THE REAL URBAN EMISSIONS INITIATIVE

Air quality and health impacts of diesel truck emissions in New York City and policy implications

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FIA Foundation and the International Council on Clean Transportation (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

Air pollution from diesel truck emissions is an environmental justice issue. In New York City, heavy-duty diesel vehicles represent a small portion of total vehicle activity but are responsible for roughly half of on-road transport nitrogen oxides (NO_x) and fine particulate matter ($PM_{2.5}$) emissions and the associated health impacts, including premature mortality. This analysis finds that people of color living in New York City are exposed to 5% more $PM_{2.5}$ attributable to diesel trucks operating in the city than average, while non-Latino white residents are exposed to 10% less. These inequities in air pollution exposure contribute to racial disparities in health outcomes.

Reducing diesel truck emissions, particularly in the most heavily burdened communities, is a pressing policy issue in New York City. Overall NO_x and $PM_{2.5}$ emissions have declined as new trucks are equipped with emission control systems to meet U.S. Environmental Protection Agency standards. However, even new diesel trucks can emit high levels of NO_x in excess of certification limits during on-road operation, particularly during low-speed urban driving conditions. Additionally, freight volumes in New York City are projected to increase by 68% by 2045. Effective city and state policies are necessary to help ensure a continued decline of diesel truck emissions.

This emissions and health impacts analyses uses real-world data, reflecting the gap between certified and on-road diesel truck emissions. We find that older diesel trucks are responsible for a large share of total emissions and resulting premature mortalities. Pre-2007 engine model year (MY) trucks make up 6%–10% of the fleet but contribute 64%–83% of diesel truck tailpipe $PM_{2.5}$ emissions. These results highlight the importance of diesel particulate filters (DPFs), which became near universal starting with 2007 engine MY trucks due to a tightening of federal emission regulations. Selective catalytic reduction (SCR) systems, used to control NO_x emissions, increased in prevalence in 2010 as the EPA fully introduced a lower NO_x limit. However, it was not until after 2015 that newly manufactured engines produced average real-world NO_x emissions close to the regulatory limit. Despite being certified to the same NO_x emissions limit, a 2010 engine MY truck has approximately double the health impact per vehicle-mile compared to a post-2015 engine MY truck. Figure ES-1 summarizes the monetary damages associated with premature mortalities attributable to diesel truck NO_x and $PM_{2.5}$ emissions by engine MY group, which can guide the development of effective emission reduction policies.

Shifting to newer, cleaner vehicles is a highly effective strategy to reduce emissions. Replacing a pre-2010 engine MY truck with a new diesel truck reduces health

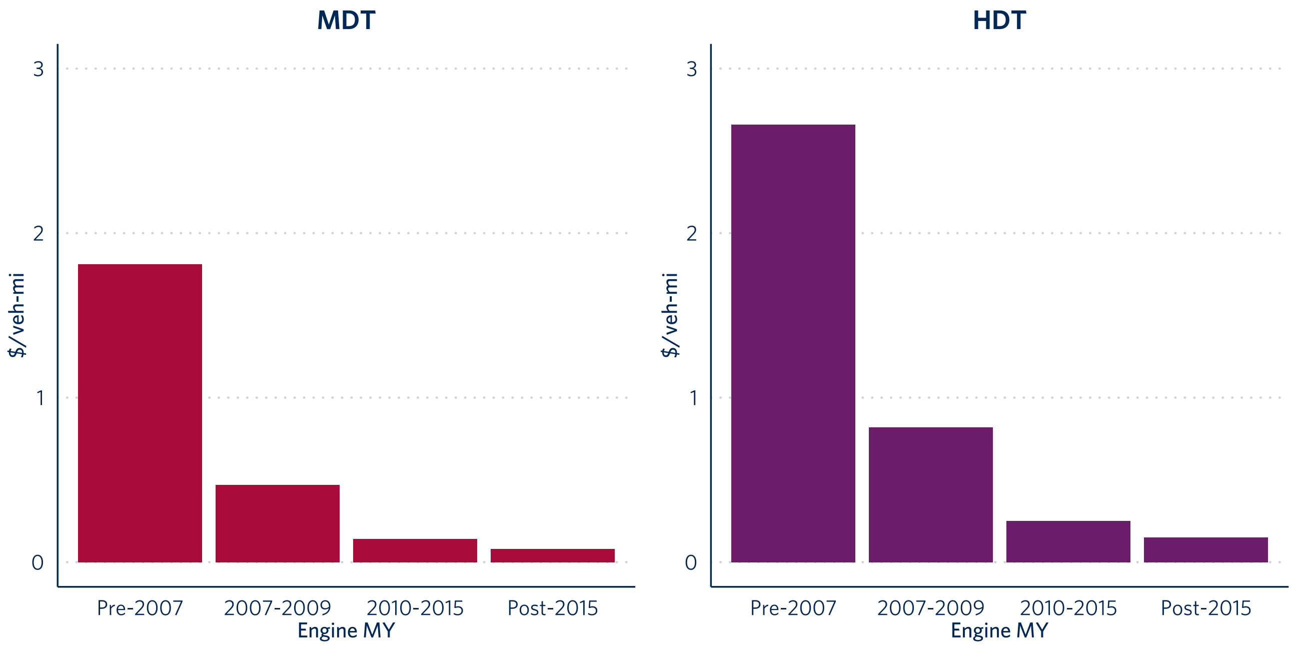

Figure ES-1. Mortality-based damages of diesel trucks operating in New York City by engine model year (MY) group. Medium-duty trucks (MDT) have a gross vehicle weight rating between 10,000 and 33,000 lb, and heavy-duty trucks (HDT) have a gross vehicle weight rating above 33,000 lb.

impacts by 81%–96%. Given the significant damages associated with these older vehicles, it is important to take an active approach in reducing their share of the fleet as opposed to waiting for natural fleet turnover.

While shifting to newer trucks is an effective short-term plan to achieve large emission reductions, long-term plans must focus on significant shifts to zero-emission freight options. Accelerating the transition to zero-emission alternatives should be a major policy focus for achieving climate goals and continuing to reduce health impacts as freight volumes increase.

The truck emission reduction policies considered in this paper, including those outlined in New York City's Smart Truck Management Plan, are summarized below in Table ES-1. Based on the analyses using real-world emissions data, we outline a set of key policies recommendations.

Table ES-1. Summary evaluation of policies to reduce diesel truck emissions in New York City

		Increasing potential emissions reduction →				
Policy	**Status**	**Operate in reduced congestion**	**Reduce individual high-emitting vehicles**	**Reduce high-emitting pre-2010 vehicles**	**Accelerate transition to zero-emission alternatives**	**Potential to address exposure disparities**
Off-hour delivery program	Implemented, planned expansion	✓				●
CBD tolling Uniform charge for all trucks	Planned	✓				●
I/M program Update testing methods, add roadside in-use testing	TRUE recommendation		✓			●●
Weight restriction enforcement	Implemented, planned expansion		✓			●●
Clean Trucks Program Expanded eligibility for pre-2010 diesel trucks	TRUE recommendation			✓		●●●
IBZ and port restrictions Emissions-based access restriction	TRUE recommendation			✓	✓	●●●
CBD tolling Emissions-based charge	TRUE recommendation	✓		✓	✓	●
Zero-emission zone	TRUE recommendation				✓	●●
Clean Trucks Program Increased rebates for battery electric vehicles	TRUE recommendation				✓	●●
Publicly accessible charging infrastructure	Planned				✓	●●
Shift to e-cargo bike deliveries Infrastructure improvements, access restrictions	Implemented, planned expansion				✓	●
Rebates for zero-emission replacements to non-road diesel engines	Planned				✓	●●●

Potential to address exposure disparities:
● = emissions reductions primarily in non-environmental justice (EJ) areas
●● = emissions reductions across the city, including in heavily burdened EJ areas
●●● = emissions reductions focused in heavily burdened EJ areas

Drastically reduce the share of pre-2010 engine MY diesel trucks to maximize emission reductions in the shortest amount of time.

- Update access restrictions at ports to restrict pre-2010 engine MY drayage truck operation. Implement similar access restrictions in other industrial areas where feasible.
- Implement emissions-based truck tolls through the Central Business District Tolling Program to incentivize shifts to cleaner vehicles.
- Expand the Clean Trucks Program eligibility, which currently offers rebates for trucks operating in defined industrial areas. Offer funding for vehicles operating throughout the city and increase the rebates for the cleanest vehicles to increase program participation.

Update inspection and maintenance program methods to effectively identify high emitters among newer diesel vehicles.

- Update the New York State emissions inspection procedure to effectively detect malfunctions using on-board diagnostics, particle number measurements, and other updated inspection methods.
- Implement in-use testing using roadside emissions monitoring systems to identify individual high-emitting vehicles for repair.

Focus emission reduction policies on the environmental justice areas currently experiencing the largest health burdens to reduce racial disparities in exposure to $PM_{2.5}$.

- Set timelines for emissions-based restrictions at ports and other industrial areas, with a target for fully zero-emission operation.
- Expand support to replace nonroad diesel engines in industrial areas with zero-emission alternatives, including transport refrigeration units (TRUs) and port equipment.

Accelerate the shift to zero-emission vehicles to achieve the largest emission reductions and to achieve climate goals.

- Commit to implementing zero-emission zones (ZEZs) or areas, taking lessons and best practices from programs and pilots implemented in cities across the world.
- Increase rebates for battery-electric vehicles through the Clean Trucks Program.
- Increase investments in publicly accessible charging infrastructure for trucks.
- Continue to incentivize zero-emission last-mile delivery through infrastructure improvements, route management, and dedicated curb space.

These policies, combined with continued research, stakeholder engagement, community input, and ongoing monitoring of implemented policies, can help New York City effectively transition to a cleaner, more sustainable freight system.

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INTRODUCTION

Traffic-related emissions are a major contributor to ambient air pollution in New York City. Fine particulate matter ($PM_{2.5}$), one of the main pollutants associated with adverse health outcomes, is estimated to be the cause of approximately 2,000 premature mortalities in New York City in 2017.[1] Heavy-duty diesel vehicles emit $PM_{2.5}$ as well as other pollutants, such as nitrogen oxides (NO_x), that lead to the formation of $PM_{2.5}$.

Heavy-duty vehicles represent a relatively small share of vehicle activity, but their emissions and associated health impacts are significant. As of 2017, heavy-duty diesel vehicles made up 6% of the vehicle activity but contributed 52% of on-road vehicle tailpipe $PM_{2.5}$ emissions and 51% of on-road vehicle NO_x emissions in New York City.[2] Diesel truck emissions result in inequitable health outcomes, as freight corridors and industrial areas are disproportionately located near low-income communities and communities of color.[3]

U.S. Environmental Protection Agency regulations have helped to significantly reduce the tailpipe emissions of new diesel vehicles in recent years, reducing overall health burdens. Current NO_x and $PM_{2.5}$ limits are both 96% lower than 1991 limits,[4] and new diesel trucks are equipped with emission control systems to limit tailpipe emissions and meet EPA standards. Total tailpipe emissions are declining as more truck owners replace their higher-emitting older diesel trucks with newer trucks equipped with emission control technologies.

However, emissions of new diesel trucks operating in real-world conditions often exceed certification limits. Intended air quality improvements are not fully realized as average NO_x emissions during on-road operation are generally higher than emissions during laboratory testing. This discrepancy can be partially attributed to certification procedures that test vehicles over a limited range of operating conditions. Compliance testing almost entirely excludes emission measurements during idling and low-speed operation.[5] As a result, diesel trucks driving in urban areas have particularly high excess emissions, with operation below 25 mph resulting in average NO_x emissions at five times the regulatory limit.[6]

In addition to differences between testing and real-world driving conditions, individual high-emitting vehicles contribute to excess emissions. New diesel vehicles' low emission rates are reliant on functional control technology. A vehicle may have deteriorated, malfunctioning, or tampered control systems that result in emissions many times above the regulatory limits. A relatively small share of high-emitting vehicles can have a large impact on average emissions.

These trends of excess emissions during in-use operation highlight the importance of using real-world data to develop effective policies to reduce vehicle-related air pollution. The Real Urban Emissions (TRUE) Initiative was established 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. In 2020, TRUE developed an extensive database of real-world emissions data for vehicles operating in the United States, compiling remote sensing data from several sources.[7] Previous TRUE work used this database to analyze general trends of U.S. heavy-duty vehicle real-world emissions, quantifying excess NO_x emissions, showing the impact of speed, and highlighting differences by engine model year (MY).[8]

Although an analysis of the database alone provides useful information for developing policies, we aim to provide additional detail by combining the real-world

1 "$PM_{2.5}$-attributable deaths" (2015–2017), Environment & Health Data Portal, New York City Department of Health and Mental Hygiene, accessed August 23, 2021, https://a816-dohbesp.nyc.gov/IndicatorPublic/VisualizationData.aspx?id=2108,4466a0,103,Summarize.

2 "2017 National Emissions Inventory (NEI) Data," U.S. Environmental Protection Agency, accessed January 2021, https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data.

3 Jean D. Brender, Juliana A. Maantay, and Jayajit Chakraborty, "Residential Proximity to Environmental Hazards and Adverse Health Outcomes," *American Journal of Public Health* 101, no. Suppl 1 (December 2011): S37–52, https://doi.org/10.2105/AJPH.2011.300183; Sacoby Wilson, Malo Hutson, and Mahasin Mujahid, "How Planning and Zoning Contribute to Inequitable Development, Neighborhood Health, and Environmental Injustice," *Environmental Justice* 1, no. 4 (December 2008): 211–16, https://doi.org/10.1089/env.2008.0506.

4 U.S. Environmental Protection Agency, "Heavy-Duty Highway Compression-Ignition Engines and Urban Buses: Exhaust Emission Standards," 2016, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100O9ZZ.pdf.

5 Francisco Posada, Huzeifa Badshah, and Felipe Rodriguez, *In-use NOx emissions and compliance evaluation for modern heavy-duty vehicles in Europe and the United States*, (ICCT: Washington, DC, 2020), https://theicct.org/publications/inuse-nox-hdvs-us-eu.

6 Huzeifa Badshah, Francisco Posada, and Rachel Muncrief, *Current state of NOx emissions from in-use heavy-duty diesel vehicles in the United States,* (ICCT: Washington, DC, 2019), https://theicct.org/publications/nox-emissions-us-hdv-diesel-vehicles.

7 Yoann Bernard et al., *Development and application of a United States real-world vehicle emissions database,* (ICCT: Washington, DC, 2020), https://theicct.org/sites/default/files/publications/US-TRUE-emissions-database-oct2020.pdf.

8 TRUE Initiative, "Remote sensing of heavy-duty vehicle emissions in the United States" (2020), https://theicct.org/sites/default/files/publications/US-TRUE-RS-HDV-emisions-oct2020.pdf.

emissions data with New York City–specific data. In this analysis, we model New York City diesel truck emissions and the resulting air quality impacts at a high spatial resolution. From these results, we quantify the human health impacts of diesel truck emissions. Additionally, we analyze differences in exposure to $PM_{2.5}$ across different populations and discuss the environmental justice implications.

While past New York City studies have modeled health impacts of heavy-duty vehicles,[9] this study introduces the use of an emissions inventory based on real-world vehicle emissions data to perform a local-level analysis. The fine spatial scale allows for a detailed analysis of the health impacts of activity in different neighborhoods and policies to reduce health disparities by race and income. Additionally, we report emissions and health impacts broken down by engine MY groups, informing policies intended to reduce diesel truck emissions as well as long-term plans to shift toward zero-emission freight options.

POLICY BACKGROUND

Past New York City studies have highlighted the environmental justice issues associated with emissions and air quality, with higher rates of premature mortality and respiratory and cardiovascular hospitalizations in areas with high rates of poverty.[10] Disparities in exposure to $PM_{2.5}$ attributable to trucks and buses by neighborhood poverty level are more pronounced compared to disparities in exposure to $PM_{2.5}$ from other sources.[11] The resulting health burdens are large, with trucks and buses accounting for half of the traffic-pollution-related premature mortalities.[12]

These health impacts and inequities were one motivation for the creation of the Hunts Point Clean Trucks Program. Hunts Point is one heavily impacted area, with links between the large volumes of truck activity and neighborhood childhood asthma rates.[13] The Clean Trucks Program gave funds to owners of older diesel trucks to replace their higher-emitting vehicles with newer diesel trucks or alternative fuel vehicles. The program has since expanded into the New York City Clean Trucks Program, offering funds for eligible trucks that regularly travel in any of the defined industrial business zones (IBZs) in the four outer boroughs.[14]

Additional policies to ensure that heavy-duty vehicle emissions continue to decline are particularly important as freight volumes increase. By 2045, total freight weight in New York City is projected to increase by 68%.[15] Currently, trucks are the main mode for freight transport in New York City, accounting for 88% of deliveries.[16] New York City Department of Transportation (NYC DOT) recently published the Smart Truck Management Plan, which includes policies to reduce truck emissions. In addition to the Clean Trucks Program, zero-emission last mile delivery solutions are highlighted in the plan as freight trends show an increase in home deliveries. Other policies also aim to reduce congestion and emissions, such as incentivized shifts to off-hour delivery and the Central Business District Tolling Program. Additionally, New York City has committed to reducing greenhouse gases by 80% by 2050 in its Roadmap to 80 x 50 plan,[17] a goal that is intertwined with reducing health impacts of vehicle emissions. In this study, we analyze the impacts of these policies and add policy recommendations to continue the reduction of truck emissions in New York City.

STUDY OVERVIEW

This study models NO_x and $PM_{2.5}$ emissions from diesel trucks operating in New York City and the associated health impacts. Results from this modeling exercise are

9 Iyad Kheirbek et al., "The Contribution of Motor Vehicle Emissions to Ambient Fine Particulate Matter Public Health Impacts in New York City: A Health Burden Assessment," *Environmental Health* 15, no. 1 (December 2016): 89, https://doi.org/10.1186/s12940-016-0172-6; Sarah Johnson et al., "Assessing Air Quality and Public Health Benefits of New York City's Climate Action Plans," *Environmental Science & Technology* 54, no. 16 (August 18, 2020): 9804–13, https://doi.org/10.1021/acs.est.0c00694.

10 Iyad Kheirbek et al., "Air pollution and the health of New Yorkers: The impact of fine particles and ozone," New York City Department of Health and Mental Hygiene (2011), https://www1.nyc.gov/assets/doh/downloads/pdf/eode/eode-air-quality-impact.pdf.

11 Kheirbek et al., "The Contribution of Motor Vehicle Emissions to Ambient Fine Particulate Matter Public Health Impacts in New York City."

12 Kheirbek et al.

13 T. Suvendrini Lena et al., "Elemental Carbon and $PM_{2.5}$ Levels in an Urban Community Heavily Impacted by Truck Traffic.," *Environmental Health Perspectives* 110, no. 10 (October 2002): 1009–15.

14 "About the NYC Clean Trucks Program," NYC Clean Trucks Program, accessed August 23, 2021, https://www.nycctp.com/about/.

15 New York City DOT, "Delivering New York: A smart truck management plan for New York City" (2021), https://www1.nyc.gov/html/dot/downloads/pdf/smart-truck-management-plan.pdf.

16 New York Metropolitan Transportation Council, "Regional Freight Plan 2018–2045" (2018), https://www.nymtc.org/Portals/0/Pdf/RTP/Plan%202045%20Final%20Documents/Plan%202045%20Individual%20Appendices/Appendix%208_Regional%20Freight%20Plan.pdf.

17 New York City Mayor's Office of Sustainability, "New York City's roadmap to 80 x 50" (2016), https://www1.nyc.gov/assets/sustainability/downloads/pdf/publications/New%20York%20City's%20Roadmap%20to%2080%20x%2050_Final.pdf.

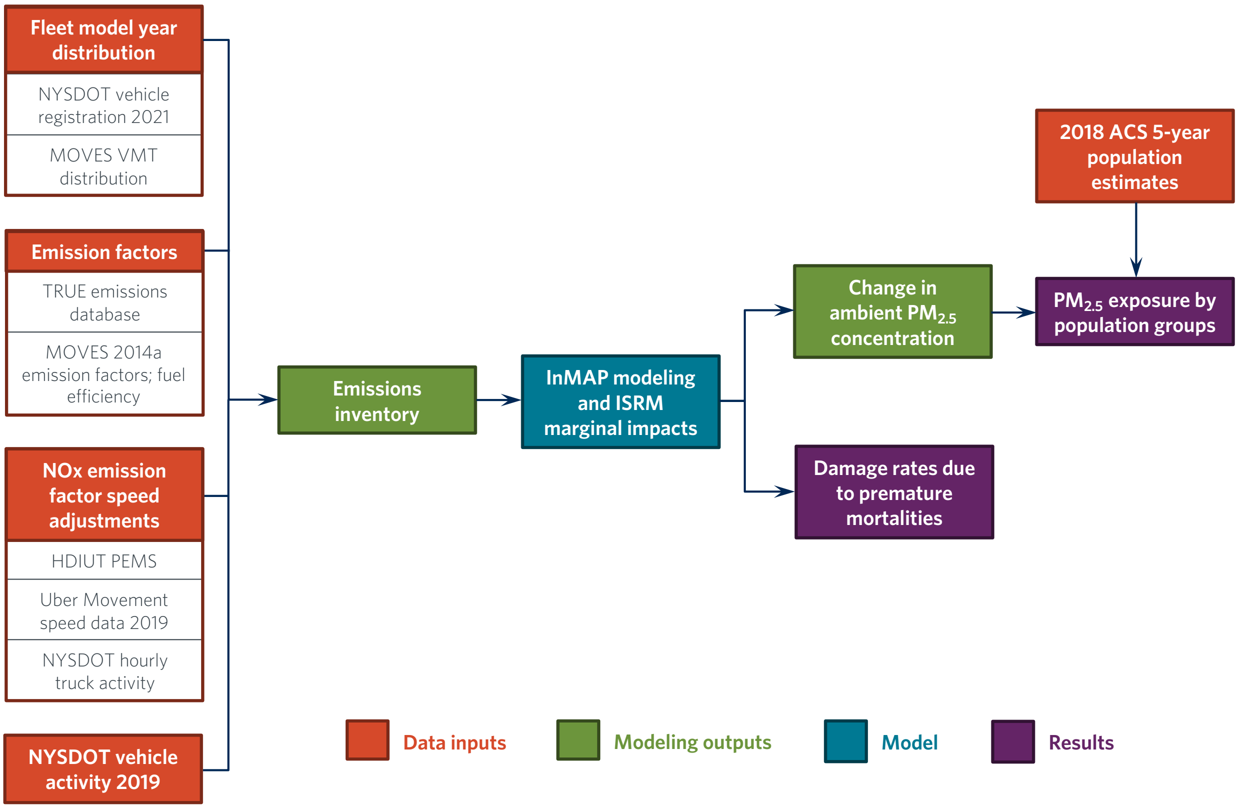

Figure 1. Overview of modeling steps and data sources.

used to provide insight into policies impacting diesel freight transport in the city. Our modeling approach involves two major components: developing a baseline emissions inventory for diesel trucks operating in New York City and analyzing the air quality and health impacts of these emissions. The steps of the analysis are summarized in this section and in Figure 1. A detailed description of the modeling approach can be found in the Appendix.

To develop the emissions inventory, average emission factors are calculated from an estimated distribution of New York City truck engine MYs and emissions data, including real-world measurements from the TRUE U.S. database. Emission factors are developed for two vehicle classes—medium-duty trucks (MDTs) and heavy-duty trucks (HDTs)—with examples of each shown in Table 1. The emission factors are combined with road segment-level speed and activity data to develop spatial emissions inventories of NO_x and $PM_{2.5}$ from diesel trucks.

Air quality impacts are modeled using the Intervention Model for Air Pollution (InMAP), a reduced-complexity air quality model. The emissions inventories are used as inputs to estimate the ambient $PM_{2.5}$ concentrations attributable to diesel truck emissions across the city. We examine disparities in exposure to ambient $PM_{2.5}$ attributable to diesel truck emissions by resident populations' race and ethnicity and socioeconomic status. Additionally, we analyze the health impact of diesel trucks by engine MY, examining the results in relation to current and proposed New York City policies to reduce diesel truck emissions.

This analysis focuses on policies relating to diesel trucks operating within New York City. These analyses rely on spatial truck activity data, which provides traffic count estimates on public roads but likely does not capture all activity within industrial areas. To account for this, we examine the potential impact of emissions from IBZs in our policy analysis, considering the surrounding environmental justice areas.

Additionally, although truck emissions in neighboring areas add to air pollution, our recommendations in this paper are primarily limited to New York City policies. We analyze medium- and heavy-duty diesel freight trucks, so city policies on refuse trucks and state policies on buses are not included. Future studies could

Table 1. MDT and HDT classifications by gross vehicle weight rating and example vehicles

TRUE analysis classifications	Heavy-duty vehicle examples		
MDT (10,000 – 33,000 lb)	 Pickup truck (>10,000 lb)[a]	 Van[b]	 Box truck[c]
HDT (>33,000 lb)	 Fuel truck[d]	 Tractor-trailer[e]	 Dump truck[f]

[a] "2017 Ford F-350 crew cab front," Wikimedia Commons, accessed August 30, 2021, https://commons.wikimedia.org/wiki/File:2017_Ford_F-350_Crew_Cab_front_4.28.18.jpg.
[b] "2008-2010 Dodge Sprinter 2500," Wikimedia Commons, accessed August 30, 2021, https://commons.wikimedia.org/wiki/File:2008-2010_Dodge_Sprinter_2500.jpg.
[c] "Box truck mobile detailing," Mobile Detailing Pros, accessed August 30, 2021, https://mobiledetailingpros.com/product/box-truck-detailing/.
[d] "Freightliner Cascadia," Wikimedia Commons, accessed August 30, 2021, https://commons.wikimedia.org/wiki/File:Freightliner_Cascadia_(4387619946).jpg.
[e] "Werner 2011 Volvo 670," Wikimedia Commons, accessed August 30, 2021, https://commons.wikimedia.org/wiki/File:Werner_2011_Volvo_670.png.
[f] "Mercedes-Benz Arocs," Wikimedia Commons, accessed January 10, 2022, https://commons.wikimedia.org/wiki/File:Mercedes-Benz_Arocs_-_dump_truck_version_(1).JPG.

focus on either of those segments of vehicle activity or a subset of freight trucks such as drayage trucks.

Finally, our policy analysis is based on the present-day health impacts attributable to diesel truck emissions. The results primarily support a discussion on changes within the truck fleet to reduce emissions rather than long-term projections of the entire freight sector such as shifts to rail or other modes, as outlined in the regional freight plan. Future work using real-world vehicle data to characterize more accurately the fleet engine MY distribution could support an analysis to model emissions over time under different activity and mode shift scenarios.

RESULTS

This section presents estimates of the air quality and health impacts of diesel truck tailpipe emissions in New York City. We model ambient $PM_{2.5}$ concentration across the city and analyze disparities in population exposure. Additionally, we quantify the impact of emissions on premature mortalities by engine MY. These results can support the development of effective strategies to reduce emissions, including focused efforts on heavily impacted areas of the city and supporting transitions away from high-emitting diesel trucks.

$PM_{2.5}$ EXPOSURE IMPACTS OF DIESEL TRUCK ACTIVITY IN NEW YORK CITY

The NO_x and $PM_{2.5}$ emissions from diesel truck activity are modeled using real-world emissions data to develop a spatially resolved emissions inventory (Figure 2). The NO_x inventory accounts for variation in emissions based on vehicle speed. The highest emission areas are major freight corridors such as the Cross-Bronx Expressway (I-95) and Brooklyn-Queens Expressway (I-278). A few emission hot spots can be identified where high-traffic roadways intersect, particularly in the Bronx and Queens.

The annual average ambient $PM_{2.5}$ concentrations attributable to these diesel truck tailpipe emissions

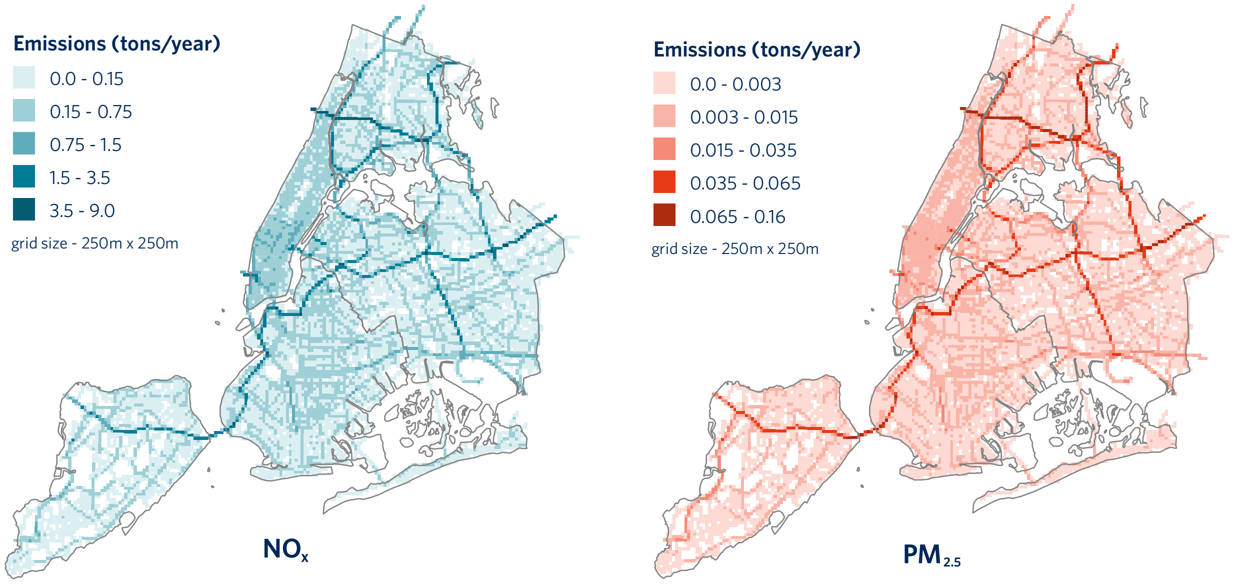

Figure 2. Diesel truck tailpipe NO_x and $PM_{2.5}$ emissions inventories.

are estimated using the $PM_{2.5}$ and NO_x inventories as inputs into InMAP (Figure 3). The results reflect direct $PM_{2.5}$ emissions as well as $PM_{2.5}$ formation from NO_x emissions and the atmospheric transport of pollutants due to wind. Although emissions can impact the air quality in other downwind regions, this analysis focuses on the pollutants emitted within New York City and the impacts on air quality within the city boundaries. High ambient $PM_{2.5}$ concentrations are observed along major truck routes and surrounding the emission hot spots at interstate intersections.

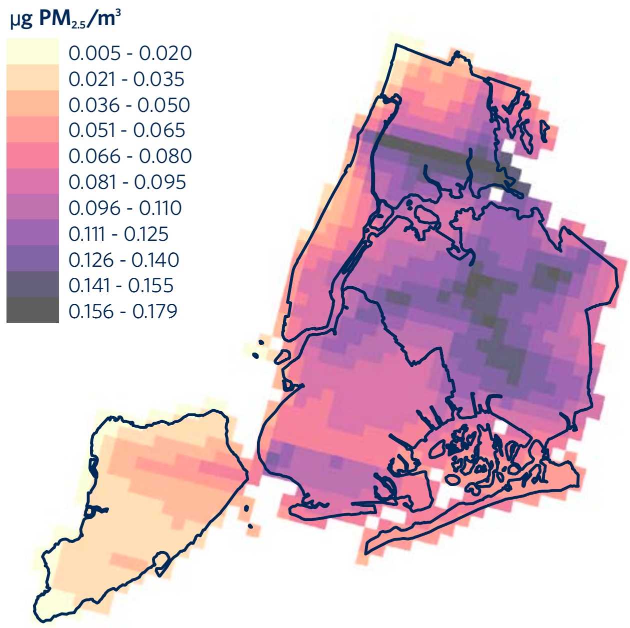

Figure 3. Ambient $PM_{2.5}$ concentrations attributable to diesel truck tailpipe emissions within New York City.

DISPARITIES IN EXPOSURE TO $PM_{2.5}$ BY RACE/ETHNICITY AND HOUSEHOLD INCOME

The ambient $PM_{2.5}$ concentrations attributable to diesel truck tailpipe emissions vary widely across the city. Given that exposure to $PM_{2.5}$ is linked to health issues, including premature mortality, the geographic variations in ambient $PM_{2.5}$ have implications for disparate health outcomes.

Figure 4 shows the difference from average population-weighted exposure to $PM_{2.5}$ for non-Latino white residents compared to people of color.[18] Results from this analysis, shown in blue, indicate that on average, non-Latino white residents are exposed to 10% less $PM_{2.5}$ from diesel trucks than average while people of color are exposed to 5% more. The disparities calculated in this analysis are presented alongside results from Tessum et al., which looked at emissions from throughout the country for populations in different

18 People of color in this analysis refers to Latino people of any race and non-Latino, non-white people.

metro areas.[19] The study, which reported data for the New York–Newark Metro area, found an even greater disparity, indicating that the differences in $PM_{2.5}$ exposure may be even larger when considering emissions and health impacts in the greater New York metro area.

Figure 5 shows a more detailed profile of $PM_{2.5}$ exposure attributable to diesel truck tailpipe emissions by racial-ethnic group.[20] The left end of each distribution represents residents that are exposed to lower levels of $PM_{2.5}$ attributable to diesel trucks, while the right ends represent residents exposed to higher levels of $PM_{2.5}$ in their neighborhood. A large share of white residents are exposed to lower levels of $PM_{2.5}$ attributable to diesel trucks. While there are people of all races living in areas with high $PM_{2.5}$ concentrations (right side of the distribution), it is disproportionately Latino, Black, and Asian residents who are exposed to the highest levels. A large share of Latino and Asian residents are exposed to above-average levels of $PM_{2.5}$ from diesel truck emissions, primarily driven by the high-activity freight corridors in the Bronx and Queens.

Figure 6 shows a similar distribution, looking at differences in exposure by household income quintile. All quintiles have relatively similar distributions, showing less of a disparity by income compared to race, echoing results from recent studies on exposure to $PM_{2.5}$ from all sources.[21] The main difference is the top income quintile distribution, which is shifted toward slightly lower $PM_{2.5}$ exposures. This is in part due to the bounds of the analysis; many high-income households live in areas of the city that are closely downwind of New Jersey and other source emissions locations that are not included in the exposure analysis. However, these analyses are valuable in determining which populations presently experience the largest air pollution burdens and will benefit most from policies to reduce diesel truck emissions within New York City.

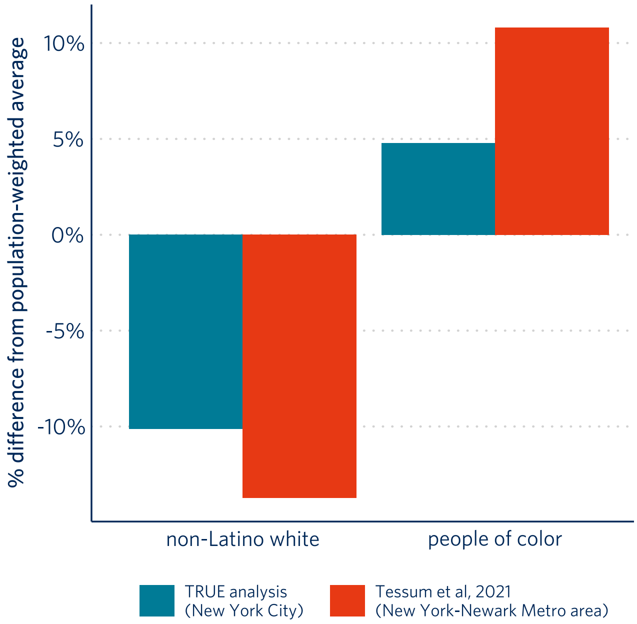

Figure 4. Disparities in exposure to ambient $PM_{2.5}$ pollution attributable to diesel truck tailpipe emissions between non-Latino white residents and people of color.

EMISSION IMPACTS BY VEHICLE AGE

The increased stringency of EPA emission standards has led to the development of emission control technologies that greatly reduce tailpipe emissions. Diesel trucks manufactured in the last decade are nearly all equipped with selective catalytic reduction (SCR) systems to control NO_x and diesel particulate filters (DPFs) to control $PM_{2.5}$. The widespread application of these technologies has led to the improvement in fleet-average emission levels over time. As overall emissions decrease, a small number of older, high-emitting trucks that remain in operation can contribute a large share of emissions. In this section, we analyze the emission and health impacts of diesel trucks by engine MY. Table 2 outlines the engine MY groups used in the analysis, as well as the corresponding EPA standard and emission control technologies implemented in nearly all vehicles to meet the standard.

Figure 7 shows estimates of the share of NO_x and $PM_{2.5}$ emissions from diesel trucks in New York City by engine MY group. The oldest group of pre-1998 engine MY vehicles has the highest average emission rate but makes up a small enough portion that its emissions share is small. However, 1998–2006 engine MY vehicles, which make up a larger but still relatively small portion of the fleet, contribute a substantial portion of

19 Christopher W. Tessum et al., "$PM_{2.5}$ Polluters Disproportionately and Systemically Affect People of Color in the United States," *Science Advances* 7, no. 18 (April 2021): eabf4491, https://doi.org/10.1126/sciadv.abf4491.

20 This distribution looks at the four largest racial-ethnic groups in New York City. Neighborhood-level work may consider analyses by more detailed racial and ethnic subgroups.

21 Jiawen Liu et al., "Disparities in Air Pollution Exposure in the United States by Race/Ethnicity and Income, 1990–2010," *Environmental Health Perspectives* 129, no. 12 (March 11, 2021), https://doi.org/10.26434/chemrxiv.13814711.v2; Ihab Mikati et al., "Disparities in Distribution of Particulate Matter Emission Sources by Race and Poverty Status," *American Journal of Public Health* 108, no. 4 (April 2018): 480–85, https://doi.org/10.2105/AJPH.2017.304297; Tessum et al., "$PM_{2.5}$ Polluters Disproportionately and Systemically Affect People of Color in the United States."

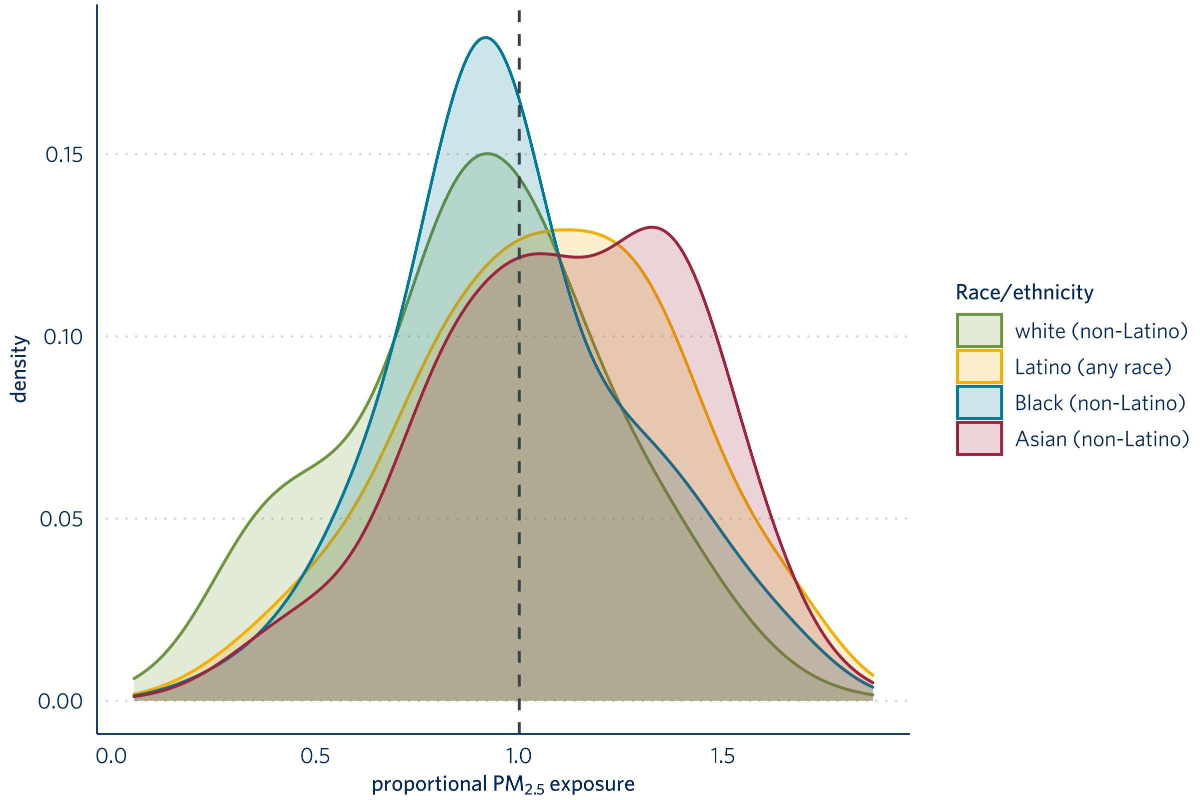

Figure 5. Exposure to $PM_{2.5}$ attributable to diesel truck tailpipe emissions by racial-ethnic group in New York City. Proportional $PM_{2.5}$ is the $PM_{2.5}$ concentration divided by the population-weighted average.

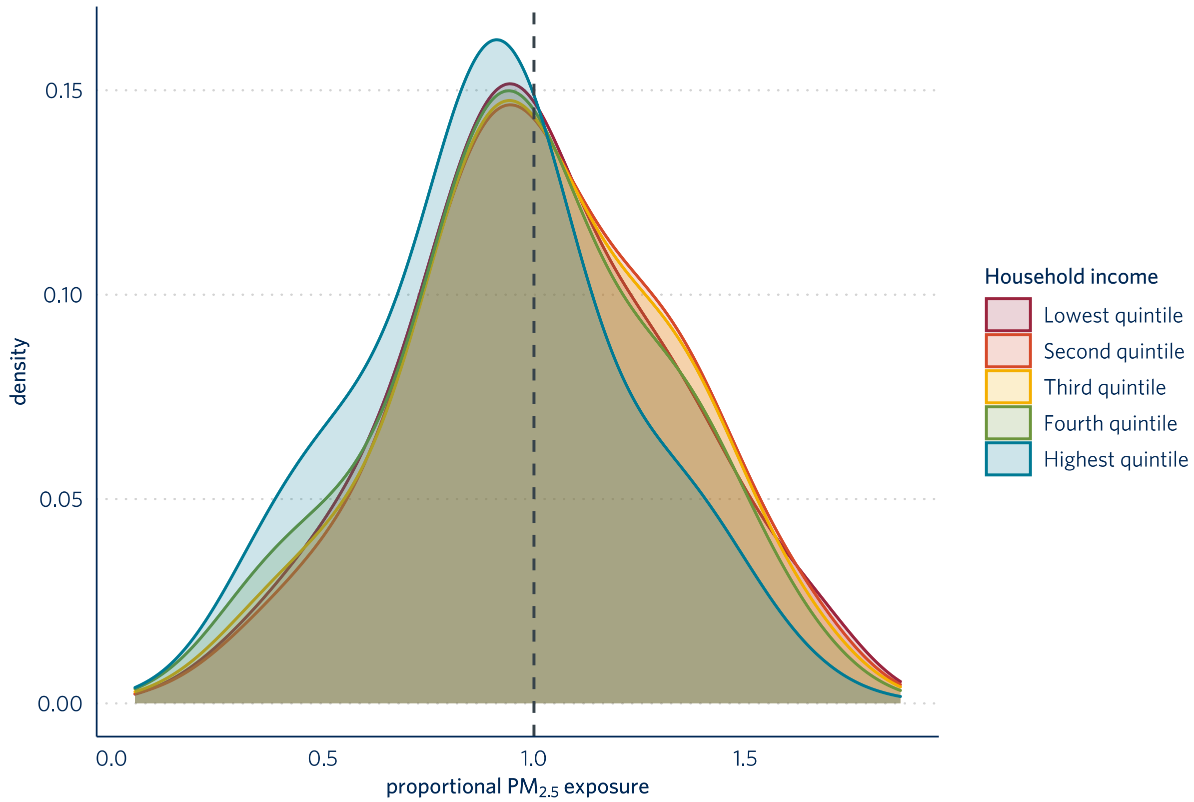

Figure 6. Exposure to $PM_{2.5}$ attributable to diesel truck tailpipe emissions by household income quintile in New York City.

Table 2. Heavy-duty diesel vehicle emission standards and control technologies by engine model year (MY) groups

Engine MY group	EPA standard introduced	Emission control technologies
Pre-1998	First NO_x limit set in 1974, lowered in 1979, 1985, 1990, and 1991 First $PM_{2.5}$ limit set in 1988, lowered in 1991 and 1994	-
1998–2003	Lower NO_x limit	-
2004–2006	Lower NO_x limit	EGR
2007–2009	Partial phase-in of lower NO_x limit Lower $PM_{2.5}$ limit	EGR, DPF
2010–2012	Full phase-in of lower NO_x limit	EGR + SCR, DPF
2013–2015	n/a	EGR + SCR, DPF
Post-2015	n/a	EGR + SCR, DPF

Notes: The 2013–2015 and post-2015 engine MY groups are not associated with the introduction of any EPA standard. However, due to observed decreases in real-world NO_x emissions from 2010 to 2016, we analyze vehicles certified to 2010 emissions limits in three separate groups.

total $PM_{2.5}$ emissions. In total, these make up 9% of the MDT fleet and 5% of the HDT fleet and contribute 77% and 58% of $PM_{2.5}$, respectively. Starting with 2007 engine MY vehicles, $PM_{2.5}$ emissions reduce significantly due to the implementation of a more stringent EPA $PM_{2.5}$ limit, which led to the near-universal application of DPFs.

Older vehicles also contribute a disproportionate share of NO_x emissions; however, this trend also includes more recent vehicles. All pre-2013 engine MY vehicle groups contribute a larger share of NO_x emissions relative to their vehicle activity. Although the current NO_x limit fully went into effect in 2010, the average real-world NO_x emissions from the first group of vehicles certified to this NO_x limit exceed the regulatory limit. NO_x emissions decreased in future model years as SCR technology improved; however, it was not until 2016 engine MY trucks that emissions during real-world operation aligned with the regulatory limit. As the oldest trucks are replaced and the fleet shifts toward newer vehicles, the excess NO_x emissions from 2010–2012 engine MY vehicles will make up an increasing share of the total.

Older, high-emitting vehicles have larger impacts on adverse health effects attributable to $PM_{2.5}$ air pollution. We use EPA's Value of a Statistical Life, estimated at $9.76 million (for the year 2021 in USD), to quantify the monetary impact of emissions on premature mortalities by engine MY.[22] Figure 8 presents the mortality-based damages attributable to $PM_{2.5}$ exposure from diesel trucks operating within New York City. The oldest vehicles show substantial damages of up to $4.30 per vehicle-mile. As shown in Figure 7, the oldest engine MY group makes up a small portion of the fleet. However, as the fleet model year distributions are developed using New York City registrations, it is possible that vehicles driving into New York City from other regions include a higher share of pre-1998 engine MY vehicles. Given the extremely high emission rates, even a single pre-1998 engine MY vehicle operating in New York City can have significant health impacts. The two engine MY groups that make up the largest portions of total fleet emissions, 1998–2003 and 2004–2006, have damage rates above one dollar per vehicle-mile for both MDTs and HDTs. Replacing one of these trucks with a new diesel truck results in a 93%–96% reduction in mortality-based damages.

22 Value of a Statistical Life estimates willingness to pay for risk reductions and is not a monetary valuation on individual lives. This analysis uses EPA's estimate of $7.4 million (base line for 2006 updated to the year 2021). "Mortality risk valuation," U.S. Environmental Protection Agency, accessed August 23, 2021, https://www.epa.gov/environmental-economics/mortality-risk-valuation#means;
"CPI inflation calculator," U.S. Bureau of Labor Statistics, accessed August 23, 2021, https://www.bls.gov/data/inflation_calculator.htm.

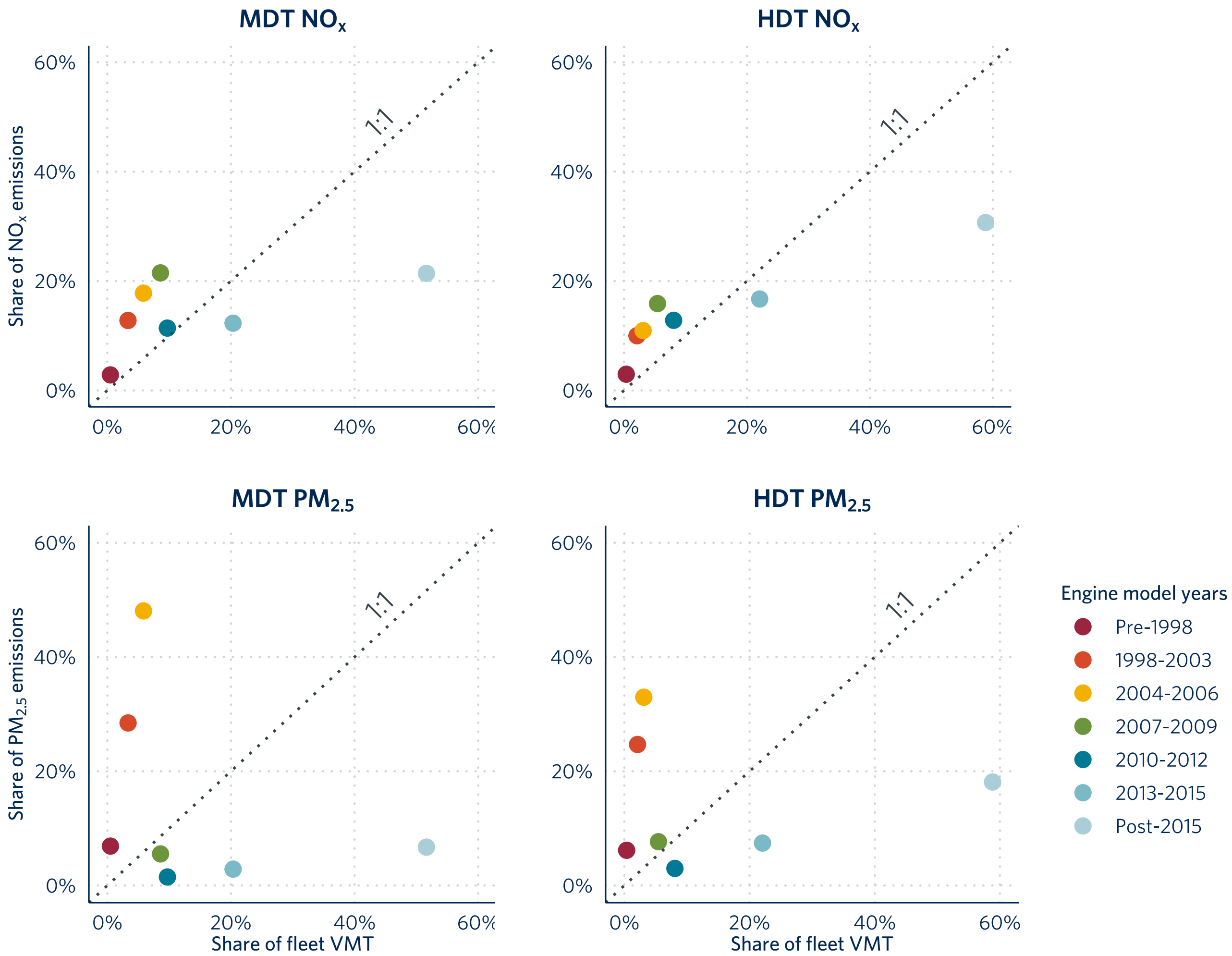

Figure 7. Share of emissions by engine model year (MY) group. Points above the line represent groups that contribute a disproportionate share of emissions.

The contribution of each pollutant to the total monetary damage varies by engine MY group. The large damage rate due to $PM_{2.5}$ emissions decreases significantly starting with 2007 engine MY vehicles due to the near-universal application of DPFs. The delayed reduction in real-world NO_x emissions after the 2010 introduction of more stringent NO_x emission standards is reflected in the mortality-based damages. The damage rate associated with 2010–2012 engine MY vehicles is almost double the rate compared to post-2015 engine MY vehicles.

The mortality-based damage rates reflect average values, meaning that individual vehicles may have much larger impacts. A high-emitting vehicle with a malfunctioning or tampered control system can cause damages that are several times higher. A new diesel truck with a nonfunctioning DPF may have emissions closer to the 2004–2006 engine MY average of $1.69 per vehicle-mile (MDT) or $2.37 per vehicle-mile (HDT). These average rates also may increase as vehicles age due to deterioration, which can result in a larger share of high-emitting vehicles.

The costs reported in this analysis only reflect damages associated with premature mortalities due to ambient $PM_{2.5}$ exposure. Past studies have found health impacts due to direct exposure to NO_2, which are not quantified in this study.[23] We also do not include the health impacts of ozone (O_3), another pollutant that forms from reactions involving NO_x. One study estimated 295 O_3-attributable premature mortalities compared to 635

23 Susan C. Anenberg et al., "Estimates of the Global Burden of Ambient $PM_{2.5}$, Ozone, and NO_2 on Asthma Incidence and Emergency Room Visits," *Environmental Health Perspectives* 126, no. 10 (October 24, 2018): 107004, https://doi.org/10.1289/EHP3766.

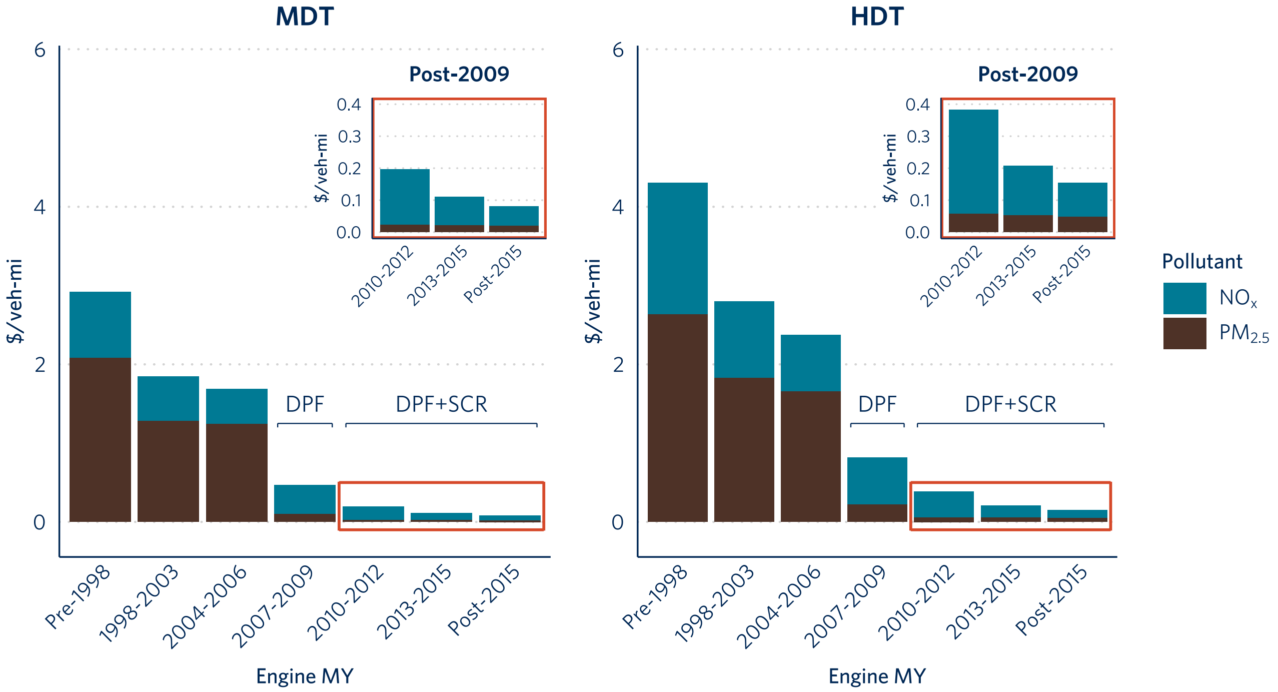

Figure 8. Mortality-based damages of diesel trucks operating in New York City by pollutant and engine model year (MY) group.

$PM_{2.5}$-attributable premature mortalities due to diesel truck emissions in the New York Metropolitan Statistical Area.[24] Additionally, these costs only reflect premature mortalities and do not incorporate morbidities. Childhood asthma is a major health issue in New York City, with hospitalizations concentrated in certain areas of the city, and the monetary damages from this analysis do not include these and other health impacts.[25]

Additionally, we do not quantify the significant climate impacts of older diesel trucks in this analysis. Black carbon (BC), a component of $PM_{2.5}$, contributes 3,200 times as much warming as CO_2 over a 20-year period.[26] The use of DPFs is highly effective in limiting BC emissions, with one real-world emissions testing study estimating a 94% reduction.[27] Diesel trucks operating in New York City that are not equipped with DPFs, estimated at 10% of MDT and 6% of HDT, continue to emit high levels of BC. The associated climate impacts, along with health impacts not included in this study, should also be considered when evaluating the benefit of replacing older diesel trucks.

Finally, this report focuses on emissions from within New York City and does not include emissions from surrounding regions. Arter et al. modeled mortality-based damages from on-road emissions in the Northeast and Mid-Atlantic, estimating that 83% of $PM_{2.5}$-attributable premature mortalities in New York City due to $PM_{2.5}$ and NO_x emissions from MDTs are from activity within New York state.[28] However, when looking at impacts from HDT, the analysis showed that the share of premature mortalities in New York City due to emissions from New Jersey (47%) outweighs the share from New York state (34%). The most effective strategies to reduce the health impacts from diesel truck emissions will require regional plans, state-level policies, and joint efforts across agencies and municipalities in addition to the actions taken by New York City.

24 Calvin Arter et al., "Mortality-Based Damages per Ton Due to the on-Road Mobile Sector in the Northeastern and Mid-Atlantic U.S. by Region, Vehicle Class and Precursor," *Environmental Research Letters* 16, no. 6 (June 1, 2021): 065008, https://doi.org/10.1088/1748-9326/abf60b.

25 "Asthma hospitalizations (Children 5 to 17 Yrs Old)" (2016), Environment & Health Data Portal, New York City Department of Health and Mental Hygiene, accessed August 23, 2021, https://a816-dohbesp.nyc.gov/IndicatorPublic/VisualizationData.aspx?id=2381,4466a0,11,Map,Estimated%20Annual%20Rate,2016.

26 T. C. Bond et al., "Bounding the Role of Black Carbon in the Climate System: A Scientific Assessment," *Journal of Geophysical Research: Atmospheres* 118, no. 11 (2013): 5380–5552, https://doi.org/10.1002/jgrd.50171.

27 Chelsea Preble et al., "In-Use Performance and Durability of Particle Filters on Heavy-Duty Diesel Trucks," *Environmental Science & Technology* 52, no. 20 (October 16, 2018): 11913–21, https://doi.org/10.1021/acs.est.8b02977.

28 Arter et al., "Mortality-Based Damages per Ton Due to the On-Road Mobile Sector in the Northeastern and Mid-Atlantic U.S. by Region, Vehicle Class and Precursor." This study reports emission impacts of various source locations by state. However, given the typical wind directions, it is reasonable to assume that a significant portion of New York State source emissions impacting New York City are from within the city.

POLICY IMPLICATIONS: REDUCING DIESEL TRUCK EMISSIONS

The analysis above highlights the inequitable $PM_{2.5}$ exposure and health burdens of diesel truck emissions. This section discusses the implications within the diesel freight truck sector, including policies currently in place, plans outlined in New York City's Smart Truck Management Plan, and additional recommendations. The following section discusses implications for transitions to zero-emission freight options.

REPLACING OLDER DIESEL TRUCKS

The pre-2007 engine MY trucks causing significant health impacts are currently at least 15 years old and will decrease in prevalence through natural fleet turnover in the coming years. However, emissions from these trucks are high enough that even a single year of operation can cause significant damage. Using average yearly VMT data from EPA MOVES, 1998–2006 engine MY MDTs cause $12,000–$23,000 in mortality-based damages per year; HDTs of the same model year group cause $36,000–$69,000 in damages per year.[29] These monetary damages quickly exceed typical rebates for a replacement vehicle, even exceeding the full upfront cost of a new truck with just a few additional years of operation. Plans to significantly reduce diesel truck emissions in the next few years cannot rely on natural fleet turnover alone and must include an active approach to replacing pre-2007 engine MY trucks.

Trucks with engine MYs of 2007 and later have lower average $PM_{2.5}$ emissions due to widespread implementation of DPFs; however, trucks manufactured in the first few years following the 2007 EPA standard exhibited trends of DPF malfunctions. One real-world emissions testing study found that 2007–2009 engine MY trucks had a high rate of deterioration, evidenced by a 50%–67% increase in BC between 2013 and 2015.[30] This increase was attributed to the large number of individual high-emitting trucks due to malfunctioning DPFs. This issue was less prevalent for later engine MYs due to improvements in DPF system design. Including the 2007–2009 engine MY trucks group in replacement efforts is important for reducing both NO_x and $PM_{2.5}$ emissions, particularly as more pre-2007 engine MY trucks are replaced.

The Hunts Point Clean Trucks Program, established in 2012, aimed to reduce the share of older vehicles on the roads by offering incentives for replacing older diesel trucks with 1992–2009 model year engines.[31] The program was highly effective in reducing emissions and the associated health impacts, particularly in the neighborhoods surrounding Hunts Point. The program expanded into the New York City Clean Trucks Program in June 2020, offering incentives for older diesel trucks regularly operating in any of the 20 defined industrial business zones (IBZs).[32] However, despite the expansion, utilization of the funding for truck replacements has slowed down significantly from the first few years of the Hunts Point program.[33]

To incentivize shifts to cleaner vehicles most effectively, the Clean Trucks Program should operate in support of other plans and initiatives such as emissions-based charges and access restrictions. Due to the significant health and climate impacts associated with older diesel trucks, it is necessary to replace older trucks operating throughout the city to significantly reduce NO_x and $PM_{2.5}$ emissions. Program eligibility should be expanded to include vehicles operating in other areas of the city with the introduction of emissions-based charges and restrictions. Additionally, truck eligibility should include 2010–2012 engine MY trucks to address the issue of excess NO_x emissions.

Through the Clean Trucks Program, truck owners replacing older diesel trucks have several options on the type of new vehicle they purchase. The program offers rebates for new diesel trucks, as well as compressed natural gas (CNG), diesel-electric hybrid, plug-in hybrid, and battery-electric vehicles.[34] Under the

29 These estimates rely on the assumption that the vehicle operates entirely in New York City in a spatial trend that reflects average truck activity. Damages associated with an individual truck would likely be lower if a substantial share of operation is outside of the city.

30 Preble et al., "In-Use Performance and Durability of Particle Filters on Heavy-Duty Diesel Trucks."

31 "Program success," NYC Clean Trucks Program, accessed November 23, 2021, https://www.nycctp.com/program-success/.

32 "Industrial business zones," NYC Clean Trucks Program, accessed November 29, 2021, https://www.nycctp.com/ibzs/.

33 "Program success," NYC Clean Trucks Program.

34 "Available funding," NYC Clean Trucks Program, accessed August 23, 2021, https://www.nycctp.com/available-funding/.

current eligibility rules and funding, CNG vehicles are incentivized over new diesel vehicles.[35]

However, CNG vehicles emit high amounts of ammonia and ultrafine particles, observed at five to 50 times higher than diesel vehicles.[36] Ammonia, a precursor to $PM_{2.5}$, is not currently regulated by the EPA, and particulate matter is regulated by weight, not particle count.[37] Additionally, large shifts toward CNG will require additional fueling infrastructure. New York City recently opened one fueling station with renewable natural gas (RNG), significantly reducing carbon emissions and climate impacts.[38] However, given that ultrafine particle emissions are similar for both CNG and RNG,[39] large investments in natural gas fueling infrastructure may not be aligned with long-term goals to drastically reduce the health impacts of medium- and heavy-duty trucks.

Both CNG and new diesel trucks do provide large benefits over older diesel trucks; however, health issues associated with tailpipe emissions remains an issue for both truck types. In terms of long-term goals for significantly reducing climate and health impacts, battery-electric vehicles are the preferable option. New York City should consider future changes in incentives for the Clean Trucks Program to prioritize funding for battery-electric vehicles in response to rapidly advancing electric vehicle technology.

EMISSION REDUCTIONS IN INDUSTRIAL BUSINESS ZONES

Health damage rates, or the health impacts associated with a given emissions amount, vary across the city depending on surrounding population density and meteorological factors. These rates, developed from InMAP, rely on simplified modeling and assumptions on the health and mortality impacts of emissions. However, the results are useful as guides on which emission source locations have large populations immediately nearby and downwind that may lead to a greater number of premature mortalities. Figure 9 shows the damage rates for the defined IBZs, with darker colors indicating emission source areas that have the potential to cause more premature mortalities. The IBZs with the highest damage rates are up to five times higher than areas with the lowest damage rates, meaning policies to reduce emissions in these specific areas can have a large impact on reducing $PM_{2.5}$-related premature mortalities. Most IBZs are surrounded by environmental justice areas, which is also an important consideration when making efforts to reduce emissions in specific locations. The IBZs with large health impact rates that are also near communities disproportionately burdened by $PM_{2.5}$ are good first candidates for action to reduce emissions such as restricting access by vehicle emission standard.

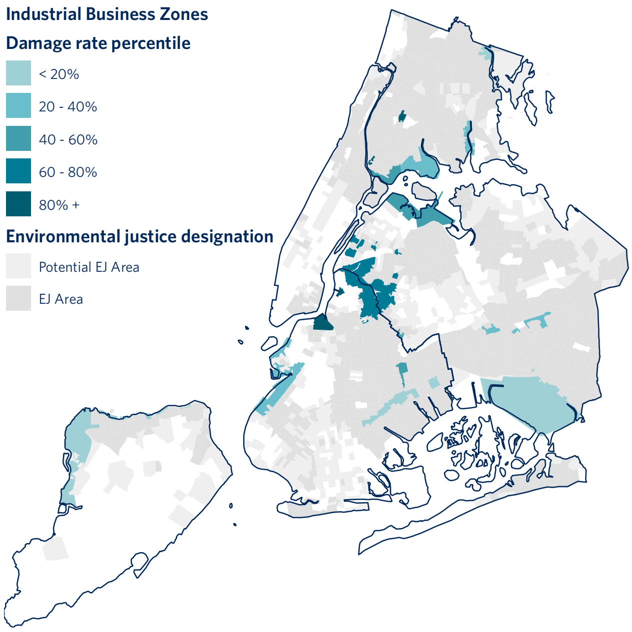

Figure 9. Damage rates by industrial business zones (IBZs) and environmental justice areas.

The Port Authority of New York and New Jersey has a policy that can, with some modifications, serve as a model for reducing diesel truck emissions in industrial areas. Drayage truck access to Port Authority marine terminals is restricted by engine MY. However, despite considering a cutoff at engine MY 2007, the plan that ultimately went into effect allows access to all post-1997 engine MY vehicles. This policy affects only a small fraction of the total vehicle fleet and fails to target the older, high-emitting vehicles that are responsible for the largest share of total

35 "FAQs—NYC Clean Trucks Program," NYC Clean Trucks Program, accessed August 23, 2021, https://www.nycctp.com/faqs/. CNG trucks receive larger incentives, two to three times the incentive for a new diesel truck of the same class. Additionally, fleets of 15 trucks or more are not eligible for rebates for new diesel trucks but may receive rebates for CNG trucks.

36 Rachel Muncrief, *A comparison of nitrogen oxide (NOx) emissions from heavy-duty diesel, natural gas, and electric vehicles*, (ICCT: Washington, DC, 2021), https://theicct.org/sites/default/files/publications/low-nox-hdvs-compared-sept21.pdf.

37 U.S. Environmental Protection Agency, "Heavy-Duty Highway Compression-Ignition Engines and Urban Buses: Exhaust Emission Standard."

38 Waste360 Staff, "Clean Energy opens RNG fueling station in NYC" (Waste360, July 12, 2019), https://energy-vision.org/wp-content/uploads/2019/10/Waste360-Clean-Energy-Opens-RNG-Fueling-Station-in-NYC.pdf.

39 Jian Xue et al., "Ultrafine Particle Emissions from Natural Gas, Biogas, and Biomethane Combustion," *Environmental Science & Technology* 52, no. 22 (November 20, 2018): 13619–28, https://doi.org/10.1021/acs.est.8b04170.

emissions. A more effective plan informed by real-world emissions data would only allow access to post-2009 engine MY vehicles. Implementing this plan at the ports and IBZs, where feasible, would reduce the burden on communities immediately next to and downwind of industrial areas with high volumes of truck activity.

Additionally, the Port Authority of New York and New Jersey can work to further reduce emissions by implementing a timeline for shifts to cleaner trucks and planning for a transition to fully zero-emission truck operation. In 2018, the Port of Los Angeles and Port of Long Beach in Southern California enacted a requirement that newly registered trucks must have engines that are 2014 MY or newer.[40] Additionally, Los Angeles has pledged to have 100% zero-emission drayage trucks operation in the ports by 2035.[41]

OFF-HOUR DELIVERY

One initiative in the Smart Trucks Management Plan is the Off-Hour Delivery Program, which aims to shift deliveries to off-peak hours between 7 p.m. and 6 a.m. NYC DOT performs outreach to businesses and transport companies, particularly those operating in the most congested areas, to highlight benefits such as time and cost savings as illustrated by a study on a past pilot program.[42]

While the main goal of this initiative is to reduce congestion, there are also emission reductions that result from traveling during off-peak hours. U.S. diesel truck emission control systems typically do not operate as well during low-speed driving,[43] particularly at speeds under 10 mph, so increases in speed may help reduce overall NO_x emissions.

We model the emission reductions in different areas of the city using Uber Movement road segment-level hourly speed data and speed-based real-world emission factors. A post-2009 engine MY truck shifting from peak hours to off-peak hours can have up to an 8.5% average reduction in NO_x emissions (Table 3). Delivery routes that operate on roads with the most severe congestion would be good candidates for shifting to off-peak hours, resulting in higher emission reductions.

There are several benefits associated with off-hour delivery, including congestion reductions, fewer parking and curb violations, and time savings for delivery drivers. However, as an emission reduction strategy, the benefits of off-hour delivery in most areas of the city are relatively minor when compared to other policies discussed in this report. While it may be a necessary component of adapting to increasing truck activity, additional policies are needed to significantly improve air quality and public health.

Table 3. Average change in NO_x emissions resulting from a post-2009 engine MY truck shifting from peak hours to off-peak hours

Borough	Change in MDT emissions	Change in HDT emissions
Bronx	-3.3%	-5.7%
Brooklyn	-3.1%	-5.9%
Manhattan	-4.3%	-8.5%
Queens	-3.6%	-5.4%
Staten Island	-3.8%	-5.3%
Overall	-3.6%	-6.2%

Note: These changes in NO_x emissions may not reflect air quality changes due to the variation in secondary $PM_{2.5}$ formation patterns by time of day.

CENTRAL BUSINESS DISTRICT TOLLING PROGRAM

The Central Business District Tolling Program is one policy that also aims to reduce congestion and emissions. Under the congestion pricing plan, which could go into effect in 2023,[44] vehicles entering the area of Manhattan south of 60th street will be charged.[45]

The pricing structure for trucks has yet to be announced, though one source reports that trucks can

40 Marc Carrel, "Drayage Truck Registry Date Should be Re-evaluated," *Advanced Clean Tech News*, December 15, 2020, https://www.act-news.com/news/port-drayage-truck-registry-date-should-be-re-evaluated/.

41 Office of Los Angeles Mayor Eric Garcetti, "Mayor Garcetti announces new request for information for zero emissions truck program at the Port of Los Angeles" (2020), https://www.lamayor.org/mayor-garcetti-announces-new-request-information-zero-emissions-truck-program-port-los-angeles.

42 "Benefits," Off-Hour Deliveries, City of New York, accessed February 14, 2022, https://ohdnyc.com/benefits.

43 Posada, Badshah, and Rodriguez, *In-use NOx emissions and compliance evaluation for modern heavy-duty vehicles in Europe and the United States.*

44 Diane Pham, "NYC congestion tolls get the federal green light," *Urbanize New York*, March 31, 2021, https://urbanize.city/nyc/post/nyc-congestion-tolls-get-federal-green-light.

45 "Central Business District Tolling Program," Metropolitan Transportation Authority (2021), accessed August 25, 2021, https://new.mta.info/document/37421.

expect a twenty-five dollar charge to enter the area.[46] An overall reduction in congestion will allow trucks to travel at higher speeds and reduce emissions; however, these air quality and health benefits are relatively small, similar in scale to those associated with off-hour delivery. If a uniform charge for all truck types is implemented, the tolling program may encourage mode shifts to other freight options such as e-cargo bikes but will largely miss out on an opportunity to incentivize shifts to lower-emitting and zero-emission trucks. New York City should consider additional measures that could result in much larger emission reductions.

EMISSIONS-BASED CHARGE

Charging trucks based on emission standards incentivizes shifts to cleaner vehicles, delivering greater emission reductions. An emission-based tolling program shares similarities with low-emission zones (LEZs), which have been highly effective in reducing emissions across European cities. In London, the LEZs and ultra-low emission zones (ULEZs) restrict vehicle access by emission standard. Heavy-duty vehicles are required to be compliant with Euro VI standards, similar to EPA 2010 standards. Noncompliant vehicles are subject to a £100 fee ($139 USD) or a higher fee of £300 ($416 USD) if they do not meet Euro IV standards.[47] Within five years of announcing the policy, the share of vehicles operating in the zone that meet Euro VI standards increased from 48% to 95%, substantially higher than the projected increase from natural fleet turnover.[48]

New York City's tolling program should implement an emissions-based truck charge to improve the program's emission reduction impact. The charging structure can be informed by the mortality-based monetary damages reported in this analysis. Vehicles traveling in the central business district have higher health damage rates compared to the city average due to high population density. Tailpipe emissions from diesel trucks not equipped with DPFs cause at least $2.50 per vehicle-mile for MDTs and $3.50 per vehicle-mile for HDTs in damages due to premature mortalities from $PM_{2.5}$ exposure.[49] New diesel trucks cause damages of $0.11 per vehicle-mile (MDT) and $0.22 per vehicle-mile (HDT).

These damage rates can help determine charges for different vehicle groups, for example, pre-2010 engine MY diesel trucks, 2010 and newer MY diesel trucks, and zero-emission trucks. As highlighted in previous sections, the emissions benefit associated with replacing older diesel trucks is substantial, up to a 96% reduction in mortality-based damages. An emissions-based truck charge under the central business tolling program would complement other city policies to reduce the share of older, high-emitting diesel trucks and increase the share of zero-emission vehicles.

LIMITED TRAFFIC ZONE

Limiting truck activity in defined zones is another way to achieve emission reductions. Madrid restricts trucks above certain weights, limiting the hours during which they can operate in the central area of the city.[50] Budapest has 15 restricted zones throughout the city, which each have different vehicle weight limits and require entry permits for heavy-duty vehicles.[51]

In addition to safety and mobility improvements for people living and traveling in the region, a limited traffic zone can help reduce congestion and emissions. A plan can be designed to support other initiatives, for example, restricting travel during peak hours to increase off-hour delivery. The plan can also incentivize shifts toward electric cargo bikes as last-mile delivery vehicles through a weight limit. The benefits of these initiatives can be maximized by providing funding support and addressing common infrastructure and regulatory barriers by implementing bike lanes suitable for e-cargo bikes and dedicating curb space for loading zones.

ZERO-EMISSION ZONE

Currently, several cities have road segments or small areas designated as zero-emission zones (ZEZs), and a greater number of cities have announced plans

46 Annie McDonough, "When's the congestion pricing check going to arrive?," *City & State New York*, July 20, 2021, https://www.cityandstateny.com/policy/2021/07/whens-congestion-pricing-check-going-arrive/183916/.

47 "How to pay a LEZ charge," Transport for London, accessed August 25, 2021, https://tfl.gov.uk/modes/driving/low-emission-zone/make-a-payment; "Current rates," Treasury Reporting Rates of Exchange, Bureau of Fiscal Service, U.S. Department of the Treasury, updated October 7, 2021, https://fiscal.treasury.gov/reports-statements/treasury-reporting-rates-exchange/current.html.

48 Mayor of London, "London low emission zone—Six month report" (September 2021), https://www.london.gov.uk/sites/default/files/lez_six_month_on_report-final.pdf.

49 Estimates by more detailed engine MY groups are available in the supplementary materials.

50 "Madrid—weight restriction," Urban Access Regulations in Europe, accessed August 25, 2021, https://urbanaccessregulations.eu/countries-mainmenu-147/spain/68-key-access-regulations/spain-access-regulations/1636-madrid-weight.

51 "Magunkról: Mi a Budapest Közút Teherforgalom?," City of Budapest, accessed August 25, 2021, https://www.budapestkozut.hu/teherforgalom/magunkrol/.

to implement larger ZEZs.[52] In 2015, Rotterdam implemented a ZEZ covering a 1.6-kilometer stretch of roadway. The plan is enforced by automated camera recognition systems at each entrance to the zone. A large portion of the roadway is grade separated, requiring fewer enforcement points.[53] Over 30 other cities in the Netherlands, including Amsterdam, have plans to implement a policy starting in 2025 to restrict commercial vehicle access in city centers to zero-emission vehicles.[54]

In 2018, Shenzhen created 10 zero-emission freight zones based on an emission hot-spot analysis, covering a total of 22 square kilometers or 1.1% of the city's area.[55] The pilot was implemented with the support of additional policies to encourage the shift to zero-emission vehicles. These incentives include diesel vehicle scrappage and electric vehicle purchase and operation subsidies along with curbside access incentives. By the end of 2019, electric vehicles made up more than a third of the city's freight fleet.

Within the United States, Los Angeles recently implemented a voluntary zero-emission area, incentivizing shifts from medium-duty diesel trucks to zero-emission last-mile delivery vehicles.[56] Additionally, Los Angeles, along with 35 other major cities, has committed to creating a ZEZ covering a major area of the city by 2030 through the C40 Cities Green and Healthy Streets Declaration.[57]

A New York City commitment to a ZEZ or zero-emission areas and a timeline for implementation would help to accelerate the transition to zero-emission freight options. The city can learn from existing programs and established best practices to define the zones and areas. Considerations include ease of implementing enforcement, including the potential to utilize central business district tolling infrastructure, truck activity volumes and emission hot-spot areas, and levels of last-mile deliveries.

WEIGHT RESTRICTION ENFORCEMENT

An increasing number of vehicles operating in New York City exceed federal weight limits, with weigh-in-motion station data showing that around 90% of single-unit trucks with four or more axles are overweight.[58] In addition to safety and pavement deterioration issues, overweight vehicles also have larger emission impacts.

Wang et al. looked at real-world emissions data from tractor-trailer trucks equipped with SCR systems, finding that the impact of weight on emissions is particularly large at low speeds. Fully loaded vehicles were found to emit 65%–85% more NO_x than unloaded vehicles when traveling at low speeds below 10 mph, and overloaded vehicles had even larger increases in emissions.[59] Reducing the number of overweight trucks through compliance programs can help reduce excess NO_x emissions. These emission reductions are particularly important on major freight corridors, and increased enforcement can help reduce air pollution in heavily burdened areas.

INSPECTION AND MAINTENANCE PROGRAMS FOR HIGH-EMITTING VEHICLES

Though newer vehicles equipped with SCRs and DPFs have lower average emissions, individual vehicles may emit high levels of NO_x or $PM_{2.5}$. High emissions may result from illegal tampering, which can include physical alterations of emissions control systems as well as software and hardware modifications.[60] Other causes of failures in control systems include malfunctions and a lack of proper maintenance. A lack of properly functioning control systems can cause even a new vehicle to have emission levels many times above

52 Hongyang Cui, Pramoda Gode, and Sandra Wappelhorst, *A global review of zero-emission zones in cities and their development process*, (ICCT: Washington, DC, 2021), https://theicct.org/sites/default/files/publications/global-cities-zez-dev-EN-aug21.pdf.

53 "Vrachtautoverbod 's-Gravendijkwal," City of Rotterdam, accessed November 29, 2021, https://www.rotterdam.nl/werken-leren/sgravendijkwal/.

54 "Green deal for zero emission city logistics," Amsterdam Economic Board, accessed August 25, 2021, https://amsterdameconomicboard.com/en/initiative/green-deal-zero-emission-city-logistics.

55 "How-to guide on zero emission zones: Don't wait to start with freight!," Transportation Decarbonization Alliance, C40 Cities, and POLIS (2020), accessed November 29, 2021, https://www.polisnetwork.eu/wp-content/uploads/2020/12/ZEZ-F_How-to-Guide_low.pdf.

56 "Santa Monica Zero Emissions Delivery Zone Pilot," Los Angeles Cleantech Incubator, accessed November 29, 2021, https://laincubator.org/zedz/.

57 "Green and healthy streets," C40 Cities, accessed November 29, 2021, https://www.c40.org/what-we-do/scaling-up-climate-action/transportation/green-and-healthy-streets/.

58 New York City DOT, "Delivering New York: A smart truck management plan for New York City."

59 Xin Wang et al., "Effects of Vehicle Load on Emissions of Heavy-Duty Diesel Trucks: A Study Based on Real-World Data," *International Journal of Environmental Research and Public Health* 18, no. 8 (April 7, 2021): 3877, https://doi.org/10.3390/ijerph18083877.

60 Frank Acevedo and Cody Yarbrough, "Tampering & aftermarket defeat devices," Midwest Clean Diesel Initiaive Steering Committee Meeting, U.S. Environmental Protection Agency (2019), https://www.epa.gov/sites/default/files/2019-05/documents/tampering-aftermarket-defeat-devices-2019-mcdi-mtg-33pp.pdf

regulatory limits. A post-2009 engine MY HDT with a nonfunctioning DPF can result in $PM_{2.5}$ emissions around 30 times higher than average, assuming it performs similarly to a pre-2007 engine MY HDT without a DPF.

New York state currently requires annual inspections for diesel vehicles registered in the New York metropolitan area, including a smoke opacity test and a visual check of control systems.[61] However, smoke opacity tests are not sensitive enough to detect all types of malfunctions that may result in increased $PM_{2.5}$ emissions, particularly in new vehicles. Additionally, the test does not measure NO_x emissions. Given that the health impacts from an average new diesel truck are primarily attributable to NO_x emissions (Figure 8), it is important to detect vehicles emitting high levels of NO_x.

Other inspection and maintenance (I/M) programs designed to test both NO_x and $PM_{2.5}$ levels with more advanced methods can help guide updates to New York state's program. The Netherlands recently updated their periodic technical inspection program, introducing a new testing method that uses an advanced particle number measurement device.[62] This testing method replaced smoke opacity tests and can detect DPF malfunctions in newer trucks. California is in the process of adding requirements to their HDV I/M program, which will use on-board diagnostic system data and other test procedures to measure the NO_x and $PM_{2.5}$ emissions of all heavy-duty vehicles entering and operating in the state.[63] Vehicles found to be in violation must receive proper maintenance or the owner may be subject to a penalty.

In addition to periodic testing, there are other procedures that may be considered for I/M programs, discussed in more detail in a past ICCT report.[64] Roadside remote sensing may be considered as a component of the I/M program to identify high-emitting vehicles for further testing. On-road heavy-duty vehicle emissions monitoring systems may be used as a more comprehensive test, measuring emissions over a longer period of operation. This method can also specifically measure BC emissions. The proposed modifications to the California I/M program would also establish a roadside emissions monitoring network to screen the in-use fleet for potential high-emitting vehicles.

As the fleet shifts toward newer trucks with lower average emissions, high-emitting vehicles will make up an increasing share of total emissions. This impact can be minimized through state-level I/M programs that address both NO_x and $PM_{2.5}$ excess emissions. Proper testing procedures are particularly important in combination with policies that incentivize the use of newer diesel vehicles to ensure that potential emission reductions are observed in real-world operation.

POLICY IMPLICATIONS: ACCELERATED TRANSITION TO ZERO-EMISSION FREIGHT OPTIONS

Shifting to zero-emission freight options is important for continuing to reduce emissions and associated health and climate impacts. Though the newest diesel trucks have lower air pollutant emissions and health impacts, their collective impact is nonnegligible. These lower emission rates are conditional upon functional control technology, and while proper maintenance can help limit the impacts, it cannot eliminate the issue of high-emitting vehicles. Further decreases in NO_x limits from EPA's Clean Trucks Initiative will help reduce average emissions from diesel heavy-duty vehicles but also cannot eliminate high emissions due to tampered or malfunctioning control equipment. Ultimately, despite recent and anticipated improvements to internal combustion engine vehicles, it is necessary to decarbonize trucks and shift to zero-emission alternatives to meet climate and health goals.

Vehicles that guarantee zero tailpipe emissions can alleviate a large portion of truck-related health burdens. Currently, battery-electric trucks and hydrogen fuel cell trucks are the two zero-emission medium- and heavy-duty options available. This section focuses on battery-electric trucks due to the larger infrastructure needs associated with hydrogen fuel cell trucks, though health benefits would result from transitions to either zero-emission option.

61 "Diesel inspections emission testing," New York State Department of Motor Vehicles, accessed August 25, 2021, https://dmv.ny.gov/inspection/diesel-inspections-emission-testing.

62 "Netherlands adopts new PTI test for DPF inspections," DieselNet, accessed October 15, 2021, https://dieselnet.com/news/2021/01npti.php.

63 SB-210 Heavy-Duty Vehicle Inspection and Maintenance Program, California Legislative Information (2019–2020), https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201920200SB210.

64 Francisco Posada, Zifei Yang, and Rachel Muncrief, *Review of current practices and new developments in heavy-duty vehicle inspection and maintenance programs,* (ICCT: Washington, DC, 2015), https://theicct.org/sites/default/files/publications/HDV%20insp-maint%20White%20Paper%20v2.pdf.

ZERO-EMISSION MEDIUM- AND HEAVY-DUTY FREIGHT TRUCKS

Due to projected increases in freight volumes, shifts toward zero-emission medium- and heavy-duty trucks are an important component of long-term plans to maintaining a downward trajectory of truck emissions and health impacts. A recent ICCT study on long-term projections of New York state heavy-duty vehicle emissions found that under a business-as-usual scenario, NO_x emissions will decline 40% from 2020 levels by 2035 but will increase by 2050, when NO_x emissions will be just 23% lower than 2020 levels.[65] Increasing the share of zero-emission trucks is necessary to counteract the effects of a growing fleet and diesel vehicle deterioration.

Medium-duty trucks, such as delivery box trucks, are good candidates for electrification in the near term. Electric box trucks are more widely available on the market compared to tractor-trailer trucks, which require more advanced technology due to heavier loads. Additionally, delivery vehicles operating within the city likely do not need to alter operation to accommodate battery range. Shifts toward electric MDTs can help begin the increase in zero-emission vehicles as battery technologies continue to advance and increase the feasibility for long-distance tractor-trailer truck travel.

Funding through initiatives like the Clean Trucks Program are important to assist with high upfront costs. Although electric truck fuel and maintenance costs are much lower compared to diesel trucks, the significant cost to purchase a new vehicle may be prohibitive for small businesses or individual truck owners. Improvements in battery technology and increased demand and production are expected to lower costs over time; however, rebates and other types of assistance to offset initial costs are important to encourage the purchase of zero-emission vehicles.

Charging infrastructure poses an additional cost and hurdle for the transition to battery-electric trucks. New York City can promote efficient, low-cost charging solutions by bringing together fleets, city agencies, and the electricity utility to identify optimal locations for building high-power charging infrastructure. An ICCT analysis found that the total cost of ownership for an electric class 6 or class 8 truck, including charging infrastructure costs, is projected to drop below diesel trucks by 2030 if electric trucks are adopted at high volumes.[66] The New York City Economic Development Corporation is supporting the creation of a publicly accessible charging network for electric trucks through incentives for installation and reduced energy costs.[67] Many early applications for electric trucks will rely primarily on depot charging; the city, state, and utility can facilitate this low-cost charging solution by providing information and potentially incentives for high-priority applications.

Electric trucks significantly reduce health impacts in the areas of operation due to zero tailpipe emissions. There are health impacts associated with the electricity required for truck operation, so continuing to increase the share of renewable electricity sources is an important component of electrification plans. However, overall health benefits of electric trucks over diesel trucks can be observed even before large shifts are made toward renewable electricity. Mortality-based damages from upstream electricity production under a 2030 business-as-usual scenario are estimated to be $0.07 per vehicle-mile for electric HDTs.[68] This cost is lower than the $0.16 per vehicle-mile cost associated with new diesel HDT emissions reported in this analysis. This gap will continue to widen as diesel trucks purchased today will likely have increasing average emissions and health impacts over their lifetime due to deterioration and electric trucks will have decreasing health impacts as more electricity comes from renewable sources. Mortality-based damages are estimated at less than $0.01 per mile under a high-renewable grid scenario.[69] Diesel trucks purchased today will be in the fleet for years to come, so shifting to zero-emission vehicles is important for current and future emission reductions. Policies should particularly support the near-term adoption of electric MDTs that

65 Ray Minjares, Jeff Houk, and Joey Juang, *Benefits of adopting California medium- and heavy-duty vehicle regulations in New York State*, (ICCT: Washington, DC, 2021), https://theicct.org/sites/default/files/publications/nys-hdv-regulation-benefits-2-may2021.pdf.

66 Dale Hall and Nic Lutsey, *Estimating the infrastructure needs and costs for the launch of zero-emission trucks*, (ICCT: Washington, DC, 2019), https://theicct.org/sites/default/files/publications/ICCT_EV_HDVs_Infrastructure_20190809.pdf.

67 "NYCEDC lays groundwork for developing truck-accessible electric charging stations throughout city," New York Economic Development Corporation, accessed November 29, 2021, https://edc.nyc/press-release/nycedc-lays-groundwork-developing-truck-accessible-electric-charging-stations.

68 Fan Tong et al., "Health and Climate Impacts from Long-Haul Truck Electrification," *Environmental Science & Technology* 55, no. 13 (June 14, 2021): 8514–23, https://doi.org/10.1021/acs.est.1c01273. This estimate reflects premature mortalities due to $PM_{2.5}$ and NO_x emissions based on electricity from the Northeast Power Coordinating Council (NPCC), which includes New York, the six New England states, and four provinces in Eastern Canada.

69 Tong et al.

are more widely available. Long-term plans for increases in zero-emission heavy-duty vehicles, including tractor-trailers, will help continue a downward trend in air pollution and health impacts.

ZERO-EMISSION LAST-MILE DELIVERY

Shifts to zero-emission last-mile delivery options vehicles such as electric cargo bikes are also an important part of emission reductions plans. Current e-cargo bike options are widely available, and the electricity needs are comparatively small. Local delivery routes with set start and end points are good candidates for shifts to e-cargo bikes. Additionally, e-cargo bikes can support the continuation of delivery access as streets or larger zones are blocked off from vehicle activity.

In New York City, e-cargo bikes are permitted to use commercial vehicle loading spaces and are exempt from paying at parking meters, which has been one effective incentive.[70] Improving street infrastructure for safer operation and adding dedicated loading zones are steps identified in the Smart Truck Management plan to support increases in e-cargo bike delivery. Additionally, e-cargo bike charging hubs, as proposed in a recent evaluation report, would help increase the adoption of e-cargo bikes.[71]

Other electric light-duty vehicles may be able to serve last-mile delivery needs as well. Electric delivery vehicles provide air quality and climate benefits over diesel and natural gas trucks and vans. Shifts toward electric delivery vehicles significantly reduce health burdens in both the neighborhoods they are delivering in as well as near the distribution centers or other origin points of the trip.

ELECTRIFYING NONROAD DIESEL ENGINES

This analysis focuses on emissions from on-road diesel truck operation; however, the NO_x emissions from other diesel engines contribute significantly to air pollution and exposure disparities. Stationary transport refrigeration units (TRUs) fueled by diesel are one source of emissions not modeled in this paper. TRUs are particularly concentrated in Hunts Point, which is next to and upwind of neighborhoods designated as environmental justice areas, many of which are currently exposed to some of the highest levels of $PM_{2.5}$ from on-road diesel truck operation. Figure 10 shows how emissions from within Hunts Point affect the $PM_{2.5}$ concentrations in the nearby areas; modeled concentrations are based on typical post-2009 diesel vehicle emissions. New York City Smart Truck Management Plan includes a proposal to electrify TRUs, which will help improve air quality in the immediately surrounding areas as well as downwind areas.

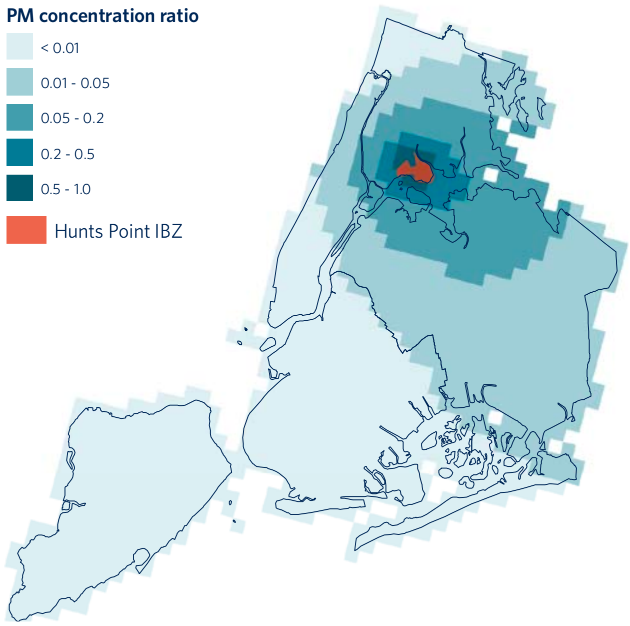

Figure 10. Modeled change in $PM_{2.5}$ concentration resulting from NO_x and $PM_{2.5}$ emitted within Hunts Point IBZ. PM concentration ratio refers to the ambient concentration at the given location divided by the concentration in the source location (within Hunts Point IBZ).

Reducing port emissions by electrifying port equipment, including cranes and locomotive switchers, are also important strategies to reduce health impacts on surrounding communities. Unlike on-road diesel engines, for which DPFs have been near universal since 2007, even the newest nonroad diesel engines meeting current EPA Tier 4f standards may not have DPFs. Non-road engines not equipped with DPFs accounted for approximately 50% of Tier 4f-certified engine families in 2016, emitting approximately four to five times more PM compared to DPF-equipped engines.[72]

70 Marica Kramer, "NYC Announces Pilot Program That Replaces Some Delivery Trucks with Electric Cargo Bikes," *CBS New York*, December 4, 2019, https://newyork.cbslocal.com/2019/12/04/nyc-electric-cargo-bikes-delivery-trucks-congestion/.

71 New York City Department of Transportation, "Commercial cargo bicycle pilot" (2021), https://www1.nyc.gov/html/dot/downloads/pdf/commercial-cargo-bicycle-pilot-evaluation-report.pdf.

72 Tim Dallmann and Aparna Menon, *Technology pathways for diesel engines used in non-road vehicles and equipment*, (ICCT: Washington, DC, 2016), https://theicct.org/sites/default/files/publications/Non-Road-Tech-Pathways_white-%20paper_vF_ICCT_20160915.pdf.

Where electrification is not currently feasible, it is not enough to encourage transitions to newer diesel engines; the nonroad engines must be equipped with DPFs to effectively limit $PM_{2.5}$ emissions as much as possible. In addition to reducing emissions from port equipment, implementing shore power infrastructure will help to reduce emissions from ships docked at ports. These plans to address the significant health and climate impacts associated with port BC emissions can be studied further in additional analyses.

POLICY RECOMMENDATIONS SUMMARY

This report evaluates several policies to reduce diesel truck emissions based on an analysis of health impacts by engine MY and a spatial analysis of $PM_{2.5}$ exposure from truck emissions. These policies, which are summarized in Table 4, have varying impacts regarding

Table 4. Evaluation of policies to reduce diesel truck emissions

		Increasing potential emissions reduction →				
Policy	**Status**	**Operate in reduced congestion**	**Reduce individual high-emitting vehicles**	**Reduce high-emitting pre-2010 vehicles**	**Accelerate transition to zero-emission alternatives**	**Potential to address exposure disparities**
Off-hour delivery program	Implemented, planned expansion	✓				●
CBD tolling Uniform charge for all trucks	Planned	✓				●
I/M program Update testing methods, add roadside in-use testing	TRUE recommendation		✓			●●
Weight restriction enforcement	Implemented, planned expansion		✓			●●
Clean Trucks Program Expanded eligibility for pre-2010 diesel trucks	TRUE recommendation			✓		●●●
IBZ and port restrictions Emissions-based access restriction	TRUE recommendation			✓	✓	●●●
CBD tolling Emissions-based charge	TRUE recommendation	✓		✓	✓	●
Zero-emission zone	TRUE recommendation				✓	●●
Clean Trucks Program Increased rebates for battery electric vehicles	TRUE recommendation				✓	●●
Publicly accessible charging infrastructure	Planned				✓	●●
Shift to e-cargo bike deliveries Infrastructure improvements, access restrictions	Implemented, planned expansion				✓	●
Rebates for zero-emission replacements to non-road diesel engines	Planned				✓	●●●

Potential to address exposure disparities:

● = emissions reductions primarily in non-environmental justice (EJ) areas
●● = emissions reductions across the city, including in heavily burdened EJ areas
●●● = emissions reductions focused in heavily burdened EJ areas

potential emission reductions and the potential to address racial disparities in exposure to $PM_{2.5}$.

Accelerating the transition to zero-emission alternatives is the strategy that can deliver the largest emission reductions over time, and policies working toward this goal should be prioritized. In the meantime as combustion engines remain on the road, replacing the oldest, highest-emitting pre-2010 engine MY vehicles is a key strategy to reducing overall emissions. Additionally, policies to reduce individual high-emitting diesel trucks are important components of plans to limit diesel truck emissions. While reducing congestion and operating in lower congestion times may help achieve other city goals, the emissions benefits of this strategy alone are relatively minor.

To reduce disparities in exposure to $PM_{2.5}$ from diesel trucks, certain policies can be designed to focus emission reductions in heavily burdened environmental justice areas. Additionally, policies aiming to reduce emissions of trucks traveling throughout the city can result in air quality improvements, particularly for communities surrounding heavily trafficked freight corridors.

These evaluations can help guide priorities in implementing the most effective policies. Key policy recommendations include the following:

Drastically reduce the share of pre-2010 engine MY diesel trucks to maximize emission reductions in the shortest amount of time. Pre-2010 engine MY trucks currently contribute a significant portion of overall emissions, much more than their share of vehicle activity. The existing Clean Trucks Program helps to replace pre-2010 engine MY trucks by offering rebates for trucks operating in defined IBZs. However, program participation levels are not nearly high enough to significantly reduce the share of older, high-emitting diesel trucks. Additional efforts are needed to incentivize shifts away from pre-2010 engine MY trucks. Setting access restrictions for ports and IBZs where feasible to restrict pre-2010 engine MY vehicles would help accelerate the replacement of the remaining older trucks. Additionally, an emissions-based truck toll through the Central Business District Tolling Program would encourage transitions to cleaner vehicles. The Clean Trucks Program can better support these policies by increasing rebates for the cleanest vehicles and expanding program eligibility for vehicles operating throughout the city. This combination of emissions-based tolling, access restrictions, and increased incentives for newer, cleaner vehicles can effectively support a rapid transition away from vehicles contributing the largest share of emissions.

Update inspection and maintenance program methods to effectively identify high-emitting vehicles as the fleet shifts to newer diesel vehicles. A small share of vehicles with malfunctioning or tampered control systems can make up a large share of overall emissions. Malfunctions in newer vehicles are often undetectable under a smoke opacity test, which is currently the only emissions test in New York state's inspection procedure. Implementing emissions testing methods such as on-board diagnostics and particle number measurement, can more effectively detect malfunctions and excess NO_x and $PM_{2.5}$ emissions. Additionally, in-use testing through roadside remote sensing can help supplement periodic testing by continuously monitoring vehicle emissions and identifying high emitters for repair.

Focus emission reduction policies on the environmental justice areas currently experiencing the largest health burdens to reduce racial disparities in exposure to $PM_{2.5}$. The current access restrictions in effect by the Port Authority of New York and New Jersey targets only pre-1997 engine MY trucks, a small portion of high-emitting vehicles. Restricting access to 2010 and later engine MY vehicles at ports would more effectively reduce emissions and the health burdens on surrounding communities. Similar policies can be implemented in IBZs where feasible, prioritizing zones near and upwind of environmental justice areas with the highest exposure to $PM_{2.5}$. These restrictions should be accompanied with timelines for ultimately transitioning to fully zero-emission operation. Increasing support to initiatives to replace nonroad diesel engines such as TRUs and port equipment with zero-emission alternatives will also target air quality improvements in surrounding environmental justice areas.

Accelerate the shift to zero-emission vehicles to achieve the largest emission reductions and to achieve climate goals. New York City should commit to zero-emission freight to ensure that emissions and health impacts continue to decline as freight volumes increase. Zero-emission zones or areas can help accelerate this shift, and the programs and pilots implemented in other cities across the world can guide the implementation. This shift to zero-emission vehicles can be better supported by increasing the rebates for battery-electric vehicles through the Clean Trucks Program, particularly as battery technology improves the feasibility of battery-electric tractor-trailers. Additional investments in the form of publicly accessible truck charging infrastructure will also support a larger-scale shift to zero-emission alternatives. Adoption of zero-emission vehicles is already increasing with shifts to e-cargo bike and electric light-duty vehicles. The city can continue to incentivize zero-emission last-mile delivery through managing routes and curb space. Through a combination of ambitious zero-emission timelines, rebates and other incentives, and infrastructural support, New York City can work toward a cleaner, more sustainable freight network.

CONTINUED RESEARCH AND POLICY MONITORING USING REAL-WORLD DATA

As highlighted in this analysis, using real-world data provides useful information to develop effective policies. This paper discusses policy implications of emissions and air quality results modeled using the U.S. TRUE database; however, there are policy areas that may benefit from further detailed study using New York City real-world data. Additionally, after policies are implemented, it would be beneficial to continue study of the policies based on real-world data to track the effectiveness in reducing emissions.

Real-world data collected in New York City would help to develop a more accurate and detailed profile of medium- and heavy-duty vehicle operation. Data on engine model years collected through license plate recognition or another method would better reflect distributions of actual vehicle operation, which includes vehicles registered in other regions. Data from multiple locations throughout the city could provide insight on spatial trends, that is, if certain areas of the city have larger shares of older vehicles. New York City real-world fleet operation data could support an analysis to project long-term emissions trends and model various scenarios.

A vehicle emissions testing campaign in New York City would provide similar information on the fleet distribution and provide the opportunity to examine other emissions issues. The impact of vehicle weight could be studied by positioning a remote sensing device near a weigh-in-motion station. The emissions readings could be analyzed with weight and speed data to develop emission factor adjustments and quantify the impact of overweight vehicles. The data can also be used to analyze whether certain vehicle types are emitting at particularly high levels, guiding future policy decisions. Additionally, more detailed information spatial trends of high-emitting vehicles could inform policies focused on specific areas of the city.

Data collection from programs implemented to reduce emissions can serve dual purposes to monitor program effectiveness and investigate other emission reduction strategies. Currently, trucks receiving funding through the Clean Trucks Program are equipped with automatic vehicle locators, which provide data that can be used to estimate emission reductions across the city. This data could be used to study the impact of other policies, such as a more detailed analysis on emission reductions associated with off-hour delivery in different areas of the city. The New York City Community Air Survey program monitors air quality at approximately 100 locations across the city, and the NO_x and $PM_{2.5}$ readings can be used to track the impact of policies.[73] Plans to continue monitoring real-world data will support effective policies to reduce diesel truck emissions and identify when additional interventions are needed.

CONCLUSION

Air pollution in New York City is a major public health issue, and reducing diesel truck emissions is an important component of plans to alleviate this burden. Diesel truck emissions in New York City have disproportionate health impacts on people of color, with many Asian and Latino residents exposed to above-average levels of $PM_{2.5}$ from diesel truck emissions. Policies may be considered to reduce emissions in communities experiencing the heaviest burdens, such as restrictions in nearby industrial areas based on engine MY.

This analysis highlights the urgent need to reduce the share of pre-2007 engine MY trucks, which make up 10% of the MDT fleet but contribute 83% of $PM_{2.5}$ emissions and 33% of NO_x emissions. HDTs of the same model year group represent 6% of the fleet and contribute 64% of $PM_{2.5}$ and 24% of NO_x emissions. Replacing an older pre-2007 engine MY vehicle results in benefits of at least $1.61/vehicle-mile for MDT and $2.22/vehicle-mile for HDT in mortality-based

73 New York City Department of Health and Mental Hygiene, "NYC Community Air Survey" (2017), https://www1.nyc.gov/assets/doh/downloads/pdf/eode/nyccas-air-survey.pdf.

damages due to $PM_{2.5}$ exposure. Additionally, 2007–2009 engine MY trucks have elevated real-world emissions and should be included in efforts to replace older diesel vehicles.

Other policies are also discussed in this paper to address the emission and health impacts of medium- and heavy-duty trucks are off-hour delivery, increased enforcements of weight restrictions, and I/M programs to reduce the impact of high-emitting vehicles. As the fleet becomes increasingly composed of newer vehicles, overall emissions will drop, but individual high-emitting vehicles will remain an issue.

Due to the projected growth of freight, efforts to reduce truck emissions could be gradually erased if not accompanied by efforts to shift away from diesel trucks. Zero-emission vehicles are an essential component of long-term freight plans. Near-term steps to accelerate this transition, such as increasing the share of zero-emission vehicles and building charging infrastructure, are critical for achieving goals of a more sustainable freight system.

This study uses a reduced-complexity model to study air quality and health impacts, with an analysis of policy implications. While the results provide a useful estimate on impact of emissions in various areas, it is also important to consider local perspectives, particularly when making decisions about efforts to reduce emissions in specific areas of the city. Residents and groups that work directly with community members have the best knowledge on observed patterns of truck activity in their neighborhoods and on health issues impacting their communities. The results and discussion on city-wide policies in this paper are intended to be used alongside regional plans, state policies, and community-level work to implement the most effective solutions toward the reduction of medium- and heavy-duty vehicle-related air pollution.

APPENDIX: DETAILED MODELING APPROACH

VEHICLE CLASSIFICATIONS

Table A1 shows the truck classifications of various data sources used in this analysis. This analysis defines medium-duty trucks (MDTs) as vehicles with a gross vehicle weight rating (GVWR) between 10,000 lb and 33,000 lb and heavy-duty trucks (HDTs) as vehicles above 33,000 lb GVWR. The EPA and Federal Highway Administration also classify trucks by weight, whereas the New York State Department of Transportation (NYSDOT) activity dataset and the heavy-duty in-use testing (HDIUT) classifications are based on vehicle type. The two classifications systems generally overlap, though there are some exceptions of single-unit trucks rated above 33,000 lb and, more rarely, combination-unit trucks rated below 33,000 lb. For this analysis, we apply MDT emission factors to single-unit truck activity with delivery truck HDIUT speed adjustments. We apply HDT emission factors to combination-unit truck activity with line-haul HDIUT speed adjustments.

ENGINE MODEL YEAR VMT DISTRIBUTION

We calculate fleet-average emission factor for MDT and HDT in New York City by multiplying each engine model year emission factor by an estimated share of total vehicle activity. To get this distribution of vehicle miles traveled (VMT) by engine MY, we begin with a vehicle count distribution. We use the NYSDOT registration database,[74] filtering for diesel vehicles registered within New York City with GVWR above 10,000 lb. The vehicle counts are then adjusted to reflect trends of older vehicles traveling fewer miles on average compared to newer vehicles. Correction factors are developed using EPA MOVES 2014 average VMT by age for single- and combination-unit trucks.[75] Figure A1 shows the total distribution of vehicle count in red and the distribution after applying the age-based correction factors in blue.

The typical ages of vehicles operating in different parts of the city and on different road types may vary. Additionally, the distribution in this analysis may differ from the actual fleet operation depending on typical ages of vehicles traveling from out of state or from other parts of New York state. However, given the data available, we rely on fleet model year distributions

Table A1. Heavy-duty vehicle classification definitions

Truck GVWR	EPA & MOVES2014 regulatory class		FHWA classifications	TRUE analysis classifications	NYSDOT activity dataset classifications	HDIUT classifications
8,501 – 10,000 lb	HDV 2b	LHD<=10k	Light duty (<10,000 lb)		Single-unit	Delivery
10,001 – 14,000 lb	HDV 3	LHD<=14k	Medium duty (10,000 – 26,000 lb)	MDT		
14,001 – 16,000 lb	HDV 4	LHD45				
16,001 – 19,500 lb	HDV 5					
19,501 – 26,000 lb	HDV 6	MHD				
26,001 – 33,000 lb	HDV 7		Heavy duty (>26,000 lb)			
>33,000 lb	HDV 8	HHD		HDT	Combination-unit	Line-haul

74 "Vehicle, snowmobile, and boat registrations," New York State Department of Motor Vehicle Registrations, accessed March 9, 2021, https://data.ny.gov/Transportation/Vehicle-Snowmobile-and-Boat-Registrations/w4pv-hbkt.

75 "MOVES versions in limited current use," U.S. Environmental Protection Agency, accessed March 12, 2021, https://www.epa.gov/moves/moves-versions-limited-current-use#moves2014-general.

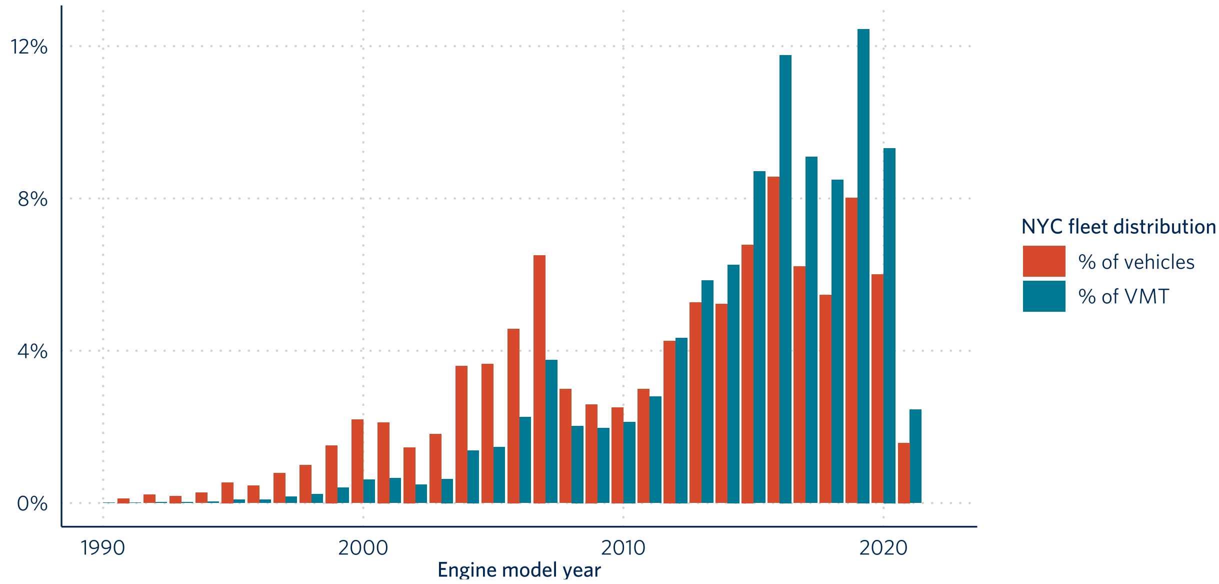

Figure A1. Fleet model year distribution based on vehicle registrations in New York City and estimated share of total VMT.

developed from New York City registrations to represent city-wide MDT and HDT averages.

EMISSION FACTORS

The two pollutants modeled in this analysis are NO_x and $PM_{2.5}$. We use real-world emissions data when available to capture trends of changes across engine model years and excess emissions observed among most model years. The NO_x emission factors are created using the TRUE U.S. database.[76] The database contains over 70,000 measurements of heavy-duty vehicles, collected from 2010 to 2018. Data for the oldest engine years before 1998 are supplemented using MOVES2014 data.[77]

We use $PM_{2.5}$ emission factors from MOVES2014.[78] Trends from other real-world emissions data sources were also considered. A large number of high-emitting 2007–2010 engine MY vehicles were observed in past remote sensing studies, resulting in higher average emissions for this engine MY group. We use two remote sensing studies to develop adjustments to $PM_{2.5}$ emission factors for 2007–2009 engine MY vehicles to reflect higher emissions than represented by MOVES.[79] The average measurements of black carbon and $PM_{2.5}$ from the two studies were found to be 3.7–5.5 times higher for 2007–2009 engine MY vehicles compared to post-2009 engine MY vehicles.[80] The 2007–2009 engine model year $PM_{2.5}$ emission factors in this analysis were adjusted upward to four times the 2010–2013 engine MY emission factors.

All emission factors are converted from fuel-based emission factors (g/kg fuel) to distance-based emission factors (g/mi) using MOVES3 fuel economy data by model year and vehicle class.[81] Figure A2 shows our estimates of emission factors for each pollutant by engine model year. We calculate the fleet-average MDT and HDT emission factors for both pollutants using the engine model year VMT distribution.

76 Bernard et al., *Development and application of a United States real-world vehicle emissions database*.

77 "MOVES versions in limited current use."

78 "MOVES versions in limited current use."

79 Chelsea V. Preble, Robert A. Harley, and Thomas W. Kirchstetter, "Control Technology-Driven Changes to In-Use Heavy-Duty Diesel Truck Emissions of Nitrogenous Species and Related Environmental Impacts," *Environmental Science & Technology* 53, no. 24 (2019): 14568–76; Gary A. Bishop, Molly J. Haugen, and Donald H. Stedman, "Investigate the durability of diesel engine emission controls," Department of Chemistry and Biochemistry, (University of Denver, March 2018), https://ww2.arb.ca.gov/sites/default/files/classic/research/apr/past/11-309.pdf.

80 The $PM_{2.5}$ data from Bishop and Haugen (2018) included one extreme outlier measurement several hundred times above the median for that model year group. We exclude this measurement to calculate the multiplier.

81 U.S. Environmental Protection Agency, "Exhaust Emission Rates for Heavy-Duty Onroad Vehicles in MOVES3" (2020), https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1010MC2.pdf. This analysis primarily uses data from MOVES2014 to maintain consistency across ICCT work except for fuel economy data, which is available in MOVES3 documentation.

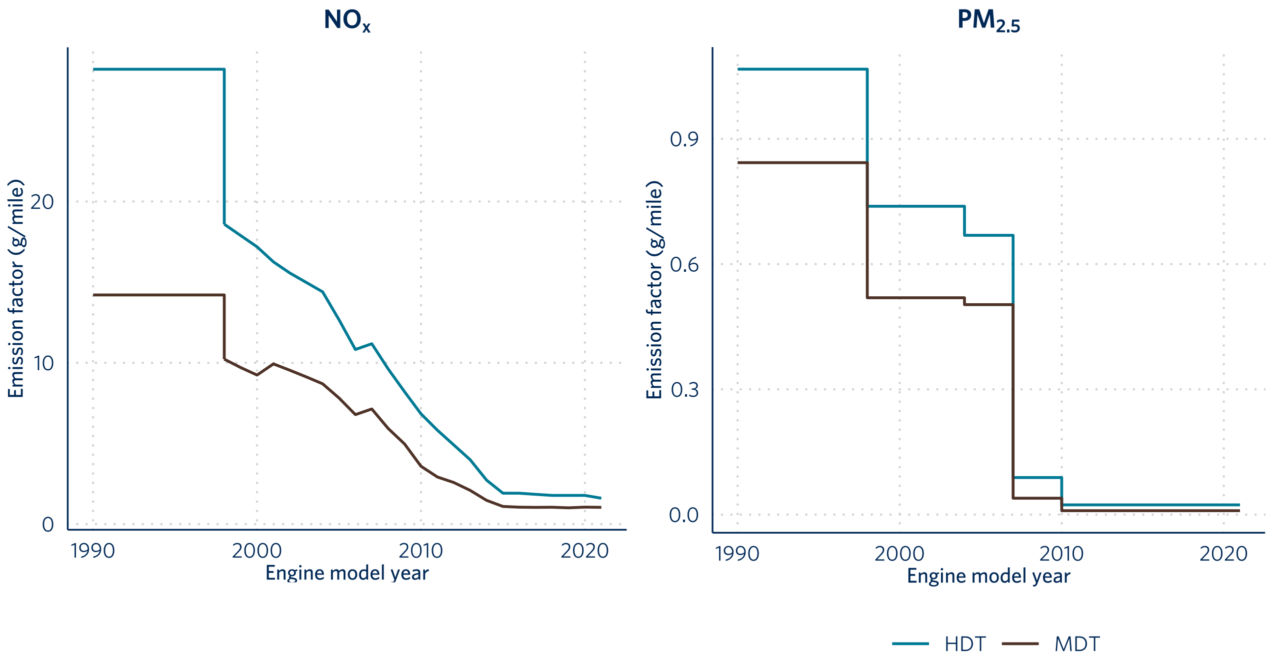

Figure A2. NO_x and $PM_{2.5}$ emission factors by engine model year.

NO_x EMISSION FACTOR SPEED ADJUSTMENTS

Diesel trucks tend to emit higher levels of NO_x during low-speed operation. Given that trucks operating within New York City often travel on highly congested roadways and operate at low speeds, we account for these higher NOx emissions using a combination of real-world emissions data and speed data associated with road segments across the city.

The HDIUT dataset was developed by measuring emissions over drive cycles with varying speeds using a portable emissions measurement system (PEMS). Measurements of emission levels are collected each second over the drive cycle. All vehicles included in this dataset are post-2009 engine MY vehicles. From data on delivery and line-haul trucks, we develop fuel-specific emission factors for different speeds, using 10 mph speed bins. Approximately 88% of measurements from the TRUE database were in the 25–50 mph range,[82] so we use this as the basis for adjustments. From the HDIUT data, each 10 mph speed bin's fuel-specific emission factor is divided by the fuel-specific emission factor associated with the 25–50 mph speed bin, resulting in an emission factor multiplier. These multipliers are only applicable for trucks equipped with SCR systems, so adjustments are only applied to the post-2009 engine MY segment of the fleet (84% of activity).

We use 2019 Uber Movement speed data, which reports hourly average speeds for road segments across New York City.[83] We use a city-wide average distribution of truck activity by hour from New York City DOT combined with the Uber Movement road segment's hourly speed profile to estimate the total percent of activity in each speed bin for each segment.[84] MDT and HDT emission factor adjustments are assigned to each road segment by using the percent of activity in each speed bin to calculate a weighted average of the HDIUT multipliers.

Figure A3 shows the share of activity in each speed bin for each road type and the average emission factor multipliers. Trucks on interstates and freeways typically operate at higher speeds, and the average emission factor is adjusted downward. However, activity on all other road types have speed distributions that result in an upward average emission factor adjustment.

82 Bernard et al., *Development and application of a United States real-world vehicle emissions database.*

83 Uber Movement (Quarterly speed statistics by hour of day for New York City, accessed April 13, 2021), https://movement.uber.com/cities/new_york/downloads/speeds.

84 Off-Hour Deliveries (New York City hourly truck volumes, accessed April 9, 2021), https://ohdnyc.com/home.

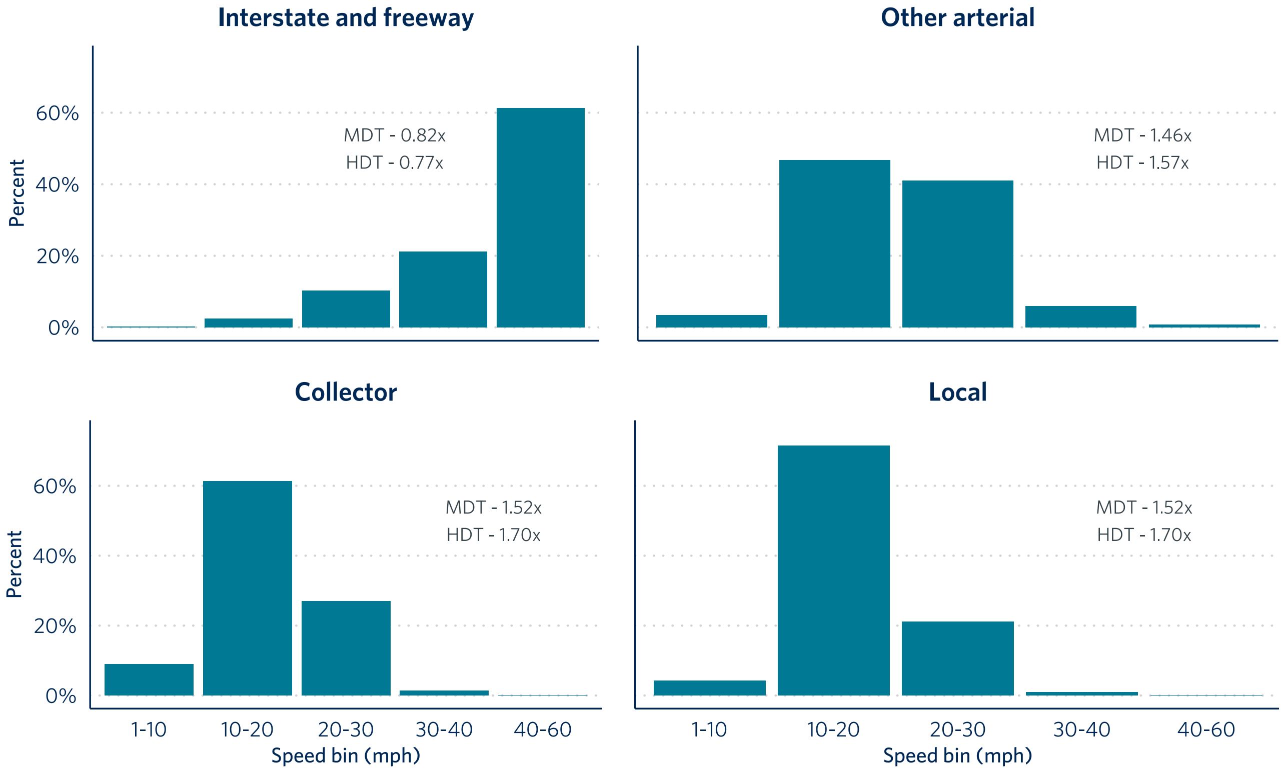

Figure A3. Distribution of activity by speed bin for each road type and average emission factor multipliers for speed adjustment.

Because Uber Movement speed data is collected from a specific subset of vehicles, namely for-hire passenger vehicles, we validate the data against INRIX speed data for three selected road segments.[85] INRIX reports speed data collected from a variety of vehicle types, including passenger and commercial vehicles of various classifications, and the three selected road segments have high volumes of truck activity and large ranges in speed. Uber Movement speeds are within 5 mph of INRIX speeds for 76% of activity, and there is no observable bias toward higher speeds in either dataset. These results provide justification for the use of Uber Movement data to model truck speeds.

TRUCK ACTIVITY DATA

Fleet-average emission factors are applied to 2019 spatial truck activity data from NYSDOT, shown in Figure A4.[86] The dataset includes a shapefile of roads with single-unit truck and combination-unit truck annual average daily traffic (AADT). Activity data is scaled down based on the percentage of diesel truck activity for each truck type, 83% of single-unit and 99% of combination-unit, as reported in the 2017 EPA National Emissions Inventory (NEI).[87] Not all vehicle activity is represented in this dataset; some smaller roads and private roads are not included. However, the total diesel truck VMT per year is within 10% of the New York City total from 2017 EPA NEI.[88] After adjusting the AADT, the NO_x speed adjustment factors are joined to the road segments in preparation for modeling the emissions inventory.

The vehicle counts reported in the NYSDOT dataset are a mix of actual and estimated counts from 2019. The impact of COVID-19 on traffic volume is not reflected in this activity dataset. However, truck activity rebounded within a few months after the first stay-at-home order was announced in March 2020,[89] indicating that 2019 truck activity data is appropriate for modeling present-day truck activity levels.

85 New York City Department of Transportation, INRIX 2019 hourly average speed data (April 31, 2021).

86 "Traffic data viewer," 2019 AADT, New York State Department of Transportation, accessed January 6, 2021, https://www.dot.ny.gov/tdv.

87 "2017 National Emissions Inventory (NEI) data."

88 "2017 National Emissions Inventory (NEI) data."

89 "The impact of COVID-19 on commercial transportation and trade activity," Geotab, updated June 9, 2020, https://www.geotab.com/blog/impact-of-covid-19/.

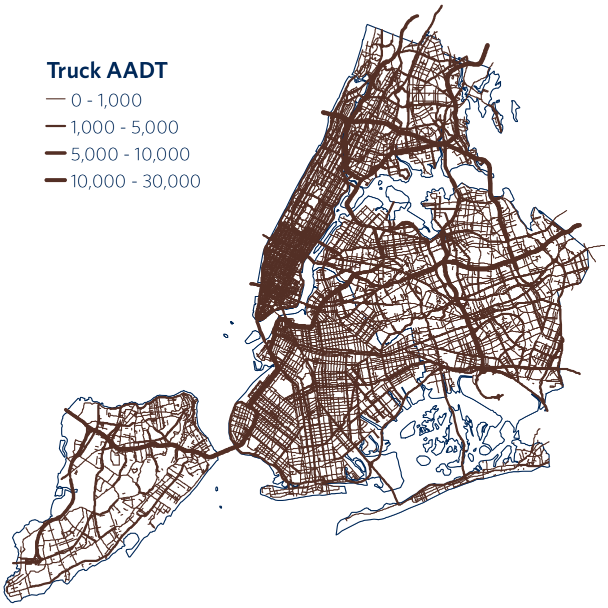

Figure A4. Spatial truck activity data.

BASELINE EMISSIONS INVENTORY

Baseline emission inventories are modeled at a high resolution of 250 x 250m. Following methods used in Kheirbek et al.,[90] we create a grid over New York City, cut the road segments at the grid boundaries, and then multiply the AADT by the road segment length to get an estimate of truck kilometers traveled on each segment. We then multiply these values by fleet-average distance-based emission factors and apply the NO_x speed adjustment factor to the portion of the fleet equipped with SCR systems (84%). Gridded emissions are developed by summing the emissions from all road segments within each grid cell, and the emissions are reported in tons per year.

AIR QUALITY AND HEALTH IMPACTS MODELING

After developing the baseline emissions inventory, we use InMAP to model the annual average concentration of $PM_{2.5}$ attributable to diesel truck tailpipe NO_x and $PM_{2.5}$ emissions. InMAP is a reduced-complexity air quality model developed from outputs of a chemical transport model using simplified assumptions of atmospheric chemistry.[91] InMAP utilizes a flexible grid resolution depending on population density, and the highest resolution of 1 x 1 km was used for this analysis.

InMAP can model $PM_{2.5}$ formation from NO_x as well as volatile organic compounds, SO_x, and NH_3, which are not modeled in this analysis. Maintaining consistency with past New York City air quality studies,[92] we use the Krewski et al. linear concentration-response function developed from the American Cancer Society study, which estimates a 6% increase in mortality rate for a 10 $\mu g/m^3$ increase in $PM_{2.5}$.[93] The model is run using the NO_x and $PM_{2.5}$ baseline emissions inventories to develop a map of ambient $PM_{2.5}$ concentration.

Additionally, we use spatial marginal damage rates from the InMAP Source Receptor Matrix (ISRM).[94] ISRM was developed from repeated runs of InMAP to estimate total damages in the source and downwind areas, assigning a rate of premature mortalities per ton of emissions to each potential emissions source location. These rates are used in combination with the emission inventories and emission factors by engine MY to develop average mortality-based damages per vehicle mile for various vehicle age groups. Additionally, we analyze the impact of emissions in the IBZs and the central business district using average emissions associated with post-2009 engine MY vehicles. Finally, we use 2018 American Community Survey 5-year estimates by census block group to analyze disparities in exposure to ambient $PM_{2.5}$ from diesel truck emissions by racial-ethnic group and household income quintiles.[95]

90 Kheirbek et al., "The Contribution of Motor Vehicle Emissions to Ambient Fine Particulate Matter Public Health Impacts in New York City."

91 Christopher W. Tessum, Jason D. Hill, and Julian D. Marshall, "InMAP: A Model for Air Pollution Interventions," *PLOS One* 12, no. 4 (April 19, 2017): e0176131, https://doi.org/10.1371/journal.pone.0176131.

92 Iyad Kheirbek et al., "$PM_{2.5}$ and Ozone Health Impacts and Disparities in New York City: Sensitivity to Spatial and Temporal Resolution," *Air Quality, Atmosphere & Health* 6, no. 2 (June 2013): 473–86, https://doi.org/10.1007/s11869-012-0185-4; Kheirbek et al., "The Contribution of Motor Vehicle Emissions to Ambient Fine Particulate Matter Public Health Impacts in New York City."

93 Daniel Krewski et al., "Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality" (Health Effects Institute, 2009), https://www.healtheffects.org/system/files/Krewski140.pdf.

94 Andrew Goodkind et al., *InMAP Source-Receptor Matrix (ISRM) dataset* (Zenodo, March 11, 2019), https://doi.org/10.5281/zenodo.3590127.

95 "TIGER/Line with selected demographic and economic data," U.S. Census Bureau (2018), accessed June 15, 2021, https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-data.2018.html.

SUPPLEMENTARY MATERIALS

Table A2. Mortality-based damages per vehicle-mile ($/veh-mi) of diesel trucks operating in New York City by engine model year (USD for 2021)

Vehicle	Engine model year group	Damages due to NO_x emissions ($/veh-mi)	Damages due to $PM_{2.5}$ emissions ($/veh-mi)	Total damages, NYC average ($/veh-mi)	Damages within CBD ($/veh-mi)
MDT	Pre-1998	0.84	2.08	2.92	4.31
	1998–2003	0.57	1.28	1.85	2.72
	2004–2006	0.45	1.24	1.69	2.50
	2007–2009	0.37	0.10	0.47	0.64
	2010–2012	0.17	0.02	0.20	0.27
	2013–2015	0.09	0.02	0.11	0.15
	Post-2015	0.06	0.02	0.08	0.11
HDT	Pre-1998	1.67	2.64	4.30	6.27
	1998–2003	0.97	1.82	2.80	4.09
	2004–2006	0.72	1.65	2.37	3.49
	2007–2009	0.60	0.22	0.82	1.13
	2010–2012	0.33	0.06	0.38	0.53
	2013–2015	0.16	0.05	0.21	0.29
	Post-2015	0.11	0.05	0.16	0.22

THE REAL URBAN EMISSIONS INITIATIVE

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