To: Dr. McAvoy, Michael Geers, and Anna Kelly
From: Kristen Belisario, Chris Stone, and Rachel Tumbleson
RE: Impacts of Largescale Electric Vehicle Deployment on Cincinnati Ambient Air Quality
Date: 4/17/2020

Dear Michael Geers and Anna Kelly,

Urban Charge is pleased to present the Impacts of Largescale Electric Vehicle Deployment on Cincinnati Ambient Air Quality.

Attached is the design report, detailing the following:

- Background and Scope of the Issue
- Cincinnati Ambient Air Background
- Modeling Analysis and Results
- Health Impacts
- Economic and Market Analysis
- Future Research and Predictions
- Explanation of Urban Charge Qualifications

Urban Charge is excited to offer air quality modeling services for the completion of this design report and is available to provide further information and answer questions/concerns. Thank you for your consideration of Urban Charge.

Respectfully Submitted,

Kristen Belisario
Chris Stone
Rachel Tumbleson

Impacts of Largescale Electric Vehicle Deployment on Cincinnati Ambient Air Quality

University of Cincinnati Environmental Engineering Senior Capstone Design Report

Urban Charge

Kristen Belisario
Chris Stone
Rachel Tumbleson

April 17th, 2020

Executive Summary

The objective of this research study is to create a quantitative analysis of the potential benefits and draw-backs associated with a large-scale shift towards sustainable transportation methods. By completing this analysis, Urban Charge hopes to gain a strong understanding of how realistic shifts in transportation habits equate to the improvement of ambient air quality in the Cincinnati area. Urban Charge has conducted an analysis of the current and past market trends pertaining to electric vehicles along with an extensive literature review. Urban Charge used The Greenhouse gases, Regulated Emissions, and Energy use in Transportation Model (GREET) as well as air quality and health modeling studies to estimate the air quality effects that could hypothetically be caused by wide scale electric vehicle deployment. Urban Charge has proposed a number of EV adoption rate scenarios that have different environmental, health, and economic factors that cultivate a general idea as to how electric vehicle deployment could improve the air quality in the Greater Cincinnati area. Considering the electricity generation mix in the region, it was found that a moderate electric vehicle (EV) adoption rate would be most beneficial for improving air quality. The moderate adoption rate of EVs suggested by Urban Charge could lead to improved ambient air quality, a reduction in negative health impacts, while also being cost effective for the region.

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1. Introduction

1.1 Background

Due to its strategic location on the Ohio River, Cincinnati established itself as a significant industrial, educational, political, and literary hub in the United States by the late 1800s. In 1890, the population had grown to be the densest in the country, with an average of 37,100 people per square mile (SOAQA, 2019). The early industrial and transportation machinery used at this time lacked effective pollution control technologies, therefore the air contained high levels of sulfur, nitrogen, and carbon. Since Cincinnati was constructed in a valley surrounded by hills, coal smoke often lay in the basins and valleys and took days to dissipate.

Since the late 1800s, a variety of regulations, with one of the most notable being the Clean Air Act (CAA), have been put in place to combat air quality emissions. Established in 1970 (revisions occurred in 1977 and 1990), the CAA's chief goal is to protect the public health and welfare nationwide. An important aspect of the CAA is that it requires the United States Environmental Protection Agency (USEPA) to establish National Ambient Air Quality Standards (NAAQS) for the six criteria air pollutants - carbon monoxide, lead, ground-level ozone, particulate matter, nitrogen dioxide, and sulfur dioxide. The USEPA is responsible for setting, reviewing, and revising these standards as well as determining whether areas meet these standards, and if a region is non-complying. Then the USEPA will work with areas to attain and maintain these standards. From 1970 to 2017, the total national emissions of the six criteria pollutants decreased an average of 73 percent, while gross domestic product grew by 324 percent (EPA(a), 2018).

1.2 Scope of the Issue

Cincinnati has some of the worst year long air pollution in the United States according to the American Lung Association's "State of the Air" report. Due to the geographical location, Cincinnati is prone to unusually high levels of particulate matter (PM) and ozone. Much of the high PM levels likely come from coal-fired power plants that line the region. Mobile transportation emissions due to the major highways, I-71, I-75, I-74, and I-275, running through the area, as well as rail, and marine fleets using the Ohio river for transport attribute to the problem as well. In various years since 1992, the Greater Cincinnati area has been considered in nonattainment according to the USEPA’s NAAQS for ozone, PM2.5, and sulfur dioxide (see Table 1 for specific years and county status) (EPA(d), 2019).

Particulate matter that is less than 10 microns in diameter poses the greatest threat to those exposed because the particles can be inhaled into your lungs, and smaller particles can enter the bloodstream and travel through the body. There are numerous studies that have linked particulate matter exposure to health problems including heart attacks, decreased lung function, aggravated asthma, irritation of the airways and difficulty breathing. Fine particles are the main cause of reduced visibility (haze) and can be carried long distances by wind and settle on the ground or surface water. Some of the environmental effects include increasing acidity in lakes and streams, depleting nutrients in soil, and contributing to acid rain effects (EPA(b), 2018).

Ground level ozone is a colorless and irritating gas that forms above the Earth’s surface. It is a secondary pollutant, formed when Nitrogen Oxides (NO_x) and Volatile Organic Compounds (VOCs) react in sunlight and stagnant air. Breathing ozone can trigger a variety of health problems including chest pain, coughing, throat irritation, and airway inflammation. Ground level ozone is also harmful to the environment and is the main ingredient in “smog”. It affects sensitive vegetation and ecosystems, including forests, parks, wildlife refuges, and wilderness areas (EPA(a), 2018). Nitrogen oxides are irritant gases, which at high concentrations causes inflammation of the airways when inhaled. NO_x is produced in the air during combustion, like in car engines of motor vehicles, and makes transportation the largest contributor to NO_x pollution (Noxite, 2018). VOCs are emitted from many different sources including paints, aerosols, and building materials. They can cause health impacts such as eye and throat irritation, headaches, and damage to internal organs.

Carbon Monoxide (CO) is a colorless, odorless gas that can be harmful when inhaled in large amounts and is released when fuel is burned. There are a number of sources for CO, but transportation vehicles are the greatest sources of outdoor CO pollution (EPA(b)). Carbon dioxide (CO_2) is a natural byproduct of humans (exhaling), forest fires, volcanoes, the burning of fossil fuels, and transportation vehicles. CO_2 has no direct impacts to human health, but it's a strong contributor to global warming and is used as a reference against the rate “global warming potential" of other greenhouse gases. CO is a criteria air pollutant and both CO and CO_2 are greenhouse gases that are linked to climate change (SEPA, 2018).

Sulfur Dioxide (SO_2) gets emitted into the atmosphere during the burning of fossil fuels, particularly coal, by power plants and other industrial facilities. It can also be emitted from natural sources like volcanoes or from vehicles or other heavy equipment when a fuel with a high sulfur content is burned. Short term exposure to SO_2 can cause respiratory issues and trouble breathing. It is also harmful to the environment because it contributes to acid rain and can be damaging to foliage and stunt growth (EPA(d), 2019).

1.3 Approach

1.3.1 Vehicle Population Mix

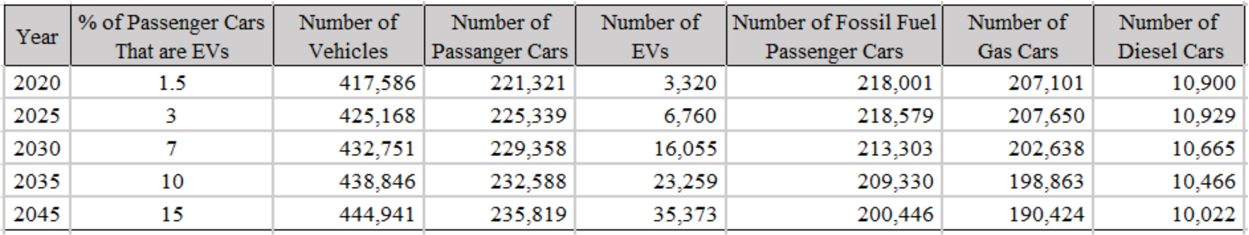
The Urban Charge team has completed extensive research regarding the current breakdown of the vehicle mix in the greater Cincinnati Region and how the different types of vehicles directly impact the ambient air quality of the area. Urban Charged has proposed several alternative electric vehicle (EV) adoption rate scenarios and analyzed how each scenario leads to reductions of the total amount of pollutants emitted from passenger cars. In the remainder of this report, fully electric passenger cars will be referred to as EVs. Three scenarios have been chosen, one with low EV adoption rates, the second with moderate EV adoption rates, and the third with high EV adoption rates.

The vehicle population mix from 2020 through 2045 for the low, moderate, and high adoption rate scenarios can be seen in Table 1, Table 2, and Table 3, respectively. The total number of vehicles in the Greater Cincinnati area was proposed based on data from the 2018 numbers from dataUSA.com, which showed each county in this area owned two cars per household. This was assumed to be true for each year 2020 through 2045, even after accounting for the forecasted population increase of about 2% every 5 years, based on the Ohio-Kentucky-Indiana Regional Council of Governments (OKI) 2010-2040 population projections on their 2040 Regional Transportation Plan. The number of passenger cars was proposed based on data showing that 53% of the Greater Cincinnati area's vehicles population consisted of passenger cars (OKI, 2019).

The number of EV's proposed for each scenario differed each year based on the rate of EV adoption for each scenario. In all three scenarios, the year 2020 was used as a baseline, with 1.5% of passenger cars assumed to be EVs, which reflects the percentage of people in Ohio who own electric vehicles (National Household Travel Survey, 2017). In the low EV adoption rate scenario, 3% of passenger vehicles were assumed to be EVs in 2025, 7% of passenger vehicles were assumed to be EVs in 2030, 10% of passenger vehicles were assumed to be EVs in 2035, and 15% of passenger vehicles were assumed to be EVs in 2045. In the moderate EV adoption rate scenario, 10% of passenger vehicles were assumed to be EVs in 2025, 20% of passenger vehicles were assumed to be EVs in 2030, 30% of passenger vehicles were assumed to be EVs in 2035, and 50% of passenger vehicles were assumed to be EVs in 2045. In the high EV adoption rate scenario, 15% of passenger vehicles were assumed to be EVs in 2025, 30% of passenger vehicles were assumed to be EVs in 2030, 65% of passenger vehicles were assumed to be EVs in 2035, and 100% of passenger vehicles were assumed to be EVs in 2045.

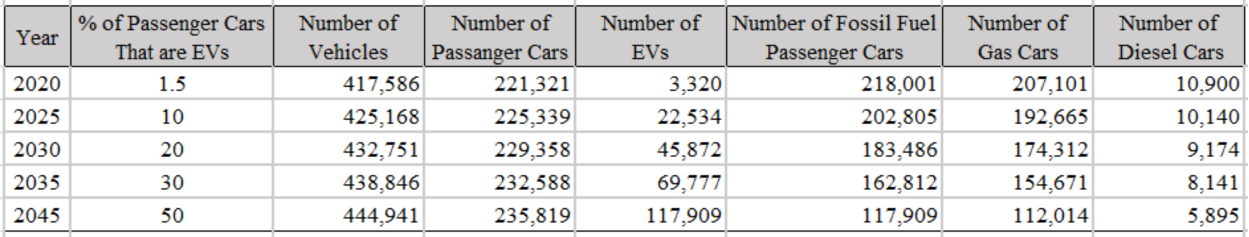
The number of fossil fuel powered passenger cars for each scenario was calculated by subtracting the number of EVs from the number of passenger cars for each year. This was done to indicate that for each EV deployed into the Greater Cincinnati area's fleet, a fossil fuel passenger car would be removed from the fleet. The number of gas and diesel passenger cars was then calculated based on data showing 95% of fossil fuel powered passenger cars are powered by gas and 5% of fossil fuel powered cars are powered by diesel (National Household Travel Survey, 2017).

Table 1. Vehicle population mix for low EV adoption rate scenario in the Greater Cincinnati area.



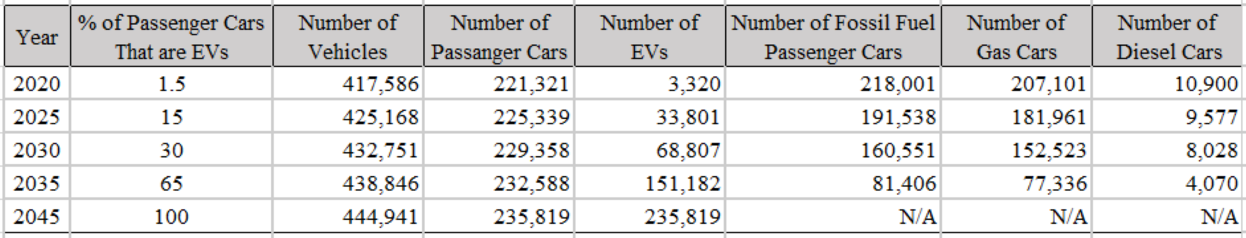
Year	% of Passenger Cars That are EVs	Number of Vehicles	Number of Passanger Cars	Number of EVs	Number of Fossil Fuel Passenger Cars	Number of Gas Cars	Number of Diesel Cars
2020	1.5	417,586	221,321	3,320	218,001	207,101	10,900
2025	3	425,168	225,339	6,760	218,579	207,650	10,929
2030	7	432,751	229,358	16,055	213,303	202,638	10,665
2035	10	438,846	232,588	23,259	209,330	198,863	10,466
2045	15	444,941	235,819	35,373	200,446	190,424	10,022

Table 2. Vehicle population mix for moderate EV adoption rate scenario in the Greater Cincinnati area.



Year	% of Passenger Cars That are EVs	Number of Vehicles	Number of Passanger Cars	Number of EVs	Number of Fossil Fuel Passenger Cars	Number of Gas Cars	Number of Diesel Cars
2020	1.5	417,586	221,321	3,320	218,001	207,101	10,900
2025	10	425,168	225,339	22,534	202,805	192,665	10,140
2030	20	432,751	229,358	45,872	183,486	174,312	9,174
2035	30	438,846	232,588	69,777	162,812	154,671	8,141
2045	50	444,941	235,819	117,909	117,909	112,014	5,895

Table 3. Vehicle population mix for high EV adoption rate scenario in the Greater Cincinnati area.

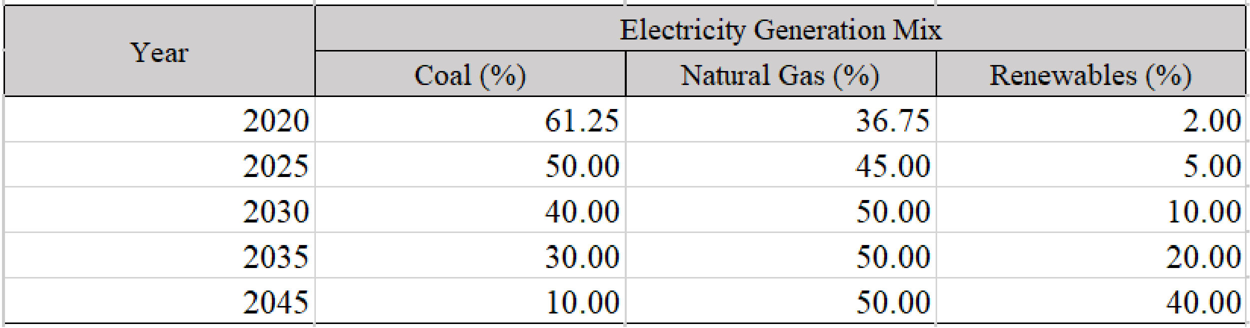


Year	% of Passenger Cars That are EVs	Number of Vehicles	Number of Passanger Cars	Number of EVs	Number of Fossil Fuel Passenger Cars	Number of Gas Cars	Number of Diesel Cars
2020	1.5	417,586	221,321	3,320	218,001	207,101	10,900
2025	15	425,168	225,339	33,801	191,538	181,961	9,577
2030	30	432,751	229,358	68,807	160,551	152,523	8,028
2035	65	438,846	232,588	151,182	81,406	77,336	4,070
2045	100	444,941	235,819	235,819	N/A	N/A	N/A

1.3.2 Electricity Generation Mix

The Greater Cincinnati area relies on a combination of coal, natural gas, and renewable sources for its energy generation. Urban Charge worked with Duke Energy to obtain an approximation of the Greater Cincinnati area's current electricity generation mix and propose realistic future grid mix ratios. The 2020 electricity generation mix was obtained based on data from the U.S. Energy Information System (EIA, 2019). Because the Greater Cincinnati area currently relies heavily on coal for its electricity generation, Urban Charge proposed electricity generation mixes from 2025 through 2045 with increasing amounts of renewable energy. This was done to show how to reduce the amount of fossil fuels used to power electric vehicles in the Greater Cincinnati area. The mix of electricity generation types from 2020 through 2045 can be seen in Table 3.

Table 3. Electricity generation mix assumed to power EVs in each scenario.



Year	Electricity Generation Mix		
	Coal (%)	Natural Gas (%)	Renewables (%)
2020	61.25	36.75	2.00
2025	50.00	45.00	5.00
2030	40.00	50.00	10.00
2035	30.00	50.00	20.00
2045	10.00	50.00	40.00

2. Modeling

2.1 Emission Factors

Sponsored by the U.S. Department of Energy’s (DOE) Office of Energy and developed by Argonne National Laboratory, The Greenhouse gases, Regulated Emissions, and Energy use in Transportation Model (GREET) is an analytical tool that simulates the energy use and emissions output of various vehicle and fuel combinations. GREET includes peer reviewed default data for various production pathways and also allows the user to input external data to obtain lifetime, or “cradle to grave”, emission factors associated with the operation and maintenance of user specified vehicles.

Urban Charge used this modeling software to calculate lifetime emission factors associated with the operation and maintenance of a gas-powered passenger car, a diesel-powered passenger car, and a fully electric passenger car in the Greater Cincinnati area. While the sources of gas and diesel were assumed to be constant for each year, the electricity grid powering the EVs consisted of the electricity generation mixes highlighted in Table 3.

For each year selected from 2020 through 2045, it was assumed that the vehicle fleet consisted of 5-year-old vehicle technology, e.g. the 2020 emission factors assumed vehicles were equipped with 2015 vehicle technology, 2025 emission factors assumed vehicles were equipped with 2020 vehicle technology, etc. The fuel economy and energy consumption values for gas, diesel, and EVs used for each year can be seen in Figure 1, Figure 2, and Figure 3, respectively.

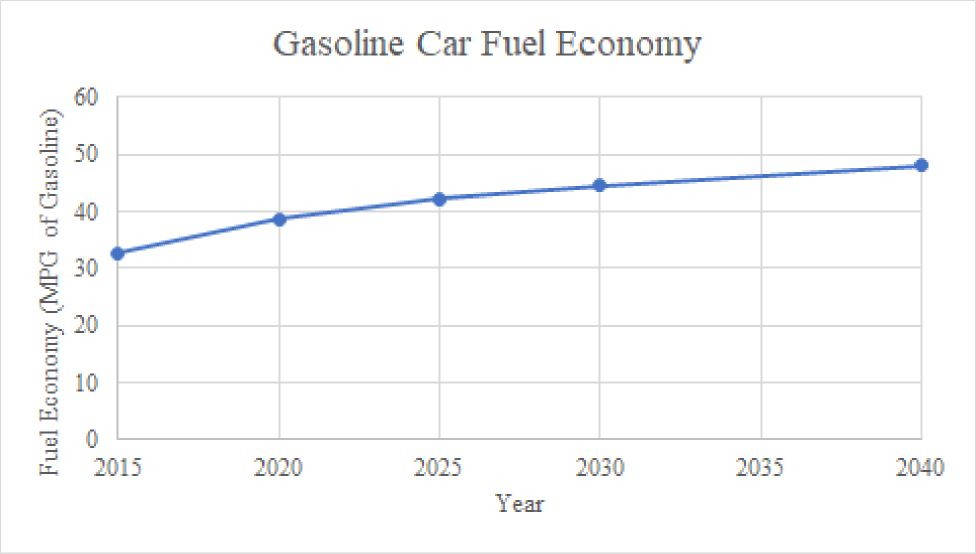


Figure 1. Fuel economy used to calculate emission factors for gasoline cars owned and operated in the Greater Cincinnati Area for 2020 through 2045. (GREET, 2020).

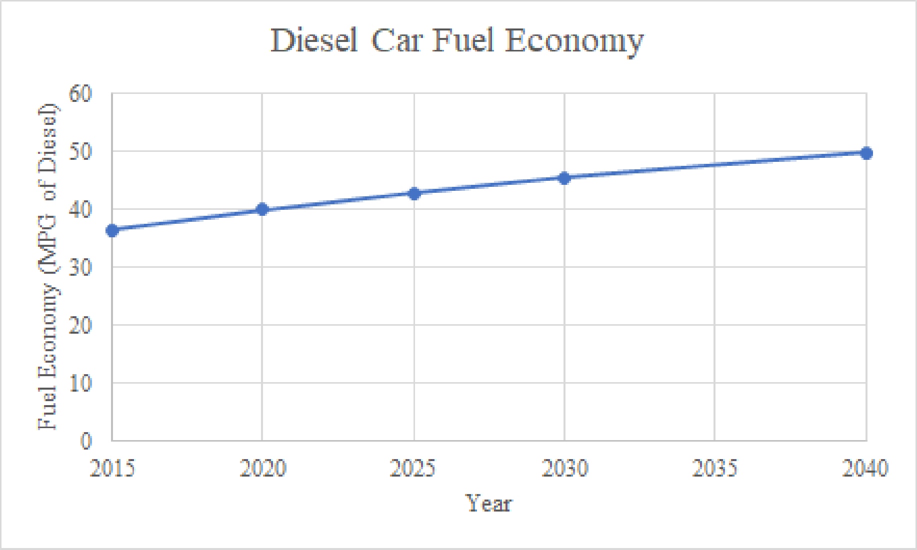


Figure 2. Fuel economy used to calculate emission factors for a diesel car owned and operated in the Greater Cincinnati Area for 2020 through 2045. (GREET, 2020).

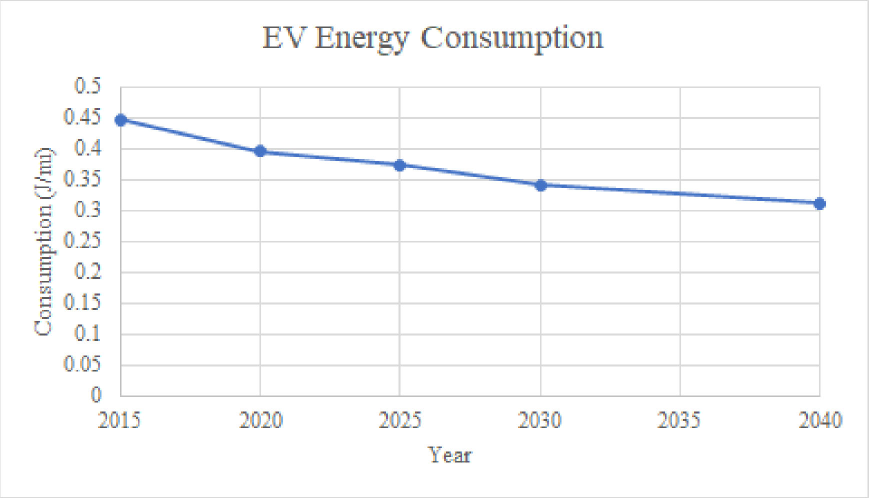


Figure 3. Energy consumption used to calculate emission factors for EV owned and operated in the Greater Cincinnati Area for 2020 through 2045. (GREET, 2020).

For each selected year 2020 through 2045, emission factors for nine major air pollutants were calculated for each vehicle propulsion type; gas, diesel, and EV. These nine pollutants were VOCs, CO, NO_x, SO_x, PM_{10}, $PM_{2.5}$, CH_4, N_2O, and CO_2, whose emission factors can be seen in Figure 1 through Figure 9, respectively. Emission factors for each vehicle type were calculated for five different years, 2020; 2025; 2030; 2035; and 2045, to show how increasing rates of electric vehicle adoption, the use of a cleaner electricity generation grid, and improved vehicle technology work together to reduce the amount of hazardous air pollutants emitted over time.

2.2 Emissions from Passenger Cars

Once emission factors for each car type were obtained, the total amount of each pollutant emitted from all passenger cars over each five-year span was calculated for the low, moderate, and fast EV adoption rate scenarios. This was done under the assumption that each car in the Greater Cincinnati area travels 26 miles per day (National Household Travel Survey, 2017).

3. Results and Discussion

The lifetime emission factors associated with the operation and maintenance of a gas-powered passenger car, diesel powered passenger car, and EV can be seen in Figure 4 through Figure 12, respectively.

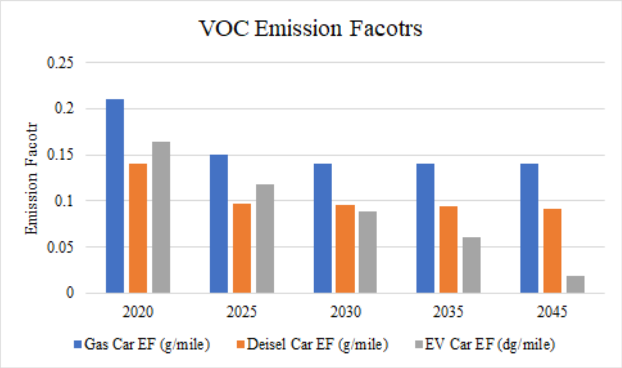


Figure 4. VOC Emission Factors associated with the operation and maintenance of a gas-powered passenger car, diesel powered passenger car, and EV in the Greater Cincinnati area from 2020 through 2045 (GREET, 2020).

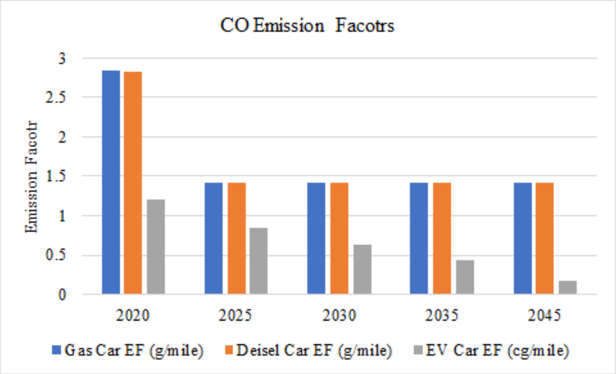


Figure 5. CO Emission Factors associated with the operation and maintenance of a gas-powered passenger car, diesel powered passenger car, and EV in the Greater Cincinnati area from 2020 through 2045 (GREET, 2020).

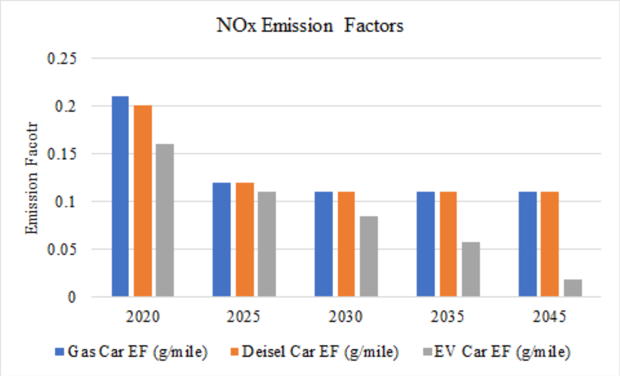


Figure 6. NO_x Emission Factors associated with the operation and maintenance of a gas-powered passenger car, diesel powered passenger car, and EV in the Greater Cincinnati area from 2020 through 2045 (GREET, 2020).

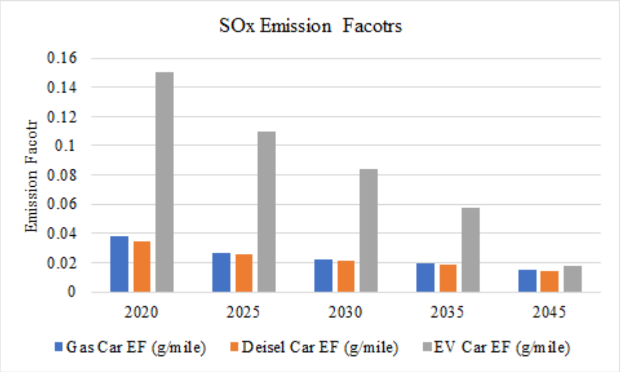
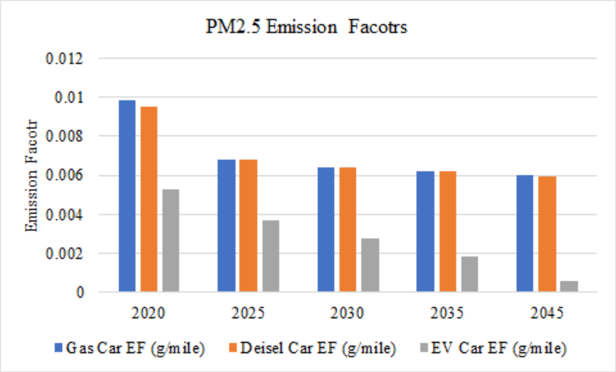


Figure 7. SO_x Emission Factors associated with the operation and maintenance of a gas-powered passenger car, diesel powered passenger car, an EV in the Greater Cincinnati area from 2020 through 2045 (GREET, 2020).



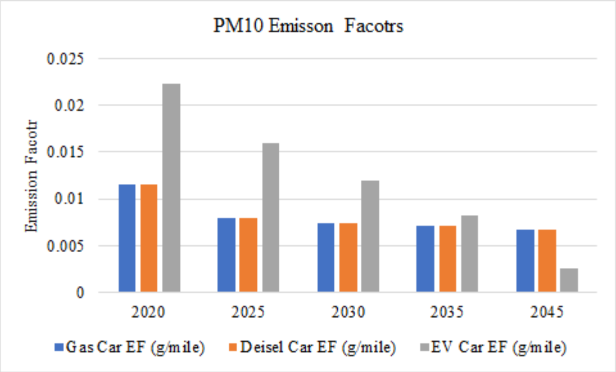
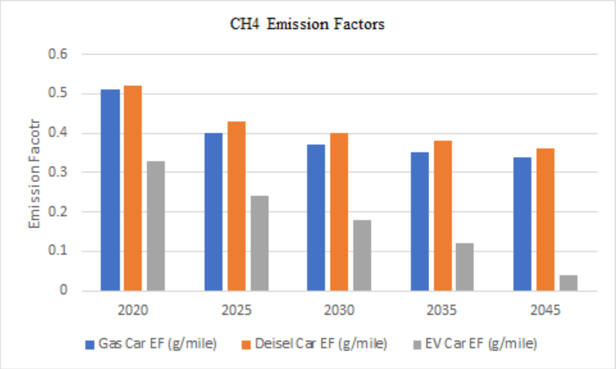


Figure 8. $PM_{2.5}$ **Emission Factors associated with the operation and maintenance of a gas-powered passenger car, diesel powered passenger car, and EV in the Greater Cincinnati area from 2020 through 2045 (GREET, 2020).**

Figure 9. PM_{10} **Emission Factors associated with the operation and maintenance of a gas-powered passenger car, diesel powered passenger car, and EV in the Greater Cincinnati area from 2020 through 2045 (GREET, 2020).**



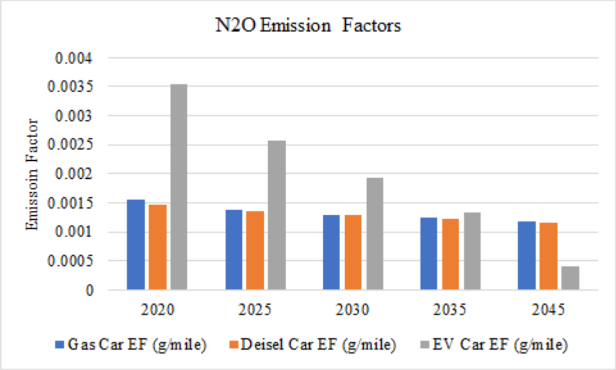


Figure 10. CH_4 **Emission Factors associated with the operation and maintenance of a gas-powered passenger car, diesel powered passenger car, and EV in the Greater Cincinnati area from 2020 through 2045 (GREET, 2020).**

Figure 11. N_2O **Emission Factors associated with the operation and maintenance of a gas-powered passenger car, diesel powered passenger car, and EV in the Greater Cincinnati area from 2020 through 2045 (GREET, 2020).**

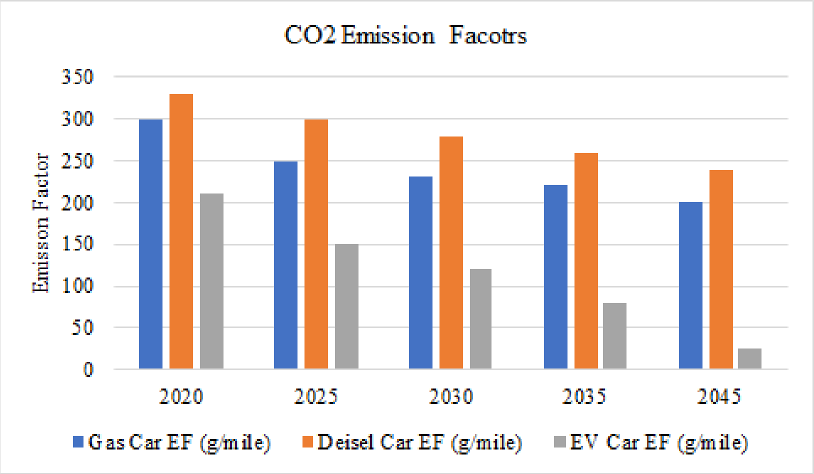


Figure 12. CO$_2$ Emission Factors associated with the operation and maintenance of a gas-powered passenger car, diesel powered passenger car, and EV in the Greater Cincinnati area from 2020 through 2045 (GREET, 2020).

The total 5-year emissions of VOCs, CO, NO$_x$, SO$_x$, PM$_{10}$, PM$_{2.5}$, CH$_4$, N$_2$O, and CO$_2$ from passenger cars in the Greater Cincinnati area from 2020 through 2045 for the slow, moderate, and fast EV adoption rate scenarios can be seen in Figure 13 through Figure 22, respectively.

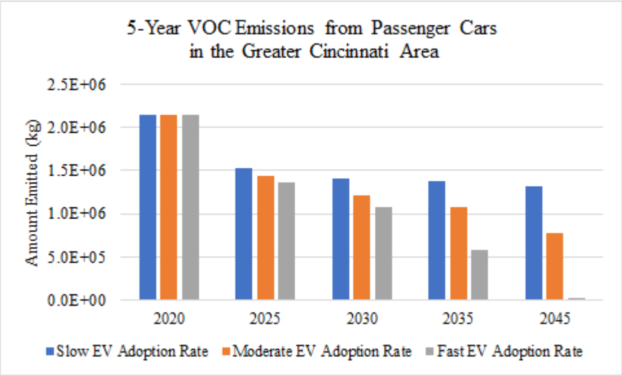


Figure 13. 5-year VOC emissions from passenger cars in the Greater Cincinnati area from 2020 through 2045 for slow, moderate, and fast EV adoption rates.

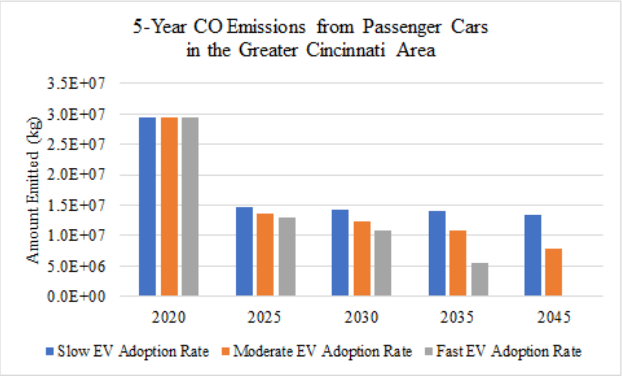


Figure 14. 5-year CO emissions from passenger cars in the Greater Cincinnati area from 2020 through 2045 for slow, moderate, and fast EV adoption rates.

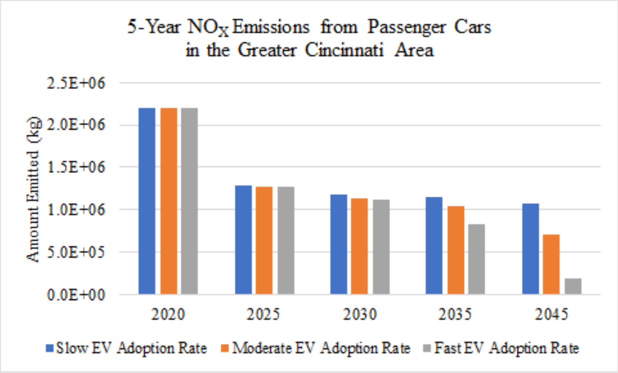


Figure 16. 5-year NO$_x$ emissions from passenger cars in the Greater Cincinnati area from 2020 through 2045 for slow, moderate, and fast EV adoption rates.

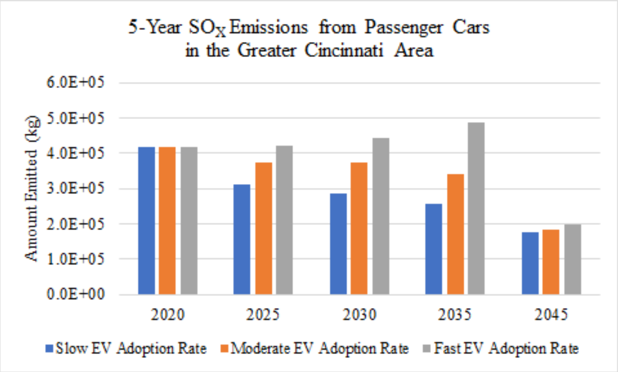


Figure 17. 5-year SO$_x$ emissions from passenger cars in the Greater Cincinnati area from 2020 through 2045 for slow, moderate, and fast EV adoption rates.

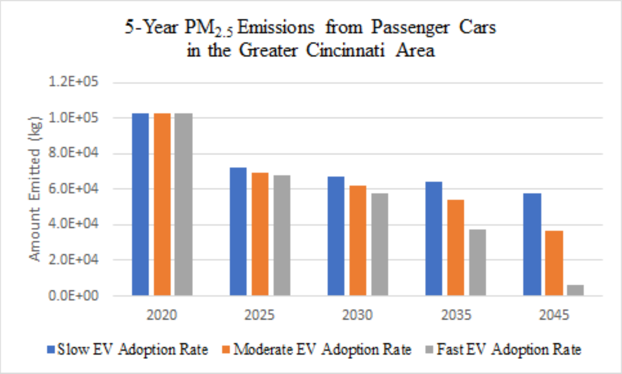


Figure 18. 5-year PM$_{2.5}$ emissions from passenger cars in the Greater Cincinnati area from 2020 through 2045 for slow, moderate, and fast EV adoption rates.

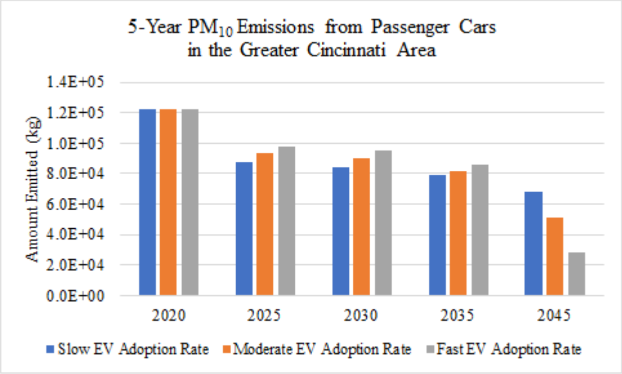


Figure 19. 5-year PM$_{10}$ emissions from passenger cars in the Greater Cincinnati area from 2020 through 2045 for slow, moderate, and fast EV adoption rates.

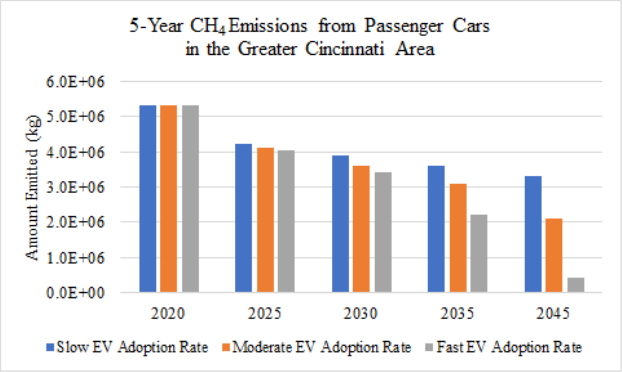


Figure 20. 5-year CH_4 emissions from passenger cars in the Greater Cincinnati area from 2020 through 2045 for slow, moderate, and fast EV adoption rates.

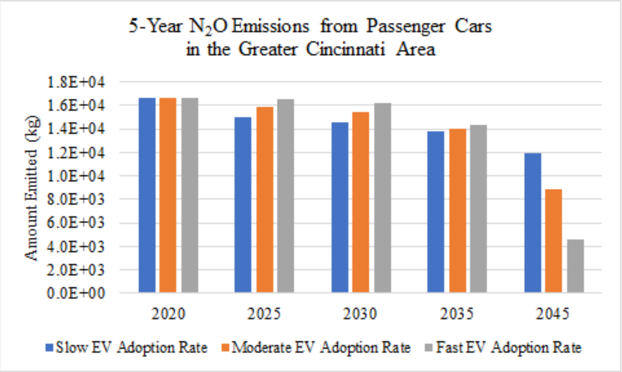


Figure 21. 5-year N_2O emissions from passenger cars in the Greater Cincinnati area from 2020 through 2045 for slow, moderate, and fast EV adoption rates.

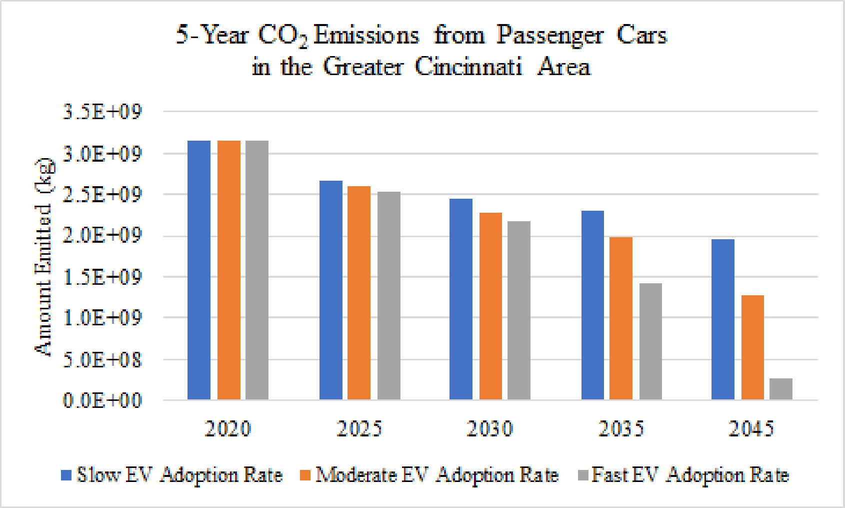
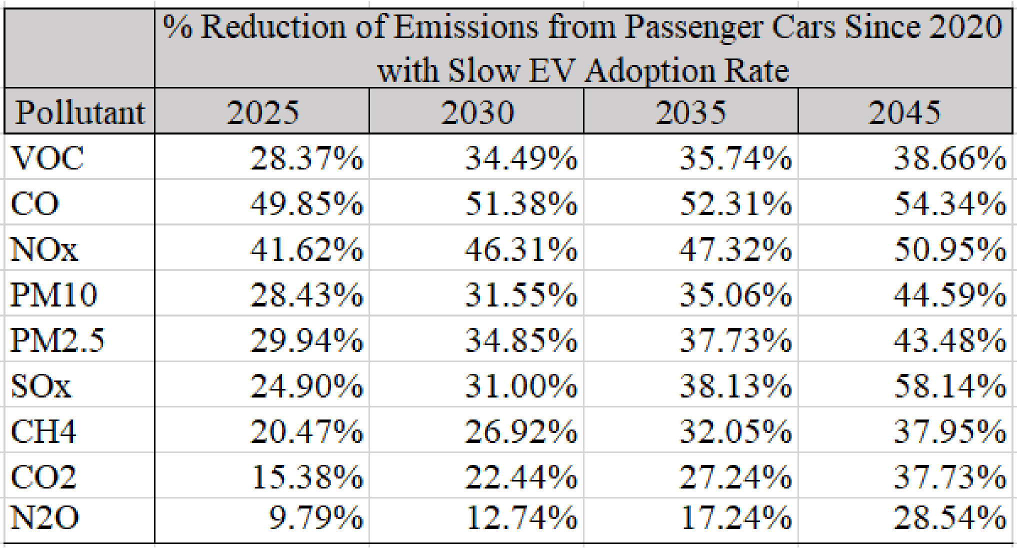


Figure 22. 5-year CO_2 emissions from passenger cars in the Greater Cincinnati area from 2020 through 2045 for slow, moderate, and fast EV adoption rates.

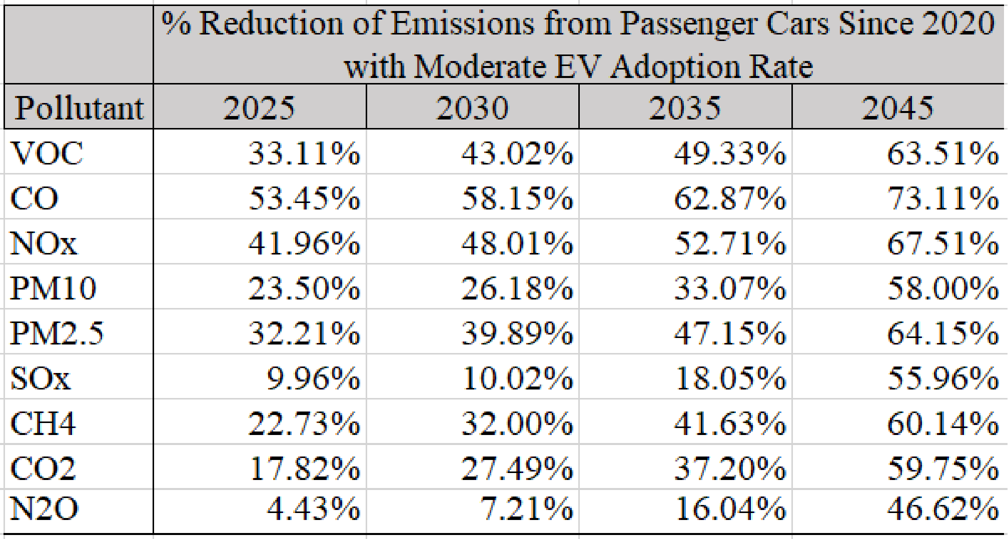
For each adoption rate scenario, the percent reduction of emissions of each pollutant from passenger cars in the Greater Cincinnati area since 2020 was calculated. These reductions for the slow, moderate, and fast EV adoption rate scenarios can be seen in Table 4, Table 5, and Table 6, respectively.

Table 4. Percent reduction of emissions from passenger cars in the Greater Cincinnati Area for each 5-year time span since 2020 for the slow EV adoption rate scenario.



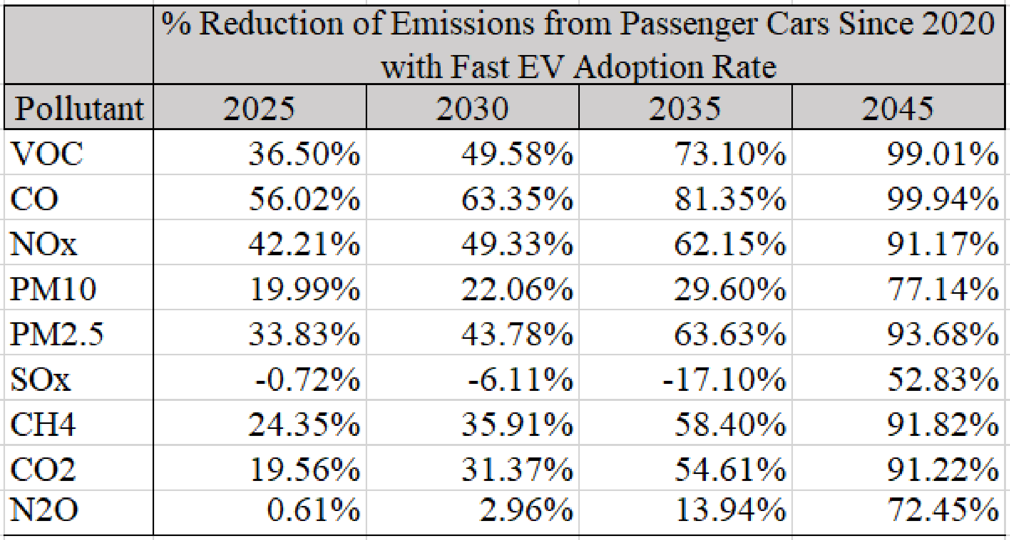
	% Reduction of Emissions from Passenger Cars Since 2020 with Slow EV Adoption Rate			
Pollutant	2025	2030	2035	2045
VOC	28.37%	34.49%	35.74%	38.66%
CO	49.85%	51.38%	52.31%	54.34%
NOx	41.62%	46.31%	47.32%	50.95%
PM10	28.43%	31.55%	35.06%	44.59%
PM2.5	29.94%	34.85%	37.73%	43.48%
SOx	24.90%	31.00%	38.13%	58.14%
CH4	20.47%	26.92%	32.05%	37.95%
CO2	15.38%	22.44%	27.24%	37.73%
N2O	9.79%	12.74%	17.24%	28.54%

Table 5. Percent reduction of emissions from passenger cars in the Greater Cincinnati Area for each 5-year time span since 2020 for the moderate EV adoption rate scenario.



	% Reduction of Emissions from Passenger Cars Since 2020 with Moderate EV Adoption Rate			
Pollutant	2025	2030	2035	2045
VOC	33.11%	43.02%	49.33%	63.51%
CO	53.45%	58.15%	62.87%	73.11%
NOx	41.96%	48.01%	52.71%	67.51%
PM10	23.50%	26.18%	33.07%	58.00%
PM2.5	32.21%	39.89%	47.15%	64.15%
SOx	9.96%	10.02%	18.05%	55.96%
CH4	22.73%	32.00%	41.63%	60.14%
CO2	17.82%	27.49%	37.20%	59.75%
N2O	4.43%	7.21%	16.04%	46.62%

Table 6. Percent reduction of emissions from passenger cars in the Greater Cincinnati Area for each 5-year time span since 2020 for the slow EV adoption rate scenario.



	% Reduction of Emissions from Passenger Cars Since 2020 with Fast EV Adoption Rate			
Pollutant	2025	2030	2035	2045
VOC	36.50%	49.58%	73.10%	99.01%
CO	56.02%	63.35%	81.35%	99.94%
NOx	42.21%	49.33%	62.15%	91.17%
PM10	19.99%	22.06%	29.60%	77.14%
PM2.5	33.83%	43.78%	63.63%	93.68%
SOx	-0.72%	-6.11%	-17.10%	52.83%
CH4	24.35%	35.91%	58.40%	91.82%
CO2	19.56%	31.37%	54.61%	91.22%
N2O	0.61%	2.96%	13.94%	72.45%

As seen in Figure 4 through Figure 12, the emission factors associated with the operation and maintenance of a gas-powered passenger car, diesel powered passenger car, and EV of all selected pollutants decreased over each 5-year time span from 2020 to 2045. For the bassline case (2020), gas and diesel passenger cars had higher emission factors than EVs for CO, NO_x, $PM_{2.5}$, CH_4, and CO_2, while EVs had higher emission factors than gas and diesel cars for SO_x, PM_{10}, and N_2O. Gasoline cars had the lowest VOC emission factor for 2020, followed by EVs, then diesel cars.

While EVs are traditionally viewed as cleaner forms of transportation than gas and diesel cars, largely due to their lack of tailpipe emissions, the EV's higher emission rates of SO_x, PM_{10}, and N_2O can be explained by the dominance of fossil fuel energy production (61.25% coal and 36.75% natural gas) used in 2020 to power EVs. By 2045, the EV's emission factors for each pollutant, aside from SO_x, decreased to a value lower than the emission factors of both gas and diesel cars. By 2045, the SO_x emission factors for a gas car, diesel car, and EV were 0.015 g/mi, 0.014 g/mi, and 0.017 g/mi, respectively. So although the EV's SO_x emission factor was higher than that of gas and diesel cars in 2045, the EV's SO_x emission factor decreased from being approximately 410% higher than the gas and diesel SO_x emission factor in 2020 to approximately 119% higher than the gas and diesel SO_x emission factor in 2045.

As seen in Figure 13 through Figure 22, in general, the total amount of pollutants emitted from passenger cars in the Greater Cincinnati area decreased over each 5-year time span from 2020 through 2045 for the slow, moderate, and fast EV adoption rate scenarios. The slow EV adoption rate scenario had the lowest amounts of pollution reduction from passenger cars from 2020 to 2045, while the fast EV adoption rate scenario had the highest amounts of pollution reduction from passenger cars from 2020 to 2045. For each adoption rate scenario, the only case where the total amount of emissions increased over any time span occurred for SO_x in the fast EV adoption rate scenario from 2020 to 2035. Although the EV's SO_x emission factors decreased over this same time period, the amount of EVs in the Greater Cincinnati area's vehicle fleet increased at a rate high enough to net an increase in SO_x emissions, given the electricity generation mixes used. It was not until 2045, with an energy generation mix of 10% coal, 50% natural gas, and 40% renewables, that the electricity grid was clean enough to cleanly support this rapid increase of EV adoption.

4. Health Impacts

4.1 Particulate Matter

Particulate matter is an air pollutant that has been linked to multiple health issues, specifically asthma, bronchitis, birth defects, cardiopulmonary disease, and other respiratory diseases. Epidemiologists have shown evidence that long-term exposure to $PM_{2.5}$ is associated with both mortality and morbidity (REVIHAAP, 2013). In many cases, the long-term effects are not always the sum of the short-term effects. In fact, the impacts from long-term exposure of PM are much more detrimental to one's health and can enhance the progression of underlying diseases.

Both ultrafine particulates ($PM_{2.5}$) and coarse particulates (PM_{10}) have similar physiological effects in humans, which shows that both types of particulate matter are comparable in acute exposure scenarios. However, because it is difficult to differentiate and fully separate the effects directly related to the different size particles, the evidence in the REVIHAAP study is weaker for coarse particles in long term studies. A major source of particulate matter is road traffic, including non-tailpipe emissions from brakes and tires as well as diesel and gasoline exhaust. Studies have linked fine PM from traffic with unfavorable birth outcomes, such as low birth weight (REVIHAAP, 2013).

As more gasoline and diesel vehicles are taken off the roads and replaced with cleaner running electric vehicles, particulate matter emissions from the vehicle fleet will decrease, represented by the decreased emissions for $PM_{2.5}$ and PM_{10} in Figures 8 and 9. Over time, as the emissions of PM from passenger vehicles decreases, it can be assumed fewer instances of PM related health issues would occur.

4.2 Nitrogen Oxides (NO_x) and Ozone

Ultrafine pollutants, such as NO_2, occur in elevated concentrations near roadways, and are associated with mortality when concentrations of 10 $\mu g/m_3$ for 24-hour averages are reached, especially for those in the age group of 65 and up. Acute respiratory health effects begin to show in as little as 1 hour of exposure, making roadways with high tail-pipe emissions a sensitive area for those who already have respiratory problems, such as asthma.

Recent experiments have shown that people exposed to ozone concentrations of 60 ppb for prolonged periods of time have impaired lung function and inflammation (REVIHAAP, 2013). This is important for the Cincinnati area because the annual average 8-hour ozone concentration in Cincinnati is very often higher than 60 ppb, shown in Figure 14 (Southwest Ohio Air Quality Agency, 2019). People regularly exposed to high ozone concentrations are often more susceptible to additional effects of other stressors, such as other air pollutants.

Because asthma is associated significantly with chronic ozone exposure as well as $PM_{2.5}$, the two pollutants coupled together are major asthma pre-cursors, especially near major roadways. In the sunny, hot summer months in Cincinnati, ozone becomes the major pollutant in the area that affects the air quality index. By reducing the amount of gasoline and diesel vehicles on the highways, fewer NO_x and VOCs would be emitted in the air. With less NO_x and VOCs, these pollutants would react slower with the sunlight and produce less ozone, potentially lowering the amount of respiratory issues to sensitive groups of people. Figures 4 and 6 show the potential reductions of emissions of both VOCs and NOx if more electric vehicles are added to the vehicle fleet.

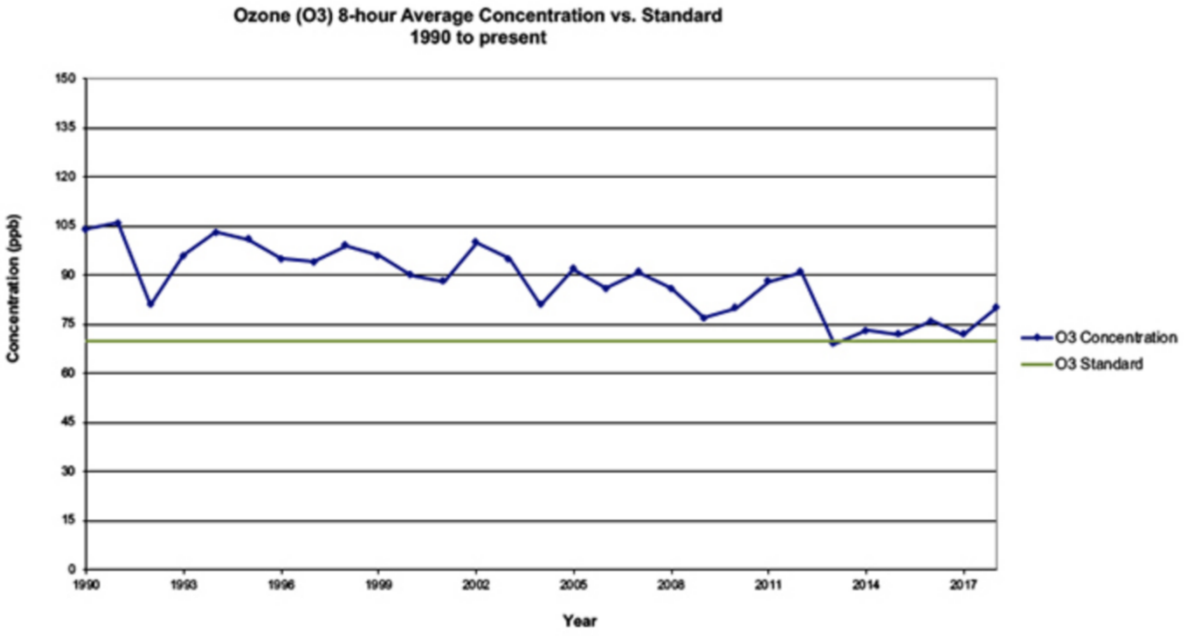


Figure 14: Annual average 8-hour ozone concentration in Cincinnati (Southwest Ohio Air Quality Agency, 2019)

4.3 Modeling Health Impacts

Cincinnati has not always had the best air quality when compared to similar cities. Multiple counties such as Warren, Butler, Hamilton, and Clermont, have reached non-attainment concentrations of pollutants such as ozone and $PM_{2.5}$. Ohio's air monitoring system was developed in 1963 and has 21 monitoring sites. Since then the USEPA has created stricter guidelines that have helped increase the air monitoring program significantly over the past decade. The goals of the ambient monitoring program are to determine compliance with the ambient air quality standards; to provide real-time evaluation and planning; and to provide daily information to the public concerning air quality in high population areas near major emission sources and in rural areas (EPA(b), 2018).

Not all emissions from vehicles are detrimental to human health. The emissions that are of most importance to health experts are $PM_{2.5}$, ozone (O_3), nitrous oxides (NO_x), and sulfur oxides (SO_x). According to the USEPA, fine particulate pollution such as that found in vehicle tailpipe emissions can be responsible for early death, cardiovascular harm, respiratory issues, may cause cancer, and may cause reproductive and developmental hard (EPA(b), 2018).

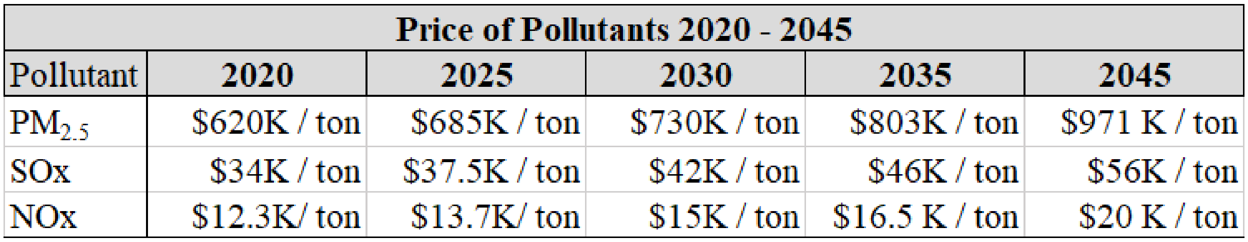
Many studies attempted to quantify the societal benefits of improved air quality. A report created by the USEPA titled 'Estimating the Benefit per Ton of Reducing $PM_{2.5}$ Precursors from 17 Sectors' that describes an approach for estimating the average avoided human health impacts, and monetized benefits related to emissions of $PM_{2.5}$ and $PM_{2.5}$ precursors including NO_x and SO_2 from 17 sectors using the results of source appointment photochemical modeling (EPA(f), 2013). The methodology consists of three relatively simple steps that produce a monetary value per ton of pollution for SO_x, NO_x, and $PM_{2.5}$.

The USEPA used photochemical modeling in order to determine ambient primary $PM_{2.5}$, SO_x and NO_x concentrations which was then coupled with BenMAP, software used to estimate health impacts as well as their economic values. The costs associated with the emissions of $PM_{2.5}$, NO_x, and SO_x were then divided by their impacts established in the previous step. This is a Health Impact Assessment (HIA) approach where changes in population-level exposure are analyzed through an application of health impacts that have been extensively studied in epidemiological literature (EPA(f), 2013).

The human health effects that were quantified in the USEPA report were non-fatal heart attacks, hospital admissions, emergency room visits, lower respiratory problems, lost work days, asthma exacerbation, and minor restricted-activity days. It can be seen that the majority of the health effects deal with lung and heart function, primarily with the elderly and young children. The economic value attributed to a health impact was dependent on a patient's willingness to pay (WTP) as well as the relative risk reduction of an incidence as a function of decreased pollution concentrations. If one were to pay $100 for the likelihood that his or her health would decrease by 0.0001%, then the WTP for an avoided statistical premature mortality amounts to $1,000,000 ($100/0.0001) (EPA(f), 2013). For cases where WTP is not applicable, a cost of illness (COI) tends to underestimate the actual value of the risk reduction.

The sources analyzed in this study were 'on-road mobile sources', which contained two estimates for the total dollar value (mortality and morbidity) per ton of directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursors in 2020. The average between the two reported values were taken for every year up to 2030. Past the year 2030, price per ton of pollutant was increased by 1.1% every five years. The cost of the health impacts from the exposure per every ton of PM2.5, SOx, and NOx can be seen in Table 10.

Table 10. Calculated Price of Pollutants ($/Ton) 2020 - 2045



Price of Pollutants 2020 - 2045					
Pollutant	2020	2025	2030	2035	2045
$PM_{2.5}$	$620K / ton	$685K / ton	$730K / ton	$803K / ton	$971 K / ton
SOx	$34K / ton	$37.5K / ton	$42K / ton	$46K / ton	$56K / ton
NOx	$12.3K/ ton	$13.7K/ ton	$15K / ton	$16.5 K / ton	$20 K / ton

The individual pollutant price was multiplied by the amount of pollutant, which varied with each adoption scenario, and then summed together, sample calculations can be found in Table 12 in the appendix. For the year 2020, at all adoption levels, health impacts from emissions totaled $115.7 million. In 2045, under the fast EV adoption rate (100% EVs), the health impacts were reduced to $23 million. The moderate adoption rate saw health impacts total $66.5 million in the year 2045 (117,909 EVs) as opposed to the slow adoption rate (35,373 EVs) where health impacts totaled to $96.6 million in 2045. The trend in total cost of health impacts over slow, moderate, and fast EV adoption rate for every year modeled can be seen in Figure 15. The price per pollutant per year can be found Table 13 in the appendix.

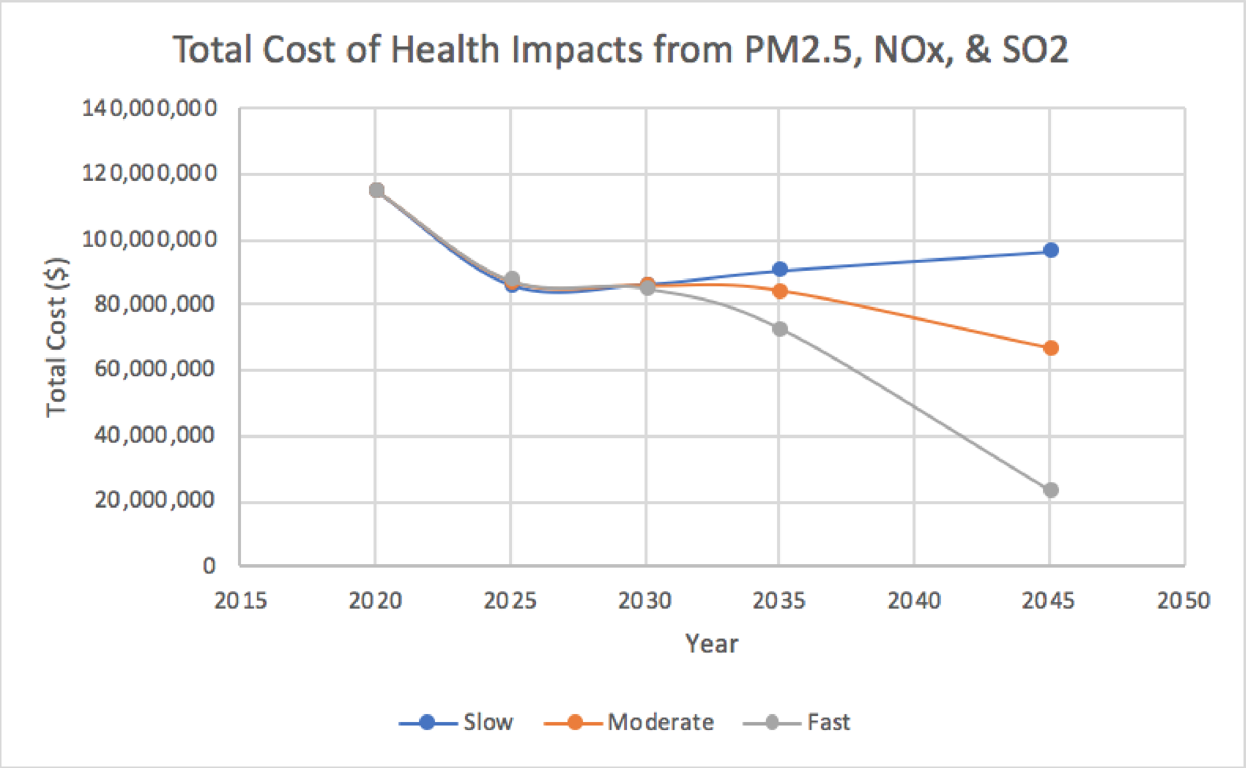


Figure 15. Total Cost of Health Impacts from PM$_{2.5}$, NO$_x$, and SO$_2$

5. Economic and Market Analysis

5.1 Types of Charging Stations

Different types of charging ports such as Level 1, Workplace Level 2, Public Level 2, and Direct Current Fast Charge (DCFC) all have associated pros and cons, and each type is slightly different from one another. Each EV comes with a charging cord that can be used in a standard electrical outlet that can be used when parked at home. This is referred to as Level 1 charging, and charges very slowly on a standard 110 voltage (V) outlet, offering about 5 miles of range per hour (RPH). Level 1 charging is typically used in a residential home and does not need additional infrastructure, which is why this type of charging is not included in the cost estimate.

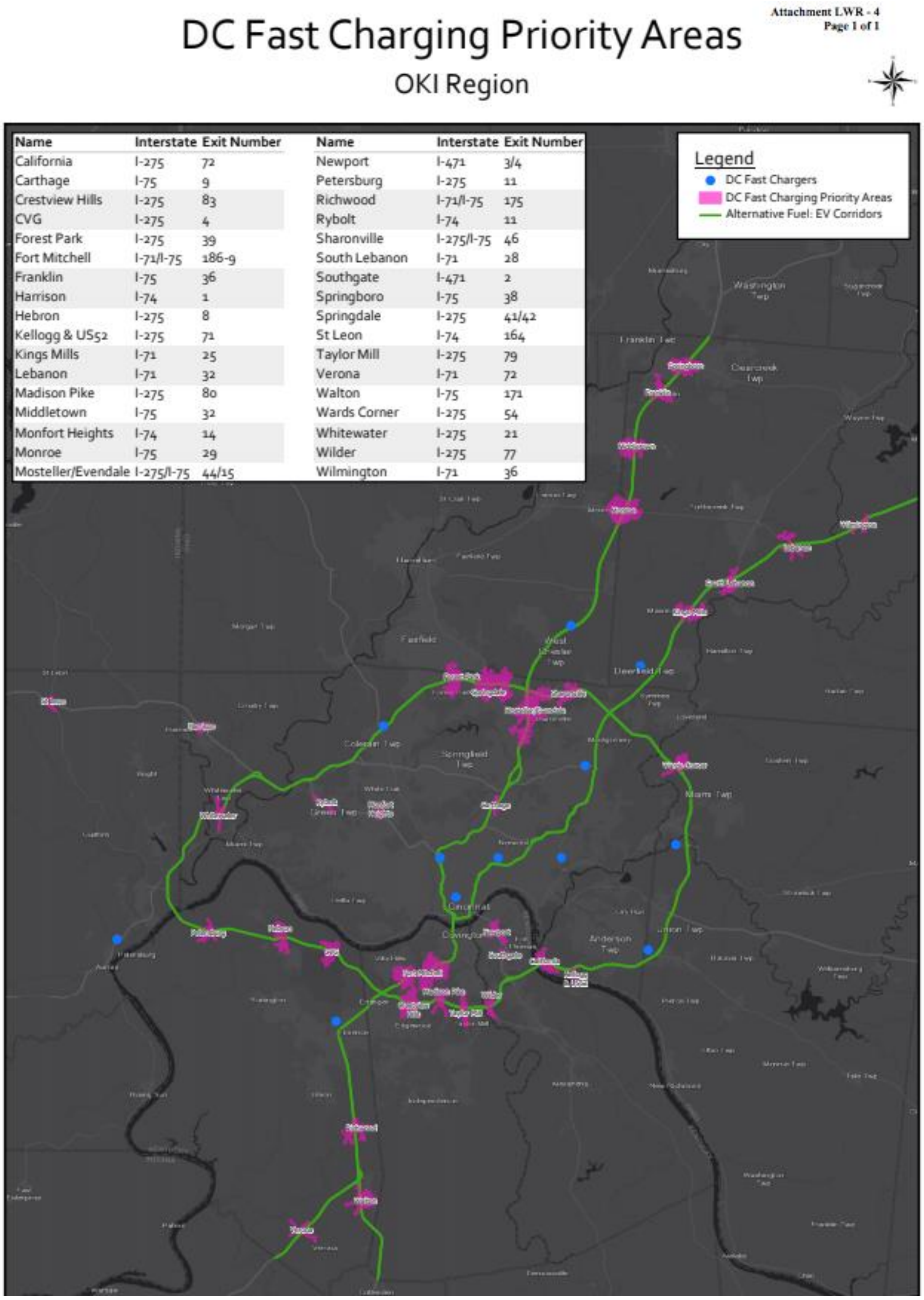
Level 2 charging ports can add anywhere from 12 to 25 miles of RPH, require a 220V outlet, and are ideal for times when a driver will be parked for at least one hour. In this cost analysis, they are broken out into Workplace Level 2, which is a charging station located at the driver's place of employment, typically in parking garages and parking lots. The other type is Public Level 2 charging, which is similar to a gas station. The Public Level 2 ports are popular near restaurants, movie theaters, sporting events, shopping centers, or anywhere a driver may spend at least an hour of their day. The goal of Level 2 chargers is to give enough battery life to allow the driver to get around town and can charge up to six times faster than charging at home with Level 1 charging.

Lastly, DC Fast chargers are used when the charging needs to happen quickly or when a driver is going on a long trip. DC Fast charging allows 100 miles of RPH or more, charging some EVs to 80 percent of battery capacity in 20-30 minutes. The DC Fast charging ports have various power levels, where the higher power levels cost more money but charge the vehicle at a faster rate.

5.2 Overview of the Ohio and Florida EV Pilot Program

Duke energy has proposed a 36-month Electric Transportation Pilot Program that will support Ohio in joining other states to advance deployment of EV infrastructure to meet growing market needs. The purpose of the pilot program is to determine the best way to implement EV charging infrastructure by collecting data on usage and consumer behavior. Duke's studies found that by 2030, nearly 150,000 EVs could be registered in Duke Energy Ohio service territory. In order to accommodate the potential moderate adoption of EVs within Duke's service area would require, approximately, 250 DFC and 5,000 level 2 chargers. This is assuming moderate growth, whereas high growth would potentially come in the form of 650,000 EVs within Duke's service area which would require 1,400 DCFC and 25,000 level 2 chargers. The proposed pilot estimates the cost associated with the installation of charging infrastructure and includes the increased utility usage in its estimate. These numbers were used to determine the overall cost required at each level of potential EV growth that can be seen in Table 1 through Table 9. Duke has also worked with the Ohio-Kentucky-Indiana Regional Council of Governments (OKI) in order to determine optimal locations for EV charging stations. OKI chose areas that are within one-half mile of a highway interstate exchange and they must have appropriate site lighting, be nearby retail and restaurant options. Their map can be seen in Figure 13 below.

Duke Energy has conducted a similar pilot in Florida some years prior where they were approved to install EV charging stations. 341 EV charging stations were installed in Florida which equated to a total cost of $3,816,599 ($11,192 per port). The 341 ports installed experienced 17,891 charging sessions over two years (November 2017 to November 2019), dispensing 242,017 kWh. Workplace chargers saw the most use, accounting for 41% of the total amount of energy dispensed which is followed by public level II chargers which accounted for 37% of the total energy dispensed. The U.S. DOE found that employees with access to charging stations are 6 to 20 times more likely to adopt an EV (US DOE, 2016). The pilot in Florida is ongoing and will be until December 22, 2022 and 189 more ports are planned to be installed.



Name	Interstate	Exit Number	Name	Interstate	Exit Number
California	I-275	72	Newport	I-471	3/4
Carthage	I-75	9	Petersburg	I-275	11
Crestview Hills	I-275	83	Richwood	I-71/I-75	175
CVG	I-275	4	Rybolt	I-74	11
Forest Park	I-275	39	Sharonville	I-275/I-75	46
Fort Mitchell	I-71/I-75	186-9	South Lebanon	I-71	28
Franklin	I-75	36	Southgate	I-471	2
Harrison	I-74	1	Springboro	I-75	38
Hebron	I-275	8	Springdale	I-275	41/42
Kellogg & US52	I-275	71	St Leon	I-74	164
Kings Mills	I-71	25	Taylor Mill	I-275	79
Lebanon	I-71	32	Verona	I-71	72
Madison Pike	I-275	80	Walton	I-75	171
Middletown	I-75	32	Wards Corner	I-275	54
Monfort Heights	I-74	14	Whitewater	I-275	21
Monroe	I-75	29	Wilder	I-275	77
Mosteller/Evendale	I-275/I-75	44/15	Wilmington	I-71	36

Figure 13. Map of Optimal EV Charging Infrastructure Locations (OKI, 2019)

5.3 Market Demand and Cost Savings

5.3.1 Costs associated with charging stations

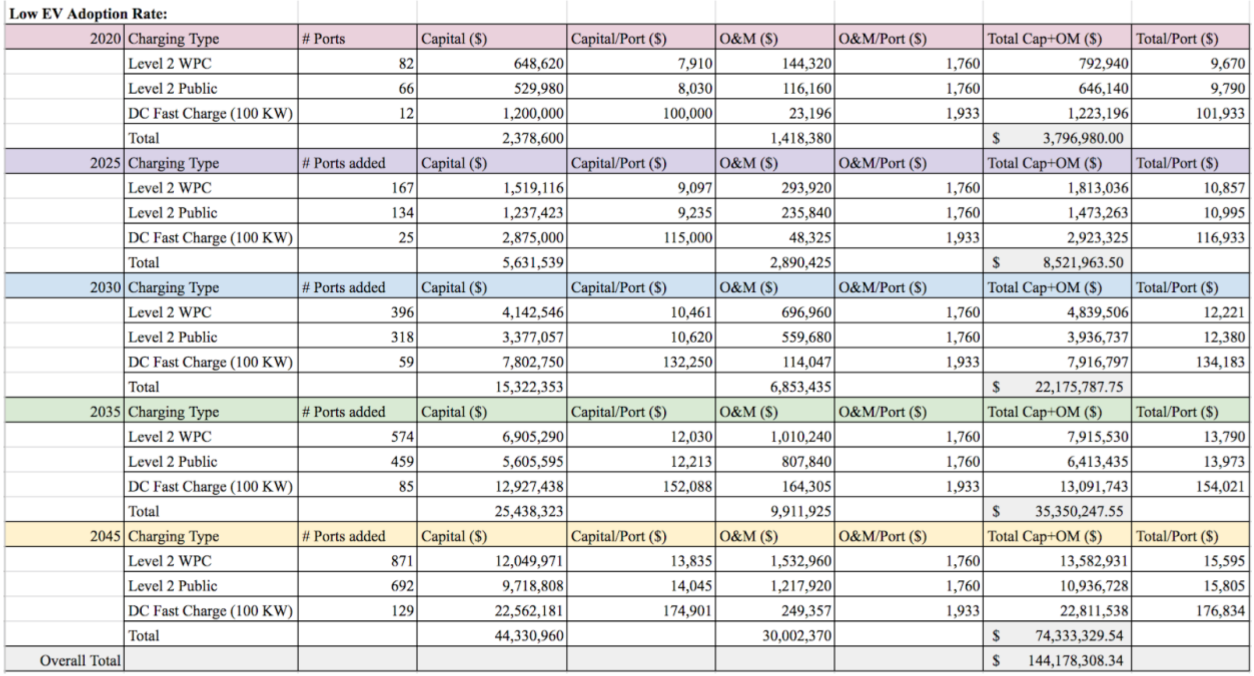
The U.S. Department of Energy's Electric Vehicle Infrastructure Projection Tool (EVI-Pro) was used to determine the number of charging stations that would be needed to support the additional EVs in the greater Cincinnati Area proposed in each EV adoption rate scenario. This tool allows the user to input the number of electric vehicles that are expected to be in a given region, and then projects the number of Workplace Level 2 Charging Ports, Public Level 2 Charging Ports, and Public DC Fast Charging Ports that would need to be installed to support the given number of plug-in EVs.

Once the number of charging stations was determined for each adoption rate scenario, the Duke Energy Florida's Annual EV Report was used to calculate the capital, operation, and maintenance costs associated with the different types of charging stations. With this information, the total amount of revenue needed for each alternative Electric Vehicle Adoption Rate was able to be determined, as seen in Table 7 through Table 9.

These tables represent a 5-year time span that calculates the capital for each charging port added, as well as the operation and maintenance costs associated with the charging stations over the 5 years. For each EV Adoption Rate, the number of ports from the years prior have been subtracted to only show the number of charging stations that would need to be added to achieve the number necessary to meet the charging demands for that time span. Over every 5-year span, the capital costs are increased by 15% to incorporate inflation rates of about 3% per year. Example calculations are provided in Table 10 and Table 11 in the appendix.

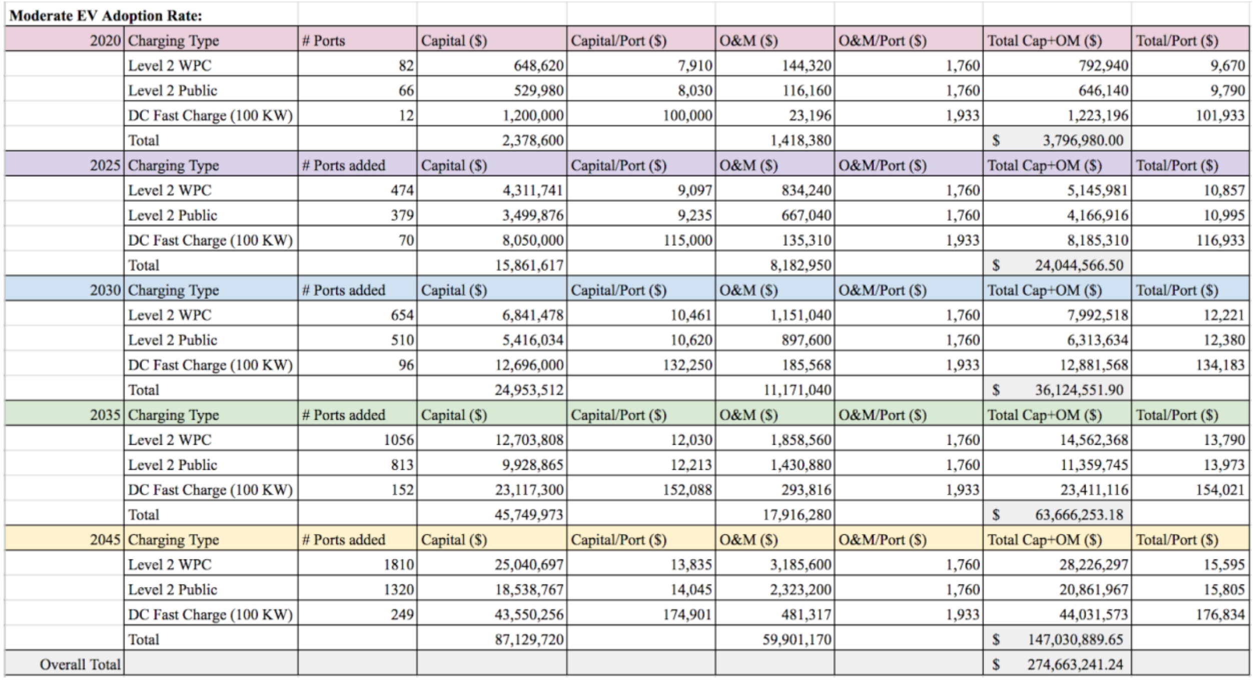
One thing to keep in mind about the costs associated with the charging station infrastructure is that no single entity or business would be responsible for purchasing the charging stations. The costs would be split between city government, local businesses, etc. The overall total cost represents how much each adoption scenario would be at the end of the 25-year time period.

Table 7. Low Electric Vehicle Adoption Rate charging infrastructure costs



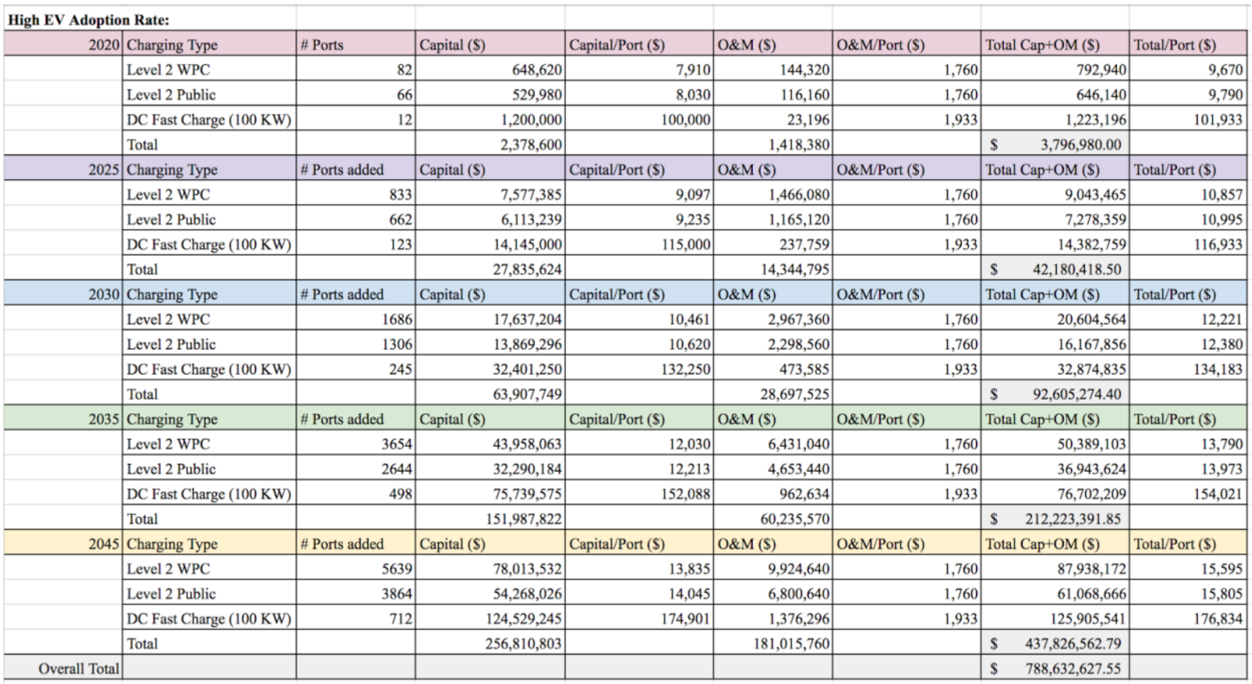
Low EV Adoption Rate:								
2020	Charging Type	# Ports	Capital ($)	Capital/Port ($)	O&M ($)	O&M/Port ($)	Total Cap+OM ($)	Total/Port ($)
	Level 2 WPC	82	648,620	7,910	144,320	1,760	792,940	9,670
	Level 2 Public	66	529,980	8,030	116,160	1,760	646,140	9,790
	DC Fast Charge (100 KW)	12	1,200,000	100,000	23,196	1,933	1,223,196	101,933
	Total		2,378,600		1,418,380		$ 3,796,980.00	
2025	Charging Type	# Ports added	Capital ($)	Capital/Port ($)	O&M ($)	O&M/Port ($)	Total Cap+OM ($)	Total/Port ($)
	Level 2 WPC	167	1,519,116	9,097	293,920	1,760	1,813,036	10,857
	Level 2 Public	134	1,237,423	9,235	235,840	1,760	1,473,263	10,995
	DC Fast Charge (100 KW)	25	2,875,000	115,000	48,325	1,933	2,923,325	116,933
	Total		5,631,539		2,890,425		$ 8,521,963.50	
2030	Charging Type	# Ports added	Capital ($)	Capital/Port ($)	O&M ($)	O&M/Port ($)	Total Cap+OM ($)	Total/Port ($)
	Level 2 WPC	396	4,142,546	10,461	696,960	1,760	4,839,506	12,221
	Level 2 Public	318	3,377,057	10,620	559,680	1,760	3,936,737	12,380
	DC Fast Charge (100 KW)	59	7,802,750	132,250	114,047	1,933	7,916,797	134,183
	Total		15,322,353		6,853,435		$ 22,175,787.75	
2035	Charging Type	# Ports added	Capital ($)	Capital/Port ($)	O&M ($)	O&M/Port ($)	Total Cap+OM ($)	Total/Port ($)
	Level 2 WPC	574	6,905,290	12,030	1,010,240	1,760	7,915,530	13,790
	Level 2 Public	459	5,605,595	12,213	807,840	1,760	6,413,435	13,973
	DC Fast Charge (100 KW)	85	12,927,438	152,088	164,305	1,933	13,091,743	154,021
	Total		25,438,323		9,911,925		$ 35,350,247.55	
2045	Charging Type	# Ports added	Capital ($)	Capital/Port ($)	O&M ($)	O&M/Port ($)	Total Cap+OM ($)	Total/Port ($)
	Level 2 WPC	871	12,049,971	13,835	1,532,960	1,760	13,582,931	15,595
	Level 2 Public	692	9,718,808	14,045	1,217,920	1,760	10,936,728	15,805
	DC Fast Charge (100 KW)	129	22,562,181	174,901	249,357	1,933	22,811,538	176,834
	Total		44,330,960		30,002,370		$ 74,333,329.54	
Overall Total							$ 144,178,308.34	

Table 8. Moderate Electric Vehicle Adoption Rate charging infrastructure costs



Moderate EV Adoption Rate:								
2020	Charging Type	# Ports	Capital ($)	Capital/Port ($)	O&M ($)	O&M/Port ($)	Total Cap+OM ($)	Total/Port ($)
	Level 2 WPC	82	648,620	7,910	144,320	1,760	792,940	9,670
	Level 2 Public	66	529,980	8,030	116,160	1,760	646,140	9,790
	DC Fast Charge (100 KW)	12	1,200,000	100,000	23,196	1,933	1,223,196	101,933
	Total		2,378,600		1,418,380		$ 3,796,980.00	
2025	Charging Type	# Ports added	Capital ($)	Capital/Port ($)	O&M ($)	O&M/Port ($)	Total Cap+OM ($)	Total/Port ($)
	Level 2 WPC	474	4,311,741	9,097	834,240	1,760	5,145,981	10,857
	Level 2 Public	379	3,499,876	9,235	667,040	1,760	4,166,916	10,995
	DC Fast Charge (100 KW)	70	8,050,000	115,000	135,310	1,933	8,185,310	116,933
	Total		15,861,617		8,182,950		$ 24,044,566.50	
2030	Charging Type	# Ports added	Capital ($)	Capital/Port ($)	O&M ($)	O&M/Port ($)	Total Cap+OM ($)	Total/Port ($)
	Level 2 WPC	654	6,841,478	10,461	1,151,040	1,760	7,992,518	12,221
	Level 2 Public	510	5,416,034	10,620	897,600	1,760	6,313,634	12,380
	DC Fast Charge (100 KW)	96	12,696,000	132,250	185,568	1,933	12,881,568	134,183
	Total		24,953,512		11,171,040		$ 36,124,551.90	
2035	Charging Type	# Ports added	Capital ($)	Capital/Port ($)	O&M ($)	O&M/Port ($)	Total Cap+OM ($)	Total/Port ($)
	Level 2 WPC	1056	12,703,808	12,030	1,858,560	1,760	14,562,368	13,790
	Level 2 Public	813	9,928,865	12,213	1,430,880	1,760	11,359,745	13,973
	DC Fast Charge (100 KW)	152	23,117,300	152,088	293,816	1,933	23,411,116	154,021
	Total		45,749,973		17,916,280		$ 63,666,253.18	
2045	Charging Type	# Ports added	Capital ($)	Capital/Port ($)	O&M ($)	O&M/Port ($)	Total Cap+OM ($)	Total/Port ($)
	Level 2 WPC	1810	25,040,697	13,835	3,185,600	1,760	28,226,297	15,595
	Level 2 Public	1320	18,538,767	14,045	2,323,200	1,760	20,861,967	15,805
	DC Fast Charge (100 KW)	249	43,550,256	174,901	481,317	1,933	44,031,573	176,834
	Total		87,129,720		59,901,170		$ 147,030,889.65	
Overall Total							$ 274,663,241.24	

Table 9. High Electric Vehicle Adoption Rate charging infrastructure costs



High EV Adoption Rate:								
2020	Charging Type	# Ports	Capital ($)	Capital/Port ($)	O&M ($)	O&M/Port ($)	Total Cap+OM ($)	Total/Port ($)
	Level 2 WPC	82	648,620	7,910	144,320	1,760	792,940	9,670
	Level 2 Public	66	529,980	8,030	116,160	1,760	646,140	9,790
	DC Fast Charge (100 KW)	12	1,200,000	100,000	23,196	1,933	1,223,196	101,933
	Total		2,378,600		1,418,380		$ 3,796,980.00	
2025	Charging Type	# Ports added	Capital ($)	Capital/Port ($)	O&M ($)	O&M/Port ($)	Total Cap+OM ($)	Total/Port ($)
	Level 2 WPC	833	7,577,385	9,097	1,466,080	1,760	9,043,465	10,857
	Level 2 Public	662	6,113,239	9,235	1,165,120	1,760	7,278,359	10,995
	DC Fast Charge (100 KW)	123	14,145,000	115,000	237,759	1,933	14,382,759	116,933
	Total		27,835,624		14,344,795		$ 42,180,418.50	
2030	Charging Type	# Ports added	Capital ($)	Capital/Port ($)	O&M ($)	O&M/Port ($)	Total Cap+OM ($)	Total/Port ($)
	Level 2 WPC	1686	17,637,204	10,461	2,967,360	1,760	20,604,564	12,221
	Level 2 Public	1306	13,869,296	10,620	2,298,560	1,760	16,167,856	12,380
	DC Fast Charge (100 KW)	245	32,401,250	132,250	473,585	1,933	32,874,835	134,183
	Total		63,907,749		28,697,525		$ 92,605,274.40	
2035	Charging Type	# Ports added	Capital ($)	Capital/Port ($)	O&M ($)	O&M/Port ($)	Total Cap+OM ($)	Total/Port ($)
	Level 2 WPC	3654	43,958,063	12,030	6,431,040	1,760	50,389,103	13,790
	Level 2 Public	2644	32,290,184	12,213	4,653,440	1,760	36,943,624	13,973
	DC Fast Charge (100 KW)	498	75,739,575	152,088	962,634	1,933	76,702,209	154,021
	Total		151,987,822		60,235,570		$ 212,223,391.85	
2045	Charging Type	# Ports added	Capital ($)	Capital/Port ($)	O&M ($)	O&M/Port ($)	Total Cap+OM ($)	Total/Port ($)
	Level 2 WPC	5639	78,013,532	13,835	9,924,640	1,760	87,938,172	15,595
	Level 2 Public	3864	54,268,026	14,045	6,800,640	1,760	61,068,666	15,805
	DC Fast Charge (100 KW)	712	124,529,245	174,901	1,376,296	1,933	125,905,541	176,834
	Total		256,810,803		181,015,760		$ 437,826,562.79	
Overall Total							$ 788,632,627.55	

5.3.2 Costs associated with the vehicle

Electric vehicles are unique in the fact that they will pay for themselves through their operation. EVs have fewer moving parts and rely on cheaper and cleaner energy. Over the life-time of a vehicle these costs add up significantly. A study completed by Ingrid Malmgren quantified the societal and personal costs of owning an EV and compared it with the societal and personal costs of owning a conventional gas-powered vehicle.

The EV modeled in her analysis was a 2016 Nissan Leaf which was compared to a 2016 Honda Civic 4-door (12.4-gallon capacity). A vehicle life of 10 years and 120,000 total miles driven was assumed. Malgrem considered the costs from regular maintenance, fuel consumption, health impacts, carbon emissions, and economic/technical developments.

The analysis assumes 100% clean, renewable energy production, which highlights the potential benefits of an EV and sets goals for which to strive for in the future (Malmgren, 2016). The price of gas is assumed to be $2.00 per gallon, a 10-year low at the time, while the cost of electricity is assumed to be 12.79 centers per kilowatt hour (kwh), the average costs of electricity in the US. (US Energy Information Administration, 2020).

According to the NYSERDA Wattplan calculator, the cost to fuel an EV over one year is $688 cheaper than the cost to fuel a Honda Civic 4-Door (NYSERDA, 2016). An EV owner using a Level II charger would expect their utility bill to increase $275 per year, so the actual savings from operating an EV comes out to $413 every year. Over the 10-year, 120,000-mile lifetime of the EV the total savings from less fueling totaled $4,130. EVs have fewer moving parts than conventional gas- or diesel-powered vehicles thus the cost of maintenance for a Honda Civic 4-door per 100,000 miles equates to $2140 while an EVs maintenance cost comes out to $900 every 100,000 miles. Adjusting for a 120,000-mile lifetime, the saving from less maintenance comes out to $1488 over the 10-year period.

The EPA has estimated that the social cost of carbon is $42.30 per ton (EPA(e), 2016). It is widely accepted that this value fails to capture all of the economic, ecological, health, and physical damages linked to climate change (Malmgren, 2016). Some other estimates equate the social cost of carbon to $220 per ton. Driving an EV reduces 4,096 pounds of carbon every year, as opposed to a conventional gasoline vehicle (NYSERDA, 2016). This means that nearly 20 tons of carbon are reduced; using the EPAs low estimate of the social cost of carbon the savings come out to $866 over the lifetime of the EV.

Health impacts are difficult to equate to some dollar amount saved and there are two methods in which to do so. Studies have attempted to attach a cost associated with the damages done to the environment per every mile driven. A mid-range value of 1.38 cents per vehicle mile travelled (VMT) was used and over the course of the 120,000 miles this results in a socialized cost of $1477.61 (Malmgren, 2016). Using this methodology, the socialized cost comes out to $1,477.61. Since there is a decent amount of variability between health impact estimates, a mid-range estimate of $1686 is used to monetize the health benefits of driving an EV over the lifetime of its operation.

Since the cost of operation of EV is lower than that of a conventional vehicle, the study takes a look at how this would change the economic development of a region. A study in Oregon found that purchasing an EV driver can increase tax revenue between $426 and $1,500 over a 10-year period because every dollar not spent on conventional vehicle maintenance has potential to go back into the economy (Malmgren, 2016). The study adopts a mid-range of $965 to represent the economic development benefit on the local economy.

The study did not quantify potential EV benefits that may come from increased driving performance and reduced insurance costs. It would be difficult to quantify the benefits from avoiding hundreds of trips to the gas station for fueling as well as how range anxiety might affect the perceived value of EVs. This study also measured the extent to which EV benefits have been quantified.

Totaling the amount saved from the operation of an EV over a 10-year, 120,000-mile lifetime comes out to $9,135. Though a Nissan Leaf costs $10,000 more than a Honda Civic upfront, the total societal and personal cost benefit over its lifetime mitigates that price difference. It is likely that the value of EV ownership will continue to increase, therefore it is expected that these benefits will become greater than reported here.

6. Conclusions and Recommendations

Based on the findings of this study, Urban Charge can confidently recommend wide scale EV adoption as a means to increase ambient air quality, given that proper actions are taken. These actions include; increasing the amount of electricity generated via renewable energy and natural gas, while decreasing the amount of electricity generated via coal. As seen in the results from the fast EV adoption rate scenario, it is possible to increase the amount of EVs in the Greater Cincinnati area's vehicle fleet at such a rate that it could cause negative impacts on the ambient air quality. Therefore, when turning to mass EV deployment as a means of improving the ambient air quality, it is important to have an understanding on how the electricity that powers the EVs is generated. Given the electricity generation mix proposed, Urban Charge would recommend implementing the moderate EV adoption rate scenario, as it creates the largest reduction of pollutants emitted while also not increasing the emissions of any pollutants. The moderate EV adoption rate would also experience a $49,167,524 decrease in costs of pollutants on human health, as opposed to the slow adoption rate, in which the cost of damage on human health decreases $18,988,589. Following the moderate adoption EV rate, there is an increase of 202,018 EVs being operated from 2025 to 2045. Assuming that each EV owner saves about $9,135 over a 10-year, 120,000-mile lifetime, the adoption of 202,018 EVs in 20 years has the potential to add $1,845,434,430 into the Greater Cincinnati Area economy.

7. Future Research and Predictions

Since only one variation of the Greater Cincinnati area's electricity generation grid was analyzed in this study, it could prove beneficial to consider other generation mixes to propose alternative scenarios that could potentially result in improving the ambient air quality. A more fossil fuel dominated fuel mix would slow the reduction in air pollutants when compared to a more renewable energy fuel mix. Because passenger cars dominate the EV market, only passenger cars were considered for this study. As more fully electric vehicle options become available to the public, further research on deploying fully electric SUVs or trucks could be valuable in future studies. In addition to passenger cars, other large emitters of particulate matter are school buses, transit buses, and semi-trucks. As fully electric models of these types of vehicles become more popular, they will lead to a significant decrease in the amount of emissions from diesel vehicles.

When it comes to the utility of EVs there is a potential for them to be used as an off-grid source of electricity. Based on where EV battery technology is headed, some experts suggest that utilizing an EV to power your home could result in a $5,000 savings (Ferber, 2011). This could be something to look into within the next decade. Though some limitations do arise, it could be difficult to estimate the increased energy demand on the grid if this was being done at a mass scale. It could be worth looking into because it could increase the attraction of owning an EV.

The future ambient air quality is difficult to fully predict due to many underlying factors such as future industrial sites, modes of transportation available to the public, and projected climate and weather changes. In this study, only the emissions from passenger cars along with a dynamic energy generation mix were considered, when in reality there are many other sources emitting air pollution. In the future, the unpredictable increase and/or decrease of emissions from a variety of mobile and stationary sources will have a direct impact on the air quality of the region.

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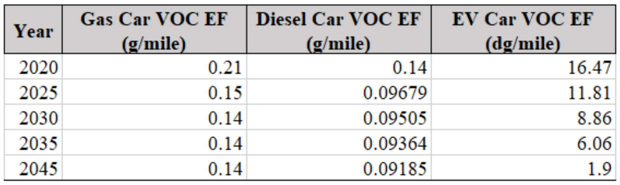
9. Appendix

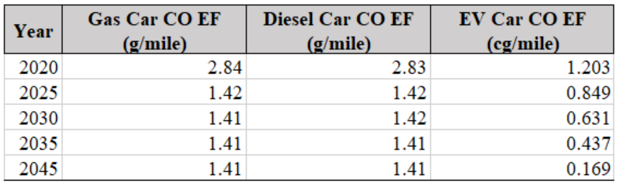
9.1 Tables and Figures

Table 1. VOC Emission Factors associated with the operation and maintenance of a gas-powered passenger car, diesel powered passenger car, and EV in the Greater Cincinnati area from 2020 through 2045.



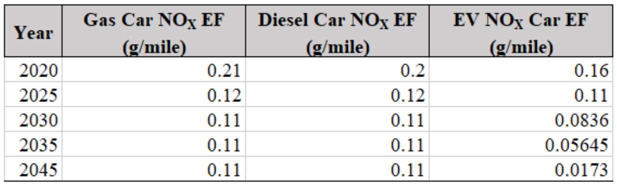
Year	Gas Car VOC EF (g/mile)	Diesel Car VOC EF (g/mile)	EV Car VOC EF (dg/mile)
2020	0.21	0.14	16.47
2025	0.15	0.09679	11.81
2030	0.14	0.09505	8.86
2035	0.14	0.09364	6.06
2045	0.14	0.09185	1.9

Table 2. CO Emission Factors associated with the operation and maintenance of a gas-powered passenger car, diesel powered passenger car, and EV in the Greater Cincinnati area from 2020 through 2045.



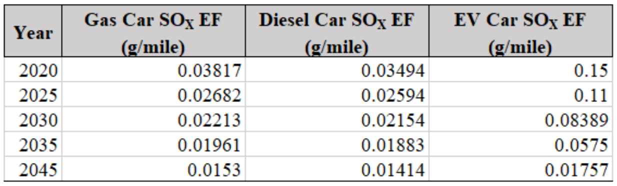
Year	Gas Car CO EF (g/mile)	Diesel Car CO EF (g/mile)	EV Car CO EF (cg/mile)
2020	2.84	2.83	1.203
2025	1.42	1.42	0.849
2030	1.41	1.42	0.631
2035	1.41	1.41	0.437
2045	1.41	1.41	0.169

Table 3. NO_x Emission Factors associated with the operation and maintenance of a gas-powered passenger car, diesel powered passenger car, and EV in the Greater Cincinnati area from 2020 through 2045 (GREET 2020).



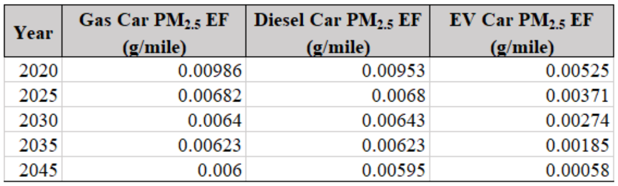
Year	Gas Car NO_X EF (g/mile)	Diesel Car NO_X EF (g/mile)	EV NO_X Car EF (g/mile)
2020	0.21	0.2	0.16
2025	0.12	0.12	0.11
2030	0.11	0.11	0.0836
2035	0.11	0.11	0.05645
2045	0.11	0.11	0.0173

Table 4. SO_x Emission Factors associated with the operation and maintenance of a gas-powered passenger car, diesel powered passenger car, and EV in the Greater Cincinnati area from 2020 through 2045 (GREET 2020).



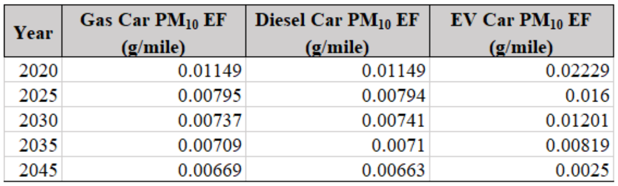
Year	Gas Car SO_X EF (g/mile)	Diesel Car SO_X EF (g/mile)	EV Car SO_X EF (g/mile)
2020	0.03817	0.03494	0.15
2025	0.02682	0.02594	0.11
2030	0.02213	0.02154	0.08389
2035	0.01961	0.01883	0.0575
2045	0.0153	0.01414	0.01757

Table 5. PM2.5 Emission Factors associated with the operation and maintenance of a gas-powered passenger car, diesel powered passenger car, and EV in the Greater Cincinnati area from 2020 through 2045 (GREET 2020).



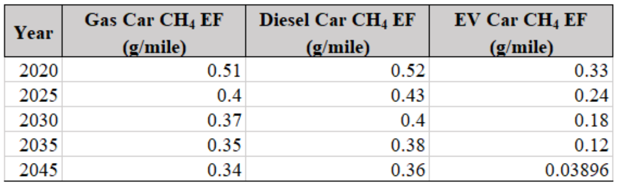
Year	Gas Car $PM_{2.5}$ EF (g/mile)	Diesel Car $PM_{2.5}$ EF (g/mile)	EV Car $PM_{2.5}$ EF (g/mile)
2020	0.00986	0.00953	0.00525
2025	0.00682	0.0068	0.00371
2030	0.0064	0.00643	0.00274
2035	0.00623	0.00623	0.00185
2045	0.006	0.00595	0.00058

Table 6. PM_{10} Emission Factors associated with the operation and maintenance of a gas-powered passenger car, diesel powered passenger car, and EV in the Greater Cincinnati area from 2020 through 2045 (GREET 2020).



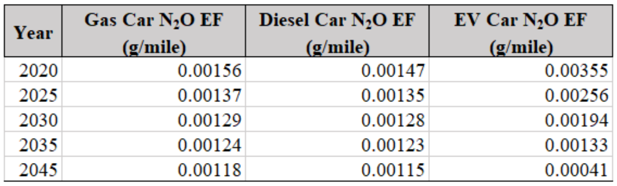
Year	Gas Car PM_{10} EF (g/mile)	Diesel Car PM_{10} EF (g/mile)	EV Car PM_{10} EF (g/mile)
2020	0.01149	0.01149	0.02229
2025	0.00795	0.00794	0.016
2030	0.00737	0.00741	0.01201
2035	0.00709	0.0071	0.00819
2045	0.00669	0.00663	0.0025

Table 7. CH_4 Emission Factors associated with the operation and maintenance of a gas-powered passenger car, diesel powered passenger car, and EV in the Greater Cincinnati area from 2020 through 2045 (GREET 2020).



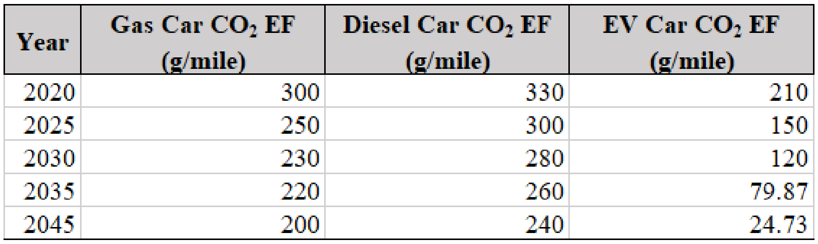
Year	Gas Car CH_4 EF (g/mile)	Diesel Car CH_4 EF (g/mile)	EV Car CH_4 EF (g/mile)
2020	0.51	0.52	0.33
2025	0.4	0.43	0.24
2030	0.37	0.4	0.18
2035	0.35	0.38	0.12
2045	0.34	0.36	0.03896

Table 8. N_2O Emission Factors associated with the operation and maintenance of a gas-powered passenger car, diesel powered passenger car, and EV in the Greater Cincinnati area from 2020 through 2045 (GREET 2020).



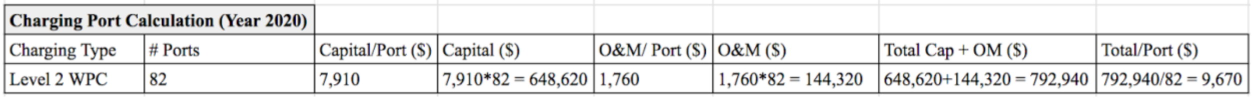
Year	Gas Car N_2O EF (g/mile)	Diesel Car N_2O EF (g/mile)	EV Car N_2O EF (g/mile)
2020	0.00156	0.00147	0.00355
2025	0.00137	0.00135	0.00256
2030	0.00129	0.00128	0.00194
2035	0.00124	0.00123	0.00133
2045	0.00118	0.00115	0.00041

Table 9. CO_2 Emission Factors associated with the operation and maintenance of a gas-powered passenger car, diesel powered passenger car, and EV in the Greater Cincinnati area from 2020 through 2045 (GREET 2020).



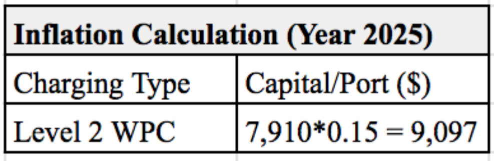
Year	Gas Car CO_2 EF (g/mile)	Diesel Car CO_2 EF (g/mile)	EV Car CO_2 EF (g/mile)
2020	300	330	210
2025	250	300	150
2030	230	280	120
2035	220	260	79.87
2045	200	240	24.73

Table 10. Sample calculation for the costs associated with each charging port



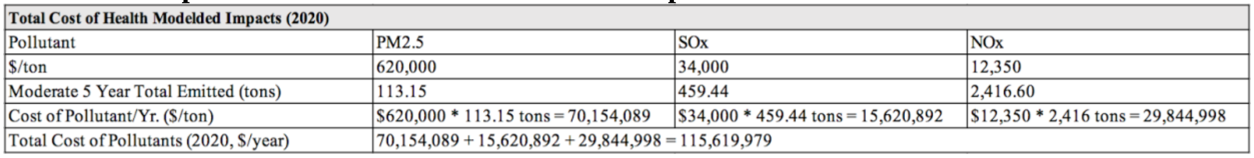
Charging Port Calculation (Year 2020)							
Charging Type	# Ports	Capital/Port ($)	Capital ($)	O&M/ Port ($)	O&M ($)	Total Cap + OM ($)	Total/Port ($)
Level 2 WPC	82	7,910	7,910*82 = 648,620	1,760	1,760*82 = 144,320	648,620+144,320 = 792,940	792,940/82 = 9,670

Table 11. Sample calculation for the costs associated with projected inflation



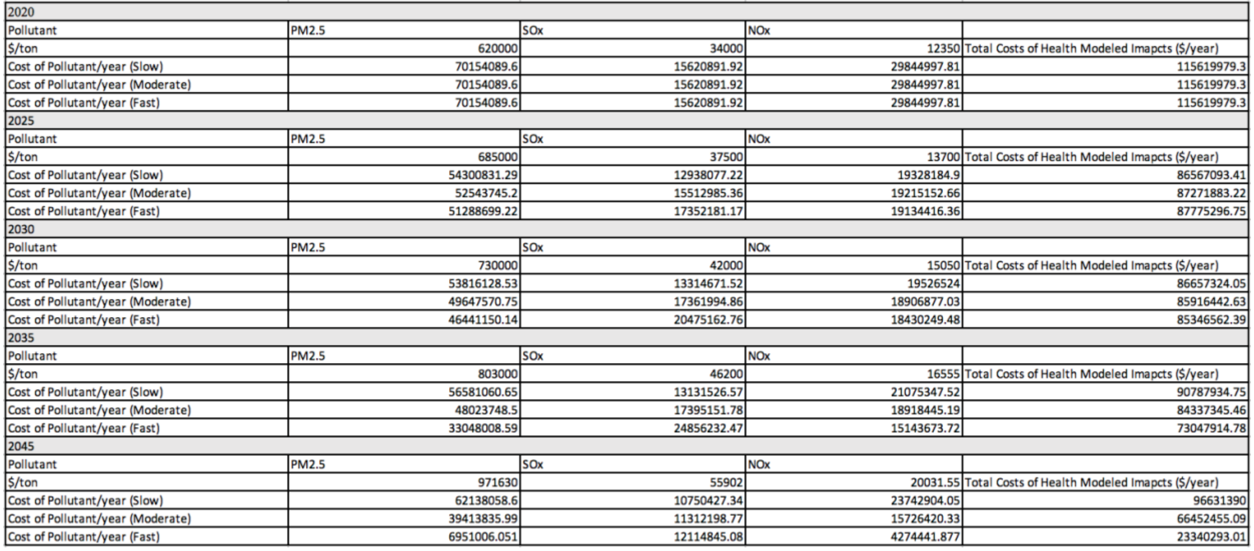
Inflation Calculation (Year 2025)	
Charging Type	Capital/Port ($)
Level 2 WPC	7,910*0.15 = 9,097

Table 12. Sample calculation for the cost of health impacts



Total Cost of Health Modelded Impacts (2020)			
Pollutant	PM2.5	SOx	NOx
$/ton	620,000	34,000	12,350
Moderate 5 Year Total Emitted (tons)	113.15	459.44	2,416.60
Cost of Pollutant/Yr. ($/ton)	$620,000 * 113.15 tons = 70,154,089	$34,000 * 459.44 tons = 15,620,892	$12,350 * 2,416 tons = 29,844,998
Total Cost of Pollutants (2020, $/year)	70,154,089 + 15,620,892 + 29,844,998 = 115,619,979		

Table 13. Price of Pollutants per Year for Slow, Moderate, and Fast EV Adoption



2020				
Pollutant	PM2.5	SOx	NOx	
$/ton	620000	34000	12350	Total Costs of Health Modeled Imapcts ($/year)
Cost of Pollutant/year (Slow)	70154089.6	15620891.92	29844997.81	115619979.3
Cost of Pollutant/year (Moderate)	70154089.6	15620891.92	29844997.81	115619979.3
Cost of Pollutant/year (Fast)	70154089.6	15620891.92	29844997.81	115619979.3
2025				
Pollutant	PM2.5	SOx	NOx	
$/ton	685000	37500	13700	Total Costs of Health Modeled Imapcts ($/year)
Cost of Pollutant/year (Slow)	54300831.29	12938077.22	19328184.9	86567093.41
Cost of Pollutant/year (Moderate)	52543745.2	15512985.36	19215152.66	87271883.22
Cost of Pollutant/year (Fast)	51288699.22	17352181.17	19134416.36	87775296.75
2030				
Pollutant	PM2.5	SOx	NOx	
$/ton	730000	42000	15050	Total Costs of Health Modeled Imapcts ($/year)
Cost of Pollutant/year (Slow)	53816128.53	13314671.52	19526524	86657324.05
Cost of Pollutant/year (Moderate)	49647570.75	17361994.86	18906877.03	85916442.63
Cost of Pollutant/year (Fast)	46441150.14	20475162.76	18430249.48	85346562.39
2035				
Pollutant	PM2.5	SOx	NOx	
$/ton	803000	46200	16555	Total Costs of Health Modeled Imapcts ($/year)
Cost of Pollutant/year (Slow)	56581060.65	13131526.57	21075347.52	90787934.75
Cost of Pollutant/year (Moderate)	48023748.5	17395151.78	18918445.19	84337345.46
Cost of Pollutant/year (Fast)	33048008.59	24856232.47	15143673.72	73047914.78
2045				
Pollutant	PM2.5	SOx	NOx	
$/ton	971630	55902	20031.55	Total Costs of Health Modeled Imapcts ($/year)
Cost of Pollutant/year (Slow)	62138058.6	10750427.34	23742904.05	96631390
Cost of Pollutant/year (Moderate)	39413835.99	11312198.77	15726420.33	66452455.09
Cost of Pollutant/year (Fast)	6951006.051	12114845.08	4274441.877	23340293.01

9.2 Company Name and Vision Statement

Company: Urban Charge

Vision Statement: Planning feasible and sustainable transportation solutions to make Cincinnati a cleaner, healthier, and more accessible city.

9.3 Acknowledgements

- Dr. Drew McAvoy for his guidance throughout the project study.
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- Dr. Sivaraman Balachandran for his guidance and clarification regarding our focus and relevant modeling software and capabilities.
- Jordan Wallpe for his extensive knowledge on EV charging infrastructure
- Zachary Stone for illustrating the team logo

9.4 Team Member Bios

Kristen Belisario is a fifth year Environmental Engineering student at the University of Cincinnati. Apart from classroom instruction, her applicable past experience includes five semesters of co-op experience with Duke Energy working in Ohio, Indiana, and North Carolina. At Duke Energy, Kristen's duties required her to work closely with air quality emissions and Energy Information Administration (EIA) Reporting of the numerous power plants across Duke Energy's regions. She also has experience working with National Pollutant Discharge Elimination System (NPDES) permitting, Spill Prevention, Control, and Countermeasure (SPCC) Plans, along with environmental risk assessments.

Christopher Stone is a fifth year Environmental Engineering student. Chris spent the first co-op's gaining experience with waste water treatment and wastewater consulting. Here Chris learned about common wastewater treatment designs and the process behind their implementation. He spent his third co-op working for Ecosil Technologies developing solvent-free, environmentally-safe coatings that were applied to metals in order to reduce corrosion and increase adhesion. He spent his last two co-ops designing Storm Water Pollution Prevention Plans with CoyleSWPPP Professionals.

Rachel Tumbleson is a fifth year Environmental Engineering student at the University of Cincinnati. For three semesters, she worked in the Wastewater Treatment department of the Metropolitan Sewer District of Greater Cincinnati. In this position she had the opportunity to learn about modern wastewater treatment processes and apply said knowledge towards managing projects aimed to maintain and/or improve plant operation. She also worked for two semesters with GE Aviation's Environmental, Health, and Safety team in both Evendale, OH and Madisonville, KY. Here she was able to gain experience in several faucets of environmental engineering including wastewater treatment, air pollution control compliance, and industrial waste stream analysis.

9.5 Team Member Resumes

The following three pages contain the resumes of each team member of Urban Charge.

Kristen R. Belisario

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Address:
8584 Sunview Drive
Broadview Heights, OH 44147

EDUCATION

Bachelor of Science, Environmental Engineering, Cincinnati, OH *Graduation May 2020*

University of Cincinnati, College of Engineering & Applied Science

- Cincinnatus Scholarship and Women in Engineering Scholarship Recipient
- Dean's List

Iceland Study Abroad, Renewable Energy and Sustainability *December 2017*

Reykjavik University, Iceland School of Energy

- Gained exclusive access to renewable energy facilities: hydropower, geothermal, and biofuel
- Coursework focusing on energy, economics, and policy taught by industry experts
- Leadership activities through Capstone project work and cultural immersion activities

WORK EXPERIENCE

Carolinas Environmental Field Support Co-Op- Duke Energy; Charlotte, NC *May 2019– August 2019*

- Evaluated secondary containments at coal plants to determine which systems were high risk
- Developed a new method to perform operator rounds and inspections to reduce time needed
- Reviewed lab information and completed a lab NPDES self-assessment to ensure compliance
- Shadowed Environmental Coordinators at power plants to get an in depth look of day to day tasks
- Organized an NPDES sampling schedule for the lab at Cliffside to better track testing days

Midwest Environmental Field Support Co-Op- Duke Energy; Plainfield, IN *January 2019– May 2019*

- Participated in numerous plant visits and witnessed stack/air quality testing and water sampling
- Assessed risk at Gibson Station after analyzing past environmental events at the plant
- Compiled a hazardous chemical list with associated reportable quantities for use at power plants
- Created monthly reports to summarize and represent YTD environmental events in the Midwest

Environmental Programs Co-Op- Duke Energy; Cincinnati, OH *January 2017- August 2018*

- Collaboratively developed a technology based Chemical Inventory tool to reduce time needed
- Drafted a business plan for the implementation process of the Chemical Inventory tool
- Reviewed and presented new NPDES permit changes at Cayuga Station to site personnel
- Lead and drafted SPCC 5-year review plans throughout the Midwest
- Trended constituents against NPDES permit parameters to determine site compliance
- Managed Energy Information Administration reporting across the Duke Energy Fleet
- Analyzed and monitored air emission rates across the Midwest power plants
- Assisted on major projects: Chemical Data Report, Chemical Inventory, Toxic Release Inventory

ACTIVITIES

Volunteer Red Cross Coordinator- have planned and run multiple blood drives	*2013—present*
Volunteer for Clean-up Cincy- volunteer to clean up around the greater Cincinnati area	*2015—present*
Member of Society of Environmental Engineers- discuss real world ENVE problems	*2015—present*
Member of Astronomy Club- debate and discuss astronomical topics and theories	*2015—present*
Member of UC Women's Club Lacrosse Team- practice leadership and teamwork	*2015—present*

Christopher Stone

I have a genuine interest and love for the environment, its natural processes, and the sciences behind conservation. I enjoy collaborating with others in order to find sustainable solutions to modern problems. I have experience in waste water treatment, NSF grant research, storm water management and am interested in learning more about infastructure.

Experience

Coyle SWPPP Professionals, Westchester OH

***Engineer Co-op*, Jan 2019 - Aug 2019**

- Designed and delivered 45 storm water pollution prevention plans to 6+ construction firms
- Oversaw 40 SWPPPs as a Project Manager
- Responsible for 25+ on-site SWPPP inspections and inspection reports in Columbus, Dayton, & Cincinnati on a weekly basis
- Routinley took on more SWPPP designs and inspections in order to increase productivity
- Initiated the integration of Trimble Buisness Center as a new designing and modeling software

Ecosil Technologies, Fairfield OH

***Engineer Co-op*, Aug 2017 - Aug 2018**

- Completed NSFs I-Corp $50,000 grant commercialization program
- Interviewed 50+ potential customers and key partners pertaining to NSF grant research
- Composed weekly 20 minute presentations to NSF board members
- Analyzed organic coatings through statistical quality control techniques
- Oversaw the maintenance and daily functions of a simulted corrosive environment chamber
- Powder coated and quality tested 250 cold rolled steel and 250 alumnium 2024 panels

Water and Wastewater Consulting Services, Westlake OH

***Engineer Co-op*, Jan 2017- May 2017**

- Created a multi view drawing of a custom built filter press in Auto CAD
- Constructed an extensive device approval manual that was delivered to clients
- Updated piping and instrumentation diagrams
- Assisted in the creation of process flow diagrams for cyanide destruction, chrome treatment, and heavy metal precipitation
- Analyzed the efficiency of devices commonly used in wastewater treatment

Contact

stonec8@mail.uc.edu
/in/christopherpstone
440-832-0988
Cincinnati OH, 45220
Availability: *May 2020*

Education

University of Cincinnati
Bachelor of Science:
Environmental Engineering, 2020
GPA: 3.29/4.00

Technical Skills

- Auto CAD
- Mathworks MATLAB
- Microsoft Suite
- InDesign
- Project Management
- Adept with engineering drawings
- Time management
- Technical writing
- Oral Presentations

Certifications & Clubs

- OSHA 10 Certification
- Nuclear Gauge Certification
- ACI Level 1 Certification
- Society of Environmental Engineers

Rachel Tumbleson

186 Dawna Dr
Wadsworth, OH
tumblerh@mail.uc.edu
(330)-212-8494

EDUCATION

University of Cincinnati, College of Engineering and Applied Sciences Class of 2020
Bachelor of Science in Environmental Engineering (ENVE)

- GPA: 3.5
- Dean's List

EXPERIENCE

Metropolitan Sewer District of Greater Cincinnati, Cincinnati, OH **May 2018 – August 2019**
Wastewater Treatment Co-op

- Created construction drawings and specifications for the replacement of 1,220 ft. of potable water piping
- Investigated designs flaws causing a thickened sludge pump to underperform
- Analyzed actuator runtime data to improve influent UV gate operation
- Examined design options for increasing relative humidity of incinerator mercury scrubber to improve efficiency
- Collected and analyzed flow and pressure data on aeration tank diffusers to establish timeline for acid cleaning

GE Aviation, Cincinnati, OH & Madisonville, KY **January 2017 – November 2017**
Environmental, Health, and Safety Co-op

- Conducted wastewater treatment sample analysis of heavy metal concentrations and pH to ensure discharge permit compliance
- Established an updated Ozone Depleting Substance inventory and a digital refrigerant service tracking system
- Created process maps for fifteen site processes to better manage the site's waste streams
- Created a lean waste, oil, and chemical management system for the rotating parts lab
- Ensured equipment and oil drum inventory complied with the site's spill prevention, control, and countermeasure plan

SKILLS & CERTIFICATIONS

- AutoCAD
- GE Aviation Certified Lean Six Sigma Yellow Belt
- Proficient with Microsoft Office Suite: Word, PowerPoint, Excel, Access, Project, Windows
- Proficient with MathWorks MATLAB

ACTIVITIES & HONORS

Leaders for Environmental Awareness and Protection, University of Cincinnati **Sept. 2015 - Present**
Parker Hannisan Engineering Scholarship, Wadsworth High School **Aug. 2015 – May 2017**
Steubenville, OH Mission Trip, Wadsworth United Methodist Church **2015, July 2016**

9.6 Request for Proposal (RFP)

Environmental Engineering Senior Capstone Project
University of Cincinnati
Impacts of Largescale Electric Vehicle Deployment on Cincinnati Ambient Air Quality

Sponsor: Duke Energy
August 2019

Objective

Develop a proposed plan for utilizing electric vehicles or other alternatively powered vehicles as a cost-effective tool for improving ambient air quality and reducing greenhouse gas emissions in the Greater Cincinnati Area.

Background

The Clean Air Act (CAA) is the comprehensive federal law that regulates air emissions from stationary and mobile sources. Among other things, this law authorizes USEPA to establish National Ambient Air Quality Standards (NAAQS) to protect public health and public welfare and to regulate emissions of hazardous air pollutants. One of the goals of the Act was to set and achieve NAAQS in every state to address the public health and welfare risks posed by certain widespread air pollutants.

Ozone is one of six common air pollutants identified in the Clean Air Act. USEPA calls these “criteria air pollutants” because their levels in outdoor air need to be limited based on health criteria. Tropospheric or ground level ozone is a harmful air pollutant, because of its effects on people and the environment. It is the main ingredient in “smog," but is not emitted directly into the air. Rather it is created by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOCs). This happens when pollutants emitted by cars, power plants, industrial boilers, refineries, chemical plants, and other sources chemically react in the presence of sunlight. Ozone is most likely to reach unhealthy levels on hot sunny days in urban environments, but it can still reach high levels during colder months. Ozone, its NOx and VOC precursor pollutants, and air emissions in general can also be transported long distances impacting air quality in downwind urban and rural areas.

Particulate matter (also called particle pollution or simply PM) is also regulated as a criteria pollutant. It is the term for a mixture of solid particles and liquid droplets found in the air. Most PM in the atmosphere forms from complex reactions of chemicals such as sulfur dioxide and nitrogen oxides, ammonia and other materials emitted from power plants, industries, automobiles and other sources. Particulate matter contains microscopic solids or liquid droplets that are so small that they can be inhaled and adversely impact health. Of these, particles less than 2.5 micrometers in diameter, also known as fine particles or PM2.5, which pose the greatest risk to health. Fine particles are also the main cause of reduced visibility (haze) in parts of the United States, including many national parks and wilderness areas.

Emissions of criteria air pollutants continue to decline from 1990 levels. These reductions are driven by implementation of stationary and mobile source regulations.5 Air quality has continued to improve; however, many areas are still not attaining the NAAQS for one or more criteria pollutants. Urban areas generally have higher concentrations of stationary and mobile sources and thus these areas are more likely to have air quality that exceed the NAAQS. Locally the Greater Cincinnati area is currently designated as non-attainment of the 2015 ozone standard.

Much of the recent reduction in air emissions have come from air pollution controls, fuel switching, and changes to business practices, including changes at stationary sources such as power plants and other factories. As a result, other source categories such as mobile sources have gained importance in improving air quality. Nationally, mobile sources constitute a large fraction of local ozone precursors.

Mobile sources are most commonly powered by internal combustion engines fueled with either gasoline or diesel fuel. Vehicle standards implemented under authority of the CAA have resulted in vehicles emitting far fewer emissions per mile traveled. However, EPA estimates that total vehicle miles traveled have increased by 191% since 1970 slowing the decline in total vehicle emissions.

Mobile sources are major contributors to greenhouse gas emissions. Carbon dioxide is generated directly from combusting gasoline and diesel fuel, which are fossil fuels. According to the Energy Information Agency, carbon dioxide emissions from the Transportation End-Use Sector exceeds the Industrial, Residential and Commercial Sectors. Improved fuel efficiency standards have reduced the amount of fuel required per mile traveled, though, the increase in total vehicle miles traveled has offset efficiency gains.

Technology advances have produced alternatives to traditional gasoline and diesel-powered vehicles. These alternatives have promise to improve urban air quality because of their low or zero emissions footprint. Advances in battery technology for example have increased the viability of electric vehicles due to greater range and lower production costs. Electric vehicles do not directly emit criteria pollutants and thus can directly improve air quality in urban areas. However, the electricity used to recharge their batteries can generate emissions. Electricity can be produced from zero emitting sources such as wind, solar, hydro, etc.; however, a large portion of electricity generated comes from combusting carbon dioxide producing fuels, although this generally occurs outside urban areas. Other vehicle alternatives include hybrids (including plug-in rechargeable) and compressed natural gas. While these alternatives still cause emissions, they generally do so at a lower rate and/or potentially have a higher thermal efficiency.

Description of the Project

The consultant team will investigate the potential for using a wide scale deployment of electric vehicles (or other alternatively powered vehicles) as a cost-effective tool for improving ambient air quality in the Greater Cincinnati Area. The team should also consider global impacts on greenhouse gas emissions. At least three scenarios for deploying different numbers and types of electric or other vehicles should be developed, which includes anticipated costs and projected environmental benefits. The team may also, if possible, assess potential health impacts of its plan based on peer accepted risk assessment approaches.

Deliverables

The consultant team should complete the following tasks by the end of the Fall Semester.

- Conduct a review of ambient air quality and air emissions inventories from different source sectors in the Greater Cincinnati area to identify potential areas of potential improvement.
- Conduct a technology review of conventional vehicles and available alternatively powered vehicles including cost of operation, and environmental footprint.
- Conduct a review of traffic patterns in the Greater Cincinnati area and identify options for most effectively deploying a fleet of electric and/or alternatively fueled vehicles
- Prepare a proposal report on the key findings and recommended options.
- Provide a presentation to the Sponsor on the key findings and recommended option.

The consultant team should complete the following tasks by the end of the Spring Semester.

- Demonstrate that the recommended reuse option is technically feasible.
- Conduct a thorough economic analysis of the recommended options including incremental vehicle ownership costs and cost to the related energy supply chain.
- Identify the infrastructure changes required to support deployment of the vehicle fleet.
- Project the changes in emissions, including greenhouse gas emissions, resulting from each option including direct vehicle emissions as well as indirect effects to the energy supply chain.
- If possible, estimate health impacts in the Greater Cincinnati area associated with the recommended options.
- Prepare a final report that includes all tasks from the Fall Semester and Spring Semester.
- Provide an oral presentation of key findings at the end of the semester.