THE REAL URBAN EMISSIONS INITIATIVE

Real-world NO_x emissions and health impacts from tampered and malfunctioning heavy-duty vehicles in Alberta, Canada

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FIA Foundation and the ICCT have established The Real Urban Emissions (TRUE) Initiative. The TRUE Initiative seeks to supply cities with data regarding the real-world emissions of their vehicle fleets and equip them with technical information that can be used for strategic decision making. TRUE will use a combination of measurement techniques to produce a granular picture of the on-road emissions of the entire vehicle fleet by make, model, and model year.

EXECUTIVE SUMMARY

Although increasingly stringent emission standards for heavy-duty vehicles (HDVs) have greatly reduced emissions of nitrogen oxides (NO_x) and other harmful pollutants in many regions, individual vehicles can emit well above the emissions limit during real-world operation. This can happen because of deliberate removal or deactivation of an emission control component—tampering—or malfunctioning of the emission control systems.

In Canada, provinces are responsible for regulating in-use vehicle emissions. The province of Alberta, which is home to a large portion of the country's freight trucks, does not have anti-tampering regulations or an inspection and maintenance program to identify and address high-emitting trucks. While it is known that tampering and vehicle malfunctions contribute to elevated NO_x emissions, there has historically been a gap in data on rates of tampered or malfunctioning vehicles. This information is key to providing detailed assessments regarding the scale of excess NO_x emissions and associated health impacts, and in crafting effective policy. To help, this analysis uses real-world data from a remote emissions sensing campaign conducted by the Clean Air Strategic Alliance to evaluate the effect of tampered or malfunctioning HDVs in Alberta. We estimate the prevalence of tampering or malfunctions, model HDV NO_x emissions through 2035, and quantify the health impacts of these emissions. The analysis finds:

Approximately 38% of HDVs that are model year (MY) 2010 and later and at least 7 years old show evidence of tampering or malfunctions, as do 20% of HDVs of all ages in Alberta. These rates of excess NO_x emissions are substantially higher than a best-estimate scenario assessed in a prior study by the International Council on Clean Transportation (ICCT).

The excess emissions from these vehicles are projected to counteract the emission reductions from fleet turnover in the coming years. Because of the high rate of tampered or malfunctioning vehicles, emission reductions over the next decade are projected to slow down substantially despite the fleet transitioning to newer vehicles certified to much lower emission limits. By 2026, the excess emissions from tampered or malfunctioning vehicles are predicted to account for over half of total emissions from HDVs in Alberta.

The cumulative health damages due to excess NO_x emissions from tampered or malfunctioning HDVs in Alberta are projected to be \$5.4 billion between 2024 and 2035. The annual health impacts are projected to increase over time, growing over 70% between 2024 and 2035.

Addressing the issue of tampered or malfunctioning HDVs such as through anti-tampering legislation and improved inspection and maintenance programs could help reduce NO_x emissions by up to 59% annually. The high prevalence of tampered or malfunctioning HDVs found in Alberta and the related air quality and health impacts of these vehicles support the following policy recommendations.

Explicitly prohibiting all tampering at a federal level in Canada is an important step to address the issue of tampering. Tampering is prohibited in the United States under the Clean Air Act. This legislation enables the Environmental Protection Agency to enforce penalties for selling or installing equipment that disrupts vehicle emission controls. Amending federal legislation to prohibit manufacturing, selling, or installing equipment that interferes with vehicle emission controls in Canada would allow authorities to take similar enforcement action.

Alberta can institute an inspection and maintenance program to monitor vehicle emissions for continued compliance. Other provinces in Canada have inspection and maintenance programs and these can serve as models for Alberta. For example, Ontario's DriveON program requires annual emission tests that help deter intentional tampering and identify malfunctioning emission control systems to effectively decrease on-road NO_x emissions.

Remote sensing technology can serve as an effective tool to identify high-emitting vehicles during on-road operation. A remote sensing component of an inspection and maintenance program that is similar to approaches used in Colorado and California can monitor high emissions from tampered or malfunctioning vehicles and ultimately help to reduce emissions from the fleet. Remote sensing data can also provide valuable insights into emission trends over time to support effective emissions-reduction plans.

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INTRODUCTION

On-road heavy-duty vehicles (HDVs) in Canada contribute substantially to ambient air pollution. They released approximately 120,000 tons of nitrogen oxides (NO_x) and 3,400 tons of fine particulate matter ($PM_{2.5}$) into the atmosphere in 2022.[1] This category of vehicles is the source of 14% of NO_x and 22% of $PM_{2.5}$ emissions from the transportation sector. Nearly half of Alberta's population lives within 1 km of a high-traffic roadway and they are exposed to elevated levels of air pollution linked to adverse health impacts.[2] In 2022, Alberta ranked second-highest among Canadian provinces in NO_x emissions from diesel HDVs, and was responsible for approximately 22% of the national total.[3] The province is also home to the country's second-largest fleet of tractor trucks and the largest fleet of pickup trucks.[4] Alberta thus has a critical role to play in national efforts to reduce transportation emissions.

While Canada has national regulations that impose increasingly stringent emission standards on HDVs, tampering with vehicles and vehicle malfunctions can undermine the effectiveness of such measures. Vehicle tampering involves the deliberate removal or deactivation of an emission control component in a certified vehicle or engine. Common tampering practices include removal of selective catalytic reduction, blocking exhaust gas recirculation, tuning of engine control units, and interfering with the exhaust temperature sensor.[5] These practices can result in significantly elevated NO_x emissions, up to 10 times higher than would be expected from typical vehicle operation.[6] Individuals may choose to alter or disable emission control systems in their vehicles to reduce costs associated with things such as the need to refill diesel exhaust fluid and to avoid maintenance of the emission control system after a vehicle's warranty expires.[7] Some provinces in Canada have enacted anti-tampering legislation and use inspection and maintenance programs to identify and address tampered or malfunctioning vehicles. Alberta is one of only three Canadian provinces that does not have anti-tampering legislation and is the most populous of the three.[8]

This report builds on a 2022 ICCT study which estimated the impact of a theoretical tampering prevalence of HDVs in Alberta over time: If 1% of HDVs in Alberta had tampered or malfunctioning emissions control systems, their excess emissions corresponded to a 3% increase NO_x emissions in 2020 and a 54% increase in 2040.[9] If left unchecked, tampering could impact Canada's work to reduce HDV emissions through vehicle turnover, stricter emissions standards, and a greater shift toward zero-emission vehicles via its 2030 Emission Reduction Plan.[10]

This report applies real-world data to estimate the prevalence of tampered or malfunctioning HDVs in Alberta and the associated NO_x emissions and health impacts. Using real-world emissions data from the Clean Air Strategic Alliance's (CASA) third remote sensing campaign in 2022, this report identifies a group of HDVs in Alberta that show evidence of tampering or malfunctions.[11]

Vehicle emissions and health models developed by the ICCT are then used to forecast the excess NO_x emissions attributable to tampered or malfunctioning HDVs and the associated health impacts through 2035, assuming sustained rates of tampering and malfunctions. The findings provide evidence to support a targeted strategy to improve Alberta's ambient air quality. They also lay the groundwork for assessing policy options to address high excess NO_x emissions from HDVs and better achieve the emission reductions intended by national emission standards.

1 Environment and Climate Change Canada, "Canada's Air Pollutant Emissions Inventory Report 2024: Chapter 2," accessed July 24, 2024, https://www.canada.ca/en/environment-climate-change/services/air-pollution/publications/emissions-inventory-report-2024/chapter-2.html.

2 Health Canada, *Exposure to Traffic-Related Air Pollution in Canada: An Assessment of Population Proximity to Roadways* (2022), https://publications.gc.ca/collections/collection_2022/sc-hc/H144-99-2022-eng.pdf.; California Air Resources Board, "Overview: Diesel Exhaust & Health," accessed July 24, 2024, https://ww2.arb.ca.gov/resources/overview-diesel-exhaust-and-health.

3 Government of Canada, "Air Pollutant and Black Carbon Emissions Inventories Online Search," accessed November 14, 2024, https://pollution-waste.canada.ca/air-emission-inventory/.

4 Caleb Braun et al., *Heavy-Duty Emissions Control Tampering in Canada* (International Council on Clean Transportation, 2022), https://theicct.org/publication/hdv-emissions-tampering-can-mar22/.

5 Braun et al., *Heavy-Duty Emissions Control*.

6 Barouch Giechaskiel et al., "Effect of Tampering on On-Road and Off-Road Diesel Vehicle Emissions" *Sustainability* 14, no. 10: 6065. https://doi.org/10.3390/su14106065

7 W. Addy Majewski, "Emission Tampering," DieselNet Technology Guide, June 2022, https://dieselnet.com/tech/emissions_tampering.php.

8 Braun et al., *Heavy-Duty Emissions Control*.

9 Braun et al., *Heavy-Duty Emissions Control*; Statistics Canada Government of Canada, "Population Estimates, Quarterly," June 27, 2018, https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1710000901.

10 Government of Canada, "2030 Emissions Reduction Plan – Sector-by-Sector Overview," accessed November 14, 2024, https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/emissions-reduction-2030/sector-overview.html.

11 Rob Klausmeier and Niranjan Vescio, *Roadside Optical Vehicle Emissions Reporter III: A Survey of On-Road Light and Heavy-Duty Vehicle Emissions* (Opus Inspection, November 2023), https://www.casahome.org/uploads/source/ROVER_III_Opus_Report-Final_Nov_2023_(amended)_v.2.pdf.

DATA OVERVIEW

From June through August 2022, CASA conducted emissions testing via remote sensing at six vehicle inspection stations in Alberta. The objectives included the continual monitoring of emissions from the on-road transportation sector to provide guidance for achieving the Canadian Ambient Air Quality Standards in Alberta.[12] The 2022 campaign was the first of the series to include emissions measurements from HDVs.

The diesel HDV dataset captured consisted of 7,320 valid emission measurements from various vehicle types, including tractor trucks, box trucks, dump trucks, and pickup trucks. Remote sensing measurements were matched with vehicle information obtained from DataOne VIN decoding and Service Alberta's vehicle registry to characterize the fleet.[13] Due to license plate capture constraints, box trucks and dump trucks—which often lack front plates—were excluded because of incomplete vehicle data. As such, this analysis focuses on Class 8 tractor trucks, often used for heavy-haul trucking and freight movement.[14] The final Alberta dataset contains 2,343 measurements.[15]

To assess how Alberta's emissions compare with a fleet subject to anti-tampering efforts, we used a Colorado remote sensing dataset from the TRUE Initiative's U.S. database.[16] The Colorado dataset was chosen because of its robust coverage of vehicle ages and driving conditions and because the state enforces federal anti-tampering regulations through the Clean Air Act and has inspection and maintenance programs.[17] The Colorado dataset included 4,198 Class 8 diesel tractor truck observations between 2019 and 2023.

To ensure comparability between datasets, adjustments were made to align ambient temperatures and engine load conditions. While the ambient temperature distributions were similar across the datasets, vehicle speeds in Colorado were generally higher. Therefore, the Colorado data was filtered to include only measurements taken under the range of vehicle-specific power observed in Alberta (-5 to 30 kW/ton), a metric that accounts for speed, acceleration, and slope at the time of measurement. The final Colorado dataset used for analysis comprised 3,451 observations.

METHODS OVERVIEW

This study estimates the prevalence of tampered or malfunctioning diesel tractor trucks on Alberta's roads and the excess emissions and health impacts associated with these vehicles through 2035, if the current trends of tampering or malfunctions are sustained. Our methodology consists of three main steps: calculating the prevalence of tampered or malfunctioning vehicles, modeling future emissions from tampered or malfunctioning vehicles, and estimating public health impacts from the projected excess NO_X emissions. A summary of the steps is below and illustrated in Figure 1, and detailed descriptions of the modeling approach are in Appendix B.

To calculate the prevalence of tampered or malfunctioning vehicles, two high-emitter thresholds were established for pre-model year (MY) 2010 and post-MY 2010 tractor trucks, based on literature about elevated emission rates and the methodology from the 2022 tampering study.[18] Observations exceeding these thresholds were considered high emitting. For Colorado vehicles, observations of high emissions were assumed to entirely reflect naturally occurring elevated emissions (e.g., time spent in cold start) from non-tampered vehicles or malfunctioning vehicles. For Alberta vehicles, observations of high emissions were attributed to a mix of naturally occurring elevated emissions and tampered or malfunctioning vehicles; the tampered or malfunctioning prevalence in Alberta was determined by taking the difference in the share of high-emitting observations between Alberta and Colorado.

12 Clean Air Strategic Alliance, "Roadside Optical Vehicle Emissions Reporter III Project Team," accessed February 4, 2025, https://www.casahome.org/past-projects/roadside-optical-vehicle-emissions-reporter-iii-project-team-53/.

13 Klausmeier and Vescio, *Roadside Optical Vehicle Emissions Reporter III: A Survey of On-Road Light and Heavy-Duty Vehicle Emissions.*

14 These vehicles have a gross vehicle weight rating of at least 33,000 lbs.

15 This study uses tractor truck RS data to estimate the prevalence of tampering within the HDV category, due to limited data from other HDV subcategories. Consequently, the Roadmap model implemented later applies this estimated tampering prevalence across the entire HDV class.

16 Yoann Bernard et al., *TRUE U.S. Database Case Study: Remote Sensing of Heavy-Duty Vehicle Emissions in the United States* (TRUE Initiative, 2020), https://www.trueinitiative.org/news/2020/october/new-report-real-world-emissions-of-us-vehicles-increase-with-age-says-60m-dataset.

17 United States Environmental Protection Agency, Office of Enforcement and Compliance Assurance, "Enforcement Alert: Aftermarket Defeat Devices and Tampering Are Illegal and Undermine Vehicle Emissions Controls," December 2020, https://www.epa.gov/sites/default/files/2020-12/documents/tamperinganddefeatdevices-enfalert.pdf.; Colorado Department of Public Health & Environment, "Automobile Inspection and Readjustment (AIR) Program," accessed August 30, 2024, https://cdphe.colorado.gov/motor-vehicle-emissions/automobile-inspection-and-readjustment-air-program.

18 Braun et al., *Heavy-Duty Emissions Control*; Chandan Misra et al., "In-Use NO_X Emissions from Model Year 2010 and 2011 Heavy-Duty Diesel Engines Equipped with Aftertreatment Devices," *Environmental Science & Technology* 47, no. 14 (July 16, 2013): 7892–98, https://doi.org/10.1021/es4006288.

To calculate excess NO_x emissions, we developed a tampered or malfunctioning vehicle emissions factor multiplier by dividing the average NO_x emissions from the high-emitting observations by emission factors integrated into ICCT's Roadmap emissions model.[19] This multiplier serves to augment the emissions from a typical vehicle to the rate expected from a tampered or malfunctioning vehicle. We then put this multiplier, the calculated data on tampering or malfunctions prevalence, Alberta-specific vehicle registration data, and assumptions on tampering trends by vehicle age into the Roadmap model.[20] Using these inputs and built-in model data on mileage, efficiency, and stock turnover, we estimated NO_x emissions through 2035. We then calculated excess NO_x emissions attributable to tampering or malfunctions by taking the difference between these results and NO_x emissions modeled assuming no tampering or malfunctions. Though the remote sensing measurements are of Class 8 tractor trucks, the estimation of excess emissions includes all Class 7 and 8 HDVs, to align with Roadmap model vehicle definitions.

The public health impact of HDVs in Alberta identified as likely tampered or malfunctioning was estimated by calculating the monetized loss associated with premature deaths due to excess NO_x pollution. This was quantified using the Value of Statistical Life, the monetary value a society places on reducing the risk of premature death, and it is referred to hereafter as health damages.[21] Premature deaths and the monetized health damages between 2024 to 2035 were estimated using the ICCT's Fast Assessment of Transport Emissions (FATE) model.[22] The FATE model includes a reduced-complexity air quality assessment tool and uses methodology consistent with the *Global Burden of Disease 2019* to estimate premature deaths from transport-

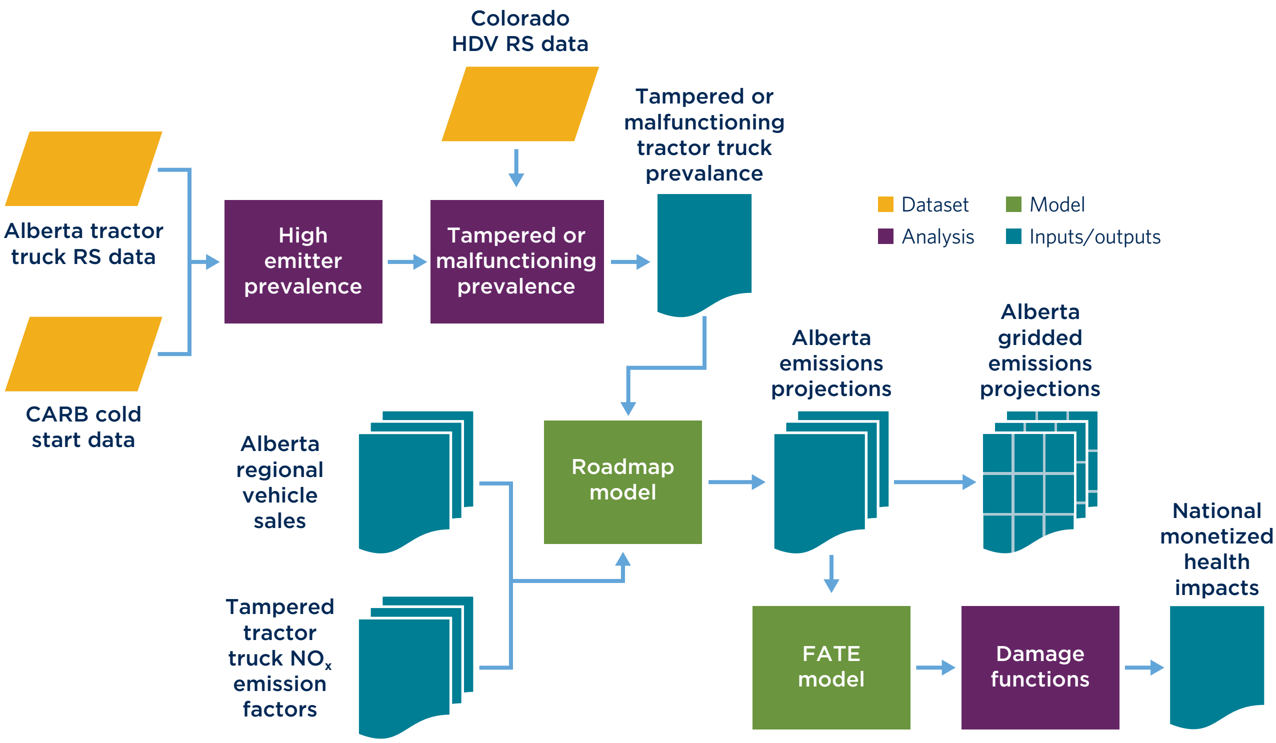

Figure 1. The methodology used to assess the prevalence of tampered or malfunctioning vehicles and model the resulting emissions and health impacts

19 International Council on Clean Transportation, "Roadmap Model Documentation," accessed September 3, 2024, https://theicct.github.io/roadmap-doc/.

20 We assume the tampering rate increases with vehicle age in accordance with vehicle operators wanting to avoid costly maintenance repairs after a vehicle's warranty period expires.

21 W. Kip Viscusi and Clayton J. Masterman, "Income Elasticities and Global Values of a Statistical Life," Journal of Benefit-Cost Analysis 8, no. 2 (2017): 226–50, https://doi.org/10.1017/bca.2017.12.

22 International Council on Clean Transportation, "FATE *Documentation* Version 2.0," 2023, https://theicct.github.io/FATE-doc/versions/v2.0/.

related air pollution.[23] Resulting damage functions in 2024 Canadian dollars per kiloton (kt) of NO_x were multiplied by the modeled excess NO_x pollution to calculate monetized health impacts of tampering and malfunctions through 2035.

NO_X EMISSIONS BY MODEL YEAR GROUP

Figure 2 illustrates the average fuel-specific NO_x emissions in Alberta across different MY groups, plotted against the NO_x regulatory limits for diesel HDVs in Canada.[24] The tractor trucks are categorized into five MY groups according to their U.S. HDV emission standard.[25] Canada's current emission standards are equivalent to the U.S. standards, enabling a direct comparison of emissions across MY groups with the vehicles in Colorado.

The emission standard introduced with MY 2010 was 83% of all truck observations. The MY 2010–2015 group shows high NO_x emissions at 21.5 g NO_x/kg fuel, over 16 times higher than the regulatory limit and akin to the emission trends observed in older vehicles. In contrast, the average emissions for the MY 2016 and newer group are more consistent with the regulatory limit, at approximately 5 g NO_x/kg fuel. While both the MY 2010–2015 group and MY 2016 and newer group are subject to the same emission standard, the difference in vehicle performance is apparent when considering fleet shares versus the shares of total emissions. The MY 2010–2015 group constitutes 24% of the tractor truck fleet but is responsible for 40% of Alberta's total NO_x emissions from tractor trucks. The MY 2016 and newer group constitutes almost 60% of the fleet yet contributes only 20% of total emissions.

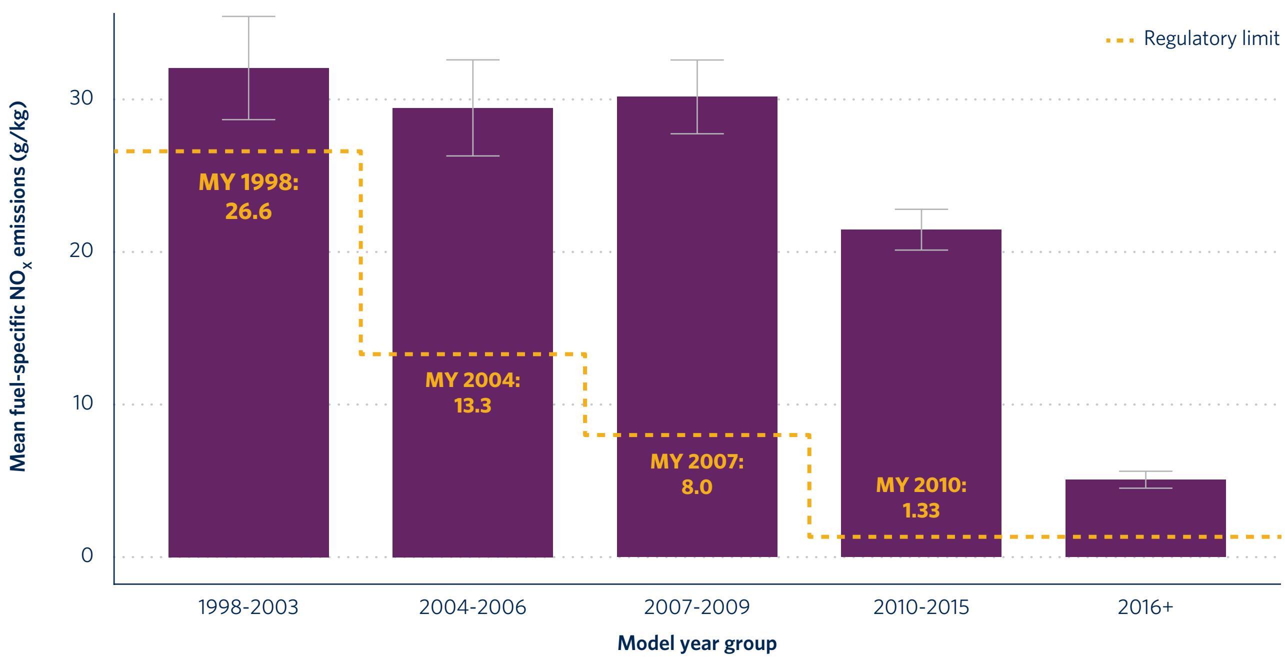

Figure 2. Mean fuel-specific NO_x emissions of diesel tractor trucks by model year group
Note: Error bars represent the 95% confidence interval.

23 GBD 2019 Risk Factors Collaborators, "Global Burden of 87 Risk Factors in 204 Countries and Territories, 1990-2019: A Systematic Analysis for the Global Burden of Disease Study 2019," Lancet (London, England) 396, no. 10258 (October 17, 2020): 1223–49, https://doi.org/10.1016/S0140-6736(20)30752-2.

24 Federal emission limits, set in units of grams per brake-horsepower hour, were converted to a fuel-specific metric (g NO_x/kg diesel fuel) using the assumption that 0.15 kg fuel is consumed per brake-horsepower hour. Bernard et al., *TRUE U.S. Database Case Study*.

25 The group of vehicles certified to the most recent emission standard, which went into effect with MY 2010 vehicles, is divided into two groups due to distinct trends in NO_x emissions between the two groups.

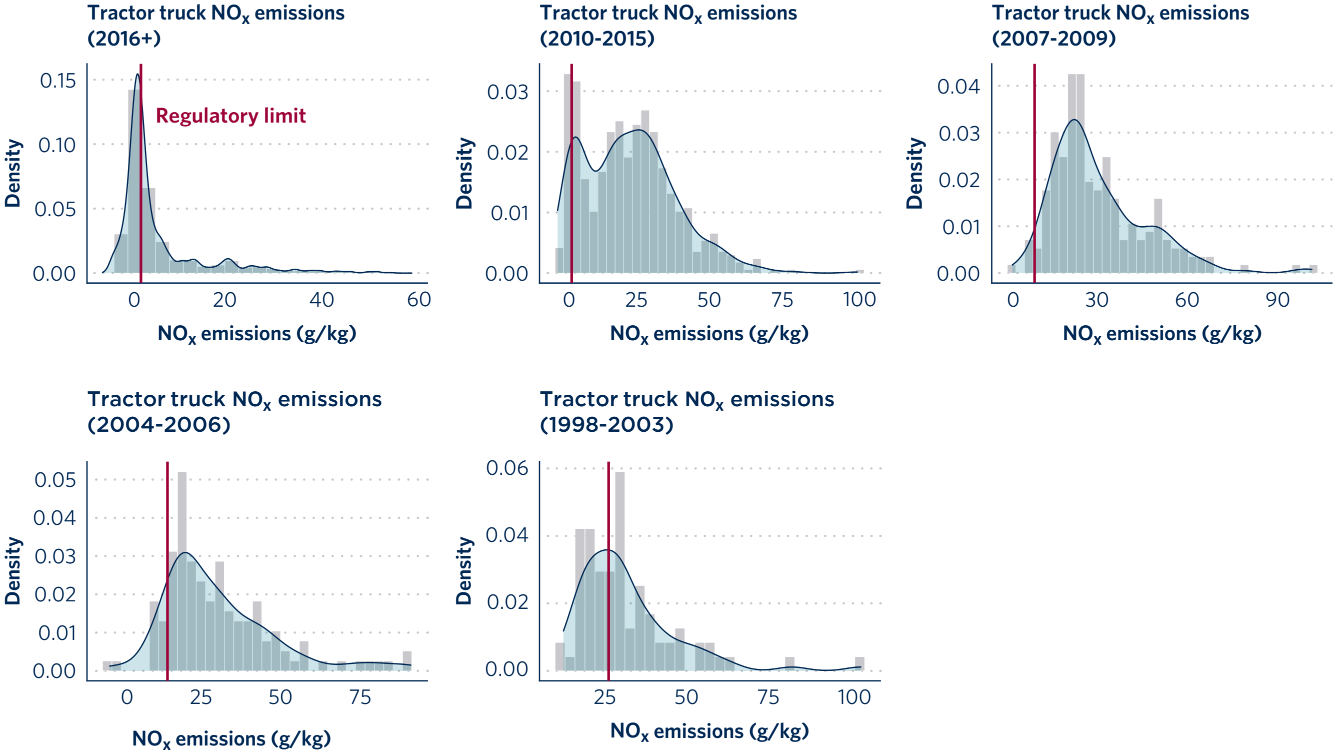

Figure 3. NO$_X$ emissions distribution of diesel tractor trucks by model year group compared with the regulatory limit

Figure 3 illustrates the emission distributions of MY groups and reveals a bimodal distribution in the MY 2010–2015 group. One mode aligns observations from the MY 2016 and newer group, while the other centers around 25g NO$_X$/kg fuel—a level 19 times higher than the limit. This second peak of high average emissions suggests a substantial subgroup of vehicles with potentially malfunctioning emission control systems. The observed emissions from this group in Alberta are like those found in tampering studies conducted in Denmark and Flanders, where tampered Euro VI trucks emitted 10 to 15 times more than typical vehicles.[26] This trend is not specific to certain vehicle makes, models, or engine types, but rather reflects a broader issue across Alberta's fleet.

Comparing this with tractor trucks in the Colorado data provides additional evidence. As shown in Figure 4, average NO$_X$ emissions for the MY 2010–2015 group in Alberta are 142% times higher than for vehicles of the same model years in Colorado and 323% higher than the MY 2016 and newer group in Alberta. However, the emissions from the MY 2010–2015 group in Colorado are only slightly higher than the 2016 and newer group, consistent with expected patterns of incremental performance improvements in newer models and emissions deterioration as vehicles age. Additionally, the smaller emission differences observed in the MY 2016 and newer groups in both regions suggest that differences in operating conditions alone do not explain the larger emissions gap for the older vehicles.

In Alberta, vehicles subject to MY 2004 and MY 2007 emission standards exhibit 86% and 76% higher emissions, respectively, than their counterparts in Colorado. As tampering rates tend to increase after vehicles age past their warranty period, this finding supports the hypothesis that excess emissions in Alberta's older vehicle groups may be linked to a higher prevalence of tampered or malfunctioning vehicles.[27] Colorado's inspection and maintenance program and U.S. federal anti-tampering legislation likely helps curb such issues.

26 The Euro VI standard is most similar to the U.S. 2010 HDV emission standards; Thomas Ellermann et al., *Measurements of Cheating with SCR Catalysts on Heavy Duty Vehicles* (The Danish Environmental Protection Agency, 2018), https://pure.au.dk/portal/en/publications/measurements-of-cheating-with-scr-catalysts-on-heavy-duty-vehicle; Niles Hooftman, Norbert E. Ligterink, and Akshay Bhoraskar, *Analysis of the 2019 Flemish Remote Sensing Campaign* (Flemish Environmental Planning Agency, 2020), https://resolver.tno.nl/uuid:7e96bc14-46e3-4e5a-8f06-e436c85160f7.

27 Braun et al., *Heavy-Duty Emissions Control*.

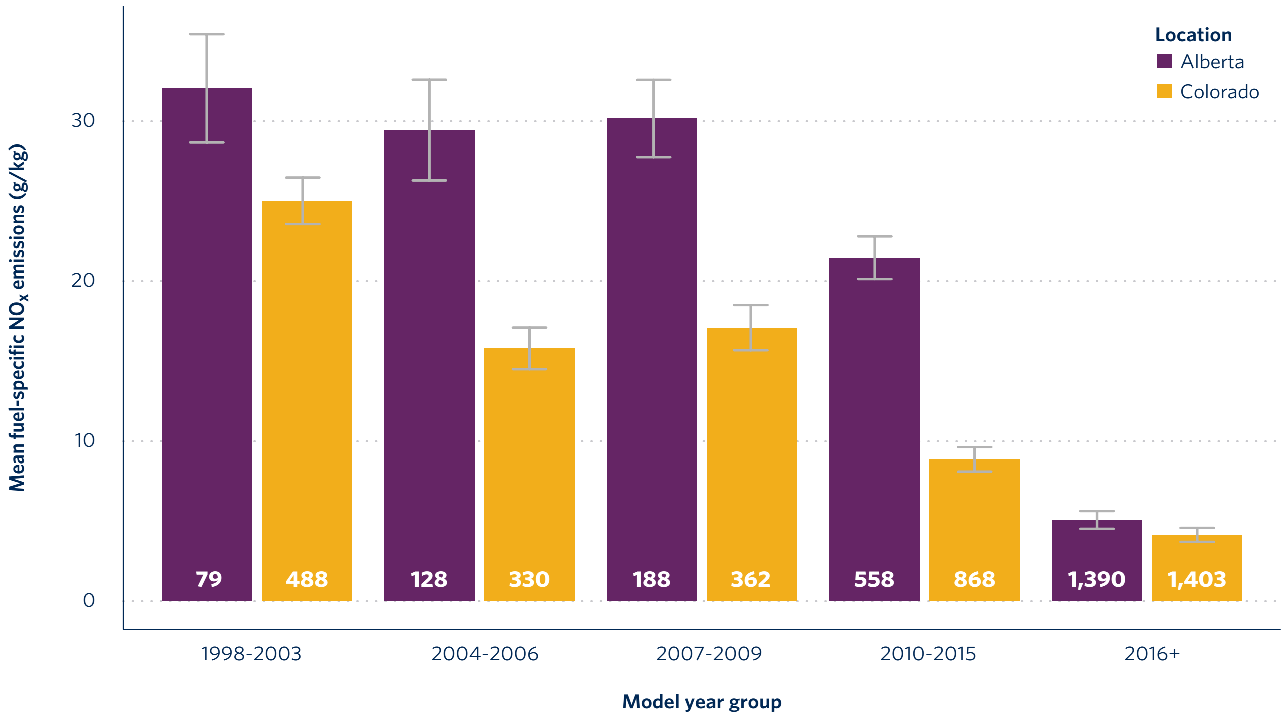

Figure 4. Average fuel-specific NO_x emissions for tractor trucks in Colorado and Alberta by model year group
Note: Error bars represent the 95% confidence interval.

ESTIMATED PREVALENCE OF TAMPERING OR MALFUNCTIONING IN ALBERTA

Here we compare high-emitting observations in the Alberta and Colorado data. Through the assumption of negligible tampering and malfunctions in the Colorado vehicles, we estimate the prevalence of tampered or malfunctioning tractor trucks in Alberta by calculating the difference in the percentage of observations showing high emissions between the two locations. Note that the assumption of no tampering or malfunctions among the Colorado fleet is conservative, as it results in a lower calculated tampered or malfunctioning prevalence among the Alberta fleet.

Remote sensing observations showing high emissions can be linked to a variety of causes beyond tampering or malfunctions. Given that remote sensing measurements capture only a brief snapshot of vehicle emissions, instances of high emissions can be observed for even vehicles with properly functioning emission control systems. For example, vehicles can show elevated emissions during cold starts due to sub-optimal (low) engine and aftertreatment temperatures that negatively impact exhaust emissions and engine performance.[28] Other contributing factors, such as diesel particulate filter regeneration and specific driving conditions, can also result in temporarily higher emissions.[29]

We employ emission thresholds to understand the observations of high emissions in both the Colorado and Alberta datasets. For full details of the emission thresholds, see Appendix A. Table 1 depicts the percentage of measurements meeting the high emissions threshold in the Alberta and Colorado datasets.[30] An example for the MY 2010–2015 group, illustrated in Figure 5, shows the highest rate of tampering or malfunctions at 38.5%.

28 Ali Zare et al., "Cold-Start NOx Emissions: Diesel and Waste Lubricating Oil as a Fuel Additive," *Fuel* 286 (February 15, 2021): 119430, https://doi.org/10.1016/j.fuel.2020.119430.

29 Hannu Jääskeläinen, "Emission Effect of Engine Faults and Service," DieselNet Technology Guide, accessed September 3, 2024, https://dieselnet.com/tech/emissions_fault.php.

30 We combined MY groups 2004–2006 and 2007–2009 into one group (MY 2004–2009) to create a larger sample size, as the two groups showed similar emission trends.

Table 1. Percentage of high-emitting vehicles and estimated prevalence of tampered or malfunctioning vehicles in the Colorado and Alberta datasets by model year group

	Model year group		
	2004–2009	2010–2015	2016 and newer
Percentage of high emitters in Alberta	29.7%	49.3%	8.3%
Percentage of high emitters in Colorado	8.5%	10.8%	3.6%
Alberta tampering or malfunctioning prevalence	**21.2%**	**38.5%**	**4.7%**

It is certainly possible that some trucks in the Colorado dataset are tampered or malfunctioning. However, our methodology is designed to produce the most conservative estimate of suspected tampering or malfunctioning prevalence in Alberta, and the assumption for Colorado allows us to subtract the full share of high-emission observations and get a lower estimate of tampering or malfunctioning prevalence among Alberta vehicles.

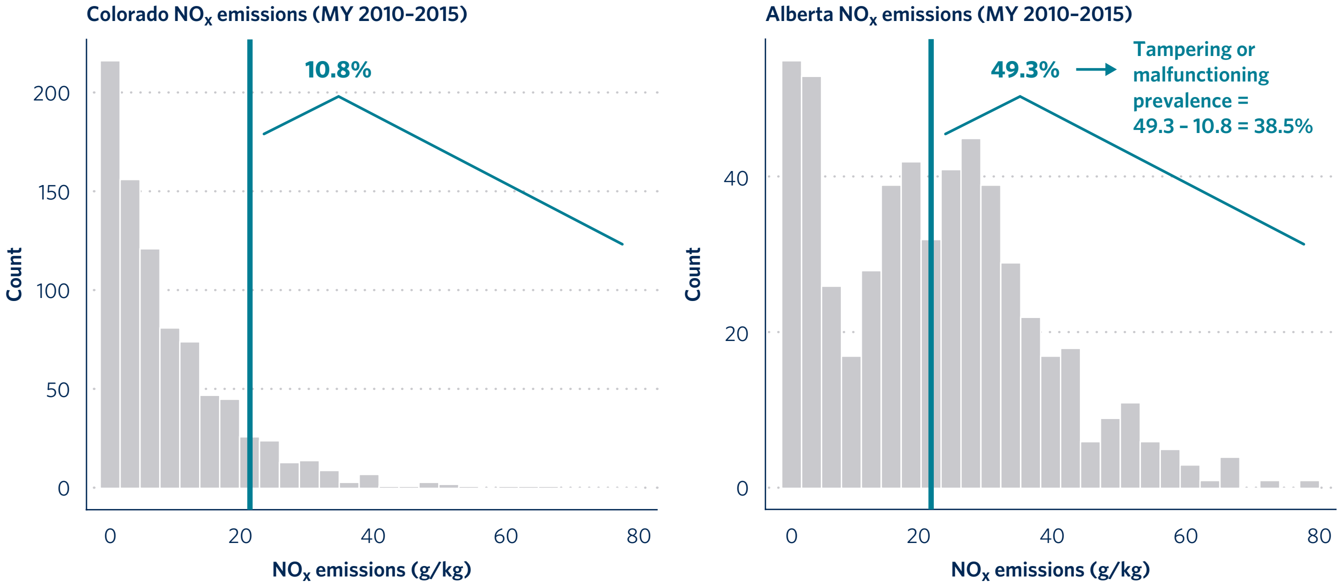

Figure 5. Suspected tampering or malfunctioning prevalence for MY 2010–2015 tractor trucks using Colorado and Alberta high-emitter percentages

EXCESS NO_X EMISSIONS IN ALBERTA THROUGH 2035

In this section, we determine the emission factors for tampered or malfunctioning vehicles and project emissions through 2035 under a typical emitter scenario representing vehicles operating with properly functioning emission control systems and a scenario reflecting our estimates of tampering and malfunctioning prevalence. This distinction enables us to quantify excess emissions through 2035.

We calculate the NO_X emission factor multiplier for tampered or malfunctioning vehicles versus typical emitters for the three MY groups (Table 2). The emission factors for typical emitters represent the average NO_X Roadmap model emission factors from MYs within that MY group.[31] In contrast, the emission factors for tampered or malfunctioning vehicles represent the average NO_X levels for measurements exceeding the high-emitter threshold. The multiplier is highest for the MY 2016 and newer group, for which typical vehicles emit the lowest NO_X emissions.

To project the NO_X emissions from Alberta's evolving fleet over time, we employed the ICCT's Roadmap model and used built-in model data specific to North America or Canada, including vehicle sales, stock turnover, mileage, vehicle efficiency, and emission factors.[32] To the default inputs, we added Alberta-specific regional sales data derived from vehicle registration information.[33] We additionally specified our assumptions for vehicle tampering or malfunctions, including emission multipliers for tampered or malfunctioning vehicles, the share of tampered or malfunctioning vehicles, and assumptions regarding tampering trends by vehicle age, to project future tampering or malfunction prevalence. More information regarding the model inputs is in Appendix B.

Figure 6 depicts the percentage of total vehicle stock projected to be tampered or malfunctioning from 2020 to 2035. The percentage of tampered or malfunctioning vehicles is projected to be highest in 2026, at 22.4% of the total stock. This highlights an expected increase in tampering associated with an aging MY 2016 and newer group. Due to fleet turnover and the lower prevalence of high-emitting vehicles in newer MYs, the share of tampered or malfunctioning vehicles is projected to slightly decrease between 2026 and 2035.

Table 2. NO_X emission factors for tampered or malfunctioning vehicles and typical emitters

Typical emitter NO_X emission factor ($g\ NO_X/kg$ fuel)			Tampered or malfunctioning vehicle NO_X emission factor ($g\ NO_X/kg$ fuel)		
MY 2004-2009	**MY 2010-2015**	**MY 2016+**	**MY 2004-2009**	**MY 2010-2015**	**MY 2016+**
14.3	6.9	4.2	51.3	34.5	33.6

31 Roadmap model emission factors fall within the 95% confidence interval of the average emissions for measurements falling below the high-emitter threshold in the Canada remote sensing data. We use Roadmap emission factors because they are based on a more comprehensive dataset and were adjusted to reflect real-world conditions in North America.

32 International Council on Clean Transportation, "Roadmap Model Documentation"; According to the Roadmap model documentation, the HDV vehicle category represent heavy-duty trucks with a GVW > 15,000 kg (33,070 lb).

33 Historical sales data was used through 2023. Beyond 2023, Roadmap compound annual growth rates for Canada were applied. Statistics Canada, "Vehicle Registrations, by Type of Vehicle and Fuel Type," December 1, 2022, https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2310030801.

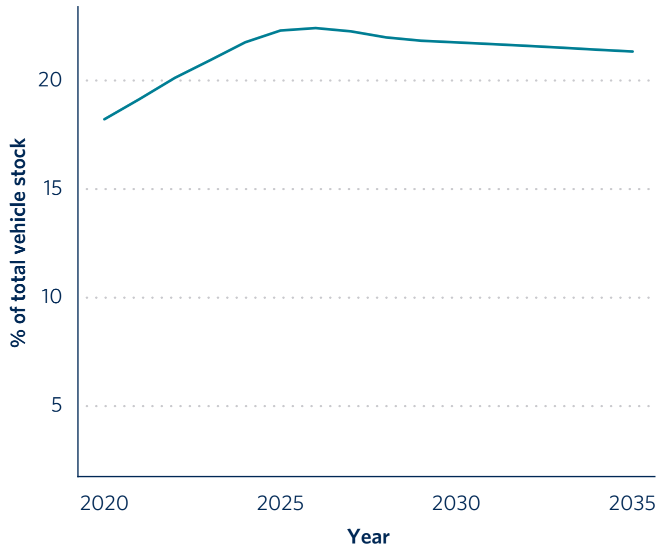

Figure 6. Estimated percentage of total vehicle stock that is tampered or malfunctioning by year

Figure 7 depicts the projected annual NO_x emissions from on-road diesel HDVs in Alberta through 2035. While both emissions from a fleet of only typical emitters and total emissions gradually decline between 2025 and 2035, an increasing share of emissions comes from tampered or malfunctioning vehicles, and these surpass the emissions of typical emitters beginning in 2026.

By 2035, the tampered or malfunctioning vehicles are projected to increase total emissions by 145% compared with the typical emissions from a clean fleet. This shows how tampered or malfunctioning vehicles severely undercut the potential emission reductions and air quality improvements associated with increasingly stringent emission standards. Emissions decrease by only 17% between 2025 and 2035 due to the substantial share of tampered or malfunctioning vehicles and their higher emissions compared with newer, cleaner vehicles with properly functioning emission control systems. However, if intervention occurs to address high-emitting vehicles starting in 2025—such as implementing federal regulations, stricter enforcement, and/or repairs of tampered vehicles—NO_x emissions could be reduced by up to 59% annually in 2035.

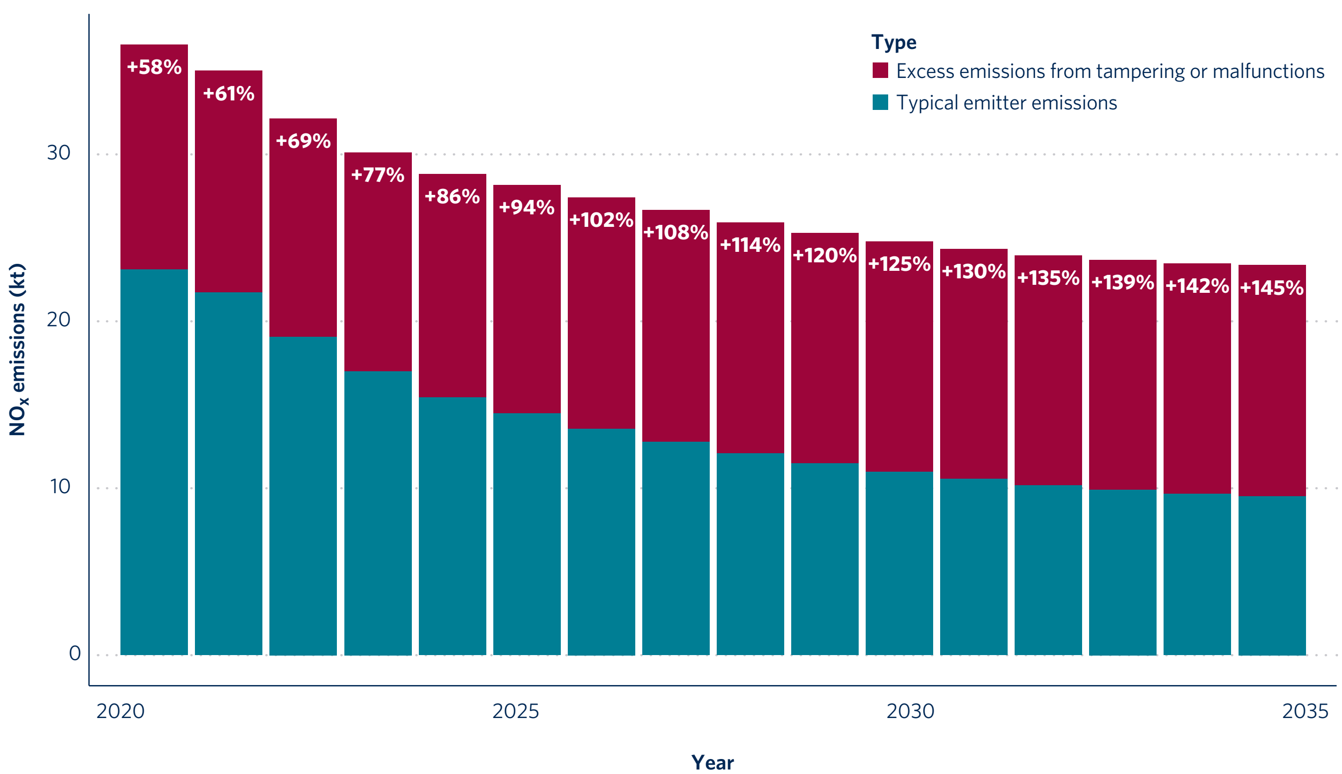

Figure 7. Projected NO_x emitted from typical emitters and from tampered or malfunctioning vehicles by year

PUBLIC HEALTH IMPACT

Tampered or malfunctioning HDVs in Alberta have public health consequences for the population. NO_X is a precursor pollutant to the secondary formation of particulate matter and ozone pollution, which contribute to premature deaths globally.[34] Exposure to air pollution causes an acute inflammatory response in the human body and that can contribute to multiple diseases, including lung cancer, stroke, and chronic obstructive pulmonary disease.[35] There is no threshold at which air pollution does not impact human health.[36]

Worldwide, NO_X pollution from diesel vehicles was associated with 107,600 premature deaths in 2015; of these, 35% were attributable to excess NO_X emissions, mostly caused by HDVs.[37] Health Canada estimated that air pollution, including but not limited to NO_X, contributed to 17,400 premature deaths in 2018, of which 2,100 were in Alberta. The monetized cost to Canada from these deaths was estimated at $139 billion (in 2020 Canadian dollars).[38]

Figure 8 shows the estimated annual health damages incurred due to excess NO_X pollution from tampered or malfunctioning HDVs in Alberta between 2024 and 2035. The health impacts are quantified considering the secondary formation of NO_X into particulate matter and ozone pollution from vehicle activity; this includes health impacts in other provinces that result from air pollution from Alberta. The annual health damages from these vehicles are estimated to be $338 million in 2024 and reach over $588 million (in 2024 Canadian dollars) in 2035 under the assumption that no new regulations or inspection and maintenance schemes to address HDV tampering and malfunctions are implemented in Alberta. The health damages per kt of NO_X emissions are projected to increase between 2024 and 2035 due to population growth and the increased share of older adults (see Table B2 in Appendix B). In total, projected cumulative excess health damages due to HDV tampering and malfunctions is $5.4 billion (in 2024 Canadian dollars). This represents an estimated 419 excess premature deaths between 2024 and 2035 (see Table B3 in Appendix B).

34 Prakash Thangavel, Duckshin Park, and Young-Chul Lee, "Recent Insights into Particulate Matter (PM2.5)-Mediated Toxicity in Humans: An Overview," *International Journal of Environmental Research and Public Health* 19, no. 12 (June 19, 2022): 7511, https://doi.org/10.3390/ijerph19127511.

35 GBD 2019 Risk Factors Collaborators, "Global Burden of 87 Risk Factors in 204 Countries and Territories, 1990-2019."

36 Lauren Pinault et al., "Risk Estimates of Mortality Attributed to Low Concentrations of Ambient Fine Particulate Matter in the Canadian Community Health Survey Cohort," *Environmental Health* 15, no. 1 (February 11, 2016): 18, https://doi.org/10.1186/s12940-016-0111-6.

37 Susan C. Anenberg et al., "Impacts and Mitigation of Excess Diesel-Related NO_X Emissions in 11 Major Vehicle Markets," *Nature* 545, no. 7655 (May 2017): 467–71, https://doi.org/10.1038/nature22086.

38 Health Canada, *Health Impacts of Air Pollution in Canada in 2018* (2024), https://www.canada.ca/en/health-canada/services/publications/healthy-living/health-impacts-air-pollution-2018.html.

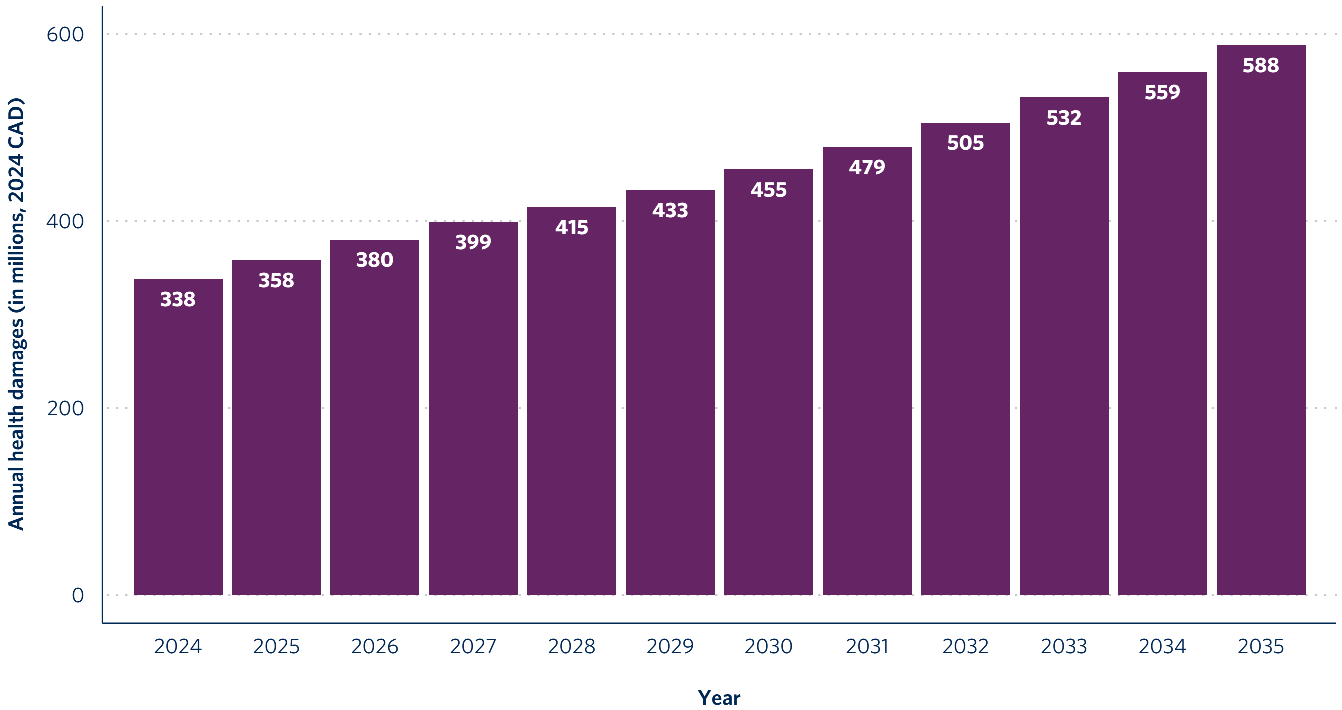

Figure 8. Estimated annual health damages from NO_x-related premature deaths due to excess emissions from HDVs likely tampered or malfunctioning in Alberta

COMPARISON WITH THE ICCT'S 2022 STUDY

The primary distinction between this study and the ICCT's 2022 study lies in the methodologies used to estimate the prevalence of tampering.[39] The 2022 study estimated tampering prevalence by adjusting the U.S. Environmental Protection Agency's tampered diesel pickup trucks study to reflect the Canadian fleet inventory.[40] To account for uncertainty, the authors created three scenarios: Low, Medium, and High, with the Low and High scenarios representing a 5% or 10% variation from the medium estimate. Incidences of HDV tampering were approximated to be one-third of that found in medium-duty vehicles for each scenario. In contrast, our study leverages remote sensing data to estimate the tampered or malfunctioning HDV prevalence in Alberta.

Table 3 lists the tampered or malfunctioning vehicle shares derived from the present study and those from the 2022 study; this share is the portion of all vehicles in the MY group that are age seven or older.[41] Our findings indicate that the tampered or malfunctioning vehicle share estimated in the present study is substantially higher than previously estimated. For HDVs subject to MY 2010 emission standards, the tampered or malfunctioning vehicle share from the present study represents a 2.75-fold increase compared with the Medium scenario projections and double the High scenario projections. One assumption in the 2022 study was that operators of HDVs would refrain from tampering to avoid being caught in places where tampering is regulated, given that HDVs often cross provincial boundaries and the border between Canada and the United States. However, the high prevalence of tampering or malfunctioning observed in the remote sensing data suggest otherwise.

39 Braun et al., *Heavy-Duty Emissions Control*.

40 United States Environmental Protection Agency, "Tampered Diesel Pickup Trucks: A Review of Aggregated Evidence from EPA Civil Enforcement Investigations," accessed November 17, 2024, https://www.epa.gov/enforcement/tampered-diesel-pickup-trucks-review-aggregated-evidence-epa-civil-enforcement.

41 Most warranties for HDVs expire after 7 years, and thus when all vehicles in a MY group reach this age, the maximum rate of tampered or malfunctioning HDVs is achieved.

Table 3. Estimated tampered or malfunctioning vehicle share by model year group for each scenario for diesel HDVs in Alberta

Scenario	Tampered or malfunctioning vehicle share		
	MY2004-2006	MY2007-2009	MY2010+
Remote sensing data	21.2%	21.2%	38.5%
2022 study – High	4.2%	17.5%	18.7%
2022 study – Medium	3.1%	13.1%	14.0%
2022 study – Low	2.1%	8.8%	9.3%

Figure 9 depicts the total annual NO_x emitted from typical emitters and the excess emissions from the tampered or malfunctioning vehicles modeled in each scenario over time. The trends observed in the present study are similar to all scenarios from the previous study, as all exhibit an overall decline in total NO_x emissions between 2020 and 2035.

While the previous study's Medium scenario suggested that excess emissions would not exceed emissions from a fleet of typical emitters through 2035, our projections show they will make up the majority of total emissions by 2030.

In 2030 and 2035, the excess emissions from tampering or malfunctions modeled using remote sensing data is approximately double what was estimated in the 2022 study's Medium scenario.

The emissions are annual projections and will accumulate over time if not addressed. As shown in Figure 10, by 2025, the cumulative emissions projected using the remote sensing data are 22% higher than that of the 2022 study's Medium scenario. By 2035, emissions projected using the remote sensing data are 31% higher than in the 2022 study's Medium scenario, or 105 kt of NO_x higher.

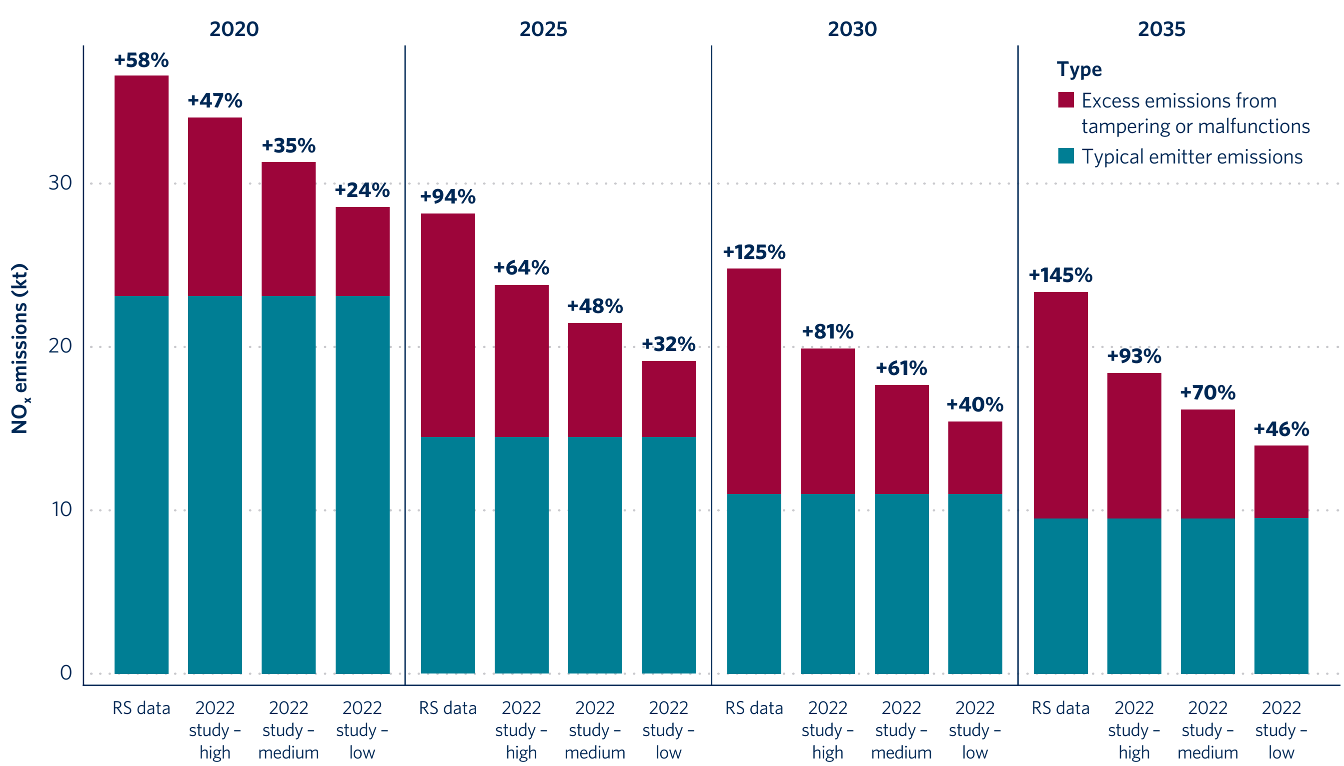

Figure 9. NO_x emitted from typical emitters and the excess emissions resulting from tampered or malfunctioning vehicles by year and scenario

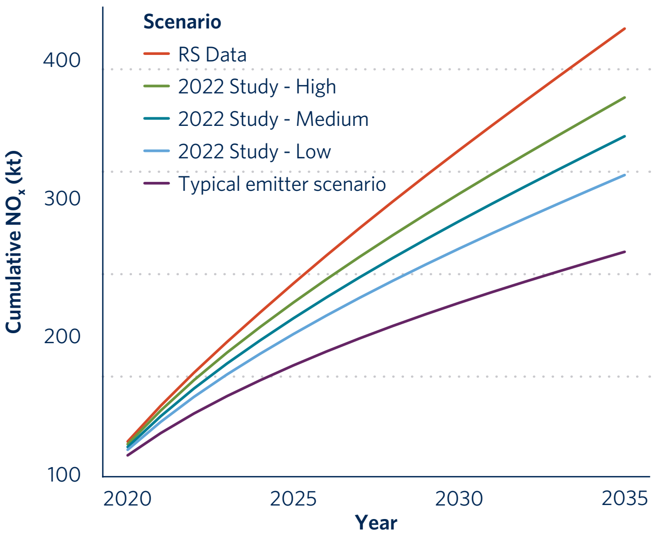

Figure 10. Cumulative NO_x emitted by scenario for diesel HDVs in Alberta

The public health impact of tampered or malfunctioning HDVs in Alberta is also greater than previously estimated. The cumulative health damages shown in Figure 11 were estimated under the same four scenarios depicted in Figure 10. The $5.4 billion in cumulative health damages by 2035 modeled using remote sensing data is approximately 50%–200% higher than previously defined tampering scenarios (see Table B4 in Appendix B).

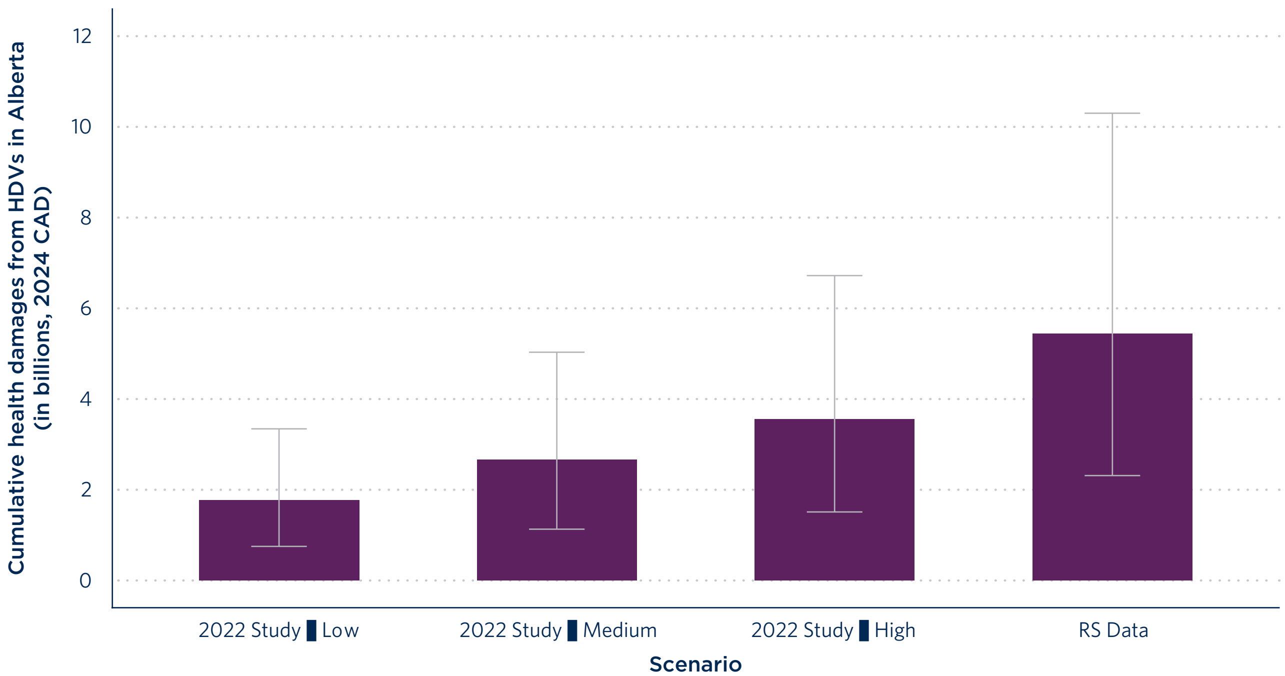

Figure 11. Cumulative health damages due to tampered or malfunctioning HDVs in Alberta between 2024 to 2035 under four different scenarios. The grey bars represent the 95% confidence range for the health damages.

CONCLUSIONS

Our findings highlight the need for policy interventions to mitigate elevated NO_X emissions from tampered HDVs. Utilizing 2022 Alberta remote sensing data, our estimates of tampered or malfunctioning tractor trucks in Alberta are significantly higher than estimated in a 2022 ICCT study of Canada. It is estimated that 38% of MY 2010 and later HDVs that are at least 7 years old and approximately 20% of HDVs of all MYs are tampered or malfunctioning. Assuming this trend continues, excess NO_X emissions from tampered or malfunctioning HDVs are projected to be nearly four times higher than those from a fleet consisting of only typical vehicles by 2035. This increase in emissions could result in excess health damages of $5.4 billion (in 2024 Canadian dollars) from premature deaths due to exposure to particulate matter and ozone pollution between 2024 and 2035.

These projections highlight that tampered or malfunctioning vehicles are an important focus for emission reductions. Policy measures in use in other countries can be established in Canada and Alberta to reduce the excess emissions and related health burdens and help attain national and provincial air quality objectives.

The comparatively higher rate of vehicles suspected to be tampered or malfunctioning in Alberta compared with Colorado suggests that anti-tampering legislation is an important piece in regulating NO_X emissions. Currently, federal legislation only prohibits tampering of emission control systems at the time of vehicle manufacture, sale, or import, and in-use vehicle regulation is designated solely to the provinces and territories.[42] Implementing a federal policy to prohibit all tampering would allow federal authorities to take enforcement actions against individuals or entities involved in the manufacturing, sale, or installation of equipment that disrupts vehicle emissions controls. This could include imposing financial penalties for each occurrence or sale of a defeat device. For example, in the United States, the Environmental Protection Agency resolved 31 civil enforcement cases related to tampering, enabled by the federal legislation.[43] Strong legislation at a federal level is important to prohibit the sale of products and services related to emission control tampering across all provinces.

In line with the practices of other Canadian provinces, Alberta can establish an inspection and maintenance program to monitor vehicle emissions to identify and address tampered or malfunctioning vehicles. Ontario's DriveON program is one example, and it requires an annual emissions test as a prerequisite for renewing vehicle registration for diesel HDVs that are at least 7 years old.[44] This not only helps enable the detection of malfunctions but could also serve as a deterrent against some types of tampering to decrease on-road NO_X emissions.

Remote sensing technology can also serve as an effective tool for robust market surveillance of high-emitting vehicles, and it provides valuable insights into emissions trends in the Alberta fleet over time. This approach was successful in Colorado, where rigorous remote sensing has aided in monitoring and reducing high emissions from tampered or malfunctioning vehicles.[45] Similarly, the California Air Resources Board implemented a smog check program for heavy-duty trucks to reduce harmful emissions and protect public health in communities most impacted by diesel air pollution.[46]

Finally, anti-tampering technologies can prevent, detect, and deter future tampering attempts. For example, in California and China, where on-board emissions monitoring regulations have been implemented, heavy-duty on-board diagnostic systems are mandatory; they collect and store NO_X emissions and fuel consumption data from the vehicle's sensors and this is then reported to the regulatory authority.[47] Introducing a comparable system in Canada would strengthen the ability to regulate vehicle tampering.

42 Canadian Environmental Protection Act, 1999 (S.C. 1999, c. 33), https://laws-lois.justice.gc.ca/eng/acts/c-15.31/page-16.html#docCont; Clean Air Strategic Alliance, "Recommendations to Reduce Non-Point Source Air Emissions in Alberta," March 2018, https://open.alberta.ca/dataset/1973e913-df86-476b-bfcb-7c32a3b56a50/resource/d993edf2-d8d4-42d7-87b2-b0d77c61732d/download/25232-casa-air-emission-report-web.pdf.

43 U.S. Environmental Protection Agency, "EPA Enforcement Annual Results FY 2020," accessed September 4, 2024, https://epa.maps.arcgis.com/apps/Cascade/index.html?appid=9dfe57199392498f872bac6bf2e4867c.

44 Government of Ontario, "DriveON: Emissions and Safety Inspection Program," Driving and roads, accessed September 4, 2024, http://www.ontario.ca/page/driveon-emissions-and-safety-inspection-program.

45 Colorado Department of Public Health & Environment, "Automobile Inspection and Readjustment (AIR) Program."

46 California Air Resources Board, "CARB Deploys 'Dirty Truck Detector' along Popular Fresno Truck Route | California Air Resources Board," accessed November 17, 2024, https://ww2.arb.ca.gov/news/carb-deploys-dirty-truck-detector-along-popular-fresno-truck-route.

47 California Air Resources Board, "CARB Gets 'REAL' to Further Cut Pollution from Diesel and Gas Vehicles | California Air Resources Board," accessed November 17, 2024, https://ww2.arb.ca.gov/news/carb-gets-real-further-cut-pollution-diesel-and-gas-vehicles.; Liuhanzi Yang and Hui He, *China's Stage VI Emissions Standard for Heavy-Duty Vehicles (Final Rule)* (International Council on Clean Transportation, 2018), https://theicct.org/publication/chinas-stage-vi-emissions-standard-for-heavy-duty-vehicles-final-rule/.

APPENDIX A. DERIVING TAMPERING OR MALFUNCTIONING PREVALENCE USING HIGH-EMITTER THRESHOLDS

Some studies have mitigated the drawbacks of using instantaneous remote sensing measurements for identifying high emitters by analyzing multiple measurements per vehicle.[48] However, the dataset from Alberta included only four diesel tractor trucks measured five times or more, making this approach impractical. To address the limitation of sample size, we propose an alternative methodology that involves establishing high-emitter thresholds. Two thresholds are determined: one for vehicles subject to the model year (MY) 2010 emission standard, and one for pre-MY 2010 vehicles.

For the high-emitter threshold applied to MY 2010 and newer vehicles, we used data from a California Air Resources Board study that employed portable emissions measurement systems on various MY 2010 and MY 2011 vehicles in California.[49] Under various vehicle load and driving conditions, 23 nitrogen oxides (NO_x) emission rates were derived for the cold-start segment of the test, which represented approximately 5% of the total trip duration. Cold starts were used as a proxy for high emitters because they are considered a worst-case scenario for NO_x emissions due to suboptimal engine temperatures that adversely affect exhaust emissions and engine performance.[50] The upper 95% confidence interval from the cold-start emission rates reported in the California Air Resources Board study was 21.0 g NO_x/kg fuel, and this is a conservative upper limit of what can be expected from a properly functioning vehicle. Applying this threshold to the MY 2010–2015 group in the Colorado remote sensing data reveals that 4.7% of measurements exceed this threshold; this aligns closely with the 5% expected during the cold-start period.

This threshold also aligns relatively well with other studies that identified high-emitting heavy-duty vehicles (HDVs). A 2013 remote sensing study in Vancouver, Canada developed a standards-based high emitter threshold of 12 g/kg NO_x for MY 2008 and newer HDVs.[51] Several European studies which used plume chasing and remote sensing also identified high-emitters for HDVs certified to a similar standard to MY 2010 and newer trucks in the United States. A 2019 Flemish study determined a high-emitter threshold of 10 g NO_x/kg, a 2020 Danish study determined a threshold of 7 g NO_x/kg, and a 2024 Scottish study determined a threshold of 24 g NO_x/kg.[52] Our threshold of 21.0 g NO_x/kg fuel, although slightly higher than found in two of the studies, remains within a conservative range of thresholds determined in other analyses.

For pre-MY 2010 vehicles, we used the methodology from a 2022 ICCT study that established emission factors for MY 1998 HDVs as a benchmark for tampering.[53] Emission control systems designed to limit NO_x are not present in MY 1998 vehicles, as these systems were not introduced until subsequent updates to the emission standards. Our analysis adopts the MY 1998 HDV diesel emission factor of 34.4 g NO_x/kg, derived from ICCT's Roadmap model.[54]

48 Kaylin Lee, Yoann Bernard, and Jonathon Cooper, *Assessment of Real-World Vehicle Emissions in Scotland in 2021* (TRUE Initiative, 2023), https://www.trueinitiative.org/publications/reports/assessment-of-real-world-vehicle-emissions-in-scotland-in-2021.

49 Misra et al., "In-Use NOx Emissions from Model Year 2010 and 2011 Heavy-Duty Diesel Engines."

50 Misra et al., "In-Use NOx Emissions from Model Year 2010 and 2011 Heavy-Duty Diesel Engines."

51 Envirotest Canada, *2013 Remote Sensing Heavy-Duty Diesel Vehicle Study* (Metro Vancouver, 2013), https://metrovancouver.org:443/services/air-quality-climate-action/emission-reduction-studies.

52 Kaylin Lee, Yoann Bernard, and Richard Riley, Assessment of Real-World Vehicle Emissions from Four Scottish Cities in 2022 (TRUE Initiative, 2022), https://www.trueinitiative.org/publications/reports/assessment-of-real-world-vehicle-emissions-from-four-scottish-cities-in-2022.; Hooftman et al., *Analysis of the 2019 Flemish Remote Sensing Campaign*; Ole Hertel et al., *Control of SCR-Systems Using Roadside Remote Sensing* (Aarhus University DCE – Danish Centre for Environment and Energy, 2020), https://dce.au.dk/udgivelser/vr/nr-351-400/abstracts/no-387-control-of-scr-systems-using-roadside-remote-sensing.

53 Braun et al., *Heavy-Duty Emissions Control*.

54 International Council on Clean Transportation, "Roadmap Model Documentation."

APPENDIX B. MODIFIED ROADMAP MODEL INPUTS

EMISSION FACTORS FOR TYPICAL EMITTERS AND TAMPERED OR MALFUNCTIONING VEHICLES

Table B1 presents the Roadmap emission factors for typical emitters alongside the tampered or malfunctioning multipliers derived from the remote sensing data, which were used to calculate tampered or malfunctioning vehicle emission factors. While the Roadmap model provides default emission factors based on U.S. standards—which Canada has adhered to since adopting the U.S. Environmental Protection Agency regulations in 1988—these factors do not account for the elevated emissions that occur under cold ambient temperature conditions. Additionally, our remote sensing data was collected during the summer season. To address this, we applied the same approach used in the 2022 ICCT report, which introduced cold-temperature multipliers to the Roadmap emission factors. These multipliers are 1.75 for pre-MY 2010 HDVs and 1.5 for MY 2010 and newer HDVs. The tampered or malfunctioning vehicle multipliers were calculated by dividing the average emission factors for tampered or malfunctioning vehicles by the Roadmap emission factors and they remain consistent across model years within each model year group.

PREVALENCE OF TAMPERED OR MALFUNCTIONING

Table B1. Emission factors for typical emitters and tampered or malfunctioning vehicles with cold temperature multipliers

Model year	Typical emitter emission factor (g NO_x/kg fuel)	Typical emitter emission factor with cold temperature multiplier (g NO_x/kg fuel)	Tampered or malfunctioning vehicle multiplier	Tampered or malfunctioning vehicle emission factor with cold temperature multiplier
1998	45.5	79.7		
1999	35.2	61.5		
2000	35.1	61.4		
2001	35.1	61.4		
2002	35.1	61.5		
2003	16.6	29.1		
2004	16.6	29.1	3.1	89.7
2005	16.6	29.1	3.1	89.7
2006	16.7	29.1	3.1	89.7
2007	11.7	20.5	4.4	89.7
2008	12.1	21.1	4.2	89.7
2009	11.9	20.9	4.3	89.7
2010	7.8	11.7	4.4	51.9
2011	7.5	11.3	4.6	51.9
2012	7.0	10.5	5.0	51.9
2013	6.0	9.1	5.7	51.9
2014	6.4	9.6	5.4	51.9
2015	6.9	10.3	5.0	51.9
2016	6.3	9.5	5.5	51.9
2017	5.6	8.4	6.2	51.9
2018	4.5	6.8	7.6	51.9
2019	4.5	6.7	7.7	51.9
2020	4.5	6.7	7.7	51.9
2021	6.1	9.2	5.6	51.9
2022	4.7	7.1	7.3	51.9
2023	4.8	7.1	7.3	51.9
2024	4.6	6.9	7.5	51.9
2025	4.6	6.9	7.5	51.9
2026	3.5	5.3	9.9	51.9
2027	3.4	5.1	10.2	51.9
2028	3.4	5.1	10.1	51.9
2029	3.4	5.1	10.1	51.9
2030	3.4	5.1	10.1	51.9
2031	3.4	5.2	10.0	51.9
2032	3.5	5.2	10.0	51.9
2033	3.5	5.2	10.0	51.9
2034	3.5	5.2	9.9	51.9
2035	3.5	5.2	9.9	51.9

VEHICLES BY AGE

To forecast tampered or malfunctioning prevalence by MY group over time, we define the tampered or malfunctioning rate as a function of vehicle age. We assume that as MY 2016 and newer vehicles age, they will reach similar tampered or malfunctioning levels as the MY 2010–2015 group.

To model this, we define a tampered or malfunctioning vehicle share (Table 3) that represents the maximum tampered or malfunctioning prevalence for each MY group. We then incorporate assumptions about how the percentage of tampered or malfunctioning vehicles increases as vehicles age. Figure B1 illustrates the function used to estimate the prevalence of tampering or malfunctioning. In this model, "zero-mile emissions" indicate a 0% tampering rate for new vehicles and the "final emissions rate due to tampering" reflects the maximum prevalence of tampering. This approach is based on the MOVES3 model and was similarly applied in the 2022 ICCT study to track changes in tampering prevalence over time.[55]

Also in line with the 2022 ICCT study's methodology, we adapt the definitions of the "end of warranty period" and "end of useful life" ages to set the beginning and end period of the linearly increasing tampered or malfunctioning prevalence. We adopted a linear growth assumption from ages 4 to 7 years that reflects a period of rising tampered or malfunctioning rates. This choice is supported by several factors. For one, vehicles generally experience heightened maintenance needs and cost-saving behaviors after their warranty period, leading to increased tampering or malfunctions. Additionally, the remote sensing data shows a significant rise in high emitters from age 4 to 7 years, with a peak at age 7 years, and a subsequent plateau, indicating that most tampering or malfunctions occur during this time frame. This methodology is also supported by a U.S. Environmental Protection Agency study on tampered diesel pickup trucks, which found that over 90% of tampering occurs within the first 7 years of a vehicle's service life.[56]

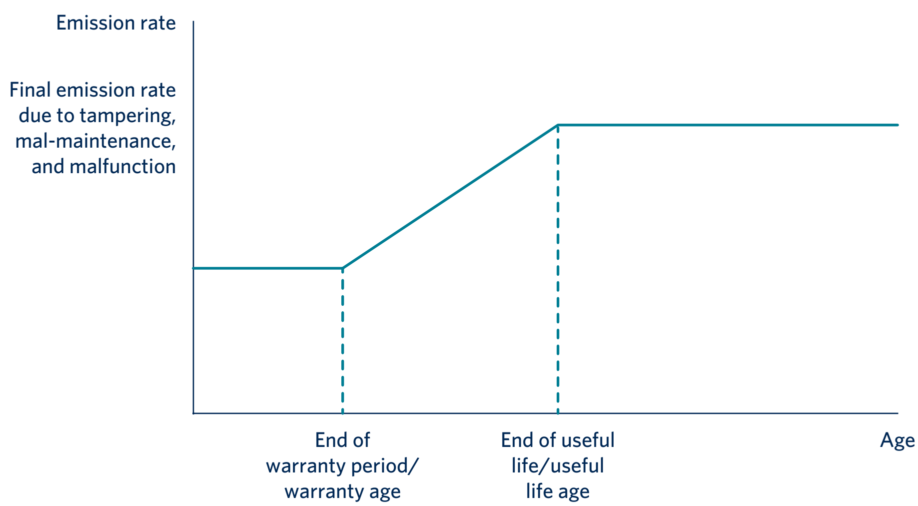

Figure B1. The implementation of age effects according to MOVES3 technical report

55 U.S. Environmental Protection Agency, *Exhaust Emission Rates for Heavy-Duty Onroad Vehicles in MOVES3* (November 2022), https://www.epa.gov/sites/default/files/2020-11/documents/420r20018.pdf.

56 U.S. Environmental Protection Agency, "Tampered Diesel Pickup Trucks."

MODELING THE PUBLIC HEALTH IMPACT OF HDV TAMPERING OR MALFUNCTIONS IN ALBERTA

After running the Roadmap model to establish the total NO_x emissions from diesel HDVs in Alberta, the Fast Assessment of Transport Emissions (FATE) model was used to determine the excess premature deaths and health damages from these emissions. The FATE model was used to establish linear regression equations to estimate the premature deaths and health damages per kt increase in NO_x. These regression equations were applied to the output of the Roadmap model to calculate the excess premature deaths and health damages from tampered or malfunctioning HDVs.

The FATE model calculates premature deaths due to exposure to ambient fine particulate matter and ozone, based on the Global Burden of Disease methodology and accounts for projected changes in population size, age distribution, and baseline disease rates. The main health outcomes assessed are stroke, ischemic heart disease, chronic obstructive pulmonary disease, lower respiratory infection, lung cancer, and diabetes mellitus type 2.[57] Health damages represent the monetized value of premature deaths, determined in FATE using the Value of Statistical Life, Viscusi method, adjusted to Canada.[58] To establish the premature deaths and health damages per kt increase in NO_x between 2024 and 2035, the FATE model was run repeatedly under numerous emission perturbation scenarios in Alberta, ranging from a 100% decrease to 100% increase in annual ambient NO_x. For each year, a simple linear regression was performed between NO_x perturbations and health damages, to establish a yearly linear regression equation that estimates health damages incurred from a given value of NO_x emissions. The same approach was taken to establish a yearly linear regression equation that estimates the number of premature deaths from a given value of NO_x emissions.

These yearly linear regression equations, referred herein as damage functions, allowed for the calculation of premature deaths and health damages per kt increase in NO_x from diesel HDVs in Alberta. The yearly premature deaths and health damages from diesel HDVs in Alberta were calculated by applying these damage functions to the NO_x emissions values from the Roadmap model, in other words, kt of NO_x from diesel HDVs in Alberta. The excess health damages for each year under each scenario were extracted from the total by subtracting the health damages in the baseline scenario, which assumes no tampered or malfunctioning HDVs.

Finally, the excess damages were converted from 2020 U.S. dollars to 2024 Canadian dollars using monthly inflation factors and the average conversion factor of 1.35 for 2024 as of May 2024.[59] The analysis revealed that the excess health damages per kt increase of NO_x in Alberta in 2024 is $25.3 million in 2024 Canadian dollars. By 2035, the health damages per kt increase in NO_x would be 42.5 million under the assumption that tampering/malfunctioning remains unregulated (Table B2).

Table B2. Health damages premature deaths per kt increase of NO_x between 2024 and 2035

Year	Damages per kt increase in NO_x (in millions, 2024 CAD)
2024	25.3
2025	26.2
2026	27.4
2027	28.7
2028	30.1
2029	31.4
2030	33.0
2031	34.8
2032	36.7
2033	38.6
2034	40.6
2035	42.5

57 International Council on Clean Transportation, "FATE *Documentation*."

58 International Council on Clean Transportation, "FATE *Documentation*."

59 U.S. Bureau of Labour Statistics, "CPI Inflation Calculator," 2024, https://www.bls.gov/data/inflation_calculator.htm; Exchange Rates UK, "US Dollar (USD) to Canadian Dollar (CAD) Exchange Rate History," August 11, 2024, https://www.exchangerates.org.uk/USD-CAD-exchange-rate-history.html.

Table B3. Cumulative excess premature deaths due to tampered or malfunctioning HDVs in Alberta between 2024 and 2035 under four scenarios

Scenario	Excess premature deaths from 2024 to 2035		
	Lower estimate	Mean estimate	Upper estimate
2022 study - Low	58	136	258
2022 study - Medium	87	205	388
2022 study - High	117	274	518
2024 – Remote sensing data	178	419	793

Table B4. Cumulative excess health damages (in 2024 billion Canadian dollars) from premature deaths due to tampered or malfunctioning HDVs in Alberta between 2024 and 2035 under four scenarios

Scenario	Lower estimate	Mean estimate	Upper estimate
2022 study - Low	0.8	1.8	3.3
2022 study - Medium	1.1	2.7	5
2022 study - High	1.5	3.6	6.7
2024 – Remote sensing data	2.3	5.4	10.3

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