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Total Cost of Ownership Based Economic Analysis of Diesel, CNG and Electric Bus Concepts for the Public Transport in Istanbul City

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Received: 3 August 2018; Accepted: 3 September 2018; Published: 7 September 2018

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Abstract: As across the world, in Turkey, several studies have been carried out by local government to use sustainable and 100% zero-emission public transport following increased public awareness. Increasing greenhouse gas emissions (GHG) due to transportation systems in the world make it necessary to establish "zero-emission sustainable transportation systems" in Turkey. In this study, an economic analysis based on actual field data is presented for Istanbul Electricity, Tramway and Tunnel General Management (IETT) to seek the suitability of an electric bus concept for Istanbul conditions. For this purpose, a dynamic model based on the Total Cost of Ownership (TCO) from well to wheel has been proposed for the three groups of transportation, namely diesel, CNG (compressed natural gas) and electric buses. The data source used in the proposed approach is created by performing actual field performance tests for diesel, CNG and electric buses under real Istanbul road, time, and trip conditions. Afterwards, the Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PB) methods considering TCO values and updated unit prices are carried out for the investment versus profitability analyses to compare the different public bus concepts. The results show that the electric bus concept with a charging station depot achieving sustainable and zero-emission goals will be the driving force to advance the electric bus concept for Istanbul Public Transport.

Keywords: CNG bus; diesel bus; electric bus; filed performance test; economic analysis; total cost of ownership (TCO)

1. Introduction

In this study, in parallel to newly emerging applications across the world, it is aimed to make the preliminary feasibility studies necessary to pass the concept of electric bus transportation in Istanbul conditions. In this context, a new model has been developed which compares three different bus concepts for diesel, CNG (compressed natural gas) and electric buses. There are two important original points in this study. The most important original point of this work is the use of a TCO-based approach in the economic evaluation of public transports. In addition, this work on electric buses is the most comprehensive work being conducted under the conditions. The existing public transport system and electric vehicle infrastructure in Istanbul is introduced below and then a literature review on electric buses are summarized. After the literature summary, the proposed approach used in this study on electric buses is explained in the light of literature review.

Public transport services in Turkey are provided mainly by the local governments. The public transportation service is the essential part of urban life especially for the metropolises like Istanbul, Ankara and Izmir. Public and private transportation sectors in Turkey have purchased a total of 6527 diesel buses and 1483 CNG busses with minimum of 12 m long, whereas only 28 electrical busses have purchased by the public administrations in the last 5 years [1]. The IETT General Management of Istanbul Metropolitan Municipality, which is in the center of this work, has purchased 1924 diesel and CNG buses with minimum 12 m long between 2011 and 2016 years. However there are no electrical buses yet in the present fleet which has more than 3000 buses of IETT [2]. Also 310,725.25 ton CO_2 e (carbon dioxide emission) have occurred for the year 2016 . This value corresponded 0.61% of total emission amount according to the current data of the Institutions of Turkey Statistics 2013. It is aimed to draw this value downwards in the direction of IETT's strategic goals [2–4].

There are many studies in the literature about zero-emission public transportation services and their possible usage on the urban life.

To reduce GHG emissions in Seoul, South Korea, all public transport vehicles were converted to CNG, and the transition to electrical buses as a second phase was also investigated. Tests of electric bus model E-Primus with ultra-low base and rapid charging system made in Seoul include performance values and rates concerning the reduction of GHG emission values. This study reported that electric buses compared to CNG bus have 21.6% more advantage per year considering economic and environmental factors [5]. The Finland government has given the concept of electric buses prominence as a clean and efficient means of transport due to their emission reduction targets and political decisions. Despite the absence of electric bus production in the country, Finland has created a test platform used by many electric bus manufacturers around the world, and this test platform has become a center for evaluating the manufactured prototypes [6]. The transportation sector is of great importance among China's energy policies. In China, studies on operational modes of battery based electric buses have been carried out including measurable subsidy efficiency and market conditions. According to China's 12th development plan, battery-based electrical vehicles have been marked as a priority area [7]. Germany is working on transportation systems that can regenerate the braking energy and store this energy with ultra-capacitors with electrical buses. At the same time, the low emission and noiselessness of these transport systems are among the criteria that Germany has pursued. Electric bus systems are currently and, in the future, defined as environmentally friendly energy saving systems that are powerful and provide low-noise, local emission reductions, easy integration and sustainable high-quality urban transport [8].

Cost-benefit analysis of buses with alternative fuel systems was carried out with reference to diesel buses. As a result, four hybrid (two series, two parallel) and one electric bus were evaluated as the most significant potential vehicle types. It is shown that increase in electrification of the bus configuration resulted in increase in energy efficiency of the buses as well. In this sense, electric buses are two to three times more energy efficient than conventional diesel buses and parallel hybrids [9]. Transportation-related factors are in the leader among the main causes of air pollution in cities of the 21st century. It is stated that it is imperative to use "zero emission vehicles" in California, USA. In this respect, at least 2% of the newly sold vehicles were zero-emission vehicles in California between 1998 and 2000 [10]. In Sweeden three different scenarios have been implemented for electric buses, which have been used for a variety of predictions for the years between 2005 and 2020. In the study, increased energy needs, limited fossil fuel resources and environmental factors are shown as the most important current problems. It is mentioned that many kinds of financially appropriate and efficient drive systems will take place in the future. Also it is predicted that the prices of batteries and ultra-capacitors will be five times cheaper in 2020 than in 2005 [11]. Another study conducted in Taiwan shows that hybrid electric buses have emerged as the best alternative to public transport for the city. It is also suggested that range values for electric buses should be increased for better alternatives. It is stated that all vehicles with alternative fuel systems provide significant benefits in terms of air pollution. It is also reported that hybrid buses are good alternatives and expected to fill the gap during the transition period until electric bus technology matures sufficiently. According to the legislation applied in the country, it is stated that income from the tax deductions resulting from exceeding the emission limits in public transportation is transferred to electric bus technology development works. However, in the medium term in the country, local government encourages the bus operators to replace their old buses with electric buses. In the long term, they are planning to establish a domestic electric bus industry as well [12].

According to the IBBG World Sustainability Report, it has been noted that, the shift from diesel fueled buses to zero-emission systems has been started in IBBG countries. In addition, Vanhool as one of the bus manufacturers have reported that their buses will be switched to largely zero-emission vehicle systems by the time of 2030. Similarly, Solaris reported that 50% of the bus lines would be converted to electric buses by 2025 [13,14].

Electric buses are used in many cities around the world. CaetonaBus electric buses have been used in Porto city of Portugal since 2011. Likewise in the United States, Ecoride35 electric buses are widely used in Altarino and California. Before all these applications, electric buses are tested in field conditions and encouraging results are obtained [15]. The electric bus concept is also one of the most important issues in the European Union (EU). There are several projects in this framework carried out within the EU commission. One of them is the "ZeEUS" (zero emission urban bus system) project aimed at switching to electric concept for urban public transportation. Over 100 high-capacity electric buses were tested in ten cities across Europe [16]. Energy storage systems used in electric buses are integrated with fast charging units in China. Accordingly, the charging of the battery bank in electric busses can be completed within 15 min [17]. In another study carried out in China, a different model for electric bus operation was introduced through special line models for electric buses [18]. Danish Government has started EDISON project to develop solution and technologies for electric vehicle (EVs) and Plug-in hybrid vehicles. The EDISONproject is being used in conjunction with renewable energy systems, and EVs are also used for energy balancing purposes in the power systems [19]. Also ELIPTIC (Electrification of Public Transport in Europe) projects aims to develop new concepts and business cases in order cases to optimize existing electric public transport infrastructure and rolling stock, saving both money and energy. The project strengthens the role of electric public transport, leading to reduced fossil fuel consumption and improved air quality [20].

Wenxiang Li et al. proposed a novel method to plan and design an electric public transport system under battery swap mode. In this context, new routing and scheduling strategies are proposed for the battery electric bus fleets based on swapping and charging demands [21]. Another study conducted by Yajing Gao et al. proposes a power consumption model for electric buses and performs the optimization of charge scheduling considering external factors such as weather conditions and policies [22]. Similarly, Rong-Ceng Leou and Jeng-Jiun Hung in [23] proposed an optimal charging schedule to minimize the energy cost. In the paper, a practical charging station is taken as an example to verify the proposed model performance. Also Ucarol Hamdi et al proposed a review the relationship between climate change and transportation systems. They mentioned, in reference to the European Union fuel consumption values in 1990, reducing the greenhouse gas emission under 20% and increasing the energy efficiency of the fuel consumption above 20% until 2020 is aimed according to United Nations Climate Change and Kyoto protocols [24].

As can be clearly seen in the literature reviews, the trend in sustainable public transport all over the world is towards the concept of electric buses. It is observed that the electric buses are not exactly at the market scale currently. In particular, the initial purchase costs for electric buses are higher than that of diesel and CNG buses. In addition, the inadequacy of the electrical bus range is still a major obstacle against the widespread use of electric buses. With the proposed method given in this paper, it is proved that the price differences due to the initial purchase cost of electric buses can be compensated for by the savings from operating costs. It is also possible to obtain a realistic amortization point in the long term with the proposed TCO-based operating model.

In this study, a quantitative approach is presented for Istanbul Electricity, Tramway and Tunnel General Management (IETT) to pass to electrical bus concept by aiming the sustainable public transportation system with 100% zero emissions. For this purpose, a dynamic model based on the TCO from well to wheel has been proposed for the three groups of transportations, namely diesel, CNG (compressed natural gas) and electrical buses. It is also emphasized that the CO_2 emission could be reduced caused by the fuel-based transportations and the cost of CO_2 reduction is considered herein as a parameter in TCO calculations.

This paper is organized as follows. Section 2 describes the Zero Emission Bus Purchase and Operation Model (ZEBusPOM) and solution methodology. While performance tests and discussions are covered in Section 3, economic analysis of bus concepts are introduced in Section 4. Finally, general evaluations, conclusions and recommendations for future work are given in Section 5.

2. Problem Definition and Solution Approach

In this study, a new approach called "Zero-Emission Bus Purchase and Operation Model (ZEBusPOM)" is proposed with the aim of passing to the sustainable and zero-emission public transportation system for Istanbul. ZEBusPOM based on TCO analysis is a new approach for the concept of sustainable public transport systems with electric buses. The flowchart of the proposed model is given as in Figure 1.

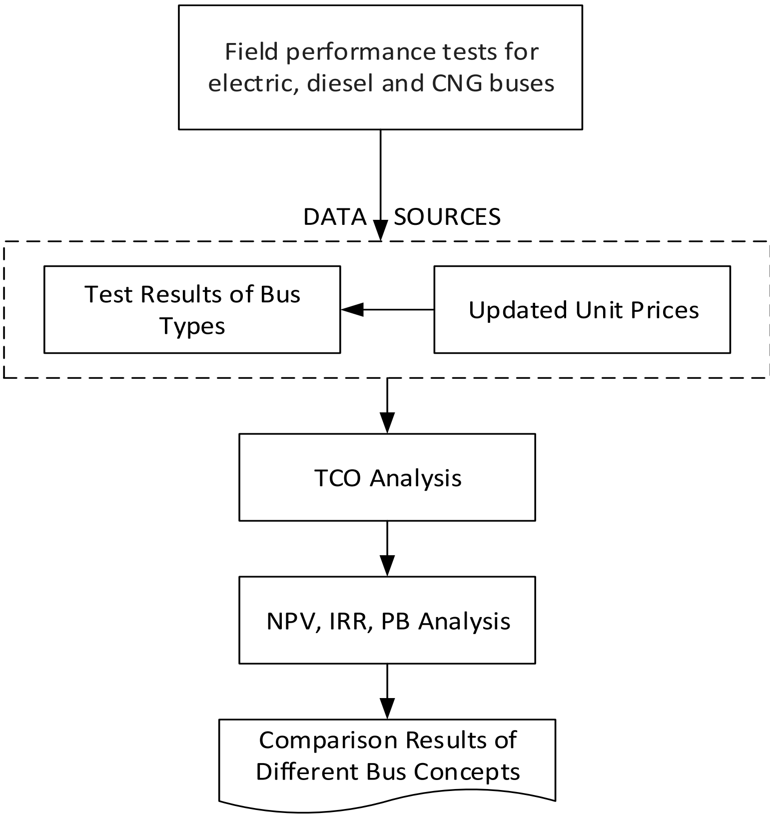

Figure 1. Flowchart of proposed zero emission bus purchase and operation model.

It is clear from Figure 1 that the proposed ZEBusPOM model consists of five steps. These calculation steps are described below.

Step 1 (Field Performance Test): The first step of the ZEBusPOM model is to perform the vehicle performance tests under actual field conditions. In this study, the result of the performance test for considered bus types are obtained in Istanbul; under real road, trip-time and travel conditions. Note that details of the performance test studies are given under Section 2.

Step 2 (Creation of Data Source): Data source is then created as a result of field tests. At this point, some of the technical and economical parameters such as average fuel cost, fuel supply time to fill the tank, energy consumption per km, total GHG emissions and average range for a full tank etc. are recorded for the data source sheet formation.

Step 3 (TCO Analysis): TCO analysis is performed in the third stage of the proposed model. The proposed TCO method takes into account the bus purchases and operational investment costs depends on the variables of transportation operators. The cost components considered in this model are given in the below sections.

Step 4 (Economic Analysis): Afterwards TCO analysis and other economic analysis such as Net Present Value (NPV), Internal Rate of Return (IRR) and Payback Period (PB) are performed to compare the considered bus concepts.

Step 5 (Evaluation of Economic Analysis and Comparison of Bus Concepts): In the final phase of the proposed approach, diesel, CNG and electric buses are compared according to the performed economic analysis. In the comparison phase, the bus purchase cost, operating cost and investment costs are considered as central variables, which are dependent upon programs of transportation.

The mathematical approach described above is modeled using MATLAB. Generally speaking, it is expected that the developed mathematical model can be an important tool for public transportation sector. Using the proposed calculations, it is possible to calculate the realistic payback and amortization period for electrical bus with respect to diesel and CNG buses. The proposed model also allows accurate comparison between conventional bus and electrical bus for leading public transportation of Turkey such as IETT, EGO (Ankara Electrical, Gas and Bus Operator) and ESHOT (Izmir Electrical, Water, Gas, Bus and Trolleybus Operator). The details and the calculations about model are given in the in the following section.

3. Performance Results and Discussion

In this part of the paper, the performance test results of the bus types given below are obtained in Istanbul under real road, trip-time and travel conditions. Buses included in the test are:

(1) 12 m Otokar Kent LF Diesel bus,
(2) 12 m Karsan Bredamenarinibus CNG bus,
(3) 10.7 m TCV Bozankaya E-Karat Electric bus,

The technical details of buses used in performance tests are given in Table 1. Also diesel and CNG buses carrying out field performance tests within the scope of the study were randomly selected from the existing fleet of the IETT.

Table 1. Technical Specifications of Diesel, CNG and Electric Buses.

Specification	Diesel Bus	CNG Bus	Electric Bus
Brand/Model	Otokar KentLF 12 m	Karsan Bredamenarinibus Avancity 12 m	TCV Bozankaya E-Karat 10.7 m
Length	12,000 mm	12,000 mm	10,700 mm
Width	2540 mm	2500 mm	2550 mm
Height	3145 mm	3373 mm	3350 mm
Max load weight	18,000 kg	12,000 kg	18,000 kg
Engine Type	Deus, EEV	Mercedes Euro V İntercooler	DC Motor
Number of Cylinders	6	6	-
Engine Capacity	7150 cc	6680 cm^3	-
Max Net Power	213 kW @ 2100 rpm	205 kW @ 2200 rpm	240 kW
Max Net Torque	1200 Nm @ 1050–1650 rpm	1000 Nm @ 1440 rpm	21,000 Nm
Residential	27 sitting + 76 standing + 1 driver	28 sitting + 60 standing + 1 driver	25 sitting + 65 standing +1 driver
Transmission	automatic ş. 4 forw. 1 back	6 forw. + PM	-
Fuel Tank	300 lt Diesel; 50 lt Adblue	1176 lt 4 pcs CNG tank (tipe 3)	200 kWh lityum ion
Maximum speed	80 km/h	70 km/h	75 km/h
Climbing	30%	-	22%

Initially, performance tests at no load and full load are carried out on two distinct lines which are 28 T bus line and 55 T bus line with different driver profiles for specified operating conditions as shown in Figure 2. 28 T and 55 T bus lines are selected for field testing since they are sufficient routs to represent the average road conditions for Istanbul. To determine the charge cycle conditions for the electric bus, the charge ability of the batteries of the buses was measured at the charge levels provided by the manufacturer. Cyclical data of the bus concepts (diesel, CNG and electric buses) in the model are achieved for the created scenarios based on the charge cycles, which take into account the fuel costs and electricity tariffs during the day, peak, and night. To model the average for the average road conditions in Istanbul; performing tests it is identified 2 different reference line. One of them is the 55 T line (Gaziosmanpaşa-Taksim »Edirnekapı) is 6 km which has an average high slope (maximum of 10.40% with an average of 4.56%) value when the Istanbul base is taken and the other 28 T line (Beşiktaş-Topkapi »Edirnekapı) is 12 km with relatively straight road conditions according to 55 T line. Performance tests were carried out by loading the buses both at no-load and at full-load conditions determined by the manufacturer. During the tests, to be able to create a linear approach in the calculations, the maximum occupancy of the buses was always ensured and instead of the passengers, weights of sandbags and water barrels were used in reference to the average passenger weight determined in the literature. In this way, the actual performance results of the vehicles are measured under identical conditions and the comparison between them is provided. Detailed performance results of each vehicle concept are given below on average values for the determined lines. Energy consumption based performance curves of vehicles are measured under variable traffic conditions at various times of the day. During the performance tests performed under the specified conditions, the electrical bus is assumed to be charged during the night in the existing IETT conditions, so that it is aimed to benefit from the advantage of the electricity unit prices. However, extra charge during the day as a range boosting factor is also considered for long line (for lines up to more than 200 km per day for IETT) lines to include the daytime conditions into the calculations. The seven basic performance criteria as well as the cost values of the vehicles used in the bus concepts evaluation based on TCO are given in Tables 2 and 3.

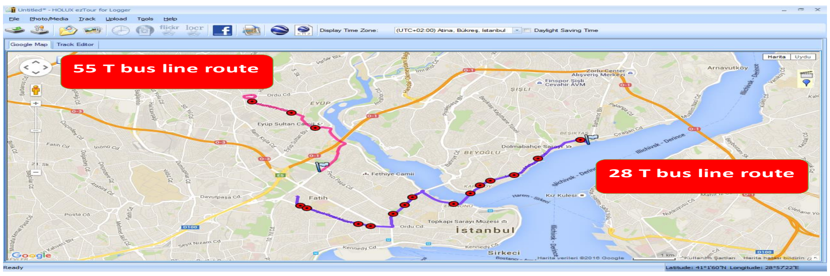

Figure 2. Routes of 28 T line and 55 T line where performance tests are performed.

Table 2. Unit Prices for Diesel, CNG and Electric Buses.

Costs	Diesel	CNG	Electric
Purchase Cost per Vehicle [€]	127,000	175,300	359,000
Purchase Cost per Vehicle [€] (5 years M&O included)	164,400	240,600	440,000
Facility Installation Cost per 250 vehicle fleet [€]	325,678.57	1,915,812.6	1,198,547.86
Amorization Cost	constant	constant	constant
Driver Cost	constant	constant	constant
Other Costs (Insurance, tax and etc.)	constant	constant	constant

Amortization, drivers and the other costs were considered equal for all vehicle concepts.

Table 3. Performance Values for Diesel Cng and Electric Buses.

Performance Criteria		**Diesel**	**CNG**	**Electric**
Fuel Supply Time-to fill the tank-(minutes)		5	15	240
M&O Cost per km		0.1004	0.1651	0.0436
Average Fuel Cost-per km-(Euro)		0.4326	0.2424	0.0410
Consumption for inclined road conditions-per km-(Euro)	Bus Line 28 T	0.3401	0.2982	0.0450
	Bus Line 55 T	0.5250	0.2461	0.0371
Capacity Factor (fullness) Consumption-per km-(Euro)	No Load	0.2595	0.2043	0.0357
	100% Full Load	0.0418	0.2638	0.0469
The Impact of Traffic Intensity for Bus Line 28 T and Bus Line 55 T-Average (km/h)		0.25	0.23	0.25
Average Range Value (for a full tank) (km)		500	500	274 [1]
Total Green House Gas (GHG) Emissions-metric tons per km-(CO_2 e)		1.34×10^{-3}	8.33×10^{-4}	-

The maximum theoretical range value that can be achieved the maximum theoretical range value for electric bus that can be obtained by using hand data when there is no passenger in 28 T bus line.

Performance results (total consumption costs, traffic density,average trip time, efficiency, total fuel consumption, total distance for diesel, CNG and electric buses are given below in Figures 3–5 respectively. Under varying traffic conditions at various times of the day, real field measurement results based on no-load and full-load conditions are summarized below for bus line 28 T and bus line 55 T .

For the performance tests conducted, the concept of "traffic density" was taken into consideration. To be able to use in calculations density; heavy traffic, fluent traffic and intensive traffic are expressed in non-quantitative terms, which is why they can not be included in calculations. In this sense, the concept of traffic density, which is defined as the ratio of the time passed to the distance, has gained a quantitative value and the obtained and used in the model by using the ratio of the total elapsed distances during the tests instead of the terms . In this way, a dynamic and realistic approach to calculations was sought.

Also all costs calculations were carried out at the rate of 1 TL = 0.2714 Euro according to the Central Bank of the Republic of Turkey dated 15 December 2016.

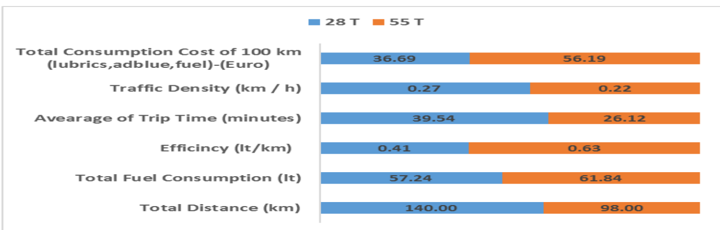

Figure 3. Average performance values in test conditions for Diesel bus.

Figure 3 gives the performance values for the diesel bus in line 28 T. gives the performance values for the diesel bus in line 28 T. Accordingly, a total of 140 km is traveled and 57.24 L of diesel fuel is consumed. The average fuel consumption per km is 0.41 L. In general, the 28 T line has almost smooth road conditions and average trip time is about 0.66 h (39.6 min). The fuel price per 100 km is 36.69 € . The average traffic intensity during the test period is also measured as 0.27 km/h.

Figure 3 also gives the performance values for the diesel in bus line 55 T. Accordingly, a total of 98 km is traveled and 61.84 L of diesel fuel is consumed. The average fuel consumption per km is 0.61 L. In general, the 55 T line has ramped road conditions and average trip time is about 0.44 h (26.4 min). The fuel price per 100 km is 56.19 €. The average traffic intensity during the test period is also measured as 0.22 km/h. The vehicle fuel consumption of the 55 T line is increased much because of quite high inclined road conditions.

Figure 4. Average Performance Values in Test Conditions for CNG Bus.

Figure 4 gives the performance values for the CNG bus 28 T line at full load and no load. Accordingly, a total of 200 km is made and 98.67 kg (118.88 m^3) of natural gas is consumed. The average natural gas consumption per km is 0.5944 m^3. In general, the 28T line has smooth road conditions and average trip time is about 0.91 h (54.6 min). The fuel price per 100 km is 30.69 €. The average traffic intensity during the test period is also measured as 0.19 km/h.

Figure 4 also gives the performance values for the CNG bus 55 T bus line. In this test, a total of 262 km is made and 106.68 kg (128.53 m^3) of natural gas is consumed. The average natural gas consumption per km is 0.4906 m^3. The average trip time is about 0.37 h (22.7 min). The fuel price per 100 km is 25.48 €.

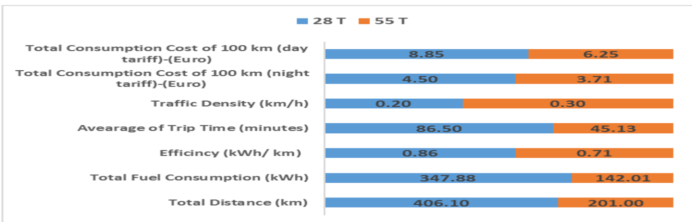

Figure 5. Average Performance Values in Test Conditions for Electric Bus.

Finally, Figure 5 shows the performance curve of the electric bus for 28 T and 55 T bus lines. For 28 T bus lines, a total of 406.10 km is traveled and energy consumption is realized as 347.88 kWh in total. The average energy consumption per km is 0.86 kWh and average trip time is about 1.44 h (86.4 min). The energy consumption price per 100 km is 8.85 € based on the day time charging, whereas it is 4.50 € on the basis of at night time charging. The average traffic intensity during the test period is also measured as 0.20 km/h. For 55 T lines, a total of 201 km is traveled and energy consumption is realized as 142.01 kWh in total. The average energy consumption per km is 0.71 kWh and average trip time is about 0.75 h (45 min). The energy consumption price per 100 km is 6.25 € based on the daytime charging, whereas it is 3.71 € on the basis of nighttime charging . The average traffic intensity during the test period is also measured as 0.30 km/h.

Performance tests were carried out based on the daily plans of the vehicles determined on the relevant lines in real trip and traffic conditions with no load and full load. Also 55 T line is higher slope value than that of the 28 T line and distance covered on 55 T line is shorter than 28 T line. The reason for this is the total km constructed differs from one another. In addition, traffic congestion has increased due to infrastructural studies that have been taking place in the route routes determined from time to time so this has also affected the performance values of the vehicles. Per unit km values are used on model calculations. Especially for the electric bus maximum road is covered. Thus vehicle approaches, especially battery performance, could be presented .

At least according to Figure 6, the difference between the fuel-based expenses of the CNG bus and electrical bus is about 25.42 € according to the night charging of the electric bus for the 28 T line, which means that electric bus can reach up to 85% saving with reference to CNG bus usage. The cost difference between diesel and electrical busses is about 27.10 € , which means that electrical bus can reach up to 87.36% saving with reference to diesel bus usage. As for the day time charging of the electric bus, the cost difference is 19.96 € , which means that electrical bus with day charging can reach up to 75% saving with reference to CNG bus usage. Moreover, electric bus with day charging can reach up to 78.72% saving with reference to diesel bus usage.

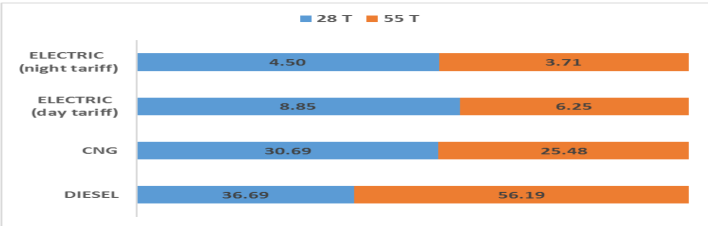

Figure 6. Cost of Energy Consumption per 100 km for Electric, Diesel and CNG Busses according to Performance Conditions.

It is also clear from Figure 6 that for 55 T line, the difference between the fuel-based expenses of the CNG bus and electrical bus is about 19.80 € according to the night charging of the electric bus. This means that electrical bus can reach up to 80% saving with reference to CNG bus usage on 55 T line. The cost difference between diesel and electrical busses is about 48.51 € . This means that electrical bus can reach up to 90.98% saving with reference to diesel bus usage. As for the day time charging of the electric bus, the cost difference is 16.52 € , which means that electrical bus with day charging can reach up to 67.11% saving with reference to CNG bus usage. Moreover, electric bus with day charging can reach up to 85.32% saving with reference to diesel bus usage on 55 T line.

4. Economic Analysis of Bus Concepts

A mathematical model based on total cost of ownership (TCO) has been established for the bus concepts determined by this study. In the TCO analysis, all operational costs of 10 years have been taken into consideration. Fuel and M&O costs of diesel, CNG and electrical buses used in the proposed model are calculated using updated prices. 10-year price forecasts for the future are calculated based on the Turkey's projected population growth, gross domestic product (GDP) and producer price index (PPI). And these costs are included in TCO of buses by their passenger carrying capacity . The proposed TCO method takes into account the bus purchases and operational investment costs depends on the variables of transportation operators. The cost components considered in this model have need future perspectives which are given below.

4.1. Future Perspectives of Maintenance and Operating Costs (M&O)

The maintenance and operating (M&O) costs are among the most important cost components of bus concepts used in TCO analysis. This cost, which is taken into account in the economic analysis, has a different weight in each bus concept [25]. The up-to-date M&O data of IETT is used in this study. Considering IETT's process and workforce in each bus depots (garages), the actual M&O costs for buses are calculated in detail per vehicle and per km [26]. Cost items used in the calculation of M&O costs per km in the depots are determined as below:

- Preventive maintenance costs,
- Vehicle body cost,
- Engine renewal costs,
- Damage & repair payments costs,
- Material cost,
- Cost of emergency response team,
- General administrative management costs,
- Depot's energy costs (electricity, water, natural gas for heating),
- Traffic insurance and vehicle inspection expenses costs,
- Taxes.

Approaches have been presented to estimate the future M&O cost by taking into account the predictions of the bus manufacturers and the institutional knowledge (especially for the diesel bus concept). In Table 4 given below, the future M&O cost per km are presented based on actual conditions for diesel, CNG and electric buses in ten-year terms of Euro are summarized.

Table 4. Analysis of M&O costs of CNG, diesel and electric buses.

Year	CNG M&O (€/km)	Diesel M&O (€/km)	Electrical M&O (€/km)
2017	0.16	0.10	0.04
2018	0.16	0.10	0.04
2019	0.16	0.10	0.04
2020	0.16	0.10	0.04
2021	0.16	0.10	0.04
2022	0.19	0.40	0.15
2023	0.19	0.45	0.15
2024	0.19	0.50	0.15
2025	0.22	0.56	0.15
2026	0.22	0.60	0.15

Here are some important things to mention about bus concepts:

As in diesel and CNG buses, there are no real-time and long-term use of electric buses in Istanbul, Turkey. Electric bus manufacturers in Turkey and Europe do not currently have effective and prominent approaches to maintenance and repair. Manufacturers provide only two- to five-year warranty as a requirement of the standards for electric buses. Contrary to diesel and CNG bus concepts in Turkey, maintenance and repair guarantee approaches without mileage limit do not apply to electric buses. In this paper a new approach should be introduced after the examination of the literature studies. This approach is based on the battery cost and the M&O costs for the future of the electric bus are calculated by Equation (1).

$$Bm\&o_{(elec)} = l(\mathrm{km}) \times m_{bkm} \; (Euro), \tag{1}$$

where, $Bm\&o_{(elec)}$ is total M&O cost of electric bus, l (km) is line length and m bkm is per km M&O cost of electric bus, when l > 450,000 km.

Two different M&O costing approaches can be defined here for electric buses. The first one is that, the renewed battery cost is added to the initial purchase cost at the end of the 5th year. The second approach is to add the cost of battery change from the first year to M&O costs per km. Considering Turkey's condition and defined operating conditions, the M&O cost per km for electric buses is calculated as 0.04 € between 1th and 5th years and as 0.15 € between 5th and 10th years.

4.2. Future Perspectives of Fuel Costs

Fuel unit price forecasts for the next 10 years are also estimated as a requirement of variable cost conditions. Despite the differences between the types of fuel used in bus concepts, the improved calculation allows future cost variances to be compared under constant and variable operating conditions. For this purpose, cost change trends of diesel, natural gas and electricity unit prices are obtained based on the historical data. Future price estimates of the fuels used in the considered bus concepts are calculated based on Turkey's GDP, population and the PPI values. In other words, it is assumed that the unit prices of these fuel types are changed only by PPI, GDP and Population, all other factors affecting cost and market conditions are assumed to be constant.

As a function of the fuel price in the past years, the unit price of diesel, natural gas and electricity is estimated by Equation (2).

$$Bf_{(d,ng,e-2014)} = Bf_{(d,ng,e-2014)} \times (1+\alpha)^{(2014-2004)}, \tag{2}$$

$$(GDP/PPI/P)_{2014} = (GDP/PPI/P)_{2004} \times (1+\beta)^{(2014-2004)}, \tag{3}$$

where d, ng and e respectively unit prices for diesel, natural gas and electricity in 2014, according to trend of 2004–2014. The realistic rate of increase in unit price change trends for each fuel type is obtained by Equation (2). Similarly, Equation (3) based on the GDP, PPI and the P (population) values, realistic growth rate is also calculated for the same period for Turkey.

$$\zeta_p = \frac{(1+\alpha)}{(1+\beta_i)}, \tag{4}$$

Here, by taking the average of ζ values determined for each parameter, a realistic increase rate based on GDP, PPI and population values of fuel types is obtained in Equation (4). As a result of the calculations made, Table 5 presents future forecasts of diesel, natural gas and electricity unit prices for the years 2017–2026.

Table 5. Diesel, natural gas and electricity unit price estimates (2017–2026).

Year	Diesel (lt/ €)	Natural Gas (m^3 / €)	ELECTRICITY (kWh / €)
2017	1.17	0.24	0.11
2018	1.23	0.26	0.11
2019	1.28	0.27	0.12
2020	1.33	0.29	0.13
2021	1.38	0.30	0.13
2022	1.44	0.32	0.14
2023	1.49	0.34	0.15
2024	1.54	0.35	0.16
2025	1.59	0.37	0.16
2026	1.65	0.39	0.17

According to these unit prices and costs, Figure 7 compares the purchase costs for each bus and the total yearly operating cost. In terms of the total operating cost for 1 year, it is estimated that the electric bus concept achieved 86.45% profit compared to the diesel bus concept and it is estimated to be 80.37% more economical according to the CNG bus concept [27].

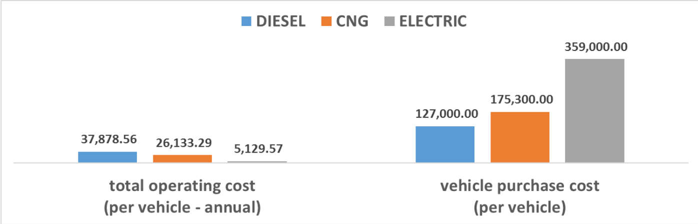

Figure 7. Comparison of bus concepts according to operation and purchase costs(Euro).

4.3. TCO Analysis

TCO analysis for any given technology is the most basic kind of cost assessment and it is simply a cost estimation which considers all the direct and indirect costs of a product or a system over its lifetime. TCO analysis is used in this study for the first time for diesel, CNG and electric bus concepts for Istanbul conditions. Performance test results under actual road, time and travel conditions, up-to-date unit and fuel prices are taken into consideration in this analysis. Afterwards the most appropriate vehicle concept are determined based on performance and analysis results. With the proposed model, the most appropriate vehicle concept is determined based on performance and analysis results. The TCO formula for a single bus used in this study is given below for Istanbul conditions based on average unit costs.

$$TCO = TCO_s + TCO_d, \tag{5}$$

where, TCO_s fixed costs, TCO_d variable costs (depot) for vehicle concepts

$$TCO_s = M_o + (P/250), \tag{6}$$

$$TCO_d = (m_{bkm} + Bf_{(d,ng,e)} + G_{hg}) \times (l_{km} \times t), \tag{7}$$

where M_o vehicle purchase cost (for 1 vehicle), P Infrastructure Installation Cost (depot) for 250 vehicles (for diesel, CNG and Electric busses),m_{bkm} maintenance cost per km, $Bf_{(d,ng,e)}$ average fuel cost per km, G_{hg} the financial value of the green house gas emission effect, t is the time variant and l_{km} is the daily range variant.

In this paper $(l_{km} \times t)$ equals to $(10 \text{ year } \times 360 \text{ days } \times 82\% \text{ oe } \times 180.24 \text{ km/day-bus})$.

The maintenance & repair and fuel costs in this formula are based on the specified IETT conditions for the 10-year period in the forecast. The average values obtained are used.

Under the IETT conditions TCO costs are calculated as 384,187.61 Euro for the diesel bus concept, 378,505.92 Euro for the CNG bus concept and 404,307.44 Euro for the electric bus concept.

In addition, as shown in Figure 8 the intersection points in TCO graph are 145.2 km for diesel-CNG bus concepts, 174.85 km for diesel-electric bus concept and 180.70 km for CNG-electric bus concept under the conditions determined parameters in next 10 years.

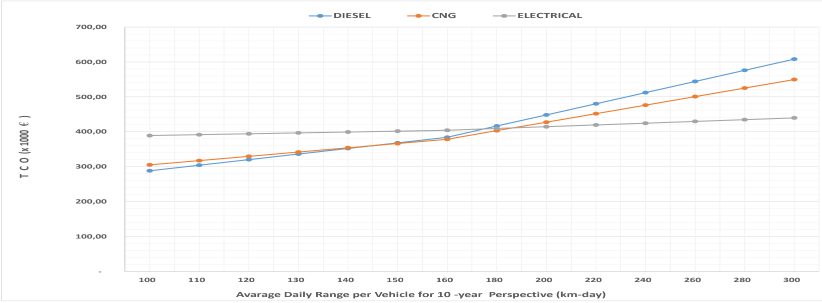

Figure 8. Comparison of bus concepts according to TCO & vehicle-km-day.

4.4. Net Present Value (NPV), Internal Rate of Return (IRR) and Payback Period (PB) Analysis

The time value of money is an important approach playing a key role in making financial decisions for all large and small sized businesses. This approach can be used to evaluate the outcome of a loss of value or a loss of money over time. Time value of money in the technical sense is the assessment of cash flows and financial movements of different time periods in same denominator or in the same time domain [27–29] .

Using the time value of money method, the following results are obtained in this study.

- The initial purchase and infrastructure installation costs of the electric bus concept are considerably higher than the diesel and CNG bus concepts.
- In terms of operating costs, the electric bus concept has advantages at a great rate.

In the study, financial analysis are carried out to determine the best suitable bus concept for Istanbul. For this purpose, TCO analysis that considers the initial purchase and yearly operating costs of the electric, diesel and CNG buses concepts are performed. Then, the results regarding public bus concept are compared with the methods of Net Present Value (NPV), Internal Rate of Return (IRR) and Payback Period (PB).

In these calculations, assumptions put forward in this article for the public transport system approach are the unit prices determined for the diesel/CNG buses purchased by IETT in 2013 and the tender unit prices for electric buses signed by ESHOT in August 2016 are taken as reference. Besides, current data of IETT is used for fuel unit prices and M&O cost.

Finally the data obtained for 250 buses in the study are calculated on the basis of 300 days and 82% oe (operation efficiency within 1 year) and the total travel and card sales revenues of the IETT in 2015 are used to find the income of 250 buses in this study. At this point, the total income distribution is made considering the passenger transport capacities of the buses where the performance tests are successfully performed.

The resulting cost of GHG emissions impact due to world carbon trade is included in the TCO for diesel and CNG buses and GHG emission effect for electric buses is taken as zero.

As one of the time value calculation of money, the equations for the Net Present Value Method (NPV) are given below for constant and variable conditions.

$$NPV = \left(\frac{(1+i)10-1}{(1+i)i10} \times (G-M) \right) - M_o. \tag{8}$$

$$NPV = -M_o + (i+1) \sum_{n=1}^{N} (G_n - M_n) \, . \tag{9}$$

Here in the calculations to be done for the internal rate of return method (IRR), the variable i is obtained from the NPV expression, which is equal to zero.

Accordingly, the internal rate of return equation is given below.

$$\left(\frac{((1+\ddot{I})10-1)}{(1+\ddot{I})10i} \times (G-M)\right) = M_o, \tag{10}$$

$$(\ddot{I}+1)\sum_{n=1}^{N}(G_n - M_n) = M_o, \tag{11}$$

Another method used for the time value of money is Payback Period (PB), which is given below.

$$PB = M_o/(G-M), \tag{12}$$

where G is the average annual revenue per bus, i is time value of money, IM is yearly operating cost per bus, $\ddot{I}$ internal rate of return, M_o is purchasing cost in Equations (5)–(9).

5. Results and Discussion

As one of the most important uses of energy, analysis in this paper indicates the usability of electric buses in the public transport. For this purpose, the performance tests of the three main bus concepts are realized under the real field conditions of Istanbul. Naturally, the obtained results are found according to the parameters belonging to Istanbul-IETT. For other cities, results should be recalculated based on the considered vehicle concepts and managerial variable costs. The assumptions put forward in this article for the public transport system approach can be summarized in the following paragraph.

The performance tests were conducted under real road, trip-time and travel conditions of Istanbul. The datas obtained for 250 buses in the study is calculated based on 300 days and 82% operation efficiency within 1 year. The resulting cost of GHG emissions impact due to world carbon trade is included in the TCO for diesel and CNG buses and this effect for electric buses is taken as zero. The result of economic analyzes obtained from the time value of money are presented according to two main factors. Firstly, the calculation based on the current and constant cost parameters is given. Secondly, future forecasts of fuel and M&O unit prices are given based on variable costs.

Under the IETT conditions TCO is calculated as 384,187.61 Euro for the diesel bus concept, 378,505.92 Euro for the CNG bus concept and 404,307.44 Euro for the electric bus concept for 10-year time period so the intersection points are; 145.2 km for diesel-CNG bus concepts, 174.85 km for diesel-electric bus concept and 180.70 km for CNG-electric bus concept under IETT conditions. The PB value for the diesel bus concept for existing IETT conditions is calculated as 2.84 years. Similarly, the PB value for CNG buses is calculated as 3.90 years. Finally, the PB value is calculated as 5.66 years for the electric bus concept. Diesel bus concept is found to be the most economical bus concept. In the calculations made according to the NPV method, the diesel bus value with an 8% discount rate is 52,311,540.54 Euro. With the same discount rate, CNG bus concept is determined as the second economic concept with 40,129,447.52 Euro. Finally, electric bus concept with 19,171,212.50 Euro is chosen as the third economic concept. Since it is a case for Turkey, these calculations are repeated for the discount rate of 12%, 14% and 16%. It is seen that same ranking with different bus prices is obtained for the applied discount rates. Considering the financial bases of the IETT, the diesel bus concept according to all other bus concepts is most advantageous one for all methods followed by the CNG bus concept and finally the electric bus concept (PB and NPV Method). Under variable cost conditions, the IRR value for the diesel bus concept is found to be 23.20%, for the CNG bus concept it is 22.97% and for the electric bus concept it is 12.95%.

Despite the high initial costs, amortization points in electric buses can be caught because of low operating costs. Analysis of TCO and financial analysis is performed using the methods of Net Present Value, Internal Rate of Return and Payback Time. Thus, decision mechanisms for local governments and the private sector can be established especially for electric bus concepts.

In light with these results, electrical bus concept can be an alternative and effective method in the future public transport system. For this purpose, it is important that mass production of the electric bus processes are accelerated and the competitive market conditions should be achieved.

6. Conclusions

In this study, a mathematical model is obtained which considers the Istanbul public transportation scale as reference. The proposed model and given analysis for transition from diesel/CNG to the electric bus concept can be directly used in the cities with more than 5000 daily active buses, such as the public transport system in Istanbul. The mathematical model can also be updated for variable conditions if it is necessary. From this perspective, a dynamic capability is given to the proposed model, which can make calculations and evaluations for other city and vehicle concepts. This model has the potential to become a platform to financially evaluate public bus investment processes not for only private sectors but also for local governments that provide public transport services. In future work, the proposed analysis can be updated for conversion of diesel buses to electric buses, so that the obtained results will be based on the new business model "diesel-electric vehicle conversion" and this conversion of system can provide a sustainable and versatile business model.

Author Contributions: Conceptualization, T.O. and N.I.; Methodology, T.O.; Software, T.O.; Validation, T.O.; Formal Analysis, T.O.; Investigation, T.O.; Resources, T.O.; Data Curation, T.O.; Writing—Original Draft Preparation,T.O.; Writing—Review & Editing, T.O and N.I.; Visualization, T.O.; Supervision, T.O.and N.I.; Project Administration, T.O.

Funding: This research received no external funding.

Acknowledgments: We would also like to show our gratitude to the Istanbul Metropolitan Municipality, General Directorate of IETT, for sharing their infrastructure and technical possibilities with us during this research.

Conflicts of Interest: The authors declare no conflict of interest.

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