THE REAL URBAN EMISSIONS INITIATIVE

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Real-world vehicle emissions in Johannesburg, South Africa

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EXECUTIVE SUMMARY

Elevated air pollution is a major challenge in Johannesburg, where yearly ambient nitrogen dioxide (NO_2) and particulate matter ($PM_{2.5}$) pollution are 2 to 3 times higher than the World Health Organization (WHO) limits. In 2024, Johannesburg was estimated to have one of the highest numbers of premature deaths attributable to road-transport pollution among all African cities. Furthermore, exposure to air pollution is not equally distributed across residents of Johannesburg. The southern region of the city is an air pollution hotspot and has the highest share of low-income households in the city.

South Africa and the City of Johannesburg have introduced policies to mitigate vehicle-related air pollution in the city, including establishing a formalized public bus network in 2000 and a minibus taxi recapitalization program in 2006. However, South Africa has not updated its vehicle emission standard regulations since 2006, when Euro 2/II standards were introduced, lagging standards in comparable economies. Nevertheless, the City of Johannesburg has committed to introducing Clean Air Zones (CAZs), designated areas of the city where air pollution reduction measures will be initiated and prioritized.

Data on the real-world exhaust emissions of vehicles in Johannesburg can inform the effective design and implementation of these zones as well as other policies to reduce vehicle emissions in the city. This study, conducted by The Real Urban Emissions (TRUE) Initiative, uses remote sensing technology to measure real-world tailpipe nitrogen oxides (NO_X), hydrocarbon (HC), carbon monoxide (CO), ammonia (NH_3), and particulate matter (PM) from vehicles in Johannesburg. Over 250,000 measurements were collected from over 145,000 unique vehicles across 11 different measurement sites in the city from July to September 2025. The study identifies high-emitting vehicle groups in Johannesburg that can be prioritized to maximize emissions reduction. The analysis supports the following conclusions and policy recommendations:

Prioritizing CAZs in central and southern Johannesburg, where overall average vehicle emissions were highest, could address unequal vehicle emission exposure. Minibus taxis, the most common form of public transport, accounted for approximately 10% of measured vehicle activity in central and southern Johannesburg, yet contributed disproportionately—between 21% and 40%—to total exhaust emissions across all pollutants in these regions. Diesel minibus taxis, which have increased in popularity in recent years, showed up to 18 times higher average PM and up to 44 times higher average NO_X emissions than their petrol counterparts. A targeted transition toward zero-emission minibus taxis would yield compounding benefits: reduced emissions, lower operating costs, and improved driver and passenger safety. Improved cycling and walking infrastructure, expanded public bus routes, and deployment of electric buses can be considered within CAZs. Electric buses could complement minibus taxis on high-demand corridors to ensure optimal connectivity and efficiency for both passengers and minibus drivers.

Strengthening and enforcing the vehicle inspection and maintenance (I&M) program in Johannesburg could address excess emissions from the oldest and highest-emitting vehicle groups. Updating Johannesburg's existing Air Pollution Control By-Law 2021 to include emissions testing for petrol vehicles alongside diesel could reduce in-use vehicle emissions. A small portion of vehicles showed elevated emissions consistent with possibly deteriorated or malfunctioning emission control systems. Data showed that petrol light commercial vehicles (LCVs) registered before 2006 made up approximately 3% of the LCV fleet but contributed 13%–20% of HC and CO emissions. Prioritizing inspection among the highest-emitting vehicle sub-groups, like large commercial fleets, could offer a more equitable approach that does not overburden small businesses and private vehicle owners. A robust I&M program implemented by the city could eventually be leveraged to operationalize CAZ vehicle entry criteria, permitting only vehicles with valid emission inspection to enter.

Establishing a minimum national standard of Euro 6d/VI-D or higher for new vehicles could reduce fleet-wide NO_X and PM emissions. Average NO_X and PM emissions among petrol passenger cars measured in Johannesburg reflected real-world emissions from European vehicles with over 10 years of in-use deterioration, and there was little improvement in NO_X emissions among all diesel vehicles across registration years. Even the newest diesel passenger cars, LCVs, and trucks registered in 2024 and 2025 showed average NO_X and PM emissions 3–14 times Euro 6/VI limits. Given the growing share of diesel vehicles in South Africa and the evidence showing meaningful reductions in real-world NO_X and PM emissions under Euro 6d/VI-D standards, adopting Euro 6d/VI-D standards or higher is critical for South Africa.

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INTRODUCTION

Elevated air pollution is a challenge in Johannesburg, South Africa's largest city with almost 5 million residents.[1] Annual ambient nitrogen dioxide (NO_2) and particulate matter ($PM_{2.5}$) pollution in Johannesburg between 2000 and 2019 were 2 to 3 times higher than the World Health Organization (WHO) limits.[2] On-road vehicle exhaust contributes 39% of $PM_{2.5}$ and 97% of NO_2 emissions, making it a major source of air pollution in the city alongside industry and biomass fuel burning.[3]

Air pollution has major impacts on residents of Johannesburg, with 92% of surveyed residents expressing concern about air pollution in the city.[4] In 2024, Johannesburg[5] was estimated to have one of the highest numbers of premature deaths related to road-transport pollution among all African cities, driven partly by an aging vehicle fleet and lagging vehicle emission control standards.[6] In that year, pollution related to road transport in Johannesburg accounted for approximately 500 premature deaths and 200 new pediatric asthma cases, representing over one death per day and one new pediatric asthma case every two days. Across the greater Gauteng region, pollution from road transport accounted for over 1,200 premature deaths and nearly 500 new pediatric asthma cases in 2024.

Exposure to air pollution and its health impacts are not equally distributed across residents of Johannesburg. The southern region—the city's most densely populated area, housing approximately 50% of the population—is an air pollution hotspot, yet formal employment is concentrated in the central and northern regions.[7] The southern region has the highest share of lower-income households in Johannesburg, with over 40% of residents earning less than R96,000 per year (approximately US$5,800). Residents in this region rely more heavily on public transportation and often face long and costly commutes to reach employment sites in the north.[8] Air pollution monitoring between 2019 and 2025 showed that the southern region of Johannesburg consistently experiences yearly concentrations of $PM_{2.5}$ pollution between 25 μg/m^3 and 35 μg/m^3, between 5 and 7 times the WHO yearly limit of 5 μg/m^3.[9] In the southwest region of Gauteng province, which includes the southern region of Johannesburg, over 65% of residents report respiratory symptoms such as coughing, tiredness, and shortness of breath—with both adults and children experiencing more concurrent symptoms the longer they reside in the region.[10]

Reducing transport-related pollution in Johannesburg could improve health outcomes and address emission exposure disparities. The City of Johannesburg joined the Breathe Cities initiative in 2023, publicly committing to reduce air pollution in the city.[11] Reducing road-transport pollution in Johannesburg will require the city and national governments to implement ambitious vehicle emission control policies. The City of Johannesburg has already committed to the introduction of clean air zones (CAZs), designated areas of the city where officials will introduce and prioritize measures to reduce air pollution. Data on the real-world exhaust emissions of Johannesburg's vehicle fleet are critical to inform the effective design and implementation of these zones. Information on real-world vehicle emissions can also illuminate additional policy opportunities to address vehicle-related air pollution in the city.

This study, the first large-scale roadside remote sensing campaign in Africa, provides insight into real-world vehicle exhaust emissions in Johannesburg. From July to September 2025, The Real Urban Emissions (TRUE) Initiative conducted vehicle emissions testing in Johannesburg using remote sensing technology to measure real-world tailpipe emissions of nitrogen oxides

1 Statistics South Africa, *Census 2022*, statistical data, 2026, https://census.statssa.gov.za/#/province/7/2.

2 State of the Global Air, *Air Pollution and Health in Cities*, statistical data, 2022, https://www.stateofglobalair.org/data-cities/#/air/plot; The WHO's annual $PM_{2.5}$ limit is 5 μg/m^3 and the NO_2 limit is 10 μg/m^3.

3 Musa Mahlatji, "City of Johannesburg Draft Clean Air Zone Policy" (presentation, Breathe Joburg Stakeholder and Grantee Convening, Johannesburg, South Africa, February 27, 2026).

4 Seriti Institute, *Defining a Clean Air Zone for Johannesburg*, accessed April 8, 2026, https://joburg.org.za/about_/government/Documents/CLEAN-AIR-FUND-FINAL-REPORT-2025.pdf.

5 Defined as the administrative boundary of Johannesburg.

6 Lingzhi Jin et al., "Global Health Benefits of Policies to Reduce On-Road Vehicle Pollution through 2040," *Environmental Research Letters* 20 (May 19, 2025): 064005, https://doi.org/10.1088/1748-9326/adcd87.

7 City of Johannesburg, *Spatial Development Framework 2040: City of Johannesburg Metropolitan Municipality* (2016), https://unhabitat.org/spatial-development-framework-2040-city-of-johannesburg-metropolitan-municipality; City of Johannesburg, *Annual Economic Review* (2025), https://joburg.org.za/departments_/Pages/Quarterly-Statistical-Publications-202425.aspx.

8 City of Johannesburg, *Annual Economic Review*.

9 Nkanyiso Mbatha et al., *Design and Development of a Clean Air Zone Policy for the City of Johannesburg* (CSIR, October 23, 2025), https://drive.google.com/file/d/1bSsumn8q-vadB7Z2tE7g-czRJ_WBfbyZ/view.

10 Section27, *Vaal Triangle Priority Area Health Impact Report* (2025), https://section27.org.za/resources/section-27-publications/.

11 "Johannesburg Launches Breathe Cities Initiative," Clean Air Fund (September 6, 2024), https://www.cleanairfund.org/news-item/johannesburg-breathe-cities/.

(NO_x), hydrocarbon (HC), carbon monoxide (CO), ammonia (NH_3), and smoke opacity from ultraviolet light (a proxy of PM exhaust emissions) from passenger cars, light commercial vehicles (LCVs), minibus taxis, trucks, and buses. The study collected over 250,000 vehicle exhaust emission measurements from over 145,000 unique vehicles across 11 measurement sites in Johannesburg. In this paper, we present an analysis of the Johannesburg fleet, including spatial variability across the city and identification of high-emitting vehicle groups that can be prioritized to maximize emission reduction. We conclude with data-informed policy recommendations that can reduce vehicle emissions in Johannesburg and the greater Gauteng region.

POLICY CONTEXT

South Africa and the City of Johannesburg have taken steps to address vehicle-related air pollution over the past 2 decades, such as establishing a minibus taxi recapitalization program, expanding the public bus network, and introducing vehicle emission standards and roadworthiness assessments.[12]

MINIBUS TAXI RECAPITALIZATION PROGRAM

Minibus taxis are the most common form of public transport in Johannesburg, operating in privatized minibus networks run by associations that serve the city, spatially segmenting the market.[13] Residents of the southern region of Johannesburg rely most heavily on minibus taxis.[14] As of 2019, there were nearly 53,000 registered minibus taxis in the city, representing approximately 3% of the total vehicle fleet but likely a much higher share of vehicle activity, given that minibus taxi drivers spend on average 9 hours per day on the road and travel 200–300 km per day.[15] The fleet is primarily powered by petrol fuel (70%)—although there is an increasing share of diesel fuel in newer vehicles—and minibus taxis are the oldest vehicles in Johannesburg with an average age of 19, 4 years older than the average age of passenger cars.[16]

South Africa's Department of Transport launched the Taxi Recapitalization Programme (TRP) in 2006, which aims to remove older and non-roadworthy minibus taxis from the roads through a voluntary surrender mechanism:[17] minibus taxi owners can scrap non-compliant vehicles in exchange for allowances toward purchasing new taxis.[18] By 2024, over 84,000 taxis had been scrapped, although the rate of scrapping has declined since 2006. Although the TRP successfully removed older and non-roadworthy taxis from the road, the focus was on vehicle safety rather than vehicle emissions, limiting the emissions reduction efficacy of the program.

PUBLIC BUS SYSTEM EXPANSION

The City of Johannesburg operates two formal public bus systems, which work alongside the minibus taxi network. The Metrobus system, established in 2000, services approximately 90,000 passengers per day across 210 routes.[19] Over half of Metrobuses are 19 years or older and under one third are certified to Euro V emission standards.[20] The Rea Vaya Bus Rapid Transit (BRT) system, established in 2009, introduced over 60 new bus stations, significantly expanding passenger transport capacity; the BRT primarily operates in dedicated lanes with signal priority to avoid congestion.[21] Through extensive negotiations, the City of Johannesburg successfully integrated taxi associations into the Rea Vaya BRT system by offering operators shares in the bus operating companies, securing their buy-in and financial stake in the new network.[22] Rea

12 Minister of Transport, *Question No. 157: Internal Question Paper No. 2 of 2024* [Ref. NW175E] (July 26, 2024), https://www.parliament.gov.za/storage/app/media/Docs/exe_rq_na/1236e7ad-eca7-4af3-904e-936a9b034bbe.pdf; Johannesburg Development Agency, "Putting the 'Rapid' Back in Bus Rapid Transit," *Public Sector Manager*, July 2025, https://www.publicsectormanager.gov.za/july-2025/features-opinions/putting-rapid-back-bus-rapid-transit.

13 Oluchi Mbonu, "Divided We Ride: The Costs of Segmented Minibus Services in Johannesburg, South Africa," *World Bank Blogs*, December 12, 2024, https://blogs.worldbank.org/en/impactevaluations/divided-we-ride--the-costs-of-segmented-minibus-services-in-joha.

14 City of Johannesburg, *Annual Economic Review*.

15 South African National Taxi Council, "Presentation on the AART Amendment Bill" (PowerPoint presentation, National Assembly Transport Committee meeting, Cape Town, South Africa, October 30, 2023), https://www.docslides.com/belinda/presentation-on-the-aart-amendment-bill#google_vignette.

16 Jehan Bhikoo et al., *Vehicle Emissions Control Strategy and Action Plan* (City of Johannesburg, Transport Department: Air Quality Unit, April 2021), https://goldenmetro.co.za/wpfd_file/coj-vehicle-emissions-control-strategy-and-action-plan_april-2021/; International Energy Agency (IEA), *Fuel Economy in South Africa* (December 13, 2021), https://www.iea.org/articles/fuel-economy-in-south-africa.

17 Minister of Transport, *Question* No. 157.

18 Minister of Transport, *Question* No. 157.

19 "Metrobus," City of Johannesburg, accessed May 20, 2026, https://goldenmetro.co.za/municipal-services/metrobus/.

20 Metropolitan Bus Services, *Metrobus First Quarter Performance Assessment Report* (2025), https://mbus.joburg.org.za/about_strat_reports.aspx.

21 Johannesburg Development Agency, "Putting the 'Rapid' Back in Bus Rapid Transit."

22 Johannesburg Development Agency, "Putting the 'Rapid' Back in Bus Rapid Transit."

Vaya buses are certified to Euro IV and V vehicle emission standards.[23] Currently, neither operator uses electric buses. However, in its 2026 budget, Metrobus allocated funds toward the purchase of electric buses and charging infrastructure, and the City of Johannesburg aims to transition to 100% electric bus procurement by 2029.[24]

Although the expansion of public buses in Johannesburg has improved residents' access to the city and workplaces, City of Johannesburg data suggest that the public bus system is still minimally used relative to the paratransit minibus taxi system.[25] In 2018, 89% of public transport trips in Johannesburg were taken using minibus taxis compared with 11% using public buses.[26] This indicates that minibus taxis are a critical form of public transport, particularly for lower-income groups who reside far from economic opportunities.[27]

VEHICLE EMISSION STANDARDS

At the national level, South Africa adopted Euro 2/II emission standards in 2006 for light- and heavy-duty vehicles but has not since updated its official regulations.[28] South Africa's vehicle emission standards now lag over 20 years behind European standards and trail comparable economies that have already adopted Euro 4/IV-equivalent standards or higher, including Morocco, Mexico, Colombia, India, and Brazil.[29]

A key barrier to adopting more stringent standards has been the availability of low-sulfur fuel. Since 2010, South African regulations have set a maximum sulfur content of 50 ppm for petrol.[30] Diesel fuel is subject to a higher limit of 500 ppm, although 50 ppm diesel is available on the market.[31] Amendments to the Regulations Regarding Petroleum Product Specifications and Standards for Implementation (also known as Clean Fuels II) by the South Africa Department of Mineral Resources and Energy—which mandates that sulfur content in petrol and diesel fuel be reduced to 10 ppm and was initially scheduled for implementation in 2023—has faced delays and is now expected to be implemented in July 2027.[32] This is a critical step to enabling the adoption of more progressive vehicle emission standards and allowing vehicles to effectively use modern emission systems like diesel particulate filters and other catalytic converters. Although vehicles may operate using modern emission systems, the elevated sulfur content in the fuel would accelerate deterioration of their emission control systems, compromising their emission performance.[33]

Despite lagging emission standards and fuel quality, there is evidence that some manufacturers are supplying heavy-duty vehicles to South Africa with engine and aftertreatment technologies that meet Euro III standards or higher.[34] However, voluntary supply is partial and uneven across manufacturers and

23 City of Johannesburg, "Rea Vaya Bus Rapid Transit System: Performance, Progress, Future" (presentation, National Assembly Transport Committee meeting, Cape Town, South Africa, September 12, 2017), https://static.pmg.org.za/1/170912_COJ.pdf.

24 Metropolitan Bus Services, *Performance Assessment Report*; City of Johannesburg, *City of Johannesburg Climate Action Plan* (March 2021), https://goldenmetro.co.za/wpfd_file/city-of-johannesburg-climate-action-plan-cap-2/.

25 Valery Louw and Mpfareleni Netswera, *Integration of Public Transport in Pursuit of Smart Cities: Case of the Rea Vaya Bus Rapid Transit (BRT) System* (2025), https://www.researchgate.net/publication/389498745_Integration_of_Public_Transport_in_Pursuit_of_Smart_Cities_Case_of_the_Rea_Vaya_Bus_Rapid_Transit_BRT_System.

26 City of Johannesburg, *Final Integrated Development Plan 2020/21* (National Treasury, December 11, 2020), https://joburg.org.za/documents_/Pages/Key%20Documents/Intergrated%20Development%20Plan/Integrated-Development-Plan.aspx.

27 City of Johannesburg, *Final Integrated Development Plan 2020/21*; Louw and Netswera, *Integration of Public Transport.*

28 Euro 2/II standards applied to all newly homologated vehicles in South Africa beginning in 2006 and all newly manufactured vehicles beginning in 2008; Joint Implementation Strategy for the Control of Exhaust Emissions from Road-Going Vehicles in the Republic of South Africa, GN 3324 of GG 25741 (12 December 2003), https://lawlibrary.org.za/akn/za/officialGazette/government-gazette/2003-12-12/25741/eng@2003-12-12; Petroleum Product Act 1977: Regulations Regarding Petroleum Products Specifications and Standards, GN 627 of GG 28958 (June 23, 2006), https://www.gov.za/documents/notices/petroleum-products-act-regulations-petroleum-products-specifications-and.

29 Kristy Langerman et al., "South Africa Needs to Accelerate the Adoption of Stricter Vehicle Emission Standards," Clean Air Journal 35, no. 1 (June 23, 2025), https://doi.org/10.17159/caj/2025/35/1.22338.

30 Joint Implementation Strategy for the Control of Exhaust Emissions from Road-Going Vehicles in the Republic of South Africa.

31 Joint Implementation Strategy for the Control of Exhaust Emissions from Road-Going Vehicles in the Republic of South Africa.

32 Avhapfani Tshifularo, "Opinion: Supporting Cleaner Fuels and the Fight against Climate Change," *Engineering News*, September 28, 2023, https://www.engineeringnews.co.za/article/opinion-supporting-cleaner-fuels-and-the-fight-against-climate-change-2023-09-28; Petroleum Products Act: Regulations Regarding Petroleum Products Specifications and Standards for Implementation, GN 784 of GG 45068 (August 31, 2021), https://www.gov.za/documents/notices/petroleum-products-act-regulations-petroleum-products-specifications-and-3.

33 Yihao Xie et al., *Soot-Free Road Transport in South Africa: A Cost-Benefit Analysis of Euro VI Heavy-Duty Vehicle Standards* (International Council on Clean Transportation, 2022), https://theicct.org/publication/africa-me-hvs-soot-south-africa-dec22/.

34 Xie et al., *Soot-Free Road Transport in South Africa.*

applications[35] and is not a substitute for harmonized national emissions standards.

ROADWORTHINESS ASSESSMENTS

The import of used vehicles is not permitted in South Africa, but secondhand sales of used vehicles within the country are common.[36] Vehicle owners in South Africa are required to obtain a roadworthiness certification before registering a vehicle in their name, including during any transfer of vehicle ownership, as stipulated by the National Road Traffic Act 93 of 1996.[37] Motor vehicles used for public transport and heavy-load vehicles must be tested for roadworthiness annually and buses must be tested biannually.[38] Routine roadworthiness assessments primarily evaluate essential vehicle safety components such as brakes, tires, steering, suspension, and lighting systems. Emissions-related assessments during these inspections are limited and focus on identifying vehicles that emit excessive or visible smoke from the exhaust system, rather than routine numerical exhaust emissions or opacity testing.[39]

Vehicles in the city of Johannesburg are subject to the Air Pollution Control By-Law 2021, which stipulates that the city may require certain vehicle groups to undergo compulsory emissions testing based on their age, engine type, fuel type, and emission-control technology.[40] As outlined in the bylaw, this emissions testing is for the identification of smoke from compression ignition engines.[41] However, the frequency and application of this testing remains unclear.

In 2021, Johannesburg published an ambitious Vehicle Emissions Control Strategy to tackle on-road vehicle emissions.[42] Proposed initiatives included the introduction of CAZs, traffic congestion charges, high-occupancy vehicle lanes to manage traffic volumes, car life-cycle limits, and expanded vehicle inspection and maintenance programs.[43] Real-world vehicle emissions data are critical to the effective design and implementation of these initiatives because they enable identification of high-emitting sub-groups that can be targeted in policy design.

REMOTE SENSING STUDY OVERVIEW

DATA COLLECTION

The TRUE initiative conducted roadside remote sensing testing to measure the real-world exhaust emissions from vehicles in the City of Johannesburg over 33 days from July 15 to September 3, 2025. In total, 253,654 measurements were collected from 145,273 unique vehicles across 11 different measurement sites. The 11 measurement sites were chosen based on their potential to provide valid measurement readings with a smooth traffic flow, a slight upward road slope to ensure vehicles are under acceleration, and a representative mix of vehicle activity across the regions of Johannesburg and traffic toward, within, and away from the city center. Measurement sites were also chosen to capture traffic coming into Johannesburg from adjoining municipalities. Measured vehicles were registered across more than 300 municipalities, and most measurements were from vehicles registered in Johannesburg (64%), Ekurhuleni (16%), and Pretoria (11%). The locations of the 11 measurement sites are shown in Figure 1, indicating the five key regions of the city measured; the breakdown of measurement sites by region and traffic direction is shown in Table 1. Traffic measured across the five regions was considered representative of Johannesburg as a whole.

35 "Decarbonising Supply Chains," DSV, accessed April 10, 2026, https://www.dsv.com/en-za/insights/expert-opinions/euro-5; "Isuzu Motors South Africa's Trucks Match Environmental Demands with Euro 5 Technology on Selected Models," Isuzu, May 19, 2022, https://www.isuzu.co.za/newsroom/isuzu-motors-south-africa-s-trucks-match-environmental-demands-with-euro-5-technology-on-selected-models; Volvo Trucks, "Volvo Trucks South Africa Introduces EURO 6 Technology to Drive Sustainability, Efficiency and Performance," press release, April 10, 2025, https://www.volvotrucks.co.za/en-za/news/press-releases/2025/apr/volvo-trucks-south-africa-introduces-euro-6-technology.html.

36 "Importing a Second-Hand or Used Vehicle," Republic of South Africa, accessed April 10, 2026, https://www.gov.za/services/services-organisations/import/importing-second-hand-or-used-vehicle; Segun Adeyemi, "South Africa's Used Car Market Hit $800 Million in January Sales," *Business Insider Africa*, February 11, 2026, https://africa.businessinsider.com/local/markets/south-africas-used-car-market-hit-over-dollar800-million-in-january-sales/l0vqvy0?op=1.

37 National Road Traffic Act 93 of 1996, GN 1892 of GG 17603 (22 November 1996), https://www.gov.za/documents/national-road-traffic-act; "Roadworthiness," Department of Transport, accessed April 2, 2026, https://www.transport.gov.za/?page_id=1185.

38 Department of Transport, "Roadworthiness."

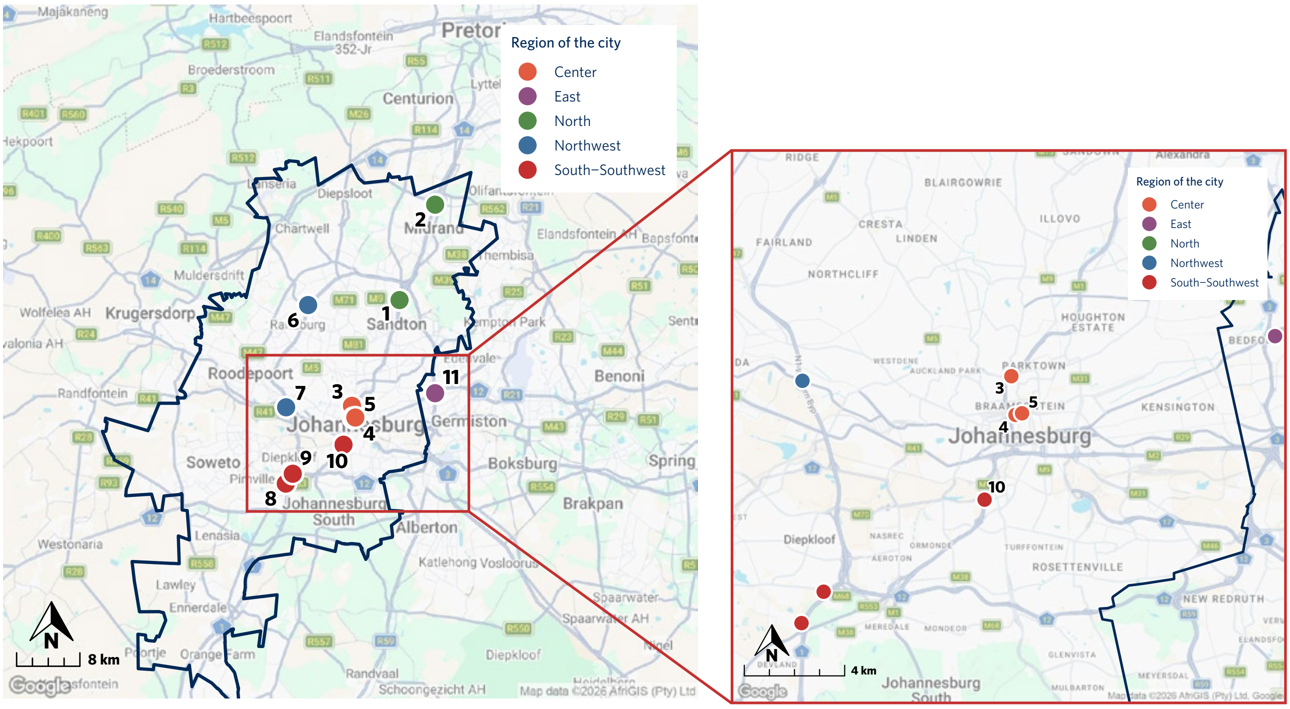
39 National Road Traffic Act 93 of 1996.

40 City of Johannesburg Metropolitan Municipality, Air Pollution Control By-Law, 2021, *Provincial Gazette* 349 (October 13, 2021), https://openbylaws.org.za/akn/za-jhb/act/by-law/2021/air-pollution-control/eng@2021-10-13.

41 City of Johannesburg, Air Pollution Control By-Law, 2021.

42 Bhikoo et al., "Vehicle Emissions Control Strategy."

43 Bhikoo et al., "Vehicle Emissions Control Strategy."



Note: Blue solid line indicates the City of Johannesburg boundary.

Figure 1. Map of measurement sites for the remote sensing study

Measurements collected at four sites (sites 2, 5, 6, and 9) yielded over half of the total measurements collected. Opus RSE led the data collection in collaboration with the City of Johannesburg, UJ PEETS, and C&M Consulting Engineers, which supported site selection and securing permits for data collection. The data collection was primarily undertaken by C&M Engineers and UJ PEETS staff with support and training from Opus RSE. The remote sensing device RSD6000 was used to collect data; it measured tailpipe carbon dioxide (CO_2), NO, NO_2, NO_X, HC, CO, and NH_3 emissions, as well as UV smoke (as a proxy for PM, and herein referred to as PM) as vehicles drove past the instrument.[44] The instrument also captured each vehicle's speed and acceleration, which were used to estimate engine power (Figure 2). Additionally, license plate numbers (LPNs) were recorded to facilitate retrieval of the vehicle's technical characteristics. LPNs were anonymized to create unique vehicle identifiers stored in the data.

SAMPLE OVERVIEW

Of the 253,654 total measurements collected, 172,367 (68%) had valid speed and positive vehicle specific power (VSP) and were correctly calibrated and audited by the remote sensing system during the operation. The LPN was captured and linked to the vehicle information for 235,108 (93%) measurements (Table 2). Data on the vehicles measured were obtained from South Africa's electronic National administrations Traffic Information System (e-NaTIS). To maximize data utilization, we applied different inclusion criteria depending on the analysis. Analyses examining only vehicle characteristics used all measurements with vehicle data (93%), while analyses of vehicle exhaust emissions included those with vehicle data and valid emission measurements (64%), with additional pollutant-specific validity conditions reducing the analytical sample to between 47% and 57% of total measurements depending on the pollutant (Table 2).

44 UV smoke is measured by the ratio of opacity to fuel burned. The measurement is dependent on various physical and chemical characteristics of exhaust PM and therefore is best suited for grouped analysis with sufficient sample size and is not suitable for determining if an individual vehicle is emitting more than the official certification limit. See Michelle Meyer et al., *Particulate Matter Emissions from U.S. Gasoline Light-Duty Vehicles and Trucks* (TRUE Initiative, 2023), https://trueinitiative.org/research/particulate-matter-emissions-from-u-s-gasoline-light-duty-vehicles-and-trucks/. PM measurement relies on opacity readings with ±1% absolute tolerance across the currently verifiable reference range.

Table 1. Remote sensing measurement sites in Johannesburg

Site ID	Number of measurements	Share of measurements	Region of the city	Traffic direction
1	2,792	1%	North	Toward center
2	51,884	20%		
3	17,086	7%	Center	Within center
4	19,846	8%		
5	58,891	23%		
6	37,001	15%	Northwest	Outside center
7	1,767	1%		
8	3,220	1%	Southwest	Outside center
9	36,188	14%		
10	1,177	1%	South	Toward center
11	23,802	9%	East	Toward center

Figure 2. Remote sensing data collection using Opus RSD6000

Table 2. Summary of measurements collected in Johannesburg

Metric	Total	Valid LPN	Valid pass[a]	Valid pass and LPN	Pollutant validity				
					CO	HC	NO_X	PM	NH_3
Measurements	253,654	235,108	172,367	162,234	124,991	131,440	118,883	143,532	142,265
Share of total	1	0.93	0.68	0.64	0.49	0.52	0.47	0.57	0.56

[a] Indicating measurements with valid VSP and speed and where the remote sensing system was correctly calibrated and audited during the operation.

Consistent with previous TRUE analyses,[45] we first converted emissions from fuel-specific values (g/kg)—a unit of emissions directly inferred from remote sensing technology—to distance-specific values (g/km)—a unit consistent with European vehicle emission limits—to allow for better contextualization of the results. We undertook this conversion using a method developed in an earlier TRUE publication.[46] In the absence of real-world fuel consumption data, we used the International Energy Agency's Mobility Model estimates for South Africa.[47] Because this study measured vehicles under urban driving conditions, it is likely that fuel consumption was higher than national estimates and therefore the distance-specific emissions presented in this study could be lower than actual emissions. We also converted truck emissions into energy-specific emissions, expressed per kilowatt-hour (kWh), to allow for comparison with European vehicle emission limits for heavy-duty vehicles.[48]

The testing conditions during this study were consistent with those of previous TRUE studies and represented urban driving conditions. The median values were 36 km/h for speed, 1.08 km/h/s for acceleration, 8 kW/t for VSP, and 25 °C for ambient temperature (Figure A1 in Appendix A). Median speed and acceleration were slightly lower among measurements collected at sites representing vehicle traffic within the city center, likely due to more congested traffic conditions or drivers mistaking the remote sensing devices for speed cameras (Figure 3).

FLEET COMPOSITION

The most frequently measured vehicles in this study were passenger cars (68%), followed by LCVs (21%), minibus taxis (6%), trucks (4%), and buses (< 1%), as shown in Figure 4.[49] The majority of passenger cars and minibus taxis measured were powered by petrol fuel, at 89% and 59%, respectively, while 61% of LCVs were powered by diesel fuel. Fewer than 30 electric vehicles were measured in this study and therefore were not included in the fleet composition analysis. Data from e-NaTIS did not allow for identification of plug-in hybrid or conventional hybrid vehicles. Vehicle class and fuel shares were consistent with 2019 e-NaTIS data for Johannesburg.[50]

Overall, 60% of the vehicles measured were resold vehicles (i.e., vehicles that were resold within the country), 38% were first-owner vehicles (i.e., vehicles that were purchased new and have not been resold), and 2% were rebuilt vehicles (i.e., those that have been substantially rebuilt, typically following an accident). The share of resold versus first-owner vehicles varied by

45 Mallery Crowe et al., *Evaluation of Real-World Vehicle Emissions in Kampala, Uganda* (International Council on Clean Transportation, 2025), https://theicct.org/publication/evaluation-of-rw-vehicle-emissions-in-kampala-uganda-jul25/; Kaylin Lee et al., *Evaluation of Real-World Vehicle Emissions in São Paulo* (TRUE Initiative, 2025), https://theicct.org/publication/evaluation-of-real-world-vehicle-emissions-in-sao-paulo-nov25/; Kaylin Lee et al., *Real-World Vehicle Emissions in Four Major Scottish Cities* (TRUE Initiative, 2024), https://theicct.org/publication/rw-vehicle-emissions-in-four-major-scottish-cities-aug24/.

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

47 "Transport," International Energy Agency, updated July 11, 2023, https://www.iea.org/energy-system/transport.

48 Because the regulatory emission limits for heavy-duty vehicles are established on an energy-specific basis (g/kWh), we converted fuel-specific emissions to energy-specific emissions using brake-specific fuel consumption of the vehicle in g/kWh according to the methodology outlined in 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/.

49 We derived vehicle classes from South Africa's e-NaTIS. Light-load vehicles with gross vehicle weights of 3,500 kg or less were classified as LCVs, and heavy-load vehicles with gross vehicle weights over 3,500 kg were classified as trucks. Buses represent large buses with over 35 seats. We identified minibus taxis using the body type (minibus or bus) and seating capacity (between 12 and 35) information stored in e-NaTIS. In this study, we also measured motorcycles, special vehicles, and minibuses under 12 seats, but because they made up only a small portion of measurements, they are grouped together as 'Other' in this report.

50 Bhikoo et al., "Vehicle Emissions Control Strategy."

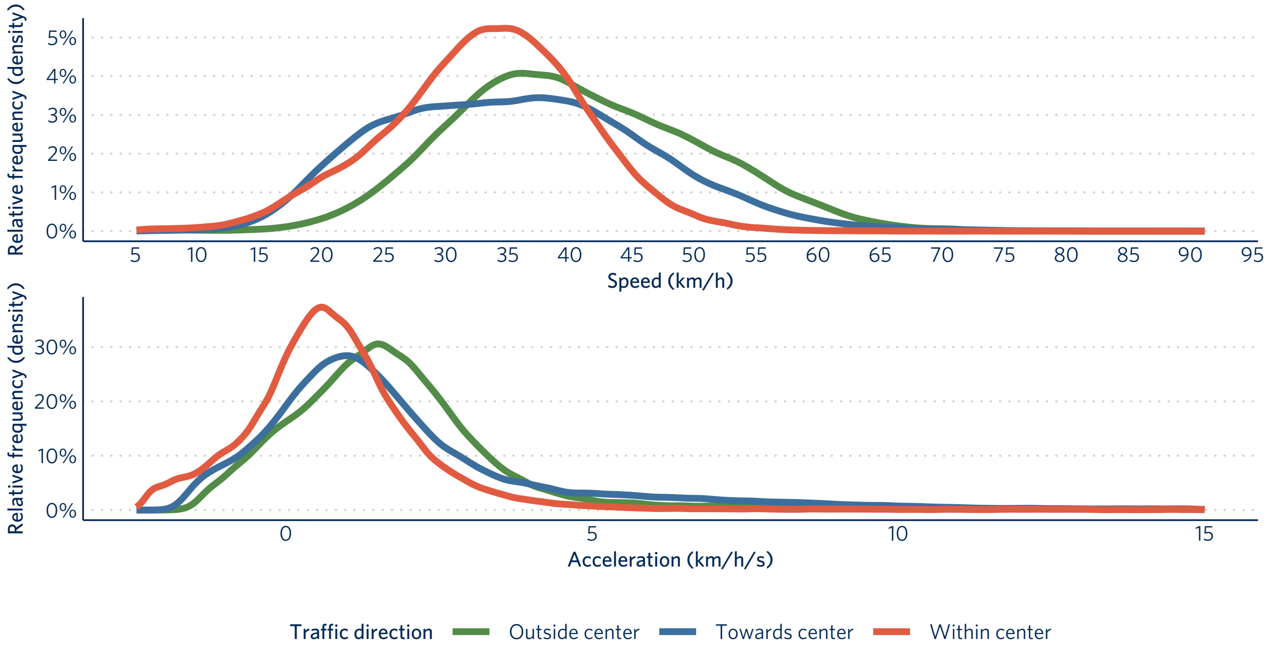
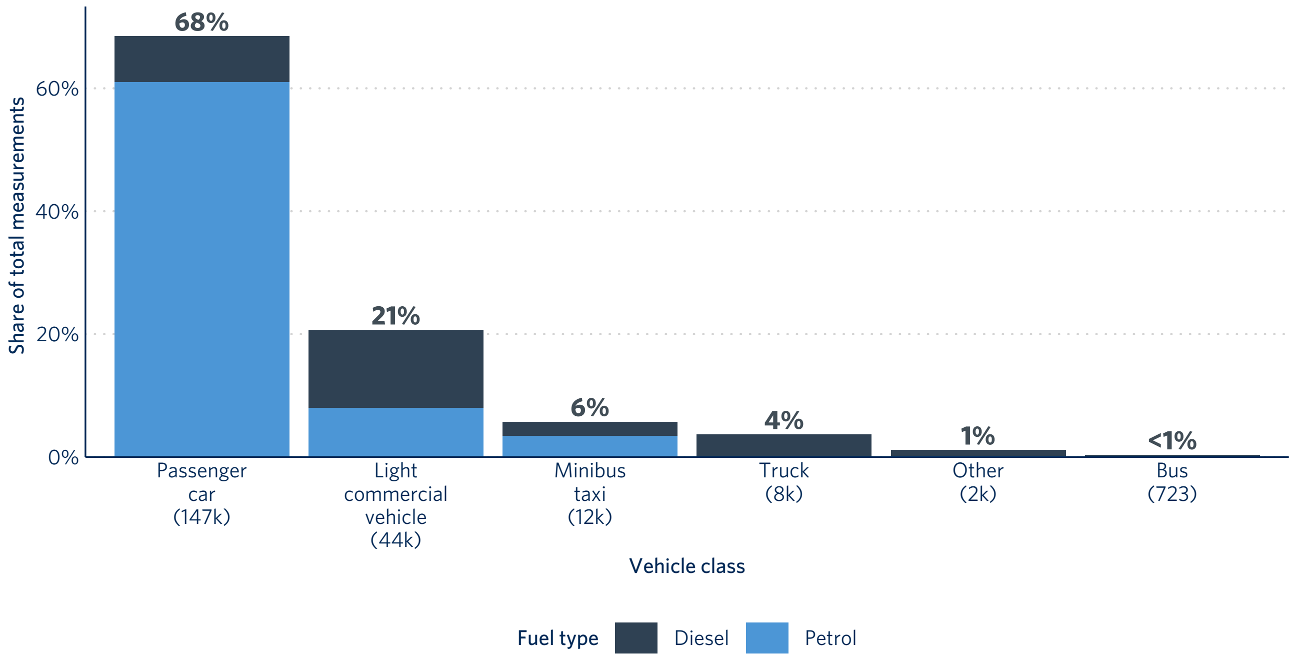


Figure 3. Speed and acceleration by traffic direction



Note: Numbers in parentheses at the bottom of the bars indicate number of measurements.

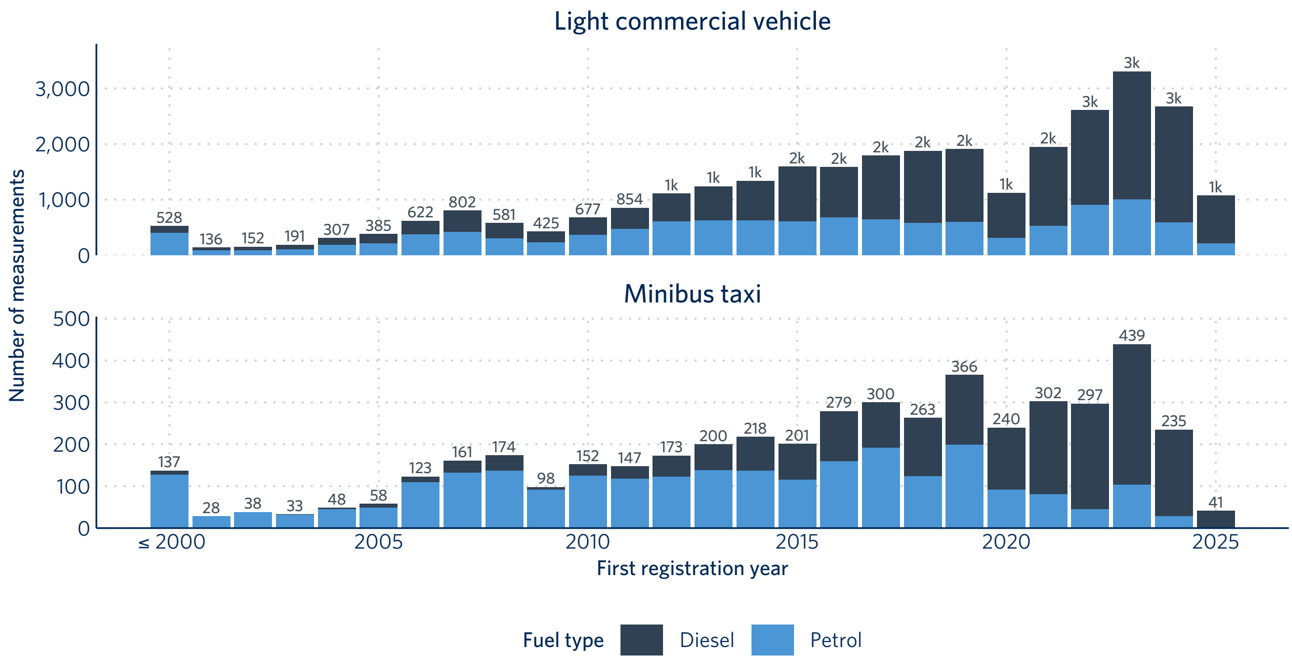
Figure 4. Share of measurements by vehicle and fuel type

vehicle class, with the highest share of resold vehicles among passenger cars (66%) and the lowest share of resold vehicles among trucks (35%; see Figure A2 in Appendix A).

The data showed an increasing share of diesel LCVs and minibus taxis among more recently registered vehicles (Figure 5).[51] The share of diesel LCVs increased from 24% among those registered before 2001 to 81% among those registered in 2025. Similarly, the share of diesel minibus taxis rose from 7% among vehicles registered before 2001 to 98% in 2025. This trend aligns with the International Energy Agency's data showing that the share of petrol light-duty vehicles has declined since 2005 in favor of diesel alternatives.[52] The Automobile Association of South Africa attributes this shift in part to the fuel efficiency of diesel engines.[53]

Vehicle activity, represented by the number of measurements collected, varied across regions of the city. The Center and South-Southwest regions showed a higher share of minibus taxi activity compared with the other regions (Figure 6). This is consistent with evidence that the southern region of Johannesburg is densely populated, housing 50% of the city's population, and communities there have lower rates of private vehicle ownership, relying more heavily on minibus taxis to reach jobs in the center and north of the city.[54] By comparison, the North and Northwest regions of the city showed the highest share of heavy-duty truck activity, consistent with northern Johannesburg being one of the industrial zones of the city.[55] A higher share of diesel passenger cars and LCVs was also observed in the North and Northwest regions of the city, particularly in comparison to the South-Southwest.

Vehicles measured in the South-Southwest were slightly older than those in other regions, with a median age of 8, 1 year older than the city-wide median. Similarly, 7% of vehicles measured in the South-Southwest were aged 20 years and older, 2–3 percentage points higher than vehicles in the northern regions of the city (Figure A3 in Appendix A). The northern regions also showed the highest share of vehicle activity from vehicles aged



Note: Numbers at the top of the bars indicate number of measurements.

Figure 5. Number of minibus taxi and light commercial vehicles by first registration year and fuel type

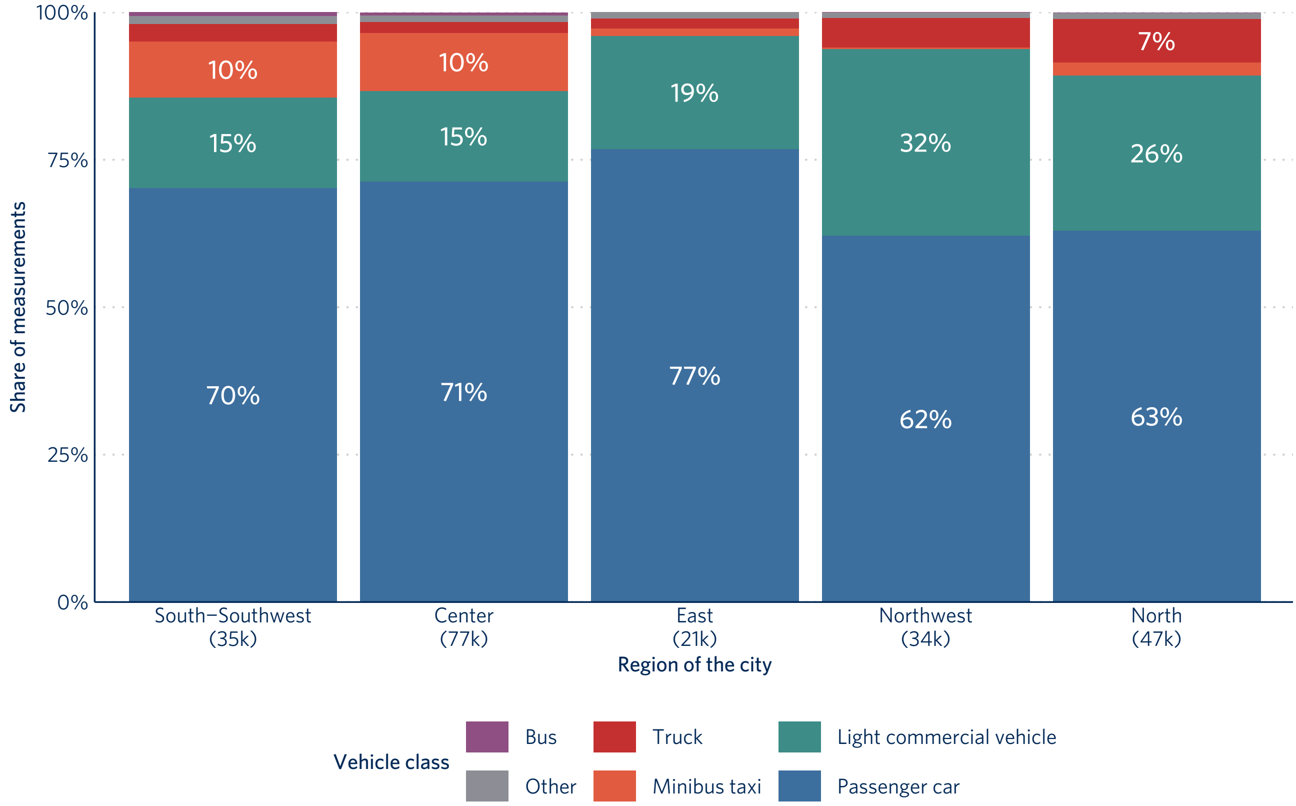
51 This trend was consistent across vehicle measurements, representing vehicle activity and unique vehicles.

52 IEA, *Fuel Economy in South Africa*.

53 "Diesel vs Petrol vs Electric Car Sales in South Africa," *Business Tech*, May 23, 2017, https://businesstech.co.za/news/motoring/176301/diesel-vs-petrol-vs-electric-car-sales-in-south-africa/.

54 City of Johannesburg, *Spatial Development Framework 2040*; City of Johannesburg, *Annual Economic Review*.

55 City of Johannesburg, *Final Integrated Development Plan 2020/21*.



Note: Numbers in parenthesis at the bottom of the bars indicate number of measurements.

Figure 6. Share of measurements by vehicle class across the different regions of Johannesburg

4 years and younger. These patterns are consistent with socioeconomic data showing that the northern regions have a higher share of high-income residents compared with southern regions, likely influencing vehicle affordability and turnover rates.[56]

VEHICLE EMISSIONS ANALYSIS

This section presents our findings on average NO_X, HC, CO, and PM emissions in Johannesburg.[57] First, we provide an overview of the average distance-specific emissions across all key vehicle-fuel groups measured in this study, followed by detailed emission trends for passenger cars, minibus taxis, and trucks by first registration year.[58]

EMISSIONS BY VEHICLE CLASS

As shown in Figure 7, diesel trucks exhibited the highest average NO_X, HC, and PM emissions. Average NO_X, HC, and PM emissions among diesel buses were also among the highest but showed large confidence intervals as there were fewer than 100 valid emission measurements. Petrol minibus taxis recorded the highest average CO emissions, at over 3 times the average from petrol LCVs. NO_X emissions from diesel passenger cars and LCVs were on average 1.5–2.4 times higher than those of their petrol counterparts. However, petrol minibus taxis showed 1.4 times higher average NO_X emissions than their diesel counterparts, likely due

56 City of Johannesburg, *Annual Economic Review*.

57 NH_3 is not currently regulated under European emission standards and therefore we did not include NH_3 results in the body of this report. However, those results are available in Appendix B.

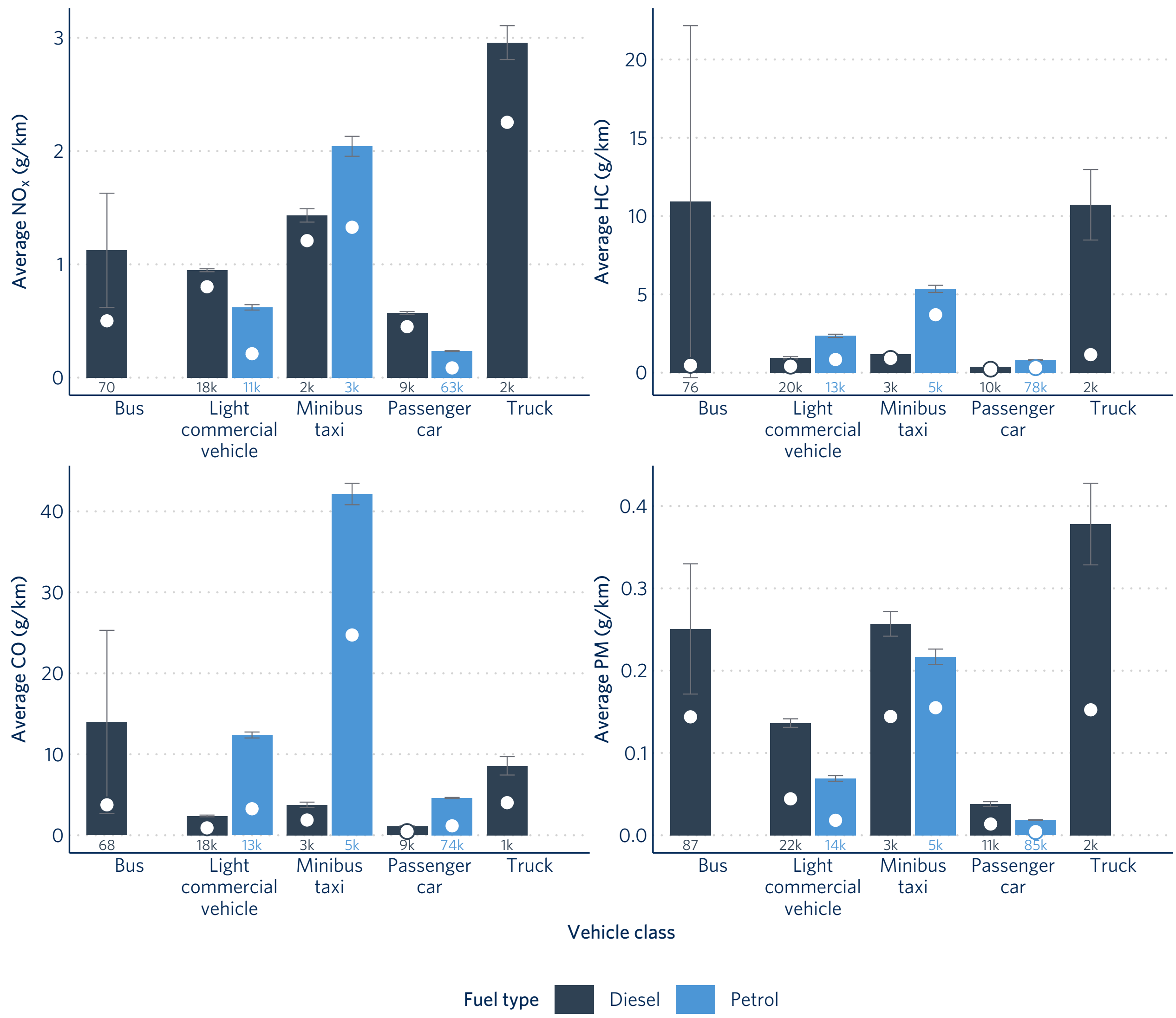
58 The minimum number of measurements considered for sub-group analysis was generally 100; one exception was trends by first registration year, for which the minimum number of measurements was 30. First registration year represents the first year the vehicle was registered in South Africa. First registration precedes the first time the vehicle is licensed in the country, and over 99% of vehicles in this study were licensed within 1 year of first registration.

to the fact that petrol minibus taxis had a higher average age of 12 years compared with 6 years for diesel minibus taxis. The higher NO_X emissions from petrol minibus taxis came primarily from the oldest, highest-emitting subsection of the fleet, which we explore in depth in the following sections.

The gap between the median and average HC, CO, and PM emissions was notable across all vehicle classes, particularly diesel trucks and buses, indicating that a small share of particularly high-emitting vehicles inflated the group average.

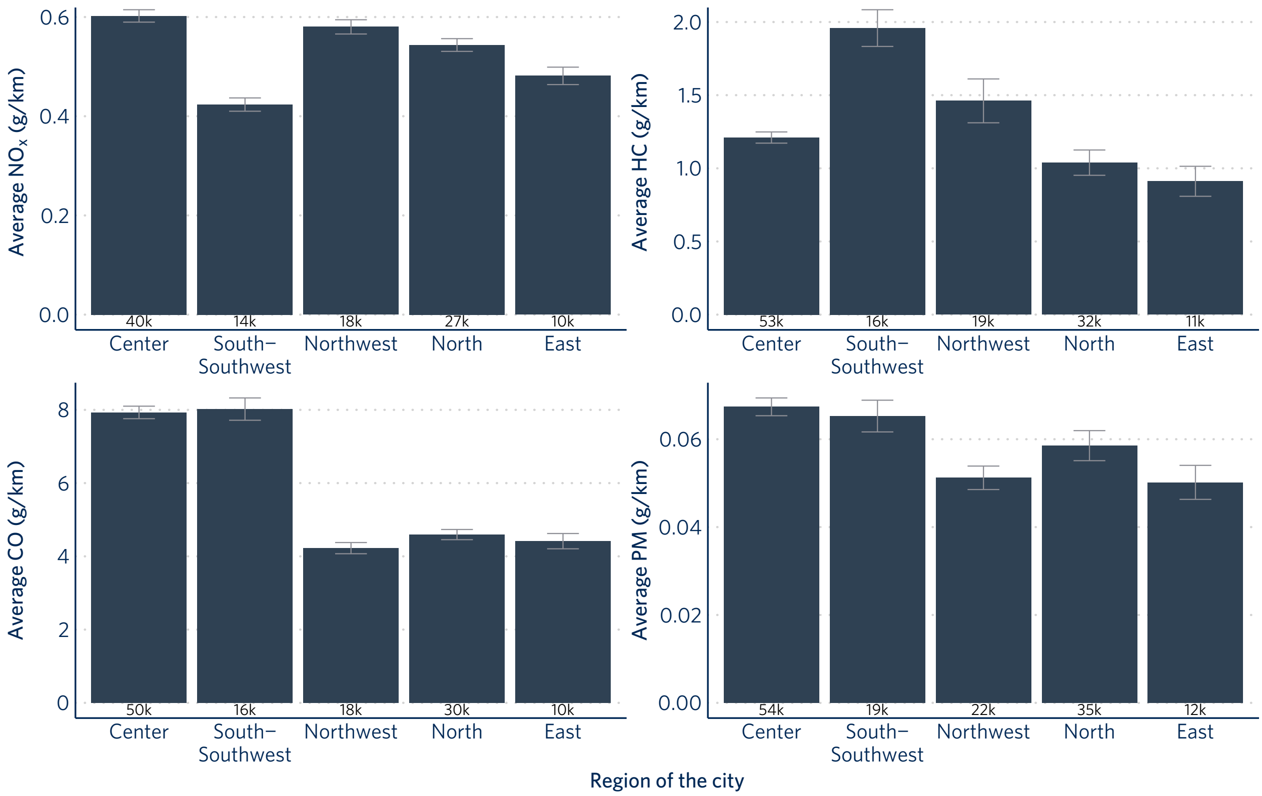
Average emissions of all vehicle classes measured varied across the five key regions of the city (Figure 8). The Center and South-Southwest regions of the city jointly exhibited the highest average CO and PM emissions, likely driven by their higher relative share of minibus taxis and the oldest, highest-emitting vehicles (Figure A3 in Appendix A).

The South-Southwest region also showed the highest total HC emissions, likely because of their higher share of petrol vehicles 20 years and older, which exhibited substantially elevated emissions relative to their younger counterparts. The highest average NO_X emissions were found in the Center, North, and Northwest regions. The



Note: Numbers at the bottom of the bars indicate number of measurements. White dots indicate the median value. Error bars represent 95% confidence interval of the estimate.

Figure 7. Average NO_X, HC, CO, and PM distance-specific emission by vehicle class and fuel type



Note: Numbers at the bottom of the bars indicate number of measurements. Error bars represent 95% confidence interval of the estimate.

Figure 8. Average NO_x, HC, CO, and PM distance-specific emissions by regions of Johannesburg

northern regions had the highest share of LCVs and trucks, both of which disproportionately contributed to average NO_x and PM in these regions. It is also possible that the higher fuel-specific and, by extension, distance-specific emissions in the Center region relative to the other regions may be driven by more stop-and-go driving conditions, as evidenced by the lower average speed and acceleration in this region (see Figure 3).

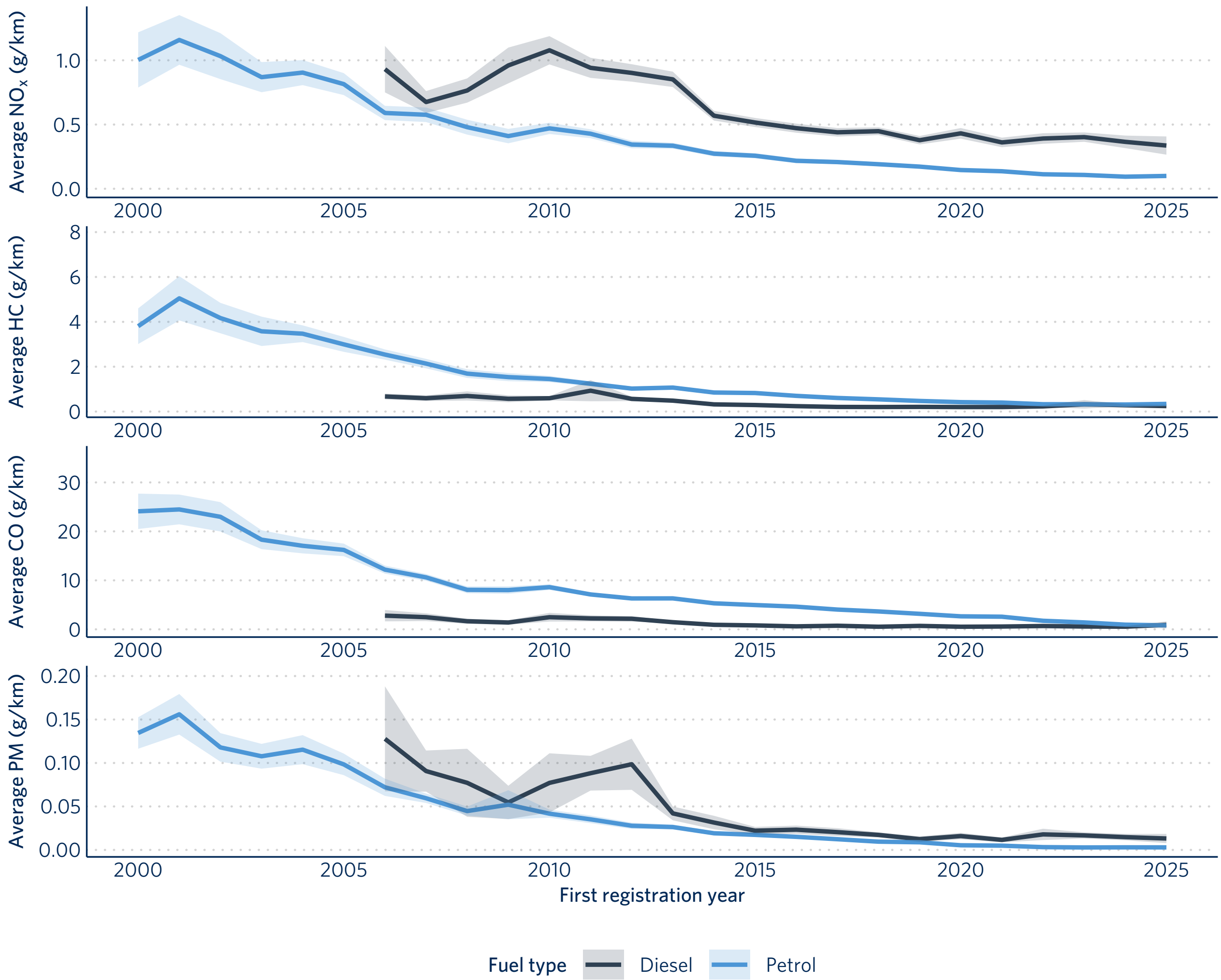
PASSENGER CAR EMISSIONS

Although vehicle emission control policies are largely unchanged since 2006, average emissions from petrol passenger cars measured in Johannesburg showed a downward trend over registration years, particularly for PM (Figure 9). Average NO_x and HC emissions among petrol passenger cars registered in 2025 were 83%–86% lower than those registered in 2006, with average emissions falling below the combined HC and NO_x Euro 2 emission limit of 0.5 g/km by 2020. PM emissions among petrol passenger cars registered in 2025 were 96% lower than those registered in 2006. However, even the newest petrol passenger cars—those first registered between 2020 and 2025—showed average NO_x emissions between 60% and 140% higher than Euro 6 limits. Compared with Europe, their real-world average emission trajectories reflected emissions of passenger cars with over 10 years of in-service deterioration.[59]

As shown in Figure 9, although average NO_x and PM emissions among diesel passenger cars registered in 2025 showed real-world emissions 67%–89% lower than those registered in 2006, they were consistently higher than those from petrol counterparts. The newest diesel passenger cars first registered in 2025, with little emissions deterioration, showed average NO_x and PM emissions between 3 and 4 times Euro 6 limits.

Resold and rebuilt petrol passenger cars showed higher average emissions than first-owner petrol passenger cars (Figure 10). Resold passenger cars registered between 2010 and 2017 showed up to 50% higher

59 International Council on Clean Transportation et al., "Real-World Vehicle Emission Factors for Cities," C40 Cities, December 2025, https://www.c40knowledgehub.org/s/article/Real-world-vehicle-emission-factors-for-cities?language=en_US.



Note: The shaded area of figure indicates the 95% confidence interval of the estimate.

Figure 9. Average distance-specific NO_X, HC, CO, and PM passenger car emissions by fuel type

NO_X, 70% higher HC, 30% higher CO, and double the PM emissions of first-owner cars that have not been resold within South Africa. Rebuilt petrol cars registered between 2010 and 2023 showed 20%–160% higher NO_X, 30%–230% higher HC, 20%–180% higher CO, and 30%–350% higher PM emissions than first-owner cars. Because rebuilt cars made up 2% of the passenger car measurements, the resulting smaller sample size yielded wider 95% confidence intervals compared with the resold and first-owner passenger car sub-groups.

As shown in Figure 11, the oldest and highest-emitting passenger cars in Johannesburg—those first registered before 2006 (i.e., before Euro 2 was introduced in South Africa)—contributed disproportionately to total passenger car emissions. Petrol passenger cars first registered before 2006 made up only 4% of the measured passenger cars but contributed 12%–24% of the fleet's total NO_X, HC, CO, and PM emissions. The oldest and highest-emitting diesel passenger cars, registered before 2015, also had an outsized impact on passenger car emissions, accounting for 13% of NO_X and 15% of PM emissions while making up just 4% of passenger car measurements. These results suggest that targeting a small share of the highest-emitting passenger cars could deliver disproportionate emission reductions in the city.

Note: Error bars represent 95% confidence interval of the estimate.

Figure 10. Petrol passenger car average NO_X, HC, CO, and PM distance-specific emissions by first registration year and vehicle history

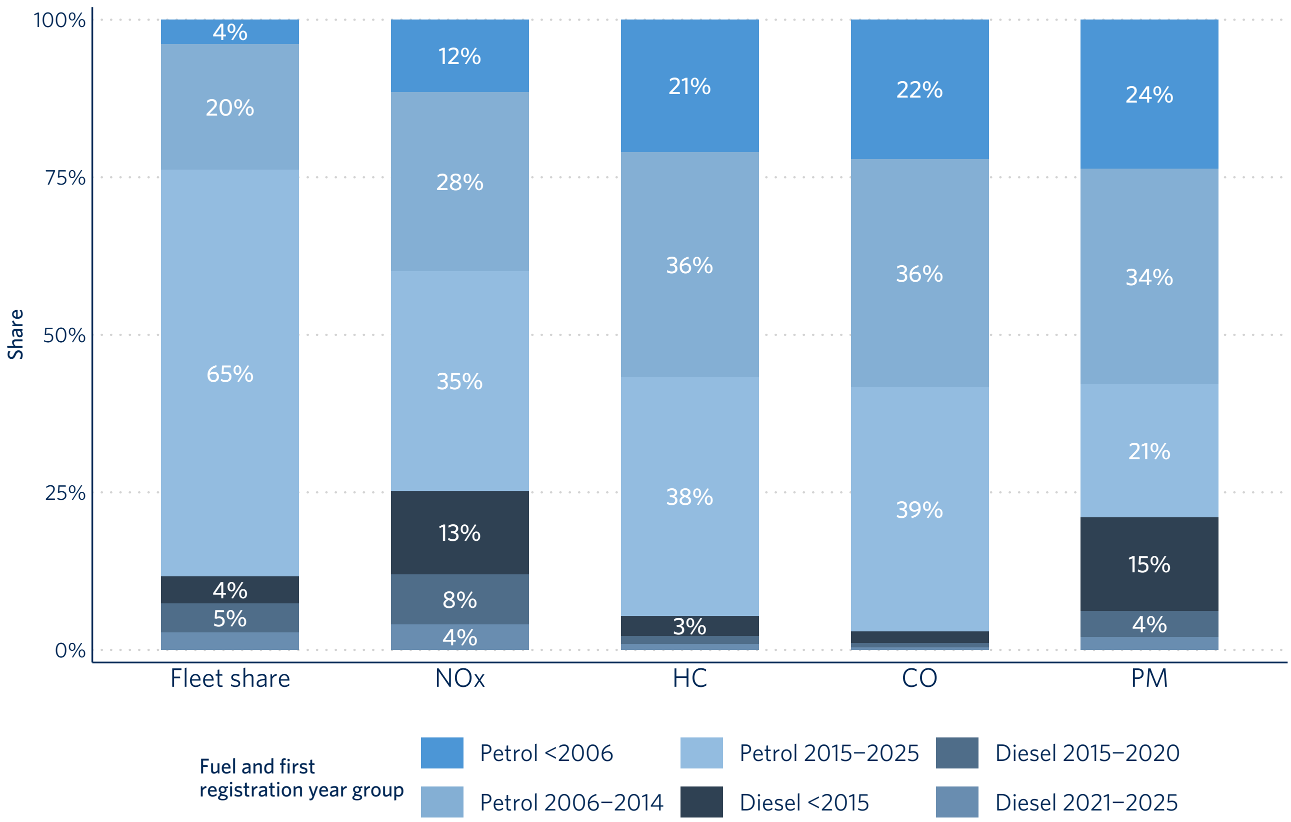


Figure 11. Share of passenger car fleet and total NO_x, HC, CO, and PM distance-specific emissions contribution by fuel and first registration year group

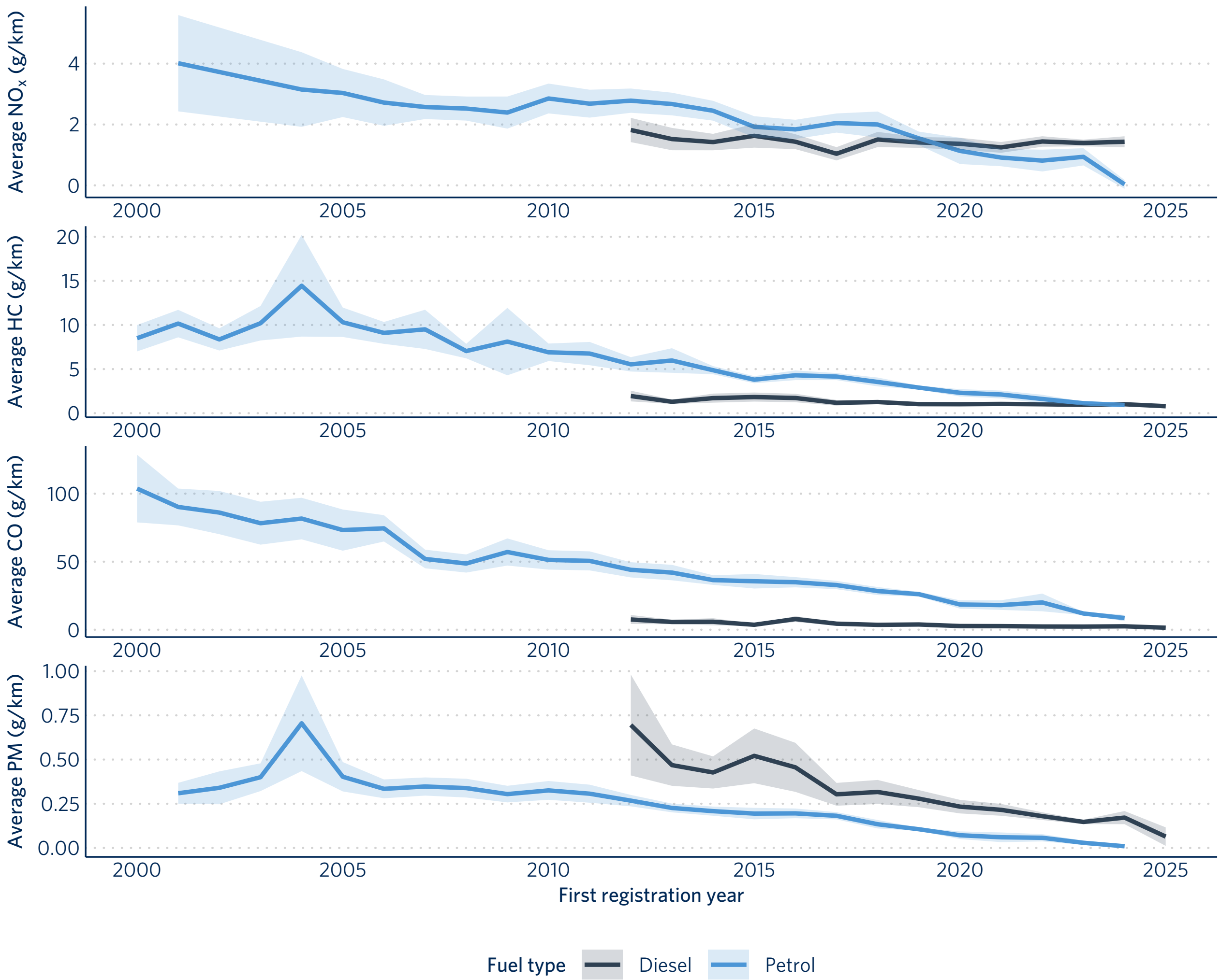
MINIBUS TAXI EMISSIONS

Real-world emissions from petrol minibus taxis decreased over registration years, but average CO emissions from petrol minibus taxis of model years 2006–2024 remained 1.7–15 times higher than the Euro 2 limit of 5 g/km for LCVs over 1,760 kg. As shown in Figure 12, the oldest petrol minibus taxis in the Johannesburg fleet were the highest emitting, with those first registered before 2006 showing over 4 times higher CO emissions on average than those registered in 2006 and after. These elevated CO emissions among the oldest petrol minibus taxis are indicative of incomplete fuel combustion, likely a result of malfunction or deterioration from high mileage with insufficient maintenance. It is also possible that—at over 1,700 meters above sea-level—Johannesburg's high elevation contributes to incomplete fuel combustion.[60] Incomplete fuel combustion leads to higher fuel consumption and operating costs.

Diesel minibus taxis showed average PM emissions up to 18 times higher than their petrol counterparts, levels consistent with the absence of diesel particulate filters, a device that can remove over 90% of PM from diesel exhausts. A similar trend was observed among diesel LCVs, with average PM emissions up to 20 times the average from their petrol counterparts (Figure A5 in Appendix A).

Average real-world NO_x emissions from diesel minibus taxis showed limited improvement over registration years and, for vehicles registered after 2019, exceeded emissions of their petrol counterparts (Figure 12). Diesel minibuses showed up to 44 times higher average NO_x emissions than their petrol counterparts. Even the newest diesel minibus taxis registered in 2024 and 2025, which were expected to have limited emission deterioration, exhibited NO_x and PM emissions between 13 and 34 times the Euro 6 type-approval limits for LCVs over 1,760 kg. Diesel LCVs first registered in 2025 showed average NO_x and PM emissions between 7 and 14 times Euro 6 limits (Figure A5 in Appendix A).

60 Yanxu Ren et al., "Effects of Altitude on Light Gasoline Vehicles: Fuel Consumption and Air Pollution," *Atmospheric Pollution Research* 16, no. 11 (2025): 102652, https://doi.org/10.1016/j.apr.2025.102652.



Note: The shaded area of the figure indicates the 95% confidence interval of the estimate.

Figure 12. Average distance-specific NO_X, HC, CO, and PM minibus taxi emissions by first registration year and fuel type

These findings are consistent with evidence from the broader South African transport sector: from 2000 to 2020, diesel vehicles contributed an increasingly large share of greenhouse gas emissions from road transport relative to petrol.[61] Given that the share of diesel minibus taxis and LCVs in Johannesburg has grown in recent years, these trends are consequential (see Figure 5). The findings demonstrate that diesel minibus taxis and LCVs are important segments to target to address the city's NO_X and PM emissions.

As shown in Figure 13, petrol minibus taxis first registered before 2006 made up only 8% of the measured minibus taxis in Johannesburg but contributed 22%–25% of the fleet's total CO and HC emissions, indicating that prioritizing emission reduction from this group could have outsized benefits.

Results for LCVs in Johannesburg were similar: petrol LCVs registered before 2006 made up approximately 3% of the segment but contributed 13%–20% of HC and CO emissions (Figure A6 in Appendix A). Diesel LCVs registered before 2015 made up 13% of the segment and contributed 30% to total PM emissions (Figure A6 in Appendix A).

Minibus taxis made up 10% of the vehicles measured in the Center and South-Southwest regions of the city but contributed 21%–40% of total vehicle exhaust emissions. Targeting minibus taxis could therefore help reduce emissions in these regions, where emissions are particularly elevated.[62]

61 Luanne Stevens, *South Africa National GHG Inventory 2000–2020 Report* (Department of Forestry, Fisheries and the Environment, 2022), https://unfccc.int/documents/634958.

62 City of Johannesburg, *Spatial Development Framework 2040*.

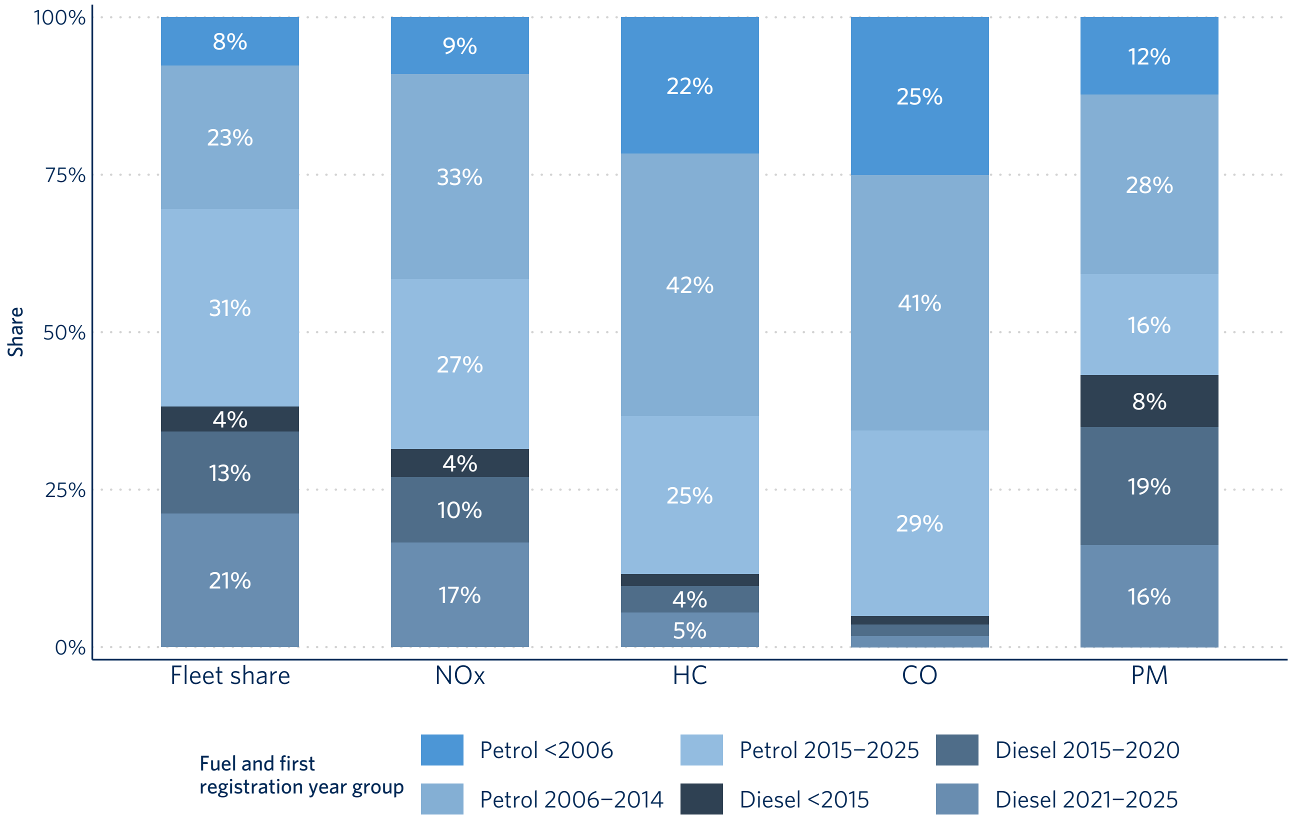


Figure 13. Share of minibus taxi fleet and total distance-specific emissions contribution by fuel and first registration year group

TRUCK EMISSIONS

Average emissions from diesel trucks showed little improvement across registration years and reflected those of European fleets with over a decade of in-service deterioration. To contextualize these emissions, Figure 14 shows the Euro VI emission limits for each pollutant, highlighting the potential emission reductions achievable by adopting Euro VI emission standards once 10 ppm sulfur diesel fuel is delivered in South Africa.[63] As shown in Figure 14, average NO_x and PM emissions of the newest diesel trucks registered in 2024 were between 5 and 11 times Euro VI limits. Other remote sensing studies have shown that the gap between real-world emissions and Euro VI limits narrows substantially among Euro VI-D certified vehicles, due to more robust in-use compliance testing.[64]

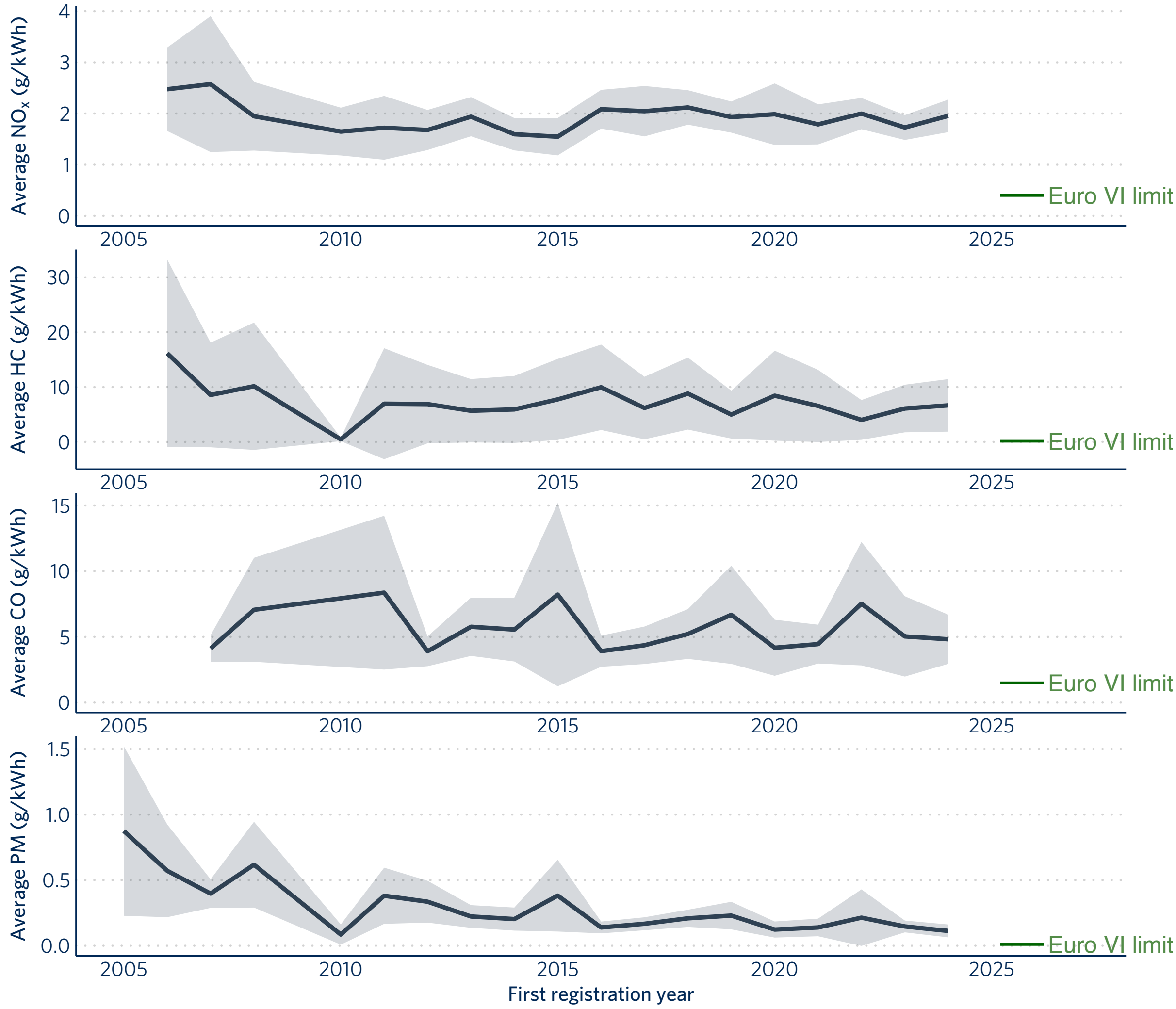
For heavy-duty vehicles belonging to the same first registration-year group, average NO_x emissions diverged substantially by brand (Figure 15), suggesting that manufacturer technology may affect real-world emissions. Among trucks registered since 2020, trucks from Mercedes-Benz, Volvo, and UD Trucks recorded average NO_x emissions 2.5–3.5 times lower than those of Hino trucks.

Average NO_x emissions by registration-year groups also differed across brands. Average NO_x emissions among Hino and Isuzu trucks increased 11%–27% among vehicles registered in 2020 and after compared with those registered between 2010 and 2014. On the other hand, average NO_x emissions among Toyota trucks decreased 50% among vehicles registered between 2015 and 2019 compared with those registered between 2005 and 2009. Although we observed inter-brand variability across all pollutants, it was statistically meaningful at the 95% confidence interval for NO_x.

This substantial inter-brand variability occurred in the absence of increased regulatory stringency since 2006 or any routine emissions inspection and maintenance requirements for heavy-duty vehicles in South Africa.

63 Achieving real-world vehicle emission reductions with Euro VI limits would require robust enforcement of standards and routine vehicle emissions surveillance.

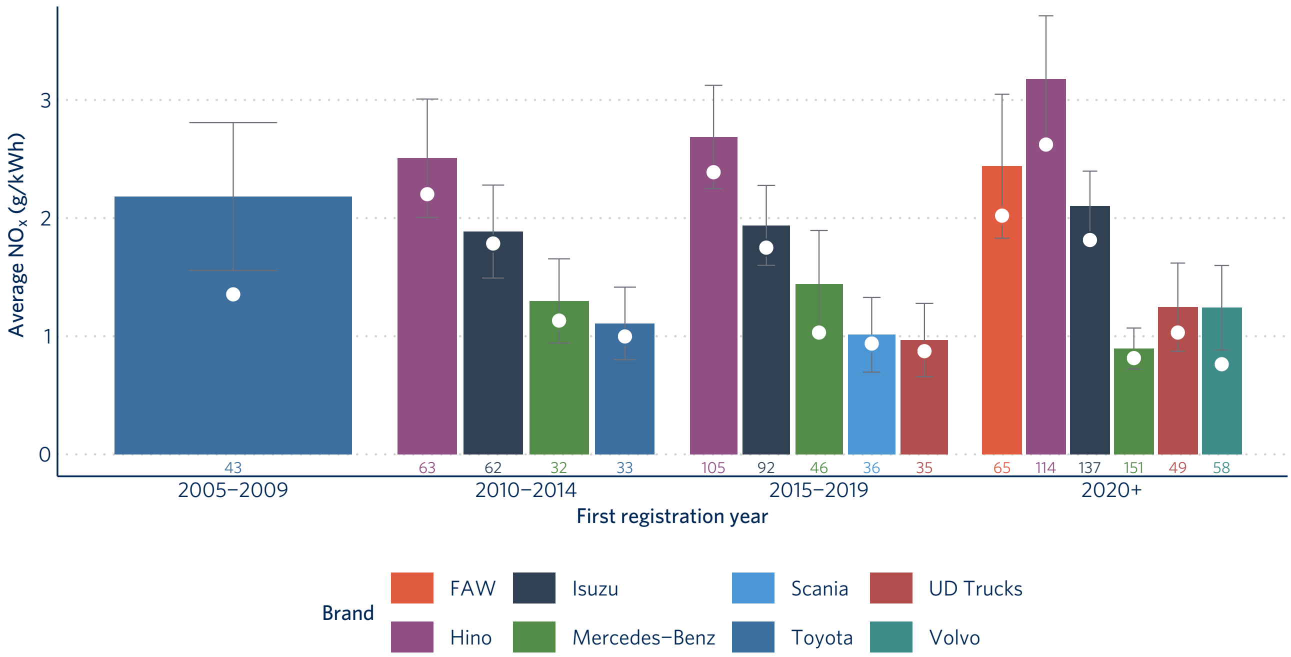
64 Kaylin Lee et al., *Evaluation of Real-World Vehicle Emissions in Warsaw* (TRUE Initiative, 2022), https://theicct.org/publication/true-warsaw-emissions-apr22/.



Note: The shaded area of figure indicates the 95% confidence interval of the estimate. Euro VI limits are shown to contextualize results.

Figure 14. Average energy-specific NO_X, HC, CO, and PM truck emissions by first registration year

This suggests that other factors are driving these differences. The differences in emissions performance may be caused by variations in manufacturer-specific engine configurations, emission control technologies, payload, duty cycle, and route profiles. These results suggest that voluntary vehicle emission standards may produce inconsistent real-world outcomes among manufacturers serving the same market.



Note: Numbers at the bottom of the bars indicate number of measurements. Error bars represent 95% confidence interval of the estimate. White dots represent the sub-group median.

Figure 15. Energy-specific NO_X emissions from diesel trucks by first registration year group and brand

CONCLUSIONS AND POLICY RECOMMENDATIONS

This study presented a detailed assessment of real-world vehicle exhaust emissions in Johannesburg. Using remote sensing technology, the TRUE Initiative collected over 250,000 measurements of tailpipe emissions for NO_X, HC, CO, PM, and NH_3 from passenger cars, LCVs, minibus taxis, trucks, and buses between July and September 2025. As the first roadside remote sensing data collection at scale on the African continent, this study provides unprecedented insight into the city's real-world fleet emissions. It identifies the highest-emitting vehicle sub-groups that are best suited for targeted emission reduction policies to support a gradual and equitable transition to a cleaner transportation sector. This assessment is particularly relevant and timely given Johannesburg's recent commitment to reduce air pollution in the city through the introduction of CAZs.

Our analysis of Johannesburg's real-world fleet emissions shows that the oldest vehicles are generally the highest emitters and contribute disproportionately to total emissions. The analysis further reveals that the southern regions of the city, which have the highest share of low-income residents, have the highest average real-world vehicle emissions. Based on these findings, this study presents the following conclusions and policy recommendations.

1. **Prioritizing vehicle-emission focused CAZs in central and southern Johannesburg, where overall average vehicle emissions were highest, could address unequal vehicle-emission exposure.**

Once the City of Johannesburg releases the CAZ policy framework, transport pollution-focused CAZs could be piloted in the central and southern areas of the city. The southern and central regions of Johannesburg showed the highest overall CO and PM vehicle emissions on average, consistent with evidence that these areas are vehicle-emission hotspots.[65] Minibus taxis were a dominant source of emissions in these areas: minibus taxis represented approximately 10% of measured vehicle activity at the Center and South-Southwest monitoring sites yet contributed between 21% and 40% of exhaust emissions across

65 Mbatha et al., *Design and Development of a Clean Air Zone Policy for the City of Johannesburg.*

all pollutants in these regions. Diesel minibus taxis showed average PM emissions up to 18 times higher and average NO_x emissions up to 44 times higher than their petrol counterparts. The increase in the share of diesel minibus taxis in recent years undermines the lower average NO_x and PM emissions observed in newer petrol minibus taxis.

Shifting to electric powertrains could reverse the increasing PM and NO_x emissions observed among minibuses. Such interventions could yield compounding benefits: reduced emissions, lower operating costs, and improved driver and passenger efficiency. Lifetime operational costs of electric minibus taxis are estimated to be 80% lower than those of their diesel counterparts, offering substantial economic benefits to operators with small profit margins.[66] Evidence shows that electrification is technically viable under current minibus taxi mobility patterns, provided that both depot and home charging are available.[67] The midday lull in minibus taxi operations is well suited for fast charging and falls outside peak power-grid demand periods.[68]

A successful transition to electric minibus taxis would require investment in charging infrastructure in the city and provincial or national financing schemes to address higher upfront costs of electric alternatives. Financing options could include the promotion of drive-to-own schemes whereby loan repayments are made progressively from operating income until the vehicle is owned outright.

The City of Johannesburg could also focus efforts on expanding charging infrastructure and deploying electric buses in the southern and central regions of the city. The City of Johannesburg can draw insights from the City of Cape Town, which plans to pilot 30 locally assembled electric buses this year.[69] The CAZ policy could include a provision for discounted bus tickets for residents within CAZs to encourage public transport use. Electric buses could complement minibus taxis on high-demand corridors to ensure optimal connectivity and efficiency for both passengers and minibus drivers. Evidence has shown improved coordination among minibus taxis can save drivers and passengers time and money.[70] In addition to reducing vehicle emissions, improving public transport connectivity and efficiency would benefit residents in the south of the city, who often face long commute times to reach employment sites in the north.[71] The CAZs could also include measures to improve safe cycling and walking infrastructure to encourage active transport alternatives.

2. **Strengthening and enforcing the inspection and maintenance (I&M) program in Johannesburg could address excess emissions from the oldest and highest-emitting vehicle groups and form the foundation of CAZ entry criteria.**

Johannesburg's Air Pollution Control By-Law 2021 permits the emission inspection of vehicles in the city. The emissions testing outlined in the bylaw applies to diesel vehicles using smoke opacity, but the extent to which this is enforced remains unclear. The existing legal framework presents an opportunity for the city to establish a robust I&M program targeting vehicle sub-groups with the highest emission contributions.

Given the higher share of petrol vehicles in Johannesburg and their disproportionate contributions to CO and HC emissions, expanding the I&M program to include emissions testing requirements for petrol engines could reduce emissions from the oldest, highest-emitting vehicle groups. Exhaust gas analyzers are widely available and suitable for identifying emission performance failures in petrol vehicles.[72] Smoke opacity tests using an opacimeter, which is affordable and simple to operate, can be used to help identify the highest-emitting diesel vehicles for repair.[73] As newer diesel vehicles with diesel particulate filters (equivalent to Euro 5/V standards or above) enter the fleet, emission-testing methods for diesel engines could be updated to be suitable for vehicles complying with higher emission standards.[74]

66 Green Cape, *Enabling the Electrification of the Minibus Taxi Industry in South Africa to Unlock the Potential for Local Manufacturing* (2024), https://greencape.co.za/wp-content/uploads/2025/02/Electrification-of-minibus-taxi-industry-industry-brief.pdf.

67 Green Cape, *Enabling the Electrification of the Minibus Taxi Industry in South Africa.*

68 M. J. Booysen et al., "A Sustainable Transition to Electric Minibus Taxis in Cape Town's Paratransit," *Nature Sustainability* 9 (April 13, 2026): 933–941, https://doi.org/10.1038/s41893-026-01808-9.

69 "City's First Electric Bus to Arrive in August," City of Cape Town, April 15, 2026, https://www.capetown.gov.za/Media-and-news/City's%20first%20electric%20bus%20to%20arrive%20in%20August.

70 Mbonu, "Divided We Ride: The Costs of Segmented Minibus Services in Johannesburg, South Africa."

71 City of Johannesburg, *Annual Economic Review.*

72 "EU: Periodic Technical Inspections (PTI)," DieselNet, accessed May 27, 2026, https://dieselnet.com/standards/eu/pti.php.

73 DieselNet, "EU: Periodic Technical Inspections (PTI)."

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

Inspecting the highest-emitting vehicle sub-groups among large commercial fleets before private vehicles could have an outsized impact on emission reductions and avoid overburdening small business owners and private vehicle owners. Commercial vehicles showed evidence of accelerated vehicle deterioration, likely due to high mileage. Petrol LCVs registered before 2006, when Euro 2 was introduced, made up approximately 3% of the LCV fleet but contributed between 13% and 20% of HC and CO emissions. Similarly, the oldest petrol minibus taxis in Johannesburg showed the highest average CO emissions of all vehicle-fuel groups measured, up to 14 times higher than Euro 2 limits. These emissions are indicative of incomplete fuel combustion and rich-air fuel mixture, likely due to vehicle deterioration associated with high-mileage. Routine vehicle inspection and follow-up maintenance can reduce in-use emissions while also improving fuel efficiency and reducing operating costs for drivers.

A mandatory I&M program could be progressively expanded to privately owned passenger cars and small business owners using an equity-focused pathway. This could entail phasing in requirements by income bracket, providing price discounts to small businesses operating with narrow profit margins and lower-income households, and allowing more time to undertake vehicle inspection. This approach could alleviate burdens on owners of the oldest petrol passenger cars—those aged over 20 years—which were more common in the southern regions of the city. More robust inspection could be mandated for resold and rebuilt petrol cars, which showed up to 180% higher CO and 230% higher HC emissions than first owner-vehicles of the same registration year.

In parallel, campaigns to increase public awareness of the benefits and incentives for voluntary inspection for small business and private vehicles could increase public acceptance of an eventual mandatory periodic I&M program in Johannesburg. The consumer advantages of inspection include improved fuel efficiency and, by extension, fuel savings, improved vehicle safety, and public health benefits from lower exhaust pollution. City-level incentives could include reduced parking fees for vehicles that pass inspection.

A robust I&M program, combined with an emissions labeling system, could eventually be leveraged to operationalize CAZ vehicle entry criteria, permitting only vehicles that pass emission inspection to enter the CAZ. Under such a system, vehicles that have undergone inspection could receive categorized emission labels, which could be used to determine CAZ access eligibility. Labels can be further used to provide additional benefits, such as free parking, and to track emission performance. In time, the highest-emitting vehicles could be restricted from entering the CAZs. Similar programs are already implemented around the world.[75] Supplementary measures to ensure equity in the CAZs, such as reduced or free vehicle inspection provided to CAZ residents and small businesses, could reduce burdens on these groups residing in the CAZs.

3. **Establishing a minimum national standard of Euro 6d/VI-D or higher for new vehicles could reduce fleet-wide NO_x and PM emissions.**

Since the adoption of Euro 2/II emission standards in 2006, South Africa has not adopted more stringent vehicle emission standards, lagging comparable economies, such as Colombia, Thailand, and Morocco, which have moved to Euro 4/IV equivalent standards or higher. South Africa is expected to adopt Clean Fuels II in 2027, which mandates 10 ppm sulfur content in petrol and diesel fuel, fulfilling the technical conditions necessary for South Africa to adopt Euro 6/VI vehicle emission standards.

Despite some reductions in average NO_x and PM emissions among more recently registered petrol passenger cars, these vehicles reflected real-world emissions comparable to European vehicles with over 10 years of in-use deterioration, and there was little change in NO_x emissions among diesel vehicles across all registration years. Even the newest diesel passenger cars, LCVs, and trucks registered in 2024 and 2025 showed average NO_x and PM emissions 3–14 times Euro 6/VI limits.

The potential NO_x and PM emission reductions resulting from mandating Euro 6d/VI-D are substantial: real-world vehicle emission studies have shown that the gap between real-world emissions and Euro 6/VI limits narrows substantially among Euro 6d/VI-D-certified vehicles, due to more robust in-use compliance

75 Explore France, "The Crit'Air Anti-Pollution Vehicle Sticker," Official Tourism Board France, updated June 11, 2026, https://www.france.fr/en/article/crit-air-anti-pollution-vehicle-sticker/; Seoul Metropolitan Government, "Outdated Vehicles Without Emission Reduction Filters to Be Prohibited in Seoul," press release, December 2, 2020, https://english.seoul.go.kr/outdated-vehicles-without-emission-reduction-filters-to-be-prohibited-in-seoul/; Meyer et al., *Assessment of Real-World Passenger Vehicle and Taxi Emissions in Mexico City* (TRUE Initiative, 2024), https://trueinitiative.org/research/assessment-of-real-world-passenger-vehicle-and-taxi-emissions-in-mexico-city/.

testing.[76] Similarly, transitioning to Euro 6d/VI-D standards could also help prevent the accelerated deterioration of emission control systems observed among high-usage vehicles, as Euro 6d/VI-D standards mandate in-service conformity testing under real-world driving conditions, a requirement absent under Euro 5/V standards.

Cost-benefit analysis shows that the health benefits of adopting Euro 6/VI standards in South Africa outweigh the costs of implementation (e.g., advanced emission-control technology).[77] Previous research has also found that pairing timely adoption of Euro 6/VI standards with accelerated electrification could triple the health benefits of vehicle electrification in Johannesburg between 2024 and 2040.[78]

Given the high share of diesel vehicles in South Africa, particularly in the heavy-duty segment, and evidence from other regions of substantially lower real-world emissions under Euro 6d/VI-D standards over Euro 5/V standards, transitioning to Euro 6d/VI-D would be critical for South Africa to achieve a meaningful reduction in vehicle emissions. There is evidence that manufacturers are already providing Euro VI trucks to the South African market.[79] Moreover, Euro VI standards introduced emission testing at altitudes of up to 1,300 m, a requirement absent under Euro V standards, which partially addresses the elevated emissions risk associated with Johannesburg's altitude of 1,700 m above sea level. Regulatory development of Euro 6d/VI-D standards could begin immediately, with adoption as soon as practicable following the 2027 fuel-quality transition. Adopting Euro 6d/VI-D standards would help protect the long-term export competitiveness of locally manufactured vehicles by aligning South Africa's vehicle-emission requirements with those of the European Union and the United Kingdom, which together account for roughly half of South Africa's automotive exports.[80]

Requiring minimum emission certification, combined with a maximum age limit for used vehicles sold within the country, could further address excess emissions from resold vehicles. The current roadworthiness certification—with limited assessment of emissions required for vehicle reselling or transfer—has shown limited impact on emissions control of resold vehicles in the real world. Policy options such as limiting the sales of used vehicles registered before 2006 (i.e., when Euro 2/II standards were mandated) or requiring additional emissions testing from dealerships could ensure that used vehicles continue to serve as a cost-effective option for lower-income households.

These policy recommendations have the potential to reduce transport-related pollution in Johannesburg through near-term and long-term interventions at the city and national levels. At the city level, key policy options include strengthening and leveraging the existing I&M framework for targeted CAZ enforcement and transitioning to electric buses. At the national level, mandating Euro 6d/VI-D emission standards after the Clean Fuels II fuel quality transition in 2027 would deliver substantial fleet-wide emission reductions. Addressing the disproportionate burden of vehicle emissions in the south of Johannesburg requires tackling minibus taxi emissions, including promoting routine emission inspection and maintenance, investing in EV charging infrastructure, and developing financing mechanisms that make electric alternatives affordable for operators.

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

77 Xie et al., *Soot-Free Road Transport in South Africa.*

78 Lingzhi Jin et al., *Health Benefits of Zero-Emission Transport through 2050* (International Council on Clean Transportation, 2026), https://theicct.org/publication/health-benefits-of-zero-emission-transport-through-2050/.

79 DSV, "Decarbonising Supply Chains"; Isuzu, "Isuzu Motors South Africa's Trucks Match Environmental Demands"; Volvo Trucks, "Volvo Trucks South Africa Introduces EURO 6 Technology."

80 Observatory of Economic Complexity, *Cars in South Africa*, dataset, March 2026, https://oec.world/en/profile/bilateral-product/cars/reporter/zaf.

APPENDIX A: SUPPLEMENTAL FIGURES

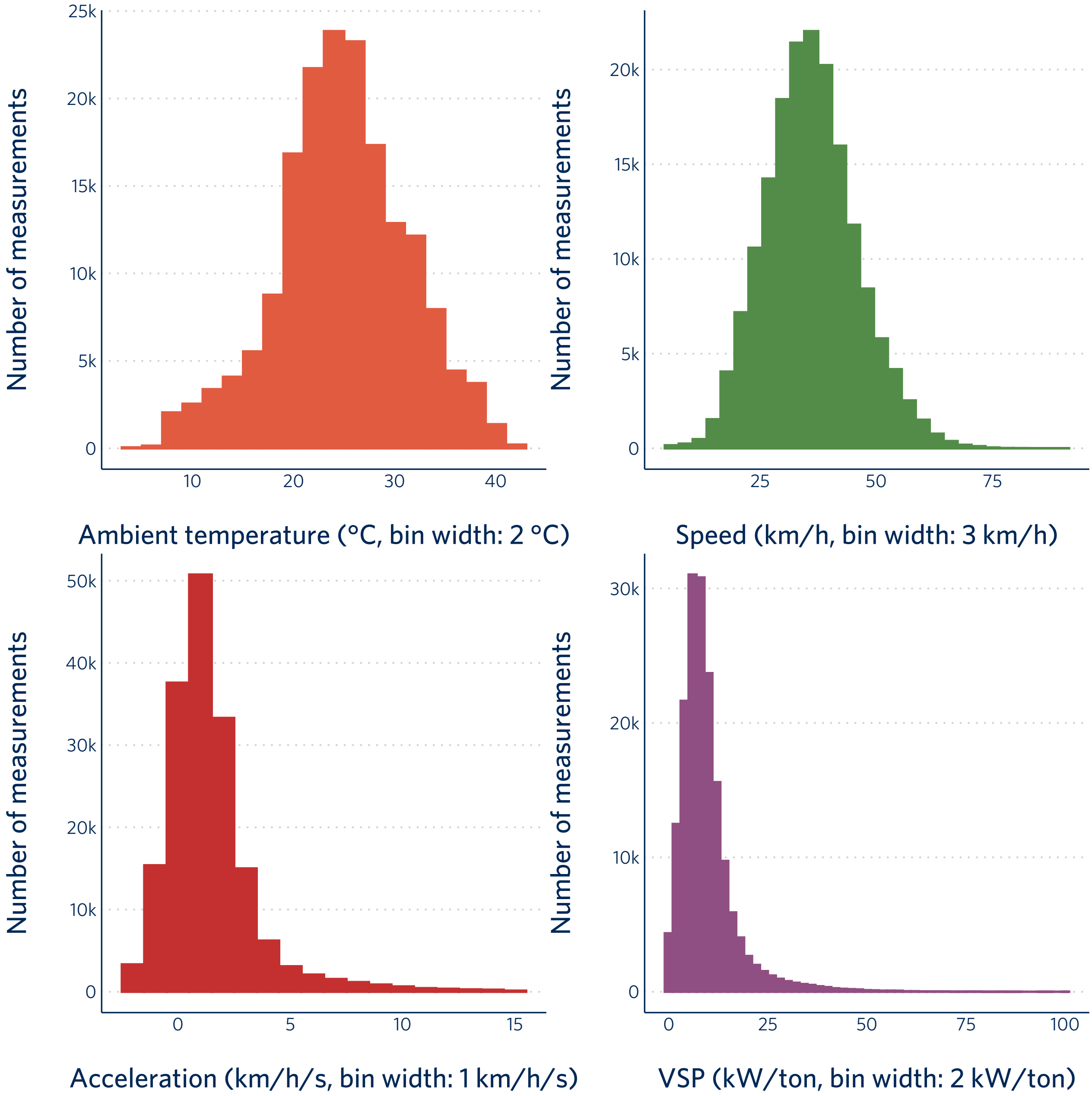


Figure A1. Summary of testing conditions

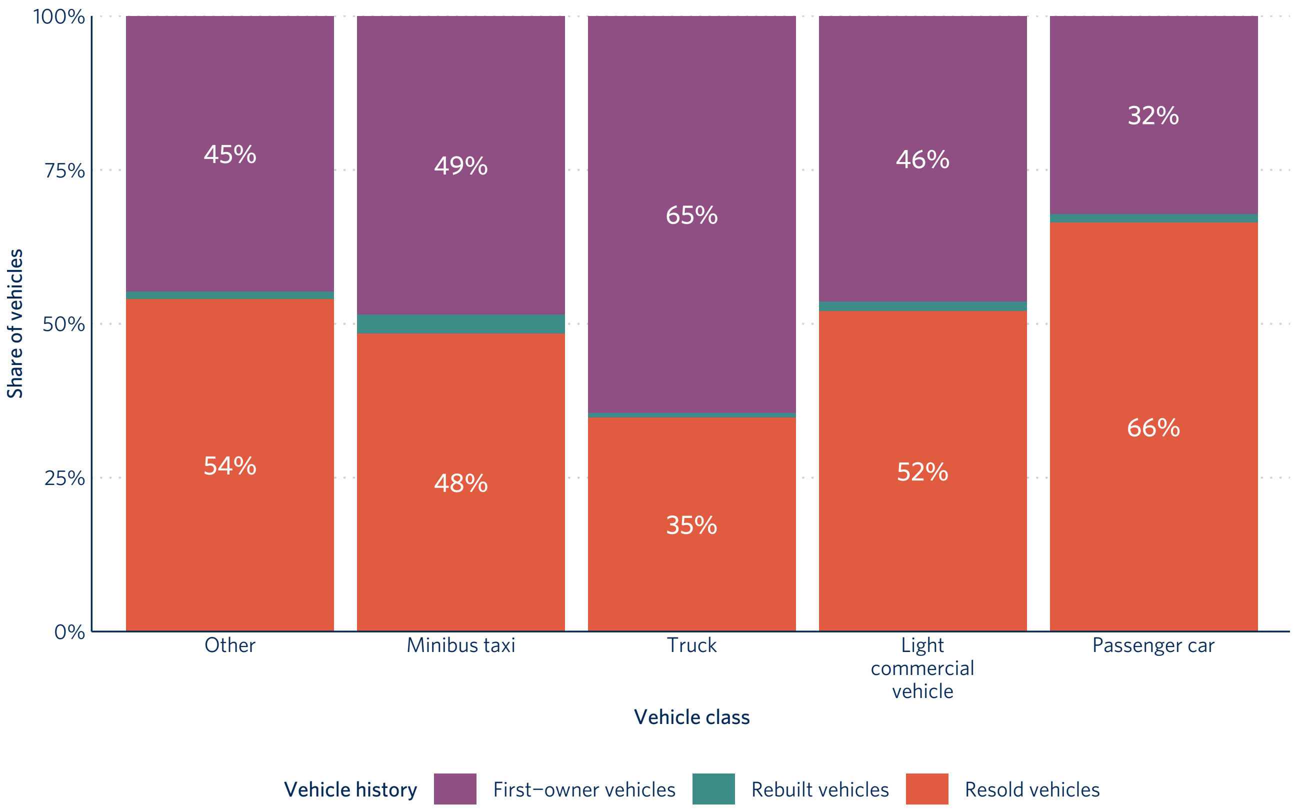


Figure A2. Share of vehicles by vehicle class and life-cycle stage

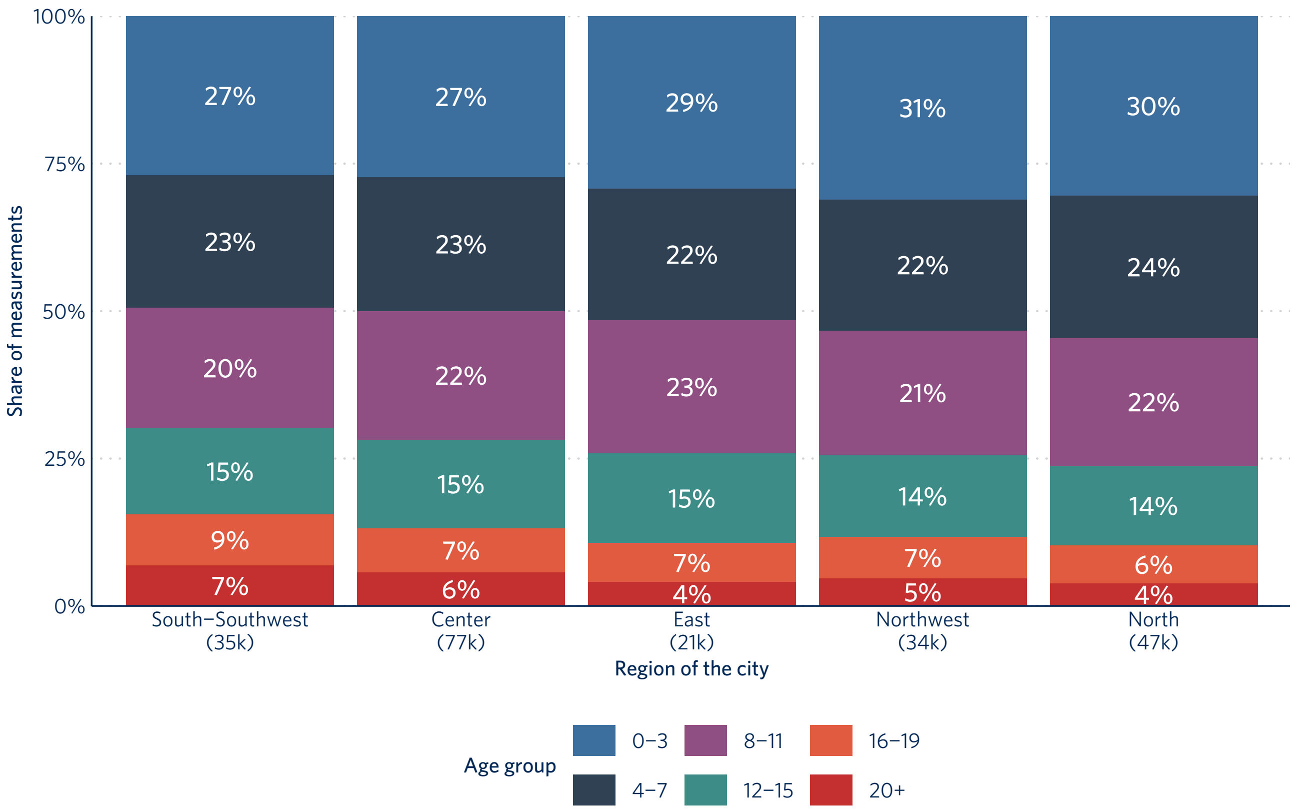
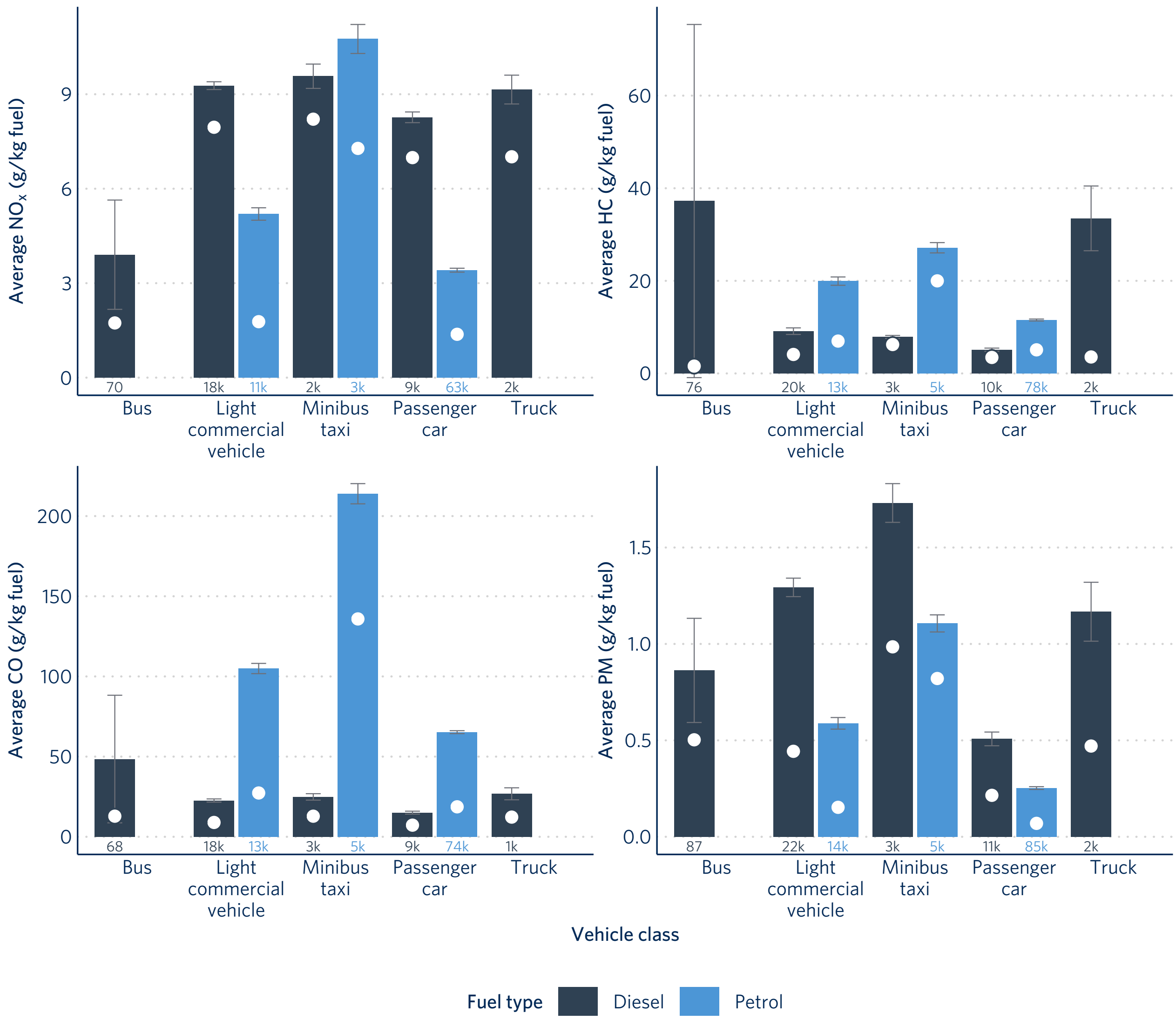
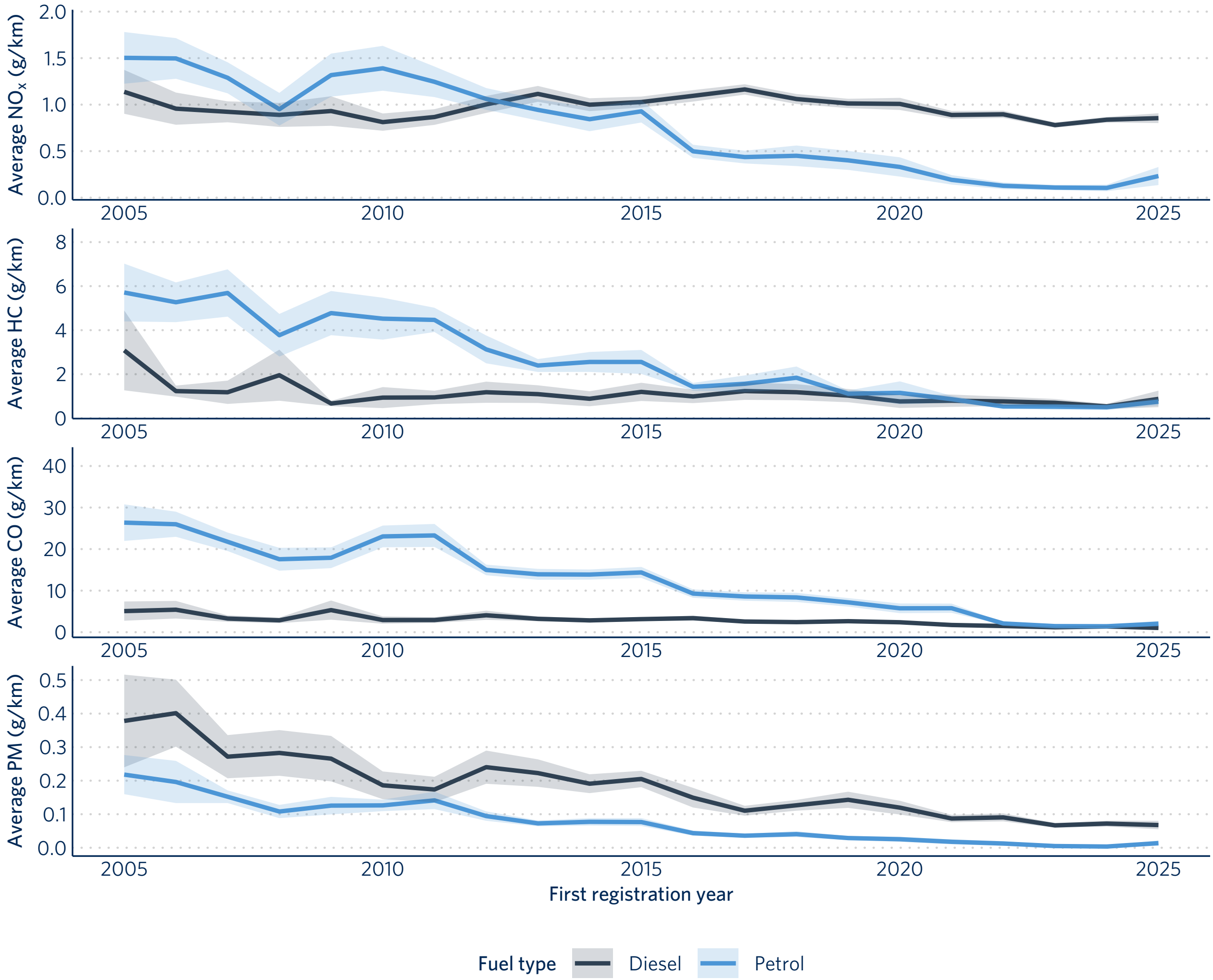


Figure A3. Share of measurements by region of the city and vehicle age group



Note: Numbers at the bottom of the bars indicate number of measurements. White dots indicate the median value. Error bars represent 95% confidence interval of the estimate.

Figure A4. Average NO_x, HC, CO, and PM fuel-specific emission by vehicle class and fuel type



Note: The shaded area of the figure indicates the 95% confidence interval of the estimate.

Figure A5. Distance-specific NO_x, HC, CO, and PM light commercial vehicle emissions by first registration year and fuel type

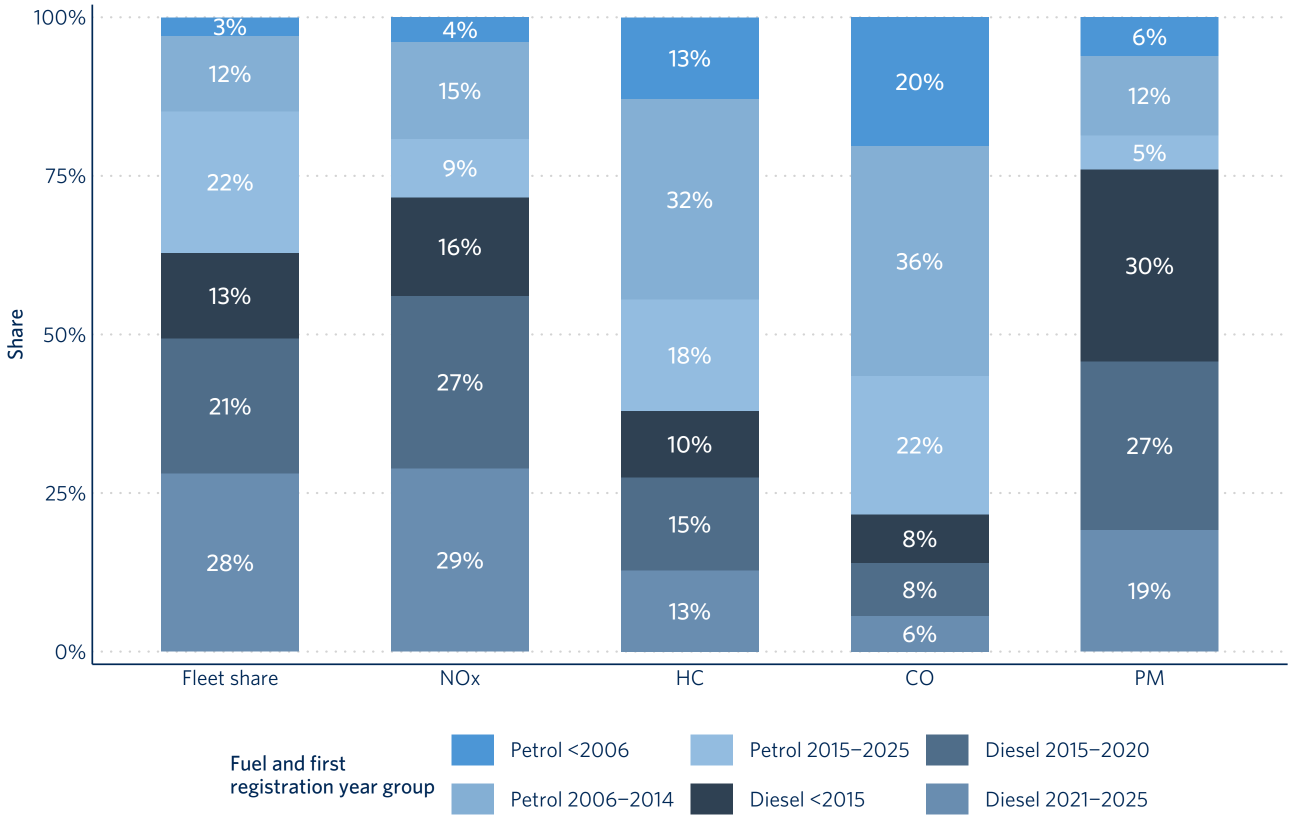
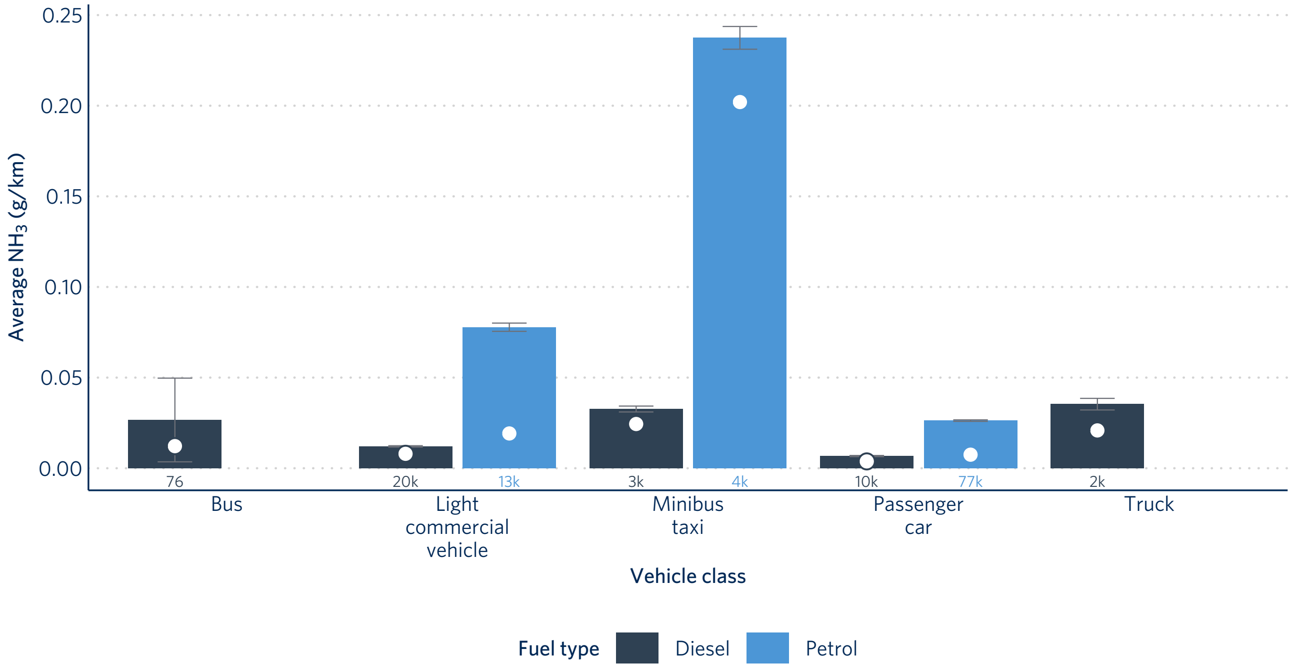


Figure A6. Share of light commercial vehicle and total distance-specific emissions contribution based on fuel and first-registration year group

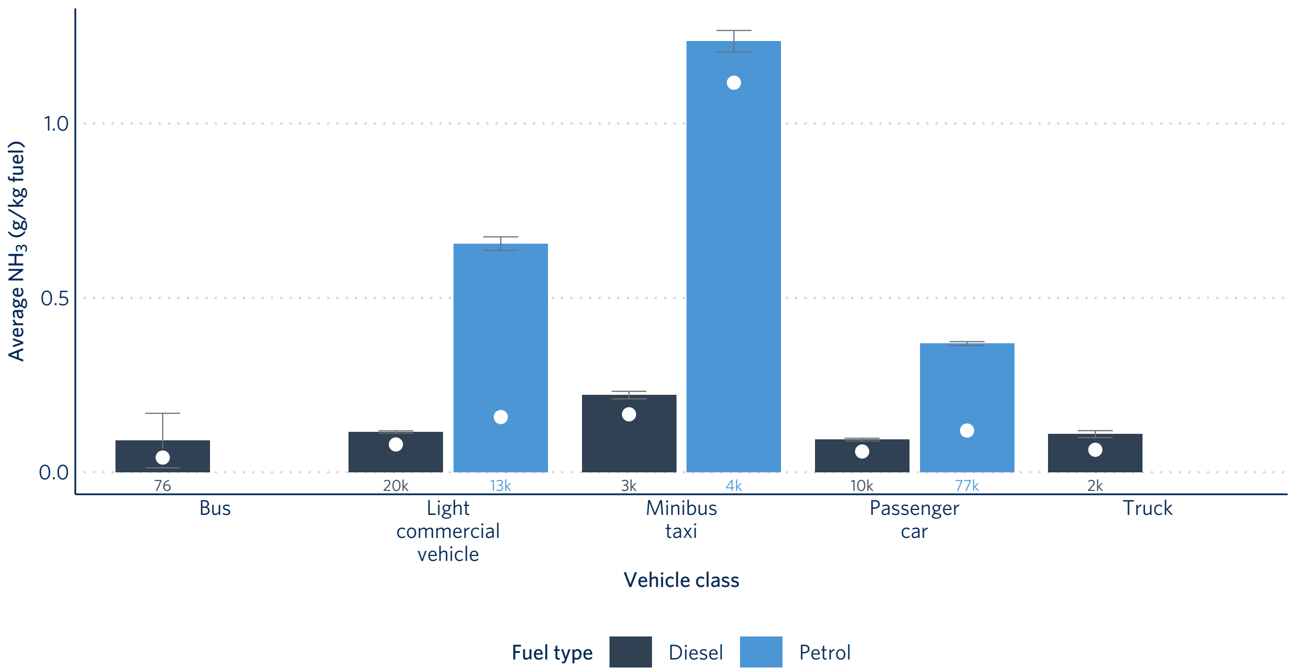
APPENDIX B: NH_3 FIGURES

NH_3 is not currently regulated under European emission standards and therefore NH_3 trends were not included in the body of this report, but figures illustrating our findings are provided below.



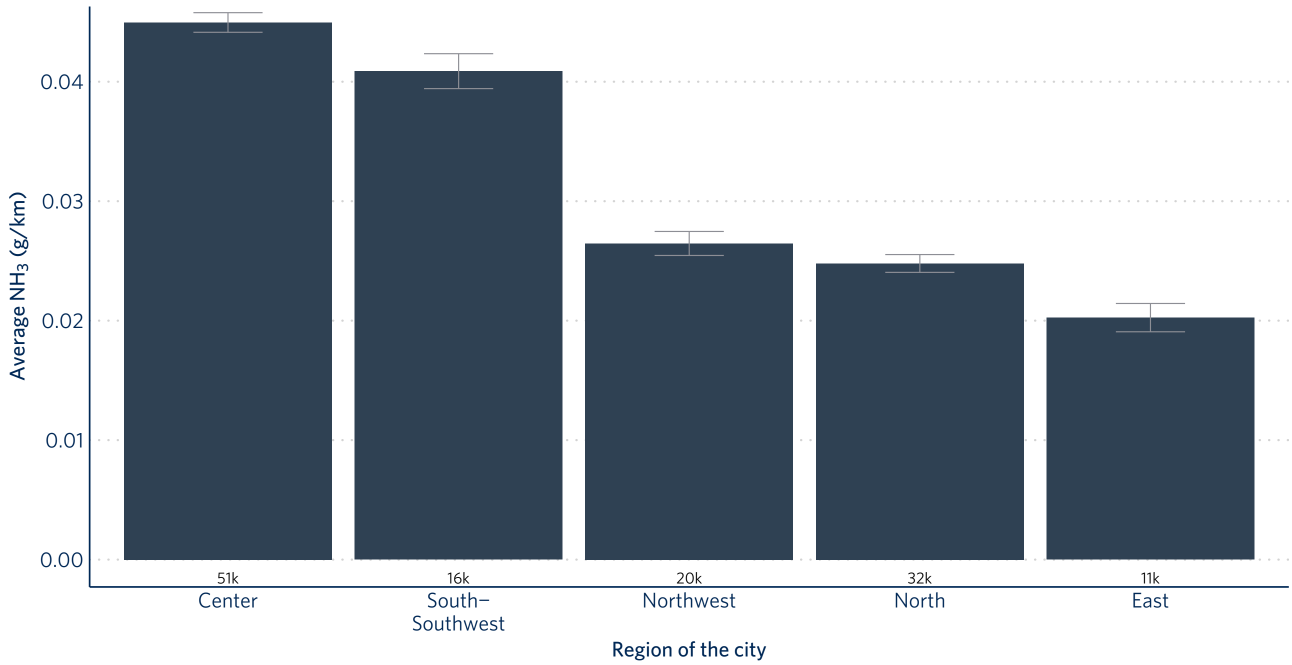
Note: Numbers at the bottom of the bars indicate number of measurements. White dots indicate the median value. Error bars represent 95% confidence interval of the estimate.

Figure B1. Average NH_3 distance-specific emission by vehicle class and fuel type



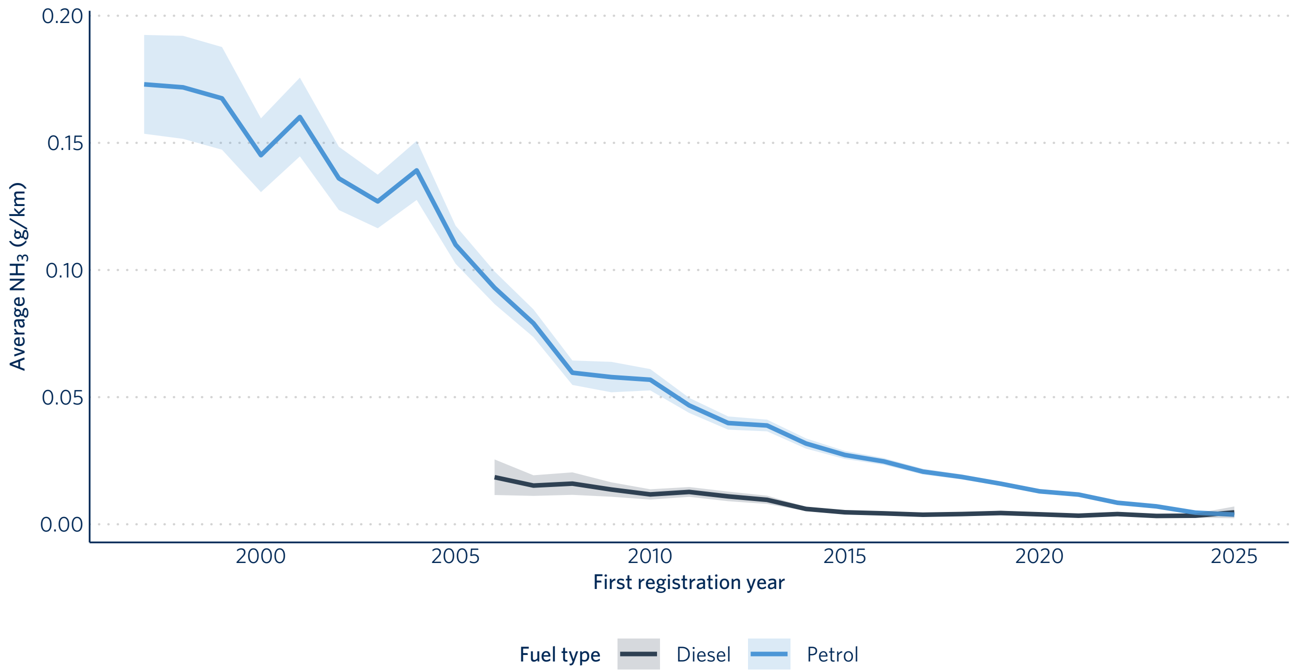
Note: Numbers at the bottom of the bars indicate number of measurements. White dots indicate the median value. Error bars represent 95% confidence interval of the estimate.

Figure B2. Average NH_3 fuel-specific emission by vehicle class and fuel type



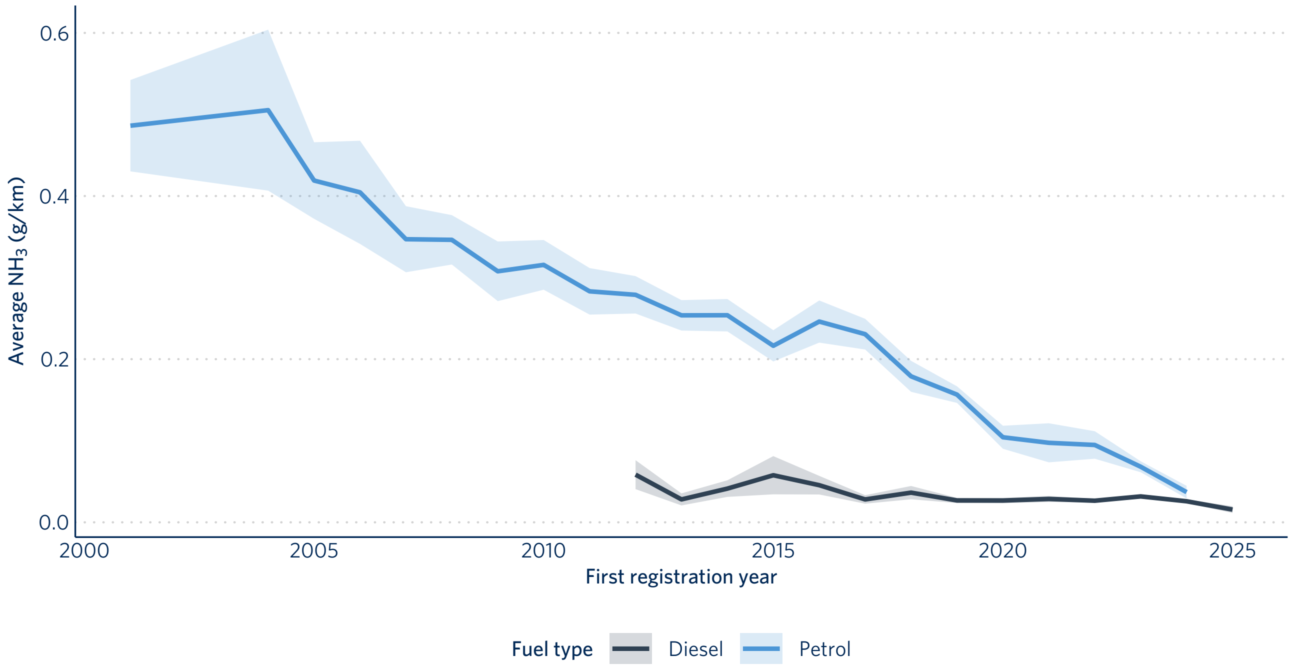
Note: Numbers at the bottom of the bars indicate number of measurements. Error bars represent 95% confidence interval of the estimate.

Figure B3. Average NH_3 distance-specific emissions by regions of Johannesburg



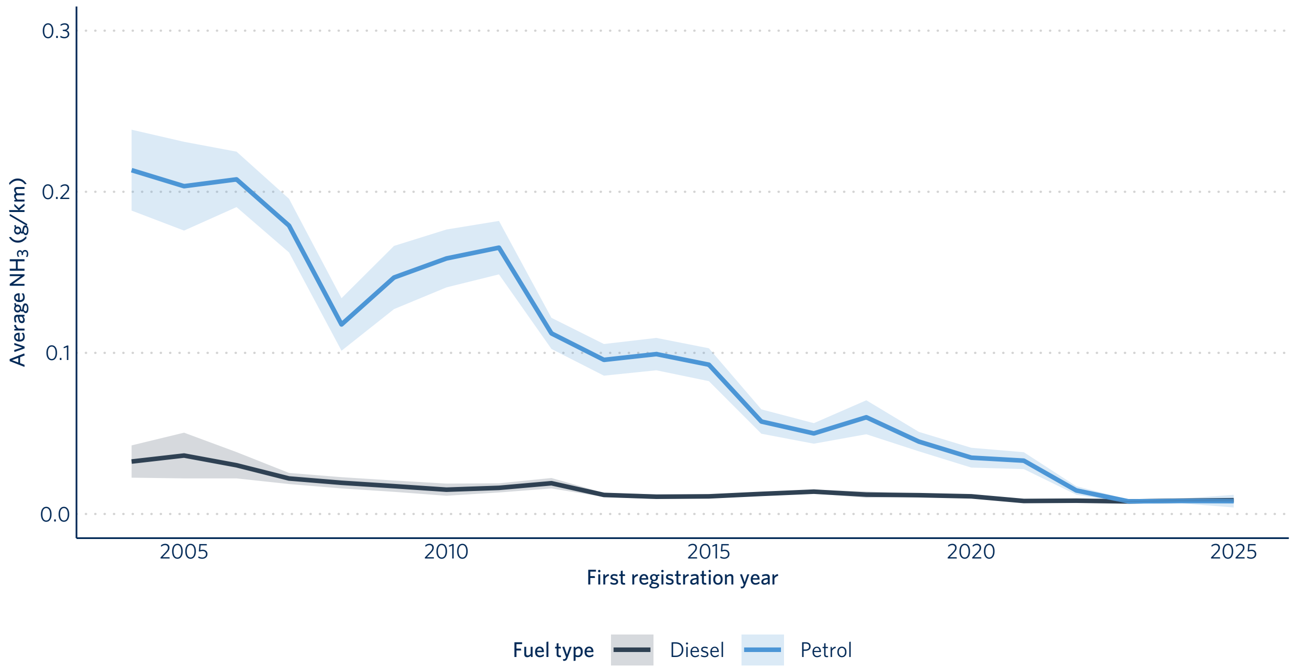
Note: The shaded area of the figure indicates the 95% confidence interval of the estimate.

Figure B4. Average NH_3 distance-specific passenger car emissions by fuel type



Note: The shaded area of the figure indicates the 95% confidence interval of the estimate.

Figure B5. Average NH_3 distance-specific minibus taxi emissions by fuel type



Note: The shaded area of the figure indicates the 95% confidence interval of the estimate.

Figure B6. Average NH_3 distance-specific light commercial vehicle emissions by fuel type

Note: The shaded area of the figure indicates the 95% confidence interval of the estimate.

Figure B7. Average NH_3 distance-specific diesel truck emissions

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