Team Control Number: #14323
Problem Chosen: B
2023 HiMCM

In a world where the climate crisis continues to loom, it's time to consider how every part of our lives impacts the climate. In cities with major public transit systems, which many rely on for their commute, one key aspect to consider is the emissions of those transit systems. One change that has begun to occur across the globe is the electrification of the public bus system. Thus, in our paper, we considered the various consequences of transitions from a diesel fleet to an all-electric fleet.

In Part I, we were asked to examine the environmental benefits of a transition and then create and apply a model to a metropolitan city of our choice whose population exceeded 500,000. We composed a model that compares the kilograms of greenhouse gasses emitted in the lifetime of a diesel bus to the number emitted in the lifetime of a battery-electric bus, then applied that model to Washington, D.C.'s Metrobus system. We found that fully transitioning its fleet of 1,600[1] diesel buses to electric buses would save 27,118,944kg CO_2 eq./kWh during its twelve-year lifetime.

In Part II, we were asked to consider the financial consequences of transitioning to an electric fleet, and then apply a financial model to the same city. We complied and determined that we would base our model off a comparative analysis between the currently used diesel buses by D.C and potential electric buses. In our model, we not only took into consideration the cost of purchase but also the cost of fuel compared to electricity and also the comparative cost of maintenance between the two. Our model concluded that D.C would save $75,461,591 in the long term if they transitioned their fleet from diesel to electric.

In Part III, we were asked to apply our ecological and financial models to three metropolitan areas—including our previously chosen city of Washington—in order to develop a 10-year plan that transportation officials could follow to transition to an electric bus no later than 2033. Through our ecological model, we found that each city stood to prevent tens of millions of kilograms of carbon dioxide or equivalent greenhouse gasses according to their energy use by transitioning to an electric fleet. Our financial model concluded that the cities could make the transition cost-effective by purchasing the buses starting now and fully replacing the fleet in 2028 because at that point lithium ion batteries are predicted to be less expensive than they currently are.

In Part IV, we were asked to write a one-page letter to transportation officials of one of the aforementioned cities and provide a recommendation for the transition to an all-electric fleet.

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[1] "Metro Snapshot 2022," WMATA, https://www.wmata.com/about/upload/Metro-Snapshot-2022_Final.pdf.

Part 0: General Information

0.1 General Assumptions

1. *Electric buses use lithium-ion batteries.* Much of the relevant literature on electric buses is based on buses powered by lithium-ion batteries. As the industry standard, lithium-ion batteries make the most sense for our project. This allows us to consider the true costs that transit systems currently face, since lithium-ion batteries are what they use, and incorporate information from existing research on the topic.
2. *Buses last for 12 years (and 250,000 miles), after which they will be replaced by a new bus.* In the US, transit systems are eligible to receive funding from the federal government to replace buses after 12 years.[2] Thus, it makes logical and financial sense that buses would have a lifetime of 12 years. This assumption allows us to consider both the financial implications of transitioning to an electric fleet and the environmental consequences of a bus's full lifetime.

Part I: Environmental Consequences

1.1 Problem Definition

The first part of the problem asked us to model the ecological consequences of transitioning a city's entire bus fleet to electric vehicles. We were asked to apply that model to a metropolitan area of our choice that does not yet employ an all-electric bus fleet.

1.2 Assumptions

1. *Each bus operates 365 days a year, and the distance traveled each day is split equally among them*. In a major city, many buses still operate on holidays, so considering all the days in a year would provide a full consideration of a fleet's emissions. Assuming equal distances allow us to find the average emissions for each bus, which helps in figuring out the emissions in a fleet as a whole.
2. *The composition of a bus–its frame and parts apart from the engine or battery–is the same regardless of whether it uses diesel or electricity*, *so the production of an electric bus (without the battery) will incur only as many emissions or fewer compared to a diesel bus.* The diesel bus's production might incur slightly more emissions because there are more parts, such as an exhaust pipe.
3. *Bus routes in major cities are similar in length to other major cities*. This allows us to consider studies done in other major cities when formulating our model.
4. *Urban buses emit CO_2 at the same rate per mile at all times*. Even with terrain changes, the stop-and-go nature of city traffic prevents cruising or other forms of efficient driving that might lower emissions per mile driven.
5. *Even as routes are adjusted periodically, the total mileage that the bus system covers,*

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[2] Christopher MacKechnie, "How Long Do Buses and Other Transit Vehicles Last?" Live About, Dotdash Meredith, January 16, 2019, https://www.liveabout.com/buses-and-other-transit-lifetime-2798844.

including all of its routes and their respective buses, will not change significantly. Demand for public transportation would not change significantly, so even as the city changes its bus routes over time, the overall mileage would not change.

6. *All current buses in use in the city are diesel*. That way, we can consider the ecological consequences of transitioning an entire fleet. Various major cities in the US, such as New York City[3] and Washington, D.C.,[4] have bus fleets where less than 1% of the buses are electric, so this assumption aligns with the reality of buses in the US.

1.3 Variables

Symbol	**Definition**	**Unit**
N	Number of buses in fleet	Buses
L	Number of bus lines	Bus lines
r	Number of times a route, assigned to a bus line, is completed daily	Bus route
E_{EV}	Lifetime emissions factor of battery electric bus fleet	kg CO_2 eq./kWh
E_D	Lifetime emissions factor of a diesel bus fleet	kg CO_2 eq./kWh
E_P	Emissions prevented when switching from diesel bus fleet to battery electric bus fleet (E_D - E_{EV})	kg CO_2 eq./kWh

We chose CO_2 eq emissions as the metric of the ecological consequences of buses because emissions are the main medium through which diesel buses influence the climate. Additionally, greenhouse gas emissions are the leading cause of climate change. CO_2 eq, short for CO_2 equivalent, is a metric measure that allows for comparisons between different greenhouse gasses. An amount of a greenhouse gas can be converted to its CO_2 equivalent, or the amount of CO_2 that would have the same global warming potential when emitted. In our model, we used *kg* CO_2 *eq./kWH*, which considers the amount of a greenhouse gas in kilograms for every kilowatt-hour. A kilowatt-hour is the amount of energy delivered by a kilowatt of power in one hour—this is a stable value of 3.6 megajoules. *kg* CO_2 *eq./kWH* is the most common unit used for greenhouse gas emissions caused by the use of fuel or other forms of energy in relevant literature.

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[3] "Transitioning to a zero-emissions bus fleet," MTA, October 13, 2023, https://new.mta.info/project/zero-emission-bus-fleet.

[4] "Zero-Emission Buses," WMATA, https://www.wmata.com/initiatives/plans/zero-emission-buses.cfm#.

1.4 Parameters

Parameter	**Value**	**Unit**	**Source, by author**
Lifetime emissions per battery	45.9	kg CO_2 eq./kWh	Bouter & Guichet.
Lifetime emissions per bus with 4 batteries	193.6	kg CO_2 eq./kWh	Bouter & Guichet.
Emissions factor of 1 completed bus route	0.6367	kg CO_2 eq./kWh	Rosero, et al.

1.5 Model Development

The first step in figuring out the lifetime emissions for an electric bus was finding the emissions from each battery. Over the lifetime of a lithium-ion battery in North America, it produces 45.9 kg CO_2 eq./kWh, a number found by an analysis of various life cycle assessment studies.[5] This includes the emissions from the raw materials, materials processing, battery manufacturing, electric vehicle operation (including charging), and end-of-life.[6] The electric buses that Washington, D.C. (our primary metropolitan area) has begun piloting have four batteries each.[7] Thus, the total emissions from batteries would be 45.9 kg CO_2 eq./kWh • 4, or 193.6kg CO_2 eq./kWh. Since we assume that the emissions from everything but the energy source would be constant between the e-buses and diesel buses—such as the metal used to construct the bus—and lithium-ion batteries are the energy source for e-buses, the lifetime battery emissions are what we will use as the lifetime emissions produced by a single electric bus. We then modeled the emissions factor of a fleet of electric battery buses accordingly:

$$E_{EV} = (45.9\, kg\, CO2\, eq./kWh\ \times\ 4) \times N\ =\ 193.6\, kg\, CO2\, eq./kWh\ \times N$$

A study in Madrid evaluating the fuel efficiency and emissions from an urban diesel bus engine during its operating period over a standard route found that the engine's tailpipe emissions had an emissions factor of 636.7g CO_2 eq./kWh per route, or 0.6367kg CO_2 eq./kWh.[8] The study evaluated Madrid's route 76 roundtrip, accumulating 17 kilometers, or 10.56 miles. A one way

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[5] Anne Bouter and Xavier Guichet, "The greenhouse gas emissions of automotive lithium-ion batteries: a statistical review of life cycle assessment studies," *Journal of Cleaner Production* 344 (10 April 2022).

[6] Yelin Deng et al, "Life cycle assessment of lithium sulfur battery for electric vehicles," *Journal of Power Sources* 343 (1 March 2017).

[7] Adam Tuss and Maggie More, "WMATA got $104M to bulk up electric bus facilities. Here's a look at the green energy changes Metro is investing in," NBC Washington, 30 August 2022, https://www.nbcwashington.com/news/local/transportation/wmata-got-104m-to-bulk-up-electric-bus-facilities-heres-a-look-at-the-green-energy-changes-metro-is-investing-in/3414105/.

[8] Fredy Rosero et al, "Real-world fuel efficiency and emissions from an urban diesel bus engine under transient operating conditions," *Applied Energy* 261 (1 March 2020).

trip on route 76 takes 28 minutes according to Madrid's public infrastructure management.

Most cities do not provide information on the mileage of their bus fleets or the individual buses in those fleets. Therefore, we chose to determine the emissions factor of a diesel bus fleet in terms of the average number of times each route in the city was completed. We assumed that every bus in the fleet would be active in completing those routes on a daily basis, 365 days a year through the fleet's 12 year lifetime. The fleet *collectively* would journey the average daily routes completed (r) on each of the bus lines (L) in the city. We can thus model the emissions factor of a fleet of diesel buses across its lifetime:

$$E_D = (0.6367\ kg\ CO2\ eq./kWh \times r \times L) \times 365 \times 12$$

For our final model, we subtracted E_{EV} from E_D, which represents the emissions saved by switching from a diesel fleet to an electric fleet.

$$E_P = E_D - E_{EV} = ((0.6367\ kg\ CO2\ eq./kWh \times r \times L) \times 4380) - (193.6 kg\ CO2\ eq./kWh \times N)$$

1.6 Application to Washington, D.C.

To estimate the collective lifetime carbon emissions of diesel buses in Washington, DC, we aimed to find the average number of times per day that a bus completed a route in the city.

We chose to evaluate emissions per route completed because D.C. does not disclose the daily mileage or use of each of the 1,600 buses, but it does list the frequency at which each of those routes is completed every day. There are 79 bus lines in Washington, D.C. proper. We sampled 10, including D.C.'s most popular lines (Pennsylvania Avenue and Wisconsin Avenue), as those best represent the city's most vital bus infrastructure. In those that we sampled, each route was completed on average 124.5 times per day. It's important to note that multiple buses follow these routes concurrently, so the route may be completed any number of times in a single hour in a day.

Route 76 in Madrid is shorter than the typical D.C. one-way route. For example, the 14th Street route takes 40-60 minutes to complete, and the Georgia Avenue to 7th Street route takes 60 minutes. Because our team has applied the Route 76 emissions quantity to D.C. bus routes, our estimation of the carbon emissions of diesel buses per route in Washington, D.C. is conservative.

In D.C. proper, $r = 124.5$ and $L = 79$. According to our model of lifetime emissions, a diesel bus system in D.C. would emit:

$$E_D, D.C. = (0.6367 \times 124.5 \times 79) \times 365 \times 12 = 27428711.3\ kg\ CO2\ eq./kWh$$

According to our model, an electric bus system in D.C. would emit:

$$E_{EV}, D.C. = 193.6\ kg\ CO2\ eq./kWh \times 1600 = 309760\ kg\ CO2\ eq./kWh$$

The difference between the two in D.C., or the emissions prevented, would be:

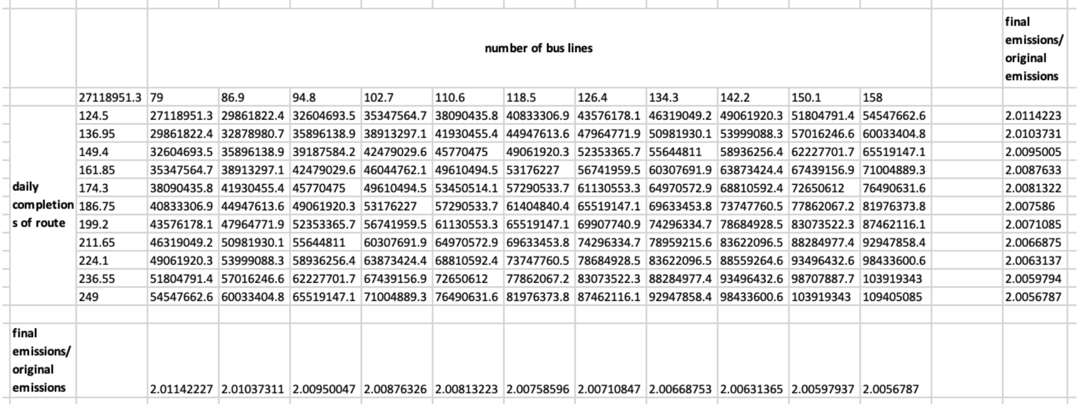
$$E_P, D.C. \;= E_D, D.C. - E_{EV}, D.C. \;=$$

$$27428711.3\ kg\ CO2\ eq./kWh\ -\ 309760\ kg\ CO2\ eq./kWh\ =\ 27118951.3\ kg\ CO2\ eq./kWh$$

Thus, Washington D.C. would prevent 27,118,951.3 kg CO_2 eq./kWh of emissions by converting their diesel bus fleet to an electric one.

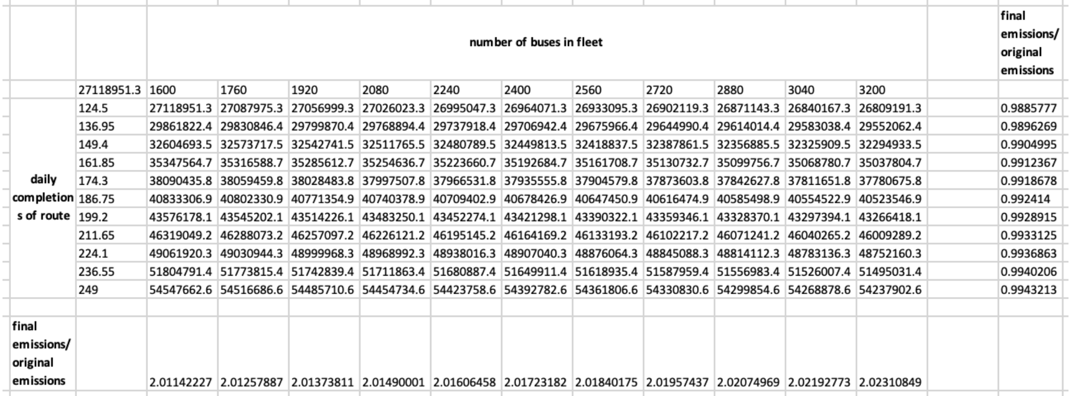
1.7 Sensitivity Analysis

Figure 1.7.1



		number of bus lines												final emissions/ original emissions
	27118951.3	79	86.9	94.8	102.7	110.6	118.5	126.4	134.3	142.2	150.1	158		
daily completions of route	124.5	27118951.3	29861822.4	32604693.5	35347564.7	38090435.8	40833306.9	43576178.1	46319049.2	49061920.3	51804791.4	54547662.6		2.0114223
	136.95	29861822.4	32878980.7	35896138.9	38913297.1	41930455.4	44947613.6	47964771.9	50981930.1	53999088.3	57016246.6	60033404.8		2.0103731
	149.4	32604693.5	35896138.9	39187584.2	42479029.6	45770475	49061920.3	52353365.7	55644811	58936256.4	62227701.7	65519147.1		2.0095005
	161.85	35347564.7	38913297.1	42479029.6	46044762.1	49610494.5	53176227	56741959.5	60307691.9	63873424.4	67439156.9	71004889.3		2.0087633
	174.3	38090435.8	41930455.4	45770475	49610494.5	53450514.1	57290533.7	61130553.3	64970572.9	68810592.4	72650612	76490631.6		2.0081322
	186.75	40833306.9	44947613.6	49061920.3	53176227	57290533.7	61404840.4	65519147.1	69633453.8	73747760.5	77862067.2	81976373.8		2.007586
	199.2	43576178.1	47964771.9	52353365.7	56741959.5	61130553.3	65519147.1	69907740.9	74296334.7	78684928.5	83073522.3	87462116.1		2.0071085
	211.65	46319049.2	50981930.1	55644811	60307691.9	64970572.9	69633453.8	74296334.7	78959215.6	83622096.5	88284977.4	92947858.4		2.0066875
	224.1	49061920.3	53999088.3	58936256.4	63873424.4	68810592.4	73747760.5	78684928.5	83622096.5	88559264.6	93496432.6	98433600.6		2.0063137
	236.55	51804791.4	57016246.6	62227701.7	67439156.9	72650612	77862067.2	83073522.3	88284977.4	93496432.6	98707887.7	103919343		2.0059794
	249	54547662.6	60033404.8	65519147.1	71004889.3	76490631.6	81976373.8	87462116.1	92947858.4	98433600.6	103919343	109405085		2.0056787
final emissions/ original emissions		2.01142227	2.01037311	2.00950047	2.00876326	2.00813223	2.00758596	2.00710847	2.00668753	2.00631365	2.00597937	2.0056787		

Figure 1.7.2



		number of buses in fleet												final emissions/ original emissions
	27118951.3	1600	1760	1920	2080	2240	2400	2560	2720	2880	3040	3200		
daily completions of route	124.5	27118951.3	27087975.3	27056999.3	27026023.3	26995047.3	26964071.3	26933095.3	26902119.3	26871143.3	26840167.3	26809191.3		0.9885777
	136.95	29861822.4	29830846.4	29799870.4	29768894.4	29737918.4	29706942.4	29675966.4	29644990.4	29614014.4	29583038.4	29552062.4		0.9896269
	149.4	32604693.5	32573717.5	32542741.5	32511765.5	32480789.5	32449813.5	32418837.5	32387861.5	32356885.5	32325909.5	32294933.5		0.9904995
	161.85	35347564.7	35316588.7	35285612.7	35254636.7	35223660.7	35192684.7	35161708.7	35130732.7	35099756.7	35068780.7	35037804.7		0.9912367
	174.3	38090435.8	38059459.8	38028483.8	37997507.8	37966531.8	37935555.8	37904579.8	37873603.8	37842627.8	37811651.8	37780675.8		0.9918678
	186.75	40833306.9	40802330.9	40771354.9	40740378.9	40709402.9	40678426.9	40647450.9	40616474.9	40585498.9	40554522.9	40523546.9		0.992414
	199.2	43576178.1	43545202.1	43514226.1	43483250.1	43452274.1	43421298.1	43390322.1	43359346.1	43328370.1	43297394.1	43266418.1		0.9928915
	211.65	46319049.2	46288073.2	46257097.2	46226121.2	46195145.2	46164169.2	46133193.2	46102217.2	46071241.2	46040265.2	46009289.2		0.9933125
	224.1	49061920.3	49030944.3	48999968.3	48968992.3	48938016.3	48907040.3	48876064.3	48845088.3	48814112.3	48783136.3	48752160.3		0.9936863
	236.55	51804791.4	51773815.4	51742839.4	51711863.4	51680887.4	51649911.4	51618935.4	51587959.4	51556983.4	51526007.4	51495031.4		0.9940206
	249	54547662.6	54516686.6	54485710.6	54454734.6	54423758.6	54392782.6	54361806.6	54330830.6	54299854.6	54268878.6	54237902.6		0.9943213
final emissions/ original emissions		2.01142227	2.01257887	2.01373811	2.01490001	2.01606458	2.01723182	2.01840175	2.01957437	2.02074969	2.02192773	2.02310849		

We conducted a sensitivity analysis to determine the extent to which changes in the variables and parameters as applied to Washington D.C.'s bus system would change the number of lifetime emissions in the fleet that we projected a transition to electric buses would prevent. We did so by increasing each variable's value by 10% of the original (D.C.) value, then determining the effect on the output of our model.

Number of lines (L) and Number of routes completed per day (r)

Because the number of emissions produced by a diesel bus fleet is a simple product of the number of lines, the number of routes per day, the quantity of emissions per route, and the days in the fleet's twelve-year lifetime, increasing either the number of lines per route or the number of routes per day by 10% of their original value increases the number of emissions prevented by the same rate. This is seen in Figure 1.7.1, where *r* and *L* increase the emissions prevented by the same rates for each corresponding value (2.01142 = 2.01142, which is the factor that emissions prevented increase by when one of the variables is held constant and the other is doubled).

Number of buses in fleet (*N*)

Thus, when seeing how the number of the buses in the fleet affects the emissions prevented compared to the other two variables, it is only necessary to do the side-by-side comparison with one of them. Doubling the daily completion of routes (*r*) more than doubles the emissions prevented regardless of the number of buses in the fleet. However, doubling the number of buses in the fleet (*N*) only slightly decreases the emissions prevented for every value of *r*. It's clear that adjusting the number of buses in the fleet has the smallest impact on the emissions prevented, while the number of lines and number of routes completed per day have the largest impact.

1.8 Discussion of Results

Strengths:

1. Our model considers the lifetime emissions of the buses, not just the emissions from one year. When looking at a policy and considering its ecological consequences, it's valuable to see what will happen in the long run, as a year or two may not be representative of the full effects. Looking at a longer period of time allows us to see how ecological trends will hold throughout various stages in an electric bus's life (first year vs last year), which leads to a more thorough analysis of the ecological consequences.
2. Our model considers the primary mechanism by which each type of bus produces greenhouse gas emissions. Diesel buses emit greenhouse gasses in the form of exhaust, often called "tailpipe emissions." While electric buses have no exhaust, they store and use electricity whose production results in some amount of carbon emissions. Our model derives emissions factors from the energy that each type of bus uses to drive at the point in the energy production process at which most of the emissions occur. The combustion of fossil fuels in the internal engines of buses, cars, and general transportation is the leading cause of climate change, while the fossil fuel combustion in the production of electricity comes in second.[9] It is therefore vital to consider those two processes not only as the main cause of emissions in the process of constructing and utilizing a bus–diesel or electric–but also as a major contributor to climate change globally.

Weaknesses:

1. Our model only considers greenhouse gas emissions of the buses themselves. While

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[9] "Sources of Greenhouse Gas Emissions," EPA, October 5, 2023, https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions#transportation

diesel buses impact the environment primarily through emissions, there are also other measures through which the climate is affected. For instance, our model does not consider the emissions from building and operating charging stations or the emissions from other infrastructure required for electric/diesel buses, but these may also be considerations when converting a diesel fleet into an electric one. There are also other contributors to climate change and the local environment, such as light, water, and noise pollution, that are not necessarily represented when simply looking at emissions.

Part II: Money Matters

2.1 Problem Definition

In this problem, we were tasked with constructing a model that focuses on the financial implications resulting from a conversion to e-buses and applying that model to the previous metropolitan area we examined, Washington D.C.

2.2 Assumptions

1. *The transition from diesel buses to electric buses is entirely new; there are no diesel-to-electric bus conversions*. This is reflective of reality, as retrofitted conversions often cost more than new buses themselves and perform significantly worse than purpose-built electric buses because they are not optimized for an electric power train[X]. Moreover, this was a necessary simplifying assumption because it would be nearly impossible to model how many new electric buses a city would opt to purchase versus how many would be diesel-to-electric converted.
2. *All buses stationed within the chosen metropolitan area will be replaced with electric buses.* The first problem describes "transitioning to an all-electric bus fleet", so we continued to model based on the assumption that all current diesel vehicles will be replaced by electric vehicles.
3. *Upfront purchase price of electric buses includes depot chargers, which are the only type of charger used.* The standard for agencies is to utilize overnight charging (depot charging), while only half use on route charging. Transit Cooperative Research Program reports that all agencies have depot charging while half utilize on-route chargers and only two use on-router wireless chargers[10]. Therefore, to standardize our model we will assume that only depot chargers are being used and purchased for the electric buses.
4. *Trends in the purchasing price of electric buses will closely follow trends in the price of lithium ion electric bus batteries.* This is a necessary simplifying assumption because… Our research determined that the single most influential factor underlying the purchasing cost of each bus is the cost of lithium ion batteries, which closely tracks the overall

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[10] Caley Johnson et al, "Financial Analysis of Battery Electric Transit Buses," National Renewable Energy Laboratory (June, 2020). https://afdc.energy.gov/files/u/publication/financial_analysis_be_transit_buses.pdf.

purchase price of electric buses[11].

2.3 Variables

Symbol	**Definition**	**Unit**
T	Total Cost	USD ($)
t	Current Year	Year
I	Cost Covered by Governmental Incentives	Percent (%)
B	Number of Buses Transitioned	Buses
C	Purchasing Cost of Electric Bus	USD ($)
D_P	Price of Diesel per Mile	USD ($) per mile
D_M	Miles per Diesel Gallon	Miles per Gallon
E_P	Price of Electricity per Mile	USD ($) per mile
E_M	Electricity Use per Mile	kWh per mile
F_E	Maintenance cost per Mile (Electric)	USD ($) per mile
F_D	Maintenance cost per Mile (Diesel)	USD ($) per mile
M	Lifetime Distance Traveled Per Bus	Miles
R	Residual Value	Percent (%)

Figure 2.3.1: Variable Definitions and Units

After defining our variables, we separated them into two categories: those that vary over time and those that stay static. Because our research revealed that the purchasing cost of each electric bus (C), the price of diesel per mile (D), and the price of electricity per mile (E) have varied

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[11] "Electric bus market size to grow by 61.03 thousand units between 2022 and 2027; Growth driven by a reduction in battery prices", PR Newswire, August 14, 2023. https://finance.yahoo.com/news/electric-bus-market-size-grow-115500181.html

significantly in the past, **we chose to develop models for each one over time**[12]. Conversely, other factors are relatively fixed costs and unlikely to vary over time. These include: cost covered by governmental incentives (I), maintenance cost per mile for electric buses (F_E), maintenance cost per mile for diesel buses (F_D), and Residual Value (R)[13]. **For these factors that are relatively static, we used literature values to determine baseline parameters** from our research to incorporate them into our model. Our final two variables, number of buses transitioned (B) and miles traveled (M), are entirely dependent on the city the model is applied to, thus it would be impossible to determine literature values for them.

2.4 Parameters

We conducted research to establish baseline parameters for the fixed values. These can be seen in **Figure 2.4.1**, below.

Parameter	**Value**	**Unit**	**Source**
F_E, Maintenance cost per Mile (Electric)	$0.55 per mile	$/mi	Peter Maloney[14].
F_D, Maintenance cost per Mile (Diesel)	$1.53 per mile	$/mi	Peter Maloney[15].
I, Percent of Cost Covered by Governmental Incentives	6.25%	%	DCIST[16]
R, Residual Value	15%	%	Caley Johnson et al.[17]
E_M, Electricity Use per Mile	2.15kWh/mi	kWh/mi	National Renewable Energy Laboratory[18]
D_M, Diesel Miles Per Gallon	4.82 mi/gallon	mi/gallon	Jimmy O'Dea[19]

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[12] "Flipping the Switch on Electric School Buses: Cost Factors: Module 1," US Department of Energy, https://afdc.energy.gov/vehicles/electric_school_buses_p8_m1.html

[13] Caley Johnson et al, "Financial Analysis of Battery Electric Transit Buses," National Renewable Energy Laboratory (June, 2020). https://afdc.energy.gov/files/u/publication/financial_analysis_be_transit_buses.pdf.

[14] Peter Maloney, Electric buses for mass transit seen as cost effective, 2019, https://www.publicpower.org/periodical/article/electric-buses-mass-transit-seen-cost-effective.

[15] Peter Maloney.

[16] "Infrastructure Law Pays for 100 New Electric Buses for Metro," DCist, June 7, 2018, https://dcist.com/story/23/06/27/100-new-electric-buses-for-metro/.

[17] Caley Johnson.

[18] Ayre, James. "Electric Buses Efficient as He**, Nrel Finds." CleanTechnica, February 22, 2016. https://cleantechnica.com/2016/02/22/electric-buses-efficient-as-he-nrel-finds/.

[19] Jimmy O'Dea, "
Electric vs. Diesel vs. Natural Gas: Which Bus is Best for the Climate?" T

Figure 2.4.1: Baseline Parameters

2.5 General Model Development

We began with a general model of the financial implications of the transition to electric buses. Through our research, we attempted to capture both the *initial* cost of the transition and the *cumulative* costs/savings of the new electric buses relative to their diesel counterparts. For a single bus, this is represented by the equation:

$$T = C(t) + M(E(t) + F_E - D(t) - F_D)$$

Where $C(t)$ represents the purchasing cost of the electric bus, M represents the lifetime distance traveled by the bus, $E(t)$ represents the price of electricity per mile, $F(t)_E$ represents maintenance cost per mile (electric), $D(t)$ represents the price of diesel fuel per mile, and $F(t)_D$ represents maintenance cost per mile (diesel).

To view the financial consequences from a larger lens, we then took into account the number of buses that need to be transitioned by multiplying our one bus model by B, the total number of buses transitioned. This is represented by the equation below.

$$T = B \times [C(t) + M(E(t) + F_E - D(t) - F_D)]$$

Finally, we took into consideration both the parameter of government incentives (I) — determining the percentage of the cost any given city would actually have to pay — and the parameter of residual value (R), the value of the vehicle at sale after government use has ceased. Using our established parameter values, we end up with the following working equation:

$$T = B \times [1 - 0.0625] \times [(1 - 0.15) \times C(t) + M(E(t) + 0.55 - D(t) - 1.53)]$$

This overall equation provides a general model for whether a transition from diesel to electric is likely to come at a net cost (positive values) or a net savings (negative values).

2.6 Variable Model Development

For the factors that varied over time, we analyzed data in the existing academic literature to model their growth by year.

To model **Price of Electricity per Mile (*E*)**, we first analyzed Average Price Data from the Consumer Price Index (CPI) at the Bureau of Labor Statistics over the past ten years on Electricity Cost per kWh[20]. Because Electricity Prices are linear in nature – there is no clear exponential or logarithmic trend that would explain their variation over time – we conducted a linear regression on the data. That data and the resulting linear regression are represented by **Figure 2.6.1**, below.

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[20] "Average energy prices for the United States, regions, census divisions, and selected metropolitan areas," US Bureau of Labor Statistics, https://www.bls.gov/regions/midwest/data/averageenergyprices_selectedareas_table.htm

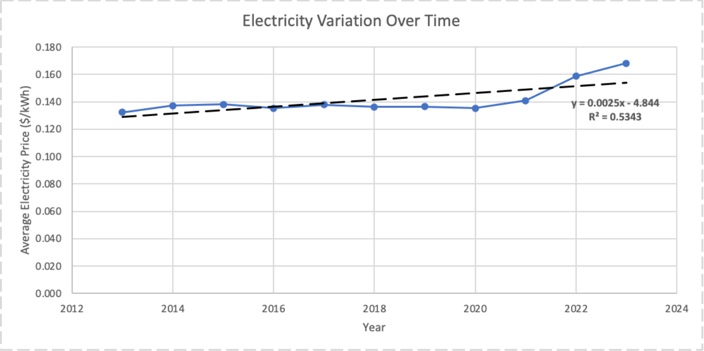

Figure 2.6.1: Electricity Variation Over Time

To find the resulting model of electricity price per mile, we took this linear regression of electricity price per kWh and applied our established parameter value for electricity use per mile (E_M) of 2.15 kWh/mi to determine electricity cost per mile. The resulting model for E is given by ***E(t)*** $= 2.15 \times (0.0025t - 4.844)$ ($/mi).

To model the **Price of Diesel per Mile** (D_P), we first analyzed diesel prices per gallon and their variation over time from thousands of data points in the US Energy Information Administration database[21]. Because Diesel Prices per Gallon are also linear in nature—again, there is no clear exponential or logarithmic trend that would explain their variation over time—we conducted a linear regression on the data. This is visualized in **Figure 2.6.2,** below.

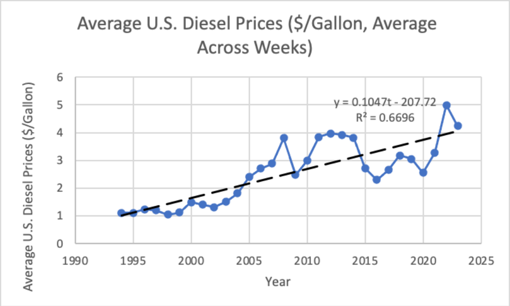

Figure 2.6.2: Historical U.S. Diesel Prices Per Gallon

To find the resulting model of Price of Diesel Per Mile ($D_P(t)$) we took our regression for diesel price per gallon and applied our established parameter value for diesel miles per gallon (D_M) of 4.82 mi/gallon. The resulting model for D_P is given by $\boldsymbol{D_P(t)} = \frac{0.1047t - 207.72}{4.82}$ ($/mi).

Finally, to model the **purchasing cost of each electric bus (*C*)**, we researched the factors underlying that cost. Through that research, we determined that the single most influential factor underlying the purchasing cost of each bus is the cost of lithium ion batteries, which closely

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[21] US Energy Information Administration, https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_w.htm.

tracks the overall purchase price of electric buses.[22]

Knowing that the two track each other closely—and due to the relative unavailability of comprehensive datasets on electric bus prices—we conducted a regression on historical battery cost using data from the Office of Energy Efficiency and Renewable Energy[23]. We decided that an exponential regression would capture the tendency for these costs to converge to a particular value—as much of the historical decrease is likely due to economies of scale, which would be unlikely to continue in the future.[12] Combined with a high R^2 value, we ultimately determined that this was a great fit of the data. This is visualized in **Figure 2.6.3**, below.

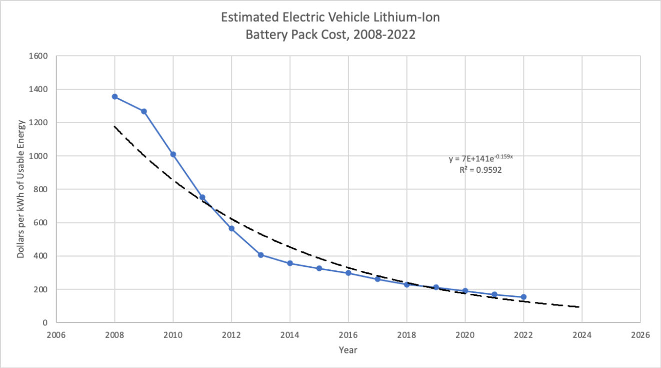

Figure 2.6.3: Historical EV Battery Cost Shifts

To determine the relative future decrease in cost as a percentage (%), we took this regression and divided it by the current cost value.

This is represented by the expression: $\frac{153-[7 \times 10^{141} \times e^{-0.159x}]}{153}$.

After calculating this relative cost decrease percentage, we applied it to the current cost value of electric buses, which our research determined was \$400,000,[24] to derive an equation for purchasing cost in a future year *t*:

$$C(t) = \frac{153-[7 \times 10^{141} \times e^{-0.159x}]}{153} \times 400,000$$

Thus, taking our earlier equation of the parameters:

$$T = B \times [1 - 0.0625] \times [(1 - 0.15) \times C(t) + M(E(t) + 0.55 - D(t) - 1.53)]$$

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[22] "Electric bus market size to grow by 61.03 thousand units between 2022 and 2027; Growth driven by a reduction in battery prices - Technavio," PR Newswire, August 14, 2023,

[23] Vehicle Technologies Office. "FOTW #1272, January 9, 2023: Electric Vehicle Battery Pack Costs in 2022 Are Nearly 90% Lower than in 2008, According to DOE Estimates." Energy.gov, January 9, 2023. https://www.energy.gov/eere/vehicles/articles/fotw-1272-january-9-2023-electric-vehicle-battery-pack-costs-2022-are-nearly.

[24] Caley Johnson et al.

We simplify each term and incorporate the equations developed for $C(t)$, $E(t)$, and $D(t)$. This produces our final model, below.

$$T = B \times 0.9375 \times \{0.85 \times (1 - \frac{153-[7 \times 10^{141} \times e^{-0.159x}]}{153}) \times 400,000) + M([2.15 \times 0.0025t] - 4.844 + 0.55 - \frac{0.1047t-207.72}{4.82} - 1.53)\}$$

2.7 Application to Washington, D.C

After researching, developing, and refining our model in sections 2.5 and 2.6 of this paper we applied our model to the city of Washington, D.C in order to analyze the financial implications of a real world city. This numerical value was sourced from Washington Metropolitan Area Transit Authority, which states that 1,600 buses operate within D.C's metrobus system[25]. To apply the above model for T to Washington, D.C, we set B to 1,600 buses[26], M to 250,000 miles[27], and t to 2023. Thus, our final model in the context of Washington D.C is shown below.

$$T = 1600 \times ([0.9375] \times \{(0.85) \times (1 - \frac{153-[7 \times 10^{141} \times e^{-0.159x}]}{153}) \times 400000) + (250,000)([2.15 \times (0.0025(2023) - 4.844) + 0.55 - \frac{0.1047(2023)-207.72}{4.82} - 1.53)\})$$

Our final model predicts a savings of $47,163 per bus across its lifetime, with the overall value of *T* = $75,461,591.

As stated in our General Model Development section, a negative value is indicative that the overall cost of diesel powered buses is greater than that of electric buses. Thus, because we are analyzing the financial implications of the transition from diesel buses to electric there will be an overall net savings indicated by our negative T value. Our results indicate that, if Washington D.C were to fully transition to electric buses, they would see a net savings of $75,461,591.

Therefore, through comparative analysis of our model and results we have determined that — despite the upfront costs of electric buses — the long term savings provide significant net benefits to D.C.

2.8 Model Assessment

We then tested the robustness of our model through sensitivity analysis, determining the relative consequence of each parameter variable, and a literature meta-analysis that compares our findings to others in the literature base. Collectively, these assessments allowed us to critically analyze our model's predictive ability.

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[25] "Metro Snapshot 2022."

[26] "Metro Snapshot 2022."

[27] Christopher MacKechnie.

2.8.1 Sensitivity Analysis

We incorporated sensitivity analysis to identify how variations in input values impact our model's results. We varied each variable and parameter by 10% in order to determine the significance of each variable in equation output, T. This can be seen in **Figure 2.8.1.1,** below.

Variable/Parameter	**Definition**	**Effect on Output**
I	Cost Covered by Governmental Incentives	+4.17%
B	Number of Buses Transitioned	+10%
C	Purchasing Cost of Electric Bus	–62.57%
D_P	Price of Diesel per Mile	44.96%
E_P	Price of Electricity per Mile	–24.33%
F_E	Maintenance cost per Mile (Electric)	–29.15%
F_D	Maintenance cost per Mile (Diesel)	+81.1%
M	Lifetime Distance Traveled Per Bus	+72.6%
R	Residual Value	+11.04%

Figure 2.8.1.1: Sensitivity Analysis for Financial Considerations

The sensitivity analysis reveals that variations in the Purchasing Cost of each Electric Bus, Price of Diesel per Mile, Price of Electricity per Mile, Maintenance cost per Mile (Electric), Maintenance cost per Mile (Diesel), and Lifetime Distance Traveled Per Bus had outsized ($> 20\%$) impacts on our results. Thus, we determined these factors to be both the most *influential* in our model and therefore the most important to model in future work to accurately predict the total cost of transitioning to an all-electric bus fleet.

2.8.2 Literature Review

We conduct a meta-analysis of existing academic literature to investigate the economic results of an electric transit bus transition and compare those results to our own findings.

Analyzing 8 articles in the existing empirical literature, we found that 6 associated savings with a transition to electric transit buses,[28, 29, 30, 31, 32, 33] while 2 suggested that such a shift would come at a net cost[34, 35]. However, the articles concluding a net cost were analyzing non-US cities — namely Brunei and Latvia. Thus, these findings largely support our results that a transition to electric buses will result in net savings over the lifetime of the bus.

2.9 Discussion of Results

Strengths:

1. Our model analyzes the financial implications of a transition to electric buses from a *total cost of ownership* point of view. We performed a holistic analysis, taking into account the purchasing price of the electric *(C)* bus but also the cost of maintenance (F_E) and operation *(E)*. Through this process we uncover not just the upfront costs of purchasing the bus but also the underlying costs of investing in a fully electric fleet of buses. This facet of our model allows us to view the financial consequences of electric buses in a more expansive, nuanced and sophisticated lens.
2. In addition to a holistic analysis, our model operates on the basis of a comparison between the total cost of a city of diesel buses versus one of electric buses. By utilizing a comparison we are able to not only determine the cost of electric buses but also model whether the replacement of current diesel buses in the city is financially beneficial.
3. Our additional data analysis of literature values relating to the pricing of electric buses adds a layer of nuance to our model. Our model assesses the pricing of electric buses in comparison to diesel buses at one specific point in time. With our additional analysis we are able to predict how factors that contribute to the cost of electric buses will change over time.

Weaknesses:

1. Our model doesn't take into consideration how terrain and weather impacts fuel

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[28] Caley Johnson et al, "Financial Analysis of Battery Electric Transit Buses," National Renewable Energy Laboratory (June, 2020). https://afdc.energy.gov/files/u/publication/financial_analysis_be_transit_buses.pdf

[29] Neil Quarles, Kara M. Kockelman, and Moataz Mohamed, "Costs and Benefits of Electrifying and Automating Bus Transit Fleets," MDPI, May 13, 2020, https://www.mdpi.com/2071-1050/12/10/3977.

[30] A. Alam et al., "Life Cycle Ownership Cost and Environmental Externality of Alternative Fuel Options for Transit Buses," Transportation Research Part D: Transport and Environment, October 8, 2017, https://www.sciencedirect.com/science/article/abs/pii/S136192091630476X#f0025.

[31] Richard Nunno, "Fact Sheet: Battery Electric Buses: Benefits Outweigh Costs," Environmental and Energy Study Institute (EESI), 2018, https://www.eesi.org/papers/view/fact-sheet-electric-buses-benefits-outweigh-costs.

[32] "VEIC and DEC Share Report on Electric Bus Pilot Project," Department of Environmental Conservation, September 5, 2023, https://dec.vermont.gov/news/veic-and-dec-share-report-electric-bus-pilot-project.

[33] "Electric Buses in America," Public Interest Research Group, October 2019, https://environmentamerica.org/wp-content/uploads/2022/07/US_Electric_bus_scrn-3.pdf.

[34] Aigars Laizāns, Igors Graurs, and Aivars Rubenis, "Economic Viability of Electric Public Busses: Regional Perspective," Procedia Engineering, February 5, 2016, https://www.sciencedirect.com/science/article/pii/S1877705816000163.

[35] Nurizyan Khairiah Yusof et al., "Techno-Economic Analysis and Environmental Impact of Electric Buses," MDPI, February 19, 2021, https://www.mdpi.com/2032-6653/12/1/31.

efficiency. For example, a bus, whether diesel or electric, driving uphill will exert significantly more energy compared to a bus driving down hill. Therefore, the amount of electricity needed for a bus to complete its route is dependent on how hilly or mountainous the terrain of the city of operation is. Moreover, Power Integrations, an innovator in the semiconductor industry, explains that electric vehicles are vulnerable to extreme temperatures.[36] They go on to state that testing finds there's an up to 30% range reduction in moderate cold and 50% in colder regions. These percentages indicate that in addition to terrain, weather significantly impacts the amount of energy vehicles exert. Therefore, a potential improvement would be to potentially include the factor of terrain and weather into our model.

Part III: Ten Year Road Map

3.1 Problem Definition

As cities transition to a fully electric bus fleet, they'll take on a significant burden in acquiring buses, accommodating the current demand for public transportation in their respective cities, and convincing the public of the utility of the transition itself. We have been asked to outline a plan to execute a full transition in three metropolitan areas, including our previously chosen city of Washington, D.C., to be completed no later than 2033.

3.2 Assumptions

1. *All funds allocated for the electric bus transition by the federal government in 2023 have yet to be used*. Washington, D.C, for example, remains in the planning stage of rolling out its electric buses, so it's reasonable to assume that those funds are still available for our use. What little of that money that could have already been spent is unknown.
2. *All cities would make a 1:1 transition, exchanging one diesel bus for one electric bus*. Cities in particular offer advantageous environments for electric buses because of their limited space.
3. *All cities will buy from the same company, purchasing the same model at the same price.* This is a reasonable assumption to make as in the real world different cities may choose to purchase buses from different companies or at different prices. However, we are unable to predict which companies these cities will purchase from, therefore, we will assume that the pricing for one electric bus remains at $400,000.

3.3 10 Year Road Map

Through research from our financial analysis of the transition from diesel to electric buses, we determined that as time goes on, the price of purchasing an electric bus will also decrease. To summarize, this is primarily due to the cost of lithium ion batteries, the power source of electric

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[36] "Impact of Climate on the Range of Electric Vehicles," Power Integrations, May 16, 2023, https://www.power.com/community/green-room/blog/impact-climate-range-electric-vehicles.

buses. These batteries are the most expensive part of purchasing an electric bus.[37] Therefore, in order to optimize net profit, cities should purchase buses when llithium ion batteries cost the least. Luckily, though through evaluating and analyzing Figure 2.6.3 we believe that it is optimal to purchase electric buses after a period of 5 years. We decided that cities should begin to purchase and replace their electric buses in 2028 due to the fact that lithium ion battery prices are predicted to drop from what they currently stand at.

Thus, when applying our financial model to our three cities (Washington D.C, Phoenix and Boston) our t-value will be held constant at 2028 because that is the year we plan on the cities purchasing their buses.

Moreover, when applying our financial model to the three cities we will be both calculating the total net savings of the purchase in the long term while also calculating the total upfront costs of purchasing the electric buses.

3.3.1 Washington, D.C.

While Washington D.C. received $104M from the Inflation Reduction Act to cover costs in transitioning to a fully electric bus fleet, but has yet to fully implement such a transition. We recommend that the city take the following steps:

3.3.1.1 Environmental Consequences

As mentioned in Section 2.6, Washington D.C. would eliminate 27,118,951.3 kg CO_2 eq./kWh in the lifetime of its bus fleet of 1600.

3.3.1.2 Money Matters

Using our financial model we were able to predict that there will be a total net savings of $\$75,461,591$ if Washington, D.C were to transition to a fleet of electric buses. However, this value would not provide us with information about how much the total purchase of the electric buses were.

Therefore, to evaluate the total cost of the upfront purchase we would only need to multiply the set cost of one electric bus by the number of electric buses within D.C.

Thus, if we multiplied the set cost of one electric bus by the number of electric buses within D.C our equation would yield the value listed below.

$$Total\ cost\ of\ purchase\ =\ 400,000\ *\ 1,600$$

$$Total\ cost\ =\ 640,000,000$$

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[37] Vishnu Nair, et al, "Medium and Heavy-Duty Electrification Costs for MY 2027- 2030," February 2, 2022, https://blogs.edf.org/climate411/wp-content/blogs.dir/7/files/2022/02/EDF-MDHD-Electrification-v1.6_20220209.pdf.

Therefore, replacing all buses within Washington D.C would cost $640,000,000. However, as noted in the beginning of section 3.3, Washington D.C. received $104M from the Inflation Reduction Act to aid in the replacement of diesel buses within the city. Moreover, through our financial analysis model in Part II we have determined we are able to save $\$75,461,591$ in the long term.

Thus, if we take the Inflation Reduction Act and the long term financial benefits into consideration we are left with $460,538,409 and save $179,461,591 in total, as seen below.

$$Total\ cost\ after\ adjustment\ =\ 1600(400000)\ -\ (104,000\,000\ +\ 75,461,591)$$

3.3.2 Boston, MA

3.3.2.1 Ecological Consequences

The MBTA employs 1,037 buses to complete 152 routes an average of 86.4 times per day, again using a sample of 10 of the routes that the city has designed.[38] It's important to note that all of the routes sampled took about 30 minutes, which is almost exactly the length of the route used in the Madrid study measuring the quantity of emissions per route.

$$E_{EV} = (45.9\ kg\ CO2\ eq./kWh\ \times\ 4)\ \times\ 1037\ =\ 190,393.2\ kg\ CO2\ eq./kWh$$

$$E_{D} = (0.6367\ kg\ CO2\ eq./kWh\ \times\ 86.4\ \times\ 152)\ \times\ 365\ \times\ 12\ =\ 36,666,432.41\ kg\ CO2\ eq./kWh$$

$$E_{P} = E_{D} - E_{EV} =\ 36,476,039.21\ kg\ CO2\ eq./kWh$$

Boston would prevent 36,476,039.21 kg CO_2 eq. /kWh in the twelve-year lifetime of its fleet of 1,037 buses if it transitioned to a fully electric fleet.

3.3.2.2 Money Matters

According to the MBTA, the Boston bus system operates 1055 buses total.[39] Therefore, we adjust the amount of buses being purchased to be 1055. Therefore, the total initial upfront costs of purchasing electric buses in the city of Boston would add up to be $422,000,000, as seen in the equation below.

$$Total\ cost\ of\ purchase\ =\ 400,000\ *\ 1,055\ =\ 422,000,000$$

However, similar to Washington D.C funds ($34.3 million) have been allocated to the transportation system to fund the transition from diesel buses to electric.[40] Moreover, through our

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[38] Massachusetts Bay Transportation Authority. "Bus Schedules." MBTA. Accessed November 14, 2023. https://www.mbta.com/schedules/bus.

[39] "The MBTA Vehicle Inventory Page," November 3, 2023, http://roster.transithistory.org/.

[40] "Healey-Driscoll Administration Announces Final Allocation of Volkswagen Settlement Funds to Support Transition to Electric Vehicles," Massachusetts Department of Environmental Protection, April 21, 2023, https://www.mass.gov/news/healey-driscoll-administration-announces-final-allocation-of-volkswagen-settlement-funds-to-support-transition-to-electric-vehicles.

financial analysis model in Part II of this paper we are able to determine that in the long run Boston will save $49,757,486.49.

Therefore, taking into consideration these two factors we are then able to calculate the adjusted cost of purchasing and replacing buses in Boston. This value will amount to …… as seen in teh equation below.

3.3.3 Phoenix, AZ

Phoenix, AZ has a population of X.

3.3.3.1 Ecological Consequences

The current diesel bus system in Phoenix employs 1061 buses ($N = 1061$) to serve 63 lines of service ($L = 63$). Each route is completed by a bus 71.8 times per day on average ($r = 71.8$), according to a sample of 10 of those lines of service.[41] Similarly to Boston, each of the routes sampled in Phoenix was about 30 minutes long.

$$E_{EV} = (45.9\, kg\ CO2\ eq./kWh\ \times\ 4) \times 1061\ =\ 194,799.6\, kg\ CO2\ eq./kWh$$

$$E_{D} = (0.6367\, kg\ CO2\ eq./kWh \times 71.8 \times 63) \times 365 \times 12\ =\ 12,614,613.66\, kg\ CO2\ eq./kWh$$

$$E_{P} = E_{D} - E_{EV} =\ 12,419,814.06\, kg\ CO2\ eq./kWh$$

Phoenix's bus system would prevent 12,419,814 kg CO_2 eq./kWh in the twelve year lifetime of its fleet if it transitioned its entire bus fleet to electric vehicles.

3.3.3.2 Money Matters

Currently, as stated in section 3.3.3.1, Phoenix employs 1061 buses. Therefore, we adjust the number of buses being purchased accordingly, producing a total upfront cost of $\$424,400,000$ as seen in the equation below.

$$Total\, cost\ =\ 1061\ *\ 40000\ =\ 424,400,000$$

However, Phoenix has also subsidized it's transportation system with $230 million dollars to switch from diesel buses to electric. Therefore, taking these subsidies and our Part II model –adjusted to the context of Phoenix– will yield a final adjusted savings of **$280,040,467**.

3.4 Discussion of Results

A strength of our model is that it takes into account not only the upfront cost of the purchase of battery-electric buses but additionally the government assistance, subsidies, and long-term financial benefits that our Part II model outlined.

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[41] "My eTransit Book," Valley Metro, https://www.valleymetro.org/maps-schedules/my-etransit-book.

A second strength is that it reduces emissions to a significant extent more immediately than even a 10-year plan might allow. Five years of tailpipe emissions in cities across the country could significantly alter global emissions resulting from public transportation. By following the most cost-effective route, we reduced emissions even further than might be expected.

A weakness to our model is the assumption that the charge of a battery-electric bus would match exactly the daily capacity of a diesel bus. In some conditions, battery-electric buses' battery performance does not cover the full length of previous bus routes.[42] That would theoretically require a larger fleet of electric buses to cover the existing demand; however, city traffic is particularly advantageous for electric buses because of its short range for a longer period of time, so the demand for vehicles likely wouldn't significantly exceed the current need.

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[42] Verbrugge, Boud, Mohammed Mahedi Hasan, Haaris Rasool, Thomas Geury, Mohamed El Baghdadi, and Omar Hegazy. "Smart Integration of Electric Buses in Cities: A Technological Review." MDPI, November 4, 2021. https://www.mdpi.com/2071-1050/13/21/12189.

Part IV: One-Page Letter

To the Washington Metropolitan Area Transit Authority:

As our world adapts to climate change and seeks to prevent it as quickly as possible, it has become increasingly clear that every emission contributes to climate change that threatens the integrity of the earth that we live on. While public transportation is one of the most efficient means of transportation available, buses continue to emit regularly. Utilizing the resources allocated by governments in the last several years to weaken those emissions, we've outlined a model that would allow the city of Washington, D.C. to transition to a fully electric bus fleet while also measuring the ecological and financial benefits of doing so.

We evaluated the current tailpipe emissions of WMATA buses–the system's primary form of emissions–in terms of the number of bus routes completed in the lifetime of the fleet. We then projected the lifetime emissions of a battery-electric bus fleet including emission associated with charging, production, and use of the batteries. We found that doing so would prevent 27,118,951.3 kg CO_2 eq./kWh in emissions.

The cost of transitioning from an entire city of diesel buses to electric buses is a heavy financial burden. When asked to evaluate the financial implications of a transition from diesel to gas we determined that a model comparing the long term costs of diesel buses and electric buses would be the most optimal. Through our model we were able to determine that despite the intimidating cost of investment that comes with purchasing electric buses the net savings are surprisingly large. We found that this was mainly due to the projected decrease in the cost of lithium ion batteries. However, the price of lithium ion batteries is projected to decrease in the near future, making electric buses a more affordable option. Through our model we determined that if Washington D.C were to switch to a fully electric bus system then we would save $\$75,461,591$ in the long term. The magnitude of this number is only another reason to jumpstart a transition to electric buses.

We strongly recommend that the city of Washington follow our plan of advertising the projected cost-effectiveness of the transition as well as the prevention of greenhouse gas emissions and then completing the transition to battery-electric buses in 2028, at which point lithium ion batteries that would power the fleet will drop in expense.

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