Electric Fleet Vehicles and Their Potential Impact on New York State and New York City Climate Goals

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Abstract

Converting fleet vehicles from internal combustion to battery electric vehicles has the potential to help New York State and New York City to achieving their Emissions goals. This paper examines the emissions impact of light duty vehicles (NYC yellow taxis and rideshare vehicles) as well as medium and heavy duty vehicles (buses and delivery trucks). Taxis and rideshare emissions were calculated for a yearly mileage of 20,000 to 80,000 miles traveled, and compared to the corresponding emissions that a battery electric vehicles would emit. The NYC bus fleet is also examined for their impact to city and state emissions. The results show that battery electric vehicles can reduce comparable emissions by 45% or more. Yellow taxis and rideshare vehicles make up anywhere from 0.11% to 2.66% of state transportation emissions and 0.53% to 12.49% of city transportation emissions. NYC buses make up 0.79% of state and 3.71% of city transportation emissions but make up 8.1% and 23.19% of state and city diesel emissions.

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List of Abbreviations

BEV – Battery Electric Vehicle	Mt - Metric Ton
CBD – Central Business District (in Manhattan)	MTA - Metropolitan Transportation Authority
CNG - Compressed Natural Gas	MtCO$_2$e - Metric tons of CO$_2$ equivalent
DCFC – Direct Current Fast Charging or DC Fast Charging	MMtCO$_2$e – Million Metric Tons of CO$_2$ equivalent
EIA – Energy Information Administration	MY - Model Year
EV – Electric Vehicle	NiMH – Nickel Metal Hydride
GHG – Greenhouse Gas	NYC – New York City
ICE – Internal Combustion Engine	NYCW – New York City/Westchester sub-region
kWh – kilowatt hour	NYS – New York State
LDV – Light Duty Vehicle	PEV – Plug-in Electric Vehicle
Li-ion – Lithium-ion	PHEV - Plug-in Hybrid Electric Vehicle
MDV – Medium Duty Vehicle	SS – Start/Stop
MHEV – Mild Hybrid Electric Vehicle	TLC - Taxi and Limousine Commission
MPGe – Mile Per Gallon Equivalent	TNC – Transportation Network Companies

Introduction

The transportation sector is now responsible for the most greenhouse gas (GHG) emissions in the United States (Milman 2018). Since the initial Intergovernmental Panel on Climate Change (IPCC) report in 1990, the world has been aware of the dangers of carbon dioxide and other GHGs in our atmosphere (IPCC 2014). In 2014 the IPCC reported that "continued emission of GHG will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems" (IPCC 2014). In order to avert a disastrous rise in average global temperatures, avoid environmental disasters, and mitigate the negative effects on human health, we need to reign in our GHG emissions from transportation.

Cities and densely populated areas are the best places to concentrate efforts on reducing GHG from transportation as they have the highest concentration of vehicles. A high density area, such as New York City, has many vehicle fleets such as bus, taxi, and livery. Along with conventional taxi fleets there are also now app-based ride hailing companies (aka rideshare, Transportation Network Companies or TNCs) that occupy the same area and purpose. If the entire fleet of NYC taxis and buses were changed over to plug-in electric vehicles (PEV), what would be the expected environmental and health benefits? How would this aid in reaching New York State and New York City goals of reducing their overall emissions? Are there other areas of opportunities for PEV adoption, such as heavy or medium duty vehicles? There are also the fleet vehicles that operate within the city, such as those in the police department, fire department, and other NYC governmental bureaus.

This paper analyzes the impacts of converting fleet vehicles in NYC from internal combustion to battery electric vehicles (BEV). Light duty vehicles (LDV) that are reviewed are NYC yellow taxis and the newly emerged TNCs. There is a brief explanation of the technology of hybrid, plug-in hybrid, and BEVs. Based on the electrical grid of the New York City/Westchester County (NYCW) sub-region, there is a comparison of emissions of ICE vehicles to BEVs based on mileage and fuel efficiency. Further expanding on fleet vehicles, heavy and medium duty vehicles are examined. This paper examines what impacts could be expected to result from the NYC bus fleet conversion, school buses and delivery vehicles. It also looks at the effects of air pollution and emission. Lastly, there are calculations that show the impacts to city and state transportation emission and how each fleet vehicle would impact those goals.

New York City and State Climate Goals

Both New York State and New York City have climate action plans that have the same goals along with goals that differ due to the uniqueness of their geophysical makeups. Both the city and state are looking to reduce GHG emissions by 80% (from 1990 levels) by 2050. The state has three intermediate goals for the year 2030. The first goal is to reduce GHG by 40%, from power generation, industry, buildings and transportation. The second is to have 50% of generated electricity come from renewable energy sources. The final goal is to increase state-wide energy efficiencies by 600 trillion Btu's from 2012 levels (NYSERDA 2015).

The New York State Energy Plan aims to reach 40% reduction in GHG emissions from 1990 levels. While the overall emissions went down for the state by 8.4% from 1990 to 2015, transportation emissions rose 20.5% during the same time period, with the largest increase coming from jet fuel. There was an increase of emissions from gasoline by 5.9%, while diesel remained mostly unchanged. Gasoline and diesel, as of 2015, made up approximately 84% of the transportation sector emissions. However, transportation emissions have gone down from their peak in 2005 from 83.7 $MMtCO_2e$ to 72.8 $MMtCO_2e$, a decrease of 13% (NYSERDA 2018, 13). According to data from the United States Energy Information Administration (EIA) on energy consumption from the transportation sector, 2017 showed an increase of 20.3% for petroleum consumed from 1990 levels, which is consistent with state data (US EIA 2019).

New York City's climate action plan, known as "80x50," aims to reduce 80% of emissions from buildings, energy supply, transportation, and waste sectors by 2050 (NYC Mayor's Office of Sustainability 2017). The goal for transportation is to reduce single occupancy vehicle trips by 75% and migrate that volume to walking, bicycling and public transit. They plan on doing this with constant improvements to the bus and subway systems, shared mobility, doubling the bike share to twice the current number of cyclists, and by expanding bike lanes (NYC Mayor's Office of Sustainability 2017, 11). There is no mention of how light duty vehicle electric vehicles play a part in this, since they have no emissions from a transportation standpoint.

In 2017, Mayor de Blasio targeted 20% of all new car registrations to be plug-ins by 2025. "Electric vehicles (EVs) represent less than one percent of all NYC vehicle registrations today, largely owing to a lack of charging opportunities. New Yorkers will need to rely on public-access, centralized, and high-speed charging locations to support the dramatic transition to EVs that is necessary to reduce transportation GHG emissions" (NYC Mayor's Office of Sustainability 2017, 12).

Specifically, "30% of citywide emissions come from the transportation sector (15.5 $MtCO_2e$). On-road vehicles are the largest source of emissions from this sector, accounting for 95.7% of emissions from transportation (29% citywide). Within this sector, vehicles that consume gasoline are the primary source accounting for 80% of transportation emissions" (NYC Mayor's Office of Sustainability 2017, 45). See Figure 1, which displays a bar graph of NYC transportation emissions.

NYC has worked to identify its sources of emissions and evaluated its potential for GHG reduction in order to assess what needs to be done to keep it within the Paris Agreement. In NYC's analysis of areas that have the potential for emission improvements, transportation has been identified as having major potential for GHG reduction. The Paris Agreement, signed by nearly every country, is a commitment to limit the global temperature rise to 1.5 degree Celsius. (NYC Mayor's Office of Sustainability 2017).

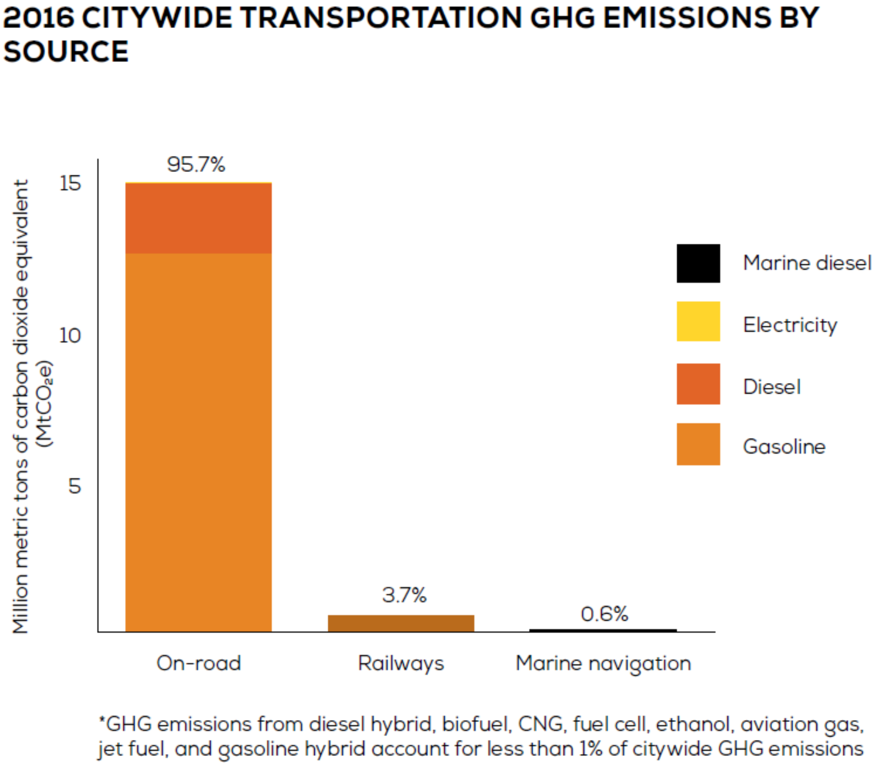


Figure 1

Figure 1 – NYC Transportation Emissions. Source: NYC Mayor’s Office of Sustainability 2017

Differences in Hybrid and Battery Electric Technology

There are many different forms of hybrid technology currently at use. Hybrids that do not generate their power from the electrical grid are start-stop, mild, and full/strong hybrids. There are also hybrids that are plug-ins that can be charged from the electrical grid. The NYC Yellow Taxi fleet has requirements on what vehicles are suitable to be used for their service, some of which are hybrids. The following section describes the current hybrid and plug-in technologies.

Hybrid (HEV)

There are three types of hybrid electric vehicles: start-stop (SS), mild hybrid (MHEV), and full/strong hybrid.

The SS hybrid refers to when the engine of a car turns off when the vehicle pauses (idles), for example at a stop light. It will then quickly restart when the car needs to move again. During breaking these cars use conventional breaking and regenerative breaking. Regenerative breaking uses the electric generator to help slow the vehicle, which in turn helps charge the onboard battery. The battery is used to power the electric generator to start the motor quickly (US EPA 2019). Start-stop technology offers the least reduction in fuel consumption, estimated at 2.1%, but also costs the least of any of the hybrid technologies (National Research Council 2015, 131).

A mild hybrid has a small electric motor and battery that assists an internal combustion engine (ICE). This allows for a smaller, more efficient engine. The electric motor is used to assist acceleration, and is recharged through regenerative breaking and through engine recharge. The use of the electric motor allows the combustion engine to shut off when the vehicle stops (US EPA 2019). The electric motors and batteries are too small to power the car by themselves. The introduction of mild hybrid technology into the Buick LaCross saw a 37% increase in fuel efficiency, from 27.8 MPG to 38.1 MPG. Another way to look at that is a 27% reduction in fuel consumption. This result is not typical however. The model year (MY) 2013 Chevrolet Malibu only saw an 11% improvement in MPG rating and 10% reduction of fuel consumption (National Research Council 2015, 132).

Full hybrids are similar to the mild hybrid but with a larger electric motor and battery. Just like mild hybrids, they assist the combustion engine when more power is needed. They also allow the car to be fully electric at low speeds and for short distances, such as stop-and-go traffic. The larger electric motor and battery capacity allow for a smaller combustion engine. These hybrids are not plug-in hybrids. The battery is powered by regenerative breaking and charged by the combustion engine (US EPA 2019). Full hybrids have two different configurations of powertrains: parallel hybrid and power-split hybrid. An example of full hybrids would be the Hyundai Sonata. The MY 2015 went from 36.6 mpg to 51.5 mpg, a 40% increase and a 28.9% reduction of fuel consumption (National Research Council 2015, 132).

Plug-in Hybrid (PHEV)

The plug-in hybrid is very similar to hybrid vehicles; it has a smaller combustion engine with a larger electric motor and battery. It has additional electronics that allow the vehicle to be charged from an electrical plug which allows some of the miles driven to be powered by electricity rather than diesel or gasoline. The battery ranges for all-electric travel vary from around 10 miles to over 40 miles (National Research Council 2015, 134). PHEVs are most commonly found in LDVs but are also becoming available in MDVs and HDVs.

PHEVs have advantages over regular hybrids. They reduce emissions due to mileage used via their battery, the battery can be charged conveniently at home, and cost of travel via electricity is cheaper than travel using gasoline or diesel. Some PHEV's range will cover most daily commuting travel via battery power, but they also offer similar range to combustion engine vehicles (National Research Council 2015, 134). There are two main types of PHEV architecture, parallel and series. Parallel PHEV can be run off of either the combustion engine or the electric motor. With a series PHEV, the electric motor powers the vehicle and there is a small engine which, when needed, is used to generate electricity for the motor (National Research Council 2015, 131).

Battery Electric (BEV)

Battery electric vehicles are only powered by the energy stored in their battery. There is no combustion engine, rather the vehicle is propelled by a single-gear electric motor. The motor is powered by the large battery. Batteries were originally lead acid, then nickel metal hydride (NiMH), and currently lithium-ion (Li-ion). As internal combustion engine vehicles are limited by the size of their gas tanks, BEV are limited by the size of the battery pack (among other things such as weight, drag, and motor efficiency) (National Research Council 2015, 136). A MY 2014 Nissan Leaf with a 24 kWh battery was rated for a range of 84 miles. A MY 2019 Nissan Leaf has two battery choices, 40 kWh and 62 kWh, rated for 150 miles and 226 miles, respectively (Nissan USA 2019).

Light Duty Fleet Vehicle Analysis

Light duty fleet vehicle analysis will concentrate on the NYC Yellow Taxi fleet as well as TNC vehicles. The analysis will examine mileage, fuel efficiency, and emissions. In addition there is a comparison between ICE and BEV emissions based on mileage and fuel efficiency.

NYC Yellow Taxi

There are some roadblocks that explain why normal customers are reluctant to purchase a battery electric vehicle. One of those reasons is “range anxiety.” Range anxiety is the fear that the vehicle will run out of electric charge before you can get some place to recharge the battery. Part of the reason for this anxiety in normal customers is that there can be an unknown with how many miles need to be driven on a given day or if there will be an available charger at their destination (or if it is functioning). Range anxiety is mostly unfounded as the vast majority of driving habits are within the range of battery electric models. A study by MIT found that 87% of all vehicles could be replaced with a sub-100-mile range EV. As EV ranges increase, 98% of all personal vehicles on the road could be replaced (Caruso 2016).

Fleet vehicles, on the other hand, normally travel around the same amount of distance day to day. The number of miles driven per day by yellow cabs in NYC is approximately 110 miles. However, a study by Hu et al. using 2015 data shows daily vehicle miles driven can be broken out into three groups: 111 mile average, 157 mile average, and 184 mile average (Hu, et al. 2017, 100). Knowing the normal operational range of yellow cabs, which is in the range of most current battery electric vehicles, means that they are prime candidates for conversion away from combustion engines.

Currently New York City has 13,587 yellow taxis in service. The number of yellow cabs has been regulated since the 1930's and is currently under the authority of the Taxi and Limousine Commission (TLC). The TLC determines which vehicles are suitable to serve as NYC yellow cabs. Currently there are nine makes and twenty-eight models that are currently available from MY 2012 and newer. Of all the approved vehicles by the TLC, eleven are hybrid and none are a PHEV or BEV (T&LC 2019). A list of all approved vehicles can be found on Supplemental Figure 01. The non-plug-in hybrid vehicles that are used by the TLC do have a higher MPG range than their non-hybrid counterparts but, with no PHEV or BEV vehicles in the yellow cab fleet, there is an opportunity to reduce transportation emissions by transitioning the fleet to BEVs.

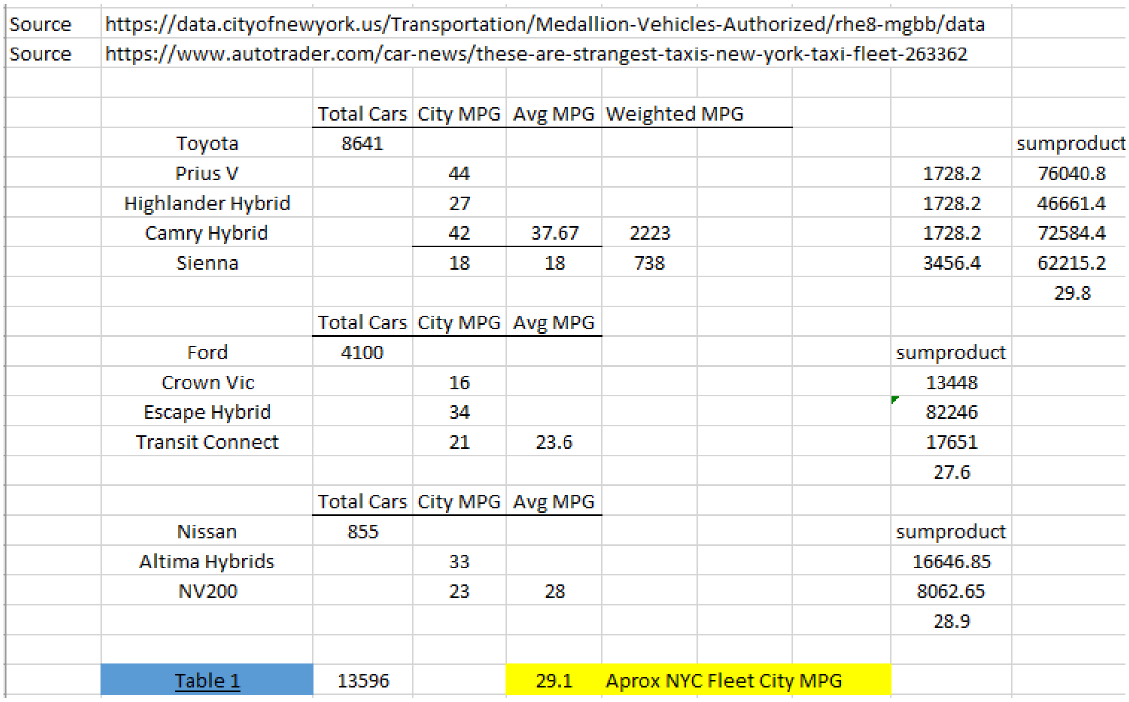
Though the TLC dictates the current new vehicle types this does not mean that there are not older cars still in service. From sourcing raw data I was able to obtain the VIN and year of 12,867 of the current 13,587 vehicles. The data showed that there are taxis still in service that are as old as model year 2009. The vast majority of all yellow taxis, 66%, are between model year 2014 and 2016. The 2017 or newer models account for 14% of the fleet (T&LC 2019). As per the TLC Fact Book, there were a total of 8,060, or 59%, hybrid yellow cabs in 2017 (T&LC 2018, 1).

In 2013 NYC yellow cabs drove just over 1 million miles per day through the Manhattan Central Business District (CBD). The Manhattan CBD is defined as 60th Street down to the Battery, river to river.

(The data that follows is for trips started and/or ended in the Manhattan CBD on weekdays in June 2013 and 2017.) Not all cabs are operating in the CBD at once. If all yellow cabs had operated in the CBD and they all resulted in 1 million miles traveled (13,587), they would have averaged around 77 miles per cab. The Schaller Consulting study calculated 9,100 taxis (67%) on average operated in the CBD, resulting in the average cab traveling 110 miles per day.

In 2017 NYC yellow cabs drove approximately 700,000 miles in the Manhattan CBD (Schaller 2017, 7). If all yellow cabs operated each day only in the CBD, they would have averaged around 51 miles per day. As previously stated, there were 9,100 taxis calculated at any one time in the CBD between 8 a.m. and midnight (Schaller 2017, 6). Using that number, an average cab traveled 77 miles per day. To account for missing data on cabs that operate outside of the CBD and overnight, Schaller's 2013 mileage of 110 miles per day will also be used. It is worth noting that Hu and colleagues state from a 2015 study that NYC yellow cabs routinely have three drivers a day and log over 70,000 miles a year (Hu, et al. 2017, 92). That would mean each shift would account for 63 miles each day, well within operating range of current BEVs.

Weighing the total number of yellow cabs by hybrid percent, then weighing the average estimated city mpg of cars known to be in service, one arrives at an estimated mpg of 29.1 mpg (see Table 1 which shows known taxi makes/models and uses their rated MPGs to estimate fleet MPG). Assuming that 9,100 yellow cabs drove 700,000 miles per day with a mpg rating of 29.1, they would use 24,055 gallons of gasoline per day. Using the EPA value of 19.4 pounds of CO_2 per gallon of gasoline, each day around 466,000 pounds of CO_2 are emitted from two-thirds of all yellow taxis in the New York City fleet. If all taxis were in service and were driving an estimated 77 miles per day, they would total 1.045 million miles per day. This would equate to 696,769 thousand lbs. CO_2/day. All taxis traveling 110 miles per day would increase that number to 996,380 lbs. CO_2/day, a 43% increase.



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Source	https://www.autotrader.com/car-news/these-are-strangest-taxis-new-york-taxi-fleet-263362								
		Total Cars	City MPG	Avg MPG	Weighted MPG				
	Toyota	8641							sumproduct
	Prius V		44					1728.2	76040.8
	Highlander Hybrid		27					1728.2	46661.4
	Camry Hybrid		42	37.67	2223			1728.2	72584.4
	Sienna		18	18	738			3456.4	62215.2
									29.8
		Total Cars	City MPG	Avg MPG					
	Ford	4100						sumproduct	
	Crown Vic		16					13448	
	Escape Hybrid		34					82246	
	Transit Connect		21	23.6				17651	
								27.6	
		Total Cars	City MPG	Avg MPG					
	Nissan	855						sumproduct	
	Altima Hybrids		33					16646.85	
	NV200		23	28				8062.65	
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	Table 1	13596		29.1	Aprox NYC Fleet City MPG				

Table 1 – NYC Yellow Taxi Fleet MPG Estimation. Source – Authors Data

Rideshare/Transportation Network Companies

As shown by the report "Empty Seats, Full Streets", miles per day for yellow cabs has declined between 2013 and 2017, as those miles have been replaced and exceeded by rideshare vehicles (Schaller 2017, 8). There are four rideshare companies operating in NYC: Uber, Lyft, Via, and Juno (Schaller 2017, 4). There is no data for 2013-14 for rideshare companies as they were just starting and data was not reported. Since the inception of rideshare in NYC there has been a meteoric rise in active vehicles, trips, and miles driven. They went from essentially nothing in 2013 to just over 200,000 trips per day, operating for over 800,000 miles per day just in the Manhattan CBD in 2017 (Schaller 2017, 6). Compared to yellow cabs, which start just over 92% of their trips in Manhattan, rideshares only start a little over half of their fares (52.8%) there. Rideshare pickup origins are much more spread out to the other boroughs in the city (T&LC 2018, 5). This means that the 800,000 miles logged per day in the CBD could roughly be only half of all TNC miles driven, making their emissions impact to NYC and NYS more substantial than yellow taxis.

The different types of vehicles that can operate for rideshare companies in New York City is much more diverse than the vehicles that can operate as a licensed yellow cab. Current minimum requirements are: car model year 2006 or newer, 4-door or minivan, good condition (no cosmetic damage), no commercial branding, and TLC plates and licenses. There are more stringent requirements for higher levels of service for each rideshare company such as black interior/exterior luxury sedan or SUV, but to get started only requires the minimums previously mentioned (Uber 2019).

Because of the relative freedom to use most types of vehicles for the purpose of a rideshare vehicle, there is no mandate for hybrid, plug-in hybrid or battery electric vehicles to be used as there is for yellow cabs. There is no data to determine how many battery electric vehicles are being used for TNCs. However, there is data stating there were 18,440 hybrids active in 2017. There were 82,794 rideshare vehicles on the road in 2017, making hybrids only 22% of all rideshare vehicles operating in NYC (T&LC 2018).

In 2017, rideshare vehicles drove over 800,000 miles per day in the Manhattan CBD, 115% of yellow taxi miles driven for the same time and area. Because of required data submitted by individual taxis, the number of taxis operating in the CBD could be calculated. The same data is not available for rideshare vehicles; therefore, we do not know how many vehicles were responsible for the 800,000 miles driven per day. The 82,794 active rideshare vehicles in 2017 were more than six times the amount of all yellow cabs on the streets of NYC.

To determine the emissions impact that the 800,000 miles driven in the Manhattan CBD some assumptions have to be made. Using the same estimated mpg of yellow cabs, 29.1 mpg, the amount of CO_2 emitted per day would be 534,667 pounds. If the average mile per gallon for all vehicles was lower at 24.9 mpg, daily CO_2 output would be 624,851 pounds, an increase of 15.5%. The MY 2017 fleet average for large manufacturers was 24.9 mpg (US EPA 2019).

There are difficulties in determining how many miles each rideshare car drives. Individuals could be driving all day for a TNC, or they could only be participating while driving to and from their regular job. One could blindly estimate the total miles driven for rideshares. It is not out of the realm of possibility that rideshare miles eclipsed 2 million miles per day. With over 80,000 active vehicles on the road in 2017, that number could be much, much higher. Driving 50 miles per day on average for 80,000 cars would be 4 million miles, 110 miles per day would be 8.8 million. Two million miles per day at a fleet average of 29.1 mpg equates to 1.33 million pounds of CO_2 daily. Using 2017 fleet average of 24.9 mpg, a drop in four miles per gallon would equate to an extra 216,672 pounds or 98 metric tons of CO_2 per day.

ICE to BEV Emissions Comparison

As previously stated, NYC Yellow Taxis have a high potential to switch over to battery electric vehicles. They operate within a known mileage each day, which is key for making sure that they have enough charge to sustain their entire shift. Another factor that favors moving away from ICE vehicles is that the NYC energy profile is cleaner than the national average. The EPA rates the sub-region of NYC and Westchester (NYCW) as emitting 635.8 lbs. of CO_2 per MWh of electricity while the national average is 998.4 lbs. CO_2/MWh (US EPA 2018). The cleaner than average energy profile means that there will be a larger than normal emissions savings (tailpipe vs. energy generated emissions). These values do not take into account any production changes over the last two years since this data is from 2016. The information will be updated with 2018 data sometime in the first quarter of 2020.

Since electric vehicles do not use a liquid fuel, their range is not estimated in how many miles they can travel on one gallon. There is an equivalent MPGe (mile per gallon equivalent) that is calculated by the EPA, but the better determination is how many kilowatt hours (kWh) are used to travel 100 miles. The less kWh used to travel 100 miles, the more efficient the vehicle. I gathered information on all the kWh/100 miles of 2019 models and calculated an average of 32 kWh/100 miles. The most efficient BEV uses 25 kWh/100 miles while the least efficient uses 44 kWh/mile (US EPA 2019).

Figures 2 and 3 graphically show emissions data for ICE and BEVs, respectively. Each graph shows pounds of CO_2 (x-axis) for a range of miles driven (y-axis) per year (10,000 to 80,000) for a range of mpg or kWh/100 miles (20-40 MPG and 25-40 kWh/100 miles). Driving 20,000 miles per year with a very efficient automobile with a 40 MPG rating (represented as CO2-40 in Figure 2) emits 9,700 lbs. CO_2 per year. Comparing that to an inefficient BEV rated at 40 kWh/100 miles (represented as CO2-40 in Figure 3), which is responsible for 5,314 lbs. CO_2 per year (through power generation), it has 45% less emissions than that of an efficient ICE vehicle. Traveling 40,000 and 80,000 miles a year would see a savings of 8,771 and 17,543 lbs. of CO_2/year per vehicle, respectively.

Using the previously calculated 29.1 MPG for 20,000 miles equals 13,333 lbs. CO_2/year. Across all 13,587 taxi cabs the total CO_2 emissions would be 181,155,471 lbs-CO_2 or 82,171[1] metric tons (Mt) CO_2 for the fleet per year; 40,000 miles a year would yield 164,348 MtCO_2/year and 80,000 would be 328,689 MtCO_2/year.

Comparatively 20,000 miles at the previously calculated 32 kWh/100 miles plus 4.48% added for line loss (EPA 2018) equals 6.687 MWh/year of electricity. Emission from the electricity generated equals 4,251 lbs. of CO_2/year or 26,199[2] MtCO_2/year, 68% less CO_2 emission over the course of the year than an ICE vehicle. The yearly difference across all 13,587 taxi cabs would be 57,758,337 lbs. CO_2 or 26,199 MtCO_2 for the fleet per year; 40,000 miles a year average would yield 52,404 MtCO_2/year and 80,000 miles a year average would be 104,807 MtCO_2/year.

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[1] 20,000 miles emissions via gasoline - 687 gallons * 19.4 lbs./gallon = 13,333 lbs. CO_2/year.
13,333 lbs. CO_2/year * 13,587 taxi = 181,155,471 lbs. CO_2/year or 82,171 MtCO_2/year.

[2] 20,000 miles emissions via electricity – 635.8 lbs-CO_2/MWh * 6.687 MWh = 4,251 lbs-CO_2/year.
4,251 lbs-CO_2/year * 13,587 taxi = 57,758,337 lbs. CO_2/year or 26,199 MtCO_2/year.

There are many factors which can adjust these numbers in either direction for both types of vehicles. No loss was assumed for idle time, driving habits, or vehicle condition. Regardless, the lower efficiency BEV will still produce less pounds of CO_2 per year than a highly efficient ICE vehicle. As the NYCW electrical grid becomes higher in renewable energy the difference will only increase. Even without an increase in clean energy, when more miles are driven, the savings of emissions become greater.

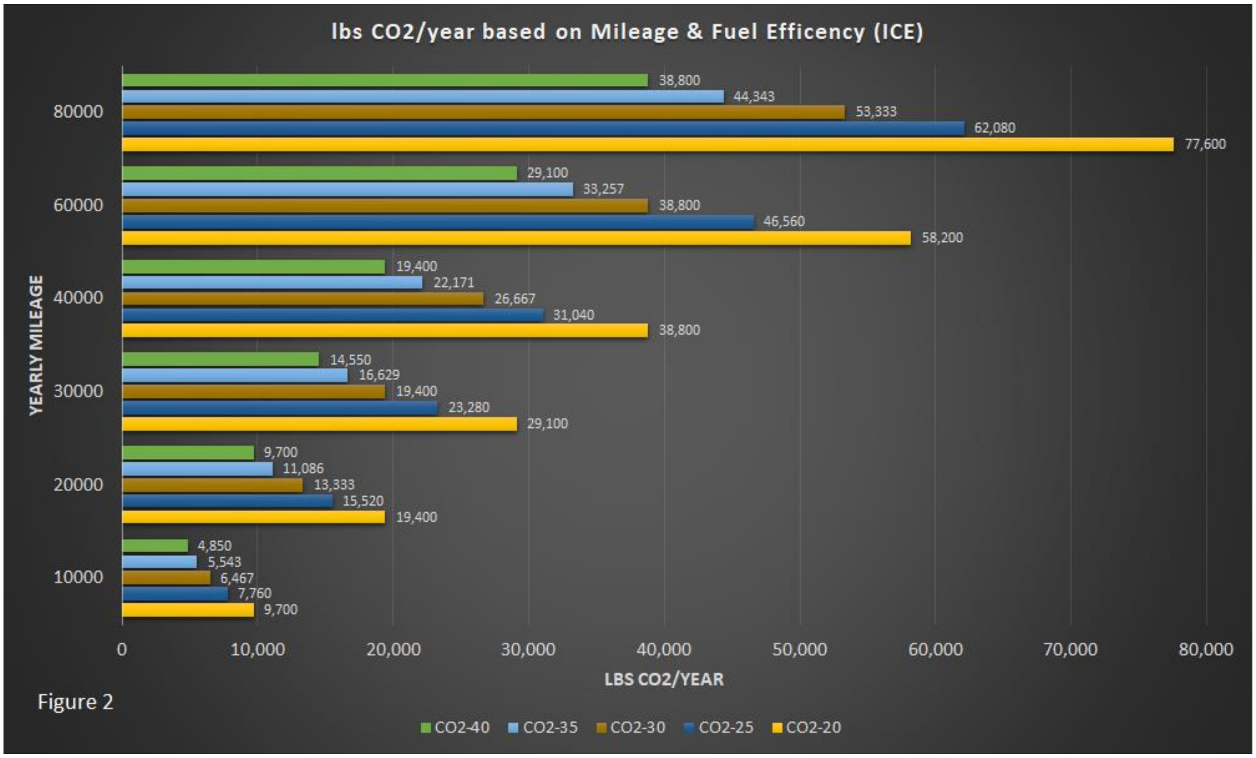

Figure 2 – ICE Emissions by MPG. Source – Authors Data 2019

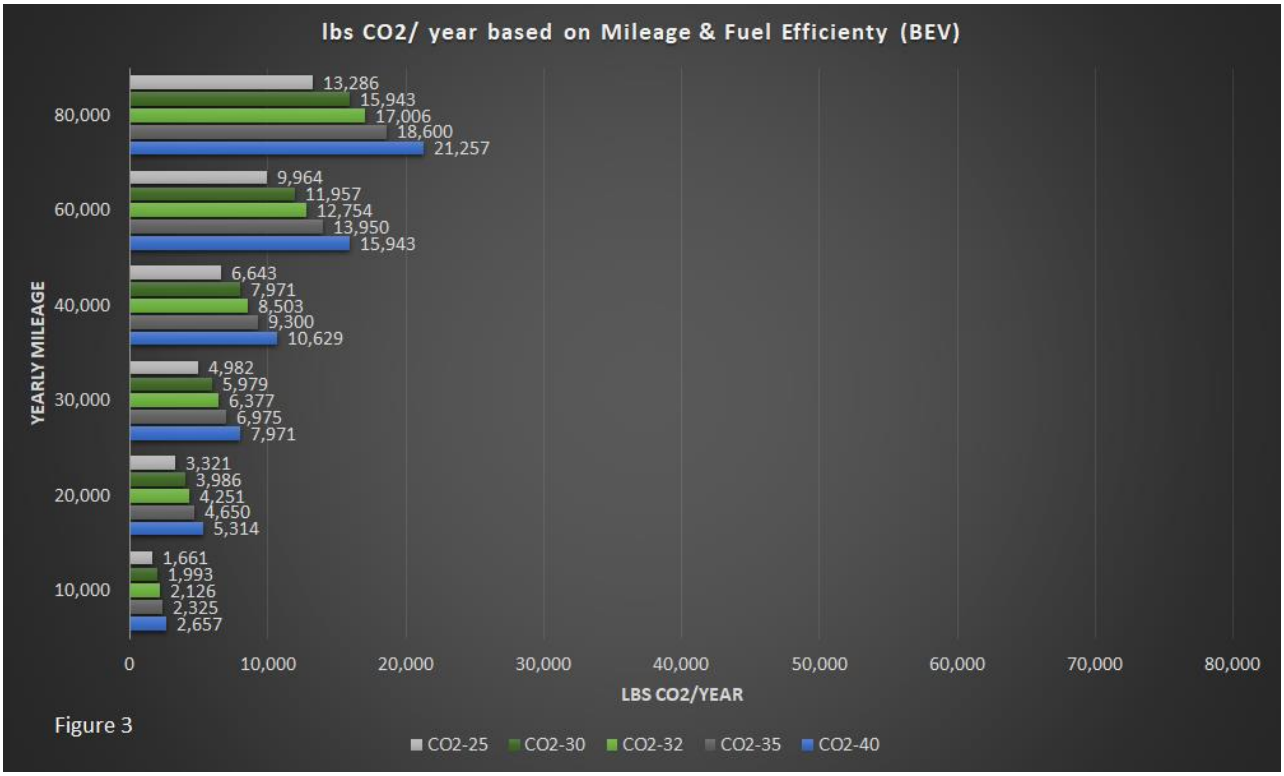

Figure 3 – BEV Emissions by kWh/100 miles. Source – Authors Data 2019

Case Study of Light Duty Fleet Vehicles

Converting LDVs to BEVs, especially taxis, is not a new idea. There have been both simulated and real life studies in China. Though not a taxi simulation, a study of driving habits and patterns of Californians gives good insight on BEV adoption.

Beijing

Beijing has already been testing out replacing their ICE taxis with electric taxis. They have seen a huge increase in taxi demand, from 26.9 million trips in 2004 to 154 million in 2014. This has caused oil consumption to increase. Globally, 33% of all oil is being consumed by the transportation sector. Emissions have naturally increased during this time as well. The amount of PM2.5 and PM10 in 2013 were nine and five times above the World Health Organization (WHO) guidelines, respectively, in

Beijing. Carbon emissions from the transportation sector, for China as a whole, are increasing at 11% per year (Zou, et al. 2016, 25).

The electric taxis that were used in this study had two car platforms which had ranges of 130 km (80 mi) and 160 km (100 mi) (Zou, et al. 2016, 30). Charging options were either level 1 or level 2 which means that there would need to be significant time required to charge the taxis, keeping them out of service for multiple hours. The electric taxis were stationary while waiting for a fare instead of driving around looking for a fare. This reduced the total miles driving from normal taxis by approximately 120 miles (Zou, et al. 2016, 30). Charging times for a BEV from zero to 100% capacity varies on the charging type. Level 1 charging can take 15 to 20 hours while Level 2 charging could be 4 to 8 hours. However, these are maximum charging time durations. Most charging does not occur when the battery is completely or nearly completely depleted of charge.

The scenario for Beijing differs from NYC in a few ways. In NYC, the majority (73.88%) of trip distance is 3 miles or less (T&LC 2018). In Beijing, 55% of trips were 37-62 miles, with the average trip for this study being 64.1 km (39.8 mi) (Zou, et al. 2016, 30). These taxis were not hailed; instead they sat idle waiting for a fare (Zou, et al. 2016, 27). This is more indicative of airport pickups, electronic hails, or other stationary location pickups.

This study did not mention the makeup of the local/regional electric gird, any increased benefits to environment or social health.

Shanghai

Deyang et al. ran a simulation for electric taxi service in Shanghai, China. The baseline was an existing taxi service. Multiple BEV configurations were simulated: 15kWh, 20 kWh, 40 kWh, 60 kWh, and 100 kWh. The economic comparison between combustion engine and battery electric taxis was a well-to-wheel life cycle (Deyang, Dan and Minmin 2016, 392). There are a few life cycle analyses that are used to calculate cost and environmental impact of vehicles. Well-to-wheel life cycle analysis is one that encompasses not only the building and life of the vehicle, but also the cost of extracting the fuel material. In the case of ICE vehicles it calculates the impact of oil exploration, extraction, and refining. For BEVs it is the mining and processing of elements such as lithium and cobalt. Another life cycle analysis that is commonly used is wall-to-wheel, which calculates the emissions from electricity generation for BEVs. That is comparable to pump-to-wheel, which is calculating emissions from burning gasoline or diesel to operate a vehicle.

Economically, the 60kWh battery taxis were the most profitable of the group. The lower battery capacity configurations were not able to make a profit, or made little profit by the 5th year of service. The 80 kWh battery taxi was not as profitable and the 100 kWh battery taxi had an upfront cost that was too high. The 60 kWh battery taxi was not as profitable as the conventional taxi due to upfront cost, which is mostly battery cost, and for lost revenue due to charging time (Deyang, Dan and Minmin 2016, 394).

An analysis of emissions at the time of this report showed that while China's electric grid was 80% coal generated, there was still a significant reduction in CO_2 emissions. "Carbon dioxide emission reduction rate of e-taxis reached 40% on average" (Deyang, Dan and Minmin 2016, 394). The greatest reduction was seen in the economically unviable 15kWh taxi, which was considered "optimal" for emissions. The 60kWh taxi was economically viable and considered "medium" for CO_2 reduction (Deyang, Dan and Minmin 2016, 394-5).

California

A thorough study (simulation) on driving habits in California looked at fleet vehicles and the opportunity to reduce emissions with battery electric technology adoption (Laberteaux and Hamza 2018). This includes battery-only and plug-in hybrid vehicles. Data showed four different driving profiles based on miles driven, trip speed, number of stops, and amount of idle time. Different car types were simulated against those driving profiles. The driving profiles ranged from least city-like driving to mostly city-like driving (lower miles, slower speeds, more stops, and higher idle time) (Laberteaux and Hamza 2018).

Results showed that "without considering the effect of time of charging on grid greenhouse gases, among notable observations regarding daytime charging…is that it does improve the greenhouse gas reduction by PHEVs and BEVs across all four vehicle groups, by varying amounts" (Laberteaux and Hamza 2018, 851). The sole battery electric vehicle simulated was for an 80 mile range, showing significant GHG reduction ratio compared to hybrid and plug-in hybrid, most notably in city-like driving conditions (Laberteaux and Hamza 2018, 852). As the battery range increases (all new BEV models have 100-335 mile range) with miles driving in a city-like scenario, the larger the reduction ratio will be for GHG emissions. This will only be further increased by the percentage of renewable energy sources for the electric grid.

Medium and Heavy Duty Vehicles

Medium and heavy duty vehicles over the last few years have started to see plug-in and battery electric variations. The most common type is the electric bus which has seen a spike in popularity in China and growing interest in the United States.

NYC Buses

As of the fall of 2018, 60% of all transit buses ran on diesel (Casale and Mahoney 2018, 6). The NYC bus fleet, as of 2016, was made up of approximately 87% diesel and diesel-hybrid buses (Aber 2016, 8). To address the potential of transitioning to battery electric buses, on 8 January 2018 Governor Cuomo announced a pilot program to test 10 electric buses based on a 2016 feasibility study. If all goes well then there is the potential to order 60 more electric buses. This is just the beginning of electric buses in NYC (Gov. Cuomo Press Office 2018). As of a 2016, NYC had 5,761 buses made of a mix of diesel, hybrid, and compressed natural gas (CNG). The fuel economy of these types of buses is 2.28, 3.19, and 1.7 MPG, respectively (Aber 2016, 9).

An analysis was done for NYC on the feasibility of utilizing electric buses by Columbia University in 2016, written by Judah Aber (Aber 2016). This study calculated yearly CO_2e emissions for the NYC bus fleet is estimated to be 577,290 Mt, slightly off from the reported amount of 563,826 Mt. Using an estimate of 2kWh/mile fuel economy, based on independent testing, it is calculated that NYC would avoid around 486 $MtCO_2$e per year by converting the entire bus fleet to battery electric buses; an electric fleet would have 91 $MtCO_2$e associated emissions due to electric charging. One of the major factors in the battery electric buses "emitting" so much less CO_2 is because of the cleaner than national average electricity supply of the NYCW sub region (Aber 2016, 13).

For a financial analysis of the cost of a diesel versus electric, certain assumptions were made regarding price of fuel, electricity, and initial purchase price. Three scenarios were created, an aggressive, a conservative, and an average. One scenario (Alternative 1, the average scenario) does not look at the health cost due to diesel emissions, instead it just concentrates on purchase price, fuel/electric cost, and maintenance cost. Initial purchase prices were estimated between $150,000 and $400,000 more for an electric bus than for a diesel bus. The difference of $300,000 was the purchase price figure used in this study. It is estimated that electric buses, over a 12 year lifespan, will cost 12.5% less per bus ($168,000) than a diesel bus (Figure 4 shows breakout of lifetime costs comparison). The payback time frame is estimated to be 7.69 years (Aber 2016, 16). This analysis is backed up by the estimates from the Chicago Transit Authority. They estimate that their electric buses saves the city nearly $80,000 year in fuel and healthcare expenses (Casale and Mahoney 2018, 7).

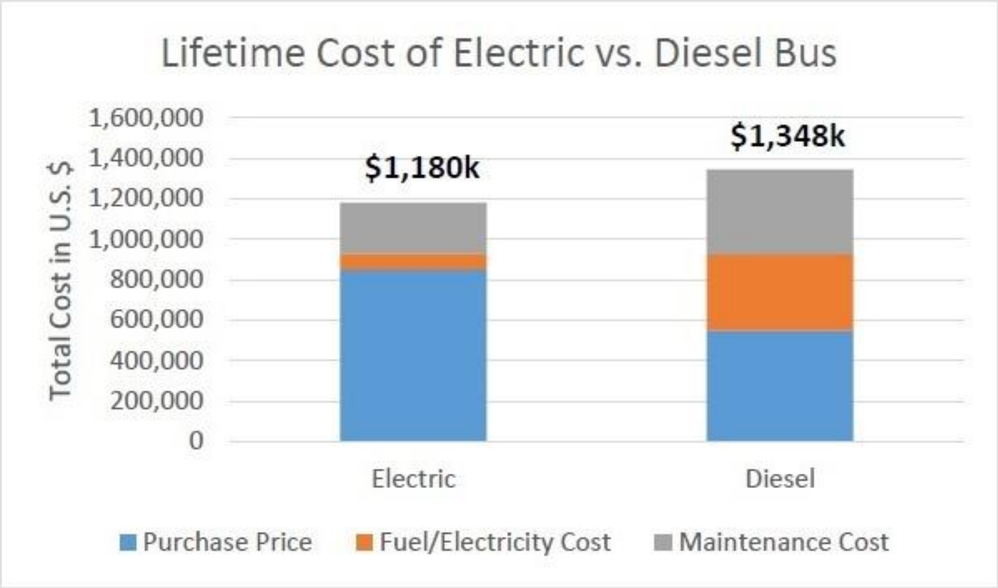

Figure 4

Figure 4: Lifetime Cost Electric vs Diesel Bus. Source – Aber 2016

The other two financial scenarios are each more aggressive towards diesel or electric on price and maintenance cost. If diesel prices are low and less savings is expected in maintenance costs, it would not make for a sound financial purchase. On the opposite scenario, with high diesel prices and more savings in maintenance costs, payback for purchasing electric buses goes from 7.69 years down to 5.71 years (Aber 2016, 17). Depending on the difference in purchase price, fuel prices, and savings in maintenance costs, the payback for an electric vehicle could be as short as 2.86 years or as long as 16.67 years (Aber 2016, 31-32).

When making the financial decisions to migrate over to electric vehicles, there is more to take into account than just purchase, fuel, and maintenance costs. There are healthcare costs that can be attributed to diesel buses for such things as respiratory problems, heart disease, and other health issues related to particulate matter, PM10 and PM2.5. This study also takes into account the costs associated with “hospitalization, the cost of emergency room visits and the cost of absence of work. Switching from diesel buses to electric buses reduces the amount of particulate matter in the air, which decreases the frequency of incidents of heart and lung diseases, which in turn reduces hospital costs and costs associated with work absence" (Aber 2016, 18).

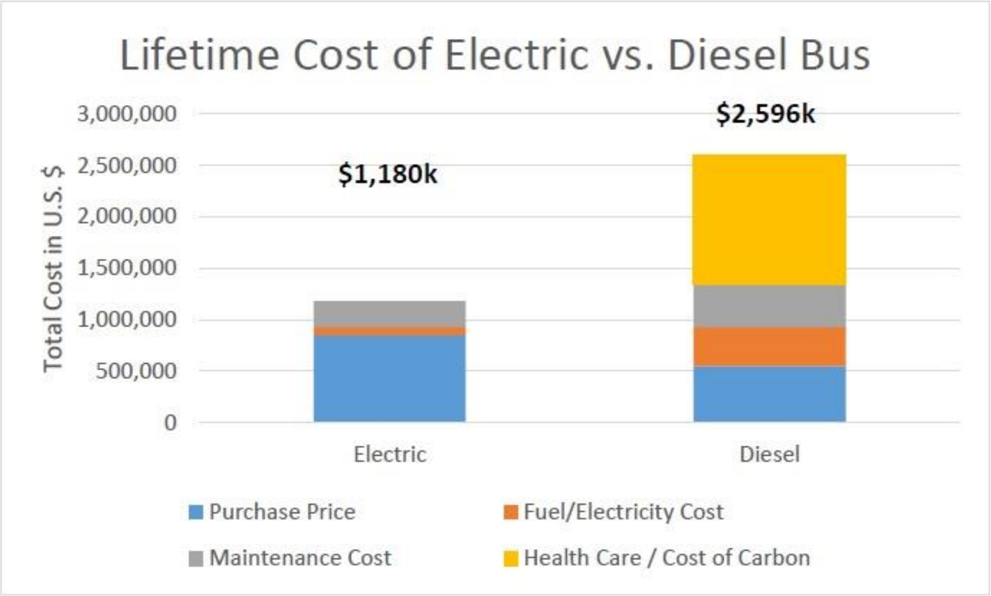

Figure 5

Figure 5 – Lifetime Cost Electric vs Diesel Bus with Healthcare Cost. Source – Aber 2016

Aber used the EPA's Diesel Emissions Quantifier calculator, showing that particulate matter reduction by removing diesel buses from NYC's fleet would reduce PM2.5 by 97.5% (Aber 2016, 5). "Each bus emits about 84 M Tons of GHG per year" (Aber 2016, 19). Healthcare cost savings from that reduction of emissions was calculated to be $150,000 per bus per year, emissions savings are expected to be $3,000 per bus and $36,000 for the life of each bus. Using the previously mentioned Alternative 1 scenario with a payback timeframe of 7.69 years, and adding a conservative healthcare savings of $100,000 (Figure 5 shows breakout of lifetime costs with health care and carbon costs), the payback timeframe drops to 2.11 years (Aber 2016, 18-20). The most extreme scenarios for payback would also be drastically reduced from a range of 2.86 to 16.67 years down to 0.69 to 5.19 years[3], respectively (Aber 2016, 31-32).

School Buses

In addition to replacing the transit bus fleet, school bus fleets can also be replaced. School buses in the United States are 95% diesel (Casale and Mahoney 2018, 6). Similar to transit buses, electric school buses have a known daily mileage which makes them ideal for conversion. They also will have a lifetime savings with or without calculating health and environmental costs. Adding in the detrimental effects that diesel emissions have on both the environment and human health only adds to widening the savings gap. Casale and Mahoney estimate that electric school buses will save $50,000 over the life of the vehicle without health or environmental costs included in the calculations (Casale and Mahoney 2018, 7-8). Fuel savings will vary from region to region based on the profile of the electric grid.

Delivery Trucks

There are other types of fleet vehicles that have the potential for replacement with battery electric technology as well. "Medium and heavy duty vehicles, Classes 3-8, consume 22% of the petroleum-based transportation energy in the United States" (Prohaska, et al. 2016, 1). These, mostly diesel, fleet vehicles would, as described below, see a vast improvement in emissions. A study by the National Renewable Energy Laboratory tested battery electric delivery trucks for Frito-Lay in one of its Washington distribution centers. Frito-Lay has the 7th largest fleet in the United States (Prohaska, et al. 2016, 3). Their trucks mostly sit idle during the day even during deliveries. Deliveries are started in the overnight/early morning and return between 10 a.m. and 1 p.m. Their drive schedule gives them flexibility for their charging times (Prohaska, et al. 2016, 10). Different charging patterns (Figure 6 shows

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[3] The three NYC Bus cost analysis figures can be seen on Supplemental Tables 1a through 1c.

three charging scenarios) can result in a 23% peak energy demand reduction for the facility (Prohaska, et al. 2016, 36).

There is a lot of idle time with the trucks when on delivery routes because when they are not driving between locations the drivers are responsible for stocking shelves, working on their customer accounts and other non-driving functions. The vehicles in the test (both electric and diesel) spent an average of 1.5 hours driving and averaged a daily distance of 40 miles (Prohaska, et al. 2016, V). The battery electric trucks were equipped with 80kWh batteries. After their routes were finished, the electric fleet had a remaining average battery capacity of 42% (Prohaska, et al. 2016, 25). The range during the test would have been drivable with a battery of 55kWh (leaving little room for reserve energy) (Prohaska, et al. 2016, 18).

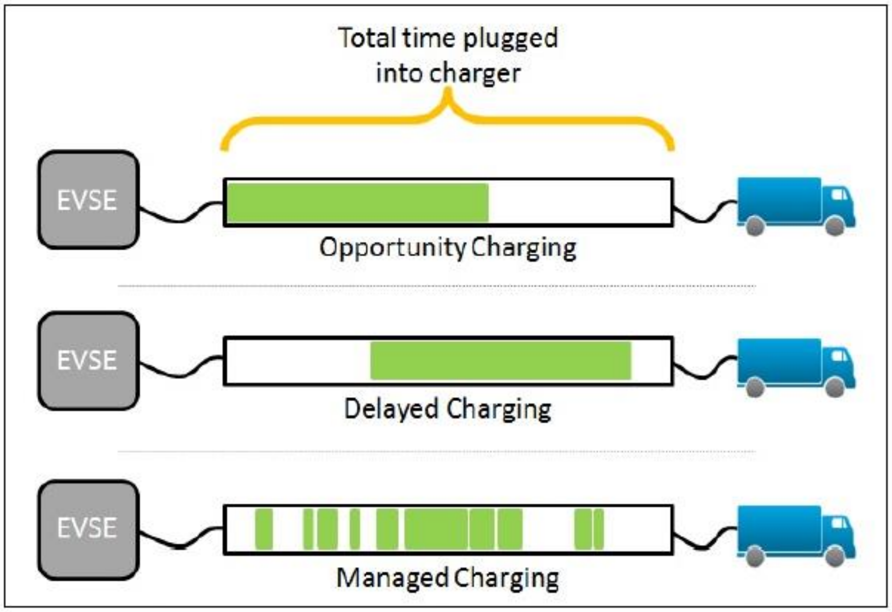

Figure 6

Figure 6 – Charging Scenarios. Source – Prohaska, et al. 2016)

During the testing period, the electric delivery vehicles showed an increased fuel efficiency of 216%. Diesel averaged 7.63 MPG while electric average 24.09 MPGe. As seen in the scatter plot of Figure 7, diesel fuel economy was relatively constant between 5 and 10 MPG. The EVs concentration had more variation but was consistently higher than diesel. Pricing during the testing in 2013 was $3.85/gal of diesel and $0.102/kWh for electric. Diesel truck cost, just in fuel, was $0.507 per mile while the electric truck was only $0.159 per mile. The breakeven point for fuel cost, assuming static electric prices, would be $1.212/gal for diesel (Prohaska, et al. 2016, 15).

Emissions also saw improvement of CO_2e of nearly half (46%). The amount of reduction is directly related to the makeup of the local electric grid sources. Puget Sound Energy (PSE) supplies power to the Frito-Lay facility. They reported their CO_2e to be 450.58 g/kWh in 2014. The total emissions per year from driving 8,488 miles per year plus losses equates to 958.51 g CO_2e/mi for each electric vehicle. In comparison, the diesel emissions for each deliver truck are 1,414.93 g CO_2e/mi. per vehicle; the annual savings is 6.136 tons of CO_2e. Figure 8 shows the growth in CO_2e savings as mileage increases (Prohaska, et al. 2016, 20-21). No health or environmental analysis on impact or cost was done between diesel and electric for this study.

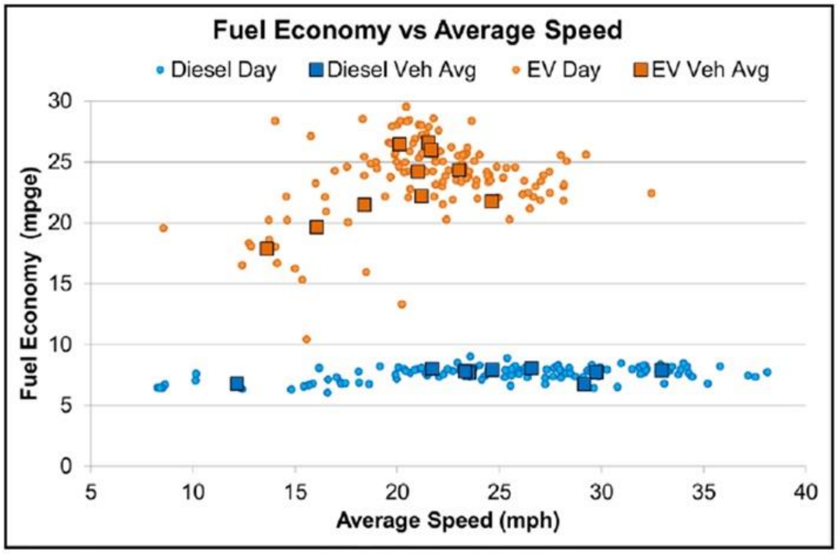

Figure 7

Figure 7 – Fuel Economy vs Average Speed. Source – Prohaska, et al. 2016

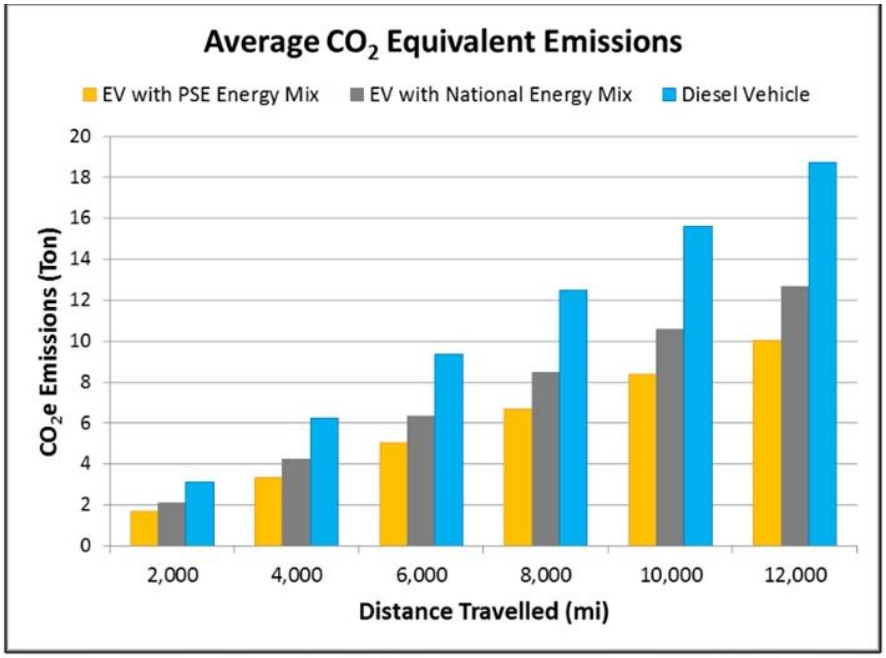

Figure 8

Figure 8 – Emissions of Miles Traveled by Energy Source. Source – Prohaska, et al. 2016

Air Pollution and Emissions

Emissions from conventional vehicles are a large source of greenhouse gases and air pollutants. Globally, vehicle emissions account for 30% of nitrogen oxides (NO_X), 10% particulate matter (PM), 54% carbon monoxide (CO), and 47% of nonmethane hydrocarbons (NMHC) or, as they are also known as, volatile organic compounds (VOC) (Requia, et al. 2018, 65). The broad term air pollution refers to man-made and natural substances that are in the air, both indoor and outdoor. Outdoor air pollution in regards to this paper, which includes the aforementioned pollutants, refers to pollutants from burning of fossil fuels and other noxious gases that are associated with the transportation and the energy sectors. Air pollution has been linked with many health ailments such as: respiratory diseases (including asthma and lung cancer), cardiovascular diseases, adverse pregnancy outcome, and premature death. In New York City "all on-road mobile sources contribute to about 320 deaths annually due to PM2.5 exposures" (NIEHS-NIH 2019).

The biggest impact of battery electric related emissions is the source make-up of the local electric grid. Since the tailpipe emissions of a BEV are replaced by electrical generation emissions, the cleaner the electrical grid the cleaner the associated emissions for a BEV. As of 2018, the average US electric grid had a lower impact of GHG emissions than gasoline (Laberteaux and Hamza 2018, 847).

The type of non-renewable energy source and the way it is burned can have an impact on the reduction or increase in GHGs and air pollutants. In a high coal energy source electrical grid, BEVs can reduce CO_2 but increase other GHGs and air pollutants. In China's most heavily coal-based province, it is estimated that BEVs can reduce CO_2 by 20% but at the cost of raising PM10 by 360%, PM2.5 by 250%, NOX by 120%, and SO2 by 370% (Requia, et al. 2018, 73).

Children are more susceptible to airborne pollution, which alone should be a motivating factor in reducing diesel emissions and removing children from those situations if possible. The "growing epidemiologic evidence indicates that long-term exposure to traffic-related air pollution, particularly diesel exhaust particles, is associated with higher prevalence of asthma and chronic respiratory symptoms. Elemental carbon, nitrogen dioxide, acid vapor and fine particulate matter were associated with deficits in lung function growth between 10 and 18 years of age" (Patel, et al. 2010, 1338). In particular, NYC has a higher child asthma hospitalization rate than in surrounding suburbs. The rates are highest in areas that have diesel emissions, such as trucking routes and bus depots (Patel, et al. 2010, 1338).

Studies of EV adoption show that EVs can significantly reduce CO_2 emissions, since the tailpipe emissions are removed and the emissions for BEVs now come from the electrical grid. Any emissions from non-renewable sources are displaced from the road to the area of energy production. Because emissions are transferred from tailpipe to power plants, the pollution they generate is most likely transferred from urban areas to sub-urban or rural areas. This transfer of emissions, though sometimes negligible, should be considered in a large scale EV adoption plan. In the case of NYCW sub-region, its energy makeup is about one-third cleaner than the national average. This is also based on 2016 data with no major EV adoption plan or push by the state, and no consideration for any increase of renewable generation sources current or future (US EPA 2018).

Battery electric vehicles can have a significant impact when replacing conventional LDV, MDV, and HDV. In the case of NYC and the fleet vehicles found there, LDV are predominantly run on gasoline. The NYC bus fleet is primarily diesel or diesel hybrid, with a few running on CNG. Diesel emissions are a large source of particulate matter, especially PM2.5. Replacing diesel buses with battery electric buses will significantly reduce PM2.5. It will not eliminate PM2.5 altogether, just removing the amount associated with tailpipe emissions. As previously stated, removing the NYC fleet diesel buses would remove 97.5% of PM2.5 that was previously produced by those buses (Aber 2016, 18).

Impacts on City and State Transportation Emission Goals

In the 2015 New York State GHG Inventory, emissions for the transportation sector was 72.8 $MMtCO_2e$. Gasoline transportation accounted for 53.6 $MMtCO_2e$ while diesel was 7.1 $MMtCO_2e$ (NYSERDA 2018, 13). I am assuming a possible range of miles traveled per taxi per year is between 20,000 and 80,000 miles (shown as “low” and “high”, respectively, in the following tables). The estimated emission for the yellow taxi fleet in NYC traveling 20,000 miles/year at 29.1 mpg is 82,170 metric tons $MtCO_2e$ /year. The taxi fleet emissions for traveling 80k miles/year at 29.1 mpg is 328,689 $MtCO_2e$. As shown in Table 2, the taxi fleet is anywhere from 0.11% to 0.45% of New York State’s overall yearly transportation emissions, and 0.15% to 0.61% of gasoline related transportation.

Scenario	Taxi Emissions	Overall Emissions	Percent of Emissions
Total NYS low	82,171 $MtCO_2e$ /year	72.8$MMtCO_2e$/year	0.113%
Total NYS high	328,689 $MtCO_2e$ /year	72.8$MMtCO_2e$/year	0.451%
Gas NYS low	82,171 $MtCO_2e$ /year	53.6$MMtCO_2e$/year	0.153%
Gas NYS high	328,689 $MtCO_2e$ /year	53.6$MMtCO_2e$/year	0.613%

Table 2 – NYC Yellow Taxi Emissions Impact on NYS. Source – Authors Data

The 2015 New York City transportation emissions, as per the 2015 New York City GHG Emissions Inventory, was 15.5 $MMtCO_2e$ total, 80% which was gasoline based (NYC Mayor's Office of Sustainability with Cventure LLC 2017). Table 3 shows that yellow taxis accounted for 0.53% to 2.12% of the total transportation emissions and 0.66% to 2.65% of gasoline emissions.

Scenario	Taxi Emissions	Overall Emissions	Percent of Emissions
Total NYC low	82,171 $MtCO_2e$ /year	15.5$MMtCO_2e$/year	0.53%
Total NYC high	328,689 $MtCO_2e$ /year	15.5$MMtCO_2e$/year	2.12%
Gas NYC low	82,171 $MtCO_2e$ /year	12.4$MMtCO_2e$/year	0.66%
Gas NYC high	328,689 $MtCO_2e$ /year	12.4$MMtCO_2e$/year	2.65%

Table 3 – NYC Yellow Taxi Emissions Impact on NYC. Source – Authors Data

The reason for such wide range of emissions is because there is no hard data on actual miles traveled for yellow taxis. Some data hints that a taxi could be driving as little as 20,000 miles a year while other information shows taxis averaging around 70,000 miles per year. Even with the wide range of data we know that the number of yellow taxis on the road does not change much, if at all year over year. Yellow taxis have been regulated since the 1930's and have remained constant over the years. The reasons for fluctuations in emissions will be from miles driven per year and fuel efficiency of their vehicles.

Rideshare vehicles, unlike yellow taxis, have no data on how many miles are driven. Since we do not know the amount of miles driven by rideshare vehicles it is difficult to determine their true emissions impact. What we do know is that rideshare vehicles dwarf the yellow taxi fleet, but what we don't know is whether these are full-time, part-time or just the random once in a while drivers. According to the 2018 TLC Factbook, the peak number of rideshare vehicles in 2017 was 82,794 (T&LC 2018). For simplicity of comparison, I assume 80,000 rideshare vehicles. If they travel the same amount of low miles (20,000) with the same mpg as yellow taxis, they would make up less than 1% of NYS emissions (shown in Table 4). Using the higher miles (80,000) that number jumps to 2.7% (shown in Table 4). I do not believe that it is realistic that all the registered rideshare vehicles drive an average of 80,000 miles per year on the job. The actual numbers are probably somewhere in the range calculated below, which don't just show the potential impact of rideshare vehicles, but all vehicles.

Scenario	Taxi Emissions	Overall Emissions	Percent of Emissions
Total NYS low	483,820 $MtCO_2e$ /year	72.8$MMtCO_2e$/year	0.67%
Total NYS high	1,935,315 $MtCO_2e$ /year	72.8$MMtCO_2e$/year	2.66%
Gas NYS low	483,820 $MtCO_2e$ /year	53.6$MMtCO_2e$/year	0.9%
Gas NYS high	1,935,315 $MtCO_2e$ /year	53.6$MMtCO_2e$/year	3.61%

Table 4 – TNC Emissions Impact on NYS. Source – Authors Data

As shown in Table 5, those 80,000 vehicles could account for anywhere from 3.12% to 12.49% of NYC transportation emissions, and 3.9% to 15.6% of the gasoline transportation emission. Again, it is highly unlikely that rideshare is at the high calculated mileage. However, over time, the emissions numbers have gone up significantly due to the number of registered rideshare drivers ballooning from 67,000, to over 100,000 in a three year period (T&LC 2018).

Scenario	Taxi Emissions	Overall Emissions	Percent of Emissions
Total NYC low	483,820 $MtCO_2e$ /year	15.5$MMtCO_2e$/year	3.12%
Total NYC high	1,935,315 $MtCO_2e$ /year	15.5$MMtCO_2e$/year	12.49%
Gas NYC low	483,820 $MtCO_2e$ /year	12.4$MMtCO_2e$/year	3.90%
Gas NYC high	1,935,315 $MtCO_2e$ /year	12.4$MMtCO_2e$/year	15.62%

Table 5 – TNC Emissions Impact on NYC. Source – Authors Data

As of 2016 NYC had 5,761 buses. Though the bus fleet is only 42% of the size of the yellow taxi fleet, emissions from the bus fleet are more than the yellow cab fleet even though taxis drove three times as many miles. Moving over to an all-electric fleet would save the city "approximately 570,000 metric tons of CO_2e per year" (Aber 2016, 2). The net savings would be 500,000 $MtCO_2e$ due to the transfer of emissions to the energy sector (Aber 2016, 2). The buses are assumed to travel 27,600 miles each year compared to 20,000 to 80,000 miles for taxis (Aber 2016, 18). They also account for a much larger share of the diesel emissions (8.1%) than taxis account for gasoline emissions (Shown in Table 6).

Scenario	Taxi Emissions	Overall Emissions	Percent of Emissions
Total NYS	575,000 $MtCO_2e$ /year	72.8 $MMtCO_2e$/year	0.79%
Total NYS Diesel	575,000 $MtCO_2e$ /year	7.1 $MMtCO_2e$/year	8.1%

Table 6 – NYC Bus Emissions Impact on NYS. Source – Authors Data

As with the state, the NYC bus fleet is responsible for more emissions for the city than taxi cabs. Buses are also responsible for almost a quarter of the diesel transportation emissions (23.19%) in the city (shown in Table 7). Taxis, in a worst case scenario, only account for around 2.6% of gasoline emissions.

Scenario	Taxi Emissions	Overall Emissions	Percent of Emissions
Total NYC	575,000 $MtCO_2e$ /year	15.5 $MMtCO_2e$/year	3.71%
Total NYC Diesel	575,000 $MtCO_2e$ /year	2.48 $MMtCO_2e$/year	23.19%

Table 7 – NYC Bus Emissions Impact on NYC. Source – Authors Data

As far as emissions are concerned, yellow taxis are only a fraction of a percent of the state, and potentially just over 2% of city transportation emissions. Rideshare could make up 0.67% to 2.66% of state emissions and possibly 3% to 12.5% of city transportation emissions, which is a much more impactful number, especially to the city. The reason for the wide range is due to the lack of data on TNC mileage. The real impactful data in the comparison is that the bus fleet is a higher percentage of emissions than taxi and rideshare vehicles. Buses account for 23.19% of all diesel emissions in NYC. Besides the $MtCO_2e$ that buses account for, there is a social impact of diesel emissions. The tailpipe emissions that are generated are released in areas that are serviced and in the areas that the bus depots are located. Replacing the bus fleet for NYC would be the low hanging fruit of addressing transportation emissions. However, updating regulations to mandate BEVs for taxi and rideshare vehicles would only have positive impacts on transportation emissions.

Conclusion

New York State and New York City are both working towards lowering their emissions by 2050. Reversing the current trend of rising transportation emissions will play a big part in reaching their goals. Both have set out to reduce their emissions by 80% of their 1990 levels. They both have shorter term goals as well that include the reduction of transportation emissions. The state is looking to cut overall emissions by 40% by 2030. Emissions have been going down but due to improvements in other sectors. Transportation emissions have been increasing. Gasoline emissions were up 5.9% and along with diesel emissions make up 84% of all transportation emissions. NYC has made a pledge to follow the Paris Climate Agreement and is working to get more people to use public transit, walk, or bike to their destination. Their goal is to have four out of every five trips made within the city be done one of those ways. To make biking easier and safer the city is increasing bike lanes. The city is also promoting electric vehicles and has a goal of 20% of newly registered vehicles to be a PHEV or BEV by 2025.

Why fleet vehicles are a good choice for conversion to battery electric is because they generally have a known distance of travel per day. They tend to travel high mileage and the more miles traveled by electric power the greater the reduction of GHGs compared to an ICE vehicle. Maintenance costs are less, and the reduction of GHGs reduces negative heath ailments such as respiratory diseases, cardiovascular diseases, pregnancy complications and even death.

The reason this report concentrated on NYC fleet vehicles is because of the amount of vehicle miles that occurs in the city compared to the rest of New York. As this report showed, converting NYC fleet vehicles could have a noticeable impact on emissions for both the city and the state. NYC accounts for 21% of the state's transportation emissions. Most notably is that NYC accounts for 35% of the state's diesel emissions. Considering the health impacts that emissions and especially diesel emissions and PM have on human and environmental health, it is important to address in such a densely populated area.

The NYC yellow cabs are a regulated fleet of vehicles that can travel up to 70-80,000 miles per year. Even with the amount of miles they log each year, they only make up about half of a percent of the state transportation emissions. With the introduction of TNCs, taxi mileage has been decreasing, at least in the Manhattan CBD. This does not mean that conversion of taxis to BEVs wouldn't have an impact. They potentially make up over 2% of transportation emissions in NYC and would avoid over 300,000 metric tons of CO_2 being released into the atmosphere every year.

Rideshare vehicles, of which there were over 80,000 in 2017, have the potential to have a very big impact on both state and city emissions. However, since there is limited data available to analyze on rideshare vehicles, estimates had to be made. The high scenario of yearly miles traveled (80,000 miles/year) is extremely unlikely to be accurate for a fleet average. There may be some vehicles which accrue that many miles but most probably don't, which is why I calculated a range of possible yearly mileage. I personally know people who have driven for a TNC and would only participate when they were on their way home from work to make a few extra dollars.

Based on the range of possible average miles driven by the fleet of rideshare vehicles, they can impact state transportation emissions from 0.67% up to 2.66%. More information is needed on miles traveled, vehicle MY, make, model, and mpg averages in order to get a clearer picture of rideshare vehicles true impact to both the city and state.

Rideshare vehicles in NYC have caused a lot of commotion over the last few years. There are both positive and negative aspects of the business model. Some positives is that TNCs service areas that are not frequented by yellow or green cabs. Over 92% of all yellow taxi cab rides originate from Manhattan. Rideshares on the other hand only start 52% of their fares there (T&LC 2018). Residence from the outer boroughs had to primarily rely on bus or subway as modes of transportation. This gives them more flexibility and freedom over their day to day lives.

The obvious negative aspect of rideshares is that it put more cars on the road driving more miles. "Estimates for the 60th Street cordon indicate that during daytime hours, taxis and TNCs likely comprise 50% or more of total vehicles traveling north or south" (Schaller 2017, 12). Unoccupied miles traveled for TNCs make up 45% of TNC mileage, compared to a taxis which is unoccupied 33% of the miles driven. The increase of vehicles in the Manhattan CBD has even slowed traffic down 18% (Schaller 2017). These are just some aspects of what has come from the development of TNCs. Analyzing the positive and negative effects that TNCs have on social, economic and environment impacts could easily be study by itself and is mostly beyond the scope of this report.

The biggest improvement in emissions of converting fleet vehicles to electric would be the NYC bus fleet. Though the bus fleet is less than half the size of the taxi fleet, they produce more emissions. If every NYC yellow cab drove 80,000 miles, the bus fleet driving just under 27,000 still produces more emissions. Worse off, they are mostly diesel emissions. These emissions contain particulate matter (PM2.5 and PM10) which are known to have health implications, especially in areas of high concentrations. Converting the bus fleet over to electric would reduce the PM from buses by 97.5%, and avoid over 500,000 $MtCO_2e$ from being emitted. Though buses only account for 0.8% of NYS transportation emissions, they are 8.1% of the state diesel emissions. They account for a much larger percent of city transportation emissions, 3.71% overall and a staggering 23.19% of city diesel emissions.

Transforming the transportation landscape is an important part of meeting emissions goals for New York State and New York City. Fleet vehicles are a good way to start to tackle transportation emissions. Conversion of the bus fleet would see notable improvements to both the city and state diesel emission and positive health and environmental impacts. A yellow taxi fleet can be adopted by the TLC through attrition, replacing older vehicles as they are taken out of service. Even though they have the smallest impact of the report, they would still have a positive impact on reducing transportation emissions.

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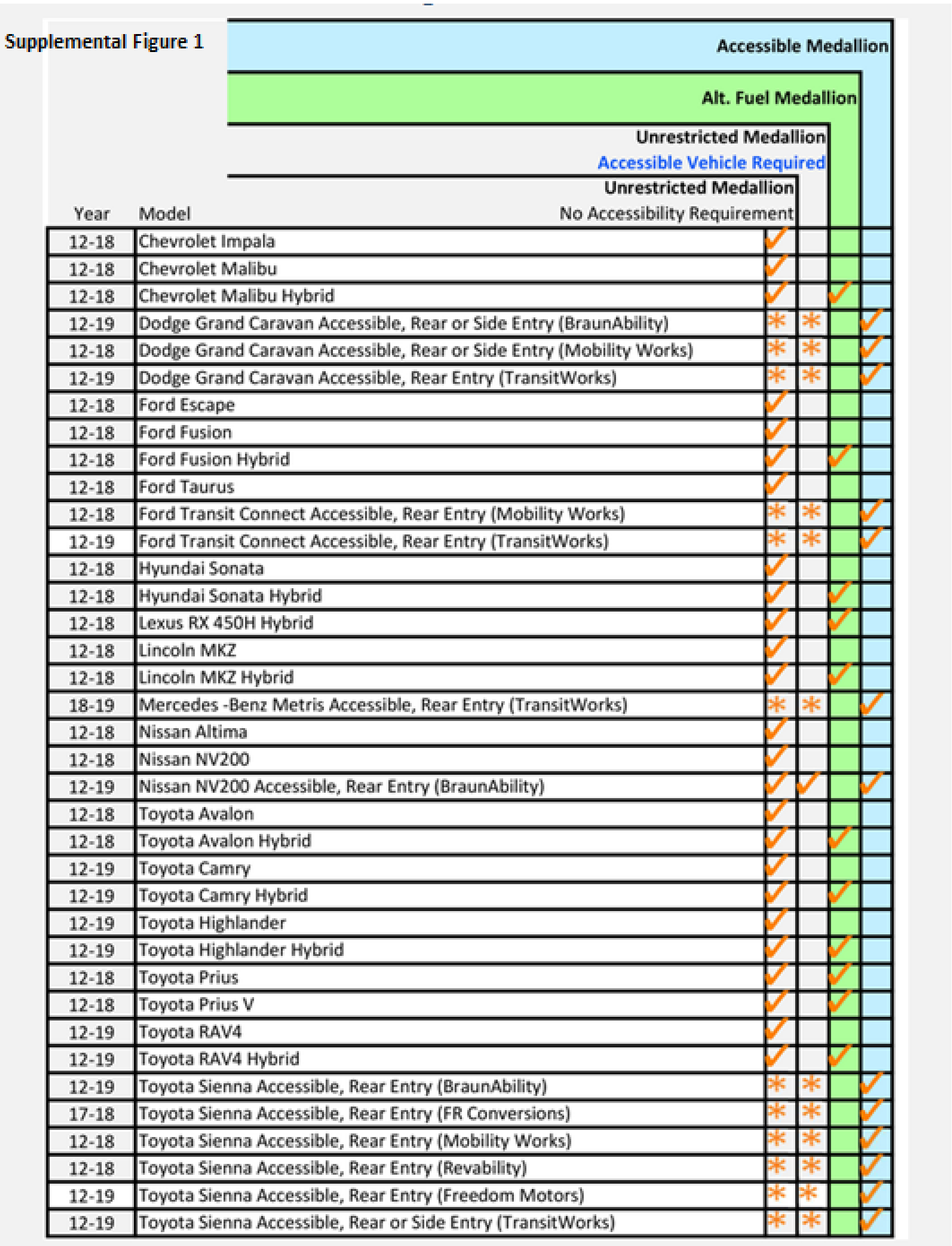
Supplemental Figures

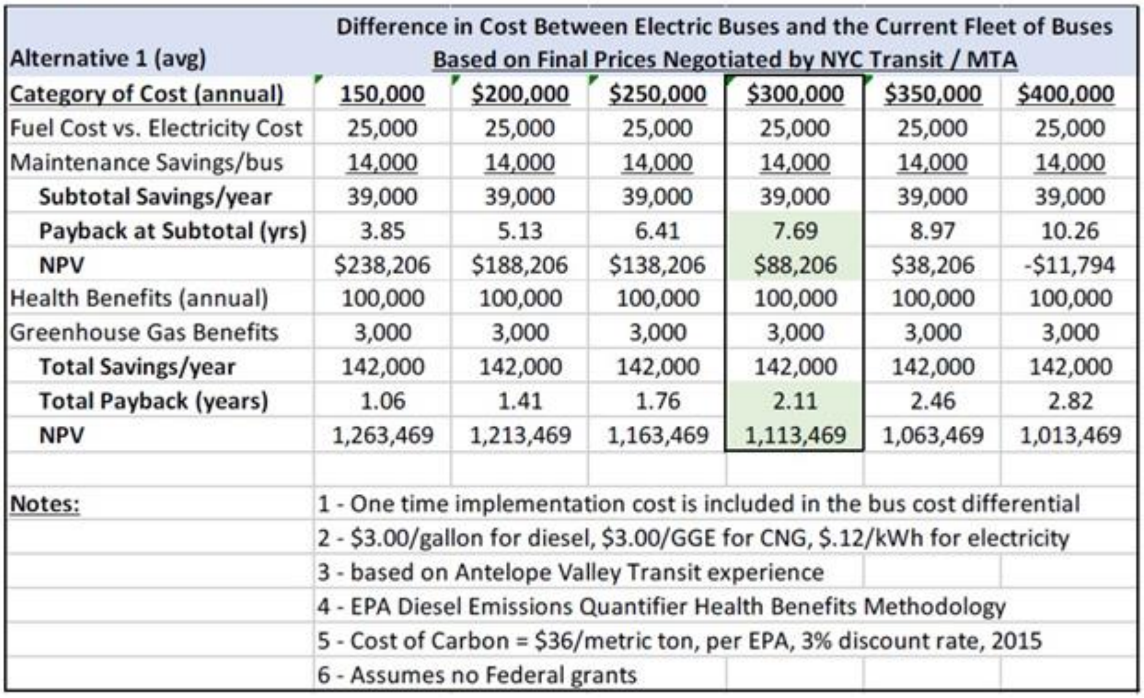


Supplemental Figure 1

Year	Model	Unrestricted Medallion No Accessibility Requirement	Unrestricted Medallion Accessible Vehicle Required	Alt. Fuel Medallion	Accessible Medallion
12-18	Chevrolet Impala	✓			
12-18	Chevrolet Malibu	✓			
12-18	Chevrolet Malibu Hybrid	✓		✓	
12-19	Dodge Grand Caravan Accessible, Rear or Side Entry (BraunAbility)	*	*		✓
12-18	Dodge Grand Caravan Accessible, Rear or Side Entry (Mobility Works)	*	*		✓
12-19	Dodge Grand Caravan Accessible, Rear Entry (TransitWorks)	*	*		✓
12-18	Ford Escape	✓			
12-18	Ford Fusion	✓			
12-18	Ford Fusion Hybrid	✓		✓	
12-18	Ford Taurus	✓			
12-18	Ford Transit Connect Accessible, Rear Entry (Mobility Works)	*	*		✓
12-19	Ford Transit Connect Accessible, Rear Entry (TransitWorks)	*	*		✓
12-18	Hyundai Sonata	✓			
12-18	Hyundai Sonata Hybrid	✓		✓	
12-18	Lexus RX 450H Hybrid	✓		✓	
12-18	Lincoln MKZ	✓			
12-18	Lincoln MKZ Hybrid	✓		✓	
18-19	Mercedes -Benz Metris Accessible, Rear Entry (TransitWorks)	*	*		✓
12-18	Nissan Altima	✓			
12-18	Nissan NV200	✓			
12-19	Nissan NV200 Accessible, Rear Entry (BraunAbility)	✓	✓		✓
12-18	Toyota Avalon	✓			
12-18	Toyota Avalon Hybrid	✓		✓	
12-19	Toyota Camry	✓			
12-19	Toyota Camry Hybrid	✓		✓	
12-19	Toyota Highlander	✓			
12-19	Toyota Highlander Hybrid	✓		✓	
12-18	Toyota Prius	✓		✓	
12-18	Toyota Prius V	✓		✓	
12-19	Toyota RAV4	✓			
12-19	Toyota RAV4 Hybrid	✓		✓	
12-19	Toyota Sienna Accessible, Rear Entry (BraunAbility)	*	*		✓
17-18	Toyota Sienna Accessible, Rear Entry (FR Conversions)	*	*		✓
12-18	Toyota Sienna Accessible, Rear Entry (Mobility Works)	*	*		✓
12-18	Toyota Sienna Accessible, Rear Entry (Revability)	*	*		✓
12-19	Toyota Sienna Accessible, Rear Entry (Freedom Motors)	*	*		✓
12-19	Toyota Sienna Accessible, Rear or Side Entry (TransitWorks)	*	*		✓

Supplemental Figure 1 – Approved NYC Taxi Makes & Models. Source TLC 2019

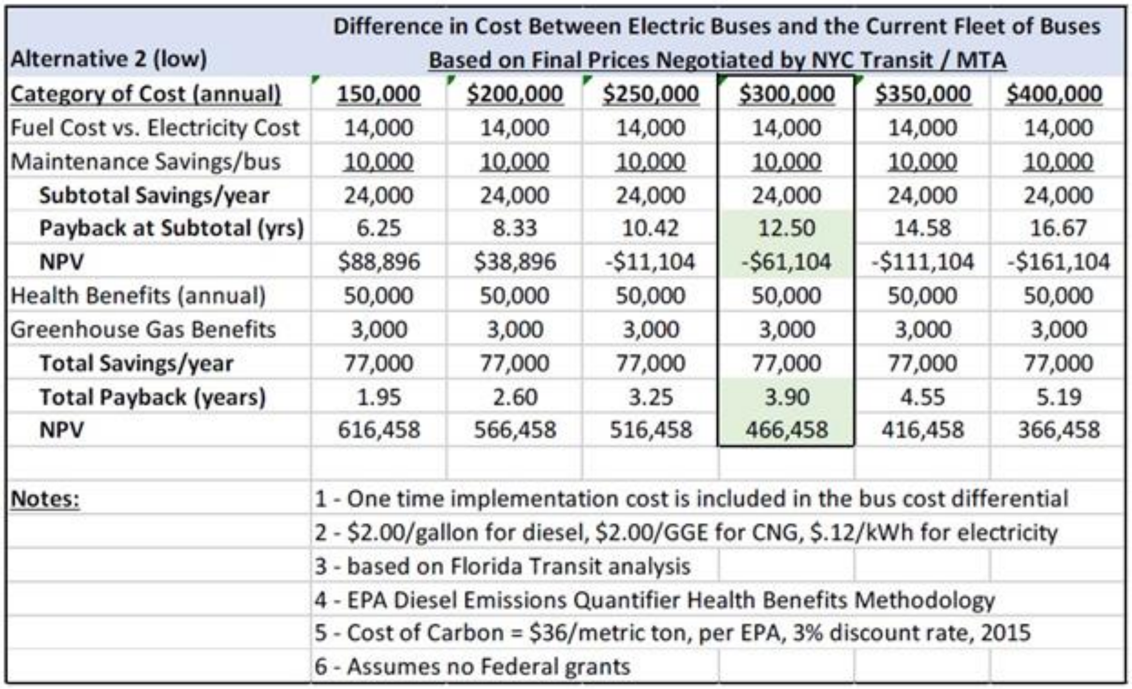
Supplemental Table 1a - **Alternative 1 – Financial Sensitivity Analysis**



Alternative 1 (avg)	Difference in Cost Between Electric Buses and the Current Fleet of Buses Based on Final Prices Negotiated by NYC Transit / MTA					
Category of Cost (annual)	150,000	$200,000	$250,000	$300,000	$350,000	$400,000
Fuel Cost vs. Electricity Cost	25,000	25,000	25,000	25,000	25,000	25,000
Maintenance Savings/bus	14,000	14,000	14,000	14,000	14,000	14,000
Subtotal Savings/year	39,000	39,000	39,000	39,000	39,000	39,000
Payback at Subtotal (yrs)	3.85	5.13	6.41	7.69	8.97	10.26
NPV	$238,206	$188,206	$138,206	$88,206	$38,206	-$11,794
Health Benefits (annual)	100,000	100,000	100,000	100,000	100,000	100,000
Greenhouse Gas Benefits	3,000	3,000	3,000	3,000	3,000	3,000
Total Savings/year	142,000	142,000	142,000	142,000	142,000	142,000
Total Payback (years)	1.06	1.41	1.76	2.11	2.46	2.82
NPV	1,263,469	1,213,469	1,163,469	1,113,469	1,063,469	1,013,469
Notes:	1 - One time implementation cost is included in the bus cost differential					
	2 - $3.00/gallon for diesel, $3.00/GGE for CNG, $.12/kWh for electricity					
	3 - based on Antelope Valley Transit experience					
	4 - EPA Diesel Emissions Quantifier Health Benefits Methodology					
	5 - Cost of Carbon = $36/metric ton, per EPA, 3% discount rate, 2015					
	6 - Assumes no Federal grants					

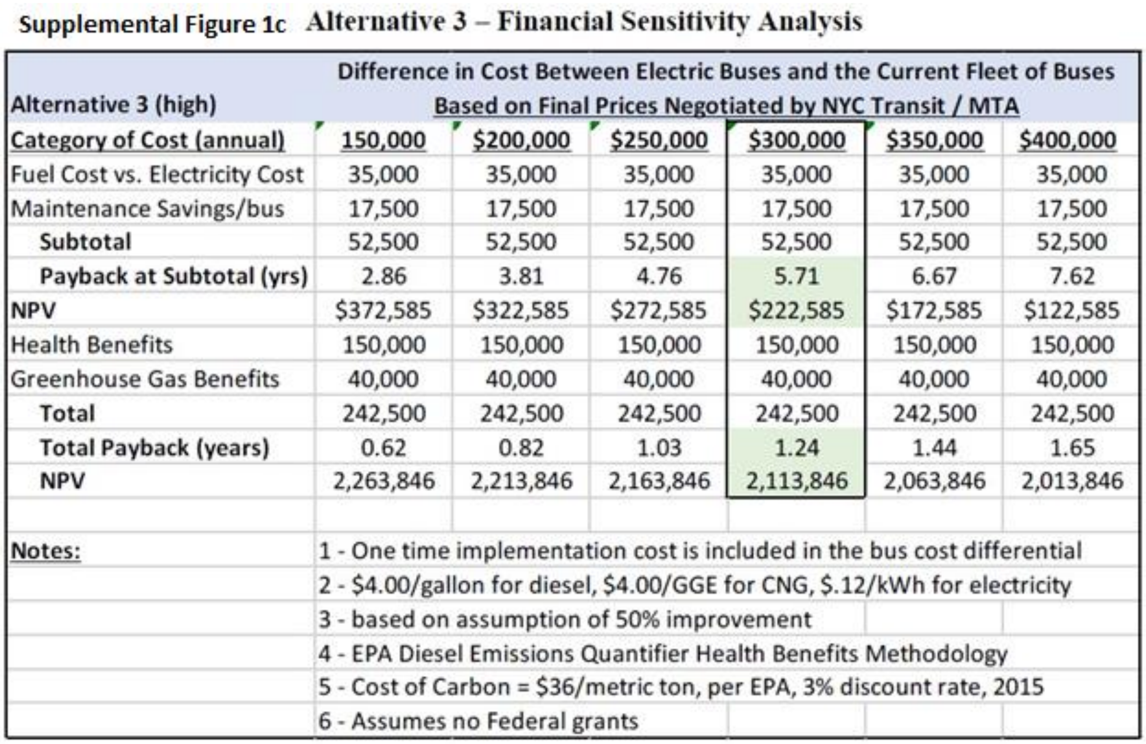
Supplemental Figure 1a – Average Financial Analysis. Source – Aber 2016

Supplemental Table 1b - **Alternative 2 – Financial Sensitivity Analysis**



Alternative 2 (low)	Difference in Cost Between Electric Buses and the Current Fleet of Buses Based on Final Prices Negotiated by NYC Transit / MTA					
Category of Cost (annual)	150,000	$200,000	$250,000	$300,000	$350,000	$400,000
Fuel Cost vs. Electricity Cost	14,000	14,000	14,000	14,000	14,000	14,000
Maintenance Savings/bus	10,000	10,000	10,000	10,000	10,000	10,000
Subtotal Savings/year	24,000	24,000	24,000	24,000	24,000	24,000
Payback at Subtotal (yrs)	6.25	8.33	10.42	12.50	14.58	16.67
NPV	$88,896	$38,896	-$11,104	-$61,104	-$111,104	-$161,104
Health Benefits (annual)	50,000	50,000	50,000	50,000	50,000	50,000
Greenhouse Gas Benefits	3,000	3,000	3,000	3,000	3,000	3,000
Total Savings/year	77,000	77,000	77,000	77,000	77,000	77,000
Total Payback (years)	1.95	2.60	3.25	3.90	4.55	5.19
NPV	616,458	566,458	516,458	466,458	416,458	366,458
Notes:	1 - One time implementation cost is included in the bus cost differential					
	2 - $2.00/gallon for diesel, $2.00/GGE for CNG, $.12/kWh for electricity					
	3 - based on Florida Transit analysis					
	4 - EPA Diesel Emissions Quantifier Health Benefits Methodology					
	5 - Cost of Carbon = $36/metric ton, per EPA, 3% discount rate, 2015					
	6 - Assumes no Federal grants					

Supplemental Figure 1b – Conservative Financial Analysis. Source – Aber 2016



Supplemental Figure 1c Alternative 3 – Financial Sensitivity Analysis

Alternative 3 (high)	Difference in Cost Between Electric Buses and the Current Fleet of Buses Based on Final Prices Negotiated by NYC Transit / MTA					
Category of Cost (annual)	150,000	$200,000	$250,000	$300,000	$350,000	$400,000
Fuel Cost vs. Electricity Cost	35,000	35,000	35,000	35,000	35,000	35,000
Maintenance Savings/bus	17,500	17,500	17,500	17,500	17,500	17,500
Subtotal	52,500	52,500	52,500	52,500	52,500	52,500
Payback at Subtotal (yrs)	2.86	3.81	4.76	5.71	6.67	7.62
NPV	$372,585	$322,585	$272,585	$222,585	$172,585	$122,585
Health Benefits	150,000	150,000	150,000	150,000	150,000	150,000
Greenhouse Gas Benefits	40,000	40,000	40,000	40,000	40,000	40,000
Total	242,500	242,500	242,500	242,500	242,500	242,500
Total Payback (years)	0.62	0.82	1.03	1.24	1.44	1.65
NPV	2,263,846	2,213,846	2,163,846	2,113,846	2,063,846	2,013,846
Notes:	1 - One time implementation cost is included in the bus cost differential					
	2 - $4.00/gallon for diesel, $4.00/GGE for CNG, $.12/kWh for electricity					
	3 - based on assumption of 50% improvement					
	4 - EPA Diesel Emissions Quantifier Health Benefits Methodology					
	5 - Cost of Carbon = $36/metric ton, per EPA, 3% discount rate, 2015					
	6 - Assumes no Federal grants					

Supplemental Figure 1b – Aggressive Financial Analysis. Source – Aber 2016