Emissions from the Taxi and For-Hire Vehicle Transportation Sector in New York City

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Abstract

The launch of app-based for-hire vehicle (FHV) services like Uber and Lyft has led to increased mobility options, but the associated increase in vehicular traffic has also presented challenges. In New York City, the number of FHVs tripled between 2010 and 2019, to over one hundred thousand, due to the advent of such companies. This study seeks to understand the impact this increase in FHV usage has had on greenhouse gas emissions in New York City. The study uses data collected by the NYC Taxi and Limousine Commission, which regulates the FHV and taxi industries, and the NYC Mayor's Office of Sustainability, which publishes the City's greenhouse gas emissions inventory. The main result of the study is that although the overall per-vehicle efficiency of the fleet has improved, the high growth in registered vehicles has led to emissions from FHVs and taxis increasing 66 percent from 2010 to 2018. Electric vehicles present an opportunity for emissions reductions in New York City's FHV fleet if barriers to vehicle adoption are adequately addressed and if adoption of EVs does not outpace vehicle attrition.

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Abstract

The launch of app-based for-hire vehicle (FHV) services like Uber and Lyft has led to increased mobility options, but the associated increase in vehicular traffic has also presented challenges. In New York City, the number of FHVs tripled between 2010 and 2019, to over one hundred thousand, due to the advent of such companies. This study seeks to understand the impact this increase in FHV usage has had on greenhouse gas emissions in New York City. The study uses data collected by the NYC Taxi and Limousine Commission, which regulates the FHV and taxi industries, and the NYC Mayor's Office of Sustainability, which publishes the City's greenhouse gas emissions inventory. The main result of the study is that although the overall per-vehicle efficiency of the fleet has improved, the high growth in registered vehicles has led to emissions from FHVs and taxis increasing 66 percent from 2010 to 2018. Electric vehicles present an opportunity for emissions reductions in New York City's FHV fleet if barriers to vehicle adoption are adequately addressed and if adoption of EVs does not outpace vehicle attrition.

Keywords: Sustainability, TNC, For-Hire Vehicle, Greenhouse Gas Emissions, New Mobility, Uber, Lyft

Introduction

Unprecedented growth in mobility options has fundamentally changed transportation in major cities. Developments in the for-hire vehicle (FHV) industry, such as the advent of on-demand services like Uber and Lyft, along with the decrease in electric vehicle battery cost, present an opportunity to transition to a zero-tailpipe emission alternative. The convenience of ordering a vehicle on a smart phone has challenged cities that are tasked with reducing vehicle use and vehicles emissions in the face of anthropogenic climate change. Many cities around the world are now at what has been called the "fork in the road" in the transportation space, unsure if we are at the brink of a future transportation dream or nightmare (Sperling et al., 2018). The fork in the road is particularly high stakes in New York City, home to the largest taxi and for-hire vehicle market in America with more than 135,000 licensed vehicles and 200,000 licensed drivers as of July 2019.

The industry, regulated by the Taxi and Limousine Commission (TLC), comprises several vehicles types: the iconic yellow taxis, which operate on a medallion system and can pick up passengers on the street or via e-hail applications anywhere in the city; green or borough taxis, which primarily serve northern Manhattan and the outer boroughs of New York City (the Bronx, Brooklyn, Queens, and Staten Island); and FHVs, which include traditional car services (also known as black cars) as well as app-based services like Uber and Lyft (NYC Taxi & Limousine Commission, 2018). To date, electric vehicle adoption in the FHV fleet is in the low double digits in terms of total vehicles in use, though the TLC operated an electric taxi pilot that ran from 2013 to 2015.

TLC-licensed vehicles provide more than one million trips every day, constituting more daily ridership than any public transportation system outside of NYC in the US. While app-based services launched in New York prior to 2013, their growth year-over-year was relatively modest. The industry has seen unprecedented growth in the FHV sector since 2013, coinciding with the increased popularity of app-based car services like Uber, Lyft, and their competitors. While many jurisdictions classify these services as Transportation Network Companies (TNCs), they are referred to in New York City as "High Volume For-Hire Services" or HVFHS. This makes a distinction between these services and other FHVs like traditional black car and livery services. These companies (Uber, Lyft, Juno and Via in NYC as of time of writing) each provide more than 10,000 daily average trips. By the end of 2018, nearly 80,000 of the approximately 135,000 TLC-licensed vehicles were performing trips in the HVFHS sector (nearly sixty percent).

Concurrent with this rapid growth, traffic speeds in the densest parts of Manhattan (Midtown) decreased to as low as an average 4.3 miles per hour in November 2018—a 30 percent decrease from 2010. FHVs account for approximately 30 percent of all traffic in Midtown. Although the growth in the FHV sector represents an increase in mobility access, it also impacts traffic congestion and GHG emissions, which threatens the City's sustainability goals.

NYC Mayor's Office of Sustainability (MOS) is tasked with the City's climate change mitigation portfolio. The office tracks the City's greenhouse gas emissions (GHG) and crafts policy to reduce emissions while also addressing environmental justice and livability. Among other sustainability goals, the City seeks to achieve eighty percent sustainable mode share by 2050. The remaining trips that cannot be readily taken using a bicycle, transit or by walking should be made using a zero-emission vehicle.

Using available data on the FHV sector collected by TLC in its regulatory capacity, as well as the GHG emissions analysis done by MOS as the City's GHG inventory modelers, this study analyzes the role growth in the FHV sector has had on emissions. This paper finds the growth in the FHV sector has led to a 66 percent increase in greenhouse gas (GHG) emissions and a 129 percent increase in vehicle miles traveled (VMT) from 2010 to 2018. The analysis also finds that TLC-licensed taxis and FHVs accounted for 19 percent of total citywide VMT in New York City in 2017. The paper discusses the impacts of mass adoption of electric vehicles (EV), as well as reducing the overall size of the FHV fleet, as pathways to reduce the emissions impact of this sector.

Literature Review

FHV use has added 5.7 billion miles traveled annually across major markets in the United States, one billion miles of which have been added in New York City alone. Schaller's *New Automobility* argues that the significant increase in VMT is tied to FHVs primarily displacing trips that would have otherwise been by transit, walking, or biking. He states that FHVs can be a valuable extension of existing sustainable modes by providing last-mile connectivity from transit, as well as serving people with disabilities (Schaller, 2018). In New York City, walking is the dominant mode last-mile connectivity, accounting for 94 percent of connections. FHVs make up less than a percent of last-mile connections (New York City Department of Transportation, 2019).

Shared FHV rides, also known as pooled rides, potentially increase the efficiency of FHV use. Sperling, Pike and Chase in *Will the Transportation Revolutions Improve Our Lives – or Make Them Worse* ? argue that autonomous and electric mobility are inevitable, but shared mobility is less certain and is in need of more purposeful policymaking. They argue that encouraging pooling electric rides by app based services is part of crafting policy that will reduce fossil fuel dependence and create a more livable city (Sperling et al., 2018).

Alemi, Circella, Handy and Mokhtarian suggest that the adoption of pooled riding can offset the negative congestion and environmental impacts of FHV adoption in *What influences travelers to use Uber?* . This article finds that airports are a core destination for FHVs, suggesting that individuals who travel long distances for business are likely adopters. The authors' analysis suggests that this is due to people using FHVs when their personal vehicle is unavailable (Alemi et al., 2018). Research has consistently found that FHV users tend to be younger, more affluent and living in urban centers with transit accessibility (Alemi et al., 2018; Schaller, 2018).

New York State supports shared rides in the structure of its FHV tax for trips originating in the Manhattan core which adds \$2.75 to single trips and \$0.75 for pooled rides. Additionally, New York City's limit on allowing vehicles to cruise without passengers in Manhattan south of 60^{th} Street no more than 31 percent of the time during peak hours encourages the potential trip efficiency coming from pooling (Joshi et al., 2019). Additionally bikeshare is on average less expensive and faster than taxis in Midtown Manhattan, fulfilling potential non-vehicular trip needs that are not absorbed by public transit (New York City Department of Transportation, 2019).

Schaller argues that shared FHVs increase VMT as they still compete primarily with non-personal vehicle trips (Schaller, 2018). Conway, Salon and King also state in *Trends in Taxi Use and the Advent of Ridehailing* that successful pooled trips only work in high density areas where multiple passengers can more reliably be matched to share a ride. Although FHV companies argue that FHVs, particularly when they provide shared rides, are a solution to reducing personal vehicle ownership, Conway et al point out that there are other alternatives. They state that providing carsharing, where the user drives a rental vehicle, has been shown to reduce car ownership. People are also more likely to commute using transit, walking, biking or carpooling if they have access to a guaranteed ride home program that will offset the cost of a taxi or FHV in the event that their sustainable mode of travel isn't available (Conway et al., 2018).

Uber and Lyft added transit and biking options to their apps to further integrate their service with other available modes in their major market (Lyft Blog, 2019a; Uber, 2019a). Lyft also offer users the option of selecting a low-emission vehicle in Seattle and Atlanta (Lyft Blog, 2019b). Uber has electrification pilots in Austin, Los Angeles, Montreal, Pittsburgh, Portland, Sacramento, San Diego, San Francisco, and Seattle (Uber, 2019b). Based on data compiled by the Union of Concerned Scientists, electric vehicle are appealing from a sustainability perspective as they produce significantly less emissions than their internal combustion engine counterparts (Reichmuth, 2018). Reducing the overall size of the FHV fleet, dispatching vehicles more efficiently, prioritizing transit deserts and electrifying vehicles are identified as key priorities for New York City based on the best available information to address congestion and GHG emissions.

Methodology

The NYC TLC collects and maintains a variety of data on licensed taxis and FHVs. Through authority granted by the New York City Charter, the TLC collects more data on the sector than any other American municipality. This data is instrumental in developing policies within the sector aimed at reducing fatigued driving and increasing driver pay and transparency, among other goals. Relevant data for this analysis includes mileage readings from odometers taken at each vehicle inspection, the vehicle's identification number (VIN), and related vehicle information associated with the VIN such as fuel efficiency in miles per gallon and fuel type. Based on the information collected, TLC can calculate annual average mile per gallon efficiency of vehicles and average weekly mileage for gasoline and hybrid vehicles in the taxi and FHV fleet.

Only medallion taxis and FHVs are included in this analysis. HVFHS companies comprise the majority of the app-based FHV fleet. (The app-based for-hire vehicles are those affiliated with a base owned by one of the app companies (e.g. Uber, Lyft, and Via)). While the TLC regulates additional vehicle types (i.e. commuter vans, street hail liveries, and paratransit vans), they make up a small percentage of the overall licensed vehicle pool and the necessary data is not available to allow for inclusion into the analysis. Not all vehicles licensed by TLC were able to be included in the analysis for a variety of reasons including incomplete data (e.g. VIN, license plate) and the removal of outliers from mileage data.

The Mayor's Office of Sustainability (MOS) conducts and publishes the citywide greenhouse gas emission inventory as codified in Local Law 22 of 2008 (Gennaro et al., 2008). The inventory covers emissions from stationary energy from the building sector and mobile emissions from the transportation sector, as well as emissions from the waste sector. The emissions factors used in MOS' inventory for 2010 to 2017 are used in this analysis and emissions factors from 2017 are applied to the 2018 data provided by TLC.

Taxi and Limousine Commission

Calculating tailpipe emissions from TLC-licensed vehicles required several steps. First, TLC identified active vehicles for each year of analysis. Next, TLC calculated the average fuel efficiency in miles per gallon (mpg) by fuel type (i.e., gasoline, hybrid-electric) for all active vehicles in each year. Then, TLC calculated overall mileage by fuel type for those active vehicles (mileage data include both miles with and without a passenger since vehicles equally contribute to emissions and congestion with or without a passenger).

Each of these steps undertaken by TLC are outlined below:

Determining Active Vehicles in Given Year

To perform the analysis, a complete list of active vehicles in a given year was required. Active vehicles can be determined in different ways. To compile the list of vehicles for total annual counts, the authors used snapshots of administrative records which capture all active vehicles at the beginning of each year. The vehicles are designated as either taxis and FHVs.

In order to calculate fuel-efficiency averages for each year, the list of active vehicles was determined through a combination of inspection records (identifying vehicles inspected at TLC's Safety and Emission's facility) and trip records (identifying license plates which performed trips in any given year). This ensured that any averages accounted for vehicles actually in use in the given year.

Calculating Average Weekly Mileage per Year and Vehicle Type

TLC analyzed internal vehicle inspection records to calculate average weekly mileage. Vehicles are inspected at regular intervals (three times per year for taxis and once every other year for FHVs), and odometer readings from inspections were used to calculate mileage accrued between inspections. TLC normalized the mileage by calculating the number of weeks between inspections. For each calendar week in each year, TLC calculated the average mileage for taxis and FHVs which incorporated all inspection intervals where the previous inspection began before that week and the subsequent inspection ended after that week. Inspection data covers all vehicle mileage, not just mileage with a passenger.

Determining Average Vehicle Fuel Efficiency per Year and Vehicle Type

Fuel efficiency data comes directly from the National Highway Traffic Safety Administration (NHTSA) VIN database. This data is queried and maintained internally by TLC and was joined with VIN data from internal records to determine the fuel type of each active vehicle in a given year. Only gasoline and hybrid-electric vehicles are included in the analysis; diesel and other fuel types were omitted as they account for a very small amount of the total vehicle fleet. [Extensive research has shown that mpg efficiency reported in the vehicle testing tends to be more favorable than real world applications due to the flexibility offered in testing. Based on a study conducted by the US Environmental Protection Agency (EPA), the shortfall between testing mpg and real world data can be as high 2% for gasoline vehicle and 11% for hybrids (Greene et al., 2015).]

Mayor's Office of Sustainability

Once TLC provided average mileage and mile per gallon efficiency for the FHV fleet, MOS was able to assign an emissions factor to determine annual GHG emissions from 2010-2018. MOS used the kilogram by CO2e (kg/CO2e) factor applied to on-road mobile sources from gasoline passenger cars as published annually in the citywide inventory as its main data source for emissions.

In order to apply the emissions factor, the average annual mpg efficiency was converted to gallons per mile. Annual gasoline usage for the fleet is then calculated using the average gallon per mile and total annual mileage. Annual gallons of fuel used is converted to liters since the emissions factors use metric units. The emissions factor is also converted from kilograms to tons. The conventional gasoline and hybrid fleets were calculated separately to account for the difference in mpg efficiencies.

Total annual tons of CO2 equivalent (tCO2e) from the FHV fleet is calculated using the total annual liters of gasoline usage and MOS' emissions factor from the annual GHG inventory. The emissions factor from the most recent GHG inventory published for 2017 data was applied to the 2018 FHV data.

Data on registered vehicle attrition modeled by TLC is used to estimate the GHG emission impact of reducing the FHV fleet size by pausing the issuance of new vehicle licenses. The total annual tCO2e was calculated on a per registered vehicle basis to create an approximation of the impact of individual vehicle attrition. TLC modeled a lower bound and upper bound attrition rate for 2020. The total emission savings from vehicle attrition was calculated for both the lower and upper bound models.

Results

The number of TLC-licensed vehicles remained relatively flat prior to 2013, due to a capped number of medallion taxis and a mature traditional FHV (black car) market. Starting in 2013, FHV licenses increased rapidly and steadily for several years with the rise of app-based services. Non-app based traditional FHVs remained relatively constant through the first half of the decade, but both the number of taxis and non-app based FHVs decreased towards the end of the decade. App-based FHVs are the only part of the sector that continued to grow throughout the decade.

Before August 2018, FHV license numbers were not restricted, although there were some initial efforts to do so by New York City Council in 2015. From 2013 to 2018, the total number of licensed vehicles grew 119 percent, and total number of FHVs increased 152 percent. Most of this growth is associated with vehicles affiliated with HVFHSs, which added nearly 78,000 app-based vehicles since 2013.

Table 1 - TLC Licensed Vehicle Fleet Breakdown by Year

	Yellow taxis	Green taxis	App-based for-hire vehicles	Other for-hire vehicles
January 2010	13,237			39,065
January 2011	13,237			37,782
January 2012	13,237		16	39,692
January 2013	13,237		668	39,275
January 2014	13,247	2,933	4,225	39,743
January 2015	13,587	5,597	12,581	39,857
January 2016	13,587	6,106	28,781	38,703
January 2017	13,587	5,573	49,283	33,511
January 2018	13,587	4,245	70,419	32,119
January 2019	13,571	3,595	88,738	29,494

Vehicle Miles Traveled

Total VMT from TLC-licensed vehicles increased 129 percent from 2010 to 2018. The largest increase occurred between 2016 and 2017 (See Table 2). Despite immense growth in the size of the regulated fleet, VMT per vehicle decreased 23 percent during the same period, mostly driven by a decrease in mileage by hybrid-electric vehicles, most of which are taxis, as well as a significant growth in the number of vehicles sharing the total fleet wide VMT.

Table 2 - Change in Annual Mileage of TLC Fleet (2010-2018)

Year	Total Annual Mileage by TLC-Licensed Vehicles	Change from Previous Year (%)
2010	2,020,171,664.61	-
2011	2,179,459,335.70	7.9
2012	2,388,870,256.32	9.6
2013	2,619,107,438.39	9.6
2014	2,950,275,830.25	12.6
2015	3,173,899,368.68	7.6
2016	3,516,838,529.73	10.8
2017	4,119,824,037.39	17.1
2018	4,626,495,553.21	12.3

Vehicle Efficiency and Fuel Type

Concurrent with vehicle growth, the share of hybrid vehicles fleet-wide increased. Hybrid vehicles are more fuel efficient than their conventional gasoline counterparts. The efficiency of these vehicles results in lower fuel usage and greater emissions savings. Hybrid vehicles only accounted for 12 percent of the licensed fleet in 2010. By 2018 hybrid vehicle accounted for over 30 percent of the total fleet. However, the increase in hybrid adoption is uneven across the fleet. Taxis increased hybrid penetration from 26 percent to 65 percent during the study period (See Table 3). FHVs, on the other hand, increased adoption only from six percent to 10 percent (See Table 4). [Note that the number of taxi vehicles does not equal the number of taxi medallions. A single medallion in a given year can be placed on multiple vehicles if a vehicle is retired or changed for a number of reasons.]

Table 3 - Conventional Gasoline and Hybrid Taxi Fleet Mix

Year	TLC Licensed Taxis	Gas %	Hybrid %
2010	15,464	74.31	25.69
2011	15,705	65.36	34.64
2012	15,484	56.71	43.29
2013	15,164	45.01	54.99
2014	16,640	39.80	60.20
2015	15,797	30.01	69.99
2016	14,389	29.72	70.28
2017	13,830	31.95	68.05
2018	13,344	35.07	64.93

Table 4 - Conventional Gasoline and Hybrid FHV Fleet Mix

Year	TLC Licensed FHVs	Gas %	Hybrid %
2010	37,782	93.83	6.17
2011	39,708	92.42	7.58
2012	41,062	91.15	8.85
2013	47,058	89.15	10.85
2014	58,295	87.78	12.22
2015	66,604	88.52	11.48
2016	80,881	88.55	11.45
2017	102,536	89.39	10.61
2018	118,737	89.90	10.10

While hybrids have a greater per-mile efficiency, on average TLC-licensed hybrid vehicles were driven more miles per week than their conventional gasoline counterparts. The fuel efficiency of the TLC regulated fleet increased 26 percent in hybrid vehicles, and 47 percent in gasoline vehicles between 2010 and 2018. (See Table 5).

Table 5 - Comparing Average MPG Efficiency and Average Weekly Mileage for Hybrid and Conventional Gasoline Vehicles

	Average Miles per Gallon	**Average Miles per Gallon**	**Avg. Weekly Mileage per Vehicle**	**Avg. We**
Year	**Gasoline**	**Hybrid**	**Gasoline**	**Hybrid**
2010	15.3	33.9	672.9	1285.6
2011	15.4	34.0	673.1	1356.8
2012	15.8	34.4	724.0	1322.7
2013	16.7	36.8	701.9	1249.8
2014	18.3	39.7	672.5	1136.8
2015	19.8	41.5	673.9	1038.5
2016	21.0	42.9	651.7	962.5

	Average Miles per Gallon	Average Miles per Gallon	Avg. Weekly Mileage per Vehicle	Avg. We
2017	22.2	43.0	634.9	899.5
2018	22.6	42.8	633.0	874.8

Emissions

This rapid and unprecedented growth underlies the analysis conducted on the impact the FHV sector has had on emissions in New York. Despite an overall growth in mpg efficiency fleet wide and a decrease in per vehicle weekly mileage, the overall growth of the fleet with the proliferation of vehicle registrations affiliated with HVFHSs has led to a significant increase in GHG emissions across the TLC-regulated industries.

Overall emissions from TLC-licensed vehicles increased 66 percent from 2010 to 2018. Emissions increased at a slower rate than overall miles traveled, which went up 129 percent over the same period, for a few reasons: there was an increase in both overall fuel efficiency and in the share of hybrid vehicles, and the new vehicles that were added travel on average fewer miles each year than the previous fleet wide average.

Table 6 - Annual Greenhouse Gas Emissions for TLC Licensed Fleet

Year	Total tco2e from TLC-Licensed Vehicles	Change from Previous Year of tco2e (%)
2010	1,025,187	-
2011	1,064,890	3.9%
2012	1,122,851	5.4%
2013	1,134,229	1.0%
2014	1,193,463	5.2%
2015	1,224,197	2.6%
2016	1,322,371	8.0%
2017	1,513,682	14.5%
2018	1,697,451	12.1%

Although the miles per gallon efficiency of the licensed fleet increased overall, thereby making the fleet mix arguably more sustainable than it was in 2010, the ballooning registrations of new vehicles and the unprecedented rapid growth in the sector led to an increase in emissions. GHG emissions in the taxi and FHV sector increased 16.4 percent from 2010 to 2014 as licensed vehicles increased 41 percent. From 2014 to 2018, emissions increased 42 percent while vehicle counts increased by 84 percent. Overall, emissions increased 66 percent between 2010-2018, while total number of vehicles increased 159 percent. The largest single year increase in emissions was 14.5 percent, which occurred between 2016 and 2017 (See Table 6). In that year, vehicles increase by 23 percent and the share of hybrids decreased nearly three percent.

Potential emissions reductions from Attrition

The number of TLC taxis and FHVs is typically reduced each year when a portion of licenses are not renewed. Assuming current vehicle attrition rates continue, there will be between 8,749 and 12,142 vehicle license holders that will not renew through 2020. This natural attrition is typically replaced by new licenses. But if we assume that no new licenses are granted to replace these vehicles in 2020 due to new regulations, and the vehicles that are retired all use gasoline, there will be a natural decrease in GHGs from TLC-licensed vehicles of approximately seven to 10 percent over the course of the year. If hybrid vehicles are replaced, the potential GHG savings decreases to between five and seven percent.

Discussion

Reducing the size of the TLC regulated fleet has the most potential for significantly reducing industry-related emissions. That being said, considering there are still vehicles that will be operating on the streets of New York in for-hire service, the most efficient and sustainable technology available option for the remaining vehicles would be the mass adoption of electric vehicles (EVs). The growth in per-vehicle efficiencies in the TLC regulated sector reveals an appetite for drivers to adopt new technologies by purchasing more fuel-efficient vehicles. EVs have a potentially lower total cost of ownership than their gasoline counterparts. Mass EV adoption would require continued new model availability with increased vehicle range and lower cost, consumer education, and a robust charging ecosystem (Seki, 2018).

Areas of Further Development to Electrify FHVs

Upfront vehicle cost, charging availability and consumer awareness are barriers to the adoption of EVs for FHV drivers. EVs are more expensive than their gasoline fueled equivalent. Incentives at the federal and state level offer up to $9,500 in rebates for the purchase of an EV, on top of discounts on toll roads, HOV lane access and state vehicle inspection waivers (U.S. Department of Energy, 2019a). Used electric vehicle markets also address the higher upfront cost of an EV for FHV drivers (Seki, 2018). Market experts believe that improving battery technology and the economies of scale of mass production will yield less expensive electric models and increased vehicle range within the next five years (Pavlenko, 2019).

The range of an EV, meaning the number of miles it can drive before needing to charge, is another variable in making the business case for FHV adoption work. Longer range vehicles do not need to stop as often to charge. Regardless of vehicle range, mid-shift FHV charging availability is crucial given the high daily mileage of FHV drivers and the negative impacts on drivers from not being able to accept rides due to lower battery concerns.

Based on data collected by TLC, hybrid vehicles on average drive 125 miles a day. Maven Gig, General Motor's carshare serving the FHV sector with EV availability, reports that on average drivers log 135 miles a day. This is well within the range of an electric Chevy Bolt, with only 10 percent of drivers on the platform going above 135 miles (Pavlenko, 2019). Assuming that a driver has access to overnight charging at their residence and a 250 mile range EV, they can meet their daily miles without needing a mid-shift charge. That being said, many drivers may want to know that fast charging is available to them in case they need it, even if they might not personally use it daily. Dedicated fast charging infrastructure has been identified as a need for FHV drivers so that they don't need to wait in a queue for their mid-shift charging session (Slowik et al., 2019).

Fueling time for a gasoline vehicle takes roughly 5 minutes, whereas for an electric vehicle fueling can take 32 to 47 minutes (Pavlenko, 2019). Time spent waiting for a vehicle to charge presents potential loss of revenue for the FHV driver. That being said, the five minute fueling time for a gasoline vehicle does not factor in time a driver might spend using bathroom facilities and eating food while on a break. Unlike a gasoline vehicle, a driver can plug their vehicle in at a charger and leave while the vehicle is fueling. If amenities are available, charging a vehicle may not be that big of a time sink for drivers (Pavlenko, 2019).

Overnight charging access is a key variable to making the EVs work for FHV drivers from an operational and cost perspective (Pavlenko, 2019; Seki, 2018; Slowik et al., 2019). Drivers who exclusively use publicly accessible fast charging face fueling costs that are up 3 to 9 times higher than that of a driver that has overnight charging at their residence (Pavlenko, 2019). While EV adoption remains low, utility demand chargers create high operational costs for fast charging developers, which in turn are often passed down to the consumer (Slowik et al., 2019). Since half of the vehicles in New York are parked on the street, this presents a significant EV adoption barrier as these drivers do not have a home garage or driveway where they could plug their vehicle into their own charger or outlet (New York City Department of Transportation, 2019). A robust EV charging network is necessary to meet the needs of drivers.

Currently, a 250-mile range electric vehicle has a lower total cost of ownership (TCO) than a conventional gasoline vehicle. However the same EV still has a higher TCO than a hybrid equivalent. The cost per mile of fueling for an FHV driver is $0.09-0.13 per mile for conventional gas vehicles, $0.06-0.08 per mile for hybrids and $0.08-0.09 per mile for EVs (Pavlenko, 2019). Considering the low hybrid penetration in the FHV sector relative to the taxi sector, despite their lower overall cost, suggests that cost per mile is not the only variable in vehicle model choice.

Opportunities from Electric Vehicles in FHV Fleets

Electric vehicles have no direct tailpipe emissions and are much more fuel efficient overall than internal combustion engine vehicles. Even when accounting for full lifecycle emissions, including vehicle manufacturing, a battery electric vehicle on average produces less than half the emissions of traditional vehicles. This remains true when accounting for charging vehicles with New York City's energy mix. In New York City, a gasoline vehicle would have to have achieve 89 miles per gallon efficiency to produce fewer emissions than an electric model (Reichmuth, 2018). Assuming that EVs replaced all conventional gasoline and hybrid vehicles los to attrition, there would still be an emissions savings of two to three percent. However, if EV adoption outpaces vehicle attrition, meaning more EVs are added to the fleet than traditional vehicles are removed, the total VMT ad related congestion in the city will not decline. The related lower vehicle speeds will continue to increase idling and emissions fleet-wide.

Although the deepest emission reductions come from transitioning from vehicle use to sustainable modes like walking, biking and taking transit, electric vehicles act as a stopgap for those trips that cannot be readily taken without a vehicle. As electric vehicle adoption remains very low in New York State, accounting for less than a percent of vehicles registered with the State DMV, adopting electric vehicles in private fleets creates a stronger business case for charging stations developers who will be able to develop a customer base (Atlas Public Policy and New York State Energy Research and Development Authority, 2019). EV adoption in FHV fleets also provides a crucial increase in the visibility of EVs, which has been identified as a way to further adoption across sectors (Slowik et al., 2019).

The private sector has taken up some of the EV awareness efforts needed to increase EV adoption among drivers. In response to government regulation in London, Uber launched its "Clean Air Plan" with resources to help transition their FHV fleet to all electric through driver engagement (Slowik et al., 2019; Uber, 2019c). Uber also has an "EV Champions Initiative" that works with seven North American markets to increase EV adoption. The initiative partners with utilities on incentives and increasing access to resources (Uber, 2018). Lyft has also offered EV drivers free charging in Portland, Oregon to help increase adoption (Dzikiy, 2019).

Based on data projections from the U.S Department of Energy, electrifying all 88,738 app based FHVs operating in New York City would require 1,110 fast charging plugs and over 1,300 level 2 charging plugs (U.S. Department of Energy, 2019b). This is assuming that half of the vehicles registered do not have access to charging at home, consistent with data from NYCDOT that half of New Yorkers park at least one of their vehicles on street (New York City Department of Transportation, 2019).Currently, there are over 1,100 level 2 charging plugs, but only 92 fast charging plugs available to the public, or 8.3 percent of the total needed.

Although the economics of charging still must be improved for those who can't readily charge at their residence, FHV drivers can take advantage of the lower maintenance costs of EVs. Maintenance cost of conventional gas vehicle is $0.061 per mile, $0.037 per mile for a hybrid and $0.026 per mile for an EV. The lower maintenance cost is linked with EVs having fewer moving parts and less wear on the braking system (Pavlenko, 2019).

The proposal announced in the "Improving Efficiency and Managing Growth in New York's For-Hire Vehicle Sector" report to maintain the cap on new FHV licenses for a year while allowing an exemption to electric vehicles will provide potential proof of concept of these benefits and will allow the City to study the impacts the electrified shared mobility further.

Conclusion

App-based high volume for-hire vehicle companies like Uber and Lyft have fundamentally changed the way people move around major cities. The data collected by New York City provides unique insights into the impact of the FHV sector's growth on congestion and greenhouse gas emissions, showing that emissions from TLC-regulated industries have increased by 66% since 2010. New authority from the New York City Council allows TLC to regulate vehicle licenses into the future. Along with a cap on idle time within the most congested parts of the city, a continuation of the vehicle license pause through 2020, and an exemption for electric vehicles, will allow the City to potentially reduce the negative impacts associated with the growth in new mobility options. Although EVs are the best available technology to address the emissions concerns resulting for FHV fleet use, it is not a substitute for investing more in bus and bike lane infrastructure, ensuring that FHVs are deployed efficiently to reduce non-revenue VMT, deprioritizing vehicle use during certain times of the day, limiting parking availability, and investing in public transit. FHV regulation will be revisited by New York City in August 2020 based on the impacts of the current rules.

Author contributions

The authors confirm contribution to the paper as follows: study conception and design: Stiles, Rodney, Schmidt, Stephan, Roberton, Jennifer; literature review: Roberton, Jennifer; data collection and results: Stiles, Rodney, Schmidt, Stephan, Roberton, Jennifer; discussion of results: Roberton, Jennifer; draft manuscript preparation: Roberton, Jennifer, Stiles, Rodney; additional editing for publication: Schmidt, Stephan. All authors reviewed the results and approved the final version of the manuscript.

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