ISSN 2959-6130

The financial impacts of the electronic bus transition

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Abstract:

This article delves into the financial impact of five factors, including the procurement cost of electric bus (e-bus), charging equipment, installation cost of charging equipment, maintenance cost of e-bus, electricity cost, and electricity cost, on the transformation of e-bus. A linear programming model for the transformation cost of e-commerce is established. Research has found that although the initial purchase cost of an e-bus is higher than that of traditional diesel buses, their operating and maintenance costs are lower and more economically competitive in the long run. Meanwhile, introducing external funds such as government subsidies can further reduce transformation costs and accelerate the popularization of e-bus in urban transportation systems. In addition, reasonable planning and layout of charging facilities can effectively reduce costs while improving the efficiency of charging facilities. Overall, this article reveals the key factors and optimization strategies in the process of electronic bus transformation through in-depth research on the cost model of electronic bus transformation. The research results have important theoretical and practical guidance for promoting the green transformation of urban public transportation systems worldwide.

Keywords: E-bus; diesel bus; ecological consequence; financial.

1. Introduction

In recent years, increasing attention to global warming and environmental issues like rising CO_2 levels, energy conservation, and emission reduction have become actively advocated behaviors. E-buses, powered by electricity, can effectively mitigate the aforementioned environmental issues. According to the report of the International Energy Agency (IEA), they claimed that we should realize "Net Zero Emissions by 2050 Scenario (NZE)" and "Electrification is one of the most important strategies" [1]. Hence, using the e-bus is an inevitable trend in the future development of urban public transportation. It will cause a 5% reduction in emissions if E-bus replaces all the traditional diesel buses worldwide [2].

The transition from diesel buses to E-bus has many positive consequences, including reducing air pollution, mitigating the environmental damage caused by oil extraction, lowering public transportation operational costs, and reducing urban noise. Considering E-buses' advantages, many cities plan to replace traditional diesel buses with E-buses. However, the transition to E-bus is difficult. It is constrained by budget and planning limitations, challenges in infrastructure development like charging stations, and a lack of experience.

2. Assumptions

Assumptions are shown in Table 1.

Table 1 Assumptions

Assumption 1:	The data used in this paper are assumed to be accurate
Justification 1:	The analysis of the ecological consequences and cost of Conversion to E-bus requires a lot of data, including fuel consumption of vehicles, vehicle emissions, prices of E-bus and charging equipment, labor costs, etc. However, there are obvious differences in the above data in different regions and a lack of accurate information. In this paper, the calculation is made by checking the relevant data, which may differ from the real data.
Assumption 2:	Assume that our selected CITY buses are all diesel buses.

Justification 2:	Different types of buses may be available in existing cities, including diesel buses, hybrids, and E-buses. Depending on the manufacturer and model, the same type of bus may differ in terms of tailpipe emissions and energy consumption. This paper considers the average and does not consider the differences due to the above reasons.
Assumption 3:	The impact of unforeseen circumstances on the data, such as traffic accidents, is not considered.
Justification 3:	The fuel consumption of a vehicle varies due to different speed situations. Vehicles waiting for traffic lights or encountering traffic accidents, etc., will increase the vehicle's fuel consumption. We do not consider changes due to accidents during the vehicle's task of carrying passengers.
Assumption 4:	Does not take into account the effects of aging equipment, etc.
Justification 4:	As the time of bus usage grows, whether electric or diesel bus. The working condition of the vehicle will change to some extent. For example, the battery's storage capacity and the conversion rate of electric energy of E-bus vehicles will decrease with the increase in usage time. For the influence of these factors, they are not considered in this paper.

3. Ecological Consequences Analysis of Using E-Bus

Ecological Consequences Analysis evaluates the environmental effects of the transition of all E-bus fleets through some quantifiable methods; we discuss both the positive and the negative consequences. The positive consequences include air pollution, natural resources, and noise. The negative consequences include electricity sources, battery manufacturing and disposal, and battery resources. The negative consequences include electricity sources, battery manufacturing and disposal, and battery resources. Each consequence is accounted for and discussed, as shown in Fig.1.

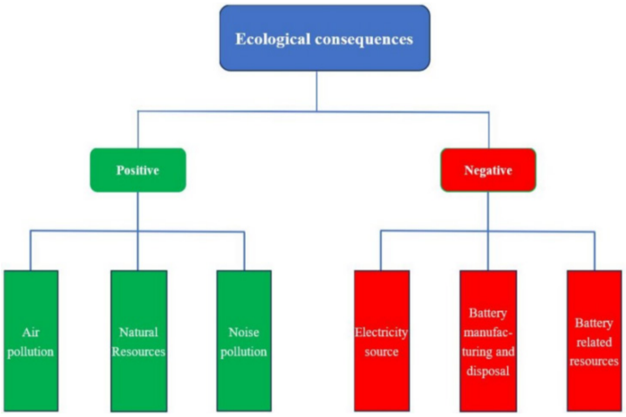

Fig.1 Ecological consequence

3.1 Positive Consequences

3.1.1 Air pollution

The reductionAir pollution reduction is the most important factor that motivates people to transition to the E-bus project. Due to air pollution, increasing CO_2 concentration, and global warming, reducing emissions has become one of the urban development goals in major countries worldwide. Diesel buses emit tailpipe gases, mainly CO, CO_2, NO_x, HC, PM, etc. (see Fig.2).

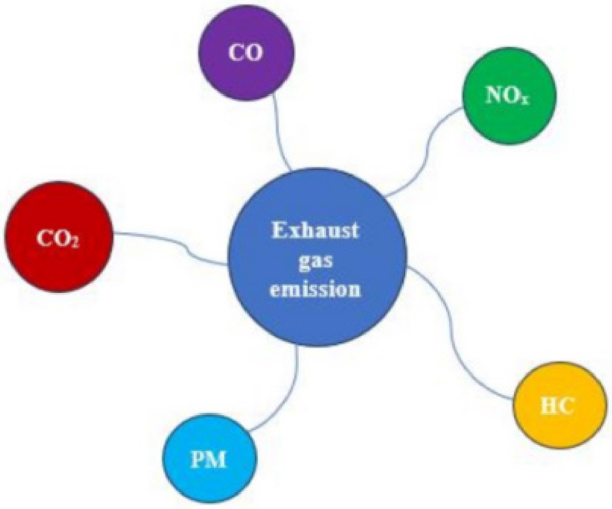

Fig.2 Air pollution

The exhaust emission and fuel consumption data of the diesel engine are shown in Table 2. According to the data in the table, the fuel consumption of different models of engines is different at different speeds.

Table 2 Unit Emission of Pollution of Diesel City Bus

Indicators according to Copert IV	Calculated values

Norm of emissions	CO	NO_x	HC	PM	Fuel consumption[g/km]	Fuel consumption[dm^3/100km]	CO_2 [g/km]
Euro III	g/km				327	38.7	975.2
	2.545	9.855	0.515	0.2			
Euro VI	g/km				305	36.1	909.6
	1.29	0.625	0.035	0.005			

The ecological consequence of the reduction of each pollution gas is defined in equation (1):

$$E = e * L * c \quad (1)$$

where: E_i - Total emission of all diesel buses of the i-th pollution gas in one year;
e_i - Emission of the i-th pollution gas per dm^3, g/ dm^3 ;
c - Fuel consumption per km, dm^3/km;
L – Total number of miles traveled by all buses in one year.

Assume that the total number of miles all buses travel in a small to medium-sized city in a year is 1.6 million kilometers, and $c = 37.4$ dm^3/100 km.

Calculate the ecological consequence of emission reduction as shown in Table 3, based on the equation (1) calculation method.

Table 3 Ecological consequence of emission of a diesel bus

	Euro III	Euro VI
CO	2.5214*10^12	1.1922*10^12
NO_x	9.7635*10^12	5.7760*10^11
HC	5.1022*10^11	3.2346*10^10
PM	1.9814*10^11	4.6208*10^9
CO_2	9.6615*10^14	8.4062*10^14

3.1.2 Natural Resources

The development of transportation cannot be separated from energy. However, traditional transportation based on petroleum energy is facing more and more energy crises. Conversion to E-bus provides a sustainable direction of transportation development. However, energy sources such as coal and oil are still the main means of electricity production and cause air pollution. However, clean and environmentally friendly methods of electricity production such as nuclear, wind, and solar power are also taking up a large and increasing proportion. Meanwhile, nuclear, wind, and solar power are renewable sources of energy that can effectively alleviate the energy crisis.

Conversion to an E-bus can help effectively relieve the energy pressure of petroleum consumption. In the following, we analyze the reduction of conversion to E-bus. Diesel is extracted from petroleum. Diesel that can be extracted from petroleum is v0 dm^3/t. The ecological consequence of natural resources reservation can be calculated by equation (2),

$$V = v0 * L * c \quad (2)$$

Where: V - Total petroleum reserved for all diesel buses in one year.

3.1.3 Noise Pollution

Electric buses have significant advantages in addressing noise pollution. Since there is no need for an engine to provide power, electric buses make less noise and provide a quieter environment for the surroundings. When driving, new energy buses start smoothly, pick up speed quickly, drive stably, and make almost no noise during driving.

In general, the noise of electric buses is around 50 dB, while the noise of diesel buses may be as high as 110 dB or more.

3.2 Negative Positive Consequences

3.2.1 Electricity Source

The conversion to E-bus converts fuel consumption to electrical energy consumption. The production of electricity also has a certain ecological consequence, related to the source of electricity, which includes Coal、Natural Gas、Nuclear Energy, and Renewable Energy. As shown in Table 4.

Table 4 Electricity source

	Ratio
Coal	20%
Natural Gas	40%
Nuclear Energy	20%
Renewable Energy	20%

Exhaust gases from coal power generation are mainly CO, CO_2, SO_2, NO_x, and PM. Exhaust gas pollution data per unit of electricity is shown in Table 5.

Table 5 Ecological consequence of electricity production

	Emission (g/kWh)
CO	0.5
CO2	2.5

SO2	250
NOx	1500
PM	35

The ecological consequence of electricity source caused by electricity consumption can be calculated by equation (3)

$$E_{1i} = e2i * L * c2 \tag{3}$$

where: E_{1i} - Total electricity production emission of all diesel buses of the i-th pollution gas in one year;
e_{2i} - Emission of the i-th pollution gas per dm^3, g/ kWh;
c_2 - Electricity consumption per km, kWh/km.
The air pollution caused by electricity sources is calculated as shown in Table 5. It is known that the electricity consumption of the tram per kilometer = 25 kWh/100 km. The corresponding pollutant gas emissions are calculated as shown in Table 6.

Table 6 Ecological consequence of electricity consumption by E-bus

	Emission (g/kWh)
CO	$2*10^5$
CO_2	$1*10^6$
SO_2	$1*10^8$
NO_x	$6*10^7$
PM	$1.4*10^6$

3.2.2 Battery Manufacturing and Disposal

The manufacturing and recycling of batteries are two key aspects of the production process of electric vehicles. Battery manufacturing requires the use of a large number of rare metals and mineral resources. At the same time, the manufacturing process of batteries also generates a certain amount of environmental pollution, such as the emission of waste gas and wastewater. In addition, the recycling of EVs is also an important aspect. If the batteries of electric vehicles are not handled properly, it may lead to the release of heavy metals and hazardous substances, causing environmental pollution.
Overall, the production and recycling of EVs impact the environment, but compared to the exhaust emissions of traditional fuel vehicles, the environmental advantages of EVs are still obvious. Measures can be taken to reduce the environmental impact of EV production and recycling, such as using clean energy, improving energy utilization efficiency, and wastewater treatment. At the same time, the government and relevant departments need to strengthen regulation and management to ensure that the manufacturing and recycling of EVs meet environmental requirements.

3.2.3 Battery-Related Natural Sources

Battery technology is the technical frontier of current technological development. With the promotion of clean and environmentally friendly electric vehicles, especially E-bus, the demand for electric vehicles and lithium batteries are gradually expanding. However, lithium is the main component in the battery of electric vehicles. Therefore, replacing the original diesel bus with an E-bus will expand the demand for and consumption of lithium metal. This will put some pressure on lithium resource mining and reserves.

4. Financial Implications Analysis

The financial impact refers to both capital inputs and corresponding benefits. Capital investment refers to the total cost of conversion to E-bus, including the acquisition cost of E-bus, the cost of charging equipment and installation, and the energy and maintenance costs of E-bus operation. The benefits refer to the environmental benefits, saving diesel, as shown in Fig.3. we also need to consider the potential funding and the decrease in the price of batteries.

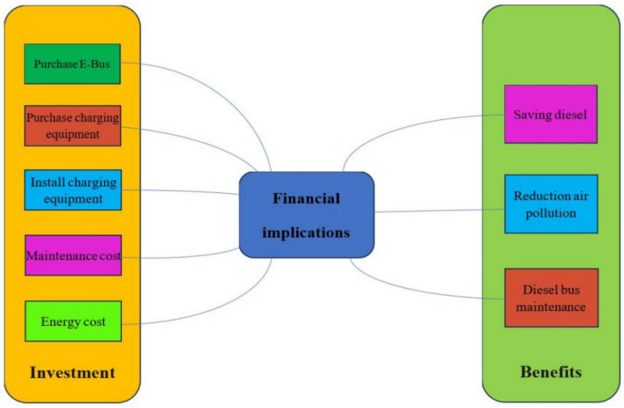

Fig.3 Financial implications model

4.1 Cost Model for E-Bus Transition

4.1.1 Purchasing Cost of E-bus and Charing Equipment

The acquisition cost includes both the E-bus and the charging equipment. Definition: p_{EB} denotes the price of one E-bus, and pc denotes the price of one charging device. We know that one charging equipment can charge multiple E-buses simultaneously, considering that E-buses at the same station can be charged at different times. Therefore, there is a proportional relationship between the number of charging devices and the number of buses.
Thus, the overall acquisition cost is calculated as in equation (4):

$$C_P = p_{EB} * N + k * p_{CE} * N \tag{4}$$

Where: k denotes the scaling factor between the number

of charging devices and the number of E-buses;
N denotes the number of charging E-buses.

4.1.2 Install Cost of Charing Equipment

The installation cost mainly refers to the labor cost for installing the charging equipment. Let $_{pL}$ denote the labor cost for installing a single charging equipment. Then, the installation cost of the charging equipment of E-bus is calculated as in equation (5):

$$C_L = k * p_L * N \tag{5}$$

Where: p_L represents the installed price per charging device.

4.1.3 Maintenance Cost of E-Bus

Maintenance cost refers to the average annual cost to upkeep the E-bus and charging equipment. After converting to all E-bus fleet, the average annual maintenance cost can be calculated by equation (6):

$$C_M = (p_{M1} + p_{battery} / T) \times N + k \times p_{M2} \times N \tag{6}$$

Where: p_{M1} and p_{M2} represent the maintenance cost per year, respectively;
C_M represents the maintenance cost per year;
$_{battery}$ denotes the price of the battery;
T represents the battery replacement cycle.

4.1.4 Energy Cost

Energy cost is important in analyzing the financial implications of conversion to an E-bus fleet. The energy cost per year of all E-bus per year can be calculated by equation (7),

$$C_E = \textit{Total Electricity Consumption} \times p_{electricity} \tag{7}$$

Where: $_{electricity}$ represents the price of diesel fuel;
C_E represents the total energy cost of the E-bus.

4.1.5 Total Cost

In summary, the overall cost of E-bus replacement can be calculated by equation (8).

$$\textit{Investment Cost} = CP + CL + CM + CE \tag{8}$$

First, relevant data were collected, as shown in Table 7.

Table 7 Related data table

	Cost
p_{EB}	One million dollars
p_{CE}	1,000-2,000 dollars
k	3.5
$p_{electricity}$	0.43 dollars
p_{M1}	4,000 dollars
$P_{battery}$	60,000 dollars
T	12 year
p_{M2}	9,500 dollars
p_L	500~1,000 dollars

Substituting data from Table 7, the results of the calculation to obtain the investment cost of the City of Las Vegas are shown in Table 8.

Table 8 Calculation results of investment costs in Las Vegas city

	Cost
C_P	402,100,000 dollars
C_L	1,120,000 dollars
C_M	16,900,000 dollars
C_E	172,000 dollars
Total	420,292,000 dollars

4.2 Benefits Model for E-bus Transition

4.2.1 Energy Cost of Diesel Bus

The cost of diesel consumption is important for analyzing the financial implications of conversion to an E-bus fleet. The energy cost per year of all diesel-bus per year can be calculated by equation (9),

$$C_{fuel} = \textit{Total Fuel Consumption} \times p_{fuel} \tag{9}$$

Where: p_{fuel} represents the price of diesel fuel;
C_E represents the total energy cost of the E-bus.
Besides, the price of diesel fuel will increase in long-term analysis. We consider an average increase rate r of the price of diesel fuel. Then, equation (10) can be rewritten to equation (11).

$$C_{fuel} = \textit{Total Fuel Consumption} \times p_{fuel}(t) \tag{10}$$

$$p_{fuel}(t) = p_{fuel}(t-1)(1+r) \tag{11}$$

4.2.2 Maintenance Cost of Diesel Bus

Diesel buses also have maintenance costs and Diesel buses are more mechanically complex and have higher annual maintenance and repair costs. Diesel buses are more complex and have higher annual maintenance and repair costs. After converting to all E-bus fleets, diesel bus maintenance costs can be saved. It can be calculated by equation (12), which shows the cost of maintenance and repair of diesel buses in the E-bus fleet.

$$C_{MDiesel} = p_{MDiesel} \times N \tag{12}$$

Where: $p_{MDiesel}$ represents the maintenance cost of diesel buses per year, respectively;
$C_{MDiesel}$ represents the total maintenance cost of all diesel buses per year.

4.2.3 Potential External Funding

In this paper, we consider the following three sources of potential external funding:
Government Subsidies and Grants: To promote Zero-emission in traffic, the government may provide finan-

cial subsidies or direct grants to encourage the conversion to E-buses.

Environmental Protection Funds: There are environmental organizations and funds aimed at improving the environment willing to provide financial support.

Corporate Partnerships and Sponsorship: The corporations that can benefit from the promotion of the electric vehicles industry are willing to provide financial support.

Let F represent the total money of all potential external fundings, and we define

$$F=\lambda\times[CP+CL+CM+CE] \tag{13}$$

lWhere: λ is the proportion of investment costs, $0\leq\lambda\leq1$.

4.3 Optimization Model for the Best Conversion to All E-bus Fleet based on Linear-programming

Based on the calculations above, the replacement cost of trams is very expensive. There will be huge financial pressure to replace them all at once. Therefore, we make a reasonable construction plan with a 10-year replacement plan. Definition $\boldsymbol{\beta}=(\beta_1,\beta_2,\ldots,\beta_{10})$ denotes the replacement ratio in each year, then we establish the optimization objective function as follows:

Solve the above model and get $\boldsymbol{\beta}$ = (0.2,0.2,0.2,0.16,0.13, 0.07,0.03,0.01,0).

4.4 Results and analysis

In our paper, we set p_{M1} = 4000 USD / year and p_{M2} =9500 USD / year. The price of diesel fuel p_{fuel} = 4.366 USD/gal and r = 5.54%.

4.4.1 Data of 3 Cities

This paper investigates the relevant data for three U.S. cities, each of which is shown in the Table 9:

Table 9 The relevant data for three U.S. cities

City	Populations	Total number of buses	Bus route mileage
Las Vegas	641903	400 units	1.6 million km
Boston	675467	100 units	800,000 km
Seattle	737015	1500 units	6.8 million km

According to the relevant data in the above table, the total cost can be accounted for by the formula we assumed above, which is explained in detail in the next subsection.

4.4.2 Result on Boston City and Seattle City

Through the survey, we know that the total population of the city of Boston is around 675,467 and has 100 buses, and the total mileage of the buses is 800,000 km, assuming that the data found is correct and bringing the relevant data into our model. The results of the calculation to obtain the investment cost of the City of Boston are shown in Table 10.

Table 10 The calculation to obtain the investment cost of the City of Boston

	Cost
C_P	100,700,000 dollars
C_L	315,000 dollars
C_M	4,225,000 dollars
C_E	75,250 dollars
Total	105,315,250 dollars

Through the survey, we know that the total population of Seattle city is around 737015, and it has 1500 buses. The total mileage of the buses is around 6.8 million km, again assuming that the data we have found out is correct and bringing the relevant data into our model. The results of the calculation to obtain the investment cost of the City of Seattle are shown in Table 11.

Table 11 The calculation to obtain the investment cost of the City of Seattle

	Cost
C_P	1,507,875,000 dollars
C_L	4,725,000 dollars
C_M	63,375,000dollars
C_E	735,300 dollars
Total	1,576,710,300 dollars

5. Strengths and Weakness

Electric buses and fuel vehicles have their advantages and disadvantages. The advantages of electric buses include environmental protection, economy, comfort, energy saving, smoothness, easy maintenance, low noise, excellent vehicle performance, and intelligence. In contrast, the advantages of fuel vehicles include longer range, faster refueling, and wide distribution of fuel stations. However, the disadvantages of fuel vehicles are also obvious, including high fuel consumption, high emissions, high noise, and high maintenance costs. Therefore, from the environmental and economic perspectives, electric buses are more suitable for developing urban public transportation. Meanwhile, with the continuous progress of battery technology and the gradual improvement of charging infrastructure, electric buses' range and charging speed will be further improved, thus enhancing their competitiveness. If a city plans to convert fuel buses to E-buses, it can refer to the model proposed in this paper, which, to a certain extent, can help the local government to implement E-buses efficiently.

6. Conclusion

Electric bus is the future of urban public transportation. It is changing our perception of public transportation with its many advantages, such as environmental protection, economy, comfort, energy saving, smoothness, convenient maintenance, low noise, excellent vehicle performance, and intelligence.

First of all, electric buses' environmental friendliness is incomparable to fuel buses. Using electricity as a power source in the city significantly reduces carbon emissions and positively improves urban air quality and protects the environment. This is conducive to improving the quality of life of urban residents and in line with the current global pursuit of green travel.

Secondly, the economy of electric buses also brings real benefits to bus companies. Electric buses have significantly lower operating and maintenance costs than fuel buses. The low cost of charging and the ease of maintenance of the batteries and motors saves bus companies significant operating costs.

In addition, the comfort level of electric buses is one of their advantages. Because electric buses are motor-driven, so they operate with low noise and smooth running, providing passengers a more comfortable ride. This is undoubtedly good news for passengers who must take the bus daily.

At the same time, electric buses' energy efficiency and intelligence further improve their competitiveness. The efficient use of electric energy and an intelligent scheduling system make electric buses more energy-efficient in operation and improve public transportation efficiency.

In summary, the electric bus is becoming an important trend in urban public transportation development with its unique advantages. It changes our perception of public transportation and improves the quality of urban life. In the future, we have reason to believe that electric buses will play a more important role in urban public transportation.

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