FEASIBILITY OF THE TRANSITION TO A BATTERY ELECTRIC BUS FLEET IN PUBLIC TRANSPORTATION

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1. Introduction

Public transportation systems are essential assets in urban areas. They provide more efficient mobility than private cars in dense areas, while also reducing traffic congestion and its environmental impacts (CMAP; 2018). More importantly, public transportation offers mobility solutions to everyone regardless of their physical and financial abilities, which means that it is also accessible to people who do not have access to a car or lack the ability to drive. This advantage over other modes of transportation plays a very important role in increasing equity, which means providing equal access to opportunities, giving the chance of equal growth and development among people of different backgrounds, abilities and goals. The biggest and most successful cities in the world also have robust public transit networks, which means not only that the benefits of transit are widely known, but also that transit has created opportunities for urban areas to develop and thrive.

1.1. Problem Statement

Having the ability to provide such service at a competitive price to a highly diverse group of people requires local government regulation. Most public transit agencies in the United States and the rest of the world rely on public subsidies, in order to remain affordable, thus accessible. Even though this looks like an ideal scenario, in reality it hides some of the biggest challenges in the transit industry. Farebox recovery ratio, the percentage of the public transit agency revenue that comes from the fares and not funding, struggles to meet 50% of the total operation and maintenance costs (RTA; 2016); at the same time federal funding, at least in the United States, is continuously declining. Declining funding means service cuts; service cuts mean lower ridership and lower farebox recovery, creating a vicious cycle that worsens the situation. This continuous lack of funding has also created infrastructure issues; in Chicago, for example, repairs and rebuilds are long overdue in most parts of the rail network, which in some cases exceed 100 years of continuous operation; old rail cars and buses that exceeded their useful life cannot be replaced on time, resulting in increased operation and maintenance costs (CMAP; 2018).

While a federal funding increase cannot be guaranteed, there are ways to improve transit service using all the available means. Transit Asset Management combines all the methods and techniques of mathematics, engineering and economics required to allocate funding to the right needs and enhance the performance of the system. Transit asset management provides all the tools to evaluate the assets, measure performance, prioritize certain activities and optimize the utilization of capital and assets in order to improve the service and restore the assets to a level that maintenance is feasible and cost effective (State of Good Repair).

Technology is also a big contributor in reducing transit costs and improving service. Public transit does not make good enough use of the technologies available, mostly due to the lack of funding. Technologies like passenger information and in-vehicle amenities such as wifi and charging docks can improve quality of service for the users. Other technologies, such as vehicle tracking, automated performance monitoring and switching to alternative energy sources can greatly improve operations, maintenance and their associated costs. While many of these technologies are already implemented or planned, there is still room for improvement in adopting new technologies or upgrading existing ones.

1.2. Goal and Objectives of the Project

This project studies the financial aspect of the vehicle replacement problem. Using purchasing, fuel, maintenance and overhaul costs, the goal is to provide a model that calculates the long-term expenses of owning, operating and maintaining a bus fleet, while at the same time compares different vehicle technologies in order to find the combination that minimizes costs in the long term.

The objectives of this analysis are defined as follows: (a) study the long-term costs of owning, operating and maintaining buses of different technologies, including diesel, hybrid, and electric; (b) study the cost projections that affect operation and maintenance of a bus fleet of different technologies; (c) compare the different bus technologies in matters of costs, using projections in different scenarios; (d) achieve and maintain State of Good Repair (SGR) in the whole fleet by the end year of the analysis; and (e) use the results to make policy recommendations and mention areas for further improvements.

The proposed model uses historical data and relevant projections to model future purchase, fuel, maintenance and overhaul costs. The model is structured in a way that allows future additions, modifications or use of more accurate datasets. That way, there is high potential that this model can support vehicle-related decision-making in public transportation.

1.3. Structure of the Paper

This paper is structured as follows. In Section 2, a background review focuses on the multiple components of this paper, their history and current approaches. Section 3 includes the methodology and the structure of the model. In section 4, a case study for the Chicago Transit Authority's bus fleet will be used to apply the proposed model, followed by a summary of the results in section 5. Finally, Section 6 includes a conclusion highlighting the findings of this case study, the benefits and limitations of the proposed model, as well as areas for further research.

2. Background

2.1. Transportation Asset Management

Transportation Asset Management, as mentioned in the Introduction, is the combination of engineering, mathematics, economics and technology in utilizing transportation assets efficiently, effectively, safely, and reliably. According to the Federal Highway Administration (FHWA), asset management in the transportation sector is a relatively new concept; it is expressed as the foundation for methods and techniques that optimize the performance and cost-efficiency of transportation facilities. It started in private companies, where the goal was clear: provide a predefined acceptable level of service while keeping costs as low as possible. While this approach is fairly easy to apply in the private sector, government agencies face many challenges, mostly because their goal is not profit but public welfare. However, public agencies care about performance and efficiency, similar to private organizations. That is why, in 1993, the US Congress passed the Government Performance and Results Act, which made performance and efficiency, the basic principles of asset management, a priority for the government.

The Transportation Research Board (TRB), in its National Cooperative Highway Research Program (NCHRP) Report in 2006, underlines the five core principles of asset management. First, it is policy-driven; the decisions are made based on predefined goals and objectives and reflect the desired condition of the system, level of service and safety, which are subject to economic, community and environmental goals. Second, it is performance-based; the goals and objectives are translated in performance measures, which can be used for daily and strategic management. Third, it includes analyses of options and tradeoffs; a set of alternatives is built and, based on the policies and budget limitations, the alternatives are evaluated in order to select the ones that fulfill the policy requirements in the most cost-efficient way. Fourth, it is based on quality information;

a great deal of attention is paid to the quality of the data used to support decision making. The evaluation should indeed be based on current data that reflect the goals and objectives, and make it easy to compare alternatives. Fifth, it includes feedback and accountability monitoring; the selected alternative or set of alternatives is continuously monitored after implementation in order to make sure that it worked as expected. The policies and requirements are hence updated for the future.

A successful and complete asset management plan must include the following steps (Li; 2018): (i) definition of goals and objectives for the transportation system, (ii) definition of the performance measures (indicators), (iii) performance modeling, (iv) needs assessment, (v) list of alternatives, (vi) evaluation of the alternatives, (vii) selection of the best alternative and programming, (viii) implementation, and (ix) feedback. In Step (i), the agency and federal laws define the targets of the transportation network. In Step (ii), these targets are expressed in terms of performance measures, using defined indicators that are easily quantifiable. Step (iii) defines the relationships among the performance measures that define the ways of performance evaluation. Step (iv) defines the performance levels and the treatment needs for each level. Step (v) includes the introduction of alternative projects. These projects are evaluated in Step (vi) based on the performance measures and methodologies, in order to select the best alternative or combination of alternatives in Step (vii), according to budget limitations. After Step (viii), which includes the implementation of the selected alternative, Step (ix) includes the evaluation of the alternative after implementation and the return to step (i). This cycle indicates that Asset Management is an iterative process of continuous revisions of the goals, performance indicators, methodologies and budget, which are refined and reconsidered because of changes in technology, data requirements and availability, as well as strategies and financial needs and abilities.

2.2. Transit Asset Management Legislation

In 2016, the Federal Transit Administration (FTA) published the final rule for Transit Asset Management (TAM) with guidelines for transit agencies, as well as the definition of State of Good Repair (SGR) and minimum requirements for the development of an Asset Management Plan, in order for the agencies to receive federal funding (49 CFR Parts 625,630). The rule is introduced as follows: "This final rule establishes a National Transit Asset Management (TAM) System in accordance with section 20019 of the Moving Ahead for Progress in the 21st Century Act (MAP-21). […] A transit asset management system is a strategic and systematic process of operating, maintaining, and improving public transportation capital assets effectively through the life cycle of such assets". Asset management was generally used long before this rule. However, this rule became mandatory for public agencies, hence providing a minimum level of financial planning, and standardized guidelines about performance measures. This rule is the foundation of the National Transit Database and Transit Economic Requirements Model.

The National Transit Database (NTD) is designed by the FTA as a tool to provide open data about transit performance using a variety of ridership, economic, infrastructure, and other data. Having wide data availability is crucial when identifying trends in the transit industry, performing calculations and analyzing statistics on a transit agency's performance. Reporting data to the NTD is a requirement by the FTA for all urban transit agencies that want to receive funding from the FTA. NTD also serves as a planning tool for smaller transit agencies that do not have the needed resources to plan and implement advanced management processes. It includes a wide variety of data, such as ridership, vehicle inventory, operational and maintenance costs, funding sources and safety event summaries. Each dataset includes raw data from transit agencies, as well as summaries and reports of the trends.

Another tool created by FTA for this initiative is Transit Economic Requirements Model (TERM), which is a software capable of conducting asset management analyses and produce reports and recommendations for transit agencies, based on the FTA standards and on continuous access to data from the agency's inventory and the whole NTD database. The main purpose of TERM is to analyze the State of Good Repair (SGR) backlog and translate it to dollar amounts, as well as define the investment needed to achieve SGR in all assets and analyze the impact of different funding alternatives and evaluation methods. It also helps agencies prioritize their investments, either by transit mode or by asset type. The methodologies that TERM uses for its functions are approved by FTA; this software package is widely available and easy to implement for small transit agencies that lack the expertise or capital needed to conduct such studies.

2.3. Electric Vehicle Technology

Electric vehicles are the vehicles that use one or more electric motors for propulsion. The sources of electricity can be numerous, from on-vehicle batteries or off-vehicle facilities that directly supply the vehicle with electricity, to fuel engines that produce electricity. Electric vehicles can be seen as battery electric cars or buses, trolleybuses, streetcars or rail vehicles with overhead wires, heavy rail passenger cars with third-rail supply, as well as diesel-electric locomotives. Electric motors were introduced in the late 1820's, long before the internal combustion engine, and they were proven to be much more efficient than internal combustion engines. The biggest reasons why they did not become widespread was the insufficient storage capacity and the energy transfer limitations. Batteries, while much more efficient nowadays, add a large amount of weight to the vehicle. Charging takes a relatively long time and the range is limited. On the other hand, building overhead wiring or third rail facilities requires a large investment. Nowadays, however, battery technology has evolved significantly and started to become financially viable for use in electric vehicles.

Public transit is an industry that does not have the opportunity to take risks and to embrace new technologies too soon. Cost-effectiveness and reliability policies make transit agencies look only for stable solutions. According to transit agencies, investing in battery electric vehicles implies three main issues. The first issue is called “range anxiety”. Transit vehicles are on the road most of the day, driven far longer distances than a typical car. This means that the limited range of batteries is not acceptable. Second, charging takes much longer than refueling which, combined with the limited range and the need for charging throughout the day, creates issues in vehicle operations and planning, as they have to stay longer in terminals to charge. Third, while electric motors are much more efficient than their internal combustion counterparts, efficiency is less stable and relies more on external factors, such as outside temperature, which can greatly affect the battery capacity, elevation changes and driving style.

While battery electric vehicles have their own advantages and disadvantages, technological innovation in the field made them much more competitive and a viable and more environmentally-friendly option for the replacement of traditional internal combustion engine vehicles. Burke and Zhao (2017) analyzed and projected fuel economy on medium and heavy duty trucks, including buses. The results showed the engine efficiency of diesel and diesel-hybrid vehicles will increase, but it will not be able to compete against the efficiency of electric motors. Proterra, a major battery electric bus manufacturer in the United States, underlines that estimated lifetime savings for a 12-year useful life are $462,000 compared to a diesel bus, $467,000 compared to a compressed natural gas (CNG) bus (the more environmentally friendly option than diesel), and $479,000 compared to a hybrid diesel-electric bus. The initial investment is higher, which is one of the main reasons why switching to an electric bus fleet is more expensive in the short term, but the maintenance savings justify the higher initial investment by savings that show up in long term analyses. Electric buses have less moving parts than diesel buses, meaning that the structure is simpler with less maintenance needs; fuel costs are also much lower thanks to the high efficiency of electric motors, but this also depends on the way the electricity is produced. In 2016, the California Environmental Protection Agency published a set of papers and reviews about the future of clean transit, highlighting the long-term financial and environmental benefits of electric buses using their projections of fuel costs, and future vehicle technology availability and price. As a result, transit agencies are moving towards switching to an electric bus fleet. In the Chicago region, CTA is testing two battery electric buses since 2015. In 2018, an order was made to add 20 more electric buses to join CTA's fleet.

3. Methodology

This project proposes a model that analyzes vehicle purchase, fuel, maintenance and overhaul costs, projects existing data into long-term and compares different vehicle technologies, in order to recommend the most cost-efficient technology. The model is structured in a way that can be easily modified or extended by changing some of the variables, extend projections by data availability or use sources with more detailed or accurate information.

The model consists of three parts. The first part includes the definition of the cost measures that will be used in the evaluation; the second part includes the selection of supporting data projections that will help with projecting the actual cost measures; finally, the third part includes the combination of the data from the two previous steps to conduct the analysis and produce the results.

3.1. Cost Measures

Selecting the right cost measures is important in order to make sure that all major costs that are affected by different vehicle technologies are included in the analysis. Some costs that are not based on the vehicle technology are not included, such as labor costs. Four cost categories are used in the analysis: vehicle purchase, fuel usage, maintenance, and overhaul. In order for the comparison to be feasible, all costs have to be expressed on an annual basis. Fuel and maintenance costs are already defined annually, but the purchase and overhaul costs are expressed as their annual equivalents.

3.2. Supportive Data Projections

In order to be able to project the cost measures into the future and support policy decisions, supportive data with available projections are used and the cost measures are expressed as functions of the supportive data. Purchase and overhaul costs are simple, because projections for these costs are readily available. Maintenance costs are calculated per mile, so the annual mileage for each bus is needed in order to estimate the total annual maintenance costs. Fuel and energy consumption is a function of the annual mileage, the diesel fuel and electricity prices, and the actual efficiency of the bus. While the mileage can be assumed a constant, both energy prices and vehicle efficiency change over time. Fuel and electricity prices affect the costs on an annual basis, while efficiency is a constant for the vehicle's useful life, but changes depending on the year of purchase. For example, in diesel and hybrid buses, fuel efficiency is derived from the annual mileage to calculate the total amount of fuel used expressed in gallons per year used; then the amount of gallons is multiplied with the diesel price of that year to estimate the total fuel cost for that year.

3.3. Cost Estimation and Assumptions

After the data are prepared in the preceding step, the next step involves combining historical data and supportive data projections to create a timeline of vehicle replacements. The timeline consists of a time period that includes replacement of vehicles of the current bus fleet at least once. This approach ensures that there is enough time to replace the whole fleet and eliminate any SGR backlogs that may exist.

In order to support decision-making without knowledge of future trends, a set of assumptions is adopted. Assumptions are important pieces in forecasting, serving as a way to recognize the flaws (if any) of the proposed model and providing suggestions for further improvements. While assumptions reduce the accuracy of the forecast, lack of knowledge of future events makes it imperative that assumptions be made; otherwise decision-making could not be possible. First, all the costs estimated in the timeline are expressed as base-year constant dollar amounts. This means that a comparison of the costs is possible, as constant dollars are used throughout the study period. Second, the annual equivalents of purchase and overhaul costs are estimated using a constant discount rate, which reflects the value of time in these investments. Third, the bus purchase price forecast does not take into account the size of the bus; for this reason and based on historical data, a constant percentage of the price is added for articulated buses; at the same time, overhaul costs are assumed to be the same between different sized vehicles, as they are mostly related to the engine. Fourth, energy efficiency for articulated buses is also calculated as a constant percentage of the standard buses, using current data. Fifth, diesel price is one of the most sensitive parameters, so a sensitivity analysis is performed to average, low, and high diesel price. Finally, the last assumption is that every vehicle will be replaced by one of the same size and fleets with few vehicles (less than 5) will not get replaced, as it is assumed that they were purchased for testing purposes.

4. Application

In order to test the model and its performance, a study was performed of the bus fleet of the Chicago Transit Authority, the second largest public transit agency in North America. As of 2019, the bus fleet consists of 1,859 buses, including 239 hybrid and 2 electric buses. Of them, 304 buses are articulated. The oldest buses were purchased in 2002, already exceeded their useful life, while the newest buses joined the fleet in early 2019. The study period covers the time from 2016 to 2040. CTA recently announced their commitment to convert the entire fleet to electric buses by 2040, so it is useful to understand if the conversion to electric buses will reduce agency costs and capital needs.

4.1. Data Collection

The required historical data, as well as supportive data projections, were obtained from publicly available sources. Historical data about the CTA are available on FTA's NTD database. The data extracted from this source include the details of the buses, the annual mileage, and the total operation and maintenance costs. Fuel efficiencies, overhaul prices and the correlation between standard and articulated buses were taken from reliable public web sources and official CTA announcements. Table 4.1 shows the overhaul prices that were selected for this project, based on CTA official announcements of past overhaul projects.

Diesel	Diesel Hybrid	Battery Electric
$174,295	$174,295	$94,295

Table 4.1 Average Overhaul Costs

The supportive data projections were obtained from a series of papers published by the Air Resources Board of the California Environmental Protection Agency, which used fuel and electricity projections (as cited by the Energy Information Administration – EIA) specifically for transportation, bus purchase cost projections (as cited by studies from the American Public Transportation Association – APTA), and bus maintenance costs per mile (as cited by APTA studies and individual transit agency inputs). Fuel efficiency projections were modeled by Burke and Zhao (2017), using polynomial interpolation for the intermediate values. The discount rate for fuel purchase by the CTA was inferred by comparing the annual fuel cost per mile on the NTD database to the fuel price for the same year.

Figure 4.1 shows the process of fuel efficiency estimation using data from Burke and Zhao (2017), while figures 4.2-4.4 show the purchase prices and efficiencies of the different vehicle technologies that are used in this project.

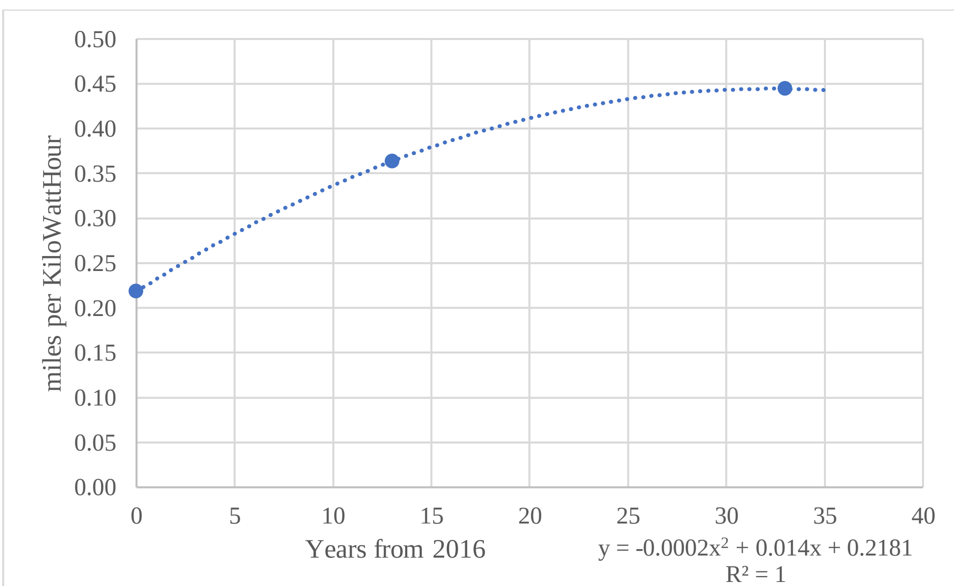

Figure 4.1 Fuel Efficiency Forecast for Electric Buses

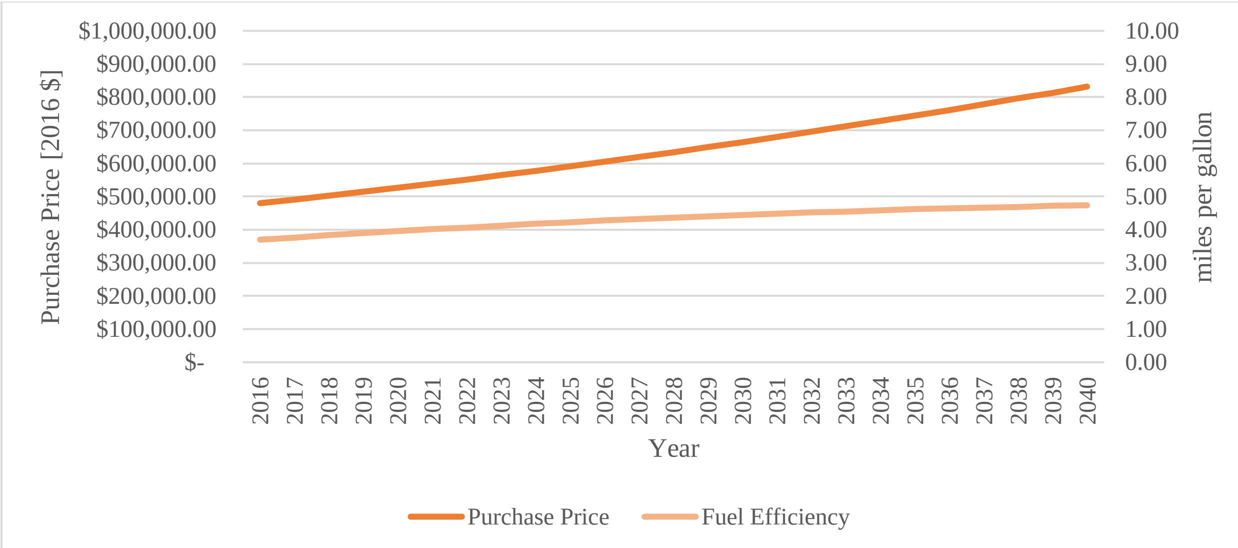

Figure 4.2 Diesel Bus Purchase Price and Efficiency Projection

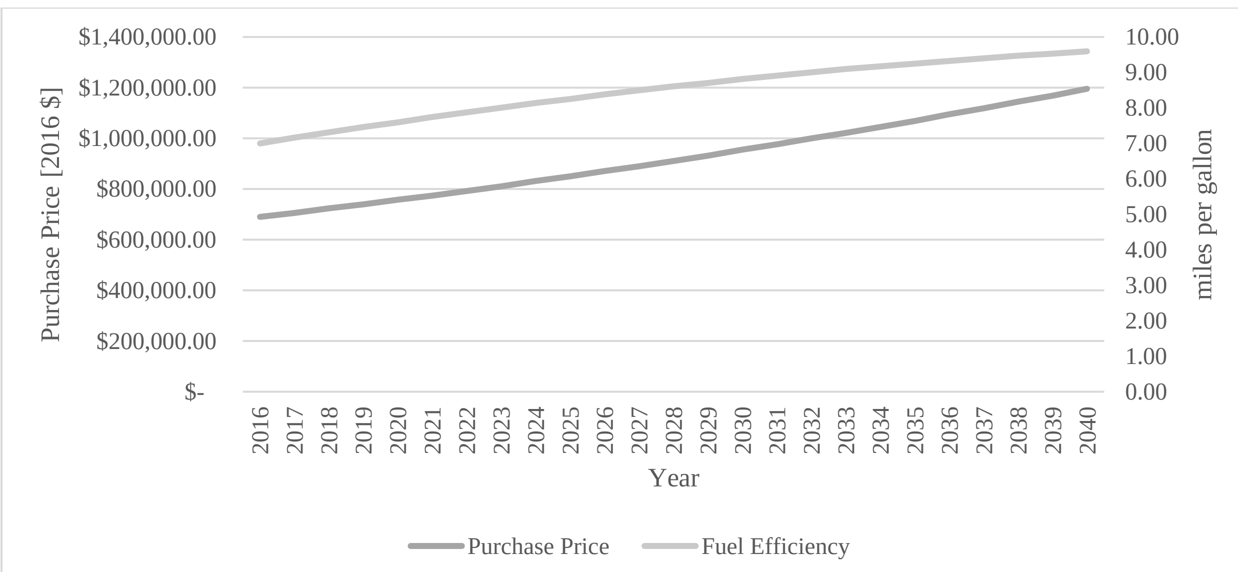

Figure 4.3 Hybrid-Diesel Bus Purchase Price and Fuel Efficiency Projection

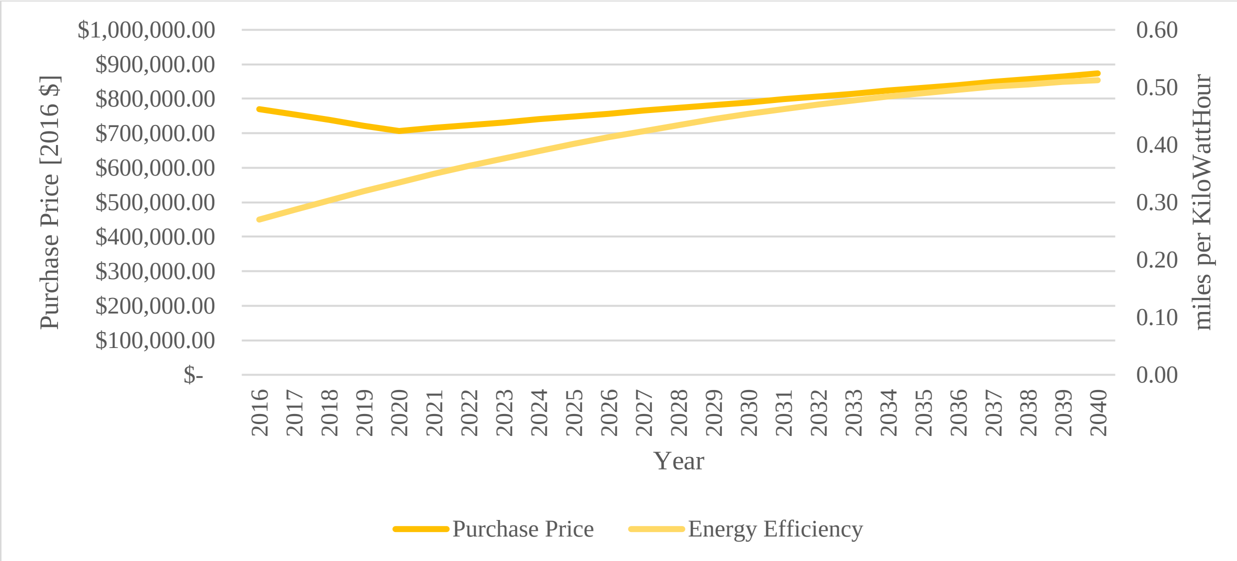

Figure 4.4 Electric Bus Purchase Price and Efficiency Projection

These figures show that bus purchase prices get higher over the years starting from 2016, except for electric buses, where the purchase price goes down until 2020 and then goes up. In case of fuel efficiency, it gets higher slowly with diesel and diesel-hybrid buses, with the latter having almost double the efficiency of a standard diesel bus. In electric buses, efficiency gets higher in a more rapid way, following current and future innovations in electric motor and battery technology.

For this project, four alternatives were considered. In the first alternative, which is also used as the base, every vehicle is replaced by one of similar technology. In the other three alternatives, vehicles are replaced with only diesel, only hybrid-diesel, or only electric buses.

4.2. Assumptions

The assumptions used in this study are:

- The useful life of the vehicles is defined by FTA recommendation as 14 years. Some of the current vehicles are kept for 15 years, as part of CTA's policy.
- Vehicle purchases are shown at the end of the year before the vehicles enter service. Mid-life overhaul costs are shown at the end of the year before the vehicles reach half of their useful life.
- Only one overhaul happens throughout each vehicle's useful life. The only exception is a life-extending overhaul that is already programmed for some of the current vehicles in the near future. Life-extending overhauls are assumed to extend the useful life for 7 years.
- Annual mileage per vehicle is assumed to be equal for each fleet type. When data is not available, 30,000 miles/vehicle/year is assumed, being close to the current average.
- Bus replacement is assumed to happen at the end of the final year of a vehicle's useful life. It is replaced by a vehicle type of the same size.

4.3. Cost Analysis

The four costs that are included in this analysis are purchase, fuel/energy, maintenance, and overhaul costs. These costs are expressed in their annual equivalents (AE). More specifically:

- Purchase Cost: Happens at the end of the year before the vehicle enters service. Converted to annual equivalent:

$$AE_{PC} = PC * (A|P, i, n), \qquad in\ 2016\ constant\ dollars$$

$where\ AE_{PC}: Annual\ Equivalent\ of\ Purchase\ Cost$

$PC: Purchase\ Cost$

$i: discount\ rate\ of\ 2.75\%$

$n: 14\ years\ of\ service$

- Fuel Cost: Annual cost based on fuel efficiency at the year of purchase, annual mileage and fuel cost at the year of calculation:

$$FC = \frac{AM}{FE} * BFC, \qquad in\ 2016\ constant\ dollars$$

$where\ FC: Fuel\ Cost$

$AM: Annual\ Mileage$

$FE: Fuel\ Efficiency$

$BFC: Basic\ (per\ mile)\ Fuel\ Cost$

- Maintenance Cost: Annual cost based on average maintenance costs per mile and annual mileage:

$$MC = AM * BMC, \qquad in\ 2016\ constant\ dollars$$

$where\ MC: Maintenance\ Cost$

$AM: Annual\ Mileage$

$BMC: Basic\ (per\ mile)\ Maintenance\ Cost$

- Overhaul Cost: Happens at the end of the year before each vehicle reaches its mid-life. Moved to the beginning of the useful life and converted to annual equivalent for the entire useful life:

$$AE_{OC} = OC * \left(P\middle|F, i, {}^{n}\!/_{2}\right) * (A|P, i, n), \qquad in\ 2016\ constant\ dollars$$

$$where\ AE_{OC} = Annual\ Equivalent\ of\ Overhaul\ Cost$$

$$OC = Overhaul\ Cost$$

$$i = discount\ rate\ of\ 2.75\%$$

$$n = 14\ years\ of\ service$$

Vehicle replacements happen each and every time a vehicle type reaches its useful life. They get replaced by vehicles of the same size; vehicle technology depends on the scenario. Each scenario is defined by diesel fuel price, based on the estimated diesel price forecast by the EIA for transportation and discounts that CTA had in the past. The base scenario uses a 7.58% discount, estimated for 2016; the low price scenario uses a discount of 27.35%, estimated for 2017; and the high price scenario uses no discount.

5. Results and Findings

5.1. Base Scenario

Figure 5.1 shows the total annual costs of each alternative; Figure 5.2 shows the cumulative costs over the 24-year period from 2016 to 2040. Figure 5.3 shows the cumulative cost change for each alternative compared to the CTA base alternative; more specifically, the cumulative cost of the CTA base alternative is subtracted from each of the other alternatives, highlighting the cost savings of each alternative.

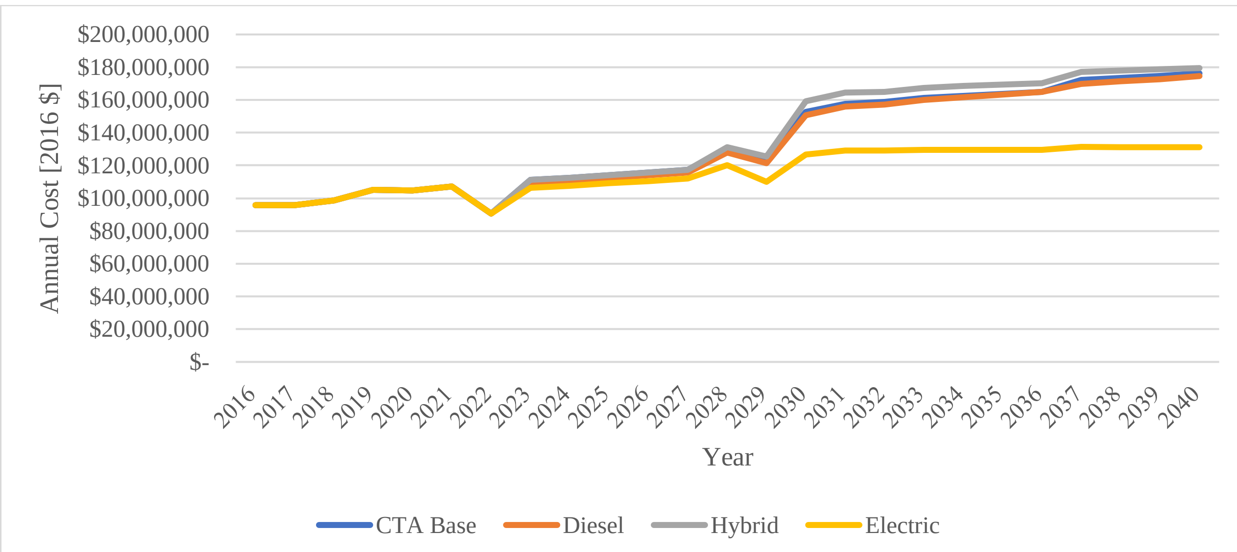

Figure 5.1 Annual Cost Forecast - Base Scenario

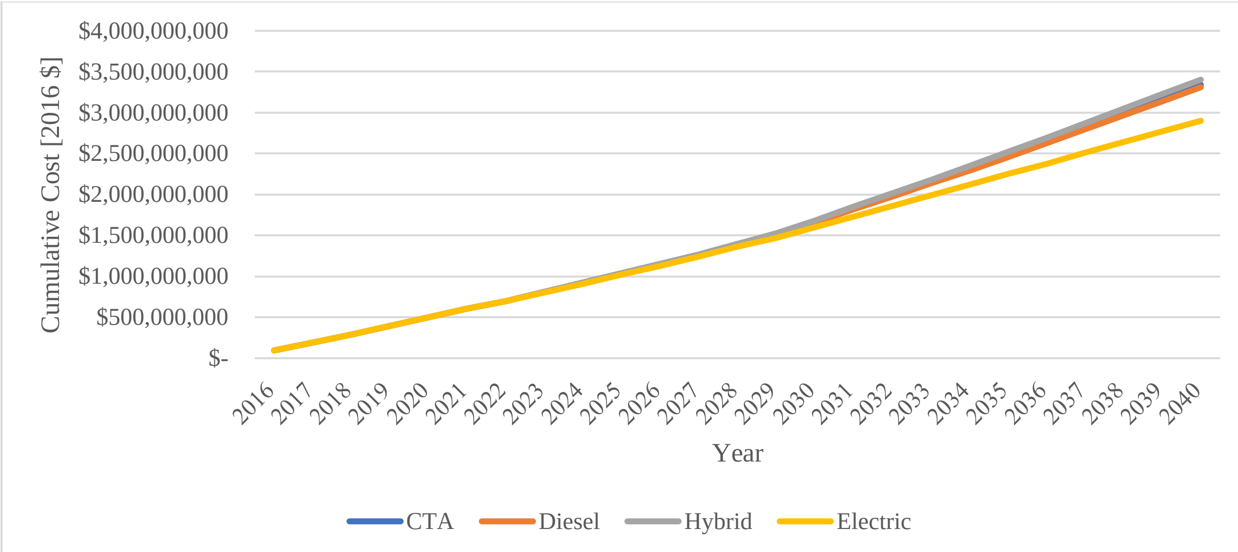

Figure 5.2 Cumulative Cost Forecast - Base Scenario

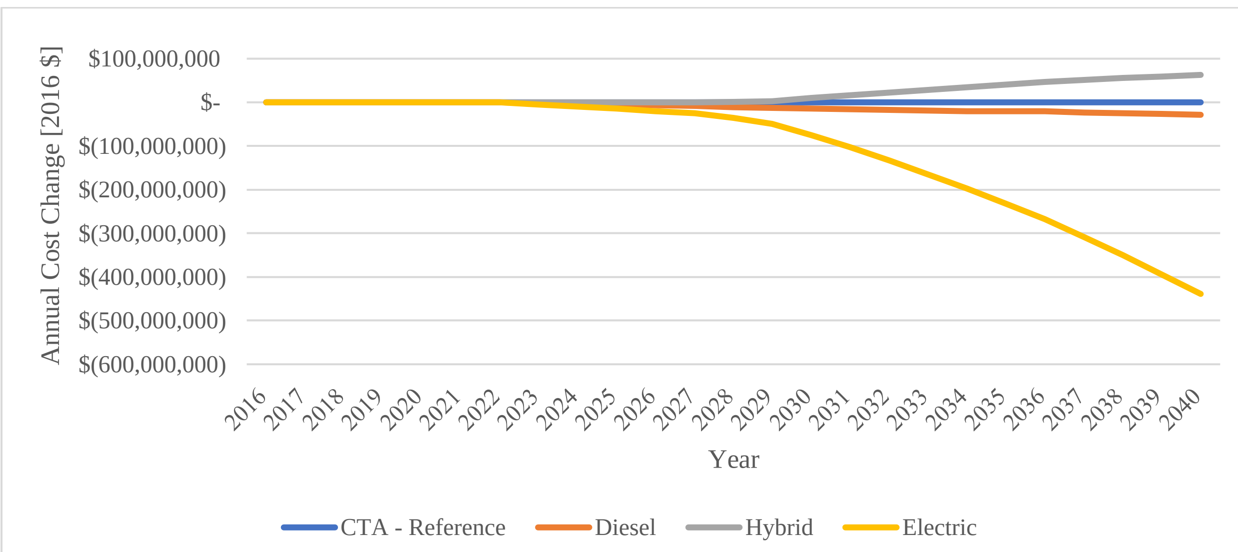

Figure 5.3 Cumulative Cost Change Forecast - Base Scenario

It can become evident that the costs associated with electric buses are lower on an annual basis. The costs associated with hybrid-diesel buses are higher than standard diesel buses, which means that, for this scenario, the fuel efficiency of the hybrid-diesel bus is not sufficient to cover the higher purchase cost.

5.2. Low Diesel Price Scenario

Similarly with the base scenario, Figure 5.4 shows the total annual costs of each alternative, Figure 5.5 shows the cumulative costs of each alternative over the 26-year period, and Figure 5.6 shows the cumulative cost change of each alternative.

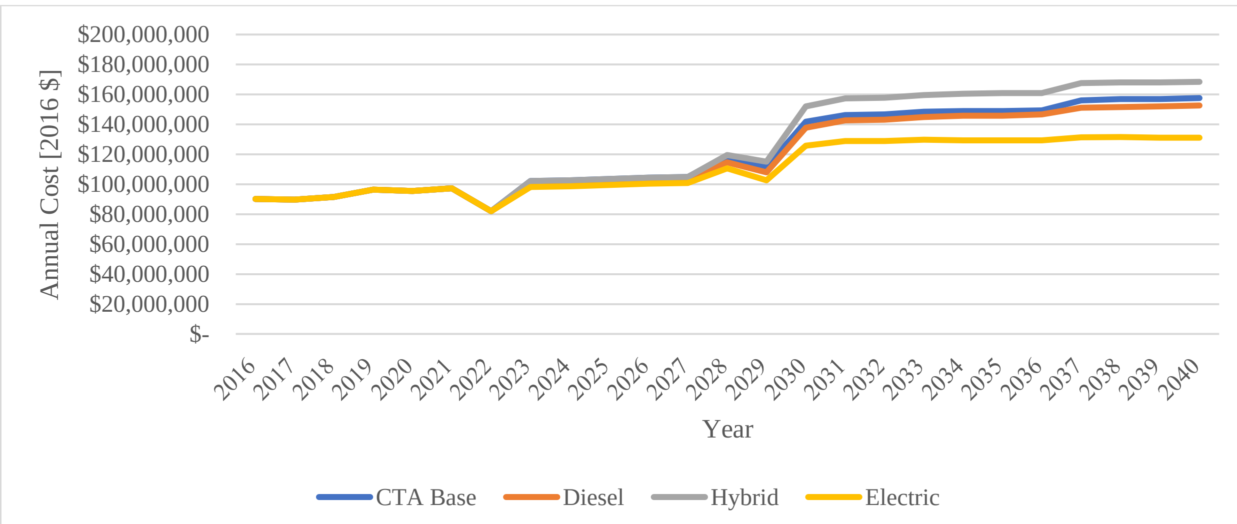

Figure 5.4 Annual Cost Forecast - Low Diesel Price Scenario

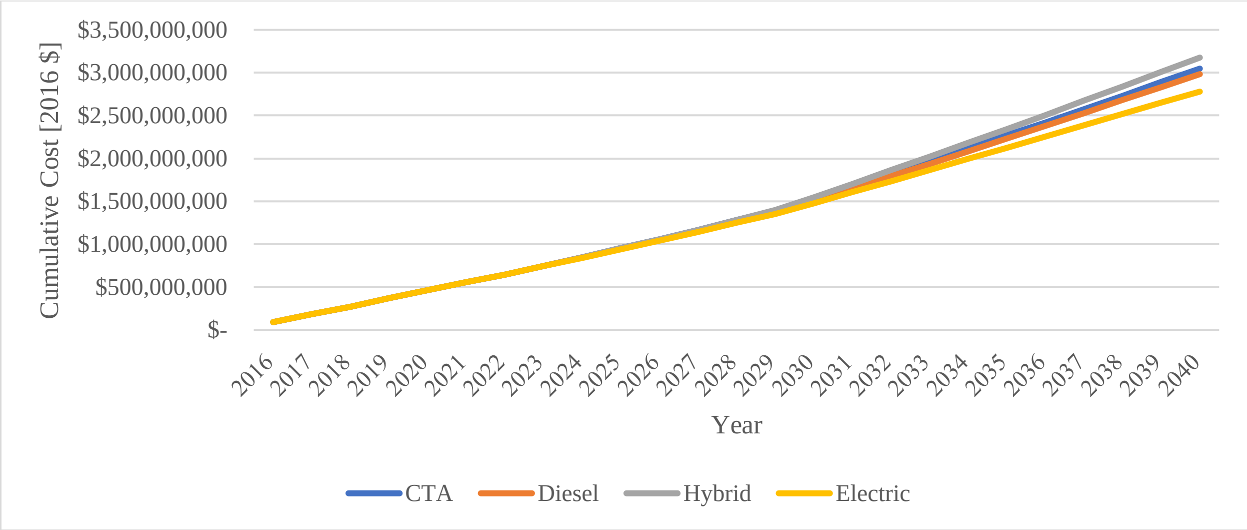

Figure 5.5 Cumulative Cost Forecast - Low Diesel Price Scenario

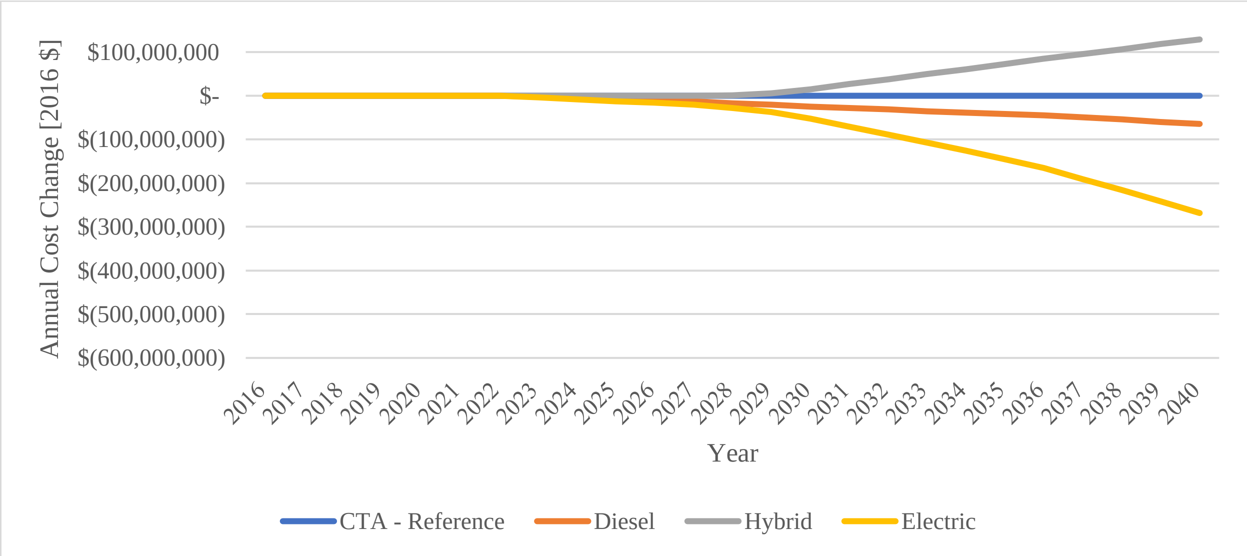

Figure 5.6 Cumulative Cost Change Forecast - Low Diesel Price Scenario

In low diesel price situations, it can be seen that hybrid-diesel buses become more expensive, due to their higher purchase cost. Electric buses, on the other hand, remain the most cost-efficient alternative, even though the low diesel price makes conventional diesel buses more competitive.

5.3. High Diesel Price Scenario

Similar to the other scenarios, Figure 5.7 shows the total annual costs of each alternative, Figure 5.8 shows the cumulative costs of each alternative over the 26-year period, and Figure 5.9 shows the cumulative cost change of each alternative.

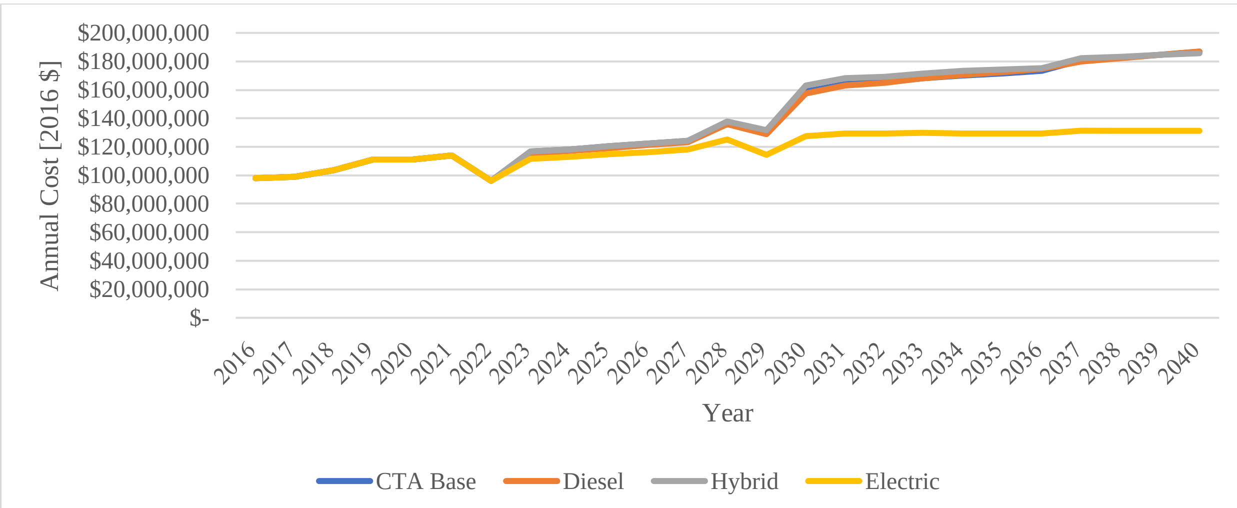

Figure 5.7 Annual Cost Forecast - High Diesel Price Scenario

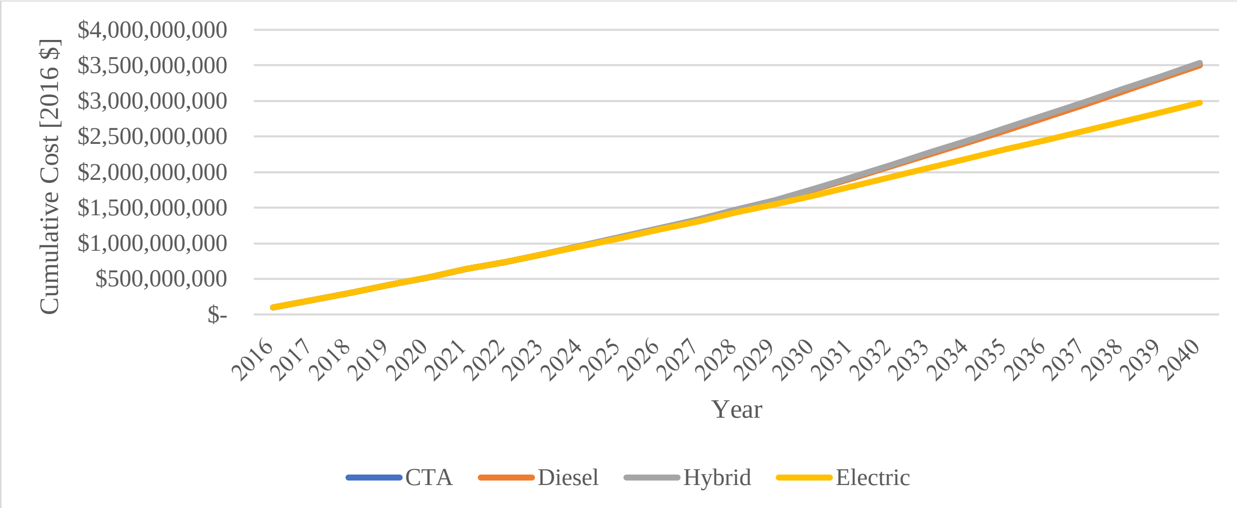

Figure 5.8 Cumulative Cost Forecast - High Diesel Price Scenario

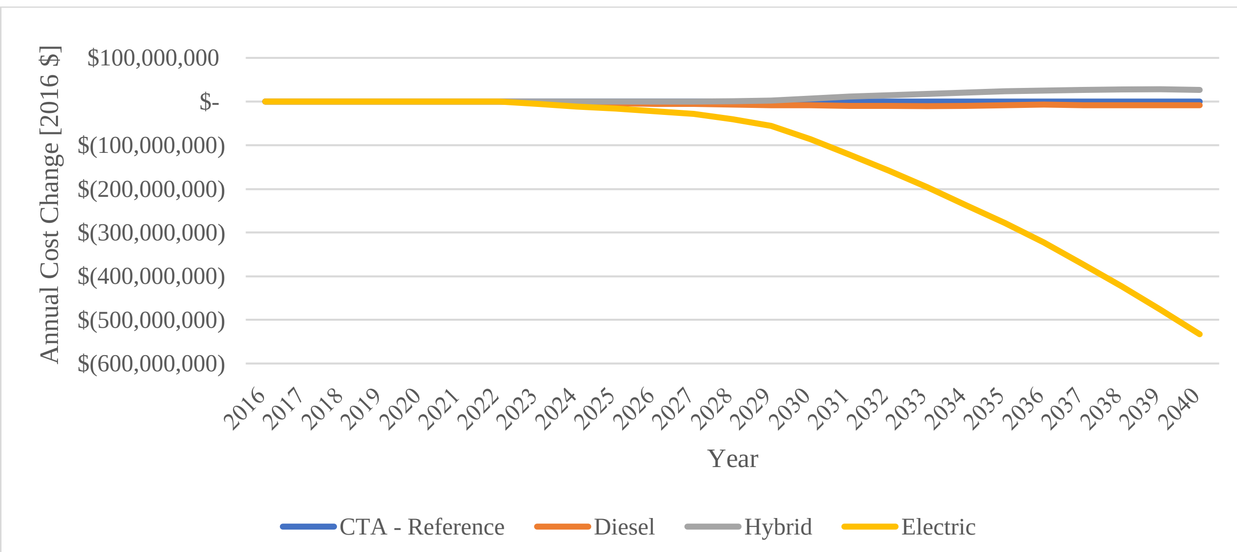

Figure 5.9 Cumulative Cost Change Forecast - High Diesel Price Scenario

In a high diesel price situation, it can be seen that hybrid-diesel buses become more competitive, as the high efficiency outweighs the higher purchase price. However, electric buses are by far the best alternative in such cases, offering the highest savings compared to any of the conventional alternatives.

5.4. Findings

The results show that in all scenarios the electric bus alternative provides the greatest cost reduction in the long run. Initial costs may be higher, but the much lower energy and maintenance costs, combined with the spreading of purchase and overhaul costs over its useful life, cause a significant decline in the annual equivalent cost of electric vehicles. The electric bus scenario offers a clear advantage over the other technologies.

Another point that should be mentioned is that hybrid buses do not offer as much of an advantage as traditional diesel buses. They indeed are more efficient, but the higher maintenance cost hinders the increased efficiency. Hybrid buses start to show an advantage in annual costs only in the high price scenario.

It has to be noted that electric buses do not include the installation of chargers at garages and terminals. Taking chargers into consideration requires a more detailed analysis and planning of the locations, which is beyond the scope of this project. Future studies may include the cost of installing chargers, or may compare different electric vehicle technologies, such as battery electric with garage/terminal charging facilities and battery electric with en-route charging systems.

6. Conclusion

Public transportation offers a direct advantage over private cars in dense urban areas. However, public transportation systems must remain affordable and efficient. Managing the assets and the operations of public transportation systems presents a big challenge. Detailed analyses of owning, maintaining and operating the vehicles of a transit fleet can provide great savings. Replacing buses with more efficient ones can help reduce costs, mitigate environmental impacts, and provide a nicer experience for riders.

In this project, the costs of owning and maintaining different types of buses are compared. Projected data is used to forecast these costs using current and historical data as a basis. Results show that electric buses are the most cost efficient, with hybrid diesel-electric buses a distant second. This analysis can help transit agencies formulate their long-term strategy relative to their vehicle replacement policy, as well as create a forceful argument for transit agencies who seek prioritized funding for the migration to a fully electric bus fleet.

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