Procurement of Electric Buses: Insights from Total Cost of Ownership (TCO) Analysis

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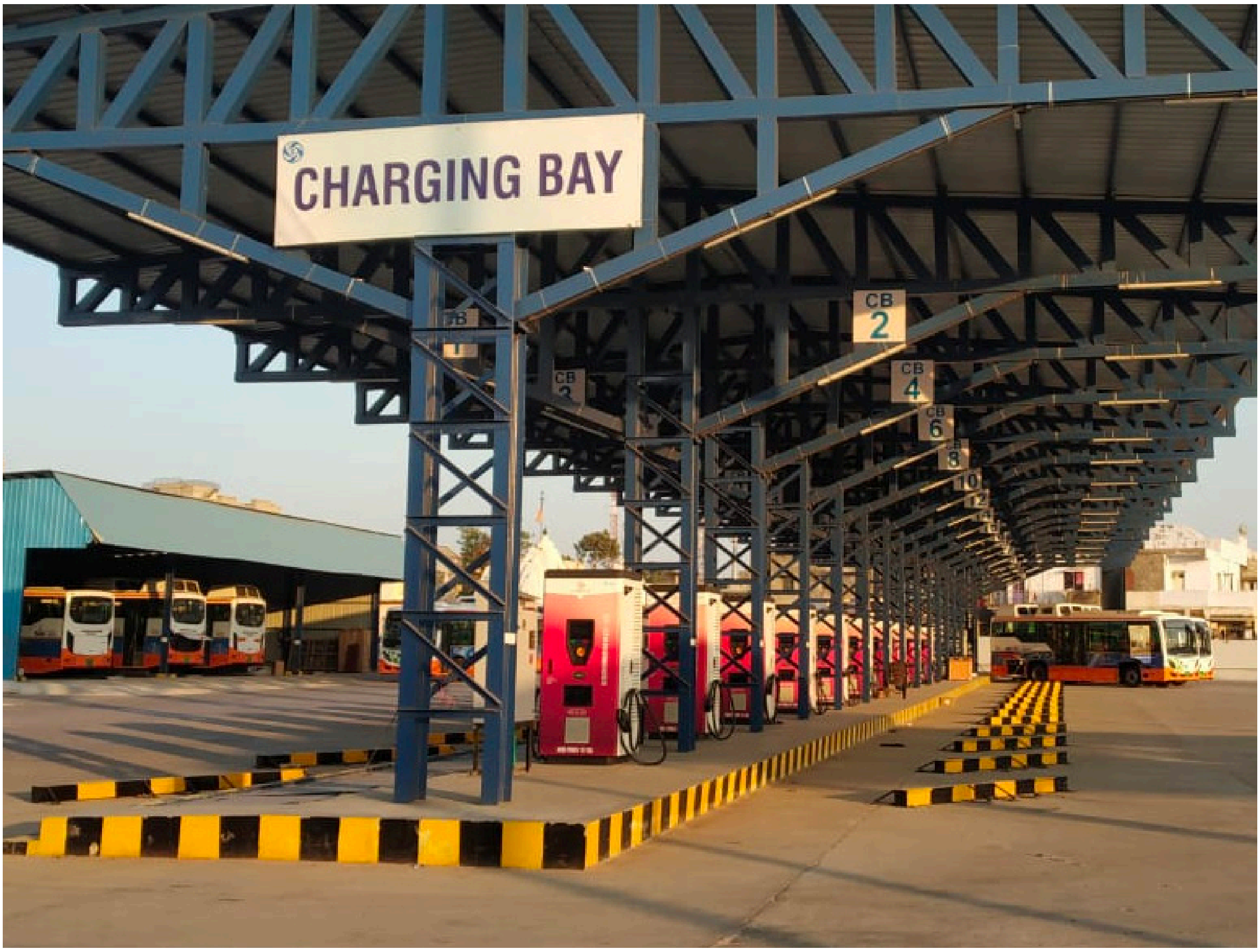

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LIST OF ABBREVIATIONS

GHG - Greenhouse Gas

TCO - Total Cost of Ownership

GCC - Gross Cost Contract

NSSO - National Sample Survey Office

EVs - Electric Vehicles

NEMMP - National Electric Mobility Mission Plan

DH - Department of Heavy Industry

FAME - Faster Adoption and Manufacturing of Hybrid and EV

BMTC - Bengaluru Metropolitan Transport Corporation

DMRC - Delhi Metro Road Corporation

VGF - Viability Gap Funding

ULBs - Urban Local Bodies

SRTUs - State Road Transport Undertakings

12m_AC_BB - 12m AC Electric Bus with 320 kWh Battery Pack

12m_AC_SB - 12m AC Electric Bus with 125 kWh Battery Pack

ICE - Internal Combustion Engine

DDD - Daily Drive Distance

RfP - Request for Proposal

EoI - Expression of Interest

ToD - Time of Day

NYC - New York City

UDDS - Urban Dynamometer Driving System

BNEF - Bloomberg New Energy Finance

AJL - Ahmedabad Janmarg Ltd.

OEM - Original Equipment Manufacturer

ToR - Terms of Reference

EXECUTIVE SUMMARY

In order to drive the national commitment to reduce greenhouse gas (GHG) emissions and improve air quality in urban areas, central and state governments have been providing lucrative fiscal incentives to promote shared mobility and clean transportation. Of the total vehicular population, buses constitute a minuscule share of 0.74%. Of this, state-owned buses constitute about 22% with a fleet utilization rate of 90%. India, typically, has between 0.5 to 1 bus per 1,000 population whereas countries like Brazil, Mexico, China have more than 2 buses per 1,000 population. To meet the demands of a rapidly increasing population, India needs around 300,000 new buses to be deployed over the next few years. This gives the country a worthwhile opportunity to transition from carbon-emitting diesel-fueled buses to cleaner, environment-friendly electric buses.

Although the deployment of e-bus fleets offers substantial benefits to India, the very idea has to be underpinned by a rather robust understanding of Total Cost of Ownership (TCO) analysis. This is especially important for a price-sensitive market like India. Through the TCO analysis, an attempt has been made to identify the key cost components and major barriers to e-bus procurement. Additionally, through a comparison with the conventional buses, a sensitivity analysis has been conducted to recognize the high and low impact variables, based on their impact on TCO per km of buses. The report also mentions the impact of central and state incentives in reducing the TCO of e-buses when compared to diesel buses. The sensitivity analysis on TCO suggests that the purchase cost, vehicle utilization, and vehicle holding period have the highest impact on the TCO per km of an e-bus, whereas the maintenance and fuel costs have relatively less impact.

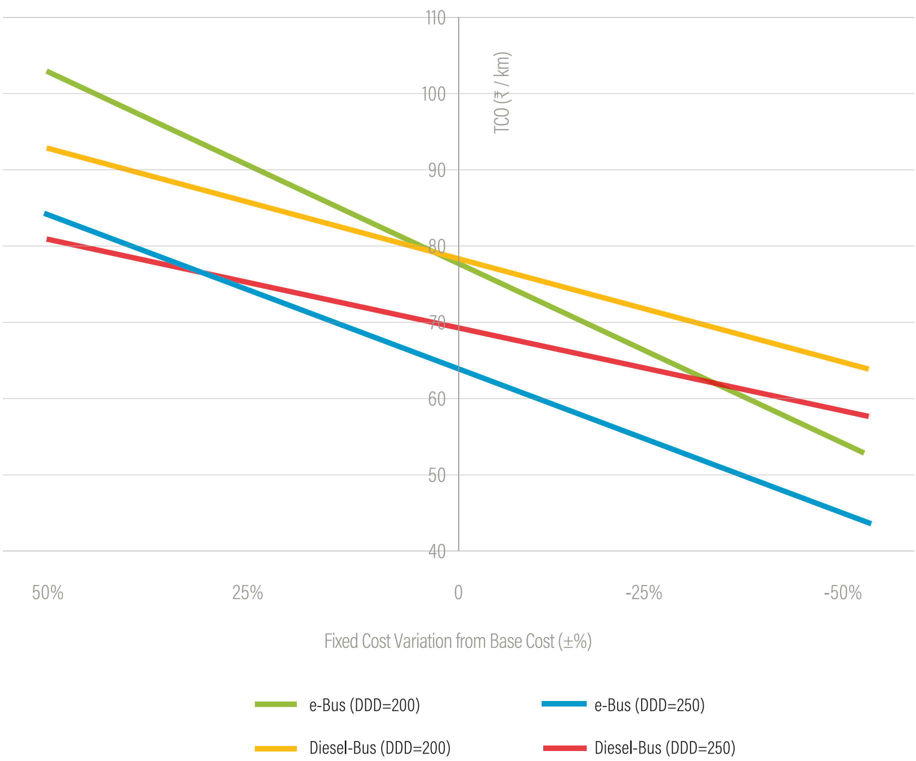
Owing to India's diverse topography, the e-bus configurations for each route needs to be context-specific. In the present scenario, 9 m length buses dominate the e-bus market, with a share of more than 80% of the total e-buses. The report also analyses the impact of the various factors on fuel consumption of e-buses and its impact on the TCO per km. With the increase in energy consumption from 0.8 kWh to 3.0 kWh, the TCO per km of e-buses increases by around 10%. Additionally, Annexure 1 provides an insight into the e-bus types, battery, and charging technologies, whereas Annexure 2 summarizes the factors which affect the performance of e-buses in terms of energy consumption and mileage.

This report identifies business models for procurement as unequivocally the most crucial factor in the successful transition to cleaner transport. Based on the TCO analysis, the report discusses business models in varying scenarios in an attempt to develop the most efficient one to reduce the capital acquisition costs. For example, the Gross Cost Contract (GCC) and battery leasing models can help in reducing the burden of high upfront acquisition costs posed by e-buses. The report proposes possible partnerships between the public and private sector to achieve these objectives. A detailed assessment of innovative business models will be handy for decision-makers, transport corporations, operators, financing partners, OEMs, and other allied stakeholders in understanding economic viability of e-buses. It will also be helpful in deciding appropriate terms to diversify risks and reduce the resource burden.

Overall, the TCO analysis conducted is aimed at providing a rigorous look into the possible areas of advancement and the associated pressure points in what is touted to be the future of Indian transportation. The sensitivity analysis in

the report is an attempt at considering the whole range of possible situations in the prices. The comparison of e–buses with the diesel-run buses puts forth a transparent analysis of the TCO per km for every impacting factor to reassert the claim that indeed, electric buses are the future, not just for economic feasibility and lowering carbon emissions but also for democratic use of public resources such as air, road space, and tax money.

Figure i | **Impact of variation in fixed cost and vehicle utilization on the break-even point**



1. E-BUS ADOPTION IN INDIA

1.1 Buses in India

In India, almost 75% of public transport trips are by bus.[1] The National Sample Survey Office (NSSO) survey on Key Indicators of Household Expenditure on Services and Durable Goods finds that bus/tram is the most preferred means of transport in both rural and urban areas. It also takes a chunk of a family's average income. As much as 66% of household expenses in rural areas, and 62% in urban areas, are due to public transportation. However, the number of registered public buses has been consistently on the decline. While personalized vehicles constitute 87%, buses constitute 0.74% of the total vehicle population.[2] Of the total number of buses, the share of public buses is 7%, which carry over 68 million passengers per day with a fleet utilization of 90%.[3] There is an urgent requirement to add at least 200,000 to 300,000 buses to the system by 2031.[4]

1.2 Electric Buses in India

Due to the high initial investment required for electric vehicles (EVs), fleet operators with high utilization of vehicles stand to benefit from adopting EVs while enjoying the benefits of lower maintenance costs resulting from economies of scale.

A shift towards clean energy for public transport brings multi-dimensional benefits. The induction of e-buses will add to the emission reduction commitments at the local level. The benefits will be much greater with the simultaneous greening of electricity generation in India. Electric buses, when compared to a conventional bus, have fewer moving parts. This results in lower and more predictable operating costs. The dependence on fossil fuels poses uncertainties due to price fluctuations, while the cost of electricity is fairly stable for e-buses. Due to the high initial investment required for electric vehicles (EVs), fleet operators with high utilization of vehicles stand to benefit from adopting EVs while enjoying the benefits of lower maintenance costs resulting from economies of scale.

The National Electric Mobility Mission Plan (NEMMP) 2020 of the government of India focuses on promoting the manufacturing and adoption of EVs in the country. As part of NEMMP, the Department of Heavy Industries (DHI) launched the Faster Adaptation and Manufacturing of (Hybrid &) EVs (FAME) initiative in April 2015. The first electric bus trial in the country was conducted by Bengaluru Metropolitan Transport Corporation (BMTC) using BYD e-buses for three months in 2014. This was followed by trials in multiple cities. Himachal Pradesh became the first state in India to operate a fleet of e-buses between Manali and Rohtang (51 km).

FAME I, with a total outlay of INR 8.95 billion, sanctioned subsidies for 390 e-buses in 11 cities. The subsidy covered around 60% of the total cost of an e-bus (INR 8.5 million to INR 10 million) to be disbursed to various state governments. Of the total allocated e-buses, around 220 are now operating in eight cities. Table 1 outlines the allocation of buses under FAME I and bid rates put forth by OEMs. Drastically varying OEM bid rates forced DHI to conduct a benchmarking study of e-buses to stabilize the rates.

[1] https://shaktifoundation.in/report/fiscal-policies-taxation-incentives-improved-public-bus-systems-india/

[2] Annual Report 2018 -19, Ministry of Road Transport and Highways

[3] Review of the performance of State Road Transport Undertakings for April, 2015 – March, 2016

[4] WRI Analysis

[5] Scheme for Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India - FAME Ind

Table 1 | **Electric Bus Procurement under FAME I Scheme**

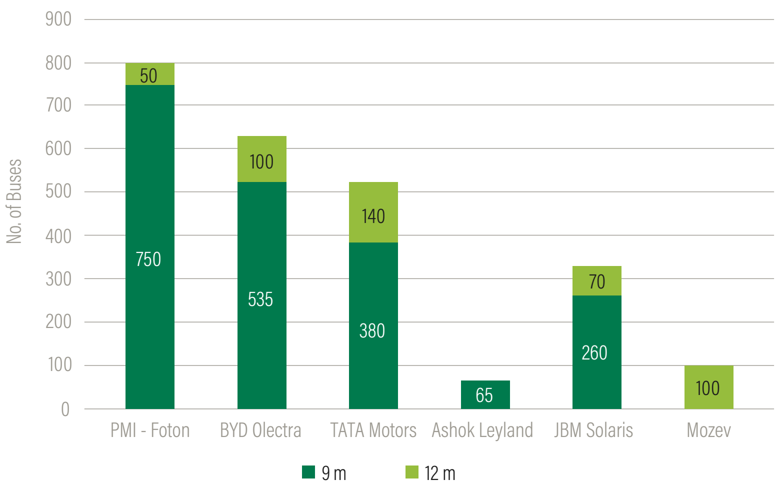
Type of Purchase	City	OEM	Type of Bus	Bid Rate	Note
GCC in Rs	Bangalore	Goldstone	9m AC	29.28	Cost of electricity borne by the authority
	Hyderabad			36.00	
	Ahmedabad	TATA		48.00	
	Mumbai	Goldstone		57.00	
	Jaipur	TATA		70.00	
	Mumbai	Goldstone	9m Non-AC	51.00	
	Bengaluru		12m AC	37.35	Cost of electricity borne by the authority
	Hyderabad			40.30	
Outright Purchase in INR million	Indore	TATA	9m AC	8.5	
	Lucknow			8.5	
	Kolkata			7.7	Price of chargers separate
	Jammu			9.9	
	Guwahati			9.9	
	Kolkata		12m AC	8.8	

FAME II was launched in March 2019 with an outlay of Rs.10,000 Crores. In the second phase of the scheme, 5,095 buses were sanctioned for intracity operations, 400 for intercity, and another 100 for Delhi Metro Rail Corporation's (DMRC) last-mile connectivity.[6] A subsidy of up to INR 20,000/kWh, with an upper limit of INR 5 million, is provided to transport corporations under the scheme. While FAME I did not specify procuring models, FAME II supports only GCC contracts.

The variability in bid rates indicates a clear need to benchmark the prices of bids. The financial and technical terms are varied to suit the needs of the agency and city of operation. A TCO analysis will help agencies frame these conditions depending on their requirements.

Of the 5,595 e-buses allocated under FAME II, 2,450 had been procured as of November 2020. Of this, 2,270 are for intracity urban services, while 180 are for intercity services. An analysis of bids is illustrated in Figure 1. Average bid prices have seen a marked increase from FAME I bids. While the average bid rate for a 9m e-bus is INR 63.3/km, it is INR 69/km for a 12m e-bus.[7] The variability in bid rates indicates a clear need to benchmark the prices of bids. The financial and technical terms are varied to suit the needs of the agency and city of operation. A TCO analysis will help agencies frame these conditions depending on their requirements.

Figure 1 | **Analysis of FAME II Bids**



Source: UITP

[6] Notification of 8th March 2019 - Scheme for Faster Adoption and Manufacturing of Electric Vehicles in India Phase II (FAME India Phase II

[7] https://india.uitp.org/uitp-india-analysis-fame-ii-tenders-across-country

Apart from central government schemes, states have pitched in to provide additional funding to enable State Road Transport Undertaking (SRTUs') transition to e-buses. To support urban bus services in Gujarat, the state government provides viability gap funding (VGF) to transit agencies and urban local bodies (ULBs). The overall VGF is 50% (maximum of INR 25/km) of the e-bus purchase price, of which INR 12.50/km is borne by the state, and the rest is borne by the ULB.[8] A detailed TCO analysis will help identify the quantum and mode of VGF required by bus agencies to operate e-buses in a financially viable manner.

1.3 Barriers to electrification of buses

Despite the promise of manifold advantages like emission-free, noise-free operations, offered by e-buses, the adoption has been varied and uneven in scale. The major barriers in accelerating e-bus adoption include the high upfront cost, issues related to planning the charging infrastructure, and anxiety related to the new technology. Common obstacles identified for the large-scale adoption of e-buses include lack of operational knowledge about electric bus systems; unfamiliar procurement and financing schemes; and institutional deficiencies in terms of authority, funding, and land for the adaptations needed.

The WRI report "Barriers to Adopting Electric Buses" identify technological, financial and institutional barriers. Lack of data and operational limitations form the key technological barriers which affect decision-making. Rigid procurement structures of agencies and lack of long-term, sustainable financing options for public transport augmentation are the key financial barriers. The crucial institutional barriers include inadequate political will, pragmatic public policy, institutional authority, funding, and land for infrastructure augmentation.

1.4 Understanding Total Cost of Ownership (TCO) for Electric Buses

> TCO analysis provides an understanding of the various components that affect the overall economic performance of e-buses over their lifetime. TCO analysis also considers cost variation due to factors such as inflation, fluctuating battery cost, residual value or salvage value of the bus, and infrastructure after the period of service.

The Total Cost of Ownership (TCO) of any mode of transport is a function of its capital and operational cost over the period of service. The complete methodology and formula is provided in Annexure 3. TCO analysis provides an understanding of the various components that affect the overall economic performance of e-buses over their lifetime. TCO analysis also considers cost variation due to factors such as inflation, fluctuating battery cost, residual value or salvage value of the bus, and infrastructure after the period of service.[9]

The advantages of undertaking a TCO analysis for transport agencies are manifold:

- Provides city bus agencies with insights on e-bus performance
- Helps take calculated decisions in selecting the right:
  - Bus technology
  - Charging infrastructure
  - Daily drive distance
  - Staff deployment
- Helps understand the pros and cons of different bus procurement models
- Helps transport corporations negotiate electricity price points from discoms
- Helps draw contracts according to the strengths of SRTUs and OEMs.
- Enables the formulation of state-level policies for VGF for e-buses
- Helps draw a roadmap for electrification of SRTUs

[8] https://wri-india.org/sites/default/files/4.D1_S1_Gujarat%20VGF%20Scheme_Vijay%20Anadkat.pdf

[9] https://wrirosscities.org/sites/default/files/barriers-to-adopting-electric-buses.pdf

Using a robust methodology for estimating the TCO, this report analyzes the various factors pertaining to procurement and deployment of e-buses. The report also compares e-buses with conventional fuel buses, using a sensitivity analysis that will help decision-makers in choosing the appropriate procurement model for the electrification of the bus fleet.

This report compares the TCO of 12m and 9m buses, and the next chapter provides details of the comparison. The various input factors considered in the analysis are discussed in Annexure 3. The primary scenario considered for TCO analysis is of outright purchase where the buses are purchased without the financing component inclusive of charging infrastructure. The operating costs include staff (conductor and driver), fuel and maintenance costs for diesel buses. For electric buses, the maintenance costs also include battery replacement cost.

State Road Transport Undertakings have been early adopters of e-buses in India. The incentives provided by the central and state governments have made their transition plans easier. Considerable variation in the technical specifications, as well as in bid rates for e-buses purchased under both procurement models, was noticed, which led to benchmarking of e-bus rates by the Department of Heavy Industry. Currently, 9-meter e-buses (more than 80% share) lead the e-bus market in India.

2. COMPARISON OF TCO OF E-BUSES AND DIESEL BUSES

In this chapter, we compare the TCO per kilometer of e-buses with their Internal Combustion Engine (ICE) counterparts. We look at 12-meter and 9-meter buses separately. Of 2,840 e-buses that were tendered out by various SRTUs under the FAME I and FAME II schemes, 2,240 were nine meters in length.

2.1 TCO Analysis of 12-meter Bus

In this section, we compare low- and high-cost models of diesel buses with e-bus variants having large (320 kWh) and small (125 kWh) battery configurations. For e-buses with a 320 kWh battery pack (12m_AC_BB), we have included the cost of one slow charger (50 kW) per e-bus for overnight charging. For e-buses with a 125 kWh battery (12m_AC_SB), the cost of a fast charger (100 kW) shared by three e-buses is included. While a 12-meter e-bus with 320 kWh battery can cover up to 300 km per charge, an e-bus with a 125 kWh battery can cover up to 150 km per charge.[10]

Figure 2 shows that the TCO per km of an e-bus with a 125 kWh battery pack (INR 53.77/km) is less than that of both high- and low-cost diesel variants. The TCO per km of an e-bus with 320 kWh battery pack (INR 77.75/km) is comparable to that of a high-cost diesel bus variant. Since SRTUs rely on external agencies for financing the upfront cost of buses, we calculated the effect of the same on e-buses. While applying an 80% loan component at an interest rate of 6.5% for seven years, the TCO of e-buses goes up to INR 85.95/km (an increase of around 10%). For a high-cost diesel bus, the cost goes up to INR 82.79/km (approximately 5% higher).

[10] DHI e-bus Benchmark - https://dhi.nic.in/writereaddata/UploadFile/Benchmark%20price%20for%20Electric%20Buses636662995963975616.pdf

Figure 2 | **Comparison of TCO per Km of 12-meter Variants of e-Buses and Diesel Buses**

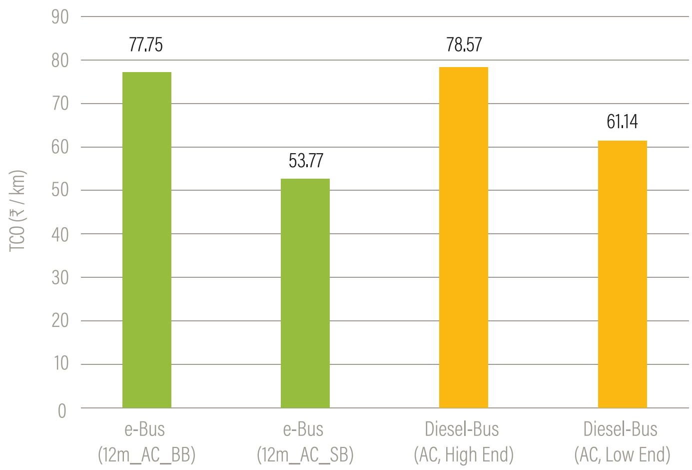
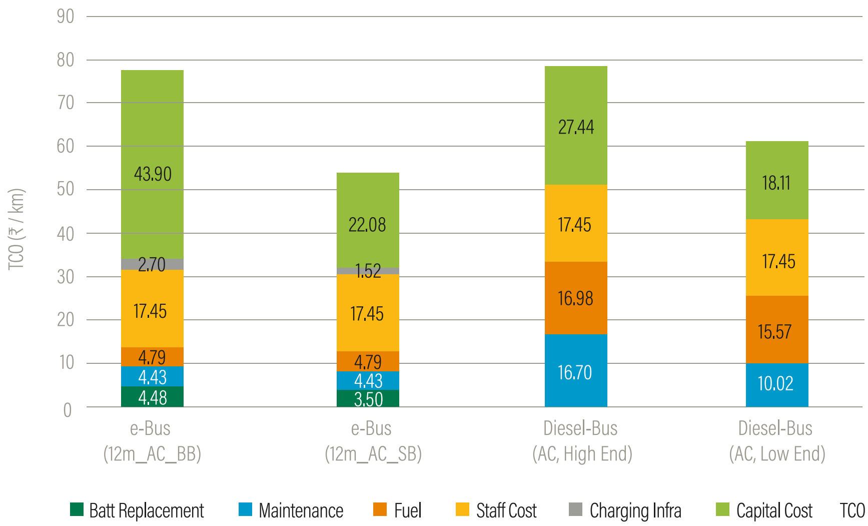


Figure 3 shows the share of the major cost components in the TCO per km for all categories of buses. For e-buses, the capital cost, which includes purchase cost and charging infrastructure costs, accounts for a significant share in the TCO per km, whereas the share of fuel and maintenance cost is much less. In the case of diesel buses, maintenance and fuel costs contribute significantly to the TCO per km. Notably, staff cost accounts for more than 22% of the total TCO per km.

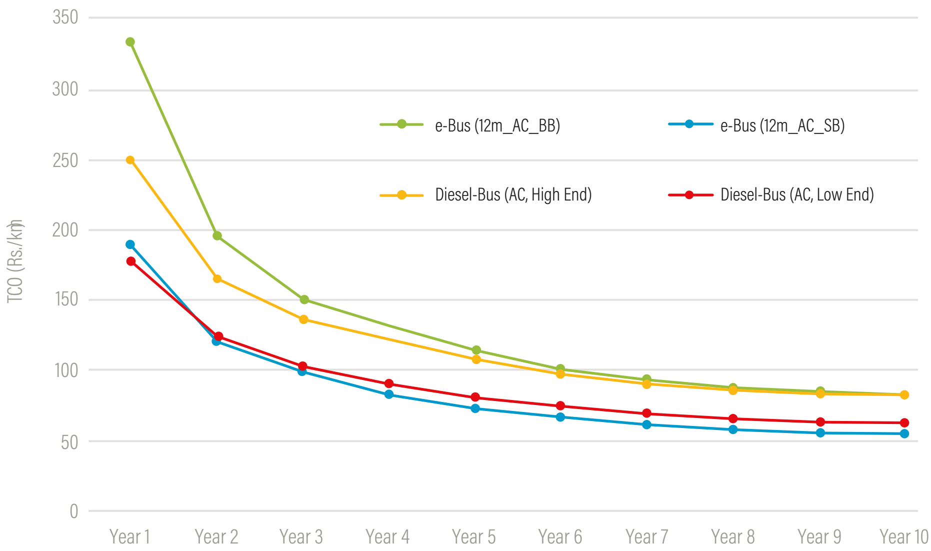
Figure 3 | **Comparison of cost components of TCO of 12-meter AC e-Buses and Diesel AC Buses**



A decrease in the purchase cost due to dropping battery prices will further reduce the TCO per km of e-buses.

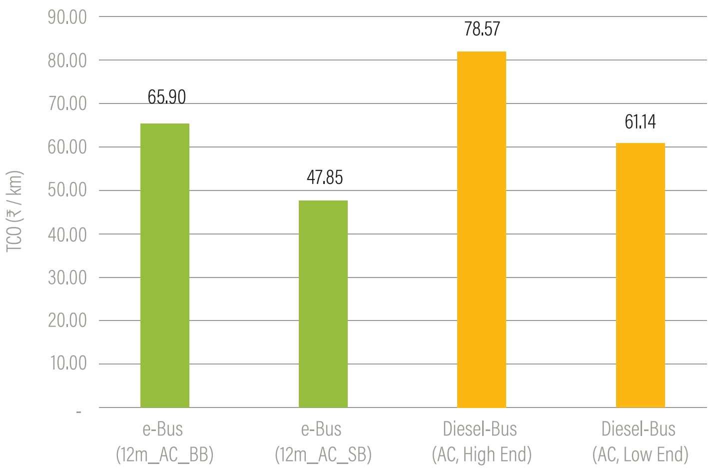
Figure 4 shows the trend in the year-wise TCO per km of e-buses in comparison with diesel variants over a service period of 10 years. For e-buses with a 320 kWh battery pack, the TCO per km is significantly higher for the first six years, compared to other variants, after which the gap reverses. The TCO per km decreases considerably as the vehicle's holding period increases. For e-buses with 125 kWh battery, the TCO per km becomes lower than for all other variants after the second year of operation. A decrease in the purchase cost due to dropping battery prices will further reduce the TCO per km of e-buses.

Figure 4 | **Impact of vehicle holding period on the TCO per km (12m Buses)**



A look at the impact of the FAME II subsidy on the TCO of buses (Figure 5) shows that for e-buses, a subsidy of INR 20, 000/kWh, not exceeding INR 5 million, brings a significant change to the TCO per km. The FAME discount brings down the TCO of an e-bus with 320 kWh battery pack to less than that of a high-end diesel bus.

Figure 5 | **TCO per Km of 12m buses with FAME subsidy**



2.2 TCO Analysis of 9m Bus

Many cities in India are currently procuring shorter Midi (9 m buses) buses. This move is aimed to address congestion and narrow roads in cities. The growing demand is an indication of what state transport corporations across the country prefer. An analysis of tenders by various cities under FAME II reveals that 81% of buses procured were nine meters.[11] An analysis of the Indian e-bus market shows that the drive range for 'medium-duty' models is between 50 km and 250 km.[12] Here, we are analyzing two types of 9-meter e-buses: one with a 180 kWh battery (9m_AC_BB) and the other with a 102 kWh (9m_AC_SB) battery. For diesel buses, we are taking into account both low-cost and high-cost models. For the TCO of an e-bus with a 180 kWh battery pack, we have taken the cost of one slow charger (50 kW charger rating) per bus. For the TCO of an e-bus with a 102 kWh battery pack,

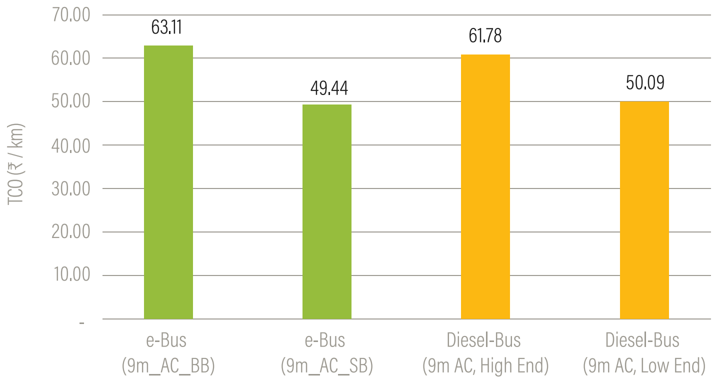
[11] https://india.uitp.org/uitp-india-analysis-fame-ii-tenders-across-country

[12] Dept of Transportation, Delhi NCT, Engagement of 1000 Low Floor Pure Electric Buses in Delhi under Gross Cost Model of Contracting, 2019

we have added the cost of a fast charger (100kW charger rating) shared amongst three buses. Inputs similar to those included in 12 meter buses are considered in the analysis for 9 meter buses (Refer Annexure 3).

Figure 6 compares the TCO per km of 9-meter e-bus variants with that of their ICE counterparts. For the 9m_AC_BB e-bus, the TCO per km is slightly higher than the high-cost diesel bus, whereas the TCO per km of the e-bus with the smaller battery pack is the lowest among all options.

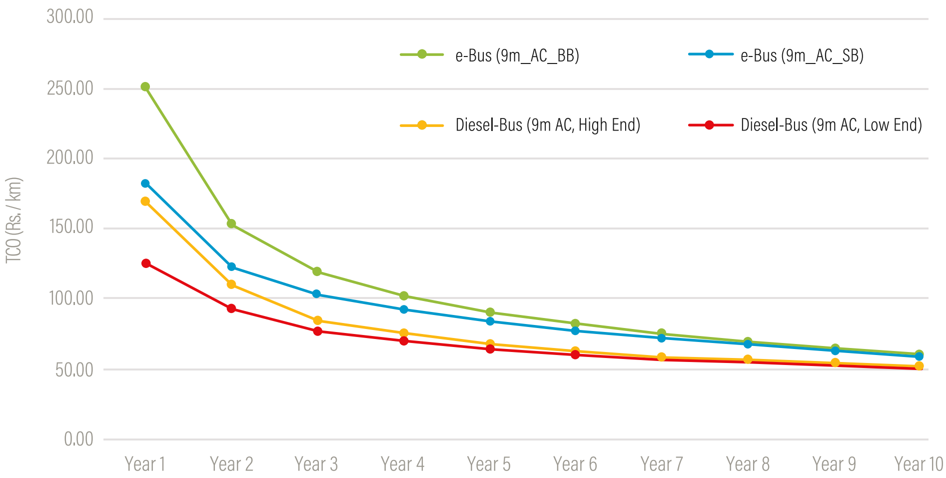
Figure 6 | **Comparison of TCO 9m AC e-buses (180 kWh and 102 kWh battery) with 9m Diesel AC Buses**



While incorporating the loan component to the TCO analysis, where the rate of interest is 10% and equity of 20% repaid in 5 years, the TCO per km increases by 10% (INR 69.5) and 8% (INR 53.34) for 9m_AC_BB e-bus and 9m_AC_SB e-bus, respectively. The increase in TCO per km for 9m_AC_High End diesel bus and 9m_AC_High End diesel bus is 5% and 4%, respectively.

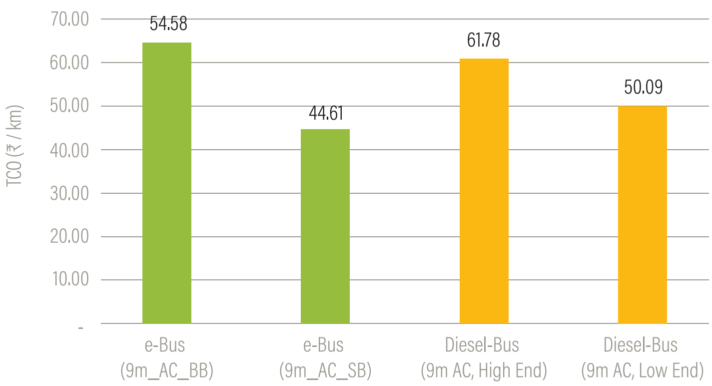
Figure 7 shows the year-wise trend of the TCO per km of 9-meter e-buses alongside their diesel counterparts. Like 12-meter e-buses with bigger battery packs, the TCO per km of the 9m_AC_BB e-buses is significantly higher in the initial years compared to other variants. The TCO per km decreases considerably as the holding period increases. The TCO of a 12-meter e-bus equals that of a high-cost diesel bus in its eighth year of service. The TCO per km of a 9m_AC_SB e-bus becomes the lowest among all options after the fifth year of the vehicle holding period or ownership.

Figure 7 | **Impact of vehicle holding period on the TCO per km (9m Buses)**



With the FAME II subsidy, the TCO per km of e-bus variants becomes comparable or less than diesel variants (see Figure 8). Note that the subsidy is linked to the battery capacity, not the vehicle type. The FAME subsidy manages to bring down the TCO of an e-bus with a big (around180 kWh) battery pack to less than that of a high-end diesel bus

Figure 8 | **TCO of 9m buses with FAME subsidy**



In contrast to diesel buses, the operational cost of e-buses decreases with higher vehicle utilization. Therefore, through a reduction in upfront costs by way of incentives, market forces and longer holding periods, state-owned corporations can achieve financial sustainability much quicker. Financing costs are also a crucial barrier for TCO of e-buses.

3. SENSITIVITY ANALYSIS

Insights from the sensitivity analysis will help institutions gauge the impact of these factors with greater precision, and aid in their decision-making process.

This chapter looks at the sensitivity analysis of TCO over various cost points of a bus. Fluctuations in fixed costs such as capital cost, and variable costs, which include vehicle utilization, maintenance costs and fuel costs, have been taken into account. Insights from the sensitivity analysis will help institutions gauge the impact of these factors with greater precision, and aid in their decision-making process.[13] A sensitivity analysis can also be used to frame terms in. Request for proposals (RfP) and tenders, which will minimize risks for all stakeholders. The percentage variation of various cost components taken for the sensitivity analysis is provided in Table 2 below.

Table 2 | **Framework for Sensitivity Analysis**

Components	Sensitivity Analysis			
Capital Cost	+50%	+25%	-25%	-50%
Vehicle Utilization				
Fuel Cost				
Maintenance Cost				
Staff Cost	+25%	+50%	+75%	+100%
Financing Cost	Scenarios detailed in Section 4.1.3			

[13] Nurhadi, L., Borén, S., & Ny, H. (2014). A sensitivity analysis of total cost of ownership for electric public bus transport systems in Swedish medium sized cities. Presented at the Transportation Research Procedia, Sevilla, Spain: Elsevier B.V.

3.1 Sensitivity Analysis for 12m Buses

In this section, we have done a sensitivity analysis on key input variables for 12-meter buses. We have varied the variables by ±25%, ±50% and have compared it with its base value. Insights from this section can help in identifying high- and low-impact input variables used in TCO analysis.

3.1.1 Sensitivity Analysis for Capital Cost

Figure 9 shows the impact of ±50% variation in the purchase cost and its impact on TCO per km of e-buses, in comparison with their ICE counterparts. With 25% reduction in purchase costs, the TCO per km of an e-bus with a big battery pack becomes less than that of a high-cost diesel bus. Despite a 50% increase in the purchase cost of an e-bus with a small battery pack, the TCO per km is lowest amongst all other options considered in the analysis.

Figure 9 | **Impact of Capital Cost on the TCO of Diesel and Electric Buses**

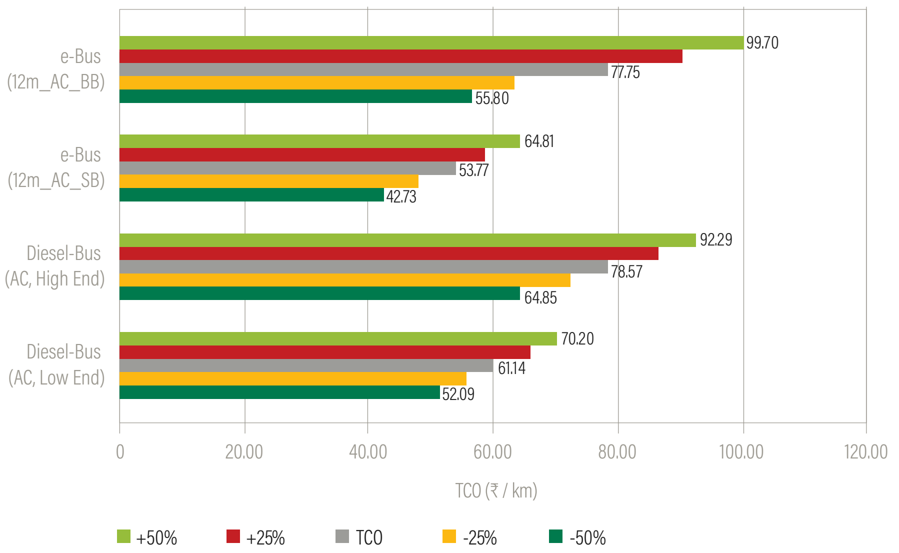


Table 3 | **Sensitivity analysis of Capital Cost on Electric and Diesel Buses over Base TCO**

	+50%	+25%	-25%	-50%
e-Bus (12m_AC_BB)	28%	14%	-14%	-28%
e-Bus (12m_AC_SB)	21%	10%	-10%	-21%
Diesel-Bus (AC, High End)	17%	9%	-9%	-17%
Diesel-Bus (AC, Low End)	15%	7%	-7%	-15%

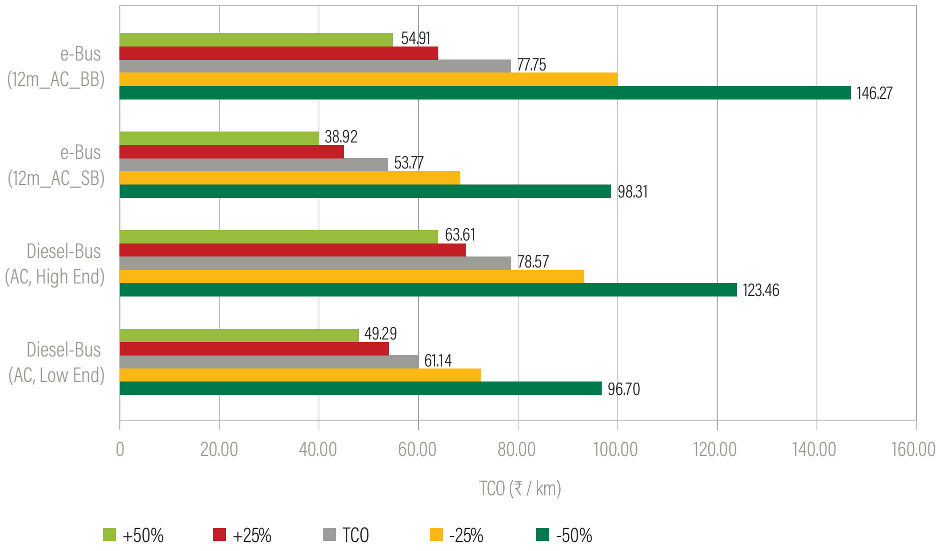
As operational costs of e-buses are relatively lower than ICE buses, the reduction in purchase cost has a more significant impact on the TCO per km of e-buses when compared to its effect on diesel buses.

In Table 3, we have listed percentage changes in TCO per km with a ±50% variation in the purchase cost of the buses. As operational costs of e-buses are relatively lower than ICE buses, the reduction in purchase cost has a more significant impact on the TCO per km of e-buses when compared to its effect on diesel buses. With ±50% variation in the purchase cost, the TCO per km of e-buses ranges between ±21% and 28%. For ICE buses, the variation is around ±15% to 17%.

3.1.2 Sensitivity Analysis for Vehicle Utilization

Figure 10 shows the impact of ±50% variation in the vehicle utilization on the TCO per km of e-buses and ICE buses. With a 50% increase in average daily drive distance from a base value of 200 km/day, the TCO per km of an e-bus with a bigger battery pack becomes comparable to that of a high-cost diesel bus. In case of an e-bus with a smaller battery pack, TCO per km is lowest even at base value. An increase in vehicle utilization further increases the financial viability compared to other bus options.

Figure 10 | **Impact of Vehicle Utilization across TCO of Diesel and Electric Bus Configurations**



In Table 4, we have listed the percentage change in TCO per km of e-buses and ICE buses with ±50% variation in the vehicle utilization. The graph shows a drastic variation in TCO per km of e-buses with changes in vehicle utilization as compared to the variations in the TCO per km of diesel buses. The financial viability of e-buses increases with vehicle utilization due to its lower operational costs.

Table 4 | **Sensitivity Analysis of Vehicle Utilization on Electric and Diesel Buses over Base TCO**

	+50%	+25%	-25%	-50%
e-Bus (12m_AC_BB)	-29%	-18%	29%	88%
e-Bus (12m_AC_SB)	-28%	-17%	28%	83%
Diesel-Bus (AC, High End)	-19%	-11%	19%	57%
Diesel-Bus (AC, Low End)	-19%	-12%	19%	58%

3.1.3 Sensitivity Analysis for Financing Cost

In order to understand the impact of financing cost on the TCO per km, we developed five scenarios in addition to the base scenario (Section 3.1). The scenarios consider variations in financial cost parameters such as equity, rate of interest and repayment period. Table 5 explains the scenarios used for the analysis.

Table 5 | **Scenarios for Sensitivity Analysis for Financing Cost on TCO per Km**

	Rate of Interest	Repayment Period	Equity
Base Scenario (Ref. Sec 2.1)	0	0	0
Scenario I	6.5 %	5	20%
Scenario II	10 %	5	20%
Scenario III	10 %	5	30%
Scenario IV	10 %	7	20%
Scenario V	12 %	5	20%

Figure 11 | **Impact of Financing Cost across TCO of Electric and Diesel Bus Configurations**

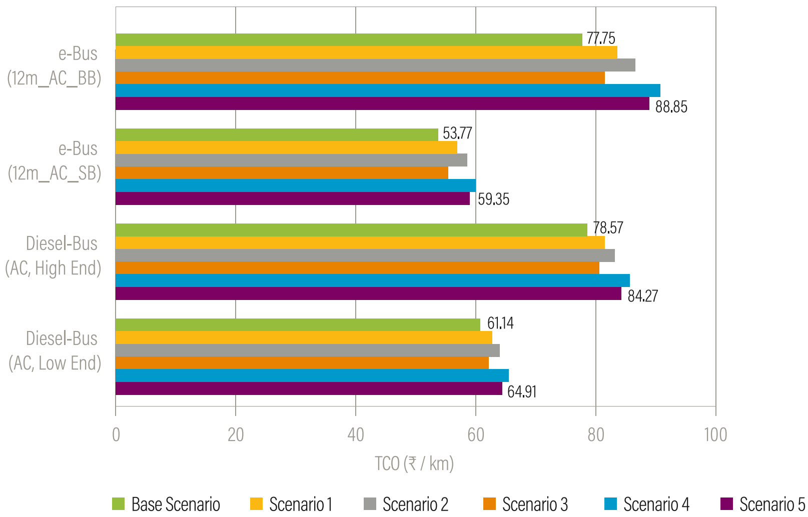


Figure 11 illustrates the impact of various scenarios of financing on the TCO per km of electric and diesel buses. Scenario III, with equity of 30% of purchase cost of bus at at 10% rate of interest over a repayment of period of five years, results in the lowest TCO per km compared to other scenarios except base scenario. As the share of equity decreases and rate of interest increases, the TCO per km also increases accordingly.

Table 6 shows that the impact of financing costs is high on e-buses, due to the high cost of purchase. Scenarios II and III offer better TCO per km than Scenario IV, with a 10% rate of interest on 75% loan component over seven years of repayment. Financing cost is a crucial element in determining TCO per km, especially in the case of e-buses. Operating agencies need to find ways to harness better financing options to create a viable environment for e-buses.

Table 6 | **Sensitivity of Financial Cost on Electric and Diesel Buses over Base TCO**

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
e-Bus (12m_AC_BB)	7%	12%	5%	17%	14%
e-Bus (12m_AC_SB)	5%	9%	3%	12%	10%
Diesel-Bus (AC, High End)	4%	6%	2%	9%	7%
Diesel-Bus (AC, Low End)	3%	5%	2%	7%	6%

3.1.4 Sensitivity Analysis for Fuel Cost

Figure 12 shows the impact of ±50% variation in the fuel cost on the TCO per km of e-buses and ICE buses. With the ±50% variation in the fuel cost, the change in TCO per km of e-buses is relatively less compared to their ICE counterparts.

In Table 7, we have listed the percentage change in TCO per km for e-buses and diesel buses with ±50% variation in the fuel cost. The analysis indicates a 3-4% reduction in TCO with a 50% decrease in electricity costs in e-buses as opposed to an 11-13% decrease in TCO of diesel buses over a 50% decrease in diesel costs. Fuel cost variation for e-buses can be attributed to variation in electricity tariff, fuel efficiency due to driving behavior, load, congestion, road conditions, etc.

Figure 12 | **Impact of Fuel Cost across TCO of Electric and Diesel Bus Configurations**

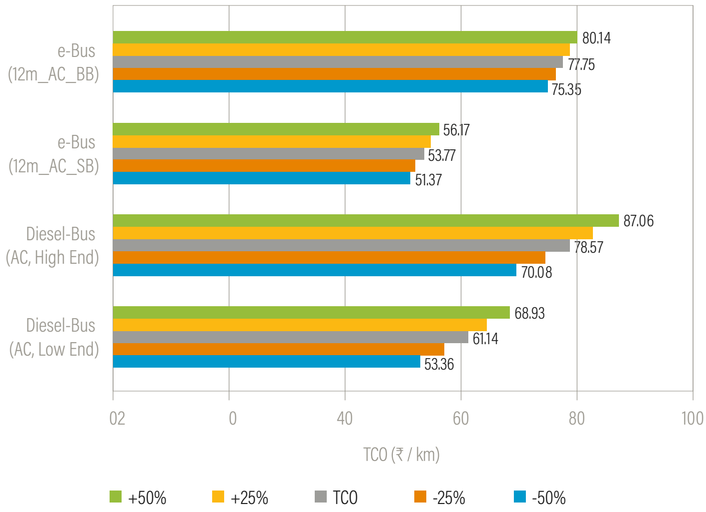


Table 7 | **Sensitivity of Fuel Cost on electric diesel bus over base TCO**

	+50%	+25%	-25%	-50%
e-Bus (12m_AC_BB)	3%	2%	-2%	-3%
e-Bus (12m_AC_SB)	4%	2%	-2%	-4%
Diesel-Bus (AC, High End)	11%	5%	-5%	-11%
Diesel-Bus (AC, Low End)	13%	6%	-6%	-13%

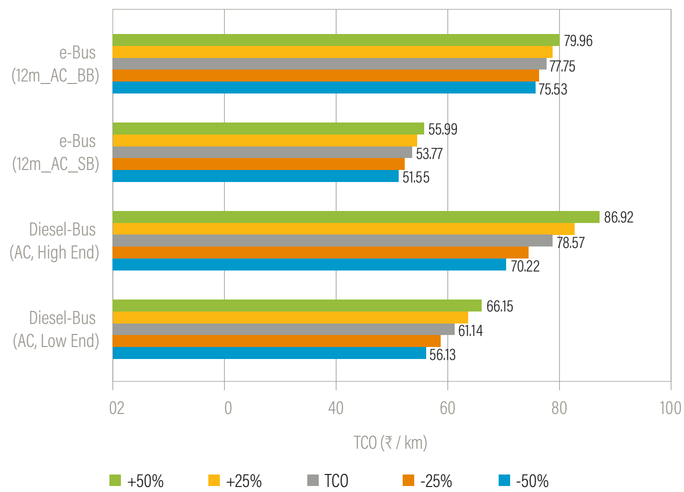
The sensitivity analysis over fuel costs suggests that changes in electricity costs have minimal impact on the TCO of e-buses as compared to the fuel cost of diesel buses. When coupled with the rising costs of fossil fuels, the TCO for diesel buses will increase in the coming years. Several states have proposed a Time of Day (ToD) tariff for electricity rates in their EV policy. ToD electricity rates provide flexibility for the operator or electricity provider to get electricity at lower-than-normal rates for charging e-buses or trading of electricity to the grid, which will result in a reduced TCO for e-buses.

The sensitivity analysis over fuel costs suggests that changes in electricity costs have minimal impact on the TCO of e-buses as compared to the fuel cost of diesel buses.

3.1.5 Sensitivity Analysis for Maintenance Cost

Figure 13 shows the impact of ±50% variation in the maintenance cost on the TCO per km of e-buses and ICE buses. As the maintenance cost of e-buses is relatively lower than ICE buses, the variation in the maintenance cost have a relatively lower impact on the TCO per km of e-buses compared to ICE buses.

Figure 13 | **Impact of Maintenance Cost across TCO of Electric and Diesel Bus Configurations**



In Table 8, we have listed the percentage change in TCO per km of e-buses and diesel buses with variation in the maintenance cost. With ±50% variation in the maintenance cost, the TCO per km of e-buses varies by 3-4%, whereas the TCO per km of diesel buses changes by 8-11%. The low maintenance cost of e-buses is mainly due to the smaller number of moving parts compared to the diesel buses.

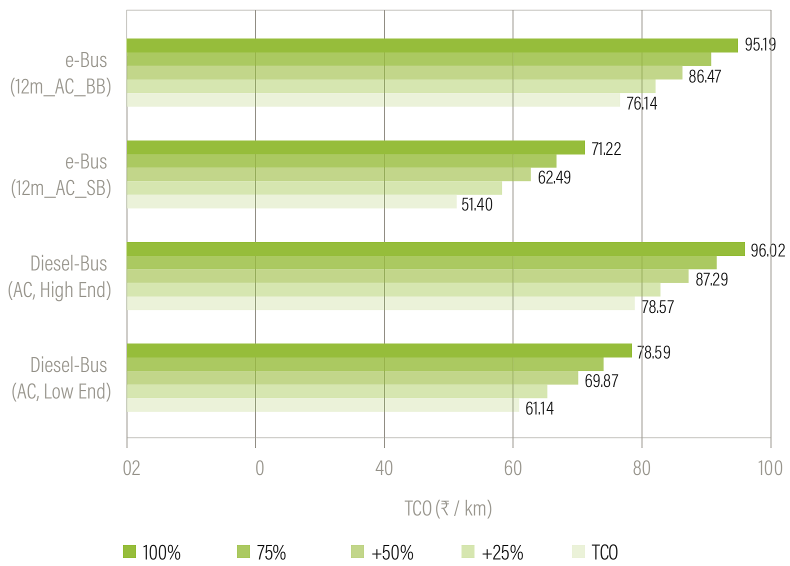
Table 8 | **Sensitivity Analysis of Maintenance Cost on TCO of Electric and Diesel Buses over Base TCO**

	+50%	+25%	-25%	-50%
e-Bus (12m_AC_BB)	3%	1%	-1%	-3%
e-Bus (12m_AC_SB)	4%	2%	-2%	-4%
Diesel-Bus (AC, High End)	11%	5%	-5%	-11%
Diesel-Bus (AC, Low End)	8%	4%	-4%	-8%

3.1.6 Sensitivity Analysis for Staff Cost

A study by Janaagraha, a non-profit organization based in Bengaluru, observed that staff costs per kilometer have risen by an average of 16% between 2013 and 2017.[14] BMTC's financial performance reports an average year-on-year rise of 10% for staff costs between the financial years 2012-13 and 2018-19. Compounding the increase in staff cost for the life of the bus, that cost would increase by 2.59 times the initial staff cost per km by the end of the life of the bus. In Figure 14, we have analyzed the impact of a 25% to 100% increase in the staff cost on the TCO per km of e-buses and diesel buses. Our analysis suggests that the TCO per km changes in the range of 25% to 39% for e-buses and in the range of 22% to 29% for diesel buses when staff cost doubles.

Figure 14 | **Staff Cost Variation on Base TCO over the Life of the Bus**



3.2 Sensitivity Analysis for 9m Buses

In this section, we have performed a sensitivity analysis on the high-impact variables for 9-meter buses, using the same variables identified for 12-meter buses. We have varied the purchase cost and vehicle utilization by ±25%, ±50% and have compared it with the base values discussed in Section 3.2.

[14] Financial brief on BMTC, Janaagraha, 2018

3.2.1 Sensitivity Analysis for Capital Cost

Figure 15 shows the impact of ±50% variation in the purchase cost on the TCO per km of 9-meter e-buses and ICE buses. With decreasing purchase cost, the financial viability of e-buses further increases compared to diesel buses.

Figure 15 | **Impact of Capital Cost across TCO of Diesel and Electric bus configurations**

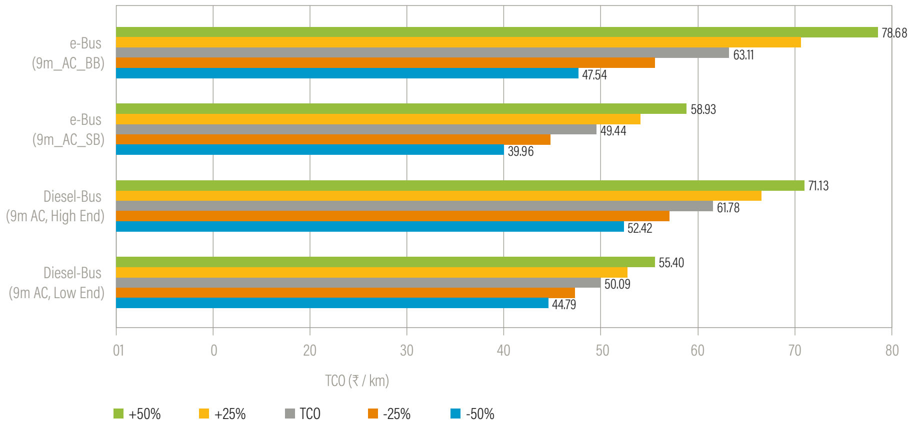


Table 9 | **Sensitivity analysis of Capital Cost on Electric and Diesel Buses over Base TCO**

	+50%	+25%	-25%	-50%
e-Bus (9m_AC_BB)	25%	12%	-12%	-25%
e-Bus (9m_AC_SB)	19%	10%	-10%	-19%
Diesel-Bus (9m AC, High End)	15%	8%	-8%	-15%
Diesel-Bus (9m AC, Low End)	11%	5%	-5%	-11%

In Table 9, we have listed the percentage change in TCO per km of e-buses and diesel buses with a variation in purchase costs. With ±50% variation in the capital cost, the TCO per km of e-buses varies by 19%-25%, whereas the TCO per km of diesel buses changes by 11-15%. The upfront fixed cost for e-buses can be reduced by economies of scale via market stabilization, choice of battery technology, optimum battery capacity and efficient planning for charging technology.

3.2.2 Sensitivity Analysis for Vehicle Utilization

Figure 16 shows the impact of ±50% variation in the vehicle utilization from the base value of 200 km/day on the TCO per km of 9-meter e-buses and ICE buses. With increasing vehicle utilization, the economic viability of the e-buses further increases compared to diesel buses.

In Table 10, we have listed the percentage change in TCO per km of e-buses and ICE buses with ±50% variation in the vehicle utilization. With greater vehicle utilization, the economic viability of the e-buses increases by up to 28% due to its lower operational cost, compared to ICE buses. The 9-meter buses are best suited for shorter trips and for intracity travel. It makes sense to rationalize routes while deploying 9-meter e-buses to maximize the daily drive distance to 250-300 km. Note that the selection of appropriate battery and charging technology is crucial for better operational flexibility and economic viability of e-buses.

Figure 16 | **Impact of Vehicle Utilization across TCO of Diesel and Electric Bus Configurations**

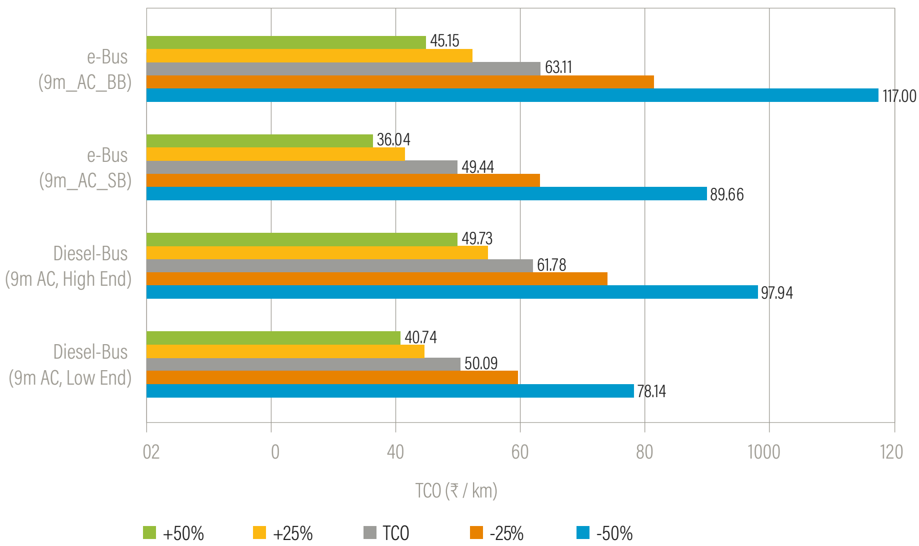


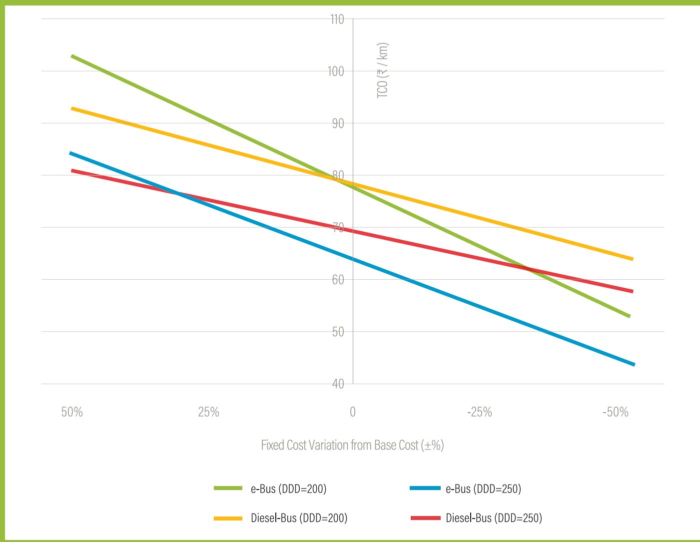
Table 10 | **Sensitivity Analysis of Vehicle Utilization on Electric and Diesel Buses over Base TCO**

	+50%	+25%	-25%	-50%
e-Bus (12m_AC_BB)	-28%	-17%	28%	85%
e-Bus (12m_AC_SB)	-27%	-16%	27%	81%
Diesel-Bus (AC, High End)	-20%	-12%	20%	59%
Diesel-Bus (AC, Low End)	-19%	-11%	19%	56%

In Table 10, we have listed the percentage change in TCO per km of e-buses and ICE buses with ±50% variation in the vehicle utilization. With greater vehicle utilization, the economic viability of the e-buses increases by up to 28% due to its lower operational cost, compared to ICE buses. The 9-meter buses are best suited for shorter trips and for intracity travel. It makes sense to rationalize routes while deploying 9-meter e-buses to maximize the daily drive distance to 250-300 km. Note that the selection of appropriate battery and charging technology is crucial for better operational flexibility and economic viability of e-buses

The sensitivity analysis suggests that the purchase cost, vehicle utilization and vehicle holding period have the highest impact on the TCO of an e-bus. Maintenance and fuel costs have a lower impact. Figure 17 shows the effect that variations in fixed costs (bus and charging infrastructure cost components) at various daily drive distances (DDD) have on TCO per km of 12-meter buses. At 250 km DDD, the TCO of an e-bus is lower than that of a diesel bus at same DDD, even when the fixed costs increase by 25%. As fixed costs reduce by 25%, the TCO of an e-bus is lower than of a diesel bus at 250 km and 200 km of DDD.

Figure 17 | Impact of Fixed Cost and Vehicle Utilization on TCO per km



Sensitivity analysis reveals that as the fixed cost of e-buses reduces, their financial viability improves at a lower DDD in comparison to diesel buses. To reduce the risk on capital costs, it is important to increase vehicle utilization and ensure better route rationalization.

4. IMPACT OF E-BUS PERFORMANCE ON TCO

There are two crucial factors that need to be taken into account while planning for e-buses in a city: the battery configuration and the topography profile of each route.

There are two crucial factors that need to be taken into account while planning for e-buses in a city: the battery configuration and the topography profile of each route. Analysis of an e-bus pilot in Oporto, Portugal, suggests that routes with shorter distances between stops, elevation and multiple curves demand more energy. Urban routes with straight stretches and multiple braking systems, on the other hand, have greater energy efficiency. The authors believe that energy recovered due to regenerative braking could offset these effects.[15] A research study on low-speed urban driving with frequent stop conditions in New York City (NYC) with an average speed of 11.4 kilometers per hour and Urban Dynamometer Driving Schedule (UDDS) with an average speed 31.5 km/h indicates that regenerative braking helps recover 67% in NYC and 57% for UDDS of the amount of energy that is dissipated while braking.[16] The insight is significant as the average speed on the arterial roads of Bengaluru during peak hours is less than 11 km/h.[17] A study simulating e-bus deployment on the airport routes of BMTC, which has higher speeds (due to its longer route length and topography), showed low to moderate fuel consumption.[18]

[15] Perrotta, Deborah & Macedo, José & Rossetti, Rosaldo & Sousa, Jorge & Kokkinogenis, Zafeiris & Ribeiro, Bernardo & Afonso, J.L.. (2014). Route Planning for Electric Buses: A Case Study in Oporto. Procedia - Social and Behavioural Sciences. 111. 1004-1014. 10.1016/j.sbspro.2014.01.135.

[16] Perrotta, Deborah & Ribeiro, Bernardo & Rossetti, Rosaldo & Afonso, J.L.. (2012). On the Potential of Regenerative Braking of Electric Buses as a Function of Their Itinerary. Procedia - Social and Behavioural Sciences. 54. 1156-1167. 10.1016/j.sbspro.2012.09.830.

[17] Draft CMP, Bengaluru 2019

[18] https://theicct.org/publications/zev-bus-fleets-dev-drive-cycles

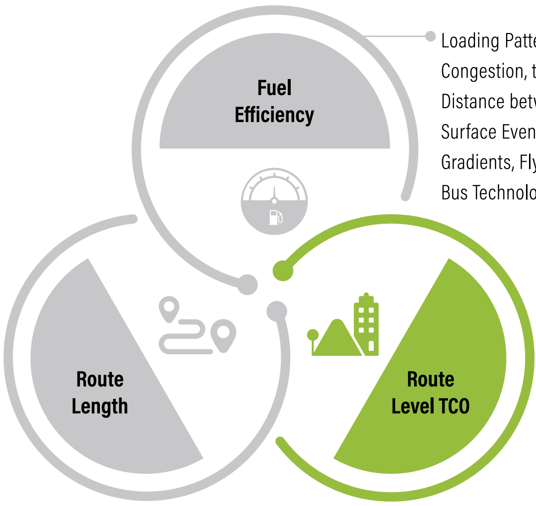
In this chapter, we analyze the impact of the bus performance factors at route level on energy consumption, and its impact on the TCO per km of an e-bus in comparison with its ICE counterparts. The analysis of literature suggests that at route level, TCO depends largely on two factors (Figure 18):

- Fuel efficiency on the route
- Daily drive distance

The fuel efficiency depends on multiple factors:

- Surface condition of the corridor, i.e. gradients, flyovers, surface evenness
- Acceleration and deceleration profile due to bus stops, congestion and traffic signals
- Ambient temperature of the area
- Bus technology and availability of regenerative braking systems

Figure 18 | **Criteria for Route Level TCO**



For example, a route in the core of the city will have short distances between stops, and frequent acceleration and deceleration due to traffic signals and congestion. These would affect the energy consumption of the bus adversely. However, with a regenerative braking system, some energy can be recovered and stored to extend the drive range. Longer bus routes to peri-urban areas of the city would have fewer halts and less congestion. However, higher speeds will increase energy consumption, which in turn will affect the TCO per km of the e-buses. Figure 19 shows the effect of various operational characteristics on the energy consumption of Volvo e-buses.[19] Topography is a crucial factor affecting energy consumption. At the moment, there is a lack of capacity in understanding performance with respect to the energy consumption in different environments, battery lifetime and depreciation. (See Annexure 2 for more details).

Figure 19 | **Operational energy margins of zero-emission buses**

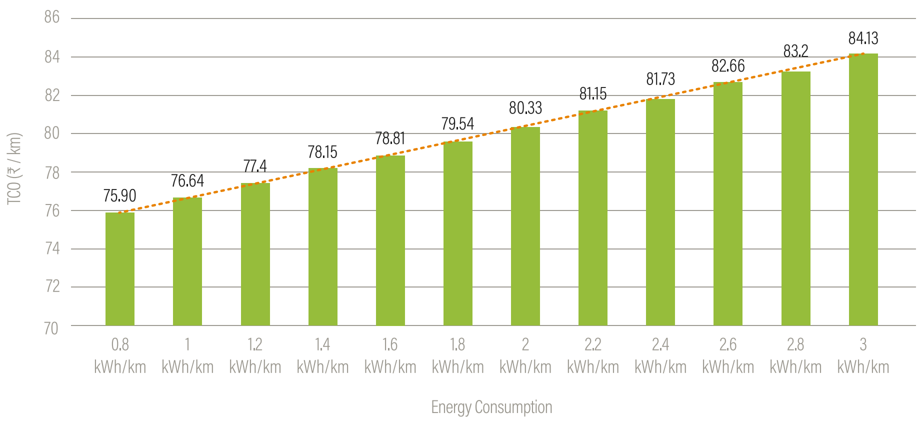
[19] Kok, Robert & de Groot, Roel & Zyl, Stephan & Wilkins, Steven & Smokers, Richard & Spreen, Jordy. (2017). Towards Zero-Emission Bus Transport.

[20] Nurhadi, Lisiana & Borén, Sven & Ny, Henrik. (2014). A Sensitivity Analysis of Total Cost of Ownership for Electric Public Bus Transport Systems in Swedish Medium Sized Cities. Transportation Research Procedia. 3. 10.1016/j.trpro.2014.10.058.

With the increase in energy consumption from 0.8 kwh/km to 2.9 kwh/km i.e., 275 % increase the TCO per km of e-bus increases by approximately 11%

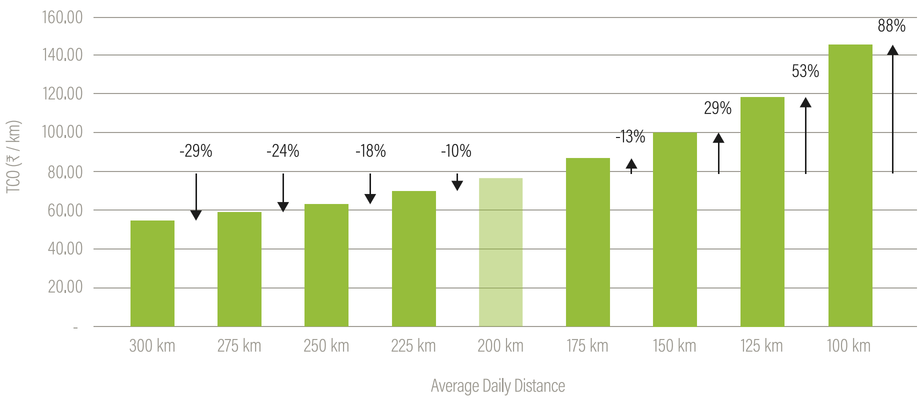
Figure 20 shows the impact of the variation in energy consumption per km due to various operational conditions, which include loading pattern, congestion and traffic signals, road gradients, and driving behavior, on the TCO per km of buses. With the increase in energy consumption from 0.8 kwh/km to 2.9 kwh/km i.e., 275 % increase the TCO per km of e-bus increases by approximately 11%. A study in Sweden echoes this trend by finding that a 10-30% increase in energy costs resulted in a 0.4-4% variation on the TCO of an e-bus. The study concludes that the energy cost, charger cost, and carbon tax are quite substantial, but not significant enough to impact the TCO.[20]

Figure 20 | **Impact of variation in energy consumption due to various factors on the TCO per km of the e-bus**



From Figure 21, it is evident that vehicle utilization has a high impact on the TCO. The figure shows that with an increase in average daily drive distance from 100 km to 300 km per day (a 200% increase), the TCO per km decreases by around 50%. This indicates that vehicle utilization or operational efficiency will have a significant impact on the TCO per km. Bloomberg's New Energy Finance (BNEF) study states that e-buses with smaller battery (e.g. 110 kWh) achieve parity with diesel buses in smaller cities with a range of 30,000 km per year. E-buses with battery greater than 350 kWh will attain parity with diesel buses at 80,000 km per year, and are suitable for larger cities.[21]

Figure 21 | **Impact of variation in the average daily drive distance on the TCO per km of e-bus**



BMTC's ordinary (non-AC, low-end) buses ply at an average operational efficiency of 87.87%. This indicates the effective scheduled km per bus is much lower than the scheduled km. The average operational efficiency of Volvo buses is 76.95%[22], which is even lower than that of ordinary buses. Therefore, buses need to be utilized at a higher range to be profitable while transitioning to electric.

[21] https://about.bnef.com/blog/electric-buses-cities-driving-towards-cleaner-air-lower-co2/

[22] BMTC Financial Performance

Energy consumption depends on multiple operational factors, but it does not affect the TCO adversely. Increasing daily distance through operational efficiency can help in reducing the TCO per km of e-buses, to ensure they are financially viable.

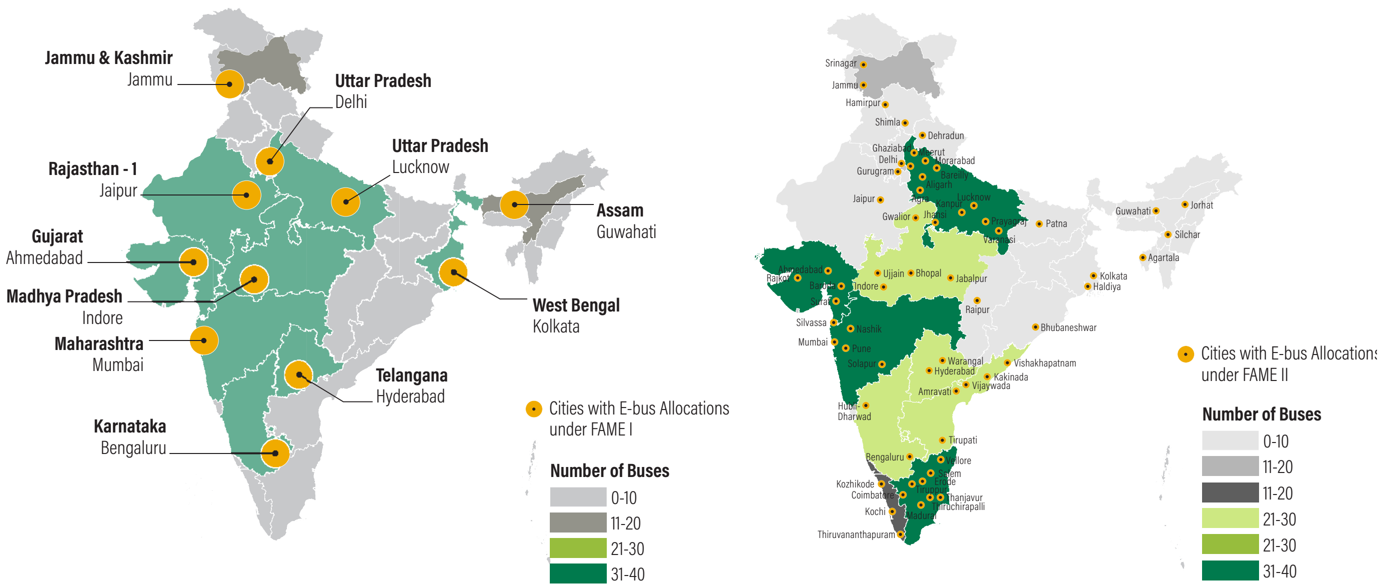
The foremost barriers to the adoption of e-buses in India are the high upfront cost, the risk and anxiety related to adopting a new technology.

5. E-BUS PROCUREMENT MODELS

E-buses represent the dawn of a new technology. Compared to conventional diesel buses, this technology is relatively untested and uncertain. The foremost barriers to the adoption of e-buses in India are the high upfront cost, the risk and anxiety related to adopting a new technology. This chapter lays out a framework for agencies that are transitioning their operations with cleaner buses. The chapter provides an overview of e-buses in the Indian context and discusses various modes to procure e-buses.

Public buses account for 7% of the total number of buses in India, and carry over 68 million passengers per day with a fleet utilization of 90%.[23] With most SRTUs in the country being cash-strapped, e-buses pose a huge financial burden on them. In order to push the adoption of e-buses in public transport, the Indian government provides financial support through the FAME scheme, which falls under the National Electric Mobility Mission Plan (NEMMP).

Figure 22 | **Spatial Comparison of E-Bus allotment under FAME I and FAME II**



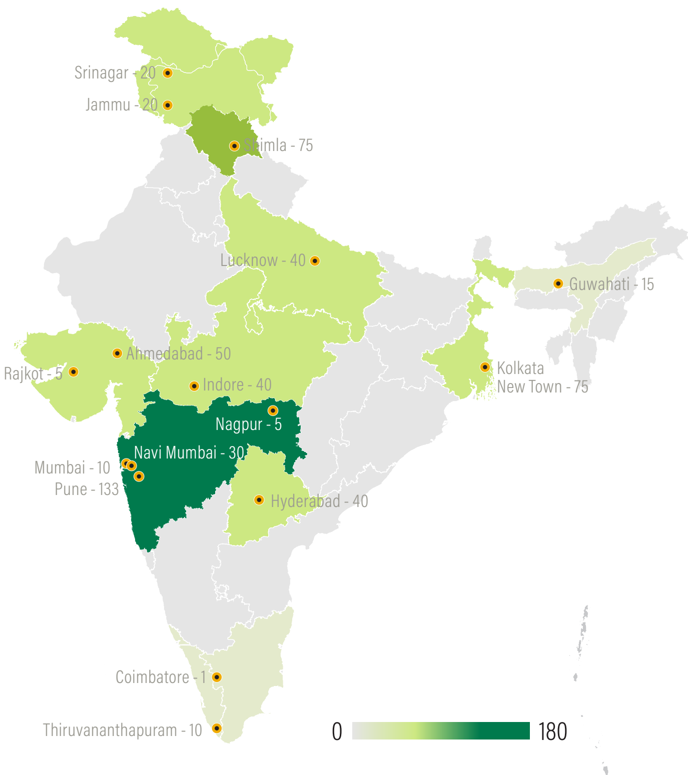
FAME I and FAME II[21] provide a combined allotment of 5,485 buses (Figure 22). However, only 1,031[24] have begun operations on the ground. Figure 23 illustrates that there is a mismatch in the number of e-buses allotted a subsidy and the actual number of e-buses running on-ground. We also note that not all the e-buses running on-ground are procured with FAME support. Pune, which has the country's largest deployment of e-buses, utilized Smart City Mission funds.[25] It is interesting to note that Ahmedabad has procured e-buses to deploy on its BRT corridor operated by Ahmedabad Janmarg Limited (AJL). These instances show that there are alternate government schemes and subsidies to procure and operate e-buses.

[23] Review of the performance of State road transport undertakings for April, 2015 – March, 2016

[24] JMKELECTRIC BUSES India Market Analysis Sep 2020

[25] Punesmartcity.in

Figure 23 | **E-Bus Deployed currently by Public agencies (Source: Various Media Sources, Dec 2020)**



Gross Cost Contract (GCC) and Outright Purchase are the two primary modes of bus procurement followed in India. Procurement practices play a key role in determining the profitability of deploying electric buses for the operator and agency.

Unlike FAME I, FAME II specified that buses can be procured only via a Gross Cost Contract (GCC) mode of procurement. One of the reasons for this shift is the rapid evolution of bus technology in the global market. GCC and Outright Purchase are the two primary modes of bus procurement followed in India. Procurement practices play a key role in determining the profitability of deploying electric buses for the operator and agency.

5.1 Procurement Models

5.1.1 Gross Cost Contract (GCC) Model

In the GCC model of procurement, the bus is owned and operated by service providers (OEM or a consortium of OEM and bus service providers) for a specific rate and period. In this model, all the earnings of the bus remain with the public bus agency (e.g. SRTUs or city bus agencies). The agency pays a pre-decided sum per unit distance to the service provider. While the agency usually provides only the conductor for the bus, the driver is deployed by the service provider. The service provider also takes responsibility for setting up the charging infrastructure, and the maintenance of both buses and ancillary services required for operation. In some instances, the agency supplies the prerequisites for setting up charging infrastructure like distribution transformer, etc. This model ensures that the responsibility of efficient service rests with the service provider. Therefore, it is in their best interest to provide requisite charging infrastructure, maintenance and other logistics. The agency is responsible for monitoring and data-sharing between the two parties to keep track of the service level benchmarks.

In an outright purchase, the public bus agency purchases the e-buses as well as the charging infrastructure. This method, while providing complete ownership of the buses and infrastructure to the agency, also places the entire risk and burden of the infrastructure and rolling stock on it

Battery leasing helps to delink the cost of the battery, which constitutes up to 40% of the cost of the bus. This model reduces the risks that come with outright purchase of battery technology and charging infrastructure.

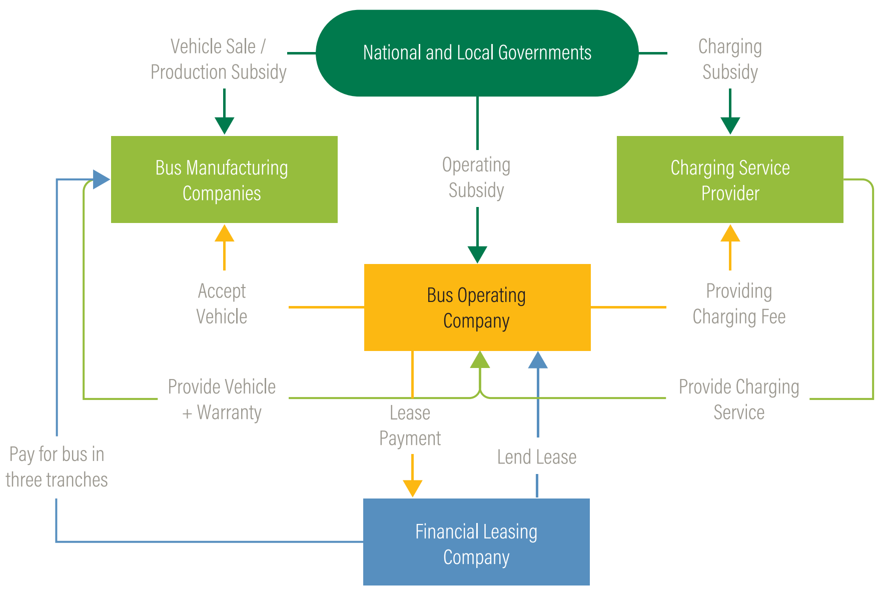
5.1.2 Outright Purchase Model

In an outright purchase, the public bus agency purchases the e-buses as well as the charging infrastructure. This method, while providing complete ownership of the buses and infrastructure to the agency, also places the entire risk and burden of the infrastructure and rolling stock on it. The agency is solely responsible in case of breakdowns, technology upgrades, maintenance and monitoring of vehicles. The agency would need to be thoroughly conversant with electric bus and charging infrastructure technologies. In smaller cities with shorter trip lengths, the e-bus supply bids were on the higher side due to low daily utilization. Such scenarios need to be analyzed carefully to decide on a procurement model. This requires increased focus in capacity building for public bus agencies.

5.1.3 Battery Leasing

This procurement model combines both outright purchase with an option of leasing the battery alone. In this case, the bus agency purchases the bus without taking ownership of the battery. The OEM or battery service providers are responsible for maintenance of the battery along with its allied charging infrastructure. Battery leasing helps to delink the cost of the battery, which constitutes up to 40% of the cost of the bus. This model reduces the risks that come with outright purchase of battery technology and charging infrastructure. A notable battery-leasing model is offered by bus manufacturer Proterra in the state of Illinois and in Park City, Utah, in the U.S. Under a 12-year battery lease, Proterra will own and guarantee the performance of the batteries throughout the life of the vehicle. The battery lease agreement provides a battery performance warranty which includes battery replacement at mid-life. This helps cities have access to the latest battery technology as it improves over time. To support the program, Proterra launched a partnership with Mitsui to create a $200 million credit facility in April 2019.[27]

Figure 24 | **Financial leasing model employed in Shenzhen**



[26] Khandekar, A., Rajagopal, D., Abhyankar, N., Deorah, S., & Phadke, A. (2018). The Case for All New City Buses in India to be Electric. Lawrence Berkeley National Laboratory. Retrieved from https://escholarship.org/uc/item/7d64m1cd

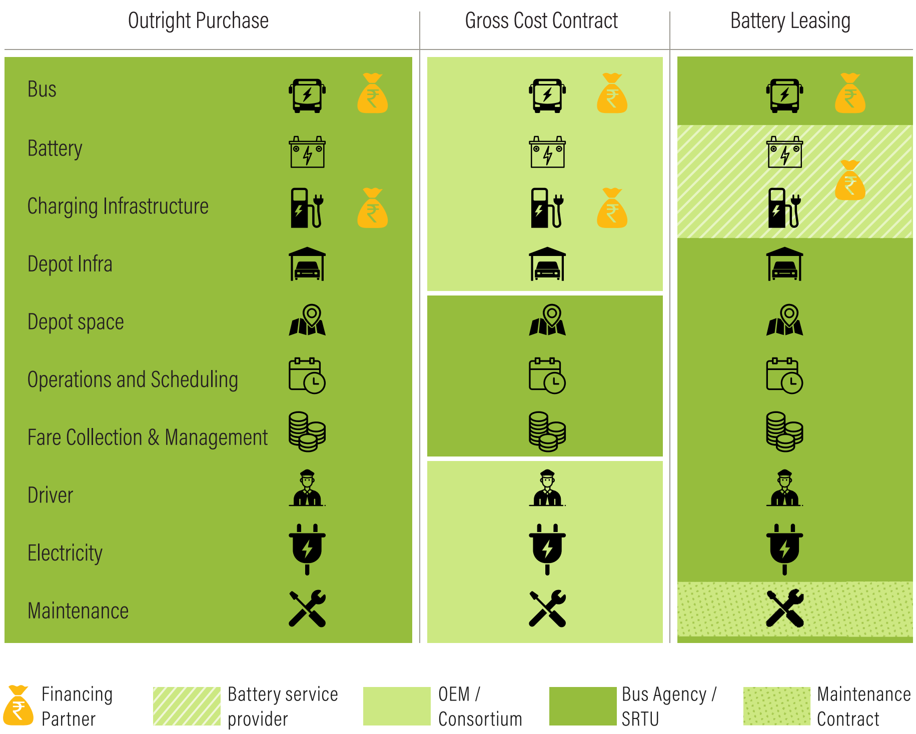
[27] https://www.proterra.com/financing-ev-fleets-with-proterra-battery-leasing-program/

[28] https://www.wri.org/blog/2018/04/how-did-shenzhen-china-build-world-s-largest-electric-bus-fleet

A successful example of this model is in Shenzhen, China. It is the first city in the world to achieve a 100% bus fleet transition to electric, with a fleet of 16,359 e-buses. Operators in Shenzhen used local and national subsidies to lease buses from manufacturers. This reduced the upfront cost of acquisition and debt financing.[28] A financial leasing company was introduced to purchase and own the e-buses. This company would then lease buses to the operator for a period of eight years. The bus operating company takes ownership after the leasing period is over, at which point, the batteries are taken back by the OEMs for recycling and/or disposal, and the body of the bus is scrapped or recycled (Figure 24).[29]

The chart in Figure 25 provides an overview of the various procurement models. In the outright mode of procurement, all cost components are borne by the operator. In most cases the SRTU which operates buses relies on banking partners for financial support to purchase e-buses and set up the charging infrastructure. In case of GCC contracts, the financing partner supports the service provider or OEM in the upfront cost of production of e-buses and charging infrastructure. The operator pays the GCC rate through the service period. In battery-leasing, the financing partner supports both the bus agency in purchasing e-buses and the battery service provider for upfront cost of batteries and setting up the charging infrastructure.

Figure 25 | **Features of Procurement Models for Buses**



5.2 TCO and Procurement Models

For an outright purchase model, the TCO includes capital and annual maintenance costs, such as fuel, battery replacement and maintenance costs, in their entirety. In the case of the GCC or Opex model of procurement, the TCO would vary as the capital cost for e-buses and charging infrastructure would be borne by both the operator and the service provider. Therefore, a GCC quote by the service provider should reflect the TCO encompassing capital cost, staff cost except conductor, maintenance and fuel cost (according to conditions in the tender). The agency will

[29] Berlin, A., Zhang, X., Chen, Y. (2020) (with ESMAP support)

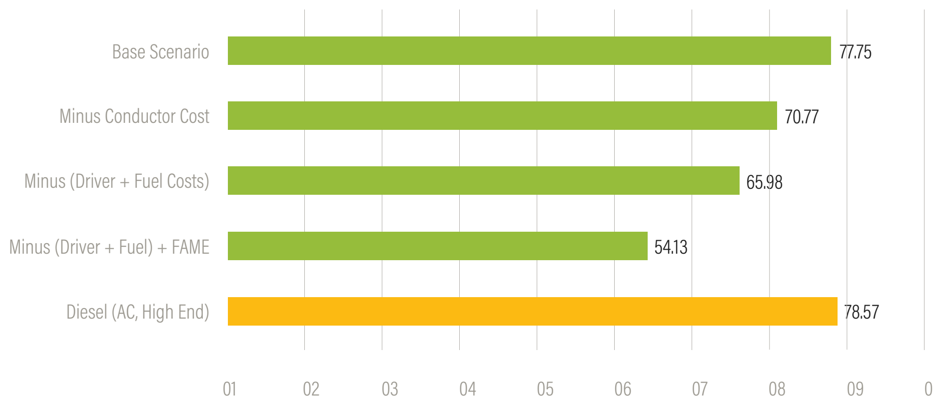
have to bear the cost of the conductor, power requirements for setting up charging infrastructure and any other overhead costs. Hence, it is crucial, and beneficial to all parties, to draw an agreement which reflects that the GCC rate is inclusive of all other costs.

In case of GCC, the capital cost component of the TCO will also reduce considerably, especially if the service provider is the OEM, which is usually the case. OEMs will be able to deploy the buses at the cost price, which will translate into lower bids. As the scale of operations increases, service providers will be able to provide maintenance and charging infrastructure at a fraction of the cost while availing better financing and insurance rates due to economies of scale. This goes a long way in reducing the TCO of e-buses. In both the models, it is usually the agency that is required to provide land for setting up depots and charging infrastructure on rent to the service provider. The civil and electrical work for this is carried out by either the agency or the service provider, based on the agreement.

In Figure 26, the TCO of electric buses procured under GCC is calculated. We consider three scenarios for the GCC:

I. The original base scenario discussed in Section 3
II. Separating the conductor cost from the base scenario: The service provider quotes the TCO, which includes capital, infrastructure and operational costs. The agency provides only the conductor for the operations, while paying the GCC rate of INR 70.77/km. .
III. Separating the conductor and fuel costs: The service provider quotes the TCO, which includes capital, infrastructure and operational costs. The agency provides the conductor for the operations, and bears the fuel cost, while paying the GCC rate of INR 65.98/km.
IV. By applying the FAME II discount on Scenario III, the agency pays a cost of INR 54.13/km, which includes conductors' salaries and fuel costs.

Figure 26 | **Variation in TCO of e-Buses in the GCC Model**



A review of FAME II bids reveals that an average L1 quote for 12-meter buses, across urban and intercity operations, is INR 69 per km27. This is higher than those received during the bidding process under FAME I. Bengaluru, for example, received bids as low as INR 37.35 indicating that rates were stabilizing rather than competitive bidding to capture markets. The insights from TCO calculation can therefore be used effectively while preparing the Terms of Reference (TOR) for awarding contracts to operators.

In a battery-leasing model, in addition to the base scenario as calculated in Section 3.1, three scenarios were attempted to arrive at the TCO:

I. Assuming that a battery-less electric bus would cost 30% less than one with a conventional battery. The 30% battery price along with battery replacement cost at midlife of the bus is amortized over the holding period of the bus (10 years) at an interest rate of 8%.

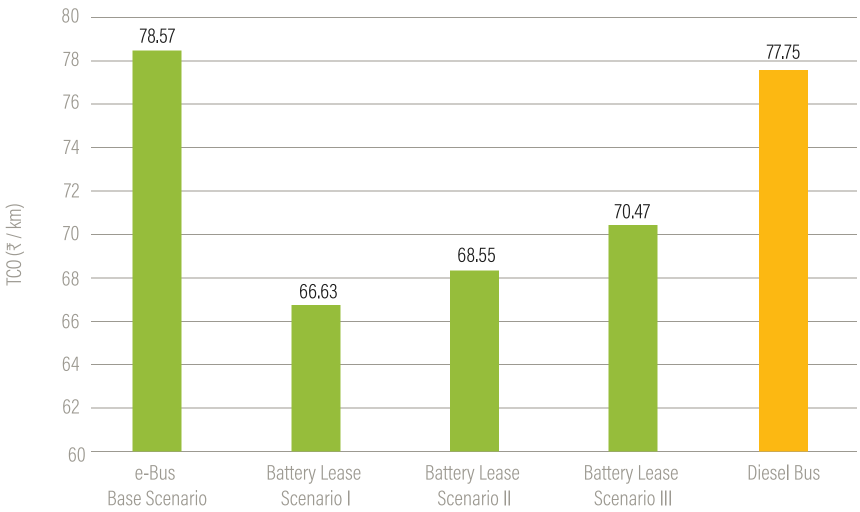
II. Assuming that a battery-less electric bus would cost 40% less than one with a conventional battery. The 40% battery price along with battery replacement cost at midlife of the bus is amortized over the holding period of the bus (10 years) at an interest rate of 8%

III. Assuming that a battery-less electric bus would cost 50% less than one with a conventional battery. The 50% battery price along with battery replacement cost at midlife of the bus is amortized over the holding period of the bus (10 years) at an interest rate of 8%.

> There are multiple factors that determine the TCO per km for battery-leasing. Some of them include battery reuse capability, effect on mileage, electricity cost, battery chemistry, charging speed and charger configuration. Financing also plays a key role in this model of procurement.

Figure 27 shows that on procuring an e-bus through battery-leasing, with 50% decrease in capital costs leads to a 14% reduction in TCO per km. The least favorable battery-leasing scenario is a 30% capital cost reduction, which offers a 9% reduction in TCO per km. On separating the fuel cost (electricity) and distributing the cost in the same manner as in the above scenarios, there is an additional 6% reduction in TCO per km. There are multiple factors that determine the TCO per km for battery-leasing. Some of them include battery reuse capability, effect on mileage, electricity cost, battery chemistry, charging speed and charger configuration. Financing also plays a key role in this model of procurement. Battery financing provided to the battery service provider, and the financing options offered to the bus agency, will leverage the risks accrued by all players. A detailed analysis that takes into consideration as many parameters as possible will be useful in understanding the effect of battery-leasing on TCO per km. Studies show that a battery subscription facility reduces the TCO of an electric bus over diesel and CNG buses by 13% and 16% respectively.[30]

Figure 27 | **TCO of E-Bus on Battery Leasing Model of Procurement**



[30] India Innovation Lab – Battery Subscription Facility Instrument Analysis, Sept 2018.

5.3 INNOVATIVE SOLUTIONS FOR E-BUS PROCUREMENT IN INDIA

A key to reducing the TCO is to identify high-impact factors and leverage them for maximum benefits.

Various best practices in e-bus deployment from across the world show that the key to effective transition is innovative partnerships. A majority of bus operations in India are by private operators who do not have access to basic resources such as land for parking and charging, or even access to incentives. Such operators will have to rely on partnerships with other players to leverage their expertise and reduce overall risks. Battery-leasing is a solution that can bring down the high upfront cost on par with diesel buses, thereby offering an opportunity for private players to transition to e-buses. Economies of scale can be achieved when multiple players come together, reducing overhead costs and subsequently reducing the TCO.

Oil companies, who are realigning themselves with the shift in fuel consumption, have begun to explore options of collaborating with charging infrastructure players and energy providers to optimize their land holdings and develop EV-friendly refueling stations. A key to reducing the TCO is to identify high-impact factors and leverage them for maximum benefits. Even financial institutions like banks and insurance companies can help rejig the cash flow model by collaborating with energy providers and reducing the burden on the agency, whether it is public or private.

Range anxiety can be addressed by developing a reliable charging infrastructure for both private and public players. SRTUs joining hands with charging infrastructure service providers to provide services to private operators during off-peak hours is a win-win solution for all. Such solutions aid in the transition of a variety of services, such as school buses, overnight tourist buses and office commute buses which operate at specific hours.

A key to viable e-bus operation is reducing risks. This can be achieved by separating components and ensuring that multiple technically compatible players are brought to the fore.

A key to viable e-bus operation is reducing risks. This can be achieved by separating components and ensuring that multiple technically compatible players are brought to the fore. Identifying risk factors and ensuring that they are financed and handled by competent stakeholders (for instance, battery management, charging infrastructure, annual maintenance) can lead to an efficient business model for e-buses in the country.

Outright purchase offers complete ownership of assets, which comes with risks of operation and technology. The GCC model reduces high upfront cost, technology, and operational costs for the agency, and the battery-leasing model reduces risks associated with charging infrastructure and battery technology. Both these models are prime examples of reducing the burden of high upfront acquisition costs posed by e-buses.

7. CONCLUSIONS AND KEY RECOMMENDATIONS

- A realistic TCO analysis should consider prevailing capital and operational costs to ensure that key cost components are identified and taken into account. The choice of e-bus type, battery capacity and charging technology according to real-world operating conditions is crucial to optimize economic and environmental profit.

- The TCO analysis makes it clear that e-buses are economical only for operations beyond 200 kms per day and if operated for at least six years, to be as financially viable as diesel buses.

- Sensitivity analysis suggests that variations in capital and financing costs, utilization of buses and vehicle holding period have a significant impact on the TCO per km of e-buses.

- With battery costs reducing, the TCO of e-buses is expected become comparable to that of diesel buses, even with a reduced daily drive distance.
- The impact of variation in fuel cost and maintenance cost is relatively lower on the TCO per km of e-buses.

- Apart from technological differences, the operational efficiency of e-buses is also important to understand to achieve financial viability. The performance of an e-bus varies significantly depending on environmental factors and driving behavior.

- TCO can be utilized as a tool while drawing expressions of interest, requests for proposals, tender documents and other forms of agreements. Factors such as holding period, staff cost, depot rent, and benchmarks can be framed with data-driven insights from TCO analysis.

- A robust framework of procurement models is crucial to accelerate e-bus adoption in India.

- The outright purchase model allows an agency to own and operate buses by bearing all the financial and technology risks. While the GCC model reduces the risk of technology and operational costs, battery-leasing models decouple the risks of charging infrastructure and battery technology from the bus. Both these models are prime examples of reducing the burden of high upfront acquisition costs posed by e-buses.

- Innovative solutions like introducing oil companies and real estate stakeholders into the EV ecosystem can turn e-buses into a viable option for even private operators.

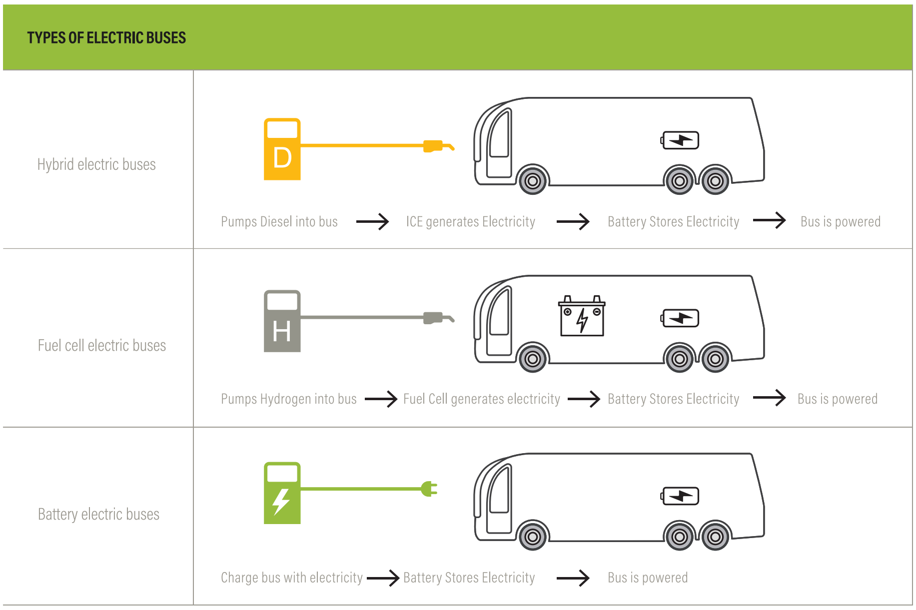
- Capital cost accounts for a significant share of the TCO of e-buses. A prudent solution to reduce this burden on one agency is to divide the risks between different players. Delinking components like bus, battery, charging infrastructure, parking and depot space, operations and financing can bring down the risk borne by various players.

ANNEXURE 1: BASIC TECHNICAL INFORMATION

Electric bus technologies vary in how they generate or store electric energy on board. Hybrid electric, fuel cell electric and full battery electric buses are currently being used in several public transport networks around the world.

- Hybrid electric buses (HEBs) generate electricity on-board during operation using a diesel engine.
- Fuel cell electric buses (FCEBs) use hydrogen fuel cells to generate electricity on-board during operation
- Battery electric buses (BEBs) store electricity on-board, and are charged either overnight, or intermittently throughout the route[31]

Figure 1 | **Types of Electric Buses**[48]



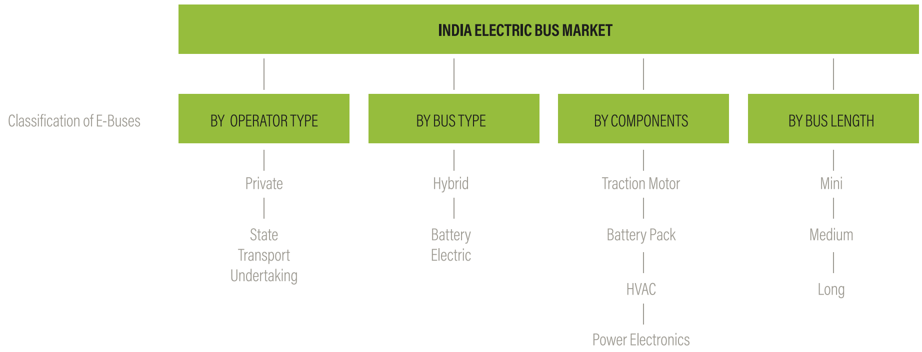
1.1 E-bus Types

In India, buses are categorized based on their gross vehicle weight (GVW). These include small buses (GVW up to 5 metric tons), light-duty bus (GVW of 5 t to 7.5 t), medium-duty bus (GVW of 7.5 t to 12 t), and heavy-duty bus (GVW exceeding 12 t). E-buses in particular are mainly categorized based on their length. Buses that are six to eight meters in length are termed as light-duty vehicles (mini bus), those that are eight to ten meters are medium-duty (midi bus), and those that are 10 meters and above are heavy-duty buses (standard bus). The 9-meter and 12-meter buses are the most prominent type of e-bus models in operation. Their selection is based on driving range, number of passengers, driving power, top speed, energy consumption rate and cost of investment.

The price of e-buses is based on bus specifications such as length, range, floor height, seating capacity and battery capacity. A 12-meter e-bus provides more seating capacity than a 9-meter one, and is costlier. E-buses with higher battery capacity provide higher range per charge, but this also increases the upfront cost.

[31] https://www.mrcagney.com/uploads/case-studies/MRC_Electric_Bus_Report__28082017.pdf

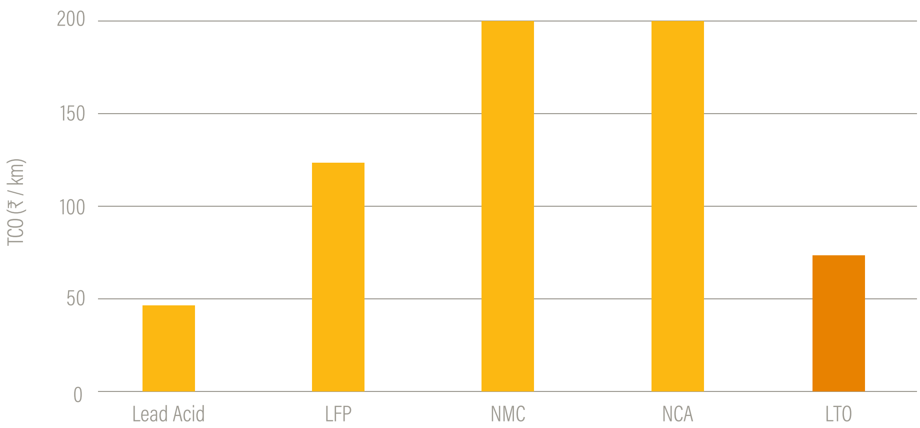
Figure 2 | **Classification of e-Buses**



1.2 Battery Technologies for E-buses

Lead-acid batteries were mainly used in electric buses until the mid-2000s. These batteries are cheaper and can perform under extreme temperatures. However, their slow charging rate (14 to 16 hours), low depth of discharge, limited cycle life and adverse environmental impacts due to presence of lead have made them obsolete. Advancements in battery cell chemistry and faster charging technologies opened up newer opportunities for lithium-ion batteries (LIBs). Due to their relatively high energy densities, long cycle life, and reduced charging time (Li, 2016), these batteries have dominated the battery market since the mid-2000s.

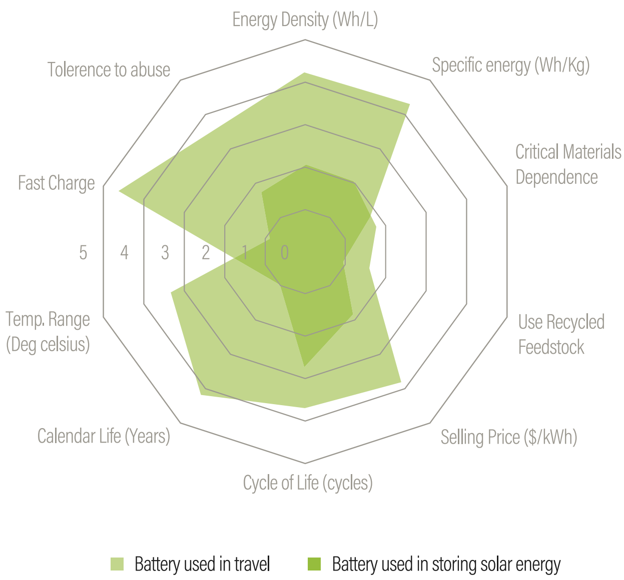
Figure 3 | **EEnergy Density of Different Battery Chemistries**



Data source : Ekstrom & Regula, 2016

Characteristics of battery performance vary depending on different operational requirements and costs involved. Figure 4 shows the performance requirements of LIBs in stationary (dark green) and Electric Vehicle (light green) applications.

Figure 4 | **Cost & Performance Metrics Used in LIB Variants for EVs**



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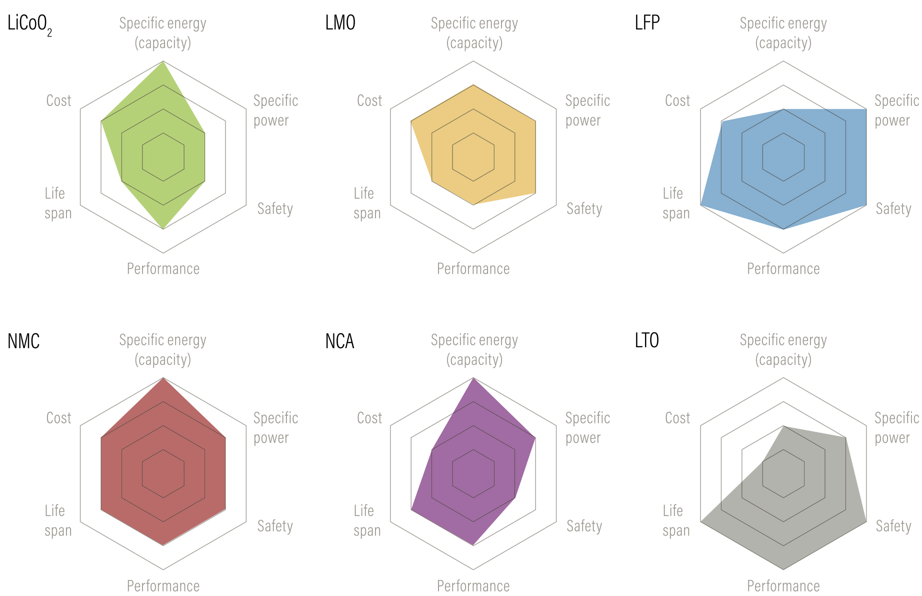
LIB's either have graphite or lithium titanate oxide (LTO) as anode materials. The cathode chemistry can be one of the following:

- Lithium Cobalt Oxide (LCO)
- Lithium Nickel Cobalt Aluminum Oxide (NCA)
- Lithium Nickel Manganese Cobalt (NMC)
- Lithium Iron Phosphate (LFP)
- Lithium Manganese Oxide (LMO)

Each composition differs in performance parameters, and needs to be chosen based on the operator's requirements. The comparison of key performance indicators of LIB variants is provided in the Figure 5.

Figure 5 | **Comparison of Types of lithium-ion batteries used in EVs, Outer Hexagon Being the Most Desirable Quantities of the Various Parameters Mapped**



The battery accounts for a significant share in the total cost of an e-bus. It is, therefore, important to choose the appropriate variant after analysing the trade-off between key performance parameters while attempting cost-effectiveness. An ideal battery possesses high power density to support acceleration, and high energy density for a longer drive range. However, technical limitations make that impossible. For example, the fast charging of the high energy density LIB variant accelerates the rate of battery degradation, which in turn reduces the battery's life. The LIB variant with high power density can support fast charging, but the limitations are relatively low energy density and high cost. Batteries with high power density can be charged fast and are best suited for opportunity charging, whereas high energy density batteries are better suited for overnight slow charging. For opportunity charging, batteries must have higher cycle life to allow multiple charging cycles in a day. The NMC, LFP and LTO variants of LIBs are mainly used in e-buses. The LFP battery is a notable e-bus battery technology due to safer operation, longer service life (if properly cooled) and the absence of cobalt (a toxic and critical material). Table 1 compares LIBs with different cell chemistries.

Table 1 | **Comparison of Li-Ion Battery properties.**[32]

Cathode	Anode	Energy density (Watte-hours/kg)	C-rate	Number of Cycles
LFP	Graphite	85-105	1C	200-2000
LMO	Graphite	140-180	0.7C-1C	800-2000
LMO	LTO	80-95	1-5C	200-25000
LCO	Graphite	140-200	0.7-1C	300-800
NCA	Graphite	120-160	0.7C	800-5000
NMC	Graphite, Silicone	120-140	0.7-1C	800-2000

1.3 Battery Performance, Life and Safety

The operating temperature range, Depth of Discharge (DoD) and C-rate (the charge or discharge rate) affects the performance of LIBs. Elevated temperature can affect the battery cycle life and in some cases can even lead to thermal runaway in the battery packs. This can cause an explosion or lead to fire during a crash. If the charging temperature goes beyond the battery's optimum temperature range, it will cause faster degradation. To avoid such accidents, e-buses should be operated and charged within permissible temperature ranges. Battery thermal management systems help in maintaining and monitoring the performance of batteries. Battery cooling can be achieved using air coolants, liquid coolants or phase change materials. Liquid coolants have a higher coefficient of heat transfer and are preferable to air coolants in a tropical country like India.

The **C-rate** determines the rate of battery charging or discharging. A 1C rate for a 200 kWh battery means that a 200 kW charger will charge the battery in one hour. A higher C-rate means faster charging, which affects battery life. LTO batteries can achieve faster C-rates, whereas for NMC or LFP a C-rate less than 1C is preferred.

[32] Compiled from different sources. (IRENA, 2015) (Battery University, 2019) (Ekstrom & Regula , 2016)

DoD refers to the degree to which a battery can be charged or discharged with respect to its total capacity. DoD is a crucial parameter that affects battery performance and life. Table 2 shows the effect of DoD on discharge cycles in NMC/LiPO4 batteries.

Table 2 | **Relationship between DOD and Discharge cycles**

Depth of discharge	Discharge cycles (NMC/LiPO4)	Technology	NMC	NMC	LFP
		Max Battery Pack Voltage	800V		
100%	300-600	Cell Nominal Capacity	60/120/240 Ah	600/100 Ah	46/60 Ah
80%	400-900	Pack Energy Density	150 Wh/kg	85 Wh/kg	56 Wh/kg
60%	600-900	100kWh system weight	666 kg	1175kg	1785 kg
40%	1000-3000	Number of cycles 100% DOD	3000-4000	>=3600	15,000-60,000
20%	2000-9000	Operating temperature range	-20 to 55 C	-20 to 55 C	-30 to 55 C
10%	6000-15000	Charging temperature range	0 to 45 C	0 to 45 C	-30 to 55 C

Data source: Ekstrom & Regula, 2016

The operating and charging temperature range of a battery varies with different chemical compositions. LTO batteries are preferred for fast charging technology. They are also costlier than NMC and LFP batteries, even though they have poor energy density. The LFP and NMC battery chemistries are cost-effective and are mainly used by e-bus manufacturers in India.

1.4 E-bus Charging Strategies and Technologies

Depending on the battery capacity and the route on which e-buses are deployed, a range of operating and charging strategies can be implemented. The limited range of battery electric buses calls for different charging strategies. This depends on the battery type, battery capacity, operational requirement, and economic aspect of charging infrastructure that is available for operation. Following are three familiar charging strategies adopted globally:

- Slow charging or overnight charging
- Fast charging
- Opportunity charging

Overnight charging is a slow charging process that uses a DC slow charger or an AC level 3 charger at bus depots. Overnight charging reduces charging anxiety during operational periods. It also ensures grid stability and longer battery life, as it charges under a controlled environment. Overnight charging also takes the burden off the grid, as it is done during off-peak hours. This eventually reduces the cost of operation.

High energy density batteries consist of bigger battery packs that increase the cost and weight of an e-bus. Increased weight lowers the passenger-carrying capacity of the e-bus. Batteries with high energy density are suited for slow overnight charging. Electric buses deployed in Kolkata have adopted DC slow (60 kW) charger technology that can charge 125 kWh (NMC) batteries in three to four hours. The Kerala State Road Transport Corporation has adopted a 380/440 V AC dedicated charging system for recharging LFP batteries (Olectra-BYD K7e-Buzz) in about three hours. Road transport corporations in Telangana,

References

BYD K9 specifications https://olectra.com/electric-bus-k9/
Successful Operation of Electric Bus Fleet – "A Case Study of Kolkata" New Delhi: The Energy and Resources Institute zeeus-e-bus-report-internet.pdf
Das, S., Sasidharan, C. & Anirudh, R., 2019. *Charging India's bus transport: A guide for planning chargng infrastructure for intra-city public busfleet*, New Delhi: Alliance for an Energy Efficient Economy (AEEE)

Himachal Pradesh, Karnataka and Maharashtra have inducted variants of Olectra-BYD electric buses with AC slow charging technology. Overnight charging is a preferred in India and is already being implemented for e-buses operational in states such as West Bengal, Kerala and Maharashtra.

Fast charging can be employed either at bus depots or en route. The facility can be either the plug-in or the battery-swapping type. DC fast chargers have higher power ratings. E-buses in Kolkata have DC fast (120 kW) chargers that can charge a 188 kWh (NMC) battery in 60 to 90 minutes. **Battery swapping** has advantages such as charging in a controlled environment, higher passenger-carrying capacity of the vehicle due to reduced battery weight, and shorter stoppages. But this costs more, as more batteries need to be procured. Standardization of batteries is also crucial for this to work. For example, Ahmedabad Municipal Corporation introduced 18 e-buses with battery-swapping facility and 32 e-buses with fast charging technology. The 50 kWh swappable battery provides a range of 40 km and eliminates the need to carry heavy batteries. This translates to higher passenger capacity.

Opportunity charging provides ultra-fast charging rates. It adversely affects the battery cycle life and increases the load on the grid significantly. Opportunity charging can be fulfilled by **DC pantographs** and inductive charging. The DC pantograph has two variations. In the first, the vehicle houses the extendable pantograph. In the second, the pantograph is mounted on a traction pole. The DC pantograph provides a fully automated charging solution but has relatively lower efficiency than the plug-in type. A DC pantograph with an input parameter of 3-ϕ AC, 415 V, 500 A will charge a battery in five to 30 minutes. **Inductive charging** is a non-contact-type opportunity charging with a higher charging rate. It is easier to use. However, harmful electromagnetic radiation is a serious health concern. Inductive charging with a 200kW charger will charge the battery at a rate of 3.33 kWh/minute.

Opportunity charging has a higher capital cost and places a heavier burden on the grid. DC pantograph and non-contact wireless inductive charging is preferred in Europe and the U.S. for opportunity charging. Both technologies require a huge capital investment, more space, and design modifications in roads and e-buses. Different charging strategies and technologies that are available for e-buses are listed below. Table 3 shows technical specifications of charging technologies based upon pilot projects implemented in India and around the globe:

Table 3 | **Charging strategies for e-buses**

Bus Charging Strategy	Contact Type	Charging Technology	Technical Specifications		
			Power Rating (kW)	Battery Rating (kWh) and Battery Chemistry	Charging Time
Overnight Charging/ Slow Charging	Plug-In Type	DC Slow Charging (DCSC)	60	125 kWh (NMC)	3-4 hr
		AC Level 3 (3-Ø, 415 V, less than 126 A)	80	324 kWh (LFP)	2-4 hr
Fast Charging	Plug-In Type	DC Fast Charging (DCFC)	120	188 kWh (NMC)	1.5-2 hr
	Battery Swapping		As per battery specification	As per battery specification	Less than 5 min
Opportunity Charging		DC Pantograph	Upto 450	240 kWh (LFP/ LTO)	Approx. 30 min (7.5 kWh/min)
	Non-contact type	Inductive	200	240 kWh (LFP/ LTO)	Approx. 72 min (3.33 kWh/min)

Annexure 2: E-bus Performance & Energy Consumption

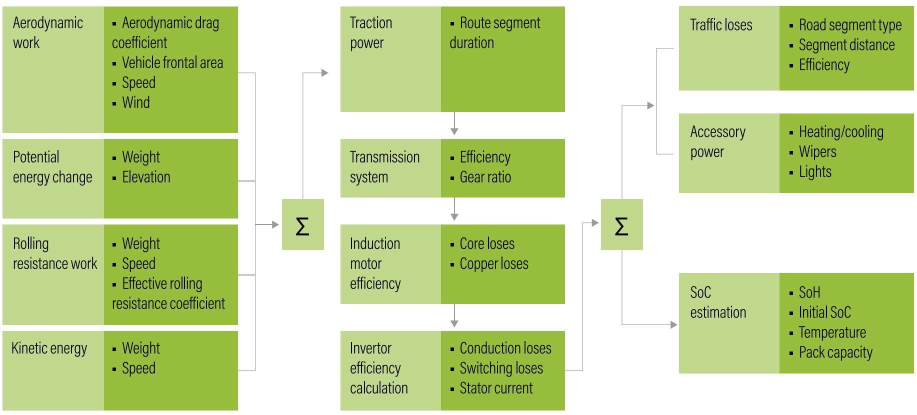
The performance of e-buses depends on terrain, environmental conditions and driving patterns. It is important to understand that these have an impact on energy consumption and mileage of e-buses.

2.1 Battery Capacity and Drive Range

To support the long drive range in e-buses, a large battery pack is required, which adds to the vehicle's weight, which in turn leads to poor mileage. In the case of diesel buses, the weight of the vehicle decreases as fuel is burned, which in turn leads to better mileage. The weight of an e-bus remains the same whether its battery is fully charged or discharged.

For a given route, the battery capacity for the driving range of e-buses indicates the energy required for the battery and traction power. The energy required in an e-bus is calculated by taking into consideration the rolling resistance, aerodynamics, and change in potential and kinetic energy of the vehicle. These factors have a significant impact on a battery's performance environment and driving factors. This is shown in Figure 1 below.

Figure 1 | **Factors involved in range estimation of e-bus**



Data source: Sarrafan, Sultano, Muttaqi & Town, 2017

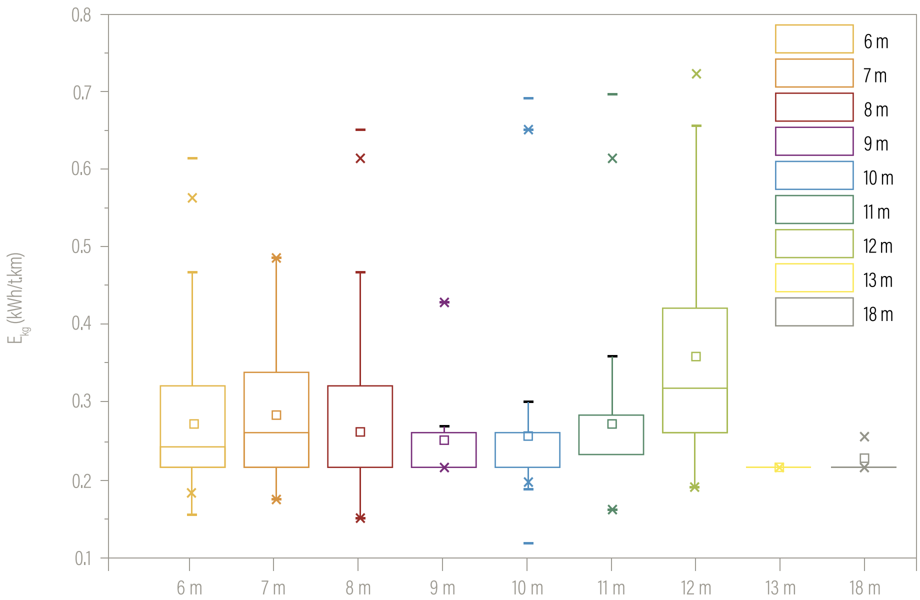
The weight of a battery varies according to its configurations. Since the gross weight of the vehicle is fixed, a trade-off needs to be made between battery weight and passenger capacity. E-buses can generate energy through regenerative braking. This energy can be stored and recovered for better efficiency. In a conventional braking system, the heat produced due to braking get dissipated into the surroundings. This results in wastage of at least 30% of the generated power.

The efficiency of e-buses is constantly increasing, due to rapidly evolving technologies. The direct drive motor required for regenerative braking is an example. It is, however, heavier than the typical motors. Therefore, it is advisable to deploy these motors on routes with frequent halts. The energy recovered through regenerative braking varies with humidity and the seasons.

2.2. Effect of Bus-Type on Performance

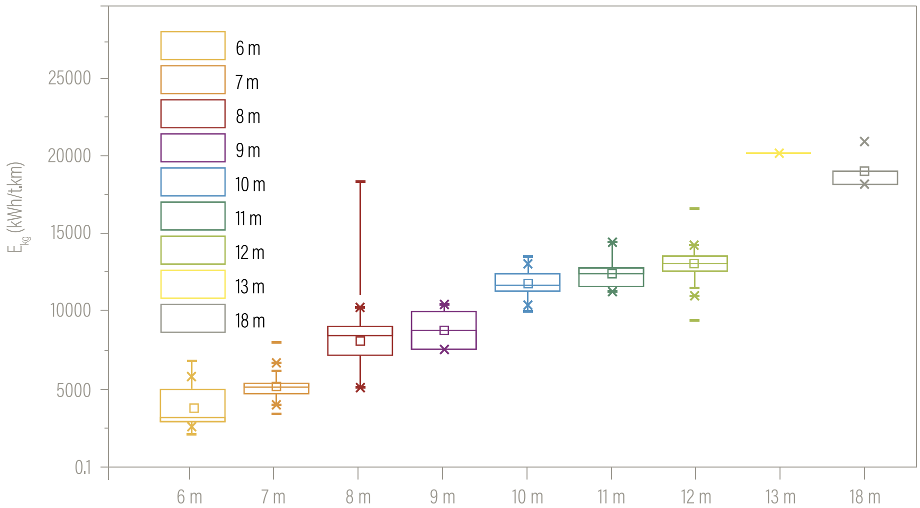
The performance of an e-bus varies depending on its length and curb weight. Energy consumption is generally calculated as energy consumed (kWh) per km. Figure 2 shows the energy consumption of e-buses of different lengths.

Figure 2 | **Energy consumption rate of different types of e-buses**



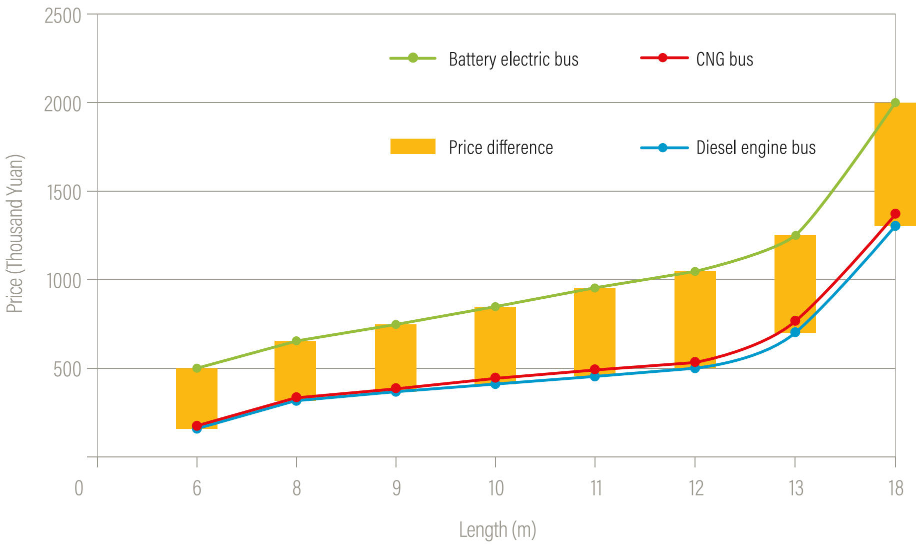
These were observed under constant driving speed conditions. Energy consumption is expected to increase in real-world driving conditions. With improvements in vehicle body weight, thermal pump air conditioning and energy recovered through regenerative braking, energy consumed per km is expected to decrease. The curb mass of e-buses significantly affects their energy consumption rate. The curb mass of different models is compared in Figure 3.

Figure 3 | **Curb mass of different types of Battery Electric Buses**



The curb mass of light-duty vehicles is around 5,000 kilograms, while a heavy-duty vehicle weighs around 125,000 kg. E-buses are heavier than ICE buses of same length, as low energy density batteries are heavy. The need for a longer range (more than 200 km) and heavy curb mass necessitates a higher battery capacity for e-buses. This also increases the upfront cost of the vehicle. The price for different sizes of e-buses available in China is presented in Figure 4.

Figure 4 | **Cost of different size of e-buses**



2.3 Effect of HVAC on performance

The heating, ventilation and air conditioning (HVAC) system is an auxiliary power demand that consumes a significant amount of the energy available in the battery. HVAC consumes 30% of battery power, and affects the vehicle's range significantly. Maintaining the cabin temperature at 17 degrees Celsius when the outdoor temperature is 35 degrees Celsius requires 12.5 kW of power. It increases the energy consumption by 0.7 kWh/km at an average speed of 18 km/h, and by 1.0 kWh/km at average speed of 12 Km/hr (Göhlich et al., 2018). This additional demand requires a heavier battery and a higher capacity charging point. The required size of the battery is calculated based on the maximum number of passengers and the battery's cell chemistry. The energy demand of an e-bus with HVAC also varies according to the number of passengers on board.

2.4. Effect of Passenger Load on Performance

A study on variation in the energy consumption of e-buses with varying bus speed and bus length was conducted with no passengers on board (Zhou et al, 2016). Considering 15 km/hr as the reference speed, the speed of e-buses was varied and energy consumption in 8-meter and 12-meter buses These observations are presented in Table 1 below. E-buses are more efficient than diesel buses while idling.

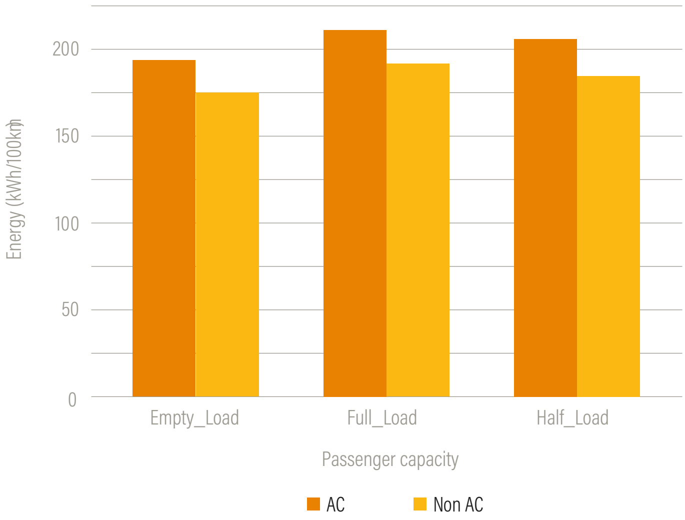
Table 1 | **Percentage change in energy consumption with 15km/hr as reference**

Bus speed	12 metre bus	8 metre bus
10 Km/hr	10%	29%
15 Km/hr	0	0
20 Km/hr	9%	16%

Data source: Zhou et al., 2016

Poor road quality restricts the smooth functioning of e-buses. The experiences of other developing countries in cities such as Bogota (Colombia) and Campinas (Brazil) show that the doors and suspension valves are prone serious damage. (Sclar, Gorguinpour, Sebastin & Li, 2019).

Figure 5 | **Change in Energy Consumption under Different Passenger Loads and Under HVAC scenarios of a 12-meter e-Bus**



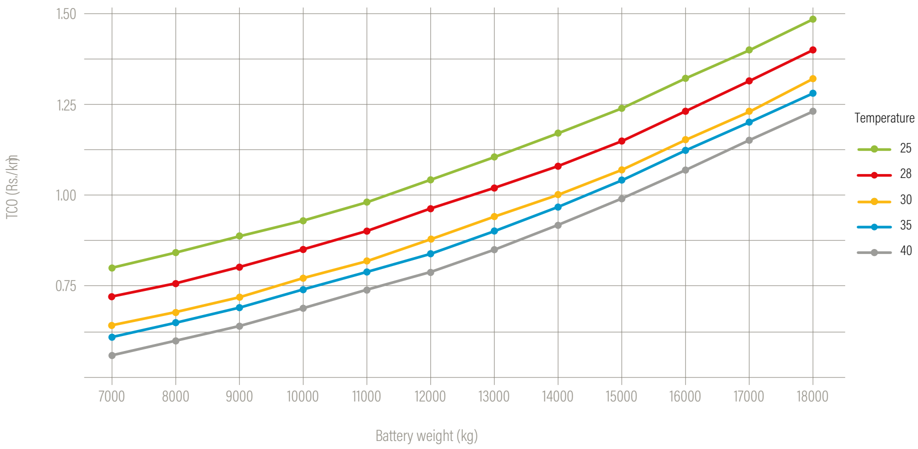
Data source: Zhou, et al., 2016

The energy consumption of e-buses was calculated under three scenarios: empty load, full load and half load. This is shown in Figure 5. Keeping the empty load scenario as a reference, the full load condition consumed 9% to 11% more energy in e-buses. In the same scenario, a diesel bus consumed 20% more energy. E-buses consumed an additional 21% to 27% of energy when fully loaded and with the air-conditioning turned on. A diesel bus consumed 48% extra energy.

2.5. Effect of Environmental Factors

Weather conditions such as temperature, atmospheric pressure and humidity affect the energy efficiency of an e-bus. Batteries are designed to be used under specified operating ranges. For example, Li-ion batteries perform efficiently under temperatures ranging between 15 and 35 degrees Celsius. A simulation study conducted on e-buses operated in Surat found that energy consumption per km increased with the temperature. The effect of humidity and atmospheric pressure was experimentally studied in Cluj-Napoca, Romania (Iclodean , Cordos & To, 2019) on 22 buses for 12 months. It was observed that a decrease in temperature (below 0 degrees Celsius) and atmospheric pressure increased energy consumption. The effect of humidity is relatively lower. However, it affects the energy recovered through regenerative braking. The energy recovered increases with an increase in the ambient temperature. Increases in humidity and air density have the opposite effect. Due to higher humidity during the rainy season, the friction between the road and tires decreases. This reduces the amount of energy recovered

Figure 6 | **Energy Efficiency with Change in Temperature (Celsius) for Different Battery Weights in Indian Scenario**

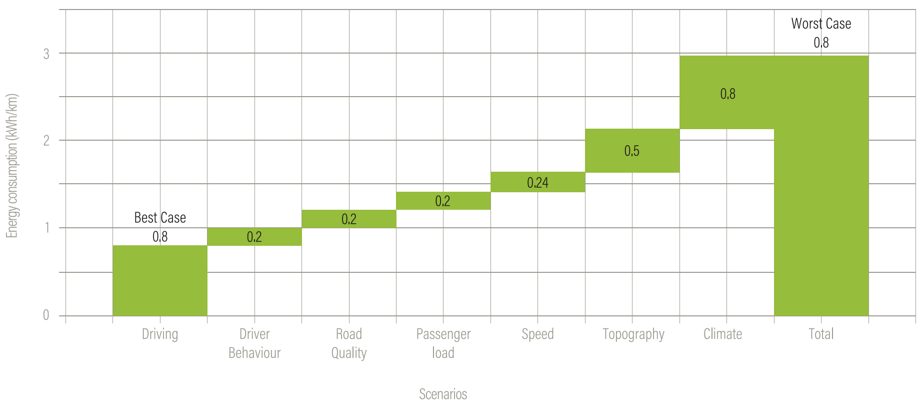


Data source: Hodge, Jeffers, Desai, Miller & Shah, 2019

2.6. Effect of multiple parameters on energy consumption

In India, electric buses are still in the pilot phase. Experimental studies and research are going on to establish the impact of different driving and environmental conditions on energy consumption. Figure 7 shows the effect of different parameters on energy consumption rates.

Figure 7 | **Energy consumption of e-buses under varied scenarios**



Data source: Kok et al, 2017

Under the best-case scenario, an e-bus consumes 0.8 kWh/km. This could go up to 2.94 kWh/km in the worst-case scenario. Adverse conditions such as driving behavior, road quality, passenger load, bus speed, topography and climatic conditions have an impact on the energy consumption of an e-bus. This leads to range anxiety, a requirement for bigger batteries, and eventually higher vehicle cost. All possible parameters must be kept in mind while planning for e-bus operations. The variation in driving speed and elevation in the route also causes faster energy consumption rates.

2.7. Comparison of E-bus performance with alternative options

TThe performance of different powertrains used in buses, such as CNG, diesel, fuel cell, battery electric buses, and series and parallel hybrid buses, were studied (Kivekäs et al, 2018) under varying driving conditions such as speed, stops per km, aggressive driving, cruise percentage and passenger capacity (Table 2). The Pearson correlation analysis was used for sensitivity analysis of these conditions on the bus types. The results showed that the energy consumption of CNG buses was higher than that of diesel buses. It also suggests that diesel buses consume more energy while carrying a higher number of passengers. Amongst all the bus types, the electric buses showed the least variation in energy consumption under different driving conditions.

Table 2 | **Comparative performance analysis of different buses under different performance conditions**

Powertrain	Pros	Cons
CNG	+Energy consumption influenced less by the agressiveness compared to the diesel bus	– Highest consumption and statistical dispersion of consumption
Diesel	+Lower consumption and consumption dispertion than with the CNG powertrain	– More affected by the agressiveness of the driving than the CNG powertrains
Parallel Hybrid	+Can yield lower consumption dispertion than series hybrid on suitable routes	– High consumption on unsuited routes with too high agressiveness and stop frequency
Series Hybrid	+Suitable for any kind of route, consistent performance	– Can have higher consumption dispersion than parallel hybrid on suburban routes
FCH	+Lowest energy consumption of hybrid powertrains	– Higher statistical dispersion of consumption compared to series hybrid
Battery electric	+Lowest energy consumption and consumption dispersion	– Limited range

Data source: Kivekäs, Lajunen, Vepsäläinen & Tammi, 2018

[41] Khandekar, Aditya, Rajagopal, Deepak, Abhyankar, Nikit, Deorah, Shruti, and Phadke, Amol. The Case for All New City Buses in India to be Electric. United States: N. p., 2018. Web. doi:10.2172/1485102.

[42] Minutes of the Meeting with State Transport Undertakings and State Transport Secretaries held on 11thApril, 2017 at IHC, New Delhi (https://dhi.nic.in/writereaddata/UploadFile/Download%20File.pdf)

[43] Du, Jiuyu & Li, Feiqiang & Li, Jianqiu & Wu, Xiaogang & Song, Ziyou & Zou, Yunfei & Ouyang, Minggao, 2019. "Evaluating the technological evolution of battery electric buses: China as a case," Energy, Elsevier, vol. 176(C), pages 309-319.

Annexure 3: Methodology & Input Details

3.1 TCO Methodology

The Total Cost of Ownership (TCO) of any mode of transport is a function of its capital and operational cost over the period of service. The inputs that constitute the TCO calculation are as follows:

1. Capital Cost
   a. Vehicle Cost
   b. Charging infrastructure Cost
   c. Tax
   d. Insurance
   e. Financing cost
   f. State incentives

2. Operational Cost
   a. Staff Cost
   b. Fuel Cost
   c. Maintenance Cost (inclusive of battery replacements for e-buses)

In addition to the above inputs, certain assumptions have been made for the TCO calculations. These assumptions have been arrived at after discussions with several bus agencies and OEMs. The assumptions include:

1. Vehicle utilization (no. of km traveled a day/ no. of days operational in a year)
2. Life/operational period of a vehicle discount rate (which indicates the 'time value of money')
3. Resale value of vehicles
4. Number of battery replacements
5. Charging infrastructure required

This methodology takes a realistic approach at calculating costs. There are several different analysis methodologies that use a bottom-up approach[33] for estimating the TCO. The analysis presented accounts for prevalent capital and operational costs. It includes sensitivity analysis due to future variations in the cost components and their impact on the TCO.

The selection of bus type for the TCO calculation is based on requirements of urban bus services, which is characterized by a daily drive distance of 200 km.[34] In India, most buses are either 9 meters or 12 meters in length. Given India's tropical conditions, air conditioning was included in the TCO calculations. Studies consider curb mass, all-electric range, driving power and speed, energy consumption rate, battery chemistry and motor technologies to evaluate e-buses.[35] In this report, a similar approach was adopted. Various bus types, daily drive range and fuel consumption were taken into account for the TCO calculation and subsequent sensitivity analysis. The two e-bus types under evaluation are:

1. 12m AC electric bus with 320 kwh battery denoted as e-Bus (12m_AC_BB)
2. 12m AC electric bus with 125 kwh battery denoted as e-Bus (12m_AC_SB)

[33] Khandekar, Aditya, Rajagopal, Deepak, Abhyankar, Nikit, Deorah, Shruti, and Phadke, Amol. The Case for All New City Buses in India to be Electric. United States: N. p., 2018. Web. doi:10.2172/1485102.

[34] Minutes of the Meeting with State Transport Undertakings and State Transport Secretaries held on 11thApril, 2017 at IHC, New Delhi (https://dhi.nic.in/writereaddata/UploadFile/Download%20File.pdf)

[35] Du, Jiuyu & Li, Feiqiang & Li, Jianqiu & Wu, Xiaogang & Song, Ziyou & Zou, Yunfei & Ouyang, Minggao, 2019. "Evaluating the technological evolution of battery electric buses: China as a case," Energy, Elsevier, vol. 176(C), pages 309-319.

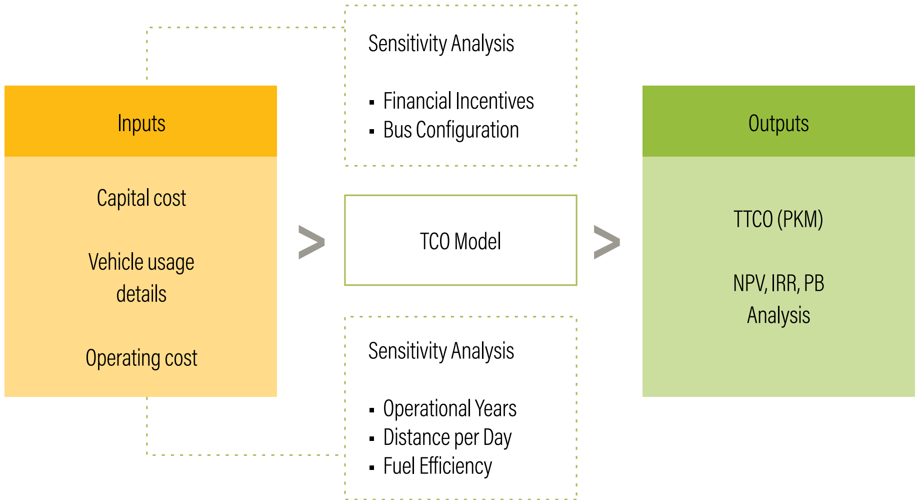
For the purpose of the calculation, the 12m_AC_BB is coupled with a slow charger while the 12m_AC_SB uses fast charging. This helps to understand the effect of various charging infrastructure costs on the TCO. The TCO is then compared with diesel buses that are currently under operation in Bengaluru:

1. 12-meter AC diesel Volvo bus BS III/ IV, denoted as Diesel Volvo Bus (AC)
2. 12-meter AC diesel Corona bus BS III/ IV (AC, low-end), denoted as Diesel Bus (AC, low-end)

The two AC diesel buses are used for long- and short-range routes in the city, and are comparable to the e-buses mentioned above. A discount factor of 10% is used for all categories of buses. A resale value of 20%[36] for e-buses and 14.9% for diesel buses[37] is employed in the analysis.

The TCO model is laid out in a chart in Figure 1. The numerical inputs in the TCO model are discussed later in this section.

Figure 1 | **Methodology of TCO**



The formula used for calculation of TCO is:

$$TCO = \frac{\left(Capex - \frac{RV}{(1+r)^N}\right) CRF + \frac{1}{N} \sum \frac{opex}{(1+r)^n}}{Mileage}$$

Where,
RV is residual value at the end of life, R is discount factor, N is lifetime in years, Mileage is the distance travelled per year, and CRF is Capital Recovery Factor; itself a function of the year:

$$CRF = \frac{r(1+r)^n}{(1+r)^n - 1}$$

[36] Kumar, Parveen & Chakrabarty, Subrata. (2020). Total Cost of Ownership Analysis of the Impact of Vehicle Usage on the Economic Viability of Electric Vehicles in India. Transportation Research Record Journal of the Transportation Research Board. 2674. 10.1177/0361198120947089.

[37] Christian Krelling & Madhav G. Badami (2020) CNG and diesel urban buses in India: A life-cycle cost comparison, International Journal of Sustainable Transportation, 14:8, 591-605, DOI: 10.1080/15568318.2019.1594468

3.2. Inputs of TCO models

3.2.1 General Inputs

Travel details				
Number of Vehicles	1			
Life of Vehicles (Years)	10			
Daily drive distance	200			
Annual number of days of operation	317			
Annual drive distance (kms)	63400			
Total distance travel (kms)	634000			
Lib cost (USD/kWh)	156			
USD to INR	74			
General Inputs	**e-Bus (12_AC_BB)**	**e-Bus (12_AC_SB)**	**Diesel Bus (AC, High End)**	**Diesel Bus (AC, Low End)**
Discount rate (%)	10	10	10	10
Resale rate (%)	20	20	14.9	14.9
12 meter Buses				
Fixed Cost				
Vehicle Cost	**e-Bus (12_AC_BB)**	**e-Bus (12_AC_SB)**	**Diesel Bus (AC, High End)**	**Diesel Bus (AC, Low End)**
Purchase Cost (₹)	1,75,00,000.00	88,00,000.00	88,00,000.00	58,07,000.00
Tax (₹)	8,75,000.00	4,40,000.00	24,64,000.00	16,25,960.00
Insurance (₹)	1,57,500.00	79,200.00	79,200.00	52,263.00
Total Financial Incentive (₹)	-	-	-	-
Charging Infrastructure Cost	**e-Bus (12_AC_BB)**	**e-Bus (12_AC_SB)**	**Diesel Bus (AC, High End)**	**Diesel Bus (AC, Low End)**
No. of Slow Charge (SC)	1.00			
Cost of SC per unit (₹)	7,50,000.00	7,50,000.00		
Total Cost of SC (₹)	7,50,000.00			
No. of Fact Charger (FC)		0.33		
Cost of FC per unit (₹)	37,50,000.00	15,00,000.00		
Total Cost of FC (₹)	-	4,95,000.00		
Installation Cost	1,50,000.00	99,000.00		
Cabling Cost	1,50,000.00	99,000.00		
Total Incentive for Charging Infra (₹)	-	-		
Variable Cost				
Staff Cost	**e-Bus (12_AC_BB)**	**e-Bus (12_AC_SB)**	**Diesel Bus (AC, High End)**	**Diesel Bus (AC, Low End)**
Staff Cost (₹/month)	1,20,000.00	1,20,000.00	1,20,000.00	1,20,000.00
Other Support Staff Cost (₹/month)	30,000.00	30,000.00	30,000.00	30,000.00
Average Fuel Cost				
Fuel Cost (₹/kWh; ₹/L)	6.00	6.00	76.00	76.00
Mileage (km/kWh; km/L)	0.77	0.77	2.75	3.00
Maintenance Cost				
Annual Maintenance Cost (₹)	4,57,589.50	4,57,589.50	17,23,212.00	10,34,054.00
Other Consumables (₹)				
Other Misc (₹)				
Battery Replacement Cost				
No. of battery replacements	1.00	2.00		
Capacity of batteries (kWh)	320.00	125.00		
Battery Cost (/kWh)	11,544.00	11,544.00		
Total battery Cost	36,94,080.00	14,43,000.00		
Battery replacement Charge	7,38,816.00	2,88,600.00		
Maintenance Cost	1,84,704.00	72,150.00		

Note:

Here, Tax – 5% for e-bus, 28% for diesel bus. Insurance – 0.90% of purchase cost of bus

3.2.2 9m Buses

9 meter Buses				
Fixed Cost				
Vehicle Cost	**e-Bus (12_AC_BB)**	**e-Bus (12_AC_SB)**	**Diesel Bus (AC, High End)**	**Diesel Bus (AC, Low End)**
Purchase Cost (₹)	1,22,97,000.00	79,90,000.00	60,00,000.00	34,00,000.00
Tax (₹)	7,37,820.00	4,49,400.00	16,80,000.00	9,52,000.00
Insurance (₹)	1,10,673.00	67,410.00	54,000.00	30,600.00
Total Financial Incentive (₹)	-	-	-	-
Charging Infrastructure Cost	**e-Bus (12_AC_BB)**	**e-Bus (12_AC_SB)**	**Diesel Bus (AC, High End)**	**Diesel Bus (AC, Low End)**
No. of Slow Charge (SC)	1.00			
Cost of SC per unit (₹)	7,50,000.00	7,50,000.00		
Total Cost of SC (₹)	7,50,000.00			
No. of Fact Charger (FC)		0.33		
Cost of FC per unit (₹)	37,50,000.00	15,00,000.00		
Total Cost of FC (₹)	-	4,95,000.00		
Installation Cost	1,50,000.00	99,000.00		
Cabling Cost	1,50,000.00	99,000.00		
Total Incentive for Charging Infra (₹)	-	-		
Variable Cost				
Staff Cost	**e-Bus (12_AC_BB)**	**e-Bus (12_AC_SB)**	**Diesel Bus (AC, High End)**	**Diesel Bus (AC, Low End)**
Staff Cost (₹/month)	1,20,000.00	1,20,000.00	1,20,000.00	1,20,000.00
Other Support Staff Cost (₹/month)	30,000.00	30,000.00	30,000.00	30,000.00
Average Fuel Cost				
Fuel Cost (₹/kWh; ₹/L)	6.00	6.00	76.00	76.00
Mileage (km/kWh; km/L)	0.77	0.77	2.75	3.00
Maintenance Cost				
Annual Maintenance Cost (₹)	4,57,431.00	4,57,431.00	8,91,404.00	6,68,553.00
Other Consumables (₹)				
Other Misc (₹)				
Battery Replacement Cost				
No. of battery replacements	1.00	2.00		
Capacity of batteries (kWh)	320.00	125.00		
Battery Cost (₹/kWh)	11,544.00	11,544.00		
Total battery Cost (₹)	36,94,080.00	14,43,000.00		
Battery replacement Charge (₹)	7,38,816.00	2,88,600.00		
Maintenance Cost (₹)	1,84,704.00	72,150.00		

Note:

Here, Tax – 5% for e-bus, 28% for diesel bus. Insurance – 0.90% of purchase cost of bus.

Source

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ABOUT WRI

WRI India, an independent charity legally registered as the India Resources Trust, provides objective information and practical proposals to foster environmentally sound and socially equitable development. WRI India's mission is to move human society to live in ways that protect Earth's environment and its capacity to provide for the needs and aspirations of current and future generations. Through research, analysis, and recommendations, WRI India puts ideas into action to build transformative solutions to protect the earth, promote livelihoods, and enhance human well-being.

We are inspired by and associated with World Resources Institute (WRI), a global research organization. Currently over 150 researchers work with WRI India in our offices in Delhi, Mumbai and Bengaluru.

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