Total Cost Of Ownership Framework for Procurement of buses used in Public Transportation

Nuri Onat
Professor of Engineering Management
Faculty of Engineering
College of Engineering
Qatar University, Doha, Qatar
onat@qu.edu.qa

Mansoor Jahangir Ahmed Khan
Graduate Student of Engineering Management
College of Engineering
Qatar University, Doha, Qatar
mk1805655@qu.edu.qa

Abstract

A study conducted on a public transport management system to deliver the best service with a defined standard of service from state regulatory bodies by utilizing & managing a high volume of vehicles in the most efficient, productive, and cost-effective way to minimize cost and as well as air pollution, carbon emissions from the transportation sector. A total cost of ownership framework is developed for evaluation of different alternative fuel bus options (Diesel, Electric and CNG) based on real-world driving conditions. In addition, Electric, CNG, and diesel buses are compared from the life cycle and Total Cost of Ownership (TCO). According to the results, it was found that electric bus TCO is less than the diesel and CNG buses i.e. electric bus TCO cost is 15% less than the diesel bus and in the case of CNG, it is 5% less over a period of 10 years use. The proposed framework provides a quantitative basis for a sustainable fleet management approach for public bus service providers.

Keywords
Total cost of ownership, public service operation, decision-making tool, sustainable transportation, and Life Cycle Cost Analysis.

1. Introduction
Transportation is the backbone for economic and social development and one of the major public services around the world. Transportation has an important share for contributing to the GHG emissions, around one-fourth of the emissions in the World. Minimizing the environmental impacts from transportation without compromising feasibility, profitability, social and economic development is a major challenge for the decision-makers around the world. Alternative fuel vehicles are promising options towards minimizing the environmental impacts, however, they introduced new challenges such as infrastructure investment (e.g. charging stations), maintenance costs (e.g. battery replacement). In this regard, Total Cost of Ownership (TCO) models are used to evaluate alternative fuel vehicle options to inform decision-makers to allocate resources efficiently to manage their public transportation fleets efficiently. In such a situation, procurement ethics inspire to form balanced procurement decisions. This consists of attainment of the best value for investment and environment. It means accounting of entire costs and its paybacks over the lifecycle of the product and this practice includes classifying the initial purchase price and projecting all future costs and revenues. Ellram (1995) explains that TCO is a type of procurement, where the decision does not conclude on the initial price of the asset.

TCO analysis passes into the attention of the people starting in the middle of the '80s, due to the expenditures in backing up IT hardware & software setups. Executives revealed that the lifecycle cost of computers & software costs 5 to 8 times more of the purchase price. At this stage, Consulting company Gartner Group in 1987 developed and indorsed TCO to evaluate costs for IT set-up. As TCO has been officially accepted and adopted worldwide. Since then, this technique has been used by companies, particularly in the industrial sector, to compute the cost of production and thus to regulate their profit margins and sales prices.

1.1 Objective

TCO is a discipline and methodology that is structured appropriately to position the costs of an investment, provides an outline for good financial analysis to account for company investments in the right place, and helps the company to justify its' investment on a sustainable feasible product. In this framework, not only the actual financial costs of an investment are enlightened, but it also permits suitable comparisons of similar alternatives. Abidingly, TCO is a decision-support technique or method connected to from life cycle perspective. Life Cycle Analysis (including life cycle cost assessment) is the way of evaluating and estimating environmental and economic costs and Life cycle-based approaches are vital to prevent pointless future losses that can ascend from concentrating only on the initial costs. There is a strong tendency in the industry and among policymakers to understand the benefits of TCO to estimate their relative benefit or loses over a period of a product's life cycle. TCO considers all costs from acquisition to disposal counting predictable costs during the lifetime of an asset (e.g. alternative fuel buses), such as acquisition, infrastructure, operation, maintenance & repair, insurance, and salvage value. Highlighting TCO for vehicle procurement includes acquisition cost and variable costs to use and operate the vehicle. One of the main purposes of TCO analysis is to shed light on vehicle procurement process. Considering that buses are characterized as one of the extensively owned valuable assets in the public transportation sector and TCO is one of the most helpful approaches among procurement decision-makers to overcome the challenge associated with achieving a sustainable transportation.

Letmathe & Suares (2017) explained that in many of the transportation sector, it a common practice to study life cycle cost before implementing the actual decision or making alternative choices, iller et al. (2017) enlightened that in 2017 National Center for Sustainable Transportation (NCST), supported by USDOT and Caltrans through the University Transportation Centers submitted a Research Report on Truck Choice Modelling: Understanding California's Transition to Zero-Emission Vehicle Trucks Taking into Account Truck Technologies, Costs, and Fleet Decision Behavior using a partial fundamentals total cost of ownership.

2. Literature Review

A literature review was conducted to understand the study and research done before on Total Cost of Ownership or Life Cycle Assessment, specifically for the buses under Public Transportation. To structure the literature review in a systematic form Scopus website was used, hence, to extract the information in relevant to the topic, an appropriate keyword was used in search engine and this search results were further filtered in subject title, research scope, nature of study and organize the entire list to come up with final list of studies all related to the topic of interest.

The data extraction from the Scopus started with foremost attention on the title of the study i.e. Total Cost of Ownership (TCO) and Life Cycle Cost (LCC), and we use the hunt key "Total Cost of Ownership" OR "Life cycle Cost" AND "bus" OR "buses", as a result 225 documents were displayed form the year 2020 to 1979 which cover the subject area of Engineering, Energy, Environmental Science, Computer Science, Social Science, Mathematics, Earth & Planetary Sciences, Material Sciences, Physics & Astronomy, Business, Management and Accounting , Chemical Engineering, Arts and Humanities, Chemistry, Decision Sciences, Economics, Econometrics and Finance, where the study of TCO & LCC was applied partially or fully in different countries.

Further, hunt was limited to English language papers, and with key used "(Total Cost of Ownership" OR" Life cycle Cost" AND" bus" OR" buses") AND (LIMIT-TO (LANGUAGE," English")", and the result showcased was 204 documents. Furthermore, we scanned all these 204 papers to concise the research to TCO & LCC in transportation sector and from the abstract all the 204 research papers were filtered which has the research and study material for Total Cost of Ownership Framework of alternative fuels but while scanning it become seemingly that the research in this field is very few and especially to our topic i.e. a framework of TCO for alternative fuels to study the cost, health & environmental impact. While reading these shortlisted papers, we excluded research papers of the studies emphasizing on the challenges for electrification, TCO applied on other types of vehicles rather than bus transportation sector and with this we reached filtering a final list of 48 articles. These shortlisted papers were studied in detail based on Sensitivity analysis, infrastructure costs, cost of emissions, vehicle/fuel types, real-world driving patterns for fuel/energy consumption. From the analysis and scanning of the article, we observed that electrical vehicle is grabbing a more attention for research, and the reason is to mitigate the environmental impacts brought by the transportation system and new country regulation to switch to electric vehicles. There are much advanced research on electric vehicle, where researchers touched the other dimensions such as upgrade of current infrastructure, high cost involved in transition period, cost optimization of new bus procurement and the challenges to meet the required range in a cost-effective way

During literature review, It was noticed that only 2 papers published so far covered the scope of our study (McKenzie and Durango-Cohen 2012), even in the study conducted by the (Goswami and Chandra Tripathi 2019) doesn't considered the cost of emissions, which conclude that only one study covers all the factors of the scope of our study. Analyzing each factor of consideration on the scale of study, we observed that the studies considered cost of emissions is very less about 21% in comparison of the other factors, on other hand even sensitivity analysis was also disregarded by many researchers while concluding theirs studies only 23% of the researchers factored in their studies. The most calculated factor was the infrastructure cost of electric bus due to transition period and adoption of electrification. It was noticed that 31% study factored the real-world driving patterns due to constraints on real world data availability

While studying in details all the 48 articles, it became apparently that only 41 articles was related to the TCO or LCC comparing different types of fuels or vehicles, most of the article shortlisted were related to the electrification of the public transport and their challenges to switch into electric vehicles(Wang et al. 2014), this study enlarged his research on Monetary Assessment of Electric Bus Charging Infrastructure, in his study he compared the total life cycle cost (TLCC) of electric bus with conventional type of fuel bus. The price was placed on the cost computation model of the charging station and battery-swapping station to estimate the cumulative costs and break-even condition. Further the economy of charging infrastructure operation was examined and analyzed. The results of this study specified that the payback time of the charging infrastructure capital is significant. The mode of charging is appropriate for the electric bus and if the government offers electricity subsidies and battery swapping subsidies for infrastructure stakeholders, in this way the infrastructure economy will be meaningfully enhanced. Moving on with different research work we found that many researches shed light on the need to switch on electric vehicle. As(Islam and Lownes 2019), specified the study for transit operators to make more knowledgeable decisions concerning the process of switching a diesel fleet with alternative fuel technology buses to minimize GHG emissions a deterministic mixed integer programming was used on the stud to optimize the bus fleet replacement by minimizing the total life cost of acquisition, operation of buses and setting up a required infrastructures; same time this will benefit in reducing the GHG emission.

On the concluding 41 articles a bibliometric analysis was carried out, it was distinguished that the study related to the cost of emission and TCO comparison on different fueled buses for public transportation took importance for research & study from last 5 years. In our research we came across only 1 article published(McKenzie and Durango-Cohen 2012), (Ercan et al. 2015)modeled TCO calculation considering infrastructure cost, cost of emissions, fuel consumption based on real driving pattern. This study contributed a model that can be easily stretched and/or revised for procurement decision to acquire new transit buses by just altering the number of buses to be purchased, constraints of setting cost where applicable, and adding weights to each factor related to objective based on their precise and detailed requirements. The results of this study specified that air related health damage, life cycle cost can be minimized with different fuel sources throughout its lifetime operation of the fleet but results had limitation of driving cycles and objective function.(Goswami and Chandra Tripathi 2019) in his research a framework was formed to assess the impact on environment and economy. There were several factors on which this study depends on such recovering data from different government entities and private group of companies. As a result, there were important changes detected between vehicle's purchase price and total cost of ownership between selected vehicles.

As sensitivity analysis is important for TCO but very few researchers conducted sensitivity analysis for their TCO model. (McKenzie and Durango-Cohen 2012)in his study conducted a sensitivity analysis for fuel price, passenger demand and EOI – LCA Sectors and manufacturing parameters. From the review literature, total 8 researchers conducted sensitivity analysis

3. Methodology

3.1 Scope of the analysis

The Total Cost of Ownership model for Qatar public transport transit buses is envisioned to profit the operator to make conversant decisions on operating best-suited fuel bus types to optimize the total operating cost in a life span of 10 years. This model aims to assist decision-makers to regulate the alternatives fuel buses in operation to extend the advantage of fleet utilization on a scale of economically feasible and environmentally friendly carbon bus fleet financially viable and worthwhile based on expected cost and emissions reduction targets of the country.

We developed an Excel-based LCCA Tool to allow decision-makers to perform 'Total Cost of Ownership (TCO) Analysis' considering the bus purchases and all operational investment costs. Bus types can differ in terms of fuel type, efficiency, and many more life-cycle performance parameters. Using this framework and the excel-based tool based on the framework, decision-makers can input fuel and vehicle unit cost data for a predetermined life-cycle period; based on computed data and information, the LCCA Tool estimates the life-cycle costs of each fuel bus type and provides an important guidance of bus fleets with specific fuel types and engine technologies from life-cycle perspective for procurement decisions.

The scope of this framework encompasses all life-cycle phases of electric, diesel, and CNG buses for comparison purposes. Excel-based LCCA tool is provided for comparison among diesel, CNG, and electric buses. The model is designed to work on the data of initial bus purchase price, fuel consumption, all relevant maintenance and repair (M&R) related costs, cost of air pollution as part of environmental impact assessment, depreciation, insurance, and operational end-of-life. Figure 1. summarizes the TCO framework.

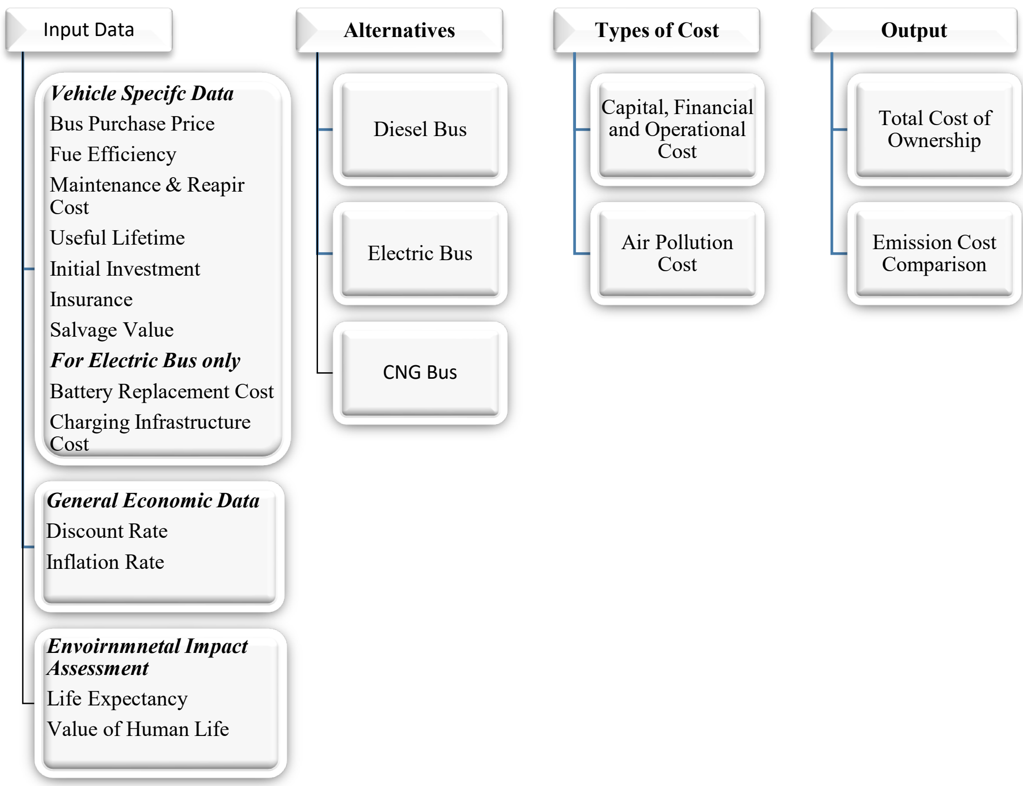


Figure 1. TCO Model Framework

4. Data Requirements and its explanations

4.1 Purchase Price

The purchase price is the initial investment made for the vehicle. A financial breakdown is made to compare the acquisition cost of different energy buses, as per the technical scope of the bus operator's requirement. The primary category of cost evaluation is the purchase price of the bus; wherein the case of the electric bus and CNG Buses, the initial investment includes infrastructure cost, workshop fit-out cost, and training expense for the supporting staff and in addition to this for electric bus charging units and its associated cost of infrastructure are accounted. The purchase price highly depends on the manufacturer, contract negotiations, and specification of the bus.

For this TCO model, we assumed that there are loans involved in buying the buses at the interest rate of 5.25% for the period of 4 years (indicating the time value of money), so in the analysis, the cost of financing is calculated, accordingly.

4.2 Fuel Efficiency

Fuel efficiency is one of the most critical data inputs for evaluating operation phase cost for bus alternatives. Globally, fuel efficiency values are estimated by legislative government agencies. Another factor that impacts fuel efficiency is the driving conditions and it depends on the driver, regional factors, and on nature of operation "Driving conditions" refers to factors influencing fuel efficiency performance in the real world. Therefore, it is very important to obtain a standard fuel efficiency value (verified under standard tests/ driving cycles) for all vehicles evaluated for comparison and procurement purposes. Self-claimed fuel efficiency labels by each manufacturer can cause misleading decisions. Other factors affecting fuel efficiency the fuel efficiency of an electric bus highly depends on spatial and techno-economic conditions such as driving patterns (e.g., the bus driven-route), route characteristics (e.g., road grade), type of electric bus used (e.g., plug-in electric, hybrid electric, battery electric, etc.), and climate conditions (extreme heat, the effect of A/C on fuel consumption, etc.). Currently, the standardized tests from either EU or the USA don't represent the driving conditions in Qatar (driving patterns, route characteristics, ridership, speed, climate conditions, etc.). Considering the standard driving cycle tests for electric and CNG buses are premature and doesn't represent the Qatar's driving conditions (hot climate, routes, topology, etc.), in this framework, we obtained fuel efficiency values from the bus operating company (pilot test for two electric buses) that made some test drives in Qatar's driving conditions. The company also had a large dataset about fuel efficiency values of diesel buses as they have been operated already under real-world driving conditions.

4.3 Fuel Price

Fuel price data is a crucial input for a life-cycle cost comparison. Estimating fuel prices for the long term is a challenging task mainly due to the dynamic nature of the factors affecting the fuel prices, such as political decisions, regional and global risks, beyond the traditional supply-demand relationship. On the other hand, electricity prices are mostly fixed in Qatar, depending on the contract type. Hence, the fuel price for the fleet is built on a projection of diesel fuel price (USD/L) and industrial electricity price rate (USD/kWh). Studying historical prices for diesel fuel, over the past 2 years, we observed that price has varied in the range of 0.47 USD to 0.55 USD. In accordance, projecting out fuel prices for the next 10 years, it would be unrealistic to assume fuel prices to remain the same at 0.55 USD level. It would also be unlikely to accept that it may go higher to 1.10 USD in the next 10 years. The initial price (price in 2020) for electricity is assumed to be 0.060 USD per kWh. The assumption used in the framework is that diesel fuel would increase at a 2% rate every year, and the electricity rate would increase by 3% every year. These values can be changed and modified using the provided excel-based tool in accordance with the changing dynamic external conditions affecting the fuel prices in the world.

4.4 Maintenance & Repair

Maintenance and Repair involve all types of repairs such periodic service (preventive maintenance), corrective maintenance and seasonal maintenance. The maintenance cost for buses is calculated as cost per kilometer (CPK), CPK includes labor and material cost, all type of preventive, **corrective** maintenance, regular wear and tear repairs, accident repair & repair of body damages, painting. Preventive maintenance is a type of maintenance that keeps up the performance and working condition of vehicles in regular operation; to minimize the possibility of breakdown. The objective of this type of maintenance is first to predict when vehicle failure could occur based on the maintenance plan defined by the Original Manufacturer Equipment (OEM), followed by preventing the failure through regularly scheduled and corrective maintenance. As a part of corrective action, any failure trend in vehicles or part observed is analyzed and studied, based on analysis a corrective action is planned; if needs entire vehicle batch goes for replacement or repair. Periodic services, where a change of oil, oil filter, and brake overhauling take place at different km intervals depends on the respective type of services. The service interval is set by the manufacturer so that it can change accordingly, F1, F2, F3 and F4 Service. The electric bus does not have the complexities of the ICE and does not require changing oil, replacing filters, etc. Besides, the design and structure of the electric bus denote that there are some driving differences with electric buses that reduce some of the wear and tear on the components. Using the maintenance model in line with the maintenance plan of the manufacturer, CPK for electric and diesel bus is calculated for the next 10 years.

The maintenance model defines the service interval, and other forms of repair and maintenance need to perform on the vehicle to maintain its roadworthy condition throughout its operational life as recommended by the bus manufacturer. Each type of bus maintenance is precisely calculated at different km intervals by accounting cost of different recourse, such as the cost of vehicle parts, the number of staff hours required to accomplish the task, and other indirect, associated costs. All incurred costs of individual maintenance activities are distributed throughout its service life to derive the CPK at different maintenance intervals.

4.5 Battery Replacement

The expected life of an electric bus battery is 8 years. After 8 years, a second life application is planned, all the fleet with the end-of-life battery will be replaced with new batteries, and accordingly, a cost for a new battery is estimated in cost evaluation based on the current market. The new battery price is accounted for 10% of the new bus price but considering a factor that all the cells will not be replaced, and a cost amount for the replacement has been adjusted. The main reason is that the useful lifetime for the bus is 10 years and the entire battery replacement would not be economically viable strategy. Hence, the battery lifetime can be extended by 2 additional years by replacing a portion of battery cells, instead of replacing the entire battery packs.

4.6 Overhead, reoccurring, infrastructure, and variable costs

Fuel/Charging Infrastructure, supporting personnel (including management), other overhead costs (such as insurance, building ownership costs, etc.) are important factors for evaluation. This cost category is very important, when a switch from conventional fuel to other energy sources takes place as a new facility needs to be set up which involves a high investment. These costs are reflected and depreciated in the TCO analysis for the total life of the asset which is of 10 years. The estimations can vary based on the way the company operates as It depends on optimal utilization of the infrastructure investment by the number of alternative buses on operation. Optimal utilization of infrastructure requires a careful planning and a smooth transition plan. In this study, we estimated the total cost of infrastructure required per bus at maximum utility condition.

4.7 General Econometric Data

The discount rate represents the time value of money, which is assumed to be 5.25%. This can be modified for future analysis, depending on the financial market conditions in Qatar. The inflation rate in Qatar averaged 2.34% from 2005 until 2020, reaching an all-time high of 16.59% in June of 2008 and a record low of -9.96% in December of 2009. Hence, for the case analysis, an average inflation rate of 2% is assumed for TCO analysis. The real discount rate (inflation-adjusted interest rate) is calculated using Eq. (1)

$$\boldsymbol{i} = \frac{(\mathbf{1} + \boldsymbol{i_r})}{(\mathbf{1} + \boldsymbol{i_f})} - \mathbf{1} \qquad (\mathbf{1})$$

Where,
i: inflation adjusted interest rate
$\boldsymbol{i_r}$: discount rate
$\boldsymbol{i_f}$: inflation rate

4.8 Insurance

The insurance rate is a function of a bus's book value; hence, it is calculated as 2% of the book value of bus alternatives. The book value is calculated using the straight-line depreciation method as follows. The insurance rate is calculated using Eq. (2).

$$I_t = I_R x \ [BV_{t=0} \frac{BV_{t=0} BV_{t=10}}{t=10} \ x \ t] \qquad (2)$$

Where,
t: Time (years)
I_t : Insurance amount (USD)
I_R: Insurance rate (2%)
$BV_{t=0}$: Book value at year 0 (purchase price)
$BV_{t=0}$: Book value at year 10 (salvage value)

4.9 End-of-life Management

The end-of-life management for buses (reuse/recycle plans) can vary from region to region depending on the available recycle, reuse, or secondary use purposes, and industries associated with the region Currently, end-of-life vehicle management is undertaken based on various conditions in Qatar. The end life of the operational fleet is defined based on the operational factors as follows.

1 End of life (fully depreciated) and not functional
2 High maintenance cost/ no availability of parts
3 Vehicle not functional, due to significant accident

4 All the vehicles ready for decommissioning have been evaluated technically & financially to define the value of the asset in the current market, and accordingly, the decision is made to suspend the fleet permanently from the operation.

Listed below are the ways to manage end of life phase.

1 To resale, the vehicle as a used vehicle and the salvage value falls in a range of 5% to 7%. Resale of the vehicle takes place either by Direct, Public, or Close Bid auction.
2 If it is non-road worthy, then sell the vehicle as scrap.
3 To donate the vehicle to other countries or region
4 To use the vehicle for corporate social responsibilities

In this TCO framework, we assumed a resale value of 5% of the initial purchase price for the vehicles compared.

5. TCO Framework

"Data input" are the parameters where all the information related to vehicle types, bus purchase price, fuel efficiency, vehicle M&R, battery replacement cost, infrastructure cost, insurance, and salvage value along with general economic data are entered. Fuel price in an average annual rate of increase for future projection. The price estimation is conducted for next 10 years. This framework relies on simple annual average estimations based on previous years. Vehicle maintenance cost are accounted based on the number of periodic service and maintenance a vehicle needs in a year. Cost per kilometer (CPK) is used in this framework to define the cost a vehicle accounts per kilometer. Based on the encoded data it will compute the life cycle cost for each bus type, reaching out the results with environmental impact.

Vehicle Data			
TCO Parameters	Diesel Bus	Electric Bus	CNG Bus
Bus Purchase Price	$137,400	$301,370	$153,000
Fuel Efficiency	0.48 L/km	0.66 kWh/Km	2.2 kg/km
Vehicle M&R	$305,758	$275,658	$364,916
Battery Replacement Cost	N/A	$8,257	N/A
Infrastructure Cost	N/A	$50,000	$1,370
Other initial overhead costs	N/A	$822	$137
Insurance	2%	2%	2%
Salvage value	$1,882	$7,628	$2,096
General Econometric Data			
Discount Rate	5.25%		
Inflation Rate	2%		
Inflation-adjusted discount rate	3.19%		

Table 1. TCO Data Input

6. Results

6.1 Life Cycle Cost

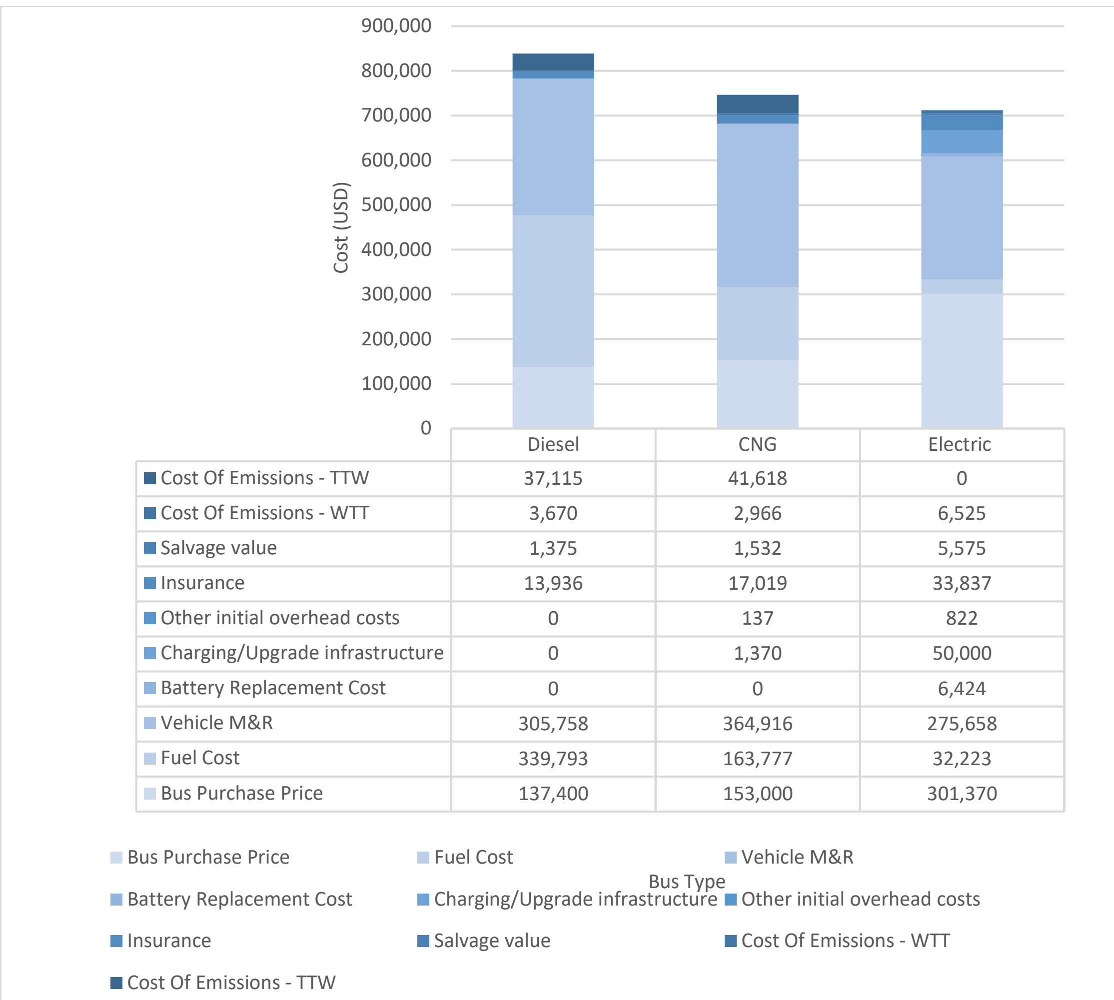
Figure 2 shows the results of the life cycle cost analysis for each bus type (USD per bus). According to the analysis, the total cost of ownership of electric bus is considerably less compared to that of diesel and CNG buses. LCC of electric bus is 15% and 5% less than the diesel bus and CNG bus, respectively, for a period of 10 years of operation. When diesel and CNG types are compared, LCC of the CNG bus is 11% less than diesel bus total cost.

Among the cost categories, the purchase price, fuel cost, and maintenance and repair are by far the most important cost categories to consider. Overall, while diesel has the lowest purchase cost, it's high fuel cost and M&R made it the highest cost alternative compared to others. Considering the traditional procurement processes which relies on the upfront initial investment costs, the best alternative could be considered as diesel buses. However, when looking at the entire lifetime, It has the highest cost. This result highlights the importance of life cycle thinking for procurement decisions and consideration of entire life-time is crucial for fleet management and procurement decisions.

As shown in Figure 2, electrification of public bus fleet can pave the way for considerable fuel cost reductions for operating companies and municipalities, depending on the electricity prices of the region. This factor indicates a direct reduction of total life cycle costs. Diesel bus technology yields high fuel costs due to its lower energy efficiency in their systems as well as higher M&R costs. In conclusion, fuel cost is one of the most important factors for cost comparisons as it adds up the highest operation cost, a small drop in fuel efficiency will have a high impact on the TCO results, henceforth to achieve the best TCO a better fuel efficiency technology bus should be favored.

Another factor that drives the high operation cost is vehicle maintenance and repair. According to the analysis results, he electric bus requires less maintenance as its total maintenance cost is $275,658, wherein for diesel and CNG is $305,758 and $364,916, respectively. When results were compared, it indicates that there is a 10% additional cost to maintain diesel fleet and 24% more for CNG bus compared to electric buses.

Conventional diesel bus is the threshold for comparison considering that they are widely accepted technology and present transport operation fleet comprise of more than 90 % of diesel fleet and all the depot and workshop is well equipped with the purpose-built facility for maintenance of diesel buses. On the other hand, electrification needs a setup of a new infrastructure to support vehicle charging and electric bus maintenance same applies to CNG fleet also but the investment for CNG bus workshop is less as it needs relatively minor upgrade of the existing infrastructure compared to electric bus infrastructure requirement.



	Diesel	CNG	Electric
Cost Of Emissions - TTW	37,115	41,618	0
Cost Of Emissions - WTT	3,670	2,966	6,525
Salvage value	1,375	1,532	5,575
Insurance	13,936	17,019	33,837
Other initial overhead costs	0	137	822
Charging/Upgrade infrastructure	0	1,370	50,000
Battery Replacement Cost	0	0	6,424
Vehicle M&R	305,758	364,916	275,658
Fuel Cost	339,793	163,777	32,223
Bus Purchase Price	137,400	153,000	301,370

Figure 2. Life Cycle Cost for alternative fuel buses

7. Conclusion and Future Work

This paper presented a comprehensive life cycle cost analysis to analyze and estimate the total cost of ownership based on the technical, financial, and environmental factors for three types of alternative fuel buses, as Diesel, CNG, and electric buses for public service operations. The operating conditions of buses were set using real driving conditions and data collected for the purchase price, fuel efficiency, maintenance pattern is all based on real world representative values. TCO Using real-world fuel efficiency values representing realistic driving conditions is one of the most important aspects to have a better planning and fleet management. Thus, where applicable, the operators should consider pilot test runs to realistically estimate the fuel cost as it is one of the most important parameters for Diesel and CNG bus operations.

Considering the recent trends in the electrification of public transport buses, we provided a benchmark to performance of widely accepted and used diesel fueled buses as a threshold, to which the outcome of the different energy technologies was compared. The framework is modeled on Microsoft excel and provided for the journal's readers for broader applications with flexible and transparent LCCA tool. The results were validated and compared with the literature. At the time of analysis, it became apparent that there were few sensitive factors for TCO calculation even a small change in an initial data recording may have a high impact on the result. This behavioral change in the outcome made us understand the importance of each factor's accuracy and real data values to attain a economically viable and environmentally friendly outcomes.

In our study end of life wasn't factored in detail for an electric bus as the option to utilize the battery pack after the useful life of the bus is still under consideration. The future work should focus more on end-of-life management and potential circular economy applications for the end-of-life management of buses to maximize the benefits for the greater society and economy.

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Biographies

Dr. Nuri Onat serves as an Assistant Professor at the Qatar Transportation and Traffic Safety Center (QTTSC). He is also the Co-founder and Co-director of Sustainable Systems & Solutions Lab (S3-Lab). Prior to joining the Qatar University, he worked as an Assistant Professor in the Department of Industrial Engineering in the City University of Istanbul. He is an Emeritus Walton Postdoctoral Research Fellow in Julie Ann Global Sustainability Institute at the Arizona State University as part of the Walton Sustainability Fellowship Program. Dr. Onat received his Ph.D. from the Civil, Environmental, and Construction Engineering Department at the University of Central Florida (UCF). Onat completed his M.S. in the Department of Civil & Coastal Engineering, under the Engineering School of Sustainable Infrastructure & Environment (ESSIE) at the University of Florida (UF), where he also received Certificate of Engineering Entrepreneurship from Engineering Innovation Institute. He also has a second master degree from the Department of Industrial Engineering & Management Systems at UCF. Prior to starting the academic

studies, he worked as a Civil Engineer in several engineering firms in Turkey, specializing in renewable power generation. He completed his B.S. in the Department of Civil Engineering at Gazi University, Turkey.
His research interests encompass theoretical and application-based approaches associated with sustainability problems. His theoretical works focus on improving the sustainability assessment methodology by broadening the scope of the assessment framework with the integration of social and economic indicators and by deepening the mechanism with integration of non-linear dynamic modeling, economic input-output analysis, and optimization. Applications of his work cover the sustainable transportation, sustainable built environment, and renewable energy systems.

Mansoor Jahangir Ahmed Khan is MSc student of Engineering Management for business brilliance course of the Qatar University. He received Bachelor of Engineering in Automobile Engineering at Mumbai University in 2011.His main aim in this research was to aid the policy and decision makers make right choice , while procuring a bus for public transportation using a TCO tool. Currently, he implements gained knowledge from his research into the industry that he works at