



Sustainable Public Transport for Urban Mobility: A Case Study on Replacing Internal Combustion Vehicles to Electric Buses

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Abstract. The importance of sustainable solutions in public transportation systems have increased due to increasing environmental problems, and energy costs. In this context, transforming bus fleets that run with internal combustion engines (ICE) to electric buses (EBs) offers significant advantages, both environmentally and economically. Compared to buses with ICE, electric buses produce nearly zero carbon emissions, improving air quality and helping reduce greenhouse gas emissions. In addition, noise pollution is significantly eliminated which positively contributes to the quality of life in cities. Electric buses have a much higher energy conversion rate than internal combustion engines. Furthermore, maintenance costs are remarkably lower because electric motors have fewer moving parts and many components related to engine and fuel system are not needed. EBs can have high initial investment, however, long-term operating costs can yield to an overall total cost advantage. Furthermore, the widespread use of EBs can enhance energy supply security in cities and supports the potential use of domestic renewable energy resources. In this study a group of routes are examined and an analysis is performed assuming current buses with ICE are converted to electric buses.

Keywords: Electric Bus, Allocation of Charging Stations For Electric Buses, Electric Bus Infrastructure Planning, Electric Bus Transportation, Sustainable Transportation.

1 Introduction

Public transportation plays an important role in global energy consumption and urban sustainability. Transportation accounts for approximately 28% of global final energy consumption, and energy demand in the bus sector continues to rise [1,2]. Bus energy consumption is influenced by both external and operational factors, including road geometry, gradient, speed, acceleration, passenger load, HVAC demand, and driving behavior [3]. Among these parameters, passenger weight, speed, and acceleration have a particularly significant impact. A sharp increase in energy consumption is observed

in situations such as high speed or aggressive acceleration as well as electromagnetic effects while high power charging. Limiting acceleration or maximum speed can have a reducing effect on overall energy demand. To model these effects, various approaches have been proposed, including vehicle-specific power models, physics-based formulations, and data-driven regression methods [1,4–6].

Real-world analyses show that 12-meter battery electric buses (EBs) operating in urban conditions typically consume approximately 1.3-1.7 kWh/km. The use of heating, ventilation, and air conditioning has also been found to increase energy demand by approximately 21-27% [7,8]. In contrast, passenger load has been reported to have a relatively limited effect on energy consumption compared to driving dynamics and auxiliary loads. Driver behavior and road conditions remain important factors across all vehicle types. Controlled trials show that aggressive driving and poor road surfaces increase energy consumption. These same data confirm that EB fleets reduce petroleum use by 85-87% and fossil fuel consumption by up to 46% [7]. It is clear that EBs have higher upfront purchase costs. However, cost-benefit studies suggest that the total cost of ownership can be lower, mainly due to reduced fuel and energy expenditures over the vehicle lifetime [9]. Electric powertrains can achieve energy conversion efficiencies above 80%, exceeding 90% under low-speed operating conditions [10]. Overall, these findings highlight both the opportunities and challenges of large-scale bus fleet electrification.

Kozłowski proposed a polynomial model to estimate energy losses during diesel-to-electric bus conversion. The model uses route and vehicle characteristics to support rapid selection of key drivetrain components, including the motor, inverter, transmission, and battery. The model outputs variables such as torque demand and energy consumption, enabling rapid evaluation of range and performance [11].

Topal evaluated the cost and payback period of retrofitting CNG and diesel buses into electric buses. He investigated the economic feasibility of this conversion. The study reported a payback period of 8.74 years for a fleet of 100 vehicles, and estimated that a retrofit cost of approximately €100,000 per vehicle would be required to achieve a five-year return on investment. These results suggest that retrofitting can be a viable option for sustainable public transportation [12]. In a subsequent study, Topal (2024) compared the performance of retrofitted EBs with newly manufactured EBs, emphasizing the impact of high initial purchase costs. This study emphasized that the retrofit option for EBs, which have low maintenance costs but high investment costs, should be evaluated in transportation policies [13]. In Lipman's 2025 review, he stated that the global EB market is growing rapidly and that battery-powered models have the best fuel economy based on actual operating data. He noted that battery-powered models are followed by hydrogen fuel cell and diesel hybrid buses. The study emphasized that high initial costs, maintenance and fuel expenses, the impact of cold weather on performance, charging, and hydrogen refueling difficulties are the main obstacles limiting the widespread adoption of electrification [14].

Given these advantages, EBs represent an attractive alternative in cities with sufficient charging infrastructure, particularly in terms of environmental and economic performance. Therefore, in this study, 13 actual bus routes in Malatya were analyzed using a multi-parameter model that considers parameters related to passenger load,

route and other parameters that directly affect the consumption. Daily energy consumption and operating costs were compared with traditional diesel buses.

The main contributions of this study are summarized as follows:

1. A consumption analysis is performed on a subset of a real world bus route system. Thirteen bus routes are studied and consumption is calculated by multi-parameter model including passenger load and route related parameters.
2. The total daily operating cost of EBs is calculated and compared with that of conventional diesel buses.

The remaining sections of the study are as follows: Section 2 discusses problem formulation. The results obtained are discussed in Section 3, Results and Discussions. Section 4 contains the conclusion.

2 Problem Formulation

In this study, a techno-economic analysis is carried out to evaluate the feasibility of replacing diesel buses with electric counterparts on selected routes. As of February 2022, there has been nearly 120 bus routes in the city of Malatya. From these routes, 13 were selected for detailed analysis. The selected routes represent more than 10% of the total bus route network in Malatya. In order to calculate the consumption costs some data are gathered. Namely, the number of passengers using the bus on that route, the number of bus stations, and the roundtrip distance.

In this study, energy consumption of an EB is calculated by the formula presented in the study [15]. The consumption of the EB includes external, topographic and operational parameters. In the study, the authors compare seven models and conclude that multiple linear regression (MLR) and support vector machines (SVM) techniques outperformed other models. Thus, in our study, the model with MLR technique shown in Eq. 1 is used for calculating the EBs consumption.

$$EC_i = \beta_0 + \beta_1 g + \beta_2 D_{Agg} + \beta_3 Road_c + \beta_4 HVAC + \beta_5 Psngr_{Load} + \beta_6 Stop_{den} + \beta_7 V_a + \beta_8 SoC_i + \beta_9 C_d + \varepsilon_i \quad (1)$$

Here, EC_i is the energy consumption on the i th route, g : the slope of the road, Dr_{Agg} : the aggressiveness level of the driver, $Road_c$: the condition of the road, $HVAC$: the energy consumed by the HVAC system, $Psngr_{Load}$: the density of the passengers, $Stop_{den}$: the stopping frequency between the bus stops, the V_a : the average speed, SoC_i : the charge level and C_d is the friction coefficient. ε_i : the i th random error. β_0 is the constant coefficient and β_1 - β_9 represent the coefficients which are shown in Table 1.

Table 1. MLR Coefficients.

| Coefficient | Value |
|-------------|-------|
| β_0 | 0.885 |
| β_1 | 0.38 |

| | |
|-----------|-------|
| β_2 | 0.065 |
| β_3 | 0.26 |
| β_4 | 0.036 |
| β_5 | 0.005 |
| β_6 | 0.128 |
| β_7 | 0.007 |
| β_8 | 0.012 |
| β_9 | 0.173 |

Authors of study in reference [15] used the following parameters in Table 2 to acquire the model.

Table 2. Model parameters.

| Parameter | Value |
|-------------------------------------|-------|
| Battery Initial State of Charge (%) | 100 |
| Max. Torque (N.m.) | 2500 |
| Battery Capacity (kWh) | 200 |
| Frontal area (m ²) | 8.32 |
| Dynamic Radius of the Tires (m) | 0.5 |
| Gear Ratio | 4.66 |
| Curb Weight (kg) | 14860 |
| Recharge Efficiency | 0.978 |
| Round Trip Efficiency | 0.971 |
| Motor Efficiency | 0.916 |
| Discharge Efficiency | 0.992 |
| Drag Coefficient | 0.6 |
| Rolling Resistance | 0.01 |
| Air Density (kg/m ³) | 1.27 |
| Ambient Temperature (°) | 20 |
| HVAC (kW) | 0 |
| Auxiliary Power (kW) | 0 |

3 Results and Discussions

Based on the passenger load (number of passengers), stop density (number of bus stops per km) a consumption is calculated for the respective route. Following assumptions are made: road condition and the driver aggressiveness parameters are set to 2 (total of three levels ranging from 1 to 3), SoC is set to 80% and average speed is

set to 30 km/h. Slope difference is calculated for the all 13 routes and there is no height difference by the end of the trip because most of the routes are formed by a ring type route. Some other routes have very minor deviation from the ring type route but the elevation difference is not observed when the height of the points are compared on the map. The results of energy consumption calculations are presented in Table 3.

Electricity prices are taken from ref [16]. Exchange rate is based on Central Bank exchange rates [17]. According to the results on Table 3, total consumption cost by EBs on these 13 routes is \$1319.58.

Table 3. The results of energy consumption calculation for EBs

| No | Line code | Daily Passengers (Ave.) | Daily trips | Number of Passengers per trip | Roundtrip distance | Number of bus stops | Bus stop per km | Calculated cons. per km (kWh) | Calculated cons. per trip (kWh) | Calculated total daily cons. (kWh) | Calculated total daily cost |
|----|-----------|-------------------------|-------------|-------------------------------|--------------------|---------------------|-----------------|-------------------------------|---------------------------------|------------------------------------|-----------------------------|
| 1 | 2A | 1487 | 10 | 144 | 22.8 | 84 | 3.68 | 2.1620 | 49.2936 | 507.7241 | \$46.46 |
| 2 | 2B | 1167 | 23 | 50 | 23.8 | 86 | 3.61 | 1.6831 | 40.0578 | 937.3521 | \$85.78 |
| 3 | 5A | 1165 | 46 | 25 | 12.6 | 28 | 2.22 | 1.3802 | 17.3905 | 799.9639 | \$73.21 |
| 4 | 6A | 2091 | 34 | 62 | 23.5 | 52 | 2.21 | 1.5639 | 36.7517 | 1249.5561 | \$114.35 |
| 5 | 8B | 2185 | 17 | 129 | 14.9 | 56 | 3.76 | 2.0960 | 31.2304 | 530.9168 | \$48.58 |
| 6 | 8D | 1452 | 44 | 33 | 8.23 | 30 | 3.65 | 1.6019 | 13.1836 | 576.1249 | \$52.72 |
| 7 | 9B | 1747 | 11 | 159 | 14.3 | 50 | 3.50 | 2.2127 | 31.6416 | 348.0577 | \$31.85 |
| 8 | 10Z | 5061 | 34 | 147 | 21.9 | 60 | 2.74 | 2.0554 | 45.0133 | 1548.4561 | \$141.70 |
| 9 | 11A | 1013 | 37 | 27 | 24.3 | 66 | 2.72 | 1.4529 | 35.3055 | 1309.8329 | \$119.86 |
| 10 | 17B | 2453 | 28 | 89 | 33 | 72 | 2.18 | 1.6950 | 55.9350 | 1543.8060 | \$141.28 |
| 11 | 20A | 1659 | 43 | 39 | 17.3 | 76 | 4.39 | 1.7279 | 29.8927 | 1279.4063 | \$117.08 |
| 12 | 152A | 3069 | 54 | 57 | 24 | 64 | 2.67 | 1.5965 | 38.3160 | 2069.0640 | \$189.34 |
| 13 | 251 | 2769 | 40 | 69 | 25.1 | 78 | 3.11 | 1.7128 | 42.9913 | 1719.6512 | \$157.37 |
| | | | | | | | | | | Total | \$1,319.58 |

Assuming similar operating conditions, fuel consumption was also estimated for the diesel bus baseline case to enable a fair comparison. A study conducted on the Sydney bus fleet reported an average fuel consumption of approximately 40–45 L/100 km for comparable diesel buses operating under urban conditions [18]. For the cost analysis, the midpoint of this range was adopted as the representative diesel fuel consumption value. Diesel fuel price data were taken from the reference source provided in [19].

Table 4. The results of energy consumption calculations for buses with ICE

| No | Line code | Daily Passengers (Ave.) | Daily trips | Number of Passengers per trip | Roundtrip distance | Number of bus stops | Bus stop per km | ICE cons. per 100 km (lt) | ICE Cons. per trip (lt) | ICE Daily total cons. (lt) | Cost of daily fuel cons. |
|----|------------------|-------------------------|-------------|-------------------------------|--------------------|---------------------|-----------------|---------------------------|-------------------------|----------------------------|--------------------------|
| 1 | 2A | 1487 | 10 | 144 | 22.8 | 84 | 3.68 | 42.5000 | 9.6900 | 99.8070 | \$136.14 |
| 2 | 2B | 1167 | 23 | 50 | 23.8 | 86 | 3.61 | 42.5000 | 10.1150 | 236.6910 | \$322.85 |
| 3 | 5A | 1165 | 46 | 25 | 12.6 | 28 | 2.22 | 42.5000 | 5.3550 | 246.3300 | \$335.99 |
| 4 | 6A | 2091 | 34 | 62 | 23.5 | 52 | 2.21 | 42.5000 | 9.9875 | 339.5750 | \$463.18 |
| 5 | 8B | 2185 | 17 | 129 | 14.9 | 56 | 3.76 | 42.5000 | 6.3325 | 107.6525 | \$146.84 |
| 6 | 8D | 1452 | 44 | 33 | 8.23 | 30 | 3.65 | 42.5000 | 3.4978 | 152.8517 | \$208.49 |
| 7 | 9B | 1747 | 11 | 159 | 14.3 | 50 | 3.50 | 42.5000 | 6.0775 | 66.8525 | \$91.19 |
| 8 | 10Z | 5061 | 34 | 147 | 21.9 | 60 | 2.74 | 42.5000 | 9.3075 | 320.1780 | \$436.72 |
| 9 | 11A | 1013 | 37 | 27 | 24.3 | 66 | 2.72 | 42.5000 | 10.3275 | 383.1503 | \$522.62 |
| 10 | 17B | 2453 | 28 | 89 | 33 | 72 | 2.18 | 42.5000 | 14.0250 | 387.0900 | \$527.99 |
| 11 | 20A | 1659 | 43 | 39 | 17.3 | 76 | 4.39 | 42.5000 | 7.3525 | 314.6870 | \$429.23 |
| 12 | ¹⁵² A | 3069 | 54 | 57 | 24 | 64 | 2.67 | 42.5000 | 10.2000 | 550.8000 | \$751.29 |
| 13 | 251 | 2769 | 40 | 69 | 25.1 | 78 | 3.11 | 42.5000 | 10.6675 | 426.7000 | \$582.02 |
| | | | | | | | | | | Total | \$4954.55 |

Using the values reported in Table 4, the total daily fuel cost for the diesel bus operation was calculated as \$4954.55. When compared with the ICE bus baseline, the results indicate that electric buses can be approximately 3.75 times more cost-efficient in terms of daily energy consumption cost.

4 Conclusion

Electric buses (EBs) have gained increasing attention in recent years, mainly due to their environmental and operational advantages in urban transport systems. EBs provide approximately 80% energy efficiency when compared to less than 40% in diesel buses. In terms of environmental impact, EBs emit zero exhaust emissions and do not pollute air whereas ICE buses emit emissions such as CO₂ and NO_x. In addition to lower emissions, EBs also improve passenger experience by providing quieter operation and reduced vibration levels. In this study, 13 bus routes in Malatya were analyzed using average daily passenger demand data collected over a one-month period, allowing route-level operational evaluation. EB total daily consumption is calculated with a multi-parameter model. According to the results, EBs can be 3.75 times more cost efficient in terms of consumption. This study reveals that EBs generally have a lower life cycle cost. Even though the initial investment may be higher than

investing in bus infrastructure with conventional buses, it can be offset in the long run depending on the total number of passengers and routes.

The analysis confirms that electrifying urban bus fleets is not only a technological transformation but also a strategic policy decision that directly contributes to sustainable mobility goals. The shift from diesel-powered buses to electric buses offers considerable environmental gains and reduced dependency on fossil fuels. However, the transition requires coordinated planning among municipalities, energy providers, and public transport authorities. The study underscores that policy frameworks, incentive mechanisms, and infrastructure investments must be aligned to ensure long-term operational reliability and economic viability. Strengthening these institutional and policy dimensions will be critical for scaling up electrification efforts in other urban regions.

It should be noted that this analysis covers only a limited subset of the overall bus route network in Malatya. In addition, certain parameters are assumed to be constant when calculating the consumption. In future studies, provided that relevant required data is obtained, consumption can be calculated with more parameters such as driver behavior, road conditions and SoC percentages.

Acknowledgments. The authors would like to thank MOTAS for providing the bus route data presented in this paper.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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