Alliance for an™ Energy Efficient Economy

ASSAM STATE TRANSPORT CORPORATION (ASTC)

Roadmap for Electrification of Bus Fleet

January 2024

ASSAM STATE TRANSPORT CORPORATION (ASTC)

Roadmap for Electrification of Bus Fleet

Prepared by: Alliance for an Energy Efficient Economy (AEEE)

PROJECT TEAM

Dr Vikas Nimesh, Senior Research Associate, AEEE

Vikas Singh Suhag, Consultant, AEEE

Dr Md Saddam Hussain, Senior Research Associate, AEEE

Anmol Jain, Research Associate, AEEE

Pramod Kumar Singh, Senior Director - Research & Programs, AEEE

Suggested citation:

Nimesh, V., Suhag, V., Hussain, M.S., Jain, Anmol; & Singh, P.K. (2024). Assam State Transport Corporation (ASTC): Roadmap for Electrification of Bus Fleet. New Delhi: Alliance for an Energy Efficient Economy

https://doi.org/10.62576/ADCM4506

Disclaimer:

This report is based on the best available information in the public domain. Every attempt has been made to ensure the correctness of data. However, AEEE does not accept responsibility for the consequences of the use of such data.

Copyright:

© 2024, Alliance for an Energy Efficient Economy (AEEE) 37, Link Road, Block A

Lajpat Nagar III, Lajpat Nagar, New Delhi-110024

info@aeee.in [W] www.aeee.in

Acknowledgements

The authors would like to express their profound appreciation to Dr Satish Kumar, President and Executive Director, AEEE for providing invaluable guidance and feedback throughout the project. The authors extend their heartfelt gratitude to Sh. Rahul Das, Managing Director of Assam State Transport Corporation, for his unwavering support and invaluable guidance during the course of this endeavor.

Additionally, the authors would like to extend their sincere thanks to Mr. Anjan Deka, Divisional Superintendent at ASTC, and Mr. Biju Deka, Senior Engineer cum Deputy General Manager at ASTC, for their indispensable assistance in data collection.

Furthermore, the authors wish to express their deep appreciation to Eeshan Bhaduri, Post-doctoral Research Fellow at the Institute for Transport Studies, University of Leeds, for his expert technical review and insightful feedback, which significantly contributed to the enhancement of this report.

Executive Summary

Assam, a north-eastern state in India, is renowned for its diverse landscapes, rich cultural heritage, and unique biodiversity. The state stands at a pivotal juncture in its development journey as it grapples with the interplay of a growing economy and an expanding population. In this situation the need for efficient and sustainable transportation solutions has become increasingly evident.

In 2021, the Government of Assam through the Electric Vehicle Policy of Assam, 2021 adopted the goal of converting its public transport fleet into electric buses by 2030.[1] To assist Assam achieve this ambition, Alliance for an Energy Efficient Economy (AEEE) has partnered with the Assam State Transport Corporation (ASTC) to prepare a roadmap for transitioning ASTC's bus fleet to electric-buses (e-buses). This report is the outcome of this partnership and elucidates the confluence of factors that underscore the necessity for developing fleet electrification roadmap for ASTC.

ASTC is a Government of Assam owned road transport corporation in Assam. It has a fleet of of 1,537 buses across 9 main divisions and 4 city services to provide transport services both inside and outside Assam. ASTC is a loss making entity and has to rely of government funding support to continue its operations. Due to shortage of funds, ASTC is unable to undertake regular maintenance of its fleet and over 320 of its buses were awaiting repairs as of April 2023. As such it has growing reliance on private operators. Given the rising population and growing urbanization, the demand for public transport in Assam is projected to increase rapidly, and to cater to this demand, ASTC will require a fleet of about 2,450 buses by 2033. If ASTC continue continues using its existing fleet and adds more diesel buses to cater to growing demand, the emissions from ASTC's fleet are projected to increase from 70,250 ton CO_2 in 2023 to 115,000 ton CO_2 by 2033, i.e., 63.7% increase.

Transitioning ASTC's bus fleet to e-buses will avoid 537,000 ton CO_2 of tailpipe emission over the 2023 to 2033 period. At the same time, e-buses offer financial benefits to ASTC in the long-term due to their lower total cost of ownership, INR 73.1 / km compared to INR 80.5 / km for the long route buses and INR 69.4 / km vs INR 78.6 / km for city operations.

If ASTC move ahead with the decision of fully transitioning its bus fleet to e-busses by 2033, an investment of approximately INR 6,150 crores will be required between 2023 and 2033. Roughly 46% of thus amount will be directed towards procuring assets including -buses, batteries, and charging stations; 9% will be directed to electricity purchases; 18% will be directed to operations and maintenance, and the remaing 27% for manpower. The annual outlay of this investment is shown in Table 1.

1 Industries and Commerce Department, Government of Assam. "Electric vehicles Policy of Assam, 2021", 12 July 2021. link

Table 1: Investment Needs for ASTC's Fleet Transition to E-Buses

Year	E-buses added	Investment needed						
		E-Buses	Battery	Charging Infra	Electricity Purchase	O&M	Others2	Total
2023	15	4.4	2.6	0.7	0.6	1.4	1.3	10.9
2024	100	32.7	17.0	5.2	4.6	11.2	10.8	81.4
2025	130	50.7	24.4	12.2	10.0	23.8	24.7	145.7
2026	205.0	85.1	38.5	23.9	18.9	43.7	48.4	258.6
2027	225	108.2	46.2	38.7	29.2	65.6	77.7	365.7
2028	225	125.5	53.3	55.9	40.2	87.5	110.8	473.3
2029	300	164.1	77.0	78.3	55.2	116.8	158.2	649.5
2030	300	179.5	85.2	102.8	71.0	146.0	211.7	796.4
2031	300	192.1	97.4	129.0	87.8	175.4	272.1	853.7
2032	300	199.1	102.6	156.1	105.5	204.7	340.2	1,108.2
2033	350	220.1	109.1	186.2	126.8	239.0	425.4	1,306.5

This report explores the current state of bus transportation in Assam, assess the feasibility and advantages of electrification, and propose a roadmap for its implementation. By undertaking this analysis, the report aims to provide ASTC with a comprehensive understanding of the potential benefits and strategic considerations surrounding the electrification of ASTC's bus fleet, ultimately contributing to the state's journey towards a sustainable and inclusive future.

- Section 1 presents background of the study, and highlights the objectives and limitations.
- Section 2 presents the situational analysis of ASTC.
- Section 3 presents case studies for e-bus deployment in India and hilly areas globally, and highlights relevant learnings for ASTC.
- Section 4 presents a comparison of internal combustion and e-bus technologies.
- Section 5 presents the key areas that ASTC should prioritise to successfully transition its bus fleet to e-buses.
- Section 6 presents summary of investment requirements for ASTC to undertake bus fleet transition and summarizes the environmental benefits of such transition.
- Section 7 presents the way forward for ASTC in the context of this roadmap.

2 Others covers ASTC's administration costs and costs related to charging infrastructure (other than equipment cost)

Acronyms

- AI – Artificial Intelligence
- APDCL - Assam Power Distribution Company Ltd.
- API – Application Programming Interface
- ASTC - Assam State Transport Corporation
- BMS - Battery Management System
- CNG – Compressed Natural Gases
- DC – Direct Current
- E-Buses – Electric Buses
- E-buses – Electric Buses
- EV – Electric Vehicle
- FAME – Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India
- FY – Financial Year
- GCC – Gross Cost Contract
- GCC- Gross Cost Contract
- GHG -Green House Gases
- GVW - Gross Vehicle Weight
- HRTC - Himachal Pradesh Road Transport Corporation
- ICE – Internal Combustion Engine
- INR – Indian Rupees
- LFP - Lithium-Iron-Phosphate
- li-ion - lithium ion
- LTO - Lithium Titanate Oxide
- NCC - Net Cost Contracting
- NDC- Nationally Determined Contribution
- NMC - Nickel-Manganese-Cobalt
- OEM – Original Equipment Manufacturer
- OEM - Original Equipment Manufacturers
- PMPML - Pune Mahanagar Parivahan Mahamandal Ltd.
- PPP – Public-Private Partnership
- RFTA - Roaring Fork Transportation Authority
- SDG - Sustainable Development Goals
- SoC - State of Charge
- STU – State Transport Units
- TCO – Total Cost of Ownership
- TSRTC- Telangana State Road Transport Corporation
- USD- US Dollar
- WBTC - West Bengal Transport Corporation

Table of Contents

CHAPTER 1

Introduction

Nestled in the north-eastern corner of India, Assam boasts a breathtaking tableau of lush tea gardens, meandering rivers, dense forests, and the majestic Himalayan foothills. Known as the ‘Land of the Red River and Blue Hills’, Assam’s cultural tapestry is woven with diverse communities, each contributing to the state’s vibrant mosaic. Assam’s unique blend of traditions, languages, and customs has made it a microcosm of India’s incredible diversity.

In recent years, Assam has witnessed transformation in its economic landscape. At same time, the state is also experiencing significant population growth. This presents a unique set of challenges and opportunities, with transportation emerging as a pivotal element in shaping the future of the state.

Assam’s geographic diversity, ranging from remote rural areas to bustling urban centers, underscores the necessity of a robust and accessible public transportation system. The public transportation system in Assam is heavily reliant on Assam State Transport Corporation’s (ASTC) bus fleet that facilitates the movement of people within the state and fosters connectivity with neighbouring regions.

ASTC’s role in providing affordable and well-connected services to major cities and rural areas in Assam became even more pronounced in the wake of the COVID-19 pandemic and the downturn in the economy led to reduced disposable income there-by limiting population’s access to more expensive private vehicles and other commercial mobility services such as taxis.

Introduction to ASTC

ASTC is a Government of Assam owned road transport corporation in Assam, operating since 1970 and constituted under the Road Transport Corporation Act 1950 with the objective of providing an efficient, adequate, economical, and properly coordinated road transport services both inside and outside Assam. Before 1970, it operated as a wing of Transport Department since 1948. As of June 2023, ASTC had a fleet of 1,537 buses across 9 main divisions and 4 city services. A brief overview of ASTC is shown in Table 2.[3]

Table 2: Overview of ASTC

Parameter	Description
Main Division	9 - Bongaigaon, Guwahati, Jorhat, Lakhimpur, Nagaon, Silchar, Sivasagar, Tinsukia, and Tezpur
City Services	4 - Jorhat, Silchar, Tezpur, and Tinsukia
Routes	210 - Bongaigaon (52), Guwahati (40), Jorhat (22), Lakhimpur (10), Nagaon (12), Silchar (15), Sivasagar (7), Tinsukia (35), and Tezpur (17)
Fleet	1,537 (ASTC - 377, Private - 1,160)
Coverage per day	1.71 lakh km[4]
Average traffic revenue	Rs 32.74/ km (ASTC buses) and Rs 1 lakh per private bus
Staff	3,054

Need for Electrification of ASTC Bus Fleet

Environmental Considerations: As the effects of climate change become increasingly evident, there is a global push towards reducing greenhouse gas (GHG) emissions, including from the transport sector. As such, the need for a cleaner, more sustainable mode of public transportation cannot be overstated. Assam, like many regions across the globe, grapples with pressing environmental concerns, including air pollution and GHG emissions. Traditional internal combustion engine (ICE) buses contribute significantly to these issues through the release of pollutants such as particulate matter, nitrogen oxides, and carbon dioxide. Electrification of the ASTC bus fleet offers a substantial reduction in tailpipe emissions, especially when grid power that will be used to charge the e-bus batteries is increasingly renewable in nature. This transition aligns with global efforts to combat climate change and improve air quality, particularly in densely populated urban areas. The electrification roadmap presents an opportunity to convert the maximum passenger kilometre (km) of travel to zero-emission transport.

Long-term Cost Savings: While the initial investment in electric buses and charging infrastructure may be substantial, the long-term operational cost savings are substantial as e-buses have lower operating and maintenance costs compared to the ICE buses. A well-planned electrification roadmap will help ASTC identify cost savings opportunities in terms of fuel and maintenance expenses, thereby improving ASTC's financial health.

Access to Funding and Grants: The electrification roadmap can make ASTC eligible/ make application process easier for ASTC to receive financial incentives from Central Government Schemes to reduce the capital costs associated with transitioning to electric buses.

Technological Advancements: In the past few years, e-bus technology has become more reliable, efficient, and cost-effective. Battery technologies have improved, offering longer ranges and faster charging times. These advancements have made electric buses a practical and viable option for public transportation agencies such as the ASTC. Through fleet electrification roadmap, ASTC can demonstrate its commitment to embracing modern and sustainable transportation solutions.

Independence from Energy Price Volatility: Electrifying the Assam State Transport Corporation (ASTC) bus fleet is essential to alleviate its vulnerability to the volatile nature of diesel fuel prices. Shifting

3 ASTC. "Bus Schedules". link

4 Estimate based on information shared by ASTC on 27 June 2023. No. of ASTC buses = 377, Run km = 146.62 lakh km. This average per bus values is then extended to private buses to estimate total run km.

to electric buses ensures stable and predictable energy costs, shielding ASTC from the financial uncertainties caused by fluctuating diesel prices. By making this strategic move, ASTC can optimize budget allocation, realize long-term cost savings, and enhance its overall sustainability while providing reliable and affordable transportation services to the community.

Reduction in Noise Pollution: Electric buses are quieter and produce less noise pollution, contributing to a more peaceful and livable urban environment. This noise reduction enhances the well-being of urban residents by mitigating daily disruptions and stress caused by transportation-related noise pollution.

Economic Development, Job Creation and Skill Development: The electrification of the bus fleet offers a multifaceted opportunity for economic development, job creation, and skill development. Local manufacturing and supply chains for electric buses and charging infrastructure can stimulate job growth. E-bus operation and maintenance require specialized skills, leading to the creation of employment opportunities. Moreover, investing in skill development programs for bus drivers, technicians, and support staff in electric vehicle technology fosters a skilled workforce. This transition can also position regions as hubs for clean transportation technology and innovation, attracting investment and enhancing their economic resilience, all while contributing to a cleaner and more sustainable urban environment.

Achievement of Developmental Goals: The electrification of the Assam State Transport Corporation (ASTC) bus fleet is a strategic move that aligns with various Sustainable Development Goals (SDGs). By adopting electric buses, ASTC is contributing to more efficient and sustainable urban mobility (SDG 11), reducing air pollution and promoting clean energy (SDG 7), improving public health and well-being (SDG 3), fostering innovation and resilient infrastructure (SDG 9), mitigating climate change impacts (SDG 13), and creating job opportunities for economic growth (SDG 8).

Key Considerations

The electrification strategy for the ASTC bus fleet should consider the following key aspects:

- Assam is experiencing a population growth trend that is expected to drive an uptick in the demand for public transportation.
- The electrification of the bus fleet represents symbolizes the integration of the transport and electricity sector. Consequently, ASTC must establish strong coordination with the Assam Power Distribution Company Ltd. (APDCL) as the distribution grid may require upgrades to accommodate increased electricity demand and changes in load patterns and tie up new generation capcity while considering its own carbon footprint. In addition, it should explore incorporation of rooftop solar systems into its charging infrastructure.
- While the operating expenses for e-buses are lower than those of ICE buses, the significant upfront costs associated with e-buses pose a potential challenge for ASTC as it currently operates at a loss of over 100 crores annually. [5] Therefore, ASTC should actively explore and utilize all available government schemes for grant funding of e-buses.
- Establishing a dependable charging infrastructure is paramount for the effective scheduling and operations of e-buses. ASTC needs to identify suitable locations for charging stations, in consultation with APDCL, and invest in installation of chargers.
- ASTC will require a trained workforce to operate and maintain e-buses which have distinct maintenance pre-requisites compared to ICE buses, necessitating technicians with specialized expertise in handling electric drivetrains and battery storage systems.
- While e-buses are environmentally friendly in terms of emissions, there are environmental concerns associated with the disposal of lithium-ion batteries. ASTC should proactively explore

5 The Sentinel. "Assam State Transport Corporation leasing out 222 off-road buses", 29 April 2023. link

recycling and disposal methods for batteries at the initial stages of fleet electrification planning, and also investigate the potential use of second-life batteries for energy storage applications.

- Assam's climate could present distinctive challenges for the operations of e-buses, particularly during the monsoon season. The challenges include loss of battery performance due to excessive humidity and water exposure, water ingress during heavy rainfall can lead to short circuits and damage electronics, and disruption to the charging infrastructure and electrical grid.

Objectives

The study aims to provide a framework for ASTC to assess the costs and benefits of electrifying its bus fleet and to subsequently take informed decisions to transition its bus fleet to e-buses. The study builds on ASTC's experience of successful trail of e-buses in 2017 and subsequent operation of 15 e-buses. The study is undertaken in a way that can be replicated for other Himalayan states as well. This report addresses the transport-related emission in Assam by facilitating the rollout of electric public buses on identified intra-city and inter-city routes which are currently catered by internal combustion engine (ICE) buses.

ASTC Experience with E-Bus

In 2017, ASTC in collaboration with Tata Motors tested 9 m e-bus in Guwahati for a period of seven days. The e-bus offered free transport service to the FIFA team and devotees from Paltan Bazaar to Maa Kamakhya Temple.

Approach

The approach for the study to electrify ASTC's bus fleet, shown in Figure 1, involves the steps:

- Conduct existing situation analysis of bus services in the state and assess the operations and service levels.
- Evaluate the e-bus and charging infrastructure technology.
- Review of national and international e-bus deployment case studies.
- Assessment of viable business models for e-bus fleet deployment.

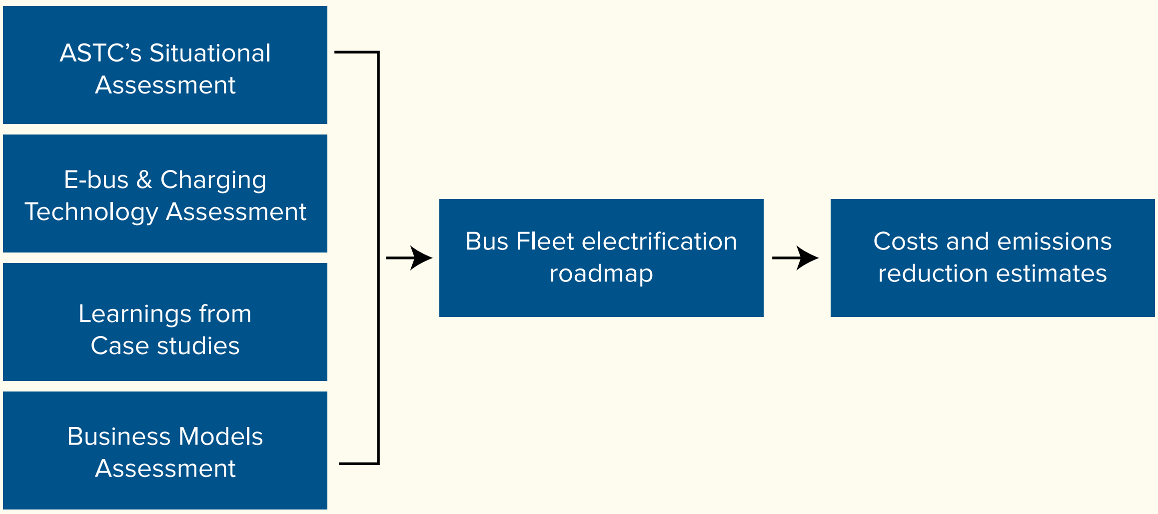


Figure 1: Approach for ASTC Buss Fleet Electrification

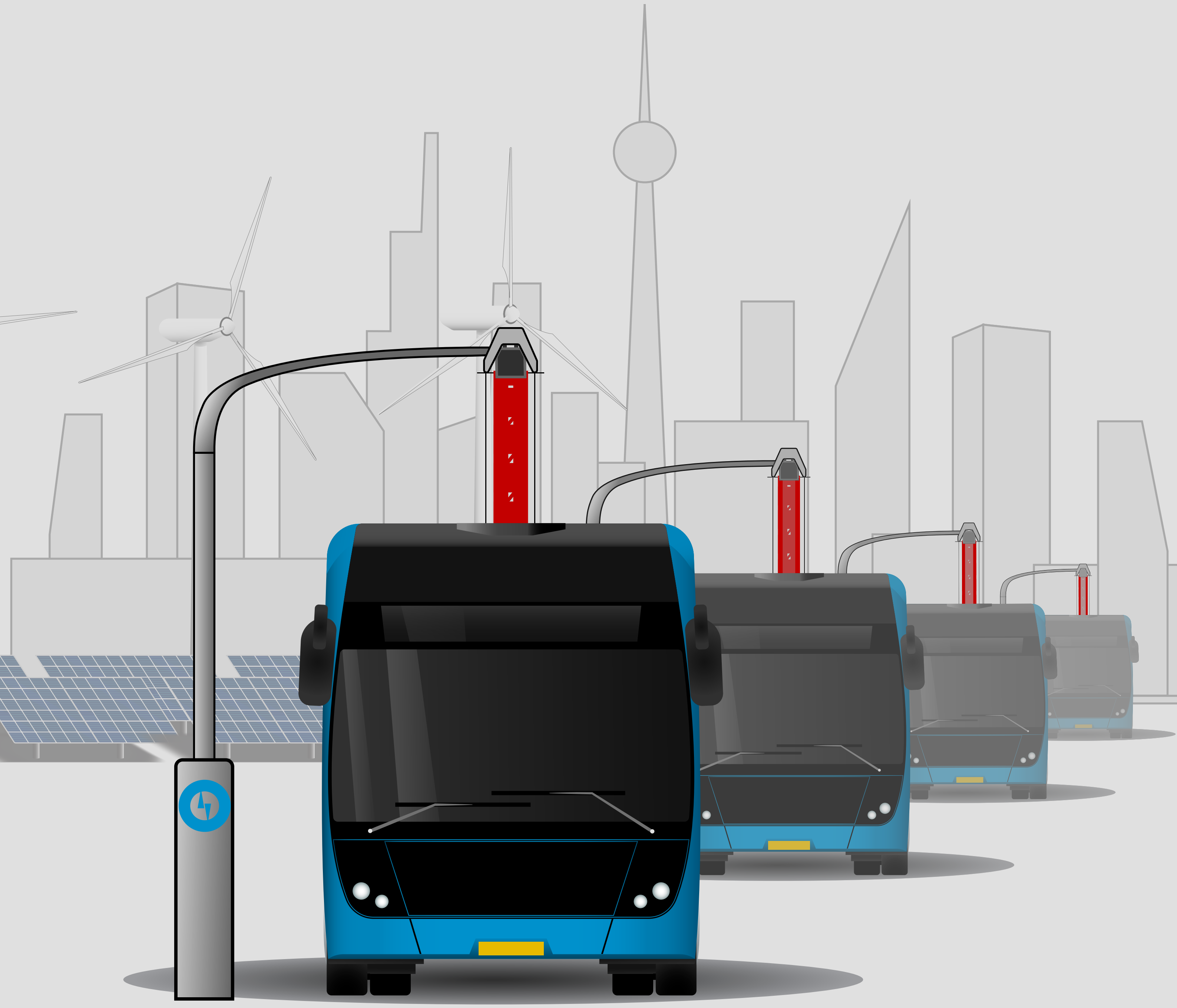
Limitations

The study is subject to the following limitations:

- The research primarily relies on secondary sources and discussions with stakeholders, as no primary research was conducted. However, it's worth noting that discussions with ASTC within the defined scope of work were ensured.
- Buses come in various seating capacities and dimensions. While the technology discussed in the report is universally applicable to buses of all sizes, specific operational aspects like costs and battery sizes may vary.
- The analysis and data collection are based on publicly available sources of information, including industry studies, journals, publications, and various research databases. However, it's important to acknowledge that the data itself has not been independently verified by the authors.
- This study covers on Scope 1 emissions for ASTC.

Greenhouse Gas Protocol categorises emissions into 3 groups:

- Scope 1 covers emissions from sources that an organisation owns or controls directly. For ASTC this would cover emissions from burning fuel from its bus fleet.
- Scope 2 are emissions that an organization causes indirectly and come from where the energy it purchases and uses is produced. For ASTC this will cover emissions related to electricity used for charging batteries.
- Scope 3 encompasses emissions that are not produced by the organzation itself and are not the result of activities from assets owned or controlled by them, but by those that it's indirectly responsible for up and down its value chain. An example of this is when organizations buy, use and dispose of products from suppliers. For ASTC, this will include all emissions not covered within the scope 1 and 2 boundaries



CHAPTER 2

Performance Analysis of ASTC

ASTC is a Government of Assam owned road transport corporation in Assam, operating since 1970 and constituted under the Road Transport Corporation Act 1950 with the objective of providing an efficient, adequate, economical, and properly coordinated road transport services both inside and outside Assam. ASTC provides reliable, safe, dependable and comfortable passenger service across rural and hilly roads, highways as well as city roads across the state. In addition, it provides interstate transport services to the neighbouring states.

- Bus fleet: Recent years have witnessed decrease in ASTC's bus fleet and its utilization has fallen. As of April 2023, ASTC faced financial constraints that prevented it from funding the necessary repair and maintenance of its bus fleet, resulting in a backlog of 321 buses awaiting repairs at terminals.[6] As a result, ASTC has increased reliance on private operated buses to meet the transportation requirements.
- Operational efficiency: The occupancy ratio for ASTC buses has remained around 0.8, and the average mileage of its bus fleet has improved to 4.7 km/l in FY22 compared to 3.7 km/l in FY13. The cost per km have increased to INR 43.40 in FY 22 compared to INR 21.8 in FY13. The earnings per km have grown at a relatively slower pace reaching INR 9.30 in FY22 compared to INR 5.90 in FY13.
- Financials: ASTC's revenue has outgrown its expenditure and it has accumulated large losses over th tears. In FY22, ASTC earned INR 80.2 crore. However, the net expenditure for the same period was INR 186.7 crore. In 2019-20, the total loss amount of the corporation was INR 82.6 crore, while in FY21 it incurred a loss of INR 97.9 crore.[7]

6 Daji World. "Assam State Transport Corporation incurs losses, unable to repair buses", April 2023. link

7 Daji World. "Assam State Transport Corporation incurs losses, unable to repair buses", April 2023. link

- Staff: To reduce expenditure on manpower, ASTC has reduced its staff from 2,153 in FY13 to 1,078 in FY 22 (more than 50% reduction) and relying more on contractual staff.
- Private sector engagement: ASTC has conracted around 1,300 private operated buses to augment its own bus fleet. From the private operate buses, ASTC makes revenue of about INR 68,500 per bus per month.
- Emissions: It is estimated that ASTC buses (including private operated buses) cover around 600 lakh km each year.[8] Based on an average mileage of 4 km/l of diesel, it is estimated that ASTC consumes around 150 lakh liters of diesel each year and emitting 70,250 ton CO_2.[9,10]
- E-buses: ASTC has been operating 15 e-buses since FY20 and ran a tender to procure 100 e-buses in FY 24.

Table 3: ASTC Performance Data

	Unit	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
Average vehicles held	Number	665	751	815	1,090	1,074	865	953	929	892	822
Average vehicles on road	Number	540	559	570	668	650	634	639	705	523	443
Fleet utilisation	%	81.2%	74.4%	69.9%	61.3%	60.5%	73.3%	67.1%	75.9%	58.6%	53.9%
Total km operated	Lakh km	248.5	279.3	284.5	300.7	266.9	291.4	245.8	234.2	160.9	139.5
Monthly average gross income	INR in Lakh	450.4	537.8	567.9	608.4	554.7	644.6	643.6	696.2	509.5	504.3
Monthly average net income	INR in Lakh	136.6	138.3	148.4	244.7	167.9	187.3	218.5	286.0	241.2	254.8
Earning per km	INR	21.8	23.1	24.0	24.3	24.9	26.1	31.4	35.7	38.0	43.4
Cost per km*	INR	15.2	17.2	17.7	14.5	17.4	18.8	20.8	19.7	20.0	21.5
Occupancy Ratio	%	78.2	71.4	73.8	75.6	74.5	77.5	87.1	85.5	79.4	82.6
Average mileage (km per litre)	Km/l	3.7	3.7	3.7	3.8	3.7	3.7	3.8	4.0	4.5	4.7
Earning per litre	Rs.	5.9	6.2	6.4	6.4	6.7	7.1	8.3	9.0	8.4	9.3
Staff	Number	2,153	2,053	1,940	1,815	1,607	1,480	1,349	1,199	1,050	1,078
Contractual staff	Number				2,172	1,972	1,773	2,040	2,307	2,481	2,264

8 Estimate based on information shared by ASTC on 27 June 2023. No. of ASTC buses = 377, Run km = 146.6 lakh km. This average per bus values is then extended to private buses (1,160 in number) to estimate total run km, with as assumption that private buses run an average of 100% more distance than ASTC buses.

9 Government of Assam. "Assam Statistical Handbook". Km/ l values average for 2012-12 to 2021-22 period.

10 One liter diesel creates 2.68 kg of CO2. link

	Unit	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
Private operated buses	Number	1,344	1,300	1,112	1,009	1,139	1,272	1,357	1,339	713	1,234
Monthly average earning from private buses	INR in Lakh	76.3	72.5	61.3	56.8	55.0	66.4	80.2	90.7	37.6	84.5
Stations and sub-stations	Number	133	133	133	133	133	133	133	133	133	133
E-buses	Number								15	15	15
*Other than pay, depreciation and interest											

Source: Government of Assam, “Statistical Handbook”.

ASTC’s overview shows that ASTC’s own bus fleet has been reducing sharply over the last few years and it is relying on private operated buses to meet growing transportation demand with increasing population and economic activity in Assam. The high occupancy ratio of around 80%, against the commonly recommended 60% occupancy ratio, indicates that ASTC is unable meet he growing travel demand efficiently. Due to increasing costs and lack of revenue increase commensurate to cost increase has led to ASTC to accumulate financial losses. ASTC is taking up measures to reduce its staff cost through outsourcing crew recruitment. A transition to e-bus can reduce fuel costs as well as improve financial position. In summary, ASTC’s performance analysis indicates the need to improve overall service levels and a necessity to electrify its bus fleet.

CHAPTER 3

Case Studies of Electric Buses in Hilly Terrain

India Case Study: Pune & Pimpri-Chinchwad

Pune Mahanagar Parivahan Mahamandal Ltd. (PMPML) is the public transport service provider for the Pune Metropolitan Region that covers the jurisdictions of Pune Municipal Corporation, Pimpri Chinchwad Municipal Corporation, three cantonment areas and areas around these regions. PMPML began procurement of 150 e-buses (25 Olectra K7 buses and 125 Olectra K9 buses) in February 2019. In January 2020, 119 e-buses were inducted operating from Bhekrainagar depot and Nigdi depot.

The electric buses were procured on a Gross Cost Contract (GCC) with a 10-year service contract, extendable by two years based on the contractors' performance. For operations, the conductor is provided by the PMPML while the driver and the maintenance staff are provided by the operator. PMPML pays a fixed cost per km operated to the operator of Rs 40.43 for 9-meter buses and Rs 58.5 for 12-meter buses, with 225 as the assured km per bus per day. For the charging of buses, 75 chargers (one charger for two buses) have been installed, as shown in Table 4.

Table 4: Type and Number of Chargers at E-Bus Depots in PMPML

	Bhekrainagar Depot	Nigadi Depot	Total Chargers
Slow chargers (80 kW)	41	28	69
Fast chargers (150 kW	4	2	6
Total Chargers	45	30	75

Source: ITDP India. "Guidance for Electric Buss Rollout in Indian Cities", June 2022.

A comparison of ICE and e-buses operated by PMPML is presented in Table 5.

Table 5: Comparison of PMPML buses

Parameter	Diesel Bus	CNG Bus	Nigadi Depot		Bhekrainagar Depot	
			12 m E-Bus	9 m E-Bus	12 m E-Bus	9 m E-Bus
Operated km/ bus/ day	208	208	182	229	229	205
Passengers/ bus/ day	587	587	795	795	795	795
Energy consumption per km (kWh-eq./ km)	2.82	2.89	1.3	1.1	1.3	1.1
Mileage	3.5 km/ l	2.9 km/ kg	0.8 km/ kWh	0.9 km/ kWh	0.8 km/ kWh	0.9 km/ kWh
Mileage per unit of energy (km/ kWh-eq.)	0.35	0.35	0.8	0.9	0.8	0.9
Average route length (km)	22	22	21	21	26	26
Fuel cost per km (Rs/ km)	19.5	18.6	6.6	5.8	6.6	5.8
Cost per km (Rs/ km)	90.6	72	75.1	56.1	75.1	56.1
Earnings per km (Rs/km)	39.6	39.6	36.0	30.7	45.8	37.3
Cancelled km	21%	21%	14%	5%		
Total cost of ownership (Rs/ km)	131	82	88	68	88	68

Source: ITDP India. "Guidance for Electric Buss Rollout in Indian Cities", June 2022.

A comparative analysis of e-buses between PMPML and Hyderabad bus service (case study below) is shown in Table 6.

Table 6: Comparison of e-bus operations in Pune & Pimpri-Chinchwad and Hyderabad

Parameter	Pune E-Bus	Hyderabad E-Bus
Km/ bus/ day	225	351
Energy Efficiency of Bus (kWh/ km)	1.30	0.98
Cost per km (excluding personnel cost and fuel cost)	58.50	33.12
Fuel cost per km (Rs/ km)	6.6	8.0
Average route length (km)	26	44

Takeaways:

- The TCO of e-buses depends on several factors including the daily run kms. Since the e-buses have a higher fixed cost compared to the ICE buses, its TCO can relatively lower than the ICE buses as the usage increases.

- The battery capacity of e-buses decreases over the lifetime. Therefore, if higher utilization routes will be selected then more e-buses will be required for the same level of service in the future or opportunity charging needs to be considered during planning phase itself.[11]
- Selection of routes with high ridership for electrification ensures that the benefits of e-buses are maximized.
- Energy efficiency of e-buses is linked not only to length of routes, but it also affected by parameters including driver training, traffic conditions, and loading on the bus. As such routes with consistent and predictable ridership should be prioritised for most efficient use of battery. A predictable ridership means a predictable load on the bus and predictable battery uses.
- Ridership should be prioritised over coverage for e-buses as it avoids the requirement of additional charging station on longer routes that often run through sparsely populated areas.
- E-buses are suitable for operating on both congested and non-congested routes. ICE vehicles burn fuel when idling and have very poor efficiency at low speeds. E-buses, on the other hand, consume a negligible amount of energy when stationary, and have comparatively better efficiency at low speeds - especially in stop-and-go traffic conditions.
- Route-wise electrification can be an effective strategy for optimal utilization of the electric buses, charging infrastructure and investments.
- E-buses typically have a limited range compared to their ICE counterparts, and charging can take several hours. As such, charging strategy should be considered in scheduling and operational efficiency of bus fleet.
- The performance of e-buses depends on the quality of the batteries. Ensuring that the batteries are reliable and have a long lifespan is essential to avoid frequent replacements, which can be costly.

India Case Study: Hyderabad

Telangana State Road Transport Corporation (TSRTC) participated in the Expression of Interest (EoI) issued by the Department of Heavy Industries (DHI) and was shortlisted to receive demand incentive for 40 buses along with ten other cities. TSRTC procured e-buses under gross cost contract (GCC), given the high up-front cost and lack of technical know-how on maintenance. Also, TSRTC operates a fleet of 3,800 city buses in Hyderabad, and about 500 of these buses are hired on GCC. This experience allowed TSRTC to choose GCC over outright purchase.

TSRTC received bids from Tata Motors, Olectra-BYD, and Mytrah NN4 Energy. Bids varied between INR 40 and INR 60 per km for both 9 m and 12 m buses. Olectra BYD was the winning bidder for both models. TSRTC negotiated with Olectra-BYD and agreed to pay INR 33/km.

TSRTC received the first lot of e-buses in January 2019 following which it started extensive trials on proposed routes. As per initial plans, e-buses were to operate on four different routes starting from different parts of the city leading to the airport. TSRTC chose the airport routes to minimize cost and maximize earnings, as these routes have fare that is higher than regular city buses. To minimize dead km, two depots were chosen. Each depot has ten charging stations capable of charging 20 buses overnight. These buses are equipped with 324 kWh batteries and can run for 250 km range on a single charge. However, TSRTC is using the fleet extensively with vehicle utilization varying between 350 and 450 km per day.

The e-buses are charged at depots overnight between 12 am and 4 am. Additional range is achieved by giving the buses a quick top-up between schedules in the afternoon. TSRTC is spending INR 7/km on

11 Opportunity charging refers to the charging of batteries wherever and whenever power is available. In simple terms, rather than waiting for the battery to be completely discharged, or for the duty cycle / work shift to be over, it is “power as you go”.

electricity bringing the cost of operation to INR 40/km. Since their launch in March 2020, the e-buses have seen a steady rise in ridership, earning about INR 40/km on most days.

Takeaways:

- Explore and tap into government incentives to reduce the upfront cost of e-buses.
- GCC can be a viable procurement model for e-buses, especially when there is high initial cost and lack of technical expertise on repair and maintenance.
- Negotiate contracts for most advantageous deals.
- Strategically select depots and routes with high profitability for e-bus deployment.

India Case Study: Uttarakhand

Uttarakhand Transport Corporation conducted trials on two of its most popular routes: Dehradun-Mussorie and Haldwani-Nainital between October and December 2018, using e-buses from Olectra, one of the leading Original Equipment Manufacturers (OEMs) in India. These routes also represent the typical hilly terrain observed across the state. The Dehradun-Mussorie route trial was conducted in two phases in October and November of 2018 while the Haldwani-Nainital route trial was conducted in December 2018. Table 7 summarises the performance data from these trials.

Table 7: Performance of e-buses during trials in Uttarakhand, 2018

Attribute	Route		
	Dehradun to Mussorie (Trial 1)	Dehradun to Mussorie (Trial 2)	Haldwani to Nainital
Period of operations	9 Oct to 4 Nov 2018	15 Nov to 27 Nov 2018	9 Dec to 31 Dec 2018
Route length	35 km	35 km	43 km
Operated kms	5,840 km	2,320 km	3,440 km
Electricity consumed	4,909 kWh	1,926 kWh	3,576 kWh
Energy efficiency	0.84 kWh / km	0.83 kWh / km	1.04 kWh / km
Income per km	INR 40.31	INR 39.82	INR 40.03
Staff and electricity cost per km	INR 12.88	INR 14.57	INR 19.08
Amount paid to OEM per km	INR 27.43	INR 25.25	INR 20.95

The total electrical energy consumed during the entire trial phase was 10,410 kWh. Considering Uttarakhand's 2018 grid emission factor of 0.353 kg-CO_2 /kWh, the e-bus trails abated 15.74 t-CO_2 eq. emissions.

Takeaways:

- E-buses serve as highly efficient instruments for curbing emissions within the transportation sector. Nevertheless, the extent of emissions reduction achievable hinges significantly upon the power source. Uttarakhand, by harnessing hydropower to charge e-bus batteries maximized emissions reduction.
- Energy efficiency of e-buses varies depending on specific route they traverse.

India Case Study: Himachal Pradesh

Himachal Pradesh Road Transport Corporation (HRTC) has been among the pioneering states in deploying e-buses in India beginning with their initial deployment of 25 e-buses for commercial operations in November 2017. While the initial buses deployed were supplied by Olectra, the state has subsequently procured 50 e-buses from Foton-PMI in their second round of procurement. The operations of the 25 Olectra e-buses were reviewed for this study. These buses are 8.9 m long and have a Gross Vehicle Weight (GVW) of 13,500 kg with a seating capacity is 25 passengers and a rated battery capacity of 180 kWh. The buses were procured in an outright purchase model at a cost of 1.90 Cr at the time of procurement.

HRTC deployed the 25 e-buses across fourteen routes in Kullu (14 buses), Manali (5 buses), and Mandi (6 buses) regions. The route lengths varied between 11 and 70 km with an average of 20 stops per route. The energy efficiency of these buses was in the range of 0.86-0.91 kWh/km across routes. On average, 21 of the 25 buses were operational daily and they performed around 110 km of the 120 km scheduled to be operated per bus per day, while the remaining scheduled-km were canceled due to several reasons. These buses witnessed 10-12 breakdowns in a year. The average steering hours per bus per day was 15 hours while the buses spent the remaining 9 hours at the depot for overnight charging and maintenance.

For charging electric buses new line of 500 kVA was built in Kullu and 650 kVA in Manali. The cost of electricity is paid by HRTC. A total of 17 slow chargers were used for the 25 buses, with a capacity of 80 kW each provided by BYD.

Takeaways:

- The functional specifications for e-buses such as the range in a single charge, fleet availability, etc. need to match their ICE counterparts especially due to the hilly terrain where depot and charging infrastructure is available in fewer locations.
- The technical specifications such as vehicle dimensions also need to be similar to ICE buses or better in the hilly terrain where the road characteristics are not identical to plain terrain. It was observed that aspects like the angle of approach and front overhang of some of the buses created operational challenges in rural and hilly areas with poor road conditions. The angle of approach is approximately 20 degrees for an ICE bus whereas for an electric bus it is around 8-10 degrees.
- Indian STUs suffer from a lack of consistent financial support from the state and municipal governments. It was observed across e-bus deployments that the lack of financial support combined with limited ticketing revenue was impeding timely contractual payments to the operators and was a key impediment to their plans to procure new e-bus fleets.

India Case Study: Kolkata

In February 2019, West Bengal Transport Corporation (WBTC) procured 80 e-buses under Phase – I of the Faster Adoption and Manufacturing of Electric and Hybrid Vehicles in India Scheme (FAME), thereby electrifying nearly 5% of its bus fleet. The fleet included 40 9m and 40 12m e-buses from Tata Motors Limited. WBTC procured the e-buses outright as it aimed to leverage its existing public transport operations infrastructure, manpower and experience.

These buses were deployed along 12 routes.9 fast chargers (each costing INR 14.9 lakhs) and 61 slow chargers (each costing INR 9.0 lakhs) were installed. WBTC's operating costs for e-buses are around INR 22/km, which is one-third of the costs for diesel buses. WBTC's experience suggests that overloading on e-buses reduces its range.

In Kolkata, electric buses were being charged irrespective of electricity load demand variations through the day. Hence, WBTC anticipates that city-level peak power requirement might surge if a large fraction of its fleet is converted to electric. To mitigate the same, it aims to explore smart charging opportunities.[12]

Takeaways:

- Incorporate an assessment of the influence of charging stations on the electrical grid during the planning phase of fleet electrification.
- When determining battery size, take into account the potential for overloading conditions.

International Case Study: Santiago (Chile)

In November 2017, Metbus, one of Santiago's private bus operators, partnered with Enel, an Italian utility company, and BYD to bring two electric 12 m BYD K9FE buses to operate under regular service in Santiago. The two buses ran for a year with five trained drivers on route 516, which takes approximately 4–4.5 hours to complete. Over the year, they covered 105,981 km and moved more than 350,000 passengers with an availability ratio of 99.23%. Operating costs were calculated at USD 0.10/km, based on a USD 0.10/kWh electricity price and an energy consumption of 1.01 kWh/km. In comparison, a diesel reference bus with an energy consumption of 0.5 liters/km operates at a cost of USD 0.86 per liter.

As a result of this pilot, Metbus worked with BYD and Enel X, an Enel subsidiary, to scale the operation by adding an additional 100 BYD K9FE units in 2019. Enel X acted as the financial agent and energy provider, and leased the buses to Metbus for 10 years; Metbus, in turn, operates the buses and provides basic maintenance, while BYD is in charge of more important maintenance operations including battery packs and electric drive trains. For the latter, Metbus negotiated a fixed maintenance rate of USD 0.09/km with BYD and there is an availability clause whereby the manufacturer is responsible for any fines incurred by buses that do not meet frequency requirements.

The total amount of the agreement between Metbus and Enel X includes a financial lease for 100 buses and charging infrastructure for 10 years, after which the assets are transferred to Metbus. As for the charging infrastructure, Metbus secured 100 BYD EVA 080KI AC chargers that deliver up to 80 kW and have an estimated charge time of 3–4 hours. Furthermore, these buses have been used to create Latin America's first electric corridor: a bus route along a major axis in Santiago, Avenida Grecia, that is operated solely with electric buses. The corridor contains 40 new state-of-the-art bus stops which include free wifi, USB chargers, bus arrival time panels, solar panels to cover electricity demands, LED lighting, wheelchair access, and, in some stations, exclusive payment zones.

Also in 2017, a similar partnership, this time led by Engie, a French utility company with operations in Chile, and Gildemeister, a local automobile dealer, launched a Yutong E12 (also known as ZK 6128) 12-meter low-floor bus pilot in Santiago. Buses Vule, a Transantiago operator, joined the initiative and operated the bus between December 2017 and May 2018. The bus completed 1,173 trips and traveled a total of 22,055 km. By June 2019, the bus had covered more than 100,000 km and had estimated operational costs of around USD 0.05 per km.

In 2018, as a result of this successful pilot program, Engie announced that it would finance an additional 100 battery electric buses and work with two Transantiago operators—Buses Vule and STP. In this agreement, Engie acted as the financial agent and provided charging infrastructure and certified renewable energy for bus operators. In March 2020, NEoT Green Mobility, an investment platform

12 The Energy And Resources Institute. "Successful Operation of Electric Bus Fleet 'A case Study of Kolkata'", 2020 .link

dedicated to financing zero-emission mobility, financed 25 King Long DM2800 electric 12 m buses to be used in Redbus' operations. They mirror the Enel business model of providing separate asset ownership for infrastructure and buses to a local transport operator.[13]

Takeaways:

- Explore business models which reduce the need for ASTC to make investments. It should explore business models where private sector procures the e-buses, operates them for a duration and then transfers ownership to ASTC.

International Case Study: Roaring Fork Transportation Authority (USA)

In 2013, Roaring Fork Transportation Authority (RFTA) launched the US' first rural bus rapid transit system, the dinosaur-branded VelociRFTA. In 2019, RFTA began a pilot electrification program, incorporating eight battery electric buses into its fleet and installing four depot charging stations. Focused on innovation and sustainability, RFTA met the challenges of electrification head on, performing intensive quality assurance testing on the buses (including loading them with 55-gallon drums to mimic maximum passenger load) and working to accurately capture charging information and maintain consistency across its preventive maintenance programs.

With the electrification initiative, RFTA wanted to test how electric buses perform at Aspen's high elevation (and cold temperatures), while capturing detailed data to determine whether the program should be expanded. Integrating new bus fleet posed operational challenges but e-buses have the additional complexity of managing charging, state of health, and battery charge. To do so, RFTA needed to integrate e-bus data with their enterprise asset management system.

The team faced several technical challenges including (i) measuring energy consumption wasn't as straightforward as it was for diesel buses - the charging data had to reflect utilization for both peak and off-peak hours for which RFTA had secured locked-in rates from the local energy company and (ii) instead of utilizing a standard API data exchange mechanism, the charging system had unique interface requirements from a 'technical handshake' perspective for the enterprise asset management system.

Intregrating e-buses with the enterprise asset management system allowed RFTA to accurately measure charging events to track energy consumption and expenditure. RFTA is now able to quantify the following savings: it cost 18 cents per mile in fuel/propulsion for an electric bus compared to 82 cents per mile for diesel vehicles, a savings of 64 cents per mile. Another priority is evaluating battery health for performance assessment, to enable RFTA to analyze battery trends over time.[14]

Takeaways:

- Understanding the battery performance in colder temperatures and at higher altitudes is essential before expanding bus fleet electrification plans.
- Integrating IT solutions with e-bus operations helps better management for the e-bus fleet.

International Case Study: Bogota (Colombia)

Bogota, the capital city of Colombia, is located 2,640 m above sea level. The city has been exploring e-buses to replace its diesel fleet to help the country meet NDC targets. The public transport system in the city is manageed by TransMilenio – the bus rapid transport owner. TransMilenio engaged private

13 C40 Knowledge Hub. "From Pilots to Scale: Lessons from Electric Bus Deployments in Santiago de Chile", June 2020. link

14 Trapeze. "Roaring Form Transportation Authority", 2019. link

operators to provide and operate feet and their remuneration is based on variable costs incurred per km travelled.

To overcome the financial barrier associated with e-buses Bogota has enforced various businesss models throughout different bidding phases to allow investors with greater investment capacity to finance e-bus transition without burdening the operators.

In 2019, Bogota kicked-off e-bus acquisition with three separate contracts. The first contract was for a direct lease, which included the supply of recharge infrastructure. The other two contracts were for concession, one for providing the e-buses and the other for operating them. This required modifying the existing concession contracts with operators, replacing diesel-powered buses with battery-electric ones. This rquired introducing of a new player, the charging infrastructure provider. The model assumed a comprehensive concession contract with the operator, which now supplies and operates the electric fleet, and a direct lease contract with the electricity supply infrastructure provider. In 2021, Bogota established two concession contracts to acquire e-buses where one agreement is for assets (e-buses and charging infrastructure) and other for operation and maintenance.

The model is flexible for TransMilenio to replace operators if they do not fulfil the requirements for excellent service. The contracts reduce risks for investors as they are backed by TransMilenio whi guarantees to pay off debts with the support of the city's fiscal support. For instance, operators can continue to drive buses, while the charging infrastructure providers are usually electricity supply companies partnering with manufacturers. TransMilenio also maintains separate accounts for remunerating each operator, allowing each player to carry out tasks only within their area of expertise. TransMilenio estimates that by electrifying the bus fleet it could avoid 94.3 thousand tons of CO_2 emissions each year.

Takeaways:

- Private sector investment, supported by payment guarantees backed by government, is a viable option for bus fleet transition to e-buses.
- Retain flexibility in contracts to allocate risks to stakeholders nest suited to handle them.

International Case Study: Quito (Ecuador)

Quito, the capital of Ecuador, is located in the foothills of the Andes Mountains at an altitude of about 3,000 m. This high altitude and hilly terrain pose unique challenges for deploying electric buses (e-buses). However, Quito is committed to (i) implementation of at least 10% of the fleet per route with e-buses by 2023, (ii) incorporate only e-buses for public transportation by 2025, and (iii) achieve 100% zero emission public transport by 2040.

In line with these goals, in 2018, the city ran trials with three e-buses (one with passenger capacity of 160 and two with passenger capacity of 80 each) from BYD for a period of two months. This was followed by integration of e-bus transition into its public policy in 2020 and a feasibility study to purchase and deploy e-buses. The tests were undertaken by private sector company UnitransQ. In 2022, a market study was conducted to purchase 26 e-buses with overhead contact line. As of 2023, a consulting contract regarding implementation of e-buses, as shown in Table 8, is in progress.

Table 8: Quito E-bus Fleet (under consideration)Technical Details

Parameter	Type A	Type B
Model	BYD K9G	BYD K11A
Passenger capacity	90	160
Battery capacity	324 kWh	438 kWh
Range	250 km / charge	250 km / charge

Source: TUMI E-bus Mission City Network Profile, ICLEI. link

Takeaways:

- Political will and support is necessary to progress projects involving diverse public and private stakeholders.
- Long-term transport planning, along with fleet electrification, needs to consider technological equipment aimed at improving safety, operational efficiency, and user experience.

Learnings from Case Studies

Review of e-bus deployment in across the globe highlights that it is feasible to operate e-buses across several hilly terrains and high-altitude locations. While the technical and functional requirements vary contextually, some of the factors affecting the success of e-bus deployment are common across regions. The following are the key learnings from the data collected and the interviews:

- E-buses have to carry the dead weight of batteries at all times irrespective of energy content in them. To support additional weight of batteries the vehicle structure is redesigned which adds weight. This additional weight of vehicle and batteries consumes energy to move.
- Concurrent development of charging infrastructure is necessary for overcome range anxiety and charging location and timing concerns.
- Technical specifications of the e-bus systems varied widely between regions. Theis includes aspects like battery capacity, type of battery (Lithium-Iron-Phosphate (LFP)/ Nickel-Manganese-Cobalt (NMC), charger capacity, charger technology (pantograph-based vs plug-in charging), type of charging (overnight vs opportunity charging during the day), location of chargers, etc.
- Functional requirements of e-buses in hilly terrains such as the daily km operated, whether the buses operating are depot or route specific, e-buses allocated per route, whether it is a pilot or large scale operations also varies significantly between cities.
- E-buses and charging technology needs to meet local operational requirements.
- One of the most important factors affecting to the charging locations as well as the availability of quality power. Moreover, the benefits of e-buses are maximized when the power source for charging the batteries is renewable in nature.
- Agencies procuring e-buses need to carry out a TCO analysis to make an informed decisions on e-bus deployment.
- There exist several business models such as outright purchase, Gross Cost Contract (GCC), and leasing models to induct e-buses. A context-specific choice based on local market conditions is needed at the time of procurement. The TCO analysis mentioned above should be customized for alternative business models to understand the relative financial implication of each of the models to allow for an informed choice.


Goldstone
Infratech
6
BYD
Build Your Dreams
EV
ELECTRIC
VEHICLE
CHARGING
STATION

CHAPTER 4

Comparison of ICE and E-buses

ICE and E-buses perform differently and an understanding of differences is important in planning for transition of ICE bus fleet to e-bus fleet. A summary of the comparison is presented in Table 9. Overall, the greatest hurdle to increased uptake of EV is their higher price tag when compared to ICE vehicles. This is mainly attributed to battery costs, the complex design of powertrain systems and relative age of technology compared to ICE technology. The number of moving parts in a full electric bus is less than in an ICE bus. ICE buses require frequent oil changes, filter replacements, periodic tune ups, exhaust system repairs, water pump, fuel pump and alternator replacements, and other maintenance. E-buses have controllers and chargers, which manage the power and stored energy levels in the battery. These are electronic devices without any moving parts, and, hence, they require little or no maintenance. The external features of the e-bus design are similar to those of an ICE bus. The main difference is that e-buses do not have tail pipe emissions.

Table 9: General Comparison of ICE and E-buses

Parameters	ICE Bus	E-bus
Power Source	Diesel / Gas	Electricity
Power generator	ICE	Battery
Fuel efficiency	3.5 – 5.0 km / l	0.9 – 1.2 kWh / km
Fuel tariff	18 – 30 INR / km	5 – 8 INR / kWh
Local emissions	High	Zero
Noise	High	Minimum
Maintenance	High	Low
Components	ICE propulsion system, transmission, power accessories, body	EV propulsion system, transmission, battery charging system, power accessories, body

Technology

E-buses are equipped with an electric propulsion system consisting of a battery and an electric motor that's linked to the driveshaft. This motor is electronically controlled via a battery management system to generate the necessary torque for vehicle propulsion. It also maintains a stable electric current while optimizing battery performance for both longevity and safety. There are various competing technologies vying for dominance in terms of traction, energy storage, and overall technology integration. Presently, the majority of commercially available electric vehicles rely on onboard chemical batteries as their primary source of electricity for operation. The main components of an EV are described in detail in this section.

Traction Source: For ICE vehicles, the internal combustion engine is the traction source. Its variation of power output, torque output and specific fuel consumption wrt to engine speed. The power output from an ICE increases with increasing engine speed, reaches a maximum and then drops very quickly. The torque from an ICE increases with engine speed, reaches a maximum value and then decreases with increasing engine speed. The power output from an electric motor increases with increasing motor speed, reaches a maximum and remains constant after that. The speed at which it attains peak power is called the 'base speed' of the motor. An electric motor starts with the maximum torque which stays at that level for most of its operating range. A comparison of ICE vehicle and EV characteristics is shown in is shown in Figure 2.

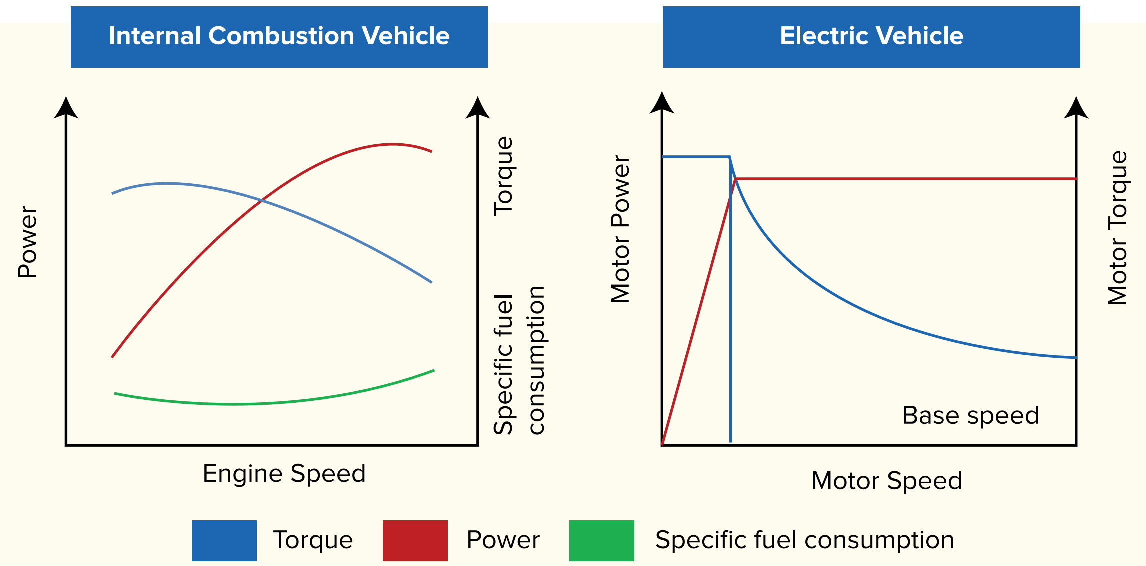


Figure 2: ICE Vehicle vs EV Characteristics

Source: Based on 'Comparison of Dynamic Characteristics of Electric and Conventional Road Vehicles', 2012. link

The power band of an engine or electric motor denotes the spectrum of speeds within which the engine or motor can function optimally. It is characterized by the range of engine speeds between the points of peak torque and peak power. ICEs exhibit a broad operating speed range, yet their power band is considerably narrower. In contrast, electric motors maintain a consistent level of torque across the majority of their operating speeds. When comparing ICEs, they tend to have lower efficiency in lower gears as opposed to higher gears. Consequently, when ICE buses navigate hilly terrain while operating in lower gears, their fuel economy tends to suffer.

The torque-speed characteristics of an ICE do not align with the ideal properties needed for a propulsion system. Consequently, a gearbox is introduced, enabling the use of a mechanical transmission with varying gear ratios to attain the desired tractive force across the entire spectrum of vehicle speeds. In contrast, when dealing with an electric motor, a single-gear transmission suffices to provide the required tractive force over the entire range of vehicle speeds.

In a hilly terrain, ICE and EV approach gradients in distinct ways. An electric motor can generate the necessary tractive force efficiently using a single gear reduction. In contrast, an ICE must operate in a low gear and at high engine speeds to achieve equivalent tractive force. Using a lower gear ratio with an ICE results in reduced fuel efficiency, whereas an EV can navigate similar gradients with minimal efficiency loss.

Battery: The source of energy in EV is onboard battery packs which store energy as electrochemical potential. These battery packs are charged through dedicated electric charging stations. Different battery technologies have evolved over time and lithium ion (li-ion) batteries are most suitable for EV applications due to high specific energy and high specific power.

Charging technology: There are two principal methods of charging batteries are described below

- Conductive charging involves establishing a physical connection between the battery and the charging station. This method has traditionally been the preferred choice for accessing grid electricity to power EVs. Standard voltage plugs and sockets in the automotive sector serve as the interface between the grid and onboard sockets.
- Inductive charging employs an electromagnetic field to facilitate the transfer of energy between the EV and the charging station. With this approach, there is no requirement for a physical connection between the energy source and the vehicle. Inductive charging operates by incorporating an induction coil within the charging station, generating an electromagnetic field. A second induction coil, positioned on the EV, harnesses power from this electromagnetic field and converts it into an electrical current used for charging the onboard battery. The advantages of such wireless charging systems encompass safety (absence of exposed conducting surfaces, thus no risk of electric shock), no need for cables, high reliability, minimal maintenance (automatic with minimal intervention required), reduced risk of theft, and an extended product lifespan due to reduced wear and tear.

The charging time for EVs depends on the charging technology, as well as factors such as battery type, storage capacity, and size. Opting for a reduced charging duration entails higher costs, primarily due to several related factors, including the utilization of more expensive battery variants constructed from materials with enhanced charge-holding capacity and the deployment of more efficient and advanced charging techniques. Therefore, the choice of charging method should be determined based on a comprehensive techno-economic analysis that takes into account the specific application requirements.

Battery Management System: EVs employ a Battery Management System (BMS) to ensure the optimal performance of a battery by operating it within specific ranges of temperature, voltage, charge and discharge rates, minimum state of charge, and other parameters.

A BMS contains sensors and controllers. Sensors measure batteries key operating parameters including temperature, current, and voltage. Based on senor readings the controller maintains the battery cells within their ideal operating ranges. Thus, BMS helps manage the depth of discharge, prevents cell voltage from dropping below tolerance levels, and safeguards against overcharging, which can lead to hazardous situations like fires or explosions. Additionally, BMS manages battery safety controls, regulates battery operating parameters, ensures uniform cell degradation within a module, and handles thermal management.

Cost of Ownership

Diesel, CNG, and e-buses are the key technology options for ASTC to meet its future bus fleet needs. The choice between these technologies can be made objectively by using TCO models that take into consideration both capital and operating costs on a per km basis and helps understand the total cost of the bus over the life of the bus taking into consideration efficiency, battery replacement, running kms, etc.

By taking the lifecycle cost approach for evaluation, TCO models help address the fundamental differences in cost structure between e-buses and other buses. E-buses are more capital-intensive but have lower operational costs than diesel and CNG buses. The TCO estimation at the bus level is carried out to compare the per-km costs of various bus technologies, as well as the fleet-level estimates to determine the overall financial requirements for ASTC.

The TCO model utilizes three categories of input parameters (i) capital costs (input parameters include vehicle purchase cost, financial incentives applicable, resale value and other cost.), (ii) operational costs (fuel/electricity costs, maintenance, staff cost and miscellaneous cost.), and (iii) bus usage details (average kms driven per day, number of operational days in a year, life of bus). A summary of the assumptions used in the TCO model is presented in Table 10.

Table 10: TCO Model Assumptions

Bus Related Information	Unit	Diesel Bus, Long, AC	E-Bus, High range, AC	Diesel Bus, Small, Non-AC	E-Bus, Short range, Non-AC
Bus Life	years	12	12	12	12
Bus Utilisation	km/ day	200	200	200	200
Annual Operating Days	days	350	350	350	350
Cost of Diesel Bus	INR	50,00,000		4,,00,000	
Cost of E-Bus (excluding battery)	INR		45,00,000		35,00,000
GST on Purchase of Bus	%	18%	5%	18%	5%
Operating Efficiency	km/l or kWh/km	4.0	1.2	4.0	1.2
Maintenance Cost	INR/km	22.0	14.0	22.0	14.0
Energy Cost	INR/l or INR/kWh	90	5	90	5
Battery capacity	kWh		250		200
Battery Life	years		6		6
Cost of Battery	INR/ kWh		10,000		10,000
Cost of Fast Charger (in INR)	INR		15,00,000		15,00,000
Cost of Slow Charger (in INR)	INR		10,00,000		10,00,000
Fast Charger O&M Costs	% of Capex		1%		1%
Slow Charger O&M Costs	of Capex		1%		1%
Cost of depot infrastructure per bus	INR		20,000		20,000

Results of TCO Analysis

Table 11 and Table 12 show the TCO comparison for diesel and e-buses for a utilization of 200 km per day. For longer distances, the TCO for e-buses wil be even more favourable.

Table 11: Per-km TCO for Diesel and E-Buses (200 km per bus per day)

Bus Related Information	Unit	Diesel Bus, Long, AC	E-Bus, High range, AC	Diesel Bus, Small, Non-AC	E-Bus, Short range, Non-AC
Bus	INR / km	11.9	12.7	10.0	11.7
Battery	INR / km		8.3		6.6
Charging Infrastructure	INR / km		10.1		10.1
Fuel / Electricity	INR / km	24.0	6.8	24.0	6.8
Operation & Maintenance	INR / km	22.0	14.2	22.0	13.2
Crew	INR / km	15.4	15.4	15.4	15.4
Others	INR / km	7.1	5.7	7.1	5.7
TCO	INR / km	80.5	73.1	78.6	69.4

Table 12: Per-km TCO share of different heads (200 km per bus per day)

Bus Related Information	Unit	Diesel Bus, Long, AC	E-Bus, High range, AC	Diesel Bus, Small, Non-AC	E-Bus, Short range, Non-AC
Bus	INR / km	14.8%	17.4%	12.7%	16.9%
Battery	INR / km		11.4%		9.5%
Charging Infrastructure	INR / km		13.8%		14.6%
Fuel / Electricity	INR / km	29.8%	9.3%	30.5%	9.8%
Operation & Maintenance	INR / km	27.3%	19.4%	28.0%	19.0%
Crew	INR / km	19.1%	21.1%	19.6%	22.2%
Others	INR / km	8.8%	7.8%	9.0%	8.2%
TCO	INR / km	80.5	73.1	78.6	69.4


ELECTRIC BUS
I.S.B.T.-43
VIA HOL
CTU ELECTRIC BUS
CTU
EICHER
CH01TB4338

CHAPTER 5

Roadmap for E-bus Deployment

This section gives an overview of the approach for ASTC to follow for electrifying its bus fleet.

Guiding Principles for Roadmap

- Deployment of E-buses involves both transport and energy sector.
- Charging infrastructure requirements cannot be an afterthought and needs to be planned at the very beginning.
- Bus operations need to take into consideration battery size, charging strategy and availability of support infrastructure.
- Funding sources and business models are important considerations for e-bus fleet rollout.
- Local conditions in Assam create an advantage for E-buses over ICE buses.
    - Better performance in hilly terrain: When travelling uphill, all buses consume energy as per the weight of the bus and efficiency of traction source. The efficiency of e-bus is higher than that of ICE buses in hilly areas. When travelling downhill, ICE buses lose energy as a result of dissipation of kinetic energy through braking, which leads to high wear and tear on the clutch and brakes. However, e-buses can significantly reduce this wear and tear leading to lower maintenance costs.
    - Better performance in start-stop traffic: The traffic conditions in cities such as Guwahati is such that traffic movement is quite slow. The average speed of any vehicle ranges from 15 to 25 kmph. When compared with a ICE buses, e-buses have high efficiency as conversion, transmission and distribution losses are very low. Also, ICE buses have high fuel consumption in idling condition and low speeds whereas e-buses do not have similar operational characteristics.

Fleet Demand and E-bus Estimation

The long-term fleet needs for ASTC has been developed assuming 2033 as the horizon year. The fleet needs assessment is carried out such that ASTC meets the objective of improving service levels and meet future needs. A 5% annual growth in ridership is considered. The analysis considers that even the private operated buses will be electrified during this period.

The age profile of the existing ASTC's fleet is used to estimate the fleet replacement timeline and is combined with the fleet augmentation needs to meet the targeted increase in ridership to estimate the fleet to be procured in each year until 2033. Given the favorable TCO of e-buses, it is assumed that all the new buses would be e-buses. While acknowledging that e-buses may not be technologically ready to replace all ASTC routes immediately, it is assumed that the technology would evolve in the coming years to meet operational needs. Based on these assumptions, Table 13 presents the annual fleet to be procured and the share of the total fleet electrified in each year.

Table 13: ASTC Bus Fleet Targets

Year	Fleet target	E-buses added in year	E-buses as % of total fleet
2023	1,537	15	1%
2024	1,565	100	7%
2025	1,645	130	15%
2026	1,735	205	26%
2027	1,825	225	37%
2028	1,915	225	47%
2029	2,005	300	60%
2030	2,105	300	71%
2031	2,215	300	81%
2032	2,325	300	90%
2033	2,450	350	100%

Depot Selection

Deployment of e-buses is both a transport and energy sector endeavour. As such, planning for e-buses requires consideration of existing electricity distribution network and the effect electricity demand from e-buses will have on the distribution network and the cost of upgrades require to accommodate increase in electricity demand. As such priority should be given to depots which necessitate small upgrades in the electrical infrastructure whereas Depots which require new distribution lines or sub-stations should be assigned lower priority.

Another consideration for e-bus deployment is the space constraint as e-buses require space in existing depots for parking and maneuvering, setting up of grid and charging infrastructure, and repair and maintenance of buses. Diesel and CNG buses require about 56 m^2 of space per bus for parking and refuelling infrastructure. E-buses require a larger area as they require and access to the bays along the charging infrastructure. Considering one charging station for four e-buses, an area of 64 m^2 will be needed per e-bus.[15] A such, depots with avenues to expand or those having large unused areas should be prioritized.

Other considerations for depot selection include selecting depots with maximum utilization of charging infrastructure and those offering low dead mileage for charging of e-buses.

15 ITDP India. "Guidance for Electric Bus Rollout in Indian Cities", June 2022.

Based on the above considerations, it is recommended that ASTC explore electrification of city depots in the near term, those near major cities in the medium term and the remaining in the long term, as shown in Table 14.

Table 14: Depots for E-bus Deployment

Near-term	Medium-term	Long-term
Paltanbazar, ISBT – Maskhuwa, Nalbari, Khanapara, Rupnagar, Noonmati, Jagiroad, Mirza, Chaygaon, Boko, Baihata Cahriali, Rangia	Sivasagar, Nagaon, Dibrugarh, Tinsukia, Jorhat, Lakhimpur, Dhemaji, Tezpur, Barpeta, Bongaigaon, Dhubri, Goalpara, Silchar, Karimganj,	All others

Route Selection

Route selection/ planning for e-buses is different from ICE buses as factors such as length of route, number and location of stops, charging locations, peak and off-peak service frequency and ridership, size of the fleet and route characteristics play an important role in optimizing charging solutions and operations of e-buses. In addition, electrification of bus fleet should not affect existing operations like route alignment or timetables. Other considerations that for e-bus route selection include:

- Route length vs effective range of e-bus considering the minimum state of charge (SoC) and loading on battery during peak ridership.
- Battery size and capacity vs energy demand considering maximum loading and required level of service / performance.
- Location of charging points along the route.
- Secondary factors such as roadside assistance, workforce with skills to operate and maintain e-buses, etc. may also be considered.
- Focus on ridership in the near term and then move focus on coverage in the medium and long-term. As such, city service routes should be prioritized due to high ridership.
- Unlike ICE buses, the performance of e-buses is not affected at idling/ slow speed, as such congested routes in city service should be prioritised.
- Prioritize routes for which e-bus can be charged at depots to ensure focused investment and more effective utilization of charging infrastructure.

Based on the above considerations, ASTC should prioritizing routes based on the routes linked to depots listed in Table 14.

Charging Technology

Charging infrastructure for e-bus fleet comprises of charging station and associated power infrastructure including the distribution grid components. E-bus fleets need different charging strategies to manage charging demand.

ASTC's service operations occur typically between 6-7 AM to 8-9 PM. The charging strategy for e-bus fleet should maximize use of the night hours that are outside of the services timings. This 6-8 hour of time is sufficient to charge the batteries to maximum SoC using slow chargers and make them ready for next day service cycle. ASTC by charging e-buses at night time will increase electricity demand at non-peak hours for APDCL and will help improve its load factor.

Deploying chargers at depots give higher freedom in route selection and could potentially allow for maximizing their use as multiple e-buses can use them. However, this strategy may require larger batteries that have enough capacity to power the e-buses through the day service cycle. On the other hand, opportunity charging requires charging stations at regular intervals and could lead to higher infrastructure costs. Also, opportunity charging stations need fast chargers and is best suited for dedicated bus corridors/ bus priority lanes/ bus rapid transit systems. Other considerations for selection of charging technology include:

- Opportunity charging stations need to be installed if the length of the trip is longer than the effective range of e-buses. For relatively smaller trips, depot charging can be used.
- Opportunity charging cannot be relied upon for short stoppage times as is typical for bus operations in India where most stops are less than a few minutes. Opportunity chargers need fast chargers typically >200 kW. A fast charger of 200 kW capacity needs about 5 minutes to charge e-bus battery to run for 15 km.[16]
- Irregularities in service schedules due to unpredictable tariff can affect available charging time for opportunity charging. In such cases depot charging is preferable.

Based on above considerations, it is recommended that ASTC adopt depot charging strategy in the near term, and then build network of opportunity charging station in the medium and long term, following the list of depots and routes listed in Table 14.

Charger Rating

Several cities that have deployed e-buses under FAME-I scheme have focused on charging strategies by deploying both slow and fast chargers, as shown in Table 15. Based on this, it is recommended that ASTC deploy a mix of slow chargers (60-80 kW) for overnight charging and fast chargers (150+ kW) for opportunity charging.

Table 15: Charger Rating in Various Indian Cities

City	Charger Power Rating
Kolkata	60 kW (overnight charging) 120 kW (opportunity charging)
Mumbai	80 kW (overnight charging) 150 kW (opportunity charging) 240 kW (overnight and opportunity charging)
Pune	80 kW (overnight charging) 150 kW (opportunity charging)
Bengaluru	200 kW (overnight and opportunity charging)
Delhi	200 kW and 240 kW (overnight and opportunity charging)
Hyderabad	80 kW (overnight and opportunity charging)

Charging Strategy

Charging strategy depends on the time taken to charge an e-bus up to maximum SoC and how it affects the downtime for the vehicle. Secondary considerations affecting charging strategy are the space availability for charging infrastructure and parking of buses. The number of chargers is lower than the number of e-buses for optimal use of charging infrastructure and associated investments. For depot charging strategy, it is recommended that ASTC dispatches a bus with maximum charge for each schedule in the timetable of the route. Each incoming bus is scheduled for charging if the SoC falls below a pre-determined level (generally the minimum SoC is prescribed the battery manufacturer), else it stays idle during the layover. Buses waiting at the layover are scheduled for charging based on charger availability and the next dispatch time, as shown in Figure 3.

16 Based on energy efficiency of 1.1 kWh/km.

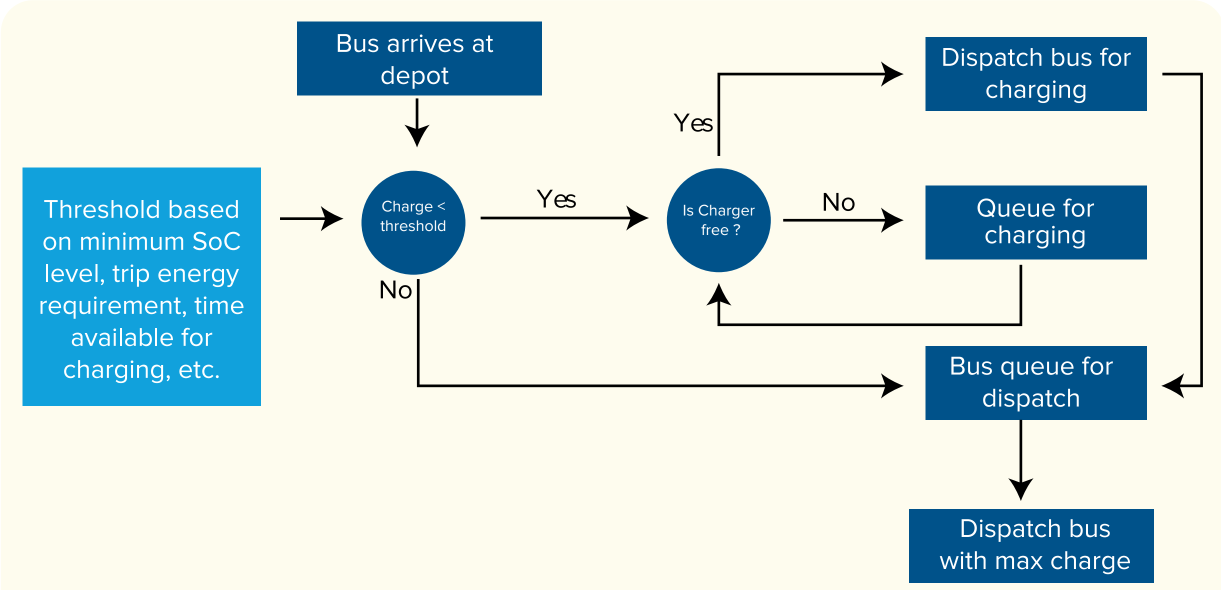


Figure 3: Flowchart Showing Approach for Charging E-buses

It is recommended that ASTC adopt intelligent planning and scheduling solutions to optimize charging process using a combination of slow and fast chargers. In addition, ASTC should explore battery swapping in the long-term.

Battery Swapping

Battery swapping for e-buses is a charging technology that allows e-buses to quickly exchange a discharged battery pack for a fully charged one, as an alternative to parking the e-bus next to the charger and wait for a few hours till it gets fully charged. This mechanism overcomes a significant disadvantage of high in-depot time during charging . Because of the reduced in-depot time, it is comparable to ICE bus refuelling time. This advantage, however, comes at the cost of a reduced range because the batteries need to be smaller and lighter for the convenience of swapping. Battery swapping can be automated using robotic arms which is an additional infrastructure over and above the battery chargers. Due to this extra cost, it is recommended that ASTC explore this option in the long-term.

Number of Charging Stations

There is no empirical formula to determine the number of charging stations for a bus fleet. Neither can comparisons with experiences be used as reference due as the number of chargers depend on several non-linked factors discussed below, but mainly the number of charging stations is an economic decision.

- Fleet size: The number of charging stations should be proportional to the size of the e-bus fleet. There should be ample number of chargers to cater to the entire e-bus fleet, minimizing waiting times. However, excessive number of charging stations will add to costs and lead to low utilization of charging stations.
- Charger compatibility: Different manufacturers employ different charging standards. The number of charging stations will depend on the mix of e-bus fleet.
- Daily mileage, battery capacity, and range: E-buses operating on long routes require larger batteries, thereby increasing the overall weight of the vehicles. Alternatively, charging stations can be strategically deployed along the route. Buses with larger batteries may require less frequent charging but may need more time at the charging station when they do recharge.

- Charging time: Fast-charging stations can reduce the number of required chargers, but they require higher upfront costs. Slower chargers may be more cost-effective but require longer downtime for the buses.
- Operational needs: While some level of downtime within certain tolerances might be acceptable, reducing it further necessitates the installation of additional charging stations or fast chargers to swiftly return the vehicles to service.
- Power grid capacity: he quantity of charging stations is constrained by the power grid's capacity. Expanding the number of chargers will necessitate grid upgrades to meet the increased demand.
- Future growth: It is prudent to install a surplus of charging stations beyond current requirements to facilitate future expansion.
- Redundancy: Consider contingency measures for charging infrastructure in the event of maintenance or equipment failures.

Battery Technology

Charging time for electric buses (e-buses) is a multifaceted aspect influenced by various factors, with charging technology and charger power rating playing pivotal roles. However, one of the most significant determinants of charging time and power lies in the choice of battery chemistry. Understanding the distinct characteristics of different chemistries is crucial for making informed decisions in the adoption of e-bus technology.

Nickel Manganese Cobalt (NMC) chemistry stands out for its rapid charging rate, making it an ideal choice for e-buses equipped with larger battery capacities. NMC chemistry excels in accommodating both opportunistic fast charging and overnight charging scenarios. This versatility is particularly valuable in urban environments where e-buses need to be ready for frequent routes and quick turnarounds.

On the other hand, Lithium Iron Phosphate (LFP) chemistry boasts low battery degradation and an extended cycle life, making it an excellent fit for slower charging strategies, such as overnight charging. E-buses equipped with LFP batteries are well-suited for long-term, sustained operation.

Lithium Titanate Oxide (LTO) chemistry offers even higher charging rates than both LFP and NMC, making it optimal for ultra-fast charging scenarios. However, LTO batteries have notably lower energy density, necessitating more frequent charging opportunities due to their reduced energy capacity. LTO chemistry is best suited for applications where rapid power replenishment takes precedence, even if it entails more frequent stops for charging.

Therefore, a strategic approach suggests that the ASTC should prioritize the adoption of NMC chemistry batteries in the near-term. NMC's balanced characteristics, offering both speed and versatility, make it an excellent choice for various operational requirements.

Power Source

ASTC is reliant on Assam Power Distribution Company Ltd. (APDCL) for supply power to the charging stations intends to set up. In 2022, APDCL's tariff category HT EV Charging Stations are obligated to pay fixed charges of INR 170/ kVA/ month and energy charge of INR 7/ kWh.[17] There is an opportunity to ASTC to reduce/ avoid charging costs by deploying rooftop solar systems. ASTC can deploy rooftop solar systems under Opex or Capex model. The choice between an Opex or Capex model for deploying these systems will hinge on ASTC's financial capacity to self-fund the rooftop solar systems. A comparison of the two models is shown in Table 16.

17 Assam Power Distribution Company Limited. "Office Memorandum", 07 May 2022. link

Table 16: Opex vs Capex Models for Rootop Solar Systems

Parameter	Capex Model	Opex Model
Ownership	ASTC owns the system	Entity other than ASTC sets up the rooftop system and sell electricity to ASTC at rate lower than APDCL
Investment	100% investment by ASTC	Zero investment by ASTC
Payments	ASTC pays for the system and O&M costs. No payments for electricity generated.	ASTC pays for electricity generated only.

Given that rooftop solar systems are restricted to depots, ASTC's dependence on APDCL for power supply will persist. Consequently, ASTC requires a strong collaborative effort with APDCL to facilitate the planning of infrastructure upgrades and address the following key aspects:

- Power infrastructure requirements: In order for APDCL to fulfill ASTC's charging infrastructure power demands, it is essential to obtain details regarding the charging station locations, their capacity, and usage characteristics. This information will enable APDCL to accurately assess the grid's potential impact and subsequently plan and execute essential upgrades.
- Grid integration: APDCL requires APDCL's bus fleet electrification plan to assess the effects of increased electricity demand on the distribution grid and devise strategies for a seamless integration.
- Charging tariff and power sector regulations: ASTC will derive benefits from ongoing interactions with APDCL to stay informed about policy and regulatory updates and changes, including tariff adjustments.
- Power outage and emergency preparedness: ASTC through discussions with APDCL must strategize for scenarios in which APDCL's distribution grid experiences power outages or encounters unforeseen events.

Contracting Models for E-bus Operations

The different bus operation contract models for ASTC to explore are described below.

- **Owner-Operator Model:** Under this model, ASTC owns the e-bus fleet and provides services through its own employees. This model is generally used where services are newly introduced, scale of operations is low, and suitable private sector players are not available or where the employee unions are strong and resist private sector's entry.
  - Recommendation. Currently, the cost of e-buses is high, and government subsidies do not encompass the private sector. Consequently, private sector ownership of e-buses is financially impractical. Furthermore, ASTC lacks manpower for the repair and maintenance of e-buses. Given these circumstances, this contracting model is not recommended in the short term.
- **Management Contracting Model:** Under this model, ASTC owns the e-buses and appoints a private operator, for a specified duration, to provide the services using the e-buses within a defined quality and service agreement. The private operator makes payments to ASTC on per km operated basis with guaranteed km per day/year and sometimes a fixed fee per day/ month for the e-buses.

Table 17: Examples of Management Contracting

City	Variation	Benefits
Indore	Buses are auctioned and sales are divided between Transport Authority and Operator at the end of the contract.	Incentivizes the Operator to keep the buses in good condition and reduces per km costs.
Ahmedabad	Ownership of buses is transferred to the Operator at depreciated value at the end of the contract.	Incentivizes the Operator to keep the buses in good condition and reduced per km costs.
Amritsar	Transport Authority provides fuel at fixed mileage.	Incentivizes Operator to keep buses in good condition and cultivate best practices to maintain mileage.
Surat	Joint procurement: Bus chasis is procured by Transport Authority and bud body by the operator. Ownership of bus is transferred to Operator at the end of contract.	Reduces investment burden on Transport Authority. Incentivizes the Operator to keep the buses in good condition.

Recommendation. ASTC has experience with this model and recently came out with a tender for 100 e-bus to be operated by private companies. As such, this contracting model is recommended in the short and medium-term.

- **Buy the Service Model:** Under this model, private operator appointed by ASTC will acquire e-buses, set up charging (or it may be provided by ASTC), and operate the buses. Based on the mode of payment by ASTC to the operator, there are two main variations in this model:
  - Gross Cost Contracting (GCC): Under this model, ASTC frames rules, identifies routes and depots, sets up fare structure and other service parameters, and procures the services from private operator. ASTC collects the fares and bears ridership risk. Private operator is paid by ASTC on the basis of fleet size and/ or run km.
  - Net Cost Contracting (NCC): Under this model, ASTC frames rules, identifies routes and depots, sets up fare structure and other service parameters, and procures the services from private operators. Private operator collects the fares and bear the ridership risk. The private operator is paid by ASTC based on run km. A comparison of the GCC and NCC models of contracting is shown in Table 18.

Table 18: Comparison of GCC and NCC Models

Parameter	GCC	NCC
Pros	• Flexible operation and easy to introduce. • Lower risk to operators results in efficient pricing. • Quality of service is part of performance parameters.	• Transfers revenue risk to the operator. • Allows Transport Authorities with limited manpower to manage the operations. • Reduces the risk of fare evasion.
Cons	• Transport Authority bears all the revenue risk. As such, strong supervision from the Transport Authority's side is needed. • Increases the risk of operators skipping passengers, and fare evasion. • Increases the risk of driving more km than needed.	• Maximizing profits is the priority rather than service quality. • Operators wait to fill up the bus and pick up passengers at unregulated stops and service scheduling is also affected.
Suitability	• Markets where accurate revenue forecasting is difficult.	• Established markets where ridership level have stabilized, and fare revisions are predictable.

Recommendation. NCC tenders have often found it difficult to receive adequate interest from private sector across India and many Transport Authorities have moved to GCC contracts. As such, it is recommended that ASTC explore GCC contracts in the medium and long-term.

Contracting Period

This section is applicable for contracting models where private sector is engaged by ASTC. The contract duration depends on the following main factors:

- Flexibility to change contracting terms: Longer duration contacts can hinder ASTC's ability to change routes, modify service timings, etc.
- Useful life of assets: Shorter duration contracts can lead to partial utilization of assets resulting in higher capex per km. On the other hand, longer duration contracts can lead to higher repair and maintenance costs and/or lower quality of service. It should be noted that e-buses have fewer moving parts and are therefore expected to last longer than ICE buses. On the other hand, their high capital cost necessitates a longer cost recovery period. Another factor to consider is the replacement life of batteries.

Recommendation:

- Management Contracting Model: 1-3 years to maximize profits by capitalizing on competition among new tender applicants.
- Buy the Service Model: >10 years to enable operators recoup investments.

Remuneration

Depending on the contracting model selected, ASTC may either provide remuneration to the operator in the GCC model or receive payment from the operator in the management contracting model. In both scenarios, ASTC has the flexibility to explore various payment structures, including combinations of options outlined in Table 19.

Table 19: Payment Structures

Compensation Type	Pros	Cons
Fixed price (INR/day)	Simple to manage and same payment for all routes	No savings on shorter routes
INR per passenger-km	Information on ridership and occupancy can be used for better service planning.	Advanced fair collections systems such as e-ticketing are needed for information collection.
INR per vehicle-km	Payment is proportional to vehicle use.	Operator is incentivised to run more km irrespective of ridership.
INR per vehicle-hours	Payment is proportional to work.	Operator incentivised to run more trips irrespective of ridership.
INR per passenger	Payment is based on usage.	Poor services during lean hours.

Recommendation: Each of the structures outlined in Table 11 has its share of drawbacks and cannot be universally applied. Therefore, ASTC should consider a combination of options.

- In the case of management contracts, ASTC should continue to employ the fixed price + INR per vehicle-km model (with a minimum guaranteed daily km commitment) for payments to be received from operators. This suggestion is based on ASTC's successful experience with this arrangement during the management contract tender for the operation of 100 e-buses owned by ASTC in 2023.
- For GCC contracts, ASTC should explore the option of INR per vehicle-km for payments to be made to operators. This recommendation aligns with the practices of other Transport Authorities across India in managing GCC contracts.

C H A P T E R

6

Impact of E-Buses

Investment Requirement

An investment of approximately INR 6,150 crores will be required between 2023 and 2033 to achieve 100% electrification of ASTC's fleet. Roughly 46% of thus amount will be directed towards procuring assets including -buses, batteries, and charging stations; 9% will be directed to electricity purchases; 18% will be directed to operations and maintenance, and the remaing 27% for manpower. The annual outlay of this investment is shown in Figure 4.

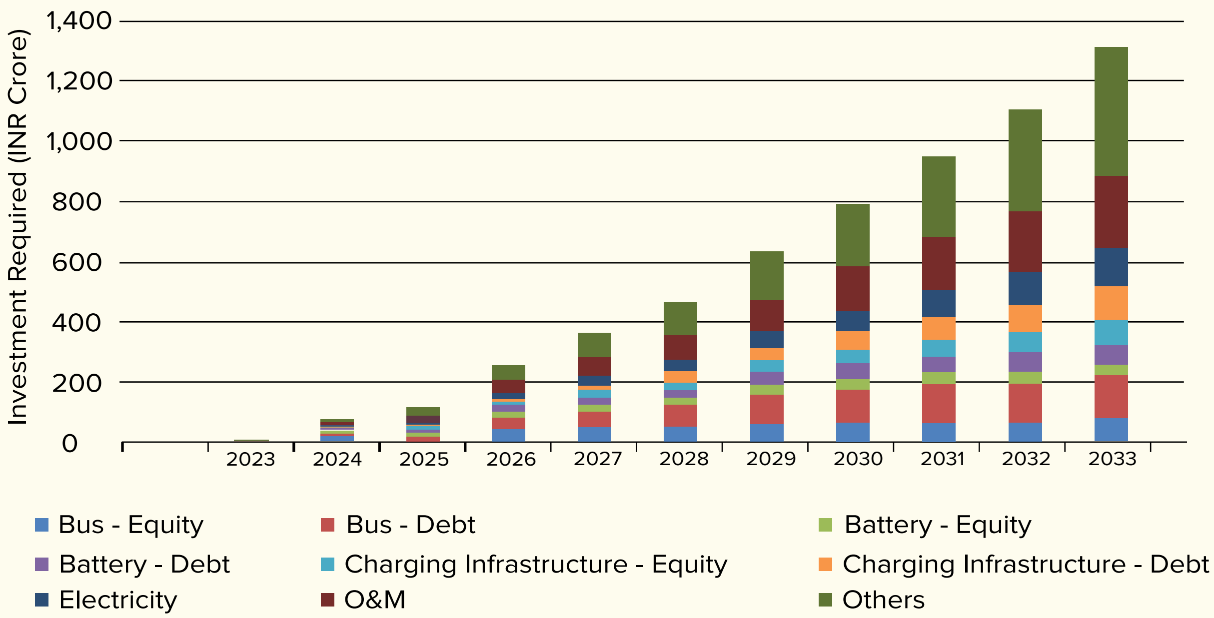


Figure 4: Investment Requirement for ASTC Bus Fleet Transition to E-buses

Environmental Benefits

It is estimated that switching to e-buses will help ASTC avoid over 500 thousand ton CO_2 emissions over the 2023-2033 period (Figure 5). It is to be noted that this number is representative of the tailpipe emissions or Scope 1 activities as defined by the Greenhouse Gas Protocol. Emissions related to electricity used for charging the batteries will fall under Scope 2 and is not covered in this study.

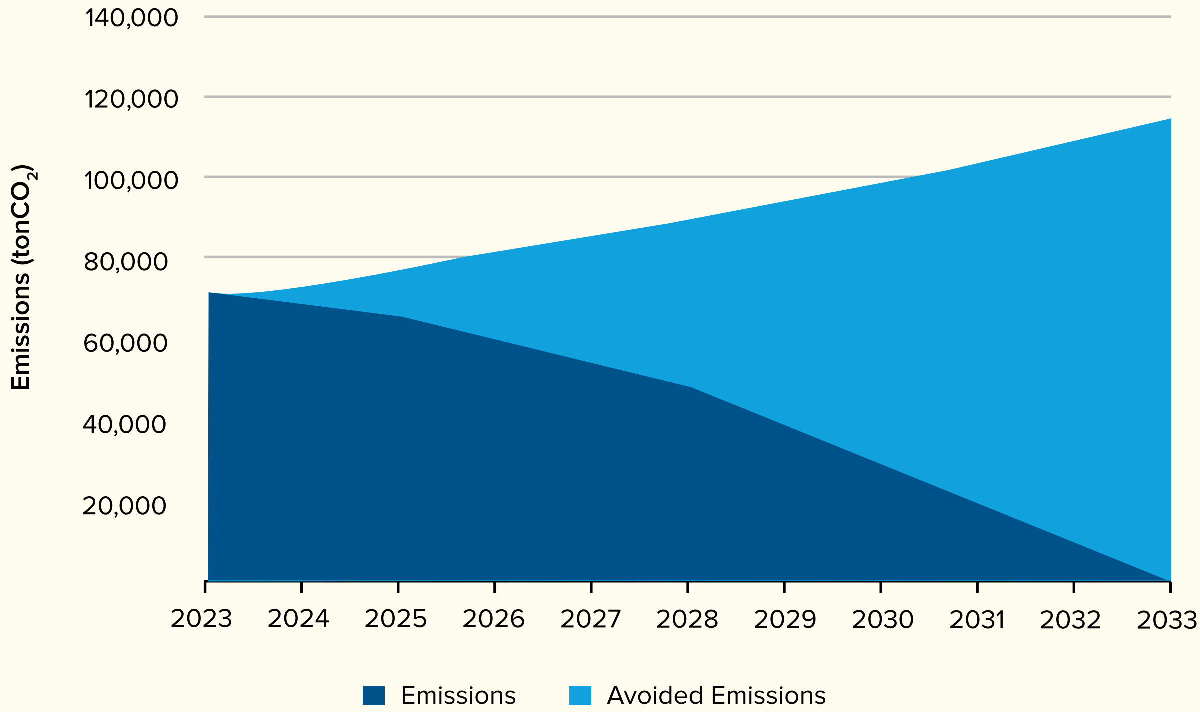


Figure 5: Emissions and Emissions Avoided with Transition to E-buses

CHAPTER 7

Conclusion and Way Forward

The roadmap for ASTC to electrify its bus fleet represents a significant stride towards sustainable and eco-friendly transportation. This report outlines key areas that ASTC must prioritise to successfully navigate towards a greener and more efficient future. As an immediate next step, ASTC should formally adopt the roadmap and integrate this into its operational planning. To do so, ASTC should undertake the following activities:

- Investments: Find the balance required between ASTC's financial stability, government funding, and fostering private sector investments.
- Planning: Undertake geospatial planning exercise to identify optimal charging infrastructure locations depending on current and prospective routes, depots, and charging strategies.
  - Stakeholder engagements:
    - Government of Assam:
      - Discuss approaches to increase modal share of public transporation.
      - Discuss business models which reduce dependence on government funding support.
    - APDCL: Undertake grid impact studies for charging station deployment.
- Capacity building: The specific capacity building needs depend on the business model chosen for e-bus procurement. However, capacity in terms of procurement process and documents for innovative business models is needed.
- Environmental benefits: ASTC should create a framework to calculate its carbon footprint segregatred by Scope 1 and Scope 2 activities to better understand the environmental benefits of transition to e-bus fleet.

Alliance for an Energy Efficient Economy™

37 Link Road, Ground Floor,
Lajpat Nagar III, New Delhi, 110 024

+91-11-41235600

info@aeee.in

www.aeee.in