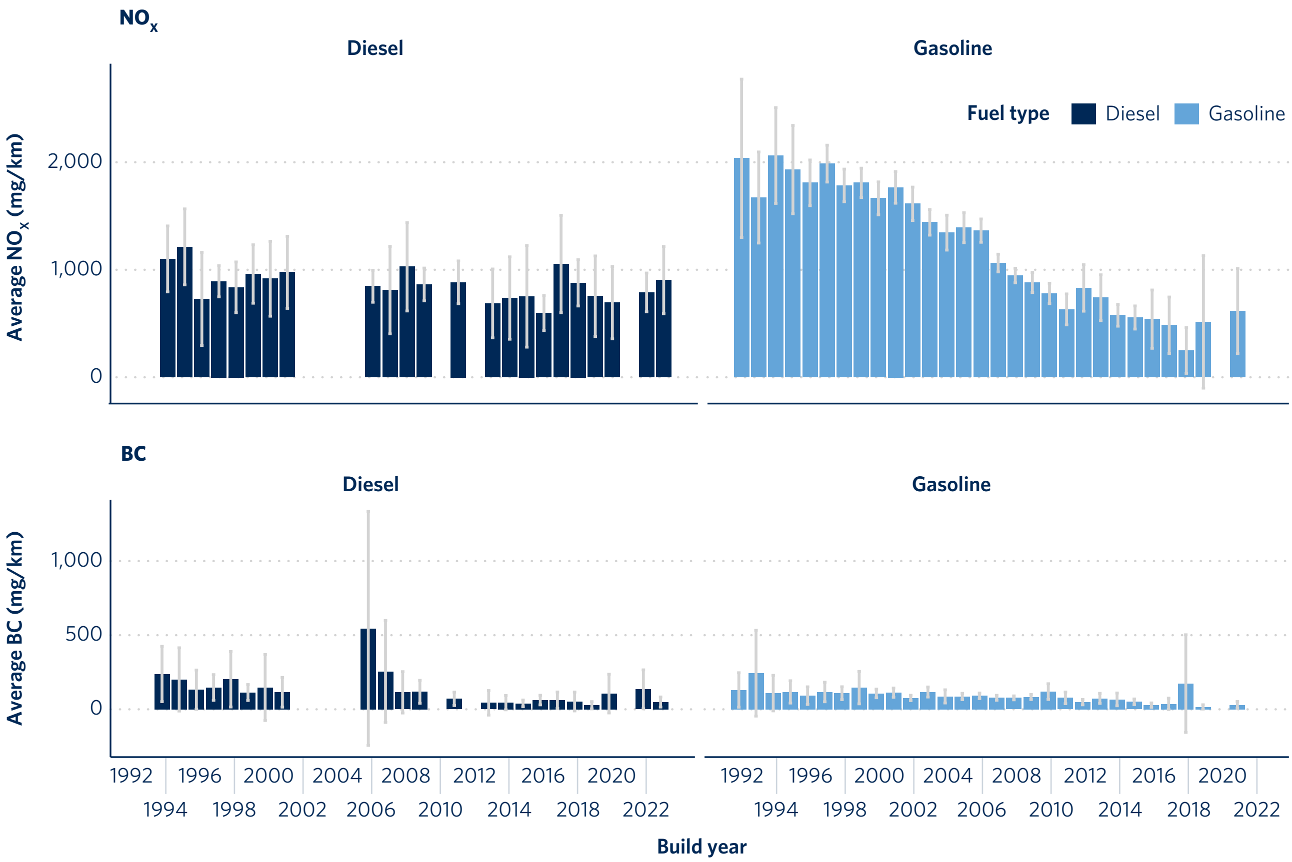

Figure A2. Passenger car average NO_x and BC emissions by build year and fuel type

Note: Error bars represent the 95% confidence interval.

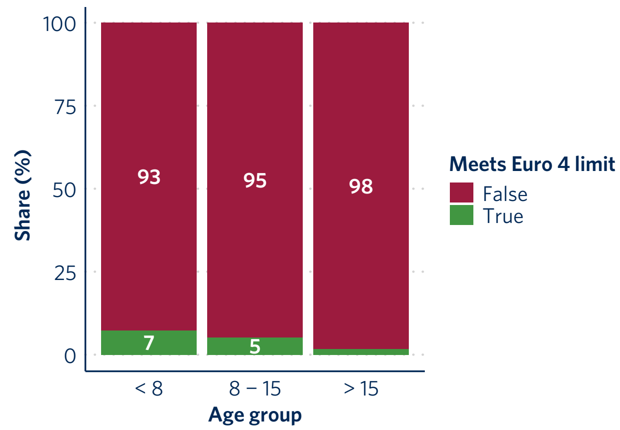

Figure A3. Share of gasoline passenger cars under the Euro 4 NO_x emissions limit of 80 mg/km by age group

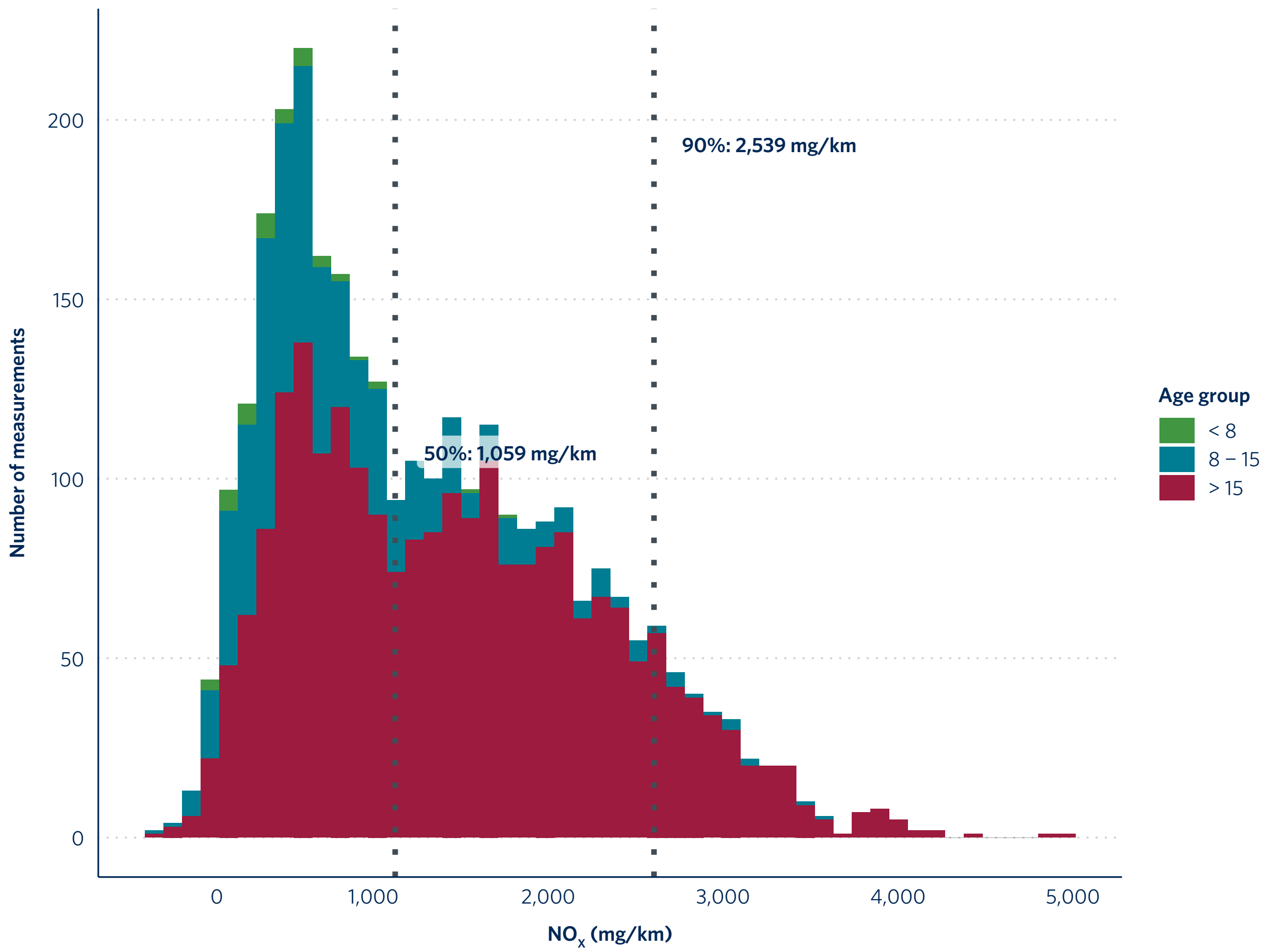

Figure A4. Gasoline passenger car NO_x emissions distributions with 50 and 90 quantiles

MINIBUS

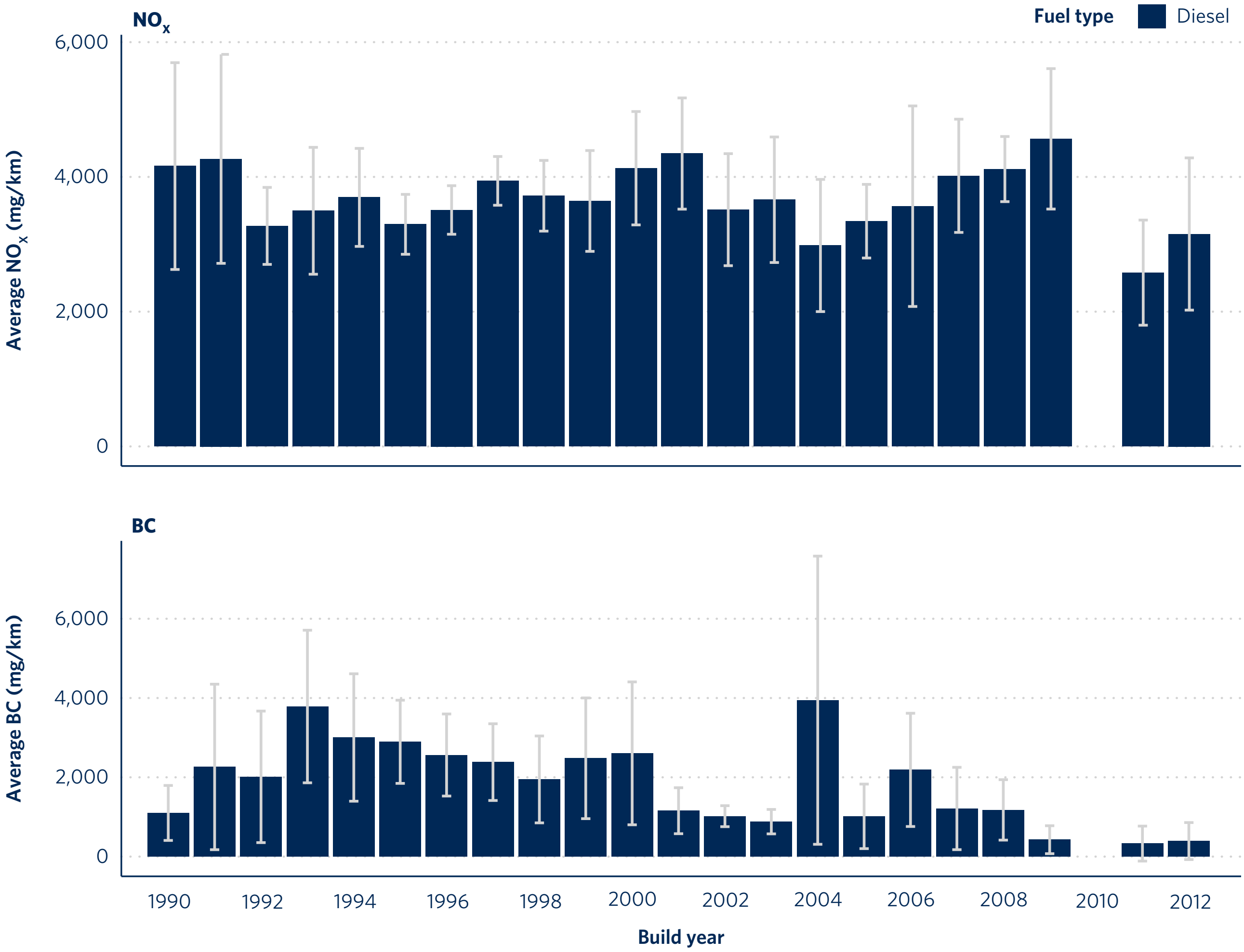

Figure A5. Minibus average NO_x and BC emissions by build year and fuel type

Note: Error bars represent the 95% confidence interval.

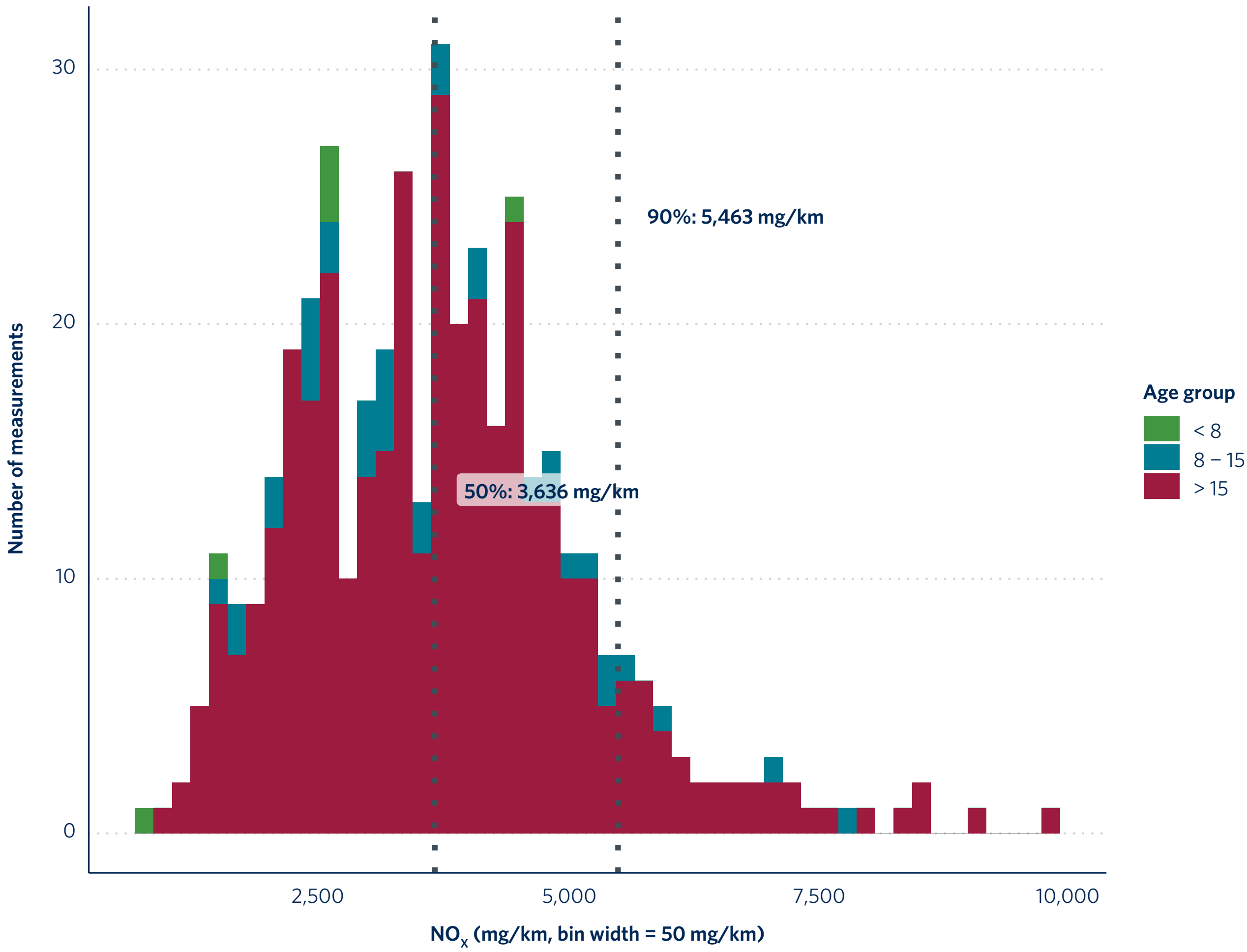

Figure A6. Diesel minibus NO_x emissions distributions by 50 and 90 quantiles

LIGHT COMMERCIAL VEHICLES

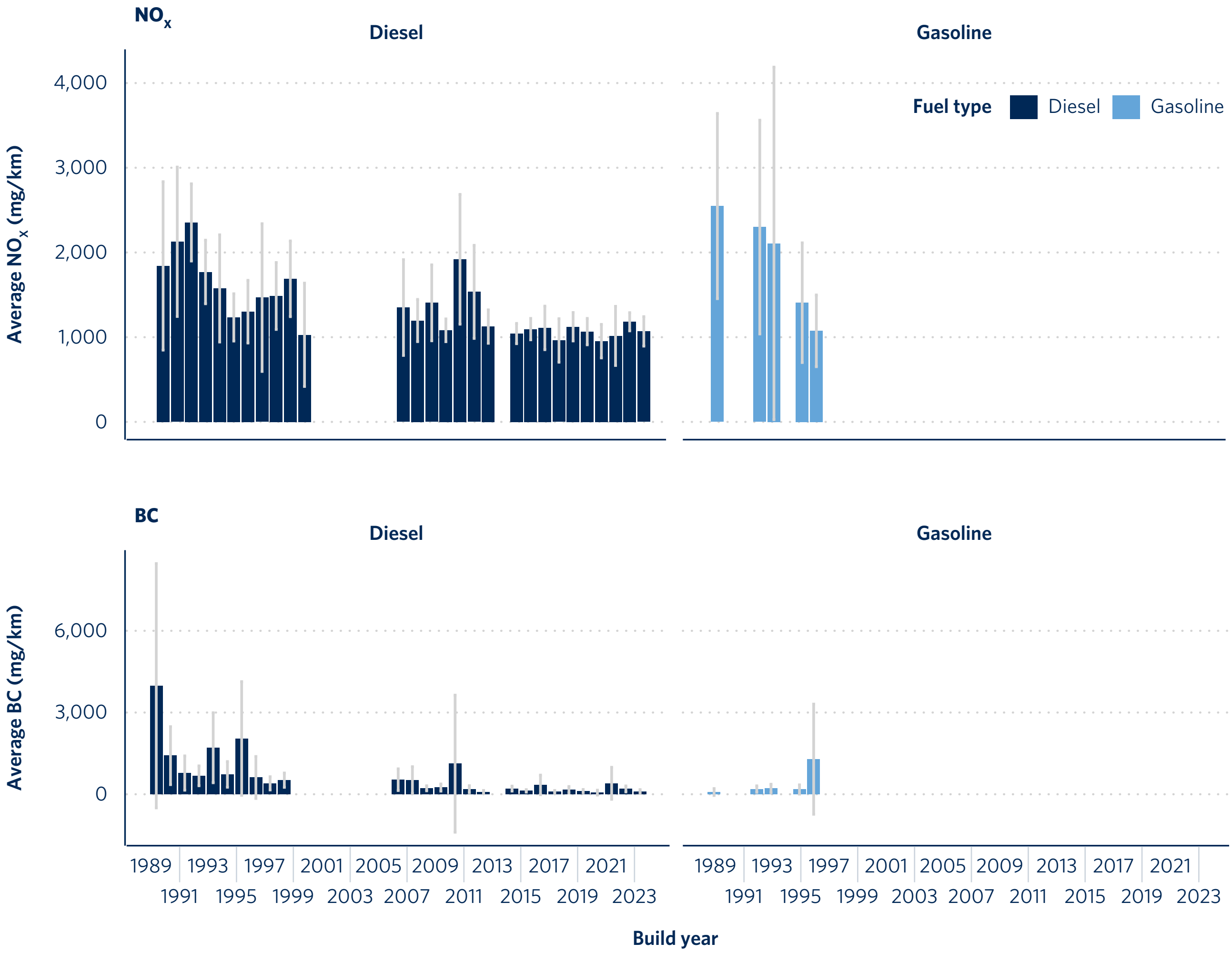

Figure A7. Light commercial vehicle average NO$_X$ and BC emissions by build year and fuel type

Note: Error bars represent the 95% confidence interval.

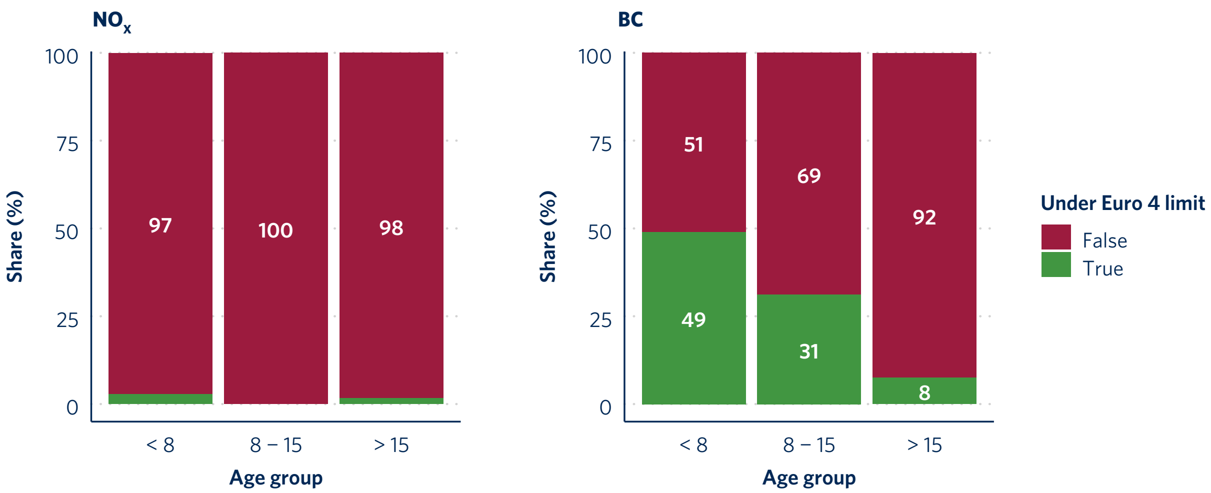

Figure A8. Share of diesel light commercial vehicles under the Euro 4 NO$_X$ (left) limit of 390 mg/km and the PM (right) limit of 60 mg/km, by age group

HEAVY COMMERCIAL VEHICLES

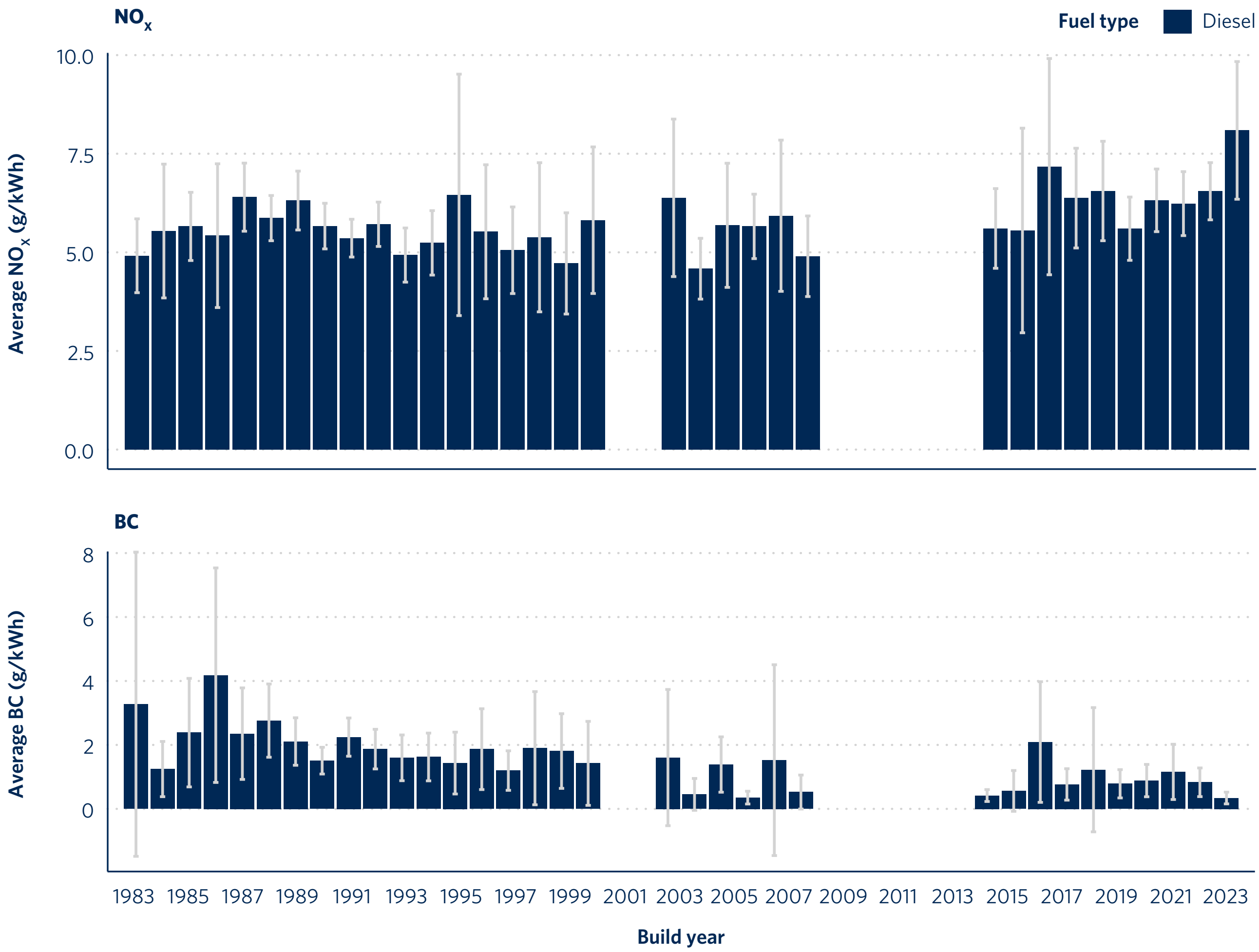

Figure A9. Heavy commercial vehicle average NO$_x$ and BC emissions by build year and fuel type

Note: Error bars represent the 95% confidence interval.

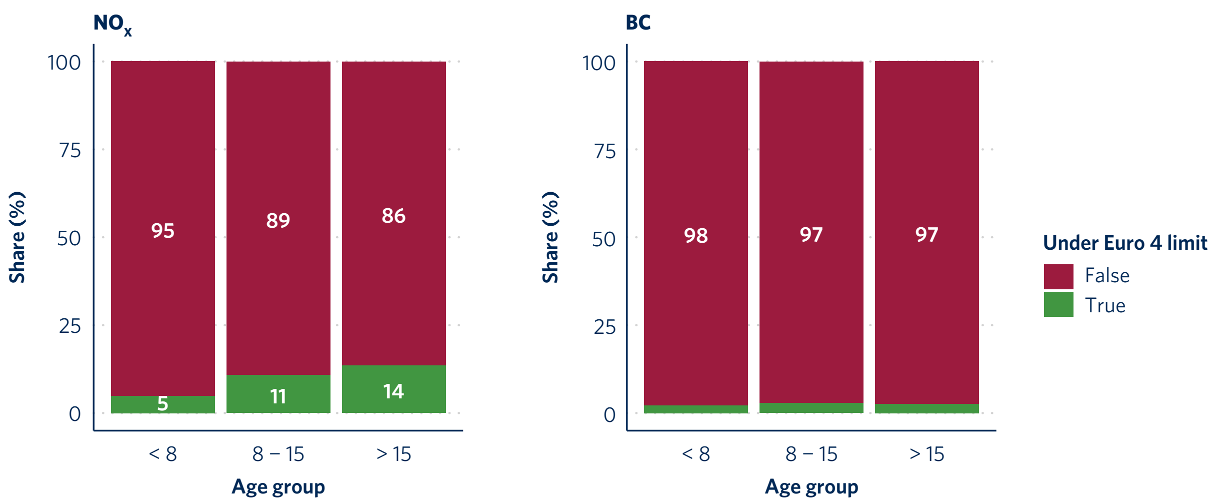

Figure A10. Share of diesel heavy commercial vehicles under the Euro 4 NO$_x$ (left) limit of 3.5 g/kWh and the PM (right) limit of 0.02 g/kWh, by age group

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