Tailpipe Emission Benefits of Medium- and Heavy-Duty Truck Electrification in Houston

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Introduction

This is an interim report on a project funded by the Energy Foundation entitled "Deploying Electric Vehicle Charging Infrastructure to Improve Air Quality." The intent of the project is to identify the vehicle segment for electrification that would benefit the Houston-Galveston, TX region the most toward ozone attainment. We argue that medium- and heavy-duty vehicles, mostly trucks, offer an often-overlooked opportunity. This interim report aims to document our findings on:

1. The size of the NOx reduction opportunity
2. The spatial distribution of the reductions
3. The co-benefits of other pollutant reductions

Throughout this report, we use the term 'electrification' to refer to powertrain electrification, regardless of the source of energy, whether it is electricity of hydrogen. We focus on electric vehicles because they have zero tailpipe emissions. Even though many would argue that electric vehicles have fuel upstream emissions, our previous analysis has shown that the fuel upstream NOx emissions from electricity or hydrogen are comparable to or less than those from fossil fuel vehicles on a per-mile basis (Xu et al., 2015). Further, the geographical scales of fuel upstream emissions are comparable among electricity, hydrogen, and fossil fuels in the Texas context - electricity is drawn in-state from the Electric Reliability Council of Texas (ERCOT) grid whereas oil and gas are produced in West Texas and refined in East Texas. Therefore, tailpipe emission reductions resulting from transportation electrification can be considered ***net*** reductions in our study area – the Houston-Galveston region.

We focus on medium- and heavy-duty trucks for three reasons. First, they are impactful. Medium- and heavy-duty vehicles, mostly trucks, have a large relative contribution to total on-road mobile-source emissions, as shown in Figure 1, according to the Houston-Galveston Area Council (H-GAC, 2019). Second, they are actionable. Medium- and heavy-duty trucks constitute less than 3% of the total vehicle population in the H-GAC area. This is comparable to observations in California (Forrest, et al., 2020). Unlike car purchases, which are typically household decisions with many behavioral considerations, truck purchases are typically business decisions driven by cost, for which incentives can be very effective. Third, they are becoming increasing feasible to electrify. Multiple commercially available models are ready for medium- and heavy-duty applications. In recent years, the lengths of truck trips have been steadily decreasing, with regional-haul operations that return to home-base every day becoming more prevalent (North American Council for Freight Efficiency, 2019). The combined trends of increase vehicle model availability and decreasing operational range make truck electrification an attainable goal.

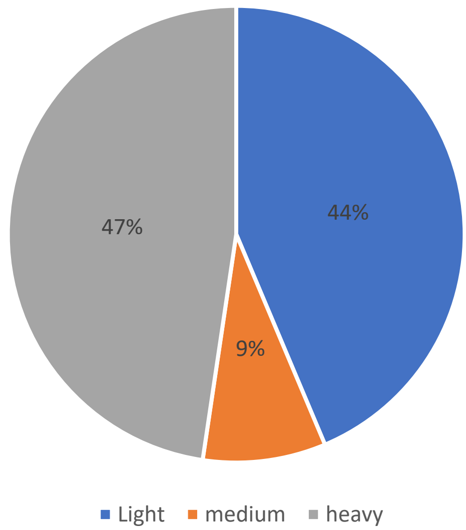


Figure 1 Relative NOx emission contributions by vehicle type (Data source: H-GAC Conformity Analysis for 2020 (H-GAC 2019))

Methodology

We calculate tailpipe emissions using an automated modeling pipeline we refer to as PATHS, or Platform to Assess Transportation, Health, connecting the travel demand model, dynamic traffic assignment (DTA) model, MOVES, and AERMOD (Meitiv, 2021). The DTA model (Chiu et al., 2011) produces vehicle trajectories, which are used to compute link aggregated traffic volumes binned by vehicle speed, vehicle type, and the hour of the day. The 24-hour total running exhaust emissions on each link of the network are computed using the projected 2020 emission rates according to 2019 Houston-Galveston Area Council Transportation Conformity Report (H-GAC, 2019). The dataset specifies the running exhaust emission rate of a number of chemical compounds for a given county, source type, hour of the day, road type, fuel type, and vehicle speed binned in 5 mph intervals. We also utilized the projected 2020 on-road vehicle mix constructed by the Texas A&M Transportation Institute (TTI) for the Texas Commission on Environmental Quality (TCEQ)'s On-Road Mobile Emissions Inventory. The vehicle mix dataset contains the source type fractions that make up the total volume at a given hour, Texas Department of Transportation (TxDOT) district, fuel type, and road type. The last input to the emissions calculation process is the link-aggregated traffic volumes. To simulate the emission reduction effects of electrification, we assume that a target percentage of traffic volume is electric vehicles, which have zero emissions according to MOVES. For this phase of the study, we assume we would electrify 40% of all vehicles. Because this is a very high percentage that can only be achieved over the medium to long term, we assume that the electrification process will reach an equilibrium where the age distribution will mirror the current vehicle age distribution.

To differentiate vehicle duty types, we use the following MOVES source types:

- Light-duty vehicles: Passenger Cars (source type ID 21), Passenger Trucks (31), and

Light Commercial Trucks (32)
- Medium-duty trucks: Refuse Truck (51), Single Unit Short-haul Truck (52), Single Unit Long-haul Truck (53), Motor Home (54)
- Heavy-duty trucks: Combination Short-haul Truck (61), Combination Long-haul Truck (62)

We further differentiate short-haul and long-haul travel by the categories of traffic assignment zones (TAZs). The TAZs include internal and external stations. Internal stations represent origins and destinations within the study area. Trips that originate/terminate at external stations represent trips that enter/leave the study area. We designate a trip as a short haul trip if neither the origin nor the destination is an external station.

Table 1 Number of Trips and Vehicle Miles Traveled (VMT)

Duty	Haul	Number of Trips	VMT
Light	Long	246,143	9,626,234
Light	Short	18,117,063	166,296,384
Medium	Long	228	4,737
Medium	Short	756,582	13,903,518
Heavy	Long	108,423	7,094,040
Heavy	Short	34,596	871,098
Total		19,263,035	197,796,011

Our VMT estimate is about 6% higher than the H-GAC modeled VMT for 2020 in the 2019 conformity analysis. Given the differences between models and the underlying transportation networks, we consider this difference acceptable.

As a co-benefit of NOx reductions, we also model reductions in fine particulate matter ($PM_{2.5}$). We model the dispersion of PM2.5 using the link-by-link emissions output as line-source emissions in EPA's pollutant dispersion model, AERMOD, using the process laid out in our recent study on the impact of Managed Lane policies on traffic and emissions in the El Paso area (Sharifi et al., 2021).

Results

Aggregate Emission Reduction Potential

As we have outlined in the previous section, our method to differentiate among vehicle types only considers the running portion of on-road mobile source emissions. Other components of on-road mobile source NOx emissions include starts and extended idle. Nevertheless, previous analysis has demonstrated that running exhaust constitutes most on-road mobile source NOx emissions (Kite, 2010). Therefore, the NOx emission reduction potential of running exhaust is a good indicator of the total emission reduction potential for electrification. Table 2 summarizes NOx emission reductions from electrifying 40% of different truck types. By summing the fourth column of Table 2, one would arrive at 15.06 tons/day in NOx running exhaust emissions reduction by electrifying 40% of all trucks.

Table 2 NOx Running Exhaust Reduction by Electrification Scenario (HDT: heavy-duty truck; MDT: medium-duty truck)

Scenario ID	Vehicle Type	Electrification Percentage	2020 NOx Reduction (tons/day)
1	HDT; Long-haul	40%	8.46
2	MDT; Short-haul	40%	5.48
3	HDT; Short-haul	40%	1.12
4	MDT; Long-haul	40%	0.00

The total running exhaust emissions from all on-road mobile sources for the same area is about 58 tons/day. The 2020 total on-road mobile emissions for the same area is 79.62 tons/day. By extension, 40% of electrification of MDTs and HDTs will reduce 21 tons/day of total emissions. In comparison, 40% of LDV electrification will lead to 8 tons/day of running emissions reduction.

Spatial Distribution of NOx Reductions

Figure 2, Figure 3, and Figure 4 show the spatial distribution of NOx reductions for electrifying 40% of heavy-duty long-haul, medium-duty short-haul, and heavy-duty short-haul trucks. We elected not to show medium-duty long-haul trucks because the total reduction is negligible. HDT long-haul and MDT short-haul present very different spatial distributions. HDT long-haul electrification reduces emissions along major corridors, whereas MDT short-haul electrification reduces emissions across secondary roadways, especially on the west side of Houston.

This difference has two implications. First, from an ozone attainment perspective, the NOx emissions from different areas in the region may have a varying degree of impact on ozone monitors due to complex atmospheric reactions. This is the subject of a parallel photochemical modeling study conducted by Alpine Geophysics, an environmental consulting firm. Second, the spatial difference leads to environmental justice questions related to air pollution and public health. The pollutant dispersion results below will provide more insights.

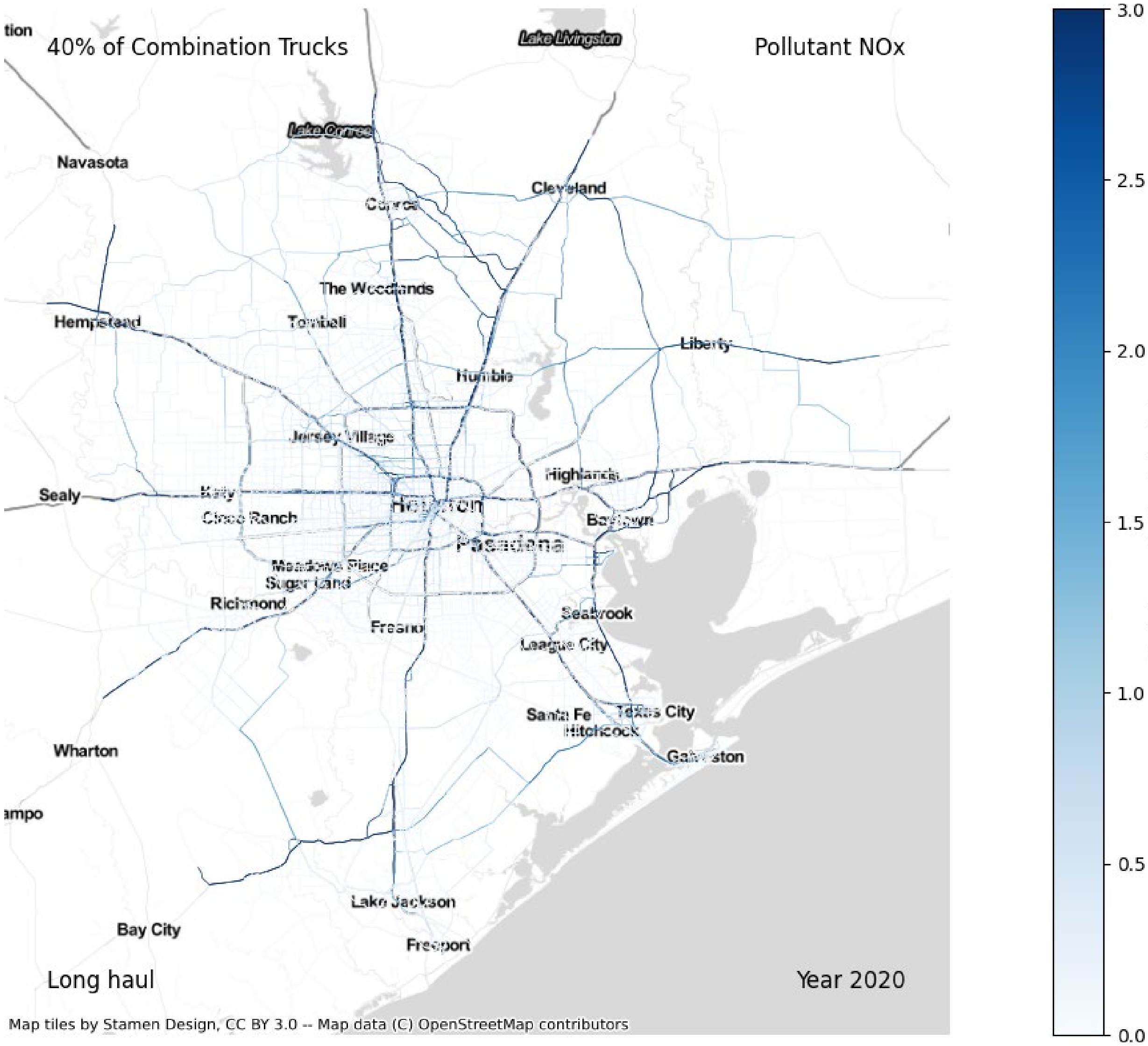


Figure 2 NOx reduction map for electrifying 40% of heavy-duty long-haul trucks

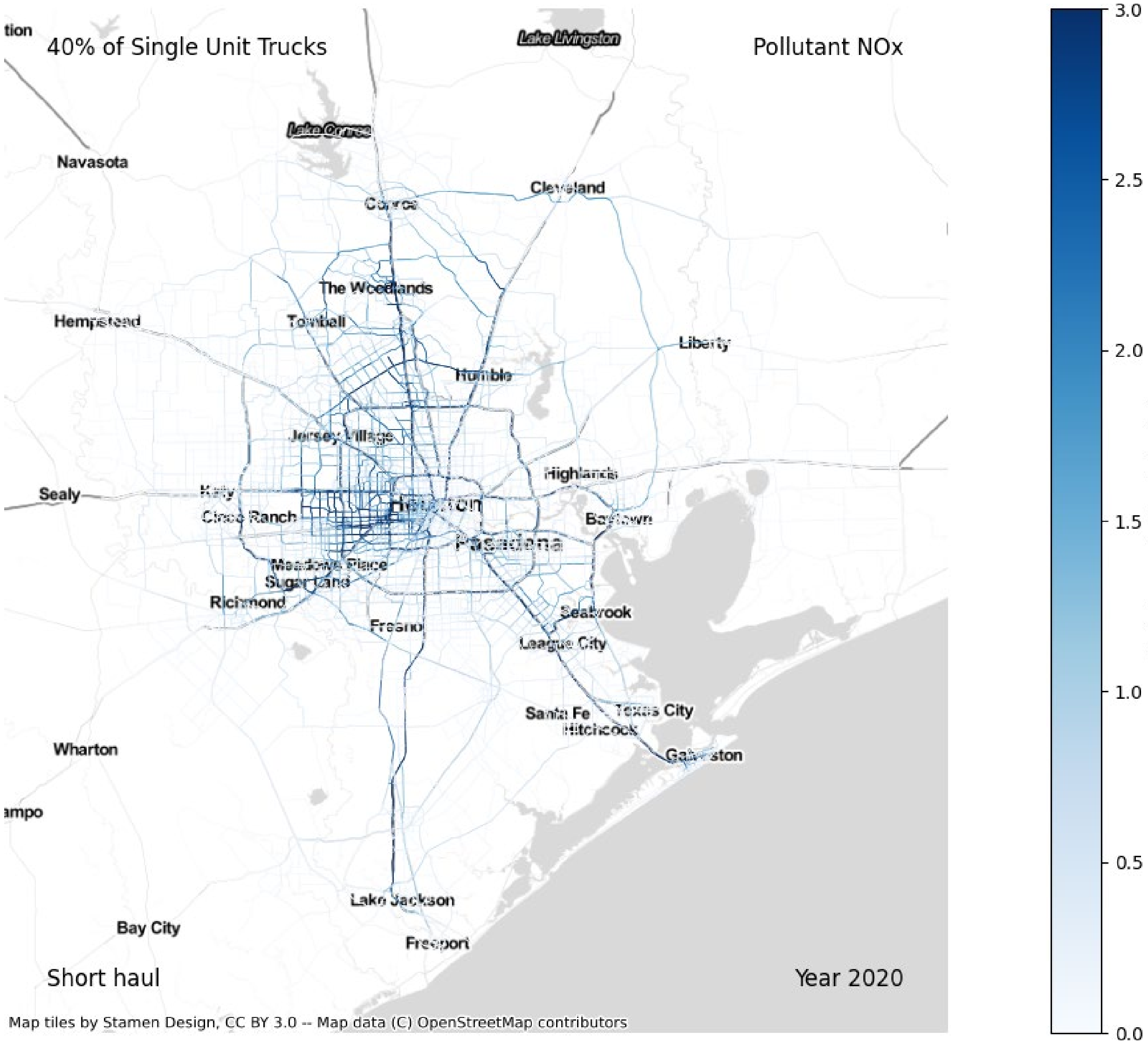


Figure 3 NOx reduction map for electrifying 40% of medium-duty short-haul trucks

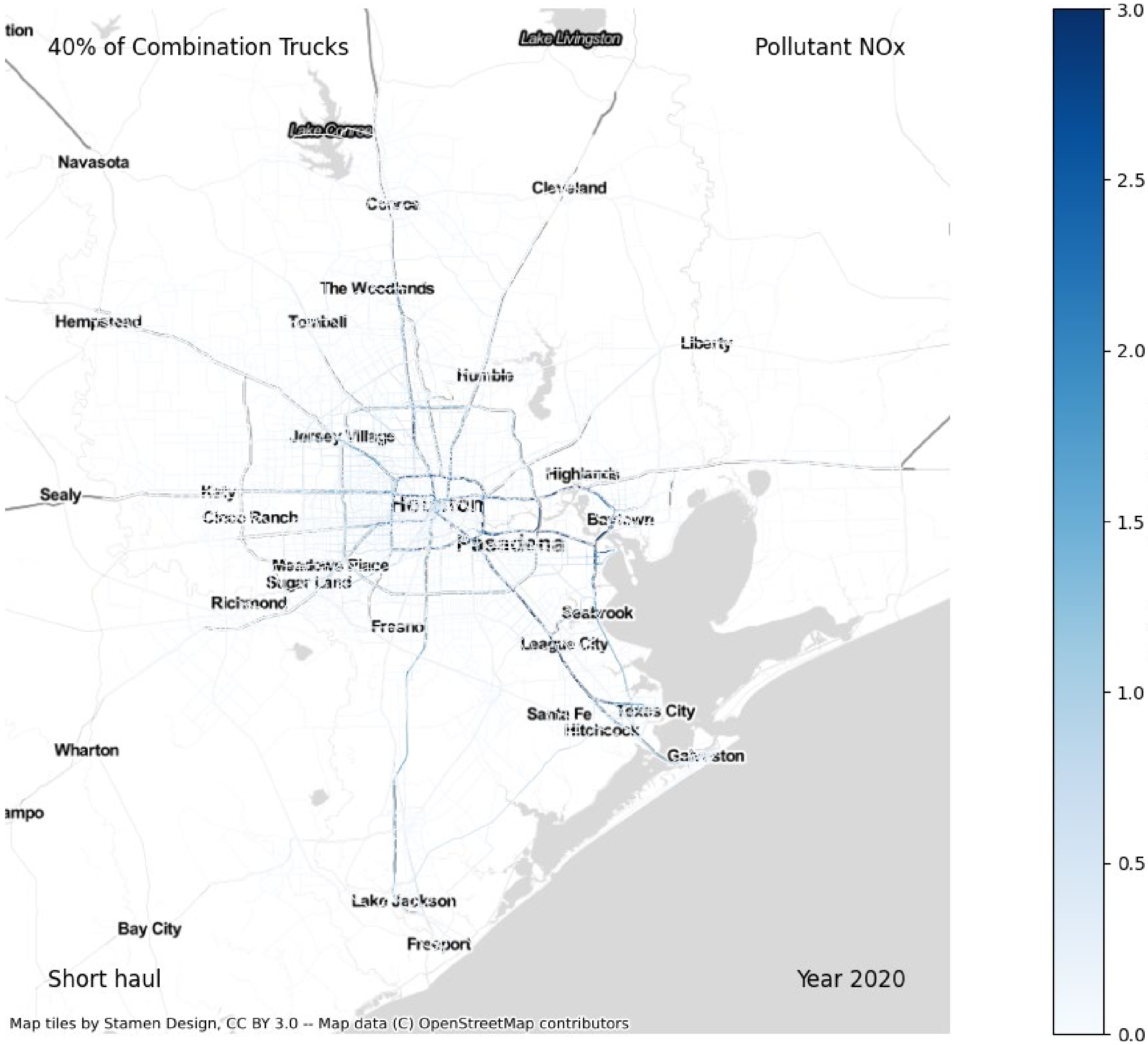
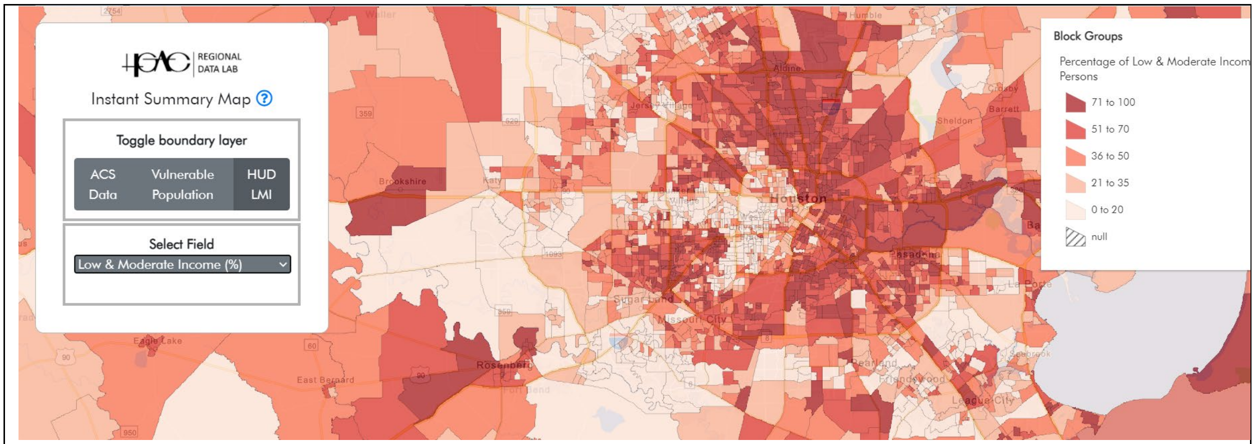


Figure 4 NOx reduction map for electrifying 40% of heavy-duty short-haul trucks

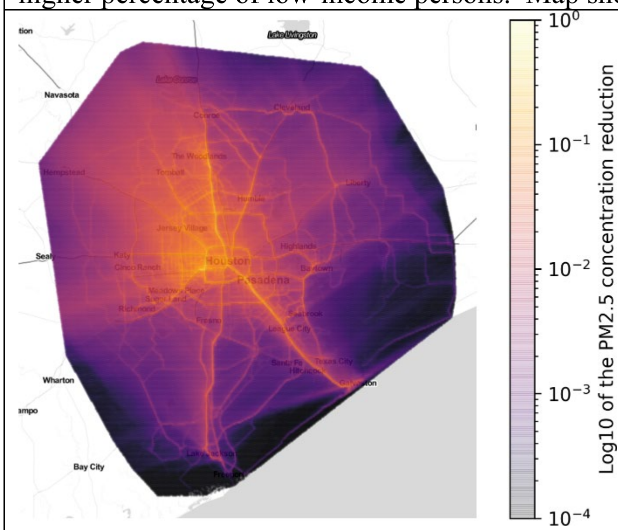
Co-benefits of PM2.5 Reduction and Distribution

The H-GAC 2019 Transportation Conformity Analysis did not include PM2.5 emission rates, so we used the 2017 TCEQ Emissions Inventory rates prepared by TTI (2019) as an approximation. Electrifying 40% of MDT and HDT will reduce 749 kg/day in PM2.5 running exhaust. We recognize that electrification will still incur tire wear, but brake wear will also be reduced due to regenerative braking. We also argue that running exhaust produces diesel particulate matter, which is considered a carcinogen according to the World Health Organization's International Agency for Research on Cancer (IARC) (Benbrahim-Tallaa et al., 2012), whereas brake and tire wear have been found to presents a low risk to human health (Marisa et al., 2020).

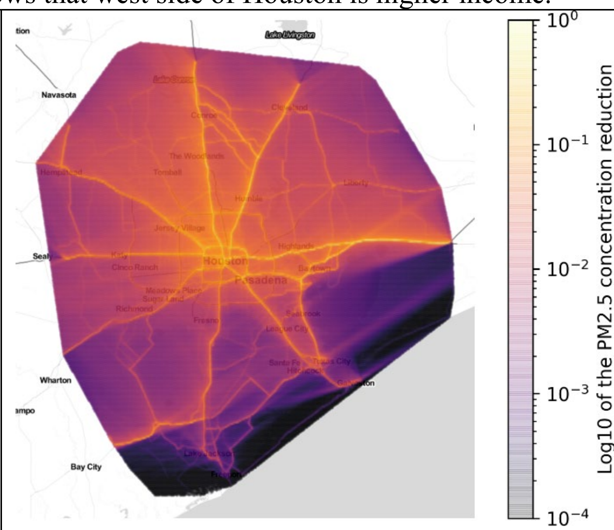
Figure 5 compares the PM2.5 dispersion patterns between MDT and HDT electrification with added context of demographic distribution. The comparison indicates that HDT electrification, even though more challenging from a technology perspective, will likely benefit more low-income persons.



Census block group map of percentage of low- and moderate-income persons. Darker color indicates higher percentage of low-income persons. Map shows that west side of Houston is higher income.



PM2.5 concentration reduction from 40% medium-duty truck electrification, showing more reduction on the west side



PM2.5 concentration reduction from 40% heavy-duty truck electrification, showing reduction distributed across the region

Figure 5 Distribution of environmental benefits from EVs across demographic groups

Discussions and Conclusions

Our analysis has found that electrifying 40% medium- and heavy-duty trucks would reduce 21 tons/day, or about 25%, of on-road mobile source NOx emissions in the H-GAC 8-county area in 2020. As of 2017, there are 109,000 medium-duty and 46,000 heavy-duty trucks in operation in the study area, compared to over 5 million light-duty vehicles. Therefore, truck electrification provides an actionable opportunity for NOx reduction. Heavy-duty long-haul trucks present the highest reduction potential if the technology becomes feasible.

Regarding the distribution of reduction benefits, HDT electrification reduces emissions along major corridors, whereas MDT electrification reduces emissions across secondary roadways, especially on the west side of Houston. Analyses are ongoing to investigate the implications of such spatial distribution on ozone attainment and equitable public health benefits.

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