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Assessing feasibility of overnight-charging electric bus in a real-world BRT system in the context of a developing country

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Payback period.

Abstract. Air pollution, as a significant urban problem in metropolises, has harmful impacts on societies in many aspects. According to the worn-out fleet of diesel buses and fossil fuel dependencies in Tehran, alternative fuels have become more popular in sustainable public transportation. Although Battery Electric Buses (BEBs) provide many benefits, their purchase price and required infrastructure are the main challenges for decision-makers. This paper provides a systematic approach to examining the environmental, traffic, and economic efficiency of Overnight-Charging Electric Buses (OCEBs) in Tehran, Iran. Environmental analysis shows that carbon oxide and nitrogen oxide will reduce to zero and eliminate dependence on fossil fuels. The payback period is predicted to be 7 years. Due to the better acceleration of OCEBs, the travel time, delay, and stop time are reduced by about 4%, 10.67%, and 5.15% on average, respectively, leading to a better experience for passengers and an increase in public transportation utility that cause more people to be drawn to OCEBs. The present results indicate the feasibility of OCEBs implementation as a sustainable transportation mode and can be useful in policymakers' decision-making and planning for the future public transport system.

1. Introduction

Air pollution is one of the most complex metropolitan problems that exerts adverse impacts on many spheres around the globe [1]. According to World Health Organization, 4.2 million people worldwide and about 27 thousand in Iran die each year from air pollution [2]. Emissions in the transportation sector were responsible for 23% of global emissions in 2013, 75% of which were related to road transport, an increase of 68% compared to 1990 [3]. Diesel engines represent the leading cause of carcinogenic gases that highlight the need for moving toward a sustainable and green public transportation system as an essential policy to reduce transport sector pollutants [4–6].

Governments all over the world have taken some steps toward switching Diesel Buses (DBs) with sustainable energy buses to minimize greenhouse gas (GHG) emissions [7–9]. Among different types of alternative fuels for buses, Electric Buses (EBs) are more suitable for emission production and energy consumption than conventional buses [10,11]. The innovation of lithium-ion battery (LIB) technology has turned electric vehicles into a renewable mobility alternative

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over the last decade that requires minimal maintenance. Some studies conclude that LIB technology is still developing, and the reliability, specific energy, and quality of such technology could be still enhanced over time. The number of urban EBs is currently growing, but the main concern of policymaking is the required infrastructure and high cost of investment [12,13]. The total operating cost of EBs is lower than that of Internal Combustion Engine Buses (ICEB) because of higher fuel efficiency, lower electricity price, and maintenance. However, high initial investment including purchasing cost and charging facilities make EBs pricy. The BEBs, also known as pure electric buses, are operated using an onboard battery package. According to the range and charge time of BEBs, they have two modes of operation: opportunity and overnight. The Opportunity Electric Buses (OPEBs) have a smaller battery pack with a short range (20–30 miles) and take 5–10 minutes to get a full charge (80%–100%), while the OCEBs are equipped with a relatively larger battery pack with a range of up to 200 miles and a much longer charging time (2–4 hrs) [14]. PROTERRA, one of the well-known manufacturers of EBs, claimed that E2max OCEBs' charging time is about 5 hrs and the range is 560 km, although these values might vary under different conditions. One of the main advantages of OCEBs is their flexibility in operating on different routes; also, unlike OPEBs, the charging infrastructure is concentrated at only one or two points; on the other hand, due to their larger batteries, OCEBs are heavier than OPEBs [15]. Although OCEBs have a higher purchase cost than OPEBs, they have lower charging infrastructure costs than OPEBs. In terms of lifetime operation costs, OCEBs and OPEBs are almost the same (0.44 versus 0.42 €/km); however, in terms of the total cost of ownership per kilometer, OCEBs are 5% cheaper than OPEBs. OPEBs require charging stations along their routes and also need to be fully recharged overnight at the depot. OPEBs are restricted in providing service because their route is limited to an area where only the charging system is established and the charging time must be considered in the bus schedule, which may lead to service disruption [16]. From the perspective of the urban environment, health, and noise pollution, it is necessary to mention that OPEBs cause various problems such as additional space for infrastructure installation, power cables along with the route/pavement, noise pollution, destruction of the beautiful appearance of the urban environment at charging stations, and safety issues in the neighborhood of charging infrastructure due to the implementation of charging stations along the route [17]. According to the aforementioned pros and cons of different types of BEBs, we consider OCEBs as the more appropriate option for public transportation in Tehran, Iran.

This paper aims to provide a systematic approach for examining the environmental, traffic, and economic efficiency of OCEBs under different operating conditions in Tehran. The main contributions of this paper are given as follows:

1. Most previous studies were conducted in developed, high-income countries. While in this paper, OCEBs' operation and their impacts were studied in Tehran, Iran, as a developing country;
2. Less attention has been paid to the effects of OCEBs on mixed traffic flow, which are addressed as gaps in our study;
3. Most previous studies have used economic approaches such as Life Cycle Assessment (LCA), while we employed microscopic simulation and economic analysis simultaneously to evaluate traffic, environment, and economic impacts of OCEBs.

Many researchers have studied BEBs in different countries. In most cases, they concluded that use of BEBs leads to zero tailpipe emission, reduces fossil fuel dependency, and is economically justified in life cycle (12 years) costs [7,18–24].

Xylia et al. investigated the impacts of electrifying Stockholm's bus fleet to reduce Carbon Oxide (CO). They used an optimization model to locate chargers and estimate emissions using LCA in different operation scenarios. Their results demonstrated the reduction of local pollutants in the city of Stockholm using BEBs [19]. Song et al. compared BEBs with DBs based on LCA and GHG emissions. They concluded that BEBs had the potential to significantly reduce GHG emissions, especially in clean power mixes [20]. Mahmoud et al. evaluated different aspects of hybrid, fuel cell, and battery-electric buses. The examined buses were hybrids (series and parallel), fuel cells, BEBs (overnight and opportunity), and diesel. They concluded that fuel cell and BE buses had an efficient performance and overnight BEB was chosen as the best solution [22]. Yu conducted a study on use of EBs in the Hong Kong public transportation system to evaluate their public acceptance and environmental impacts. He concluded that BEBs had long-term payback periods and no exhaust emissions. Besides, the barriers to public acceptance of BEBs were lack of infrastructure support, battery capacity, and battery anxieties [24]. Lajunen and Lipman investigated LCA and CO emissions of BE, fuel cell, diesel, and natural gas buses. Life cycle costs include purchase, service, maintenance, and potential CO emission costs. According to the simulation results, alternative fuels significantly enhance the efficiency of the buses. BEBs substantially reduce CO emissions and energy consumption by 75% [7]. The Global Green Growth Institute conducted a comprehensive study on India's public transportation system, outlined the benefits of

EBs, and explored the implications of their operations. It was concluded that EBs did not have any exhaust emissions as the main cause of air pollution in urban areas [14]. Aber conducted a study on the implementation of EBs in the New York bus fleet and examined their economic, health, and environmental impacts. He found that replacing the current fleet with the EBs would reduce the air pollution caused by DBs and realized that the life cycle cost (12 years) of EBs was 12.5% lower than DBs [21].

According to the literature review, it can be concluded that OCEBs represent an appropriate solution to clean transportation and their high cost was related to battery, complexity of system design, and their new and emerging technology. The complexities of BEB operations make decision-making challenging; thus, it is essential to thoroughly examine the different technology options and operating models of BEBs.

The paper is presented in the following way: Data and methods are discussed in the 'Methodology' section; the results and discussion are presented in the 'Data analysis' section; and the 'Conclusions' section provides the main conclusions, limitations, and recommendations for future research.

2. Methodology

Microscopic simulation models are becoming increasingly popular tools for designation, optimization, and analysis of transportation networks and management policies [25,26]. Aimsun is used as a microscopic simulation tool to simulate the operation of OCEBs on Bus Rapid Transit (BRT) line 7 in Tehran, Iran. Afterward, outputs are assessed in terms of economic feasibility and environmental and traffic performances. Figure 1 illustrates the flowchart for the proposed methodology.

Of note, Aimsun is equipped with pollutant emission model to calculate different emission rates in various traffic flow and geometric conditions [27]. Many studies used Aimsun pollutant emission model to analyze the environmental impacts of their proposed scenarios [28–30]. Aimsun calculates different pollutant emissions of vehicles based on vehicle and fuel types factors in three modes of acceleration, deceleration, and idling. Afterward, the emission rate of each vehicle will be calculated based on the slope of the streets and the speed of traffic flow. Finally, Eqs. (1) to (3) are used to calculate the emission rate using the model proposed by Panis et al. [27]. According to the studies, CO and NO_x are the most critical and hazardous pollutants that could be studied and analyzed in terms of their environmental impacts in Aimsun [31].

$$ER_{seg} = \frac{E_{seg}}{L_{seg} * t_{seg}}, \tag{1}$$

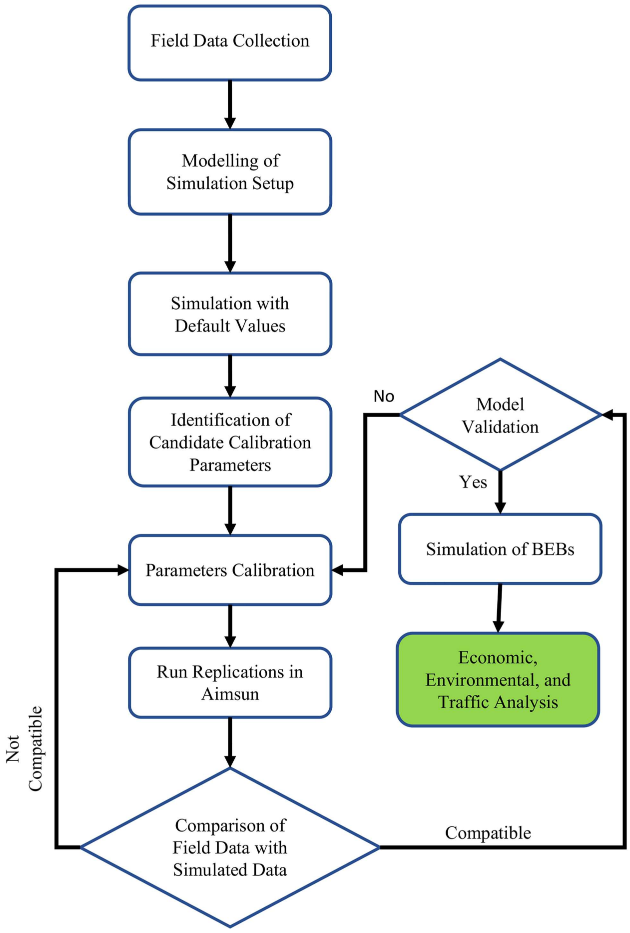


Figure 1. Flowchart for the proposed methodology.

$$E_{seg} = \sum ER_i * VP_i * L_{seg}, \tag{2}$$

$$t_{seg} = \frac{L_{seg}}{V_{seg}} * 3600, \tag{3}$$

where ER_{seg} accounts for segment emission rate, ER_i emission rate of vehicle i, VP_i number of vehicles i, t_{seg} segment travel time, L_{seg} segment length, and V_{seg} segment speed.

Moreover, traffic data and other related information have been collected from field surveys and organizations [32]. First, input data are used to model the case study, including route geometry, stations, schedules, buses, and the infrastructure. A large amount of data is required for the microscopic simulation of BRT in Aimsun. Such data include the digital map of the site for exact drawing, route information including path length, longitudinal slope, number of lanes, and lane width. It also requires intersection information including traffic flow of each approach legs, control type, traffic signs and signals, surface marking, turnings, traffic signals timing, and precise detector location. Information of public transportation systems such as buses' physical and technical characteristics, headways, timetables, station locations, infrastructure information, station stopping times, distance between stations, etc. is also required. After collecting the data needed, the 7th line of BRT in Tehran was simulated based on default parameters. To achieve more reliable outputs, calibration and validation of the simulation model were conducted through the comparison of field and simulated data to increase model accuracy and confidence. The calibration and validation processes are discussed in Section 3.1. Afterward, OCEBs are simulated as a sustainable transportation mode in Aimsun and the important outputs such as travel time, speed, delay, flow, emissions, and fuel consumption were derived.

2.1. *The environment under analysis: the city of Tehran*

As the capital of Iran, Tehran is the most congested and populated city in Western Asia, with a population of around 8.8 million people. It has been subject to congestion and air pollution due to the growth in urban population and car ownership. Local authorities are trying to reduce severe air pollution by introducing sustainable and green transportation [31]. The seventh line of Tehran's BRT is one of the most extended lines (18 km) of public transit, which transfers a large number of passengers from the northernmost point of Tehran to the southern point. All along the bus route, there is a dedicated and exclusive lane. Based on Tehran public transportation administration reports, this line transfers 220,000 passengers daily and the average travel time at peak hour is about 80 minutes. Figure 2 illustrates the 7th line of Tehran's BRT system scheme [32]. More than 70% of Tehran's pollutants are emitted by clunker buses because 97% of buses are old and more than 80% of urban air pollution is induced by low-quality fuel [33]. In this regard, the 7th line of Tehran's BRT operation is simulated and after calibration and validation of the model, OCEBs as sustainable public transportation are analyzed. Traffic simulation and economic analysis are conducted to derive the required outputs in the next section.

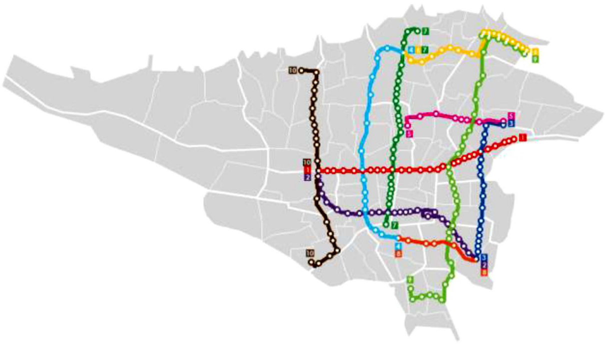


Figure 2. The 7th line of Tehran's BRT system scheme [31].

3. Data analysis

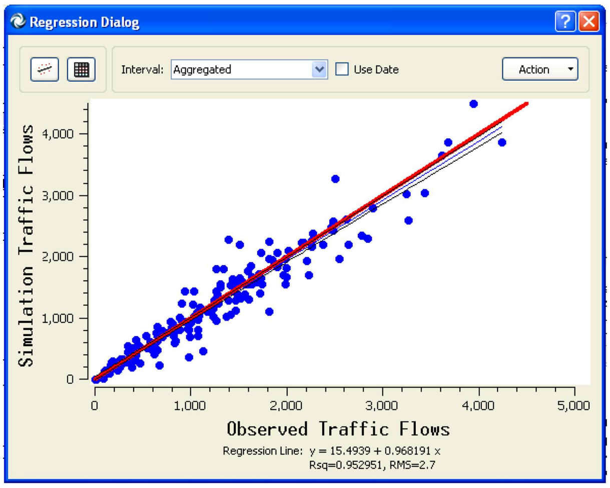
3.1. *Traffic simulation*

To simulate the real operation of buses, calibration as the process of determining values of the model parameters is crucial [34]. A well-calibrated model needs to assign a reasonable value to each vehicle to accurately simulate the dynamic interactions in the traffic flow in terms of mixed-traffic operations, where numerous fast and slow-moving modes create a complex environment [35]. This paper selected traffic flow and travel time parameters for calibration. After calculating appropriate values, we compare the volume of vehicles at different intersections to complete the calibration process. Figure 3 compares the field and simulated volume data. Given the R square of 0.95 and Root Mean Square (RMS) of 2.7, it was found that the calibration of the model was performed properly. In the case of travel time, simulated and field data were compared and the calculated RMSE (Eq. (4)) was 1.23. In addition, the emission rate of buses in the simulation model was compared with the real data, and no significant differences were observed at a confidence interval of 95% (Figure 4).

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}, \tag{4}$$

where n is the number of iterations in the simulation model, y_i the observed value, and $\hat{y}_i$ the predicted value in the model.

Validation is an essential phase in the model development process to assess the model reliability. In addition, no model can be confirmed till the validation checks have been passed [36]. Validation is defined as the process of testing the model with independent data used in the calibration to examine the model



Interval: Aggregated ☐ Use Date

Regression Line: y = 15.4939 + 0.968191 x
Rsq=0.952951, RMS=2.7

Figure 3. Comparison of traffic flows in the simulation model and real data.

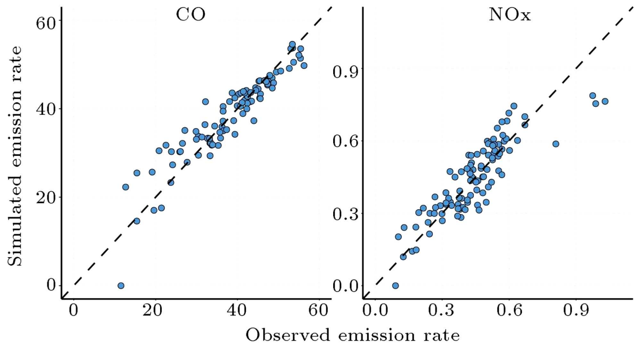
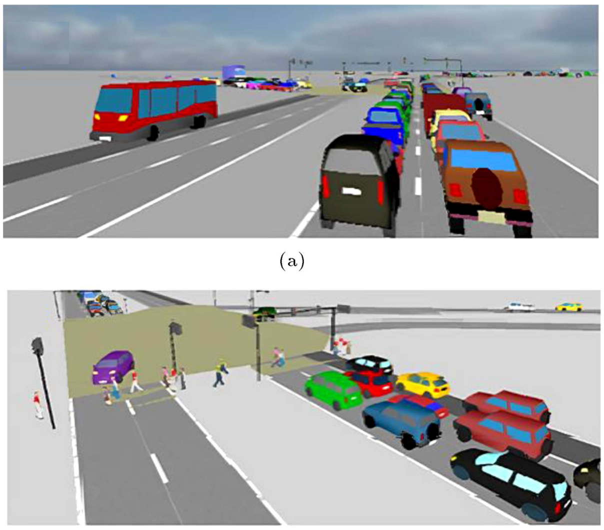


Figure 4. Comparison of emission rate of buses in the simulation model and real data.


(a)

(b)

Figure 5. Simulation environment in Aimsun.

appropriateness in reproducing the reality. In this regard, the validation of the simulated model was performed for another day, and the results indicated that the model worked accurately.

After simulating the operation of the 7th line of Tehran's BRT and calibration and validation of the model, travel time and environmental indicators were calculated. Given the stochastic nature of the simulation, it is necessary to run multiple replications and compute the average to derive the results [37]. Therefore, according to the proposed equations and studies, 10 replications were considered to calculate the average of required outputs. The simulation environment of the network is presented in Figure 5. Moreover, the exclusive BRT lane (Figure 5(a)) and the impacts of different elements in signal timing such as pedestrian volume are given in Figure 5(b).

Regarding the old bus fleet of Tehran, OCEBs were simulated as a solution. Operational characteristics of BYD and 18 m-battery electric bus were used as input parameters in Aimsun and required outputs were derived [38], as shown in Figure 6.

As DBs experienced long stops at intersections, they faced environmental problems such as increased fuel consumption and pollutant emissions. Besides, stop-go driving led to an increase in air pollution because of the longitudinal slope of the route. Hence, an attempt is to enhance the system efficiency by replacing the existing fleet with OCEBs. Compared to conventional buses, OCEBs provide zero tailpipe emission, silent movement, improved acceleration, lower fleet operating costs, and less fossil-fuel dependence [17,19–21]. Regarding better acceleration of OCEBs, the travel time was reduced by about 4% and passengers faced lower delays, leading to an increase in public transportation utility. More people will shift to OCEBs. Regarding zero tailpipe emission and no diesel consumption of OCEBs [17,19–21], CO and NO$_x$ emissions eliminated and reduced fossil fuel dependencies.

Regarding the importance of traffic performance assessment in projects, we investigated various indicators such as average speed, delay, flow, density, and stop time. Figure 7 illustrates the traffic performance indicators of OCEBs compared with DBs. As could be seen, the delay and stop time of OCEBs are less than DBs. According to better acceleration and power of electric buses, OCEBs reduced delays and stop time by 10.67% and 5.15% on average, respectively. Moreover, flow, density, and average speed increased by 3%, 3.1%, and 2.93% on average, respectively. According to the aforementioned traffic performance indicators, it is found that OCEBs are more appropriate than DBs. In this regard, they are a suitable solution to traffic and environmental problems in Tehran. However, due to their high capital cost, an economic analysis should be conducted to justify their implementation.

3.2. Economic analysis

Benefit-Cost Analysis (BCA) accounts for the variations of costs and benefits attained by potential enhancement of the existing facilities [39]. BCA can be used in decision-making to help assess whether 1) a project should be implemented or not; 2) when a project is implemented, BCA may show that a project does not pass the economic tests at the moment, but would be worthwhile 10 years later; and 3) which scenario should be funded regarding the limited resources, among several competing alternatives and plans. Considering the high capital cost of OCEBs, careful BCA should be conducted to assess the implementation feasibility and the potential benefits and costs to calculate the payback period.

3.2.1. Travel time saving value

In Aimsun, travel time accounts for the average time that it takes for each bus to travel on a specific route [40] and is calculated using Eq. (5):

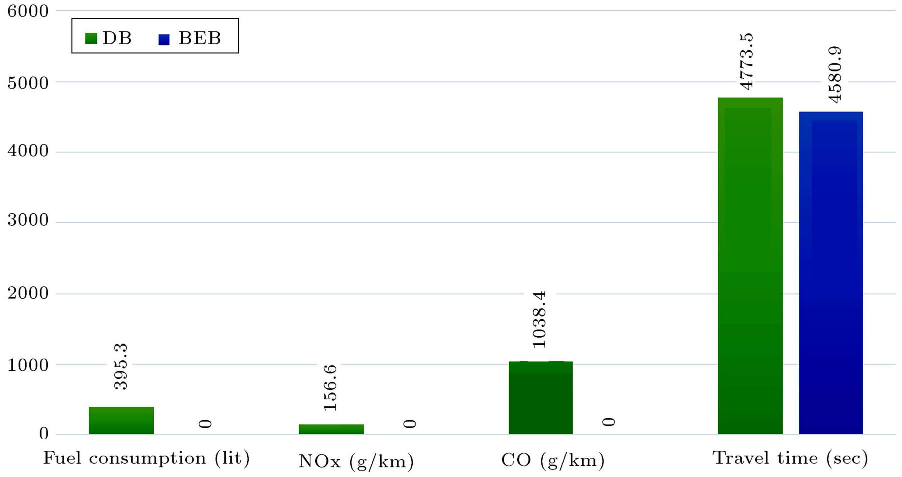


Figure 6. Comparison of travel time and environmental indicators of DBs and OCEBs.

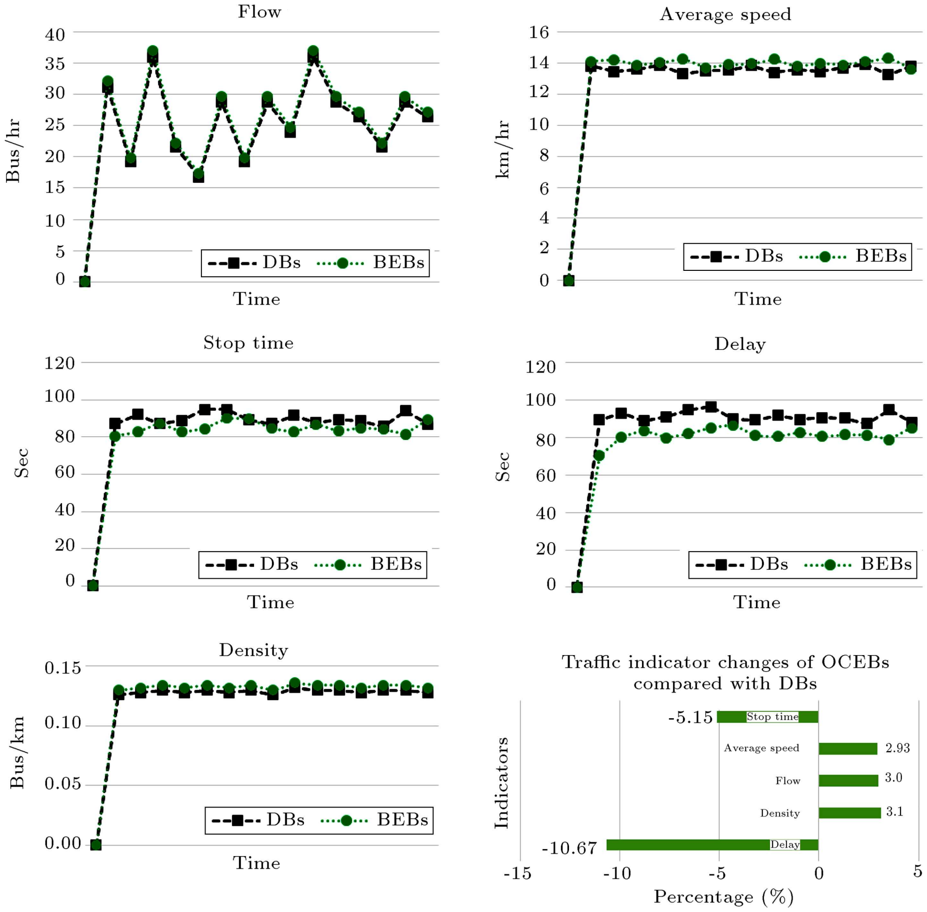


Figure 7. Traffic indicator of OCEBs compared to DBs.

$$TT_i = \frac{TEX_i - TEN_i}{D_i} * 1000, \tag{5}$$

where the entry time of the ith bus is recorded as TEN_i (sec) and its corresponding exit time is stated as TEX_i (sec). D_i accounts for the total distance traveled of vehicle (i) in meter and the average travel time per km of vehicle (i) is denoted by TT_i (sec). Value Of Time (VOT) is calculated according to Eq. (6) to determine the financial value of time duration for passengers [31,32]:

$$VOT_B = \frac{s}{T * 12 * D}, \tag{6}$$

where VOT_B is the VOT of passengers (\$/hr), s is the average annual household income (\$), T is the average monthly working hours (hr), and D accounts for the household size. Regarding passengers' information and statistics published by the Central Bank of the Islamic Republic of Iran and the Bureau of Economic Statistics, the VOT is calculated as \$1.5 per hour (1 US Dollar is equivalent to 42,105 Iranian Rials [41]).

Considering \$1.5 per hour and transferring of 220,000 passengers on this line, the amount of time saved by travelers is calculated in relative terms. According to the studies conducted by various scientists, the efficiency and superiority of OCEBs are long-term, and their benefits and costs should be considered during their life cycle costs (12 years) using time series data [19,21]. It should be noted that Holt-winters method is used to forecast the required values using XLSTAT software. Holt-Winters method, also known as triple exponential smoothing, comprises three smoothing equations:

1. The first part is called the average or level, which shows the general behavior of the model;
2. The second part is the trend (line slope), which is constant in time but is considered as the parameter of variables;
3. The third section, which changes periodically, is also used to show seasonal changes [42].

The simple form of the Holt-Winters time series model (without trends and seasonal changes) is presented as Eq. (7):

$$S_t = \alpha \frac{y_t}{I_{t-L}} + (1-\alpha)(S_{t-1} + b_{t-1}), \tag{7}$$

where y_t is the observed value corresponding to time t and S_t is the smoothed value at time t. Moreover, I is a seasonal index and L is the length of the seasonal changes. If the model has a trend, the model specification is shown using Eq. (8):

$$b_t = \gamma(S_t - S_{t-1}) + (1-\gamma)b_{t-1}. \tag{8}$$

In case of seasonal changes, Eq. (9) should also be considered as the model specification:

$$I_t = \beta \frac{y_t}{S_t} + (1-\beta)I_{t-L}. \tag{9}$$

Using statistics and information available in the Iranian Statistical Organization, the VOT was calculated from the year 2002 to 2018 and predicted with a 95% of confidence interval for the next 12 years using times series method (Figure 8). According to the VOT and number of passengers, the financial value of reduced travel time is predicted to be about \$209 million during the lifetime of OCEBs.

3.2.2. CO and NO$_x$ elimination costs

In a research study conducted by Boardman et al. (2017), the estimated CO and NO$_x$ reduction costs were about \$890 per ton and \$4790 per ton in 2016, respectively. The costs account for some issues that affect direct and indirect aspects of human life. Regarding the 12-year life cycle of OCEBs, CO and NO$_x$ costs are forecasted using times series data obtained from previous studies and illustrated in Figures 9 and 10, respectively [43].

The financial value of CO and NO$_x$ elimination is predicted to be about \$1.62 and \$1.25 million over the lifetime of OCEBs (12 years), respectively.

3.2.3. Diesel consumption elimination costs

Regarding OCEBs not consuming diesel and reducing fossil fuel dependencies, the diesel cost elimination should be considered a benefit of these vehicles. Re-

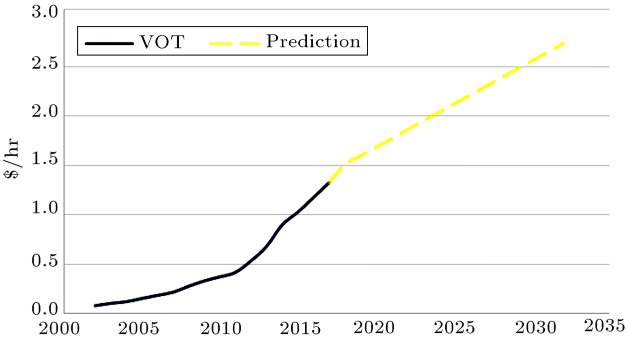


Figure 8. Forecast of Tehran residents' VOT in the lifetime of OCEBs.

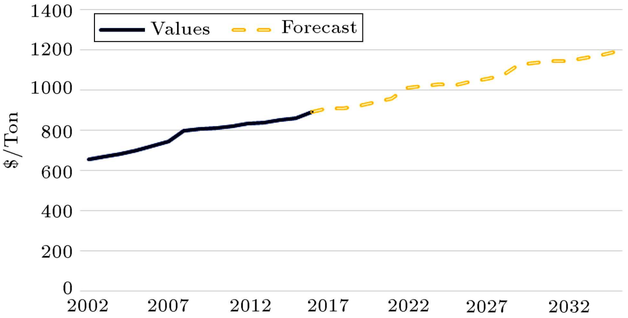


Figure 9. Forecast of CO reduction cost during the lifetime of OCEBs.

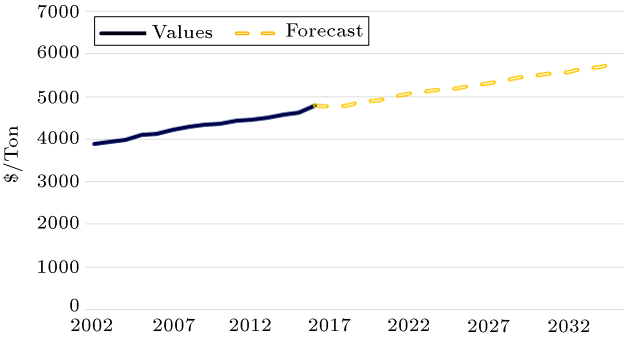


Figure 10. Forecast of NOx reduction cost during the lifetime of OCEBs.

garding the 12-year life cycle of OCEBs, the cost of diesel is also predicted using time series method. For this purpose, using statistics and information available from the Iranian Census Bureau and Knoema [44], we extracted the diesel price from 2002 to 2018 and predicted the price with a 95% confidence level for the next 12 years using statistical methods, illustrated in Figure 11.

The financial value of diesel consumption elimination is predicted to be about \$140 million over the lifetime of OCEBs (12 years).

3.2.4. *Electricity consumption cost*

It is important to note that, given previous research, a limited number of OCEBs are tested in developed countries, and their power consumption is measured in the field. BYD, the OCEB that we considered as the case of our research, is capable of travelling on routes with a maximum slope of 15% and its power consumption is estimated at 1.5 kW/km [38]. After simulating the BYD bus in Aimsun and considering the electricity consumption profile as a normal distribution (N(1.5, 0.5)), we estimate the electricity price during the lifetime of OCEBs with a 95% confidence level, illustrated in Figure 12. The total kilometer traveled by the fleet is about 3560 km, and the total electricity consumed is estimated to be about 5380 kW.

The financial value of the power consumption of OCEBs is predicted to be about \$1.05 million over the lifetime of OCEBs (12 years).

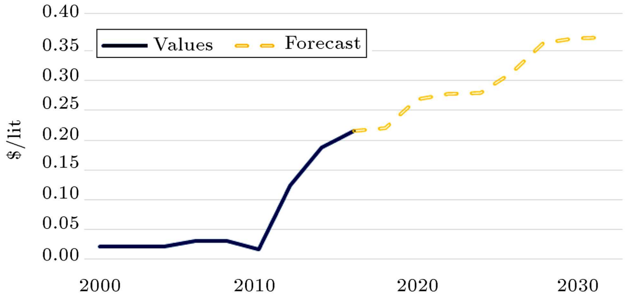


Figure 11. Forecast of diesel cost during the lifetime of OCEBs [41].

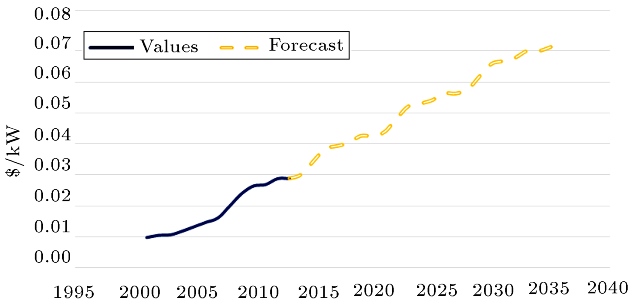


Figure 12. Forecast of Electricity price during the lifetime of OCEBs.

3.2.5. *Purchase price of OCEBs and charging infrastructures as a new transportation fleet*

According to the information gathered from the Tehran Bus Organization, Line 7 has 200 DBs. In order to replace the current fleet with the BYD OCEBs, their purchase price should be considered in the economic analysis. Regarding the exhaustion of the existing fleet, the sale price of DBs has been neglected. According to [38], the cost of each OCEB is \$950,000, and since there are 200 buses in the current fleet, the total cost of OCEBs will be \$190 million. Regarding OCEBs equipped with an overnight charging method, the cost of the charging infrastructure should be taken into account at the depot location (Railway and Tajrish Square). In Aspen, US, it costs about \$40,000 to set up a charging station and regarding 200 new OCEBs in the new fleet, \$8 million should be considered for this purpose in the BCA [45].

3.2.6. *Return on investment*

One of the investment evaluation methods is the payback period, which helps determine when an investment's initial cash outflow is supposed to be recovered from the cash inflows provided by the investment [46]. In this paper, the monetary aspects of travel time saving, elimination of pollutant emissions, and fuel consumption reduction account for the benefits, and the purchasing prices of charging infrastructure, OCEBs, and electricity consumption incorporate costs (Figure 13). Regarding the long-term return of investment of OCEBs, the payback period of the investment was estimated about 7 years in Tehran. This value varied from 5 to 8 years in previous studies based on countries' development level and their public transportation system [18,24,47].

Furthermore, Net Present Value (NPV) and Internal Rate of Return (IRR) were calculated in order to assess the economic aspects of OCEBs. NPV is the difference between the present value of cash inflows and the present value of cash outflows over a period of time, and IRR is a discount rate that makes the NPV of all cash flows equal to zero in a discounted cash flow analysis, which is calculated using Eqs. (10) and (11), respectively:

$$NPV = \sum \frac{C_t}{(1+r)^t} - C_0, \tag{10}$$

$$\sum \frac{C_t}{(1+IRR)^t} = C_0, \tag{11}$$

where C_0 is the initial investment, C_t represents the cash flow, and r is the discount rate (5%). According to the calculated costs and benefits of OCEBs during their life cycle, the NPV and IRR are \$74.75 million and 12%, respectively, indicating the efficiency and profitability of these vehicles.

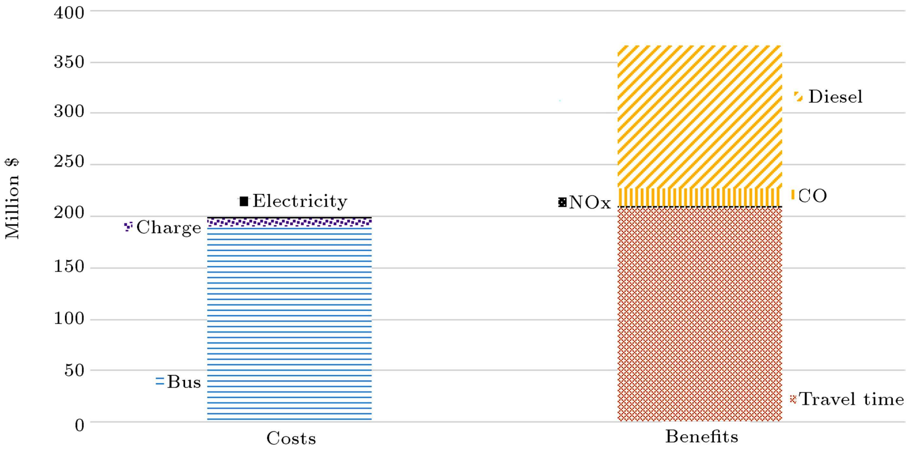


Figure 13. Costs and benefits of OCEBs implementation during their lifetime.

4. Conclusion

Despite the many benefits of Overnight Charging Electric Buses (OCEBs) such as zero tailpipe emission, silent movement, improved acceleration, low fleet operating costs, and lower fossil-fuel dependence, their purchase price and required infrastructure are the main challenges of decision-makers. Hence, it is crucial to thoroughly evaluate their performance before implementing them in a real-world network. This paper provides a systematic approach to examining the environmental, traffic, and economic impacts of OCEBs under different operating conditions in the 7th line of Tehran's BRT.

Results showed many environmental, economic, and social benefits of implementing OCEBs in the 7th line of Tehran's BRT. In terms of the environmental impacts of these vehicles, it was concluded that by converting Diesel Buses (DBs) into OCEBs, Carbon Oxide (CO) and Nitrogen Oxide (NOx) would be reduced to zero and dependence on fossil fuels eliminated. Also, implementing OCEBs was critical to improving urban health because of less noise and air pollution related to fossil fuels. In terms of economic analysis, the payback period, net present value, and internal rate of return of these vehicles were calculated. The payback period of OCEBs was predicted to be about 7 years, and their benefits were expected to be $173 million until their lifetime length (i.e., 12 years). In terms of traffic performance of OCEBs, travel time was reduced by about 4% and delay and stop time were reduced by approximately 10.67% and 5.15% on average, respectively, due to better acceleration of OCEBs. Also, flow, density, and average speed increased by about 3%, 3.1%, and 2.93% on average, leading to a better experience for passengers and an increase in public transportation utility that caused more people to attract OCEBs.

The current study is subject to some limitations. First, the main outcomes can only be generalized to the Iranian city and similar Middle East urban environments. Nevertheless, they cannot be applied to other countries or cultures because of their different perspectives. However, the above raises some discussion points useful for the next comparative studies exploring the differences in the environment and public transportation systems in other countries. It is important to note that it is difficult and sometimes impossible to evaluate all the costs involved in transportation systems; in this regard, it is recommended to consider the impact of noise pollution and people shifting to OCEBs in economic analysis for further research. Also, it is recommended to conduct a comparative study between the OCEBs and electric opportunity bus to achieve more insightful findings in choosing the most appropriate form of EBs in Tehran.

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