TECHNICAL NOTE
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Pollutant emissions from light-duty vehicles across North America: A comparative analysis

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A recent report on real-world vehicle emissions in Mexico City marked a significant milestone for The Real Urban Emissions Initiative (TRUE), and it was a result of TRUE's first-ever remote sensing campaign in Latin America.[1] With the Mexico City campaign, TRUE now possesses real-world emissions data from three of the largest and most populous countries in North America. The previously compiled U.S. database includes more than 70 million measurements from vehicles in Colorado and Virginia.[2] TRUE also taps remote sensing data provided by the Clean Air Strategic Alliance (CASA) from its recent ROVER III campaign in Alberta, Canada.[3] These complementary datasets—encompassing hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxide (NO) emissions—pave the way for a comparative analysis of real-world light-duty vehicle (LDV) emissions across the continent.

The datasets capture a wide range of driving conditions representative of vehicles in real-world operation. Figure 1 provides an overview of each dataset.[4] The remote sensing equipment observed a limited number of diesel LDVs; measurements from these vehicles were less than 1% of the total in the majority of locations. As a result, our focus for this analysis is on gasoline LDVs, which consist of light-duty trucks (LDTs), passenger cars (PCs), and taxis. While the observed driving conditions were relatively comparable across locations, Mexico City had more measurements showing higher ambient temperatures, lower vehicle speeds, and lower vehicle accelerations than the other three datasets. Additionally, the Mexico City and Colorado measurement sites are at higher elevations on average than the other sites, and thus measurements for atmospheric pressure were lower in those two locations.

1 Michelle Meyer, Leticia Pineda, Carlos Jimenez, and Tim Dallmann, "Assessment of Real-World Passenger Vehicle and Taxi Emissions in Mexico City" (TRUE Initiative, 2024), https://theicct.org/publication/true-assessment-of-rw-pv-and-taxi-emissions-in-mexico-june24.

2 Michelle Meyer, Tanzila Khan, Tim Dallmann, and Zifei Yang, "Particulate Matter Emissions from U.S. Gasoline Light-Duty Vehicles and Trucks" (TRUE Initiative, 2023), https://www.trueinitiative.org/publications/reports/particulate-matter-emissions-from-us-gasoline-light-duty-vehicles-and-trucks.

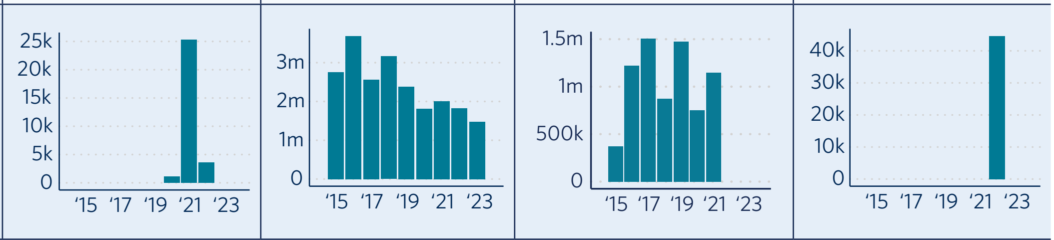
3 Rob Klausmeier and Niranjan Vescio, "Roadside Optical Vehicle Emissions Reporter III: A Survey of On-Road Light and Heavy-Duty Vehicle Emissions" (Clean Air Strategic Alliance, 2023), https://www.casahome.org/uploads/source/ROVER_III_Opus_Report-Final_Nov_2023_(amended)_v.2.pdf.

4 For this analysis, we consider only measurements using Opus model RSD5000 and newer instrumentation. This excludes Colorado measurements from 2010 to 2014 that were captured using a previous model instrument.

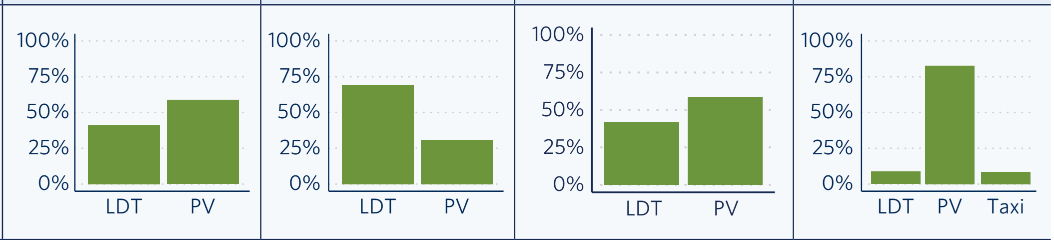
Figure 1. Summary of measurements, ambient conditions, and driving conditions by location

Metric	Alberta, Canada	Colorado, United States	Virginia, United States	Mexico City, Mexico
Number of measurements	30,012	21,679,943	7,352,329	44,655
Number of sites	15	186	200	21

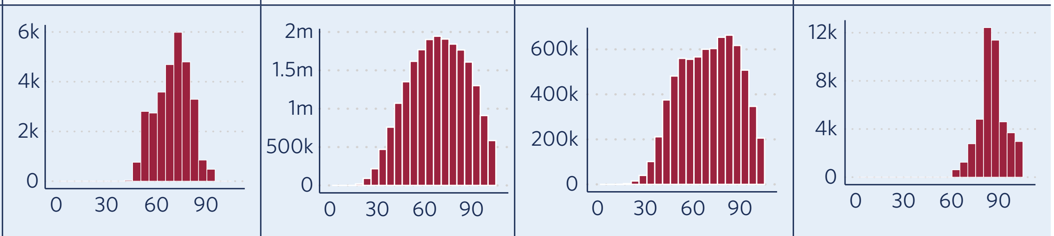
Number of measurements per year



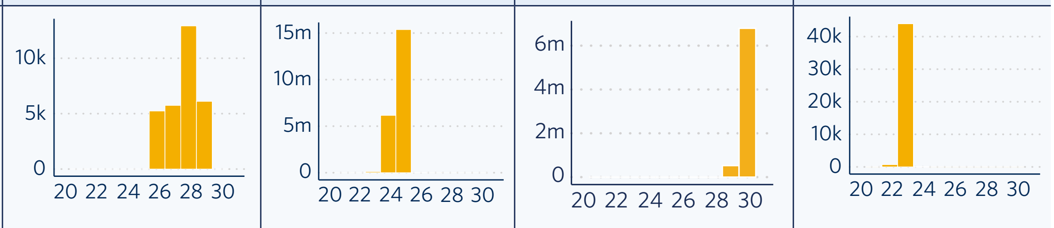
Percentage share of measurements per vehicle category



Number of measurements by ambient temperature (°F)



Number of measurements by ambient atmospheric pressure (inHg)



Acceleration (mi/h/s) over speed (mi/h)

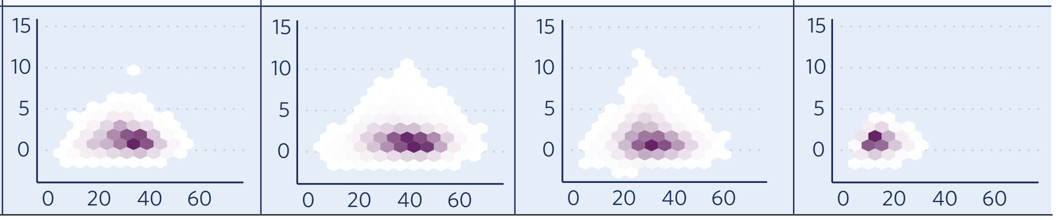
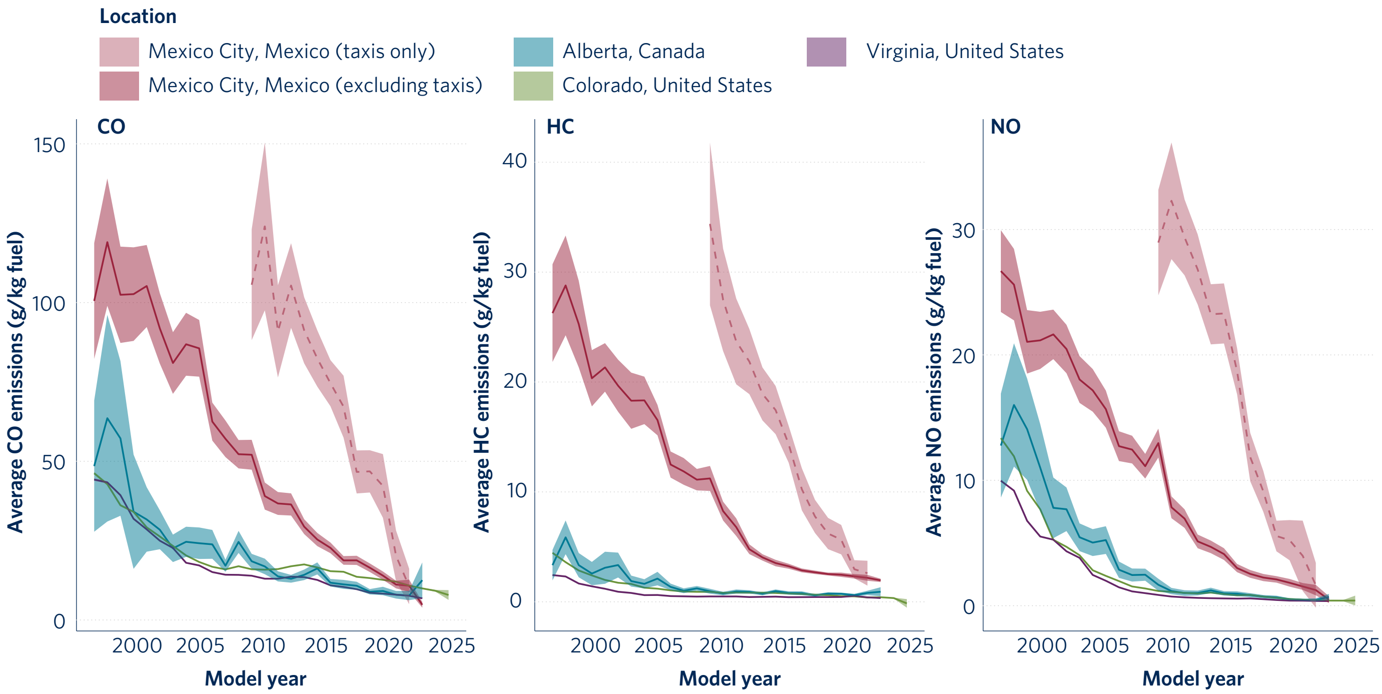


Figure 2 summarizes the emission trends for HC, CO, and NO by model year (MY) for gasoline LDVs in the four locations, as well as for taxis in Mexico City. Between MY 1997 and MY 2022, there is a consistent and substantial decrease of at least 70% in fleet-average emissions for each pollutant across all locations. Notably, due to data limitations, taxis could not be differentiated from the general passenger vehicle (PV) category in the Alberta, Colorado, and Virginia datasets, and thus are not presented separately. However, Mexico City has one of the largest taxi fleets in in the world—approximately 10 times larger than New York City's taxi fleet—and this underscores the significance of this distinction for Mexico City's emissions profile.[5]

The emission trends of pollutants in Alberta, Virginia, and Colorado are closely aligned, reflecting Canada's adoption of U.S. Environmental Protection Agency standards since 1988.[6] However, variations in emission trends between locations persist due to several factors, including fleet composition, driving conditions, ambient conditions, vehicle deterioration rates, and differences in inspection and maintenance programs. Notably, LDVs of MY 2015 and newer measured in Colorado exhibit 21%–35% higher CO emissions than those in Alberta and Virginia. This trend may be partially attributed to Colorado's high elevation, which leads to lower atmospheric pressure. CO emissions tend to increase at lower atmospheric pressure due to the combined effects of increased fuel consumption and reduced combustion efficiency.[7] Other factors may include different fleet compositions and differences across their inspection and maintenance programs. HC emissions measured in Alberta and Colorado consistently surpass those in Virginia, which could also be linked to higher elevations, similarly leading to reduced combustion efficiency. Moreover, pre-MY 2010 vehicles in Alberta demonstrate elevated NO levels, averaging 1.5 times higher than those in Colorado and 1.9 times higher than those in Virginia. This suggests that older LDVs in Alberta may experience higher levels of deterioration or malfunction compared to Colorado and Virginia. Both Colorado and Virginia have implemented preventative measures in the form of inspection and maintenance programs to address emissions from high-emitting vehicles. Elevation may also play a role in the higher NO emissions in Alberta, although studies have suggested this trend is more complex due to the influence of factors such as engine and environmental temperatures, as well as the efficiency of three-way catalytic converter shields.[8]

Vehicles in Mexico City exhibited significantly higher emissions across all pollutants than the other three locations studied. However, emissions have shown a notable decline over model years, reaching levels similar to those of the other locations for some pollutants. Prior to MY 2005, LDVs in Mexico City displayed CO levels approximately 3.3

Figure 2. Average emissions by model year for gasoline LDVs in each location



Note: Shaded regions represent the 95% confidence interval.

5 Pino Bonetti, "Mexico City Modernizes Huge Taxi Fleet with HERE and L1BRE," *HERE360 news (blog), HERE Technologies*, November 17, 2017, https://www.here.com/learn/blog/mexico-city-modernizes-huge-taxi-fleet-with-here-and-l1bre.

6 "Canada: Light-Duty: Emissions," TransportPolicy.net, accessed March 28, 2024, https://www.transportpolicy.net/standard/canada-light-duty-emissions/.

7 Zhiwen Jiang, Lin Wu, Haomiao Niu, Zhenyu Jia, Zhaoyu Qi, Yan Liu, Qijun Zhang, Ting Wang, Jianfei Peng, and Hongjun Mao, "Investigating the Impact of High-Altitude on Vehicle Carbon Emissions: A Comprehensive On-Road Driving Study," *Science of The Total Environment*, 918 (2024): 170671, https://doi.org/10.1016/j.scitotenv.2024.170671.

8 Jiang et al., "Investigating the Impact of High-Altitude."

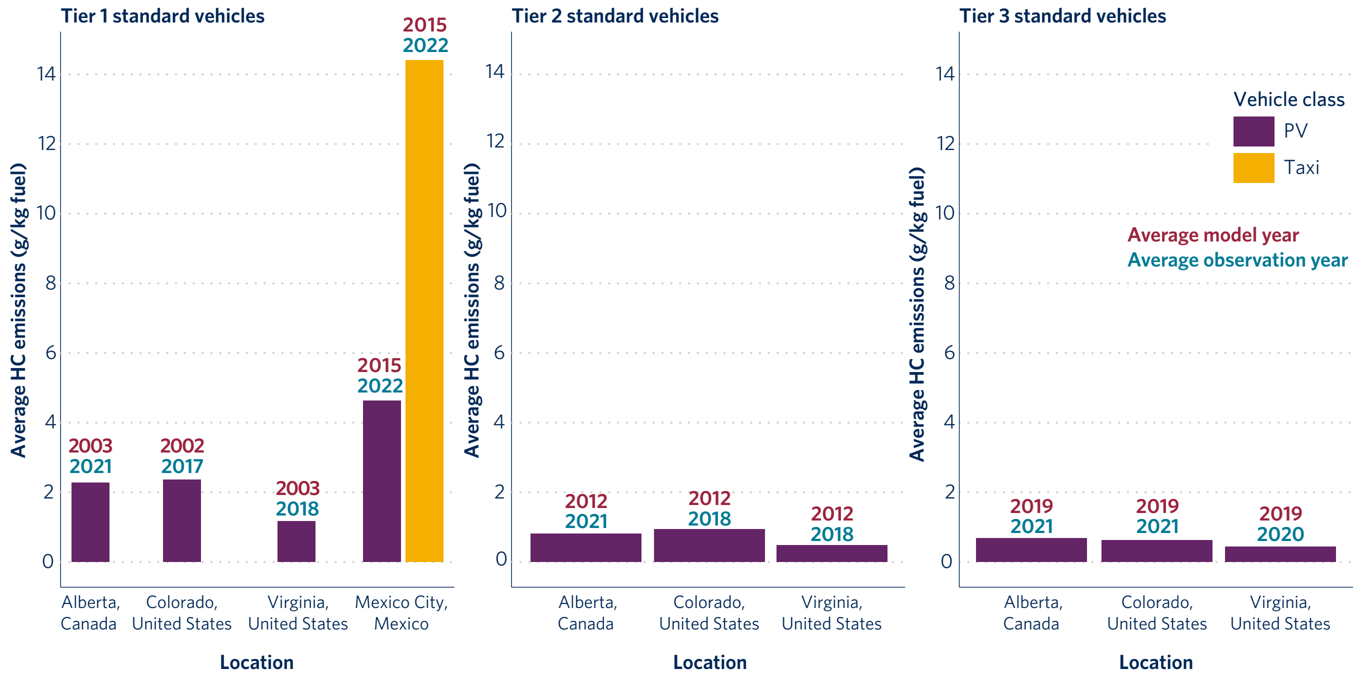
times higher and NO levels approximately 4.2 times higher than those in Virginia. However, by MY 2022, average CO and NO emissions from Mexico City vehicles are similar to that of vehicles measured in the United States and Canada. This trend does not hold true for HC emissions. Even the newest LDVs in Mexico City exhibit HC levels that are higher than that of MY 1999 LDVs in Virginia and MY 2002 LDVs in Colorado. Mexico's gasoline contains higher sulfur levels due to fuel availability and consequentially contributes to the elevated HC emissions and accelerated emissions deterioration observed across pollutants.[9] Mexico City measurement sites also show the lowest ambient atmospheric pressure of the testing locations, further influencing the higher CO and HC emissions in newer model years. Taxis in Mexico City exhibit emissions similar to other LDVs in Mexico City that are 10 years older, resulting in vehicle emissions across all pollutants that are, on average, 2.7 to 3.9 times higher than those of non-taxi LDVs. Only the newest taxis of MY 2022 show emissions levels on par with non-taxi LDVs.

To better evaluate emissions performance across locations, we compare HC emissions across vehicles meeting the same or equivalent emission standards. Mexico's current national emission standard, last updated in 2005, is most closely aligned with the U.S. Tier 1 standard.[10] Meanwhile, the current emission standards in the United States and Canada are Tier 3. Figure 3 illustrates the average HC emissions for PVs across different locations, categorized by emission standard, including taxis for Mexico City. Notably, despite Mexico City's Tier 1 PVs being 12 or more years newer on average, they emit around 2 to 4 times higher HC, respectively, than PVs in the United States and Canada. The disparity is even larger for Mexico City taxis, which emit 6 to 12 times more HC than U.S. and Canadian PVs.

The higher HC emissions among Mexico City vehicles are linked to the issue of evaporative emissions, or HC emissions related to fuel evaporating and leaking into the atmosphere. A previous remote sensing study comparing different sets of remote sensing data from Colorado and Mexico City found that the ratio of HC emissions to CO emissions for average Mexico City vehicles aligned with results from a sample of vehicles in Colorado that were identified to have excess evaporative emissions.[11] As mentioned earlier, the higher sulfur levels in Mexico's gasoline also contribute to elevated HC emissions and faster emissions deterioration.[12]

Results from Canada and the United States provide useful evidence in addressing HC emissions, precursors to ozone pollution, which, in Mexico City, is exacerbated by the region's high elevation, basin shape, and intense solar radiation.[13] The transition from Tier 1 to Tier 2 standards in Alberta, Colorado, and Virginia led to relative HC reductions of 60%–64%, underlining the critical importance

Figure 3. Average HC emissions per kilogram of fuel burned, segmented by emission standard, location, and vehicle class



9 Katherine O. Blumberg, Michael P. Walsh, and Charlotte Pera, "Low-Sulfur Gasoline & Diesel: The Key to Lower Vehicle Emissions" (International Council on Clean Transportation, 2003), https://theicct.org/publication/low-sulfur-gasoline-and-diesel-the-key-to-lower-vehicle-emissions/; Meyer et al., "Emissions in Mexico City."

10 "Mexico: Light-Duty: Emissions," TransportPolicy.net, accessed April 22, 2024, https://www.transportpolicy.net/standard/mexico-light-duty-emissions/.

11 John Koupal and Cindy Palacios, "Analysis of 2019 Mexico City RSD HC Levels," memorandum to Tim Dallmann and Leticia Pineda, March 1, 2021, https://theicct.org/wp-content/uploads/2022/04/ERG_Mexico-City-2019-RSD-Analysis_Updated-March-1_Clean.pdf.

12 Blumberg, Walsh, and Pera, "Low-Sulfur Gasoline & Diesel"; Meyer et al., "Emissions in Mexico City."

13 Meyer et al., "Emissions in Mexico City."

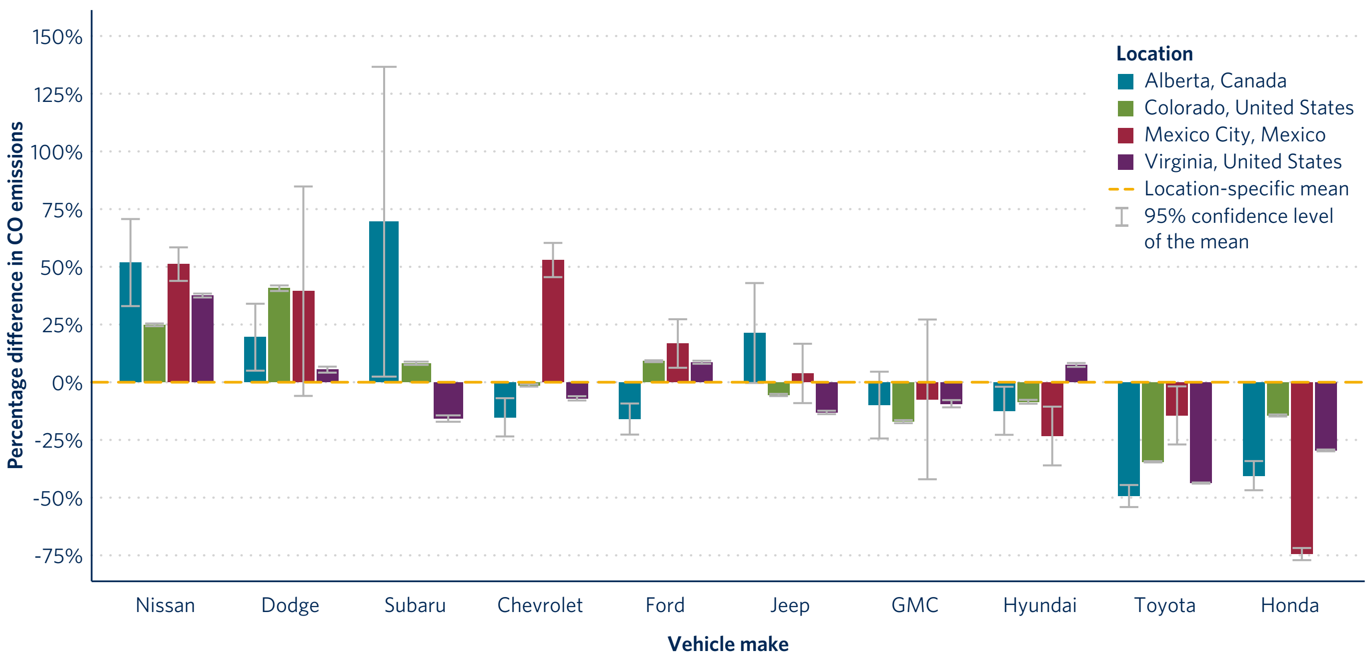
of adopting Tier 2 regulations. Subsequent shifts from Tier 2 to Tier 3 standards in Virginia and Alberta yielded additional HC reductions of 15%–17%, indicating that the bulk of emissions mitigation occurs with the adoption of Tier 2 standards alone. These results suggest that Mexico City and surrounding regions can likely substantially reduce HC emissions from vehicles by adopting a more stringent emission standard like the U.S. Tier 2 standard and moving toward ultra-low sulfur gasoline.

Lastly, we examine the performance of specific LDV vehicle makes, excluding taxis, across various North American locations. Figure 4 shows the CO emissions performance of the most common vehicle makes. The findings are presented as the percentage difference from the region's fleet average CO emissions for Tier 2 and Tier 3 vehicles in the United States and Canada, as well as for MY 2006 and later vehicles in Mexico City. We emphasize the results for CO emissions due to their consistent patterns across locations, and we showcase the highest and lowest emitting makes. Refer to the appendix for results by make concerning NO and HC emissions.

Across locations, Nissan emerges as the highest emitting vehicle make, exhibiting 25%–50% higher-than-average CO emissions across all locations. Dodge vehicles also show consistently higher-than-average CO emissions. While Subaru vehicles displayed above-average emissions in both Colorado and Alberta, emissions were 16% below average in Virginia. Similarly, Ford vehicles showed emissions 11% above the average in Colorado, Mexico City, and Virginia, but 16% below average in Alberta. Chevrolet stands out as one manufacturer with substantially different results in Mexico City compared with the other three locations. Conversely, two of the most popular brands, Toyota and Honda, emerge as the vehicle makes with the least emissions. They exhibit emissions ranging from 15% to 75% below average across all four locations.

The expansion of TRUE Initiative projects into new cities and regions enables more location-by-location comparisons. These comparative analyses provide insights into emission trends over time, the impact of regulatory standards, and vehicle performance. The findings of this North American comparative analysis illustrate the importance of adopting world-class emission and fuel regulations in Mexico, which would result in lower emissions over a vehicle's lifetime. Furthermore, the comparison of vehicle makes reveals notable differences in emissions, highlighting the potential for consumers to assist in reducing emissions through their purchasing choices.

Figure 4. Difference in CO emissions from the location-specific mean by vehicle make



Note: Figure shows manufacturers accounting for at least 5% of the light-duty vehicle fleet in at least one location, excluding taxis. Locations are included for vehicle makes with more than 100 measurements.

APPENDIX: EMISSIONS BY LIGHT-DUTY VEHICLE MAKE

This section builds on the above discussion on CO emissions to include results for NO and HC emissions. The findings are displayed as the percentage difference from the region's pollutant-specific fleet average for the most common Tier 2 and Tier 3 vehicle makes in the United States and Canada, as well as for vehicles MY 2006 and later in Mexico City. Emissions of both NO and HC exhibited greater variability across locations compared to CO emissions. However, highlighting the location-specific trends can help inform consumer choices.

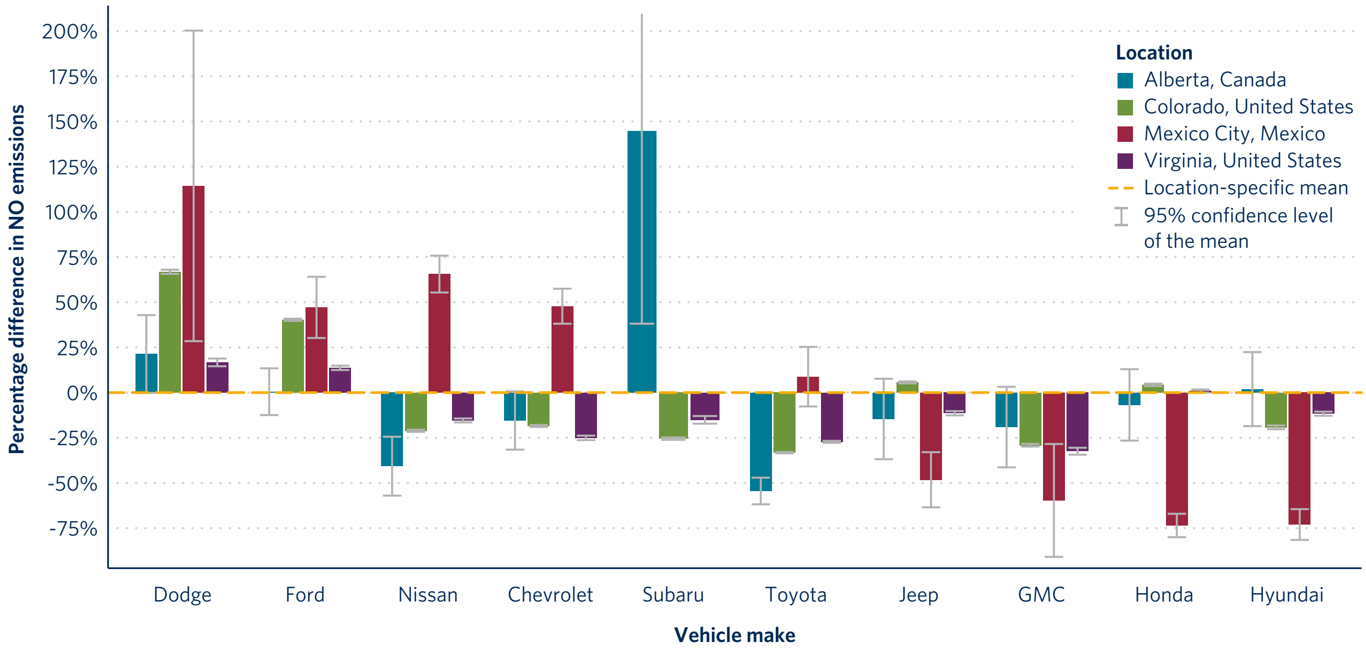
NO EMISSIONS

Figure A1 illustrates the performance of the most common vehicle makes for NO emissions. Dodge emerges as the vehicle make with the highest emissions across locations, with NO emissions ranging from 17% to 67% higher than the mean for the United States and Canada. While Ford demonstrates higher-than-average emissions for Colorado, Mexico City, and Virginia, emissions from Ford vehicles in Alberta are approximately average for the region. Nissan and Chevrolet exhibit emissions exceeding 45% above the mean for Mexico City, despite showing below-average emissions in the United States and Canada. Conversely, GMC demonstrates the lowest NO emissions across all locations. In Mexico City, Honda and Hyundai emit nearly 75% less NO emissions than the mean, while in the United States and Canada, Toyota emerges as a low emitter.

HC EMISSIONS

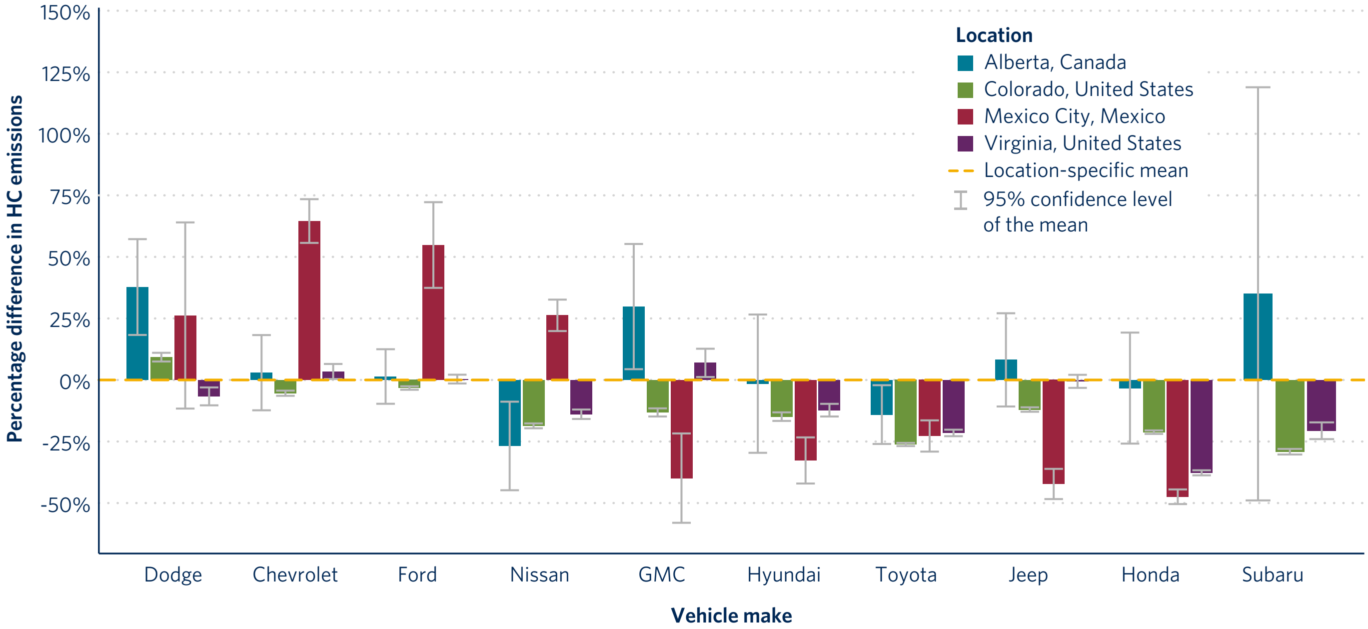
Figure A2 showcases the performance of the most common vehicle makes for HC emissions. Contrary to NO and CO trends, HC emissions for the most common makes in the United States and Canada generally fall below the average, with Dodge being the only make showing higher-than-average emissions in at least three locations. Conversely, there is considerable variability in Mexico City, where Chevrolet and Ford emerge as the highest emitters, ranging from 54% to 65% above the mean. Moreover, GMC demonstrates HC emissions that are roughly 25% higher in Alberta, though the standard error is large. Across locations, Hyundai, Toyota, and Honda consistently emerge as the lowest emitting makes, while GMC, Jeep, and Honda are the lowest emitting makes in Mexico City.

Figure A1. Difference in NO emissions from the location-specific mean by vehicle make



Note: Figure shows manufacturers accounting for at least 5% of the light-duty vehicle fleet in at least one location, excluding taxis. Locations are included for vehicle makes with more than 100 measurements.

Figure A2. Difference in HC emissions from the location-specific mean by vehicle make



Note: Figure shows manufacturers accounting for at least 5% of the light-duty vehicle fleet in at least one location, excluding taxis. Locations are included for vehicle makes with more than 100 measurements.

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