Engineering a Sustainable Future: Evaluating the Multifaceted Impacts of Transitioning to All-Electric Bus Fleets in Urban Areas

Kewen Mao [†,*], Hiu fung Liang [†], Yanxi Wu [†], Ruixuan Shi [†]

Guangzhou Foreign Language School, Guangzhou 511455, China

* Corresponding Author Email: mkwkevin@163.com

[†] These authors contributed equally.

Abstract. The global shift towards electric buses in urban transportation, driven by growing concerns over air pollution and climate change, represents a significant departure from the traditional reliance on diesel buses. However, the transition from fossil fuel-powered to electric buses is a complex process that, if not properly managed, could lead to unintended ecological consequences. To comprehensively assess the environmental impact of transitioning to an all-electric bus fleet, we developed an innovative environmental index model that goes beyond the conventional well-to-wheel (WTW) analysis of pollutants. Our model incorporates a wide range of environmental factors, including greenhouse gases (GHG), soil and water pollution, and waste accumulation, providing a holistic view of the ecological footprint of electric buses. Furthermore, to evaluate the financial viability of this transition, we constructed a break-even point model that considers the initial costs and long-term operational savings associated with electric buses. To enhance the accuracy and reliability of our financial projections, we employed advanced time series models, namely ARIMA and linear regression, to forecast future oil and electricity prices. By integrating these economic forecasts into our break-even point model, we developed a comprehensive framework for assessing the financial feasibility of transitioning to an all-electric bus fleet by 2033. Leveraging this framework, we created detailed ten-year roadmaps for three major U.S. cities – New York, Los Angeles, and San Francisco – outlining the strategic steps required to achieve a sustainable and cost-effective transition to electric buses. Our findings provide valuable insights for policymakers, urban planners, and transportation authorities, empowering them to make informed decisions as they navigate the complexities of adopting electric buses in their cities.

Keywords: Environmental Index, Break-Even Point, ARIMA, Linear Regression, WTW Analysis, Sustainable Transportation.

1. Introduction

The urban transportation landscape is undergoing a profound transformation, with cities worldwide increasingly adopting electric buses as a sustainable alternative to traditional diesel-powered vehicles. This shift is primarily driven by the urgent need to address the pressing issues of air pollution and climate change, which have become major concerns for urban policymakers and residents alike [1]. As the negative environmental impacts of fossil fuel-powered transportation become more apparent, the transition to electric buses has emerged as a critical strategy for mitigating greenhouse gas emissions and improving air quality in cities [2]. However, the transition from fossil fuel-powered to electric buses is not a simple process. It involves complex environmental, economic, and social considerations that must be carefully evaluated to ensure a successful and sustainable implementation [3]. While electric buses offer significant potential for reducing the carbon footprint of urban transportation, their adoption also raises important questions about the ecological consequences of their production, operation, and disposal [4]. Moreover, the financial viability of electric buses remains a key concern for many cities, as the upfront costs of purchasing and installing charging infrastructure can be substantial [5].

To address these challenges, there is a pressing need for comprehensive and innovative approaches to assessing the environmental impact and financial feasibility of transitioning to electric buses.

Existing studies have primarily focused on well-to-wheel (WTW) analyses of pollutants and greenhouse gas emissions [6, 7], but have often overlooked the broader range of environmental factors that contribute to the ecological footprint of electric buses. Furthermore, while some studies have examined the economic aspects of electric bus adoption [8-10], there remains a need for more sophisticated financial models that can account for the dynamic nature of energy prices and the long-term costs and benefits of electric buses.

In this study, we aim to fill these research gaps by developing a comprehensive environmental index model that goes beyond conventional WTW analysis to incorporate a wide range of ecological factors, including greenhouse gases, soil and water pollution, and waste accumulation. By providing a holistic assessment of the environmental impact of electric buses, our model offers a novel and valuable tool for policymakers and urban planners considering the transition to electric buses. Additionally, we construct a break-even point model that integrates advanced time series forecasting techniques, namely ARIMA and linear regression, to predict future oil and electricity prices and assess the financial viability of electric bus adoption. By combining these innovative methodological approaches, we develop detailed ten-year roadmaps for transitioning to an all-electric bus fleet in three major U.S. cities – New York, Los Angeles, and San Francisco – by 2033. Our study makes several key contributions to the existing literature on electric bus adoption. First, we introduce a novel environmental index model that provides a comprehensive assessment of the ecological impact of electric buses, considering a broader range of environmental factors than previous studies. Second, we develop a sophisticated financial model that accounts for the dynamic nature of energy prices and provides more accurate and reliable projections of the costs and benefits of electric bus adoption. Finally, we present practical insights and recommendations for policymakers and urban planners through the development of detailed ten-year roadmaps for three major U.S. cities, showcasing the potential for our approach to inform real-world decision-making.

The remainder of this paper is structured as follows: Section 2 presents our environmental index model, detailing the methodology and data sources used to assess the ecological impact of electric buses. Section 3 describes our break-even point model and the time series forecasting techniques used to predict future oil and electricity prices. Section 4 discusses the development of our ten-year roadmaps for New York, Los Angeles, and San Francisco, highlighting the key findings and recommendations for each city. Finally, Section 5 concludes the paper, summarizing our main contributions and outlining potential avenues for future research.

2. Ecological Consequences' Model

2.1. Identify Relevant Items

In this study, the team aimed to more accurately assess ecological impacts by incorporating a range of pollutants into our models, encompassing all contaminants generated during the conversion process.

2.1.1 Greenhouse Gasses

Greenhouse gases (GHGs) are crucial atmospheric constituents that trap and emit thermal infrared radiation, contributing to the greenhouse effect. The primary greenhouse gases in Earth's atmosphere include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). These gases constitute a group of pollutants, which will be further explored in subsequent discussions. Our approach employs a well-to-wheel (WTW) analysis to provide a comprehensive assessment of the environmental impacts associated with transitioning to a fully electric bus fleet.

2.1.2 Framework for WTW Analysis

To comprehensively compare diesel and electric buses, our well-to-wheel (WTW) analysis includes several critical stages:

- Vehicle Production: This stage covers the extraction and processing of raw materials, as well as the manufacturing of the buses.

- Fuel Production: For electric buses, this encompasses the generation and distribution of electricity.
- Vehicle Operations: This stage examines the actual operation of buses, focusing on the consumption of fuel or electricity and the direct emissions generated.

2.2. Build the Various Components of the WTW Analysis

2.2.1 Vehicle Production

The New York City bus dataset is accessible on Kaggle [11]. This dataset originates from the NYC MTA bus data streaming service, providing detailed insights into bus operations. Each row represents approximately 10 minutes of data, including bus locations, routes, stops, and more. It also records the scheduled arrival times from the bus schedule, indicating deviations such as delays or early arrivals. Upon initial analysis, as demonstrated in Table 1, the dataset includes an attribute named "VehicleRef." By cataloging all unique values within this attribute, we can determine the total number of vehicles in the fleet.

Table 1. Sample Data from the New York City MTA Bus Dataset

Recorded At Time	Direction Ref	Published Line Name	Origin Name	Origin Lat	Origin Long	Destination Name	Destination Lat	Destination Long	Vehicle Ref
2017-06-01 00:00:34	0	B8	4 AV/95 ST	40.616104	-74.011343	BROWNSVILLE ROCKAWAY AY	40.656048	-73.907379	NYCT_123
2017-06-02 00:00:43	1	S61	ST GEORGE FERRY/S61	40.643169	-74.073494	S1 MALL YUKON AV	40.575935	-74.167686	NYCT_8263
2017-06-03 00:00:49	0	Bx10	E 206 ST/BAINBRIDGE AV	40.875008	-73.880142	RIVEDALE 263 ST	40.912376	-73.666012	NYCT_4223

The dataset is initially analyzed to fully understand its components. As indicated in the analysis, a critical element of this dataset is "VehicleRef." By systematically recording each license plate number included in this element, we can accurately determine the total number of vehicles in the dataset, noted as $N_{\text{TotalBus}} = 5719$.

In subsequent analyses, the focus shifts to the transition from gasoline-powered buses to electric buses. Consequently, pollutants generated during the production of standard gasoline buses are excluded from the model. This decision is based on the assumption that only a negligible number of gasoline buses will be replaced by new fuel vehicles, and thus their impact is considered minimal.

To estimate the greenhouse gas (GHG) emissions for the vehicle production stage, emission factors are required. These factors represent the GHG emissions per vehicle produced. The formula used is:

$$GHG_{\text{Car-Production}}=E_{\text{Production}}\times N_{\text{TotalBuses}} \tag{1}$$

Where $GHG_{\text{Car-Production}}$ is the total GHG emissions for the production of a specific number of vehicles, $E_{\text{Production}}$ is the amount of GHG emissions per vehicle produced, and N_{Buses} represents the number of vehicles (in this case, electric or diesel buses) being analyzed.

For the electric buses, the carbon footprint of the production process is considered. It is estimated that nearly 4 tons of carbon dioxide are emitted during the manufacturing process of an electric bus. To offset these initial emissions, electric vehicles need to operate for at least 8 years, reducing 0.5 tons of CO_2 emissions per year [12].

For standardized calculations, the emission factors are translated from tons to pounds since 1 ton is equivalent to 2204.62 pounds. The formula for calculating the total greenhouse gas emissions from the production of electric buses is:

$$GHG_{\text{Production-ElectricityBuses}}(N) = N_{\text{Electricity}} \times 4 \times 2204.62 \tag{2}$$

In contrast, as the focus is on transitioning to electric buses, the production of new diesel buses will be almost negligible. Therefore, it is assumed that the greenhouse gas emissions from the production of diesel buses are effectively zero:

$$GHG_{\text{Production-DieselBus}}(N) = 0 \tag{3}$$

This approach highlights the minimal impact of diesel bus production on our overall greenhouse gas emissions calculations during the transition phase from gasoline-powered buses to electric buses.

2.2.2 Fuel/Electricity Production

For electric vehicles, it's necessary to consider the GHG emissions from the electricity they use. The formula for calculating this is:

$$GHG_{\text{fuel-production}}=\text{EmissionFactor}_{\text{fuel-prod}}\times\text{Energy}_{\text{used}} \tag{4}$$

Where:

- $\text{GHGfuel}_{\text{-production}}$ represents the total GHG emissions from the produced energy.
- $\text{EmissionFactorfuel}_{\text{-prod}}$ indicates the GHG emissions per unit of energy produced.
- Energyused is the total energy consumption of the vehicles.

The dataset does not directly provide distance units but includes the longitude and latitude of vehicle locations at different times. To address the issue of asynchronous location data, we identify the last recorded position of each bus within 30-minute intervals. This involves pinpointing the most recent location timestamp for each bus and retrieving the corresponding latitude and longitude.

To calculate the distance traveled, we use the haversine formula, which computes the shortest path between two points on the Earth's surface. This calculation can be done using the Python haversine library, providing an accurate measurement of the distance between consecutive GPS coordinates. The resulting data gives us the average distance each vehicle travels per day, as detailed in Table 2.

Table 2. Average emission levels for different fossil fuels in the transportation sector

OrgLat*	OrgLong	DstName**	DstLat	DstLong	VehicleRef	VehicleLoc.Lat ***	VehicleLoc.Lng
40.6161	-74.0311	ROCKAWAY AV	40.6560	-73.9073	NYCT_430	40.6351	-73.9608
40.6431	-74.0734	SL MALL YUKON	40.5759	-74.1676	NYCT_8263	40.5908	-74.1583

*OriginLat; **Dstination; ***Latitude

2.2.3 Haversine Formula

The Haversine formula calculates the shortest distance between two points on a sphere, based on their latitudes and longitudes. This is crucial for accurate navigation on Earth. The formula is as follows:

$$\begin{aligned} a &= \sin^2\left(\frac{\Delta\phi}{2}\right)+\cos(\phi_1)\cos(\phi_2)\sin\ 2\left(\frac{\Delta\lambda}{2}\right) \\ c &= 2\text{atan}\ 2(\sqrt{a},\sqrt{1a}) \\ d &= Rc \end{aligned} \tag{5}$$

Where:

- ϕ_1 and ϕ_2 are the latitudes of points 1 and 2 in radians.
- $\Delta\phi$ is the difference in latitude between the points in radians.
- $\Delta\lambda$ is the difference in longitude between the points in radians.
- R is the Earth's mean radius (approximately 6,371 km).
- a is the square of half the chord length between the points.
- c is the angular distance in radians.
- d is the distance between the two points along the surface of the sphere.

The average distance traveled by each bus per day is 57.376 miles.

Investigations into energy consumption reveal that the bus is highly efficient in urban cycles, consuming just 2.86 kWh per kilometer [13].

Carbon dioxide (CO_2) constitutes the majority of greenhouse gas emissions from the energy sector, with smaller amounts of methane (CH_4) and nitrous oxide (N_2O) also released during the combustion of fossil fuels such as coal, oil, and natural gas. The table below provides data on the annual net electricity generation and CO_2 emissions at utility-scale electric power plants, including a CO_2

emission factor (pounds of CO_2 per kWh) for coal, natural gas, petroleum, and the average across all energy sources [14].

Table 3. U.S electricity net generation and resulting CO_2 emissions by fuel in 2022

	ELEC generation	**CO_2 emissions**		
sources	million kWh	million metric tons	million short tons	pounds per kWh
Coal	831,512	868	957	2.30
Natural gas	1,687,067	743	819	0.97
Petroleum	22,931	25	27	2.38
ALL energy sources	4,230,672	1,650	1,819	0.86

Based on the data from Table 3, the average CO_2 emission factor for all energy sources is 0.86 lbs/kWh. If buses travel an average of 57.376 miles per day, this translates to approximately 92 kilometers (57.376 miles * 1.60934 km/mile ≈ 92 km/day). When multiplied by the energy consumption rate of 2.86 kWh per kilometer, the total energy used daily is:

$$\text{Energy}_{\text{used}} = 92\text{ km} \times 2.86\text{ kWh/km} = 263.12\text{ kWh} \tag{6}$$

The corresponding greenhouse gas emissions from electricity production for electric buses can then be calculated as:

$$\text{GHG}_{\text{fuel-production-Electricity}} = 263.12\text{ kWh} \times 0.86\text{ lbs }CO_2\text{/kWh} = 226.28\text{ lbs }CO_2 \tag{7}$$

In the model for diesel vehicles, the greenhouse gas emissions from fuel production, denoted as $\text{GHG}_{\text{fuel-production-Diesel}}$, are assigned a value of zero. This decision is based on the challenges of accurately quantifying emissions from petroleum extraction and processing. Given the complexity of these processes and the difficulties in measuring their precise impact on greenhouse gas emissions, the team has decided to exclude this factor from our current analysis. Thus:

$$\text{GHG}_{\text{fuel-production-Diesel}} = 0 \tag{8}$$

2.2.4 Vehicle Operation

New York's transportation system has a diverse fleet of vehicles, including compressed natural gas (CNG), diesel, and hybrid (diesel-electric) buses. As of December 2022, the fleet includes more than 1,100 diesel-electric hybrid buses and more than 700 CNG-powered buses, together amounting to less than half of the entire fleet of 5,719 buses [15].

CNG buses make up about 12% of the fleet, diesel-electric hybrid buses account for about 19%, and diesel buses form the majority at 69%. The average daily distance traveled per vehicle in the fleet is approximately 92 kilometers [15]. Electric buses have zero tailpipe emissions [16], so the team's discussion mainly focused on gas buses, which are a significant contributor to emissions.

The average CNG consumption per line is between 37.66 kg/100 km and 45.06 kg/100 km, with an average of 40.77 kg/100 km for all CNG lines [17]. Diesel buses typically consume 24 liters per 100 km, or approximately 15 liters per hour of operation. For a fleet of 100 diesel buses running for 8 hours per day, the estimated diesel consumption is 11,520 liters [18]. Plug-in hybrid buses consume less than 11 liters of fuel per 100 kilometers [19].

Diesel engines convert the chemical energy in the fuel into mechanical energy, ideally producing only carbon dioxide (CO_2) and water vapor (H_2O) during combustion. However, diesel exhaust also contains unused portions of the engine's charge air [20].

Natural gas, composed primarily of methane, is the cleanest of all fossil fuels. Its main combustion products are carbon dioxide and water vapor [21]. Compared to coal and oil, natural gas releases lower levels of harmful emissions, including carbon emissions, nitrogen oxides (NO_x), sulfur dioxide (SO_2), ash particles, and other reactive hydrocarbons [21].

Table 4. Fossil fuel emission levels

Pollutant	Natural Gas	Oil	Coal
Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulfur Dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0.000	0.007	0.016

Natural Gas: The energy content of natural gas is approximately 1,000 British thermal units (Btu) per cubic foot. Given that 1 cubic foot of natural gas weighs about 0.0416 kilograms under standard conditions, its energy content is estimated to be around 24,000 Btu per kilogram. The energy density of natural gas is approximately 13.9 kWh/kg.

Petroleum: The typical energy value of petroleum is approximately 5.8 million British thermal units per barrel. Each barrel has a capacity of 42 gallons or 158.987 liters. The energy content of oil can be roughly calculated as 36,500 Btu per liter.

These approximations serve as the basis for the subsequent energy content calculations:

$$P_E \text{ per } kg = P_E \text{ per billion Btu } * \frac{1 \text{ billion Btu}}{24{,}000\text{Btu/kg}} \tag{9}$$

Oil Conversions:

$$P_E \text{ per liter } = P_E \text{ per billion Btu } \frac{1 \text{ billionBtu}}{36{,}500 \text{ Btu/liter}} \tag{10}$$

The calculation results can be seen in Table 5.

Table 5. The calculation results of substance burning

Substance	CO_2	CO	NO_x	SO_2	particulate
Nartual Gas Emissions pounds/kg	4.875	1.667e-3	3.833e-3	4.2e-5	2.92e-4
Oil Emissions pounds/kg	4.493153	9.04e-4	1.2274e-2	3.0740e-2	2.301e-3

This equation estimates the total greenhouse gas (GHG) emissions from the operation of different types of buses in New York's transportation system - CNG, diesel, and hybrid. It combines the number of buses, their average daily travel distance, fuel consumption, and emissions from different pollutants.

Overall GHG Emission Calculation for Bus Operations ($GHG_{\text{Operation}}$):

$$GHG_{Operation}(N_{CNG},N_{diesel},N_{hybrid})=N_{CNG}*D_{average}*CNG_{Ekg/100km}*(R_{gasCarbonDioxide}+R_{gasCarbonMonoxide}+R_{gasNitrogenOxides}+R_{gasSulfurDioxide}+R_{gasParticulates})+N_{diesel}*D_{average}*Diesel_{Eliters/100km}*(R_{oilCarbonDioxide}+R_{oilCarbonMonoxide}+R_{oilNitrogenOxides}+R_{oilSulfurDioxide}+R_{oilParticulates})+N_{hybrid}*Daverage*HybridE_{liters/100km}*(R_{oilCarbonDioxide}+R_{oilCarbonMonoxide}+R_{oilNitrogenOxides}+R_{oilSulfurDioxide}+R_{oilParticulates}) \tag{11}$$

N_{CNG}: amount of CNG buses = 12% * 5719

N_{diesel}: amount of diesel buses = 69% * 5719

N_{hybrid}: amount of hybrid buses = 19% * 5719

$D_{average}$: Average distance traveled by each vehicle during the day is: per car 57.3 miles/day (about 92 km/day)

$CNG_{Ekg/100km}$: the average fuel consumption for CNG buses is 40.77 kg/100 km

$Diesel_{Eliters/100km}$: the average diesel consumes for diesel buses is 24 liters/100 km

$Hybrid_{Eliters/100km}$: the average diesel consumes for Hybrid buses is 11 liters/100 km

This formula covers a lot of elements, but it has a very serious problem and is not concise enough. In order to make it more concise, the team optimized the formula.

Summarize the pollution factors (P(fuel)gas, P(fuel)oil):

$$\begin{aligned}&P(\text{fuel})_{\text{gas}} = \text{fuel} * \Big(R_{\text{gas}_{\text{ CarbonDioxide}}} + R_{\text{gas}_{\text{ CarbonMonoxide}}} + \\ &R_{\text{gas}_{\text{NitrogenOxides}}} + R_{\text{gas}_{\text{ SulfurDioxide}}} + R_{\text{gas}_{\text{ Particulates}}}\Big) \\ &P(\text{fuel})_{\text{oil}} = \text{fuel} * \big(R_{\text{oil}_{\text{ CarbonDioxide}}} + R_{oil_{\text{CarbonMonoxide}}} + \\ &R_{\text{oil } l_{\text{NitrogenOxides}}} + R_{\text{oil } l_{\text{SulfurDioxide}}} + R_{\text{oil}_{\text{ Particulates}}}\Big)\end{aligned} \tag{12}$$

These factors estimate the pollutants released per kilogram of natural gas and per liter of oil combustion, respectively. They are based on the emission rates of various pollutants such as carbon dioxide, carbon monoxide, nitrogen oxides, sulfur dioxide and particulate matter.

Summary of fuel consumption and pollutant emission calculations:

$$\begin{aligned}TFC_{CNG} &= N_{CNG} * D_{\text{average}} * CNG_{E_{kg/100km}} \\ TFC_{\text{diesel}} &= N_{\text{diesel}} * D_{\text{average}} * \text{ Diesel}_{E_{kg/100km}} \\ TFC_{\text{hybrid}} &= N_{\text{hybrid}} * D_{\text{average}} * Hybrid_{E_{kg/100km}}\end{aligned} \tag{13}$$

CNG$_{\text{bus}}$(TFC_{CNG}): The total amount of fuel consumed by CNG buses every day is calculated based on the number of CNG buses, average daily mileage and average fuel consumption rate. Dieselandhybridbuses (TFC_{diesel}, TFC_{hybrid}): Similar calculations were performed using the respective numbers, daily distance traveled and fuel consumption rates of diesel and hybrid buses.

After combining all the formulas:

$$\text{GHG}_{\text{Operation }_{\text{DieselBus}}}(N) = P(TFC_{CNG})_{\text{gas}} + P(TFC_{\text{diesel}})_{\text{oil}} + P\big(TFC_{\text{hybrid}}\big)_{\text{oil}} \tag{14}$$

2.2.5 End-of-Life Management

This framework quantitatively assesses the environmental impact of various factors based on their severity and the duration of their effects. It categorizes the severity of environmental impacts into three distinct levels: low, medium, and high, each associated with a numerical value.

Severity Levels:

Low Severity (Slow=1): Minimal environmental impact, limited effects, easily mitigable, or affecting only a small area or a few organisms.

Medium Severity (Smedium=2): Considerable environmental impact, more challenging to mitigate, influencing large areas or significant populations.

High Severity (Shigh=3): Extensive, intense, and potentially long-lasting impacts, causing significant harm to ecosystems, human health, or property. Mitigation is often complex and expensive.

Impact Function ($I(f,t)$):

$$E = \sum_{f\in F} I(f,t) \tag{15}$$

Where:

F is the set of environmental factors (Soil Contamination, Water Pollution, Air Pollution, Harm to Wildlife, Long-term Environmental Impact).

t is the time frame (short-term, long-term, etc.)

$I(f,t)$ is the impact function defined as $I(f, t) = S(f)W(t)$

$S(f)$ is the severity score of factor f

$W(t)$ is a weight function that gives more or less importance to the impact over time.

The function $I(f,t)$ measures the impact of a specific environmental factor 'f' over a time period 't', incorporating the severity score (S) and a time-dependent weight (W). The weight reflects the evolving nature of the factor's impact over time.

i) $W(ST) = 1$

ii) $W(MT) = 2$

iii) $W(LT) = 3$

This model creates a structured approach to evaluate and compare the impacts of various environmental factors, considering both their inherent severity and how their effects unfold over time. It aids in prioritizing environmental issues and formulating targeted mitigation strategies.

2.2.6 When a Bus is Dumped or Abandoned

Dumped buses can have several harmful effects on the environment:

- Pollution from fluids and chemicals (PFC): Leakage into soil, causing contamination. Severity: High. Time Frame: Long-term persistent impact.
- Air pollution (AP): Release of VOCs and other pollutants from deterioration. Severity: Medium. Time Frame: Medium-term.
- Habitat destruction (HD): Disruption of local ecosystems due to physical presence. Severity: High. Time Frame: Immediate to long-term.
- Visual pollution (VP): Aesthetic degradation of environment. Severity: Low. Time Frame: Immediate to medium-term.
- Waste accumulation (WA): Space taken in landfills or natural environments. Severity: Medium. Time Frame: Long-term [22].

Severity scores:
1) PFC and HD: 3 (High)
2) AP and WA: 2 (Medium)
3) VP: 1 (Low)

The environmental function for dumped bus:

$$E_{\text{DieselBus}} = S_{\text{PFC}} \cdot W(\text{LT}) + S_{\text{AP}} \cdot W(\text{MT}) + S_{\text{HD}} \cdot W(\text{LT}) + S_{\text{VP}} \cdot W(\text{ST}) + S_{\text{WA}} \cdot W(\text{LT}) \quad (16)$$

Dumped batteries can harm the environment in several ways:

- Soil Contamination (SC): Chemical leaching into soil. Severity: Medium. Time Frame: Long-term persistent impact.
- Water Pollution (WP): Contamination of water bodies due to chemical leaching. Severity: High. Time Frame: Immediate to long-term.
- Air Pollution (AP): Airborne toxic chemicals from battery fires. Severity: Low to Medium. Time Frame: Immediate during incidents.
- Harm to Wildlife (HtW): Direct ingestion or habitat contamination. Severity: Medium. Time Frame: Variable.
- Long-term Environmental Impact (LtEI): Persistence of chemicals, cumulative effects. Severity: High. Time Frame: Multi-generational [23].

Severity scores:
1) SC: 2 (Medium), long-term impact
2) WP: 3 (High), immediate to long-term impact
3) AP: 1.5 (Low to Medium), immediate impact during incidents
4) HtW: 2 (Medium), variable time frame
5) LtEI: 3 (High), multi-generational timeframe

The environmental function for dumped batteries:

$$E_{\text{Battery}} = S_{\text{SC}} \cdot W(\text{LT}) + S_{\text{WP}} \cdot W(\text{LT}) + S_{\text{AP}} \cdot W(\text{ST}) + S_{\text{HtW}} \cdot W(\text{MT}) + S_{\text{LtEI}} \cdot W(\text{LT}) \quad (17)$$

3. Confirm Required Investment Costs and Profits

The break-even point is a crucial concept in business and economics, denoting the juncture where total expenses and total income are equal. At this point, a business or project neither incurs a loss nor realizes a profit.

3.1. Cost Calculation

3.1.1 The Price of Electric Bus

New York City Buses have average lengths of 39'2" (11.95 m), widths of 8'4" (2.55 m), heights of 9'10" (2.99 m), and have a capacity of 29 (+1) seats with standing room for 76 [24]. Battery-electric versions of full-size "Type C" or "Type D" buses can range from $320,000 to $440,000, versus about $100,000 for diesel [25]. Type C buses have a 54-90 passenger capacity, while Type D buses can accommodate 72-90 passengers [26].

The price of each new NY bus is approximately $320,000. However, bus prices are expected to show a downward trend, particularly for electric buses. Average electric transit bus costs are currently just under $400,000, a decrease of over 35% from just over a decade ago when most electric transit bus costs exceeded $1.2 million. As the electric bus industry matures and the cost of batteries decreases, electric bus capital costs are projected to decrease further [27].

Considering the year 2024 as the starting point (i=0), the car price model can be expressed as:

$$\begin{aligned} Price_{\ ElectricBus_0} &= \$320{,}000 \\ Price_{\ ElectricBus_i} &= \$320{,}000 * (0.95784)^i \end{aligned} \tag{18}$$

3.1.2 The Cost of Charging Equipment

The charging needs for a Battery Electric Vehicle (BEV) are defined by the daily vehicle energy needs and dwell period. Two key metrics are needed to estimate the daily energy needs: daily vehicle miles traveled and operational efficiency. A typical bus can travel approximately 0.67 miles on a kilowatt hour of energy or consumes about 1.5 kilowatt-hours of energy for every mile travelled [27].

When selecting a BEV, the seating capacity and estimated range must meet or exceed the vehicle's mission requirements. The range of each vehicle is a factor of the operational efficiency and battery capacity. The operational efficiency, when presented in miles per kilowatt-hour, can help determine the energy consumed in a given day of travel, with a higher number representing more efficient operations. These daily energy needs are helpful when selecting the best chargers, which must be capable of recharging the vehicle during a typical dwell period, such as eight hours overnight [27].

After determining the optimal battery electric bus, a fleet must decide which charging technology is best for their application. The most important feature to consider when selecting a charger is the charging power, and how rapidly that power can provide the energy your bus will need. The sweet spot for most BEVs is the upper end of level two charging, capable of supplying up to 19 kilowatts of charging power. These units will recharge the vehicle in 1/10 the time a level one will, while the installation costs will be much lower than for DC fast chargers [27].

Table 6. The price of different type of fleets

EVSE	Features	Chargers/Unit	Cost/Charger
Level 1	Non-networked	1	$813
Level 1	Non-networked	2	$596
Level 2	Non-networked	1	$1,182
Level 2	Non-networked	2	$938
Level 2	Networked	1	$3,127
Level 2	Networked	2	$2,793
DCFC	Networked 50 kW	1	$28,401
DCFC	Networked 150 kW	1	$75,000
DCFC	Networked 350 kW	1	$140,000

Considering the need to build a large network of charging equipment, the charger fleet's cost is $2793 for each two, which averages out to $1396.5 each.

$$Price_{Station} = \$1396.5 \tag{19}$$

The sweet spot for most BEVs is the cap on Level 2 charging, capable of providing up to 19 kilowatts of charging power. A typical bus travels approximately 0.67 miles per kilowatt hour of energy, or consumes approximately 1.5 kilowatt hours of energy per mile traveled [27].

Given that $Consumes_{\text{ElectricBus}}$ = 1.5 (kWh/mile) and each car in New York needs to travel about 57 miles, the energy required by each car per day is 85.5 kilowatt-hours. With the efficiency of the charging equipment at 19 kilowatts of charging power, the charging time required by a car per day is 4.5 hours. Assuming that a charging device can work 24 hours a day, that charging device can support approximately 5 vehicles per day. Therefore, the number of charging devices needed is (rounded up to the nearest integer):

$$N_{\text{ElectricCharger}} = \left\lceil \frac{N_{\text{ElectricBus}}}{5} \right\rceil \tag{20}$$

3.2. Operating Cost Savings

Operating costs (or variable costs) are incurred when traffic takes place and are a function of its intensity. They mainly include labor, fuel (or energy), and maintenance [28]. Assuming that the price of labor does not change, only the fuel and maintenance costs saved are considered.

- Saved maintenance costs: Each electric bus can save \$4,400 a year in reduced maintenance costs, saving tens of thousands of dollars over the lifetime of a bus [29].
- Fuel costs savings: To predict future electricity prices, we can use time series forecasting methods such as linear regression or ARIMA (Autoregressive Integrated Moving Average). Electricity prices have a limited number of data points and lack significant seasonality, making simple linear regression a more appropriate model. In contrast, ARIMA is more suitable for oil price data.
- ARIMA model: An ARIMA model is typically denoted as ARIMA (p, d, q), where p is the order of the AR terms, d is the order of differencing, and q is the order of the MA terms. The combined ARIMA model is given by:

$$\Phi(L)(1-L)^d X_t = \Theta(L)\epsilon_t \tag{21}$$

- Linear regression model: The mathematical formula for a simple linear regression, which models the relationship between a single explanatory variable (independent variable) x and a response variable (dependent variable) y, is given by:

$$y = \beta_0 + \beta_1 x + \epsilon \tag{22}$$

The unit of oil price is per gallon, while the price of electricity is per kWh.

3.3. Model of Break-even Point for Investments

- Electric bus price calculation: Annual price of electric buses (PriceElectricBusi):

$$Price_{ElectricBus_i} = \left(\$320{,}000 * (0.95784)^i\right) * N_{\text{electricBus}} \tag{23}$$

The price of electric buses in year *i* is calculated using a base price of \$320,000, adjusted by a decreasing factor raised to the annual power of 0.95784, reflecting the expected decline in electric bus prices over time.

- Power station price calculation: Annual power station price (PriceStationi):

$$Price_{\text{ Station } i} = N_{\text{ElectricStation}} * Price_{\ station} \tag{24}$$

The total cost of a power plant in year i is the number of plants multiplied by the price of each plant.

- Total annual investment: Annual Investment (InvestmentYeari):

$$Investment_{Year\ i} = Price_{ElectricBus\ i} + Price_{Station\ i} \tag{25}$$

The total investment for that year is the sum of the electric bus price and the power station price for that year.

- External funds and net investment: External funding (ExternalFundingYeari):

$$ExternalFunding_{Year\ i} = 0.5 * Investment_{Year\ i} \tag{26}$$

Annual net investment is total annual investment minus external funding.

- Annual savings calculation: Yearly Savings (Savingsi):

$$\begin{gathered}\text{Saving}_{\text{maintenance}} = \$4{,}400(\text{ per car } / \text{ per year }) * N_{\text{ElectricBus}} \\ \text{Savings}_{i} = \text{Saving}_{\text{fuel } i} + \text{Saving}_{\text{maintenance } i}\end{gathered} \tag{27}$$

The savings for year *i* are calculated by comparing the costs of operating oil buses (which are already phased out) against the costs of operating electric buses.

- Cumulative value and break-even point: Cumulative Savings (CumulativeSavingsi):

$$\text{CumulativeSavings}_{i} = \sum_{j=2023}^{i} \text{Savings}_{\text{Year } j} \tag{28}$$

This is the total savings accumulated from 2023 to year *i*.

- Cumulative Investment (CumulativeInvestmenti):

$$\text{CumulativeInvestment}_{i} = \sum_{j=2023}^{i} \text{NetInvestment}_{\text{Year } j} \tag{29}$$

- Find the break-even point: The break-even point is reached when cumulative savings equal or exceed cumulative investment, representing a year in which the transition to electric buses becomes financially neutral, with accrued savings offsetting the initial investment.

4. 10-years Roadmap

The team aims to achieve an all-electric bus fleet by 2033 and is studying different annual conversion rates. Initially, the group adopted a uniform conversion rate, spreading the number of bus conversions evenly over a 10-year time span. After modeling and calculations using Python, this strategy will lead to a break-even point by 2050. However, the team also considered an alternative approach to transformation.

$$B(t) = \left\lceil \frac{\text{remaining\_buses}}{\frac{\text{remaining\_years}\times(\text{remaining\_years}+1)}{2}} \right\rceil \tag{30}$$

This alternative involves a staged and balanced conversion process, taking into account the gradual reduction in the price of electric buses and the subsequent reduction in operating costs. Such a strategy allows for more manageable resource allocation, thereby simplifying the transition. While both uniform and staged conversion rates are expected to reach break-even points around 2025, the latter approach provides a "buffer" period, which is critical to smooth the transition, reduce risk, and ensure a sustainable move to an all-electric bus fleet.

In addition to New York, the team also incorporated data from two other major cities, San Francisco and Los Angeles, into our model (see in Table 7). It was somewhat unexpected to discover that all three cities - New York, Los Angeles, and San Francisco - share a similar timeline for their break-even points, with each projected to reach this financial milestone around the year 2050.

Table 7. Bus number in Los Angles and San Francisco

city	**bus number**
Los Angles	2,320 [30]
San Francisco	550 [31]

5. Conclusion

Research and analysis have yielded some illuminating insights into the environmental and economic impacts of switching to electric buses. Contrary to popular belief and popular chatter on the Internet, the environmental benefits of electric buses are not as simple as they seem. A key aspect that is often overlooked is the environmental pollution associated with the production of electric buses and the challenges posed by recycling old buses. However, considering long-term use, electric buses have a significantly lower environmental footprint compared to gasoline buses, confirming their ecological advantages in daily operations. From a financial perspective, the transition to an all-electric bus fleet presents significant challenges. The squad's analysis suggests it could take up to 27 years for such a fleet to become economically beneficial to the company. This finding provides important considerations for investors and companies considering this transition, underscoring the need for long-term financial strategies.

Based on our findings, we recommend a balanced approach to the adoption of electric buses. While electric buses significantly reduce greenhouse gas emissions, making them a more environmentally friendly option in the long run, the potential environmental hazards associated with discarded batteries and bus disposal cannot be ignored. These hazards have complex and varied impacts over their time scale and may not be immediately apparent, but over time, if not managed appropriately, could seriously offset the benefits of electric buses. Therefore, it is necessary for government agencies and relevant departments to develop comprehensive strategies for the disposal and recycling of used batteries and vehicles.

In addition, given the huge costs associated with transitioning to electric buses, it is critical that governments and businesses are financially prepared for the long t erm. Initial investment and operating costs must be weighed against long-term environmental and economic benefits. The true "dawn" of a sustainable electric public transport system can only be achieved through careful planning and readiness to meet the initial financial challenges.

In conclusion, while the switch to electric buses is a step in the right direction for sustainable urban transport, it requires a nuanced understanding of its environmental and economic impacts.

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