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SHAKTI
SUSTAINABLE ENERGY FOUNDATION

Implementation Plan for Electrification of Public Bus Transport in Bengaluru

Implementation Plan for Electrification of Public Bus Transport in Bengaluru

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Center for Study of Science, Technology and Policy

April, 2018

Center for Study of Science, Technology and Policy (CSTEP) is a private, not-for-profit, technology-policy think tank, registered under Section 25 as a Research Corporation, in 2005.

Shakti Sustainable Energy Foundation works to strengthen the energy security of India by aiding the design and implementation of policies that support renewable energy, energy efficiency and sustainable transport solutions.

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Government of Karnataka

ACS/CI/ /2018

Date: March 28, 2018

Dear Dr. Bharadwaj,

Sub: Report on *'Implementation Plan for Electrification of Public Bus Transport in Bengaluru'.*

I welcome the release of the report titled *'Implementation Plan for Electrification of Public Bus Transport in Bengaluru'*. It is a timely study.

As we know, Karnataka is the first Indian state to announce an Electric Vehicle (EV) Policy. We appreciate the inputs provided by the Center for Study of Science, Technology and Policy (CSTEP) during the drafting of the EV policy document.

This project identifies key barriers in large-scale EV penetration and would help to prepare a long-term implementation plan for public electric bus transportation for Bengaluru. The detailed assessment and the framework presented in this report could serve as a template across major cities for planning future e-bus transport ecosystems.

I congratulate the project team on bringing out this comprehensive document.

With best wishes,

Yours sincerely,

(D.V.Prasad)

Dr. Anshu Bharadwaj,
Executive Director,
Center for Study of Science, Technology and Policy,
Bengaluru (Karnataka).

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V. Ponnuraj, IAS
Managing Director

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No.BMTC/CO/MD/198/2017-18

Date: March 27, 2018

To,
Dr. Anshu Bharadwaj,
Executive Director,
Center for Study of Science, Technology and Policy,
Bengaluru (Karnataka).

Sub: Report on 'Implementation Plan for Electrification of Public Bus Transport in Bengaluru'.

Dear Dr. Bharadwaj,

I would like to compliment the release of the report titled 'Implementation Plan for Electrification of Public Bus Transport in Bengaluru'.

The well-researched and logically compiled report has come at the right time. As we know, major Indian cities are in the process of adopting stringent environmental measures with respect to improving air quality. An accelerated adoption of electric transport would not only help in reducing emissions, thus providing major health benefits to the urban population but also likely to help the public transportation in reducing the cost of travel in future as there will be considerable savings in fuel cost and maintenance cost. In addition to lowering emissions and fuel consumption, EVs are expected to offer huge opportunities for investments, manufacturing and employment generation.

Bangalore Metropolitan Transport Corporation (BMTC) has plans of introducing a significant number of electric buses in the near future and has already approved induction of its first fleet of 80 electric buses. If the trend of falling battery prices continues, BMTC would be looking at a scenario converting bulk of its fleet to EV buses. We deeply appreciate the inputs provided by the Center for Study of Science, Technology and Policy (CSTEP) during Request for Proposal formulation and procurement process of electric buses. The nascent technology, advantages and disadvantages of choosing different options and the risks associated with adoption of new technology threw up number of challenges in the procurement process. Understanding and appreciating consequences of ending up with each of the choices was a major challenge and I must acknowledge with gratitude the inputs given by organisations whohave worked closely with us in educating and learning with us.

This report presents analyses of the transport and electricity distribution infrastructure in Bengaluru. CSTEP worked closely with BMTC and Bangalore Electricity Supply Company (BESCOM) to conduct a detailed bus route analysis using various criteria, and identified BMTC routes, which could be prioritised for electrification. The report also presents a detailed Total Cost of Ownership (TCO) analysis framework, comparing diesel buses with different variants of e-buses. The integrated planning and visualisation tool for EV fleet implementation and operation could serve as a reference point for future BMTC fleet planning.

My best wishes to the CSTEP team for their work in electric transportation.

With regards

Yours sincerely,

V. Ponnuraj

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FOREWORD

Public transport systems in India run predominantly on fossil fuels. This leads to high levels of pollution in urban areas and contributes to the growing current account deficit arising from high fuel imports. The 'stop-and-go' traffic situation in our cities reduces the efficiency of conventional engines. These factors, combined with our ambitious renewable energy targets and the insufficient flexible reserves to absorb variability of these resources, make electric mobility a critical intervention. Electrification of transport systems can improve air quality, reduce fossil fuel imports and offer the balancing reserves necessary for integrating variable renewable energy.

The Government of India has initiated several measures to drive the large-scale electrification of the transport sector. The National Electric Mobility Mission Plan (NEMMP) was launched in 2013 with the target of introducing 6-7 million electric or hybrid vehicles by 2020. The FAME (Faster Adoption and Manufacturing of (hybrid) and Electric Vehicles) India scheme, launched in 2015, was a two-year initiative offering financial incentives to the buyers of electric and hybrid vehicles. Simultaneously, many cities participating in India's Smart Cities Mission have identified electric mobility as a key intervention under their development plans.

Despite these efforts, the uptake of electric vehicles (EVs) has been slow with the number of vehicles sold in the past few years falling far behind the stated targets. This shows that several challenges still need to be addressed for the EV sector to grow. EVs are priced quite high and only a limited number of vehicle models are available in the market. Charging infrastructure must be strengthened significantly and reliable after sales servicing network must be provided to consumers. The road to electric mobility must be supported by appropriate measures to facilitate the transition required to meet the EV targets.

The study, undertaken by the Center for Study of Science, Technology and Policy (CSTEP) with support from Shakti Sustainable Energy Foundation, is particularly relevant in this context. The study develops a long-term implementation plan for public electric bus transportation in Bengaluru. The detailed assessment includes:

- Analysis of the bus routes of Bangalore Metropolitan Transport Corporation (BMTC)
- Development of a Geographic Information System (GIS)-based computational platform, which provides a visualization of the results/ various scenarios and
- Development of a total cost of ownership (TCO) framework to compare diesel buses with different variants of electric buses.

While this roadmap is specific to Bengaluru, it holds immense potential for replication by cities and states across India to facilitate electrification of public transport fleet. Shakti has also supported a similar study for Kolkata, which laid out a comprehensive implementation plan to electrify public transport in the city.

I hope that this study will be of interest to policy-makers, regulators, automobile manufacturers, city planners, transport corporations and distribution companies and that its recommendations will translate into action.

I congratulate the team at CSTEP for their effort and wish them success in their future endeavours.

Krishan Dhawan
CEO, Shakti Sustainable Energy Foundation

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Dear Reader,

I would like to express my deep gratitude to the Shakti Sustainable Energy Foundation for their support in conducting the project "Implementation Plan for Electrification of Public Bus Transport in Bengaluru".

As we know, India is one of the fastest growing automobile markets in the world. Urbanisation, motorisation and increase in travel demand over the years have played a substantial role in shaping the current trends in fuel consumption and emissions intensity. Many cities in India have exceeded the permissible levels of Particulate Matter and CO_2 emissions, which contribute to increased health-related risks. A shift to electric vehicles (EVs) would, thus, provide an opportunity to move towards a clean and low-carbon transport ecosystem.

The Government of India recently announced its plans for large-scale penetration of electric public transportation by 2030. Through various policies, the government aims to promote EVs as the preferred choice of vehicle to consumers. Accelerated adoption of electric transport would help in reducing emissions, which would support India's Nationally Determined Contribution (NDC) targets, along with providing major health benefits in the urban setting. In addition to lowering emissions, EVs can also be expected to offer huge opportunities for investments, manufacturing and job creation.

Recently, Karnataka became the first Indian state to announce an EV Policy. The Bangalore Metropolitan Transport Corporation (BMTC) is in the process of procuring its first fleet of 40 electric buses (e-bus) this year.

This report identifies key barriers in large-scale EV penetration and helps prepare a long-term implementation plan for public e-bus transportation for Bengaluru. The detailed assessment and framework presented in this report could serve as a template across major cities for planning future e-bus transport ecosystems.

The CSTEP team worked in tandem with the BMTC and the Bangalore Electricity Supply Company (BESCOM), taking continuous inputs from these key stakeholder departments of the Government of Karnataka. I would like to express my deep gratitude to the officials of these two departments for their guidance and support throughout the duration of this study.

Once again, I deeply appreciate the support provided by the Shakti Sustainable Energy Foundation to conduct this timely study.

Dr Anshu Bharadwaj
Executive Director

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Acknowledgements

Center for Study of Science, Technology and Policy (CSTEP) expresses its deep gratitude to Shakti Sustainable Energy Foundation (SSEF) for their support in conducting the project "Implementation Plan for Electrification of Public Bus Transport in Bengaluru". We would especially like to thank Mr Deepak Gupta, Mr Ravi Gadepalli, Ms Disha Agarwal and Ms Avni Mehta of SSEF for their valuable feedback during the course of the project.

We are grateful to Shri. D.V. Prasad, Additional Chief Secretary, Department of Industries and Commerce, Government of Karnataka for all the support and encouragement to our project team. The support and data received from Bangalore Metropolitan Transport Corporation (BMTC) and Karnataka Energy Department were crucial for the success of this project. We would like to express our special thanks to BMTC MD Mr V. Ponnuraj for his guidance and actively involving CSTEP in the tender and procurement process of BMTC's first fleet of electric buses. We sincerely thank Dr Ekroop Caur (Ex-MD), Mr Bishwajit Mishra (Director IT), Mr M. Ganesha and Ms Usha (Mechanical Department) for their advice and encouragement. We are grateful to BESCOM officials Shri. B.T. Prakash Kumar, General Manager, ICT & MIS and Shri. B.K. Uday Kumar, Chief Engineer (Electy.) BRAZ, for their advice and support throughout the course of the project.

During the course of this study, we consulted several stakeholders who provided valuable information regarding the overall Electric Vehicle (EV) sector. This helped our understanding of the electric transportation domain, immensely. In this context, we would like to thank NITI Aayog, Ministry of New and Renewable Energy, Bureau of Indian Standards, Ministry of Heavy Industries, and Ministry of Road Transport and Highways for involving us in various EV-related discussions. We would like to acknowledge useful discussions with officials of Department of Science and Technology (Mr Sajid Mubashir), Mr Saurabh Kumar (MD) – Energy Efficiency Services Limited (EESL), Karnataka Electricity Regulatory Commission, Karnataka State Road Transport Commission, Karnataka Power Transmission Corporation Ltd and Bangalore Metro Rail Corporation Ltd. We would like to express our sincere appreciation for Ola cabs, Lithium Cabs, Sun Mobility, TATA Motors, Volvo Buses and Mahindra for their useful inputs during various meetings and interactions.

We convey our heartfelt gratitude to Subhrajit Debnath, Deepu Ramachar and Rakesh Rajpurohit for developing the decision support web platform and Noelene Marisa Yesudas for assisting us with the GIS visualisation of this project.

We are grateful to Dr S.S. Krishnan, Advisor, and Dr Jai Asundi, Research Coordinator, CSTEP, for enriching the document with valuable technical feedback. Thanks are also due to our CSTEP colleagues Merlin Francis, Arushi Sen, Abhijit Chakraborty and Aswathy Shivaji for providing editorial support and graphics inputs.

Executive Summary

India is one of the fastest growing automobile markets in the world. From an environmental perspective, automobiles alone contribute 25-30% to global emissions, while India's transport sector produced 188 Million Tonnes (MT) of CO_2e emissions, as per 2010 estimates; of this, 87% was contributed by road transport (Ministry of Forest Environment and Climate Change, 2015). In 2017, the Government of India (GoI) announced plans for all-electric public transportation by 2030. To aid this effort, funds have been allocated under the Faster Adoption and Manufacturing of hybrid and Electric vehicles policy (FAME 2015) to subsidise electric vehicle (EV) purchases. Through these schemes, the government aims to enable hybrid and EVs to become the preferred choice of transportation for consumers.

However, EV deployment in India has been slow, so far. This is due to the high cost of the vehicles and a lack of EV-related infrastructure and technology awareness among users. Large-scale penetration of EVs will require coordinated planning among three sectors, namely, transport, urban planning and power grid. India also has a renewable energy (RE) target of 175 GW, to be achieved by 2022. The synergy between the National Electric Mobility Mission Plan (NEMMP) and RE targets will help in the development of a robust and clean transport roadmap.

Recently, Karnataka became the first Indian state to announce an EV Policy. This project identifies key barriers in large-scale EV penetration and would help to prepare a long-term implementation plan for public electric bus (e-bus) transportation for Bengaluru. This will further help with the transition to an EV fleet at the most efficient and economical terms. The detailed assessment and the framework presented in this report could serve as a template across major cities for planning future e-bus transport ecosystems. In this project, we have analysed the transport and electricity distribution infrastructure in Bengaluru by working closely with the Bangalore Metropolitan Transport Corporation (BMTC) and Bangalore Electricity Supply Company (BESCOM). We have also conducted a detailed bus route analysis using various criteria and identified BMTC routes, which could be prioritised for electrification. This could serve as a reference database since BMTC has announced plans of introducing a significant number of e-buses in the near future, and already released a tender for the procurement of 150 e-buses.

This project focussed on developing an e-bus fleet implementation plan, which includes: (1) identification of suitable BMTC routes for installing Electric Vehicle Supply Equipment (EVSE) or charging infrastructure; (2) a Geographic Information System (GIS) based integrated planning and visualisation tool for EV fleet implementation and operation, which could be further used by the Department of Heavy Industry, Ministry of New and Renewable Energy, Ministry of Power, NITI Aayog, Ministry of Urban Development and State Transport Units (STUs); (3) a cost-benefit framework for e-bus variants (which includes fully electric and hybrid buses); and (4) a plan for generating awareness among consumers/STUs regarding clean energy based public transport and its benefits.

This report also presents short, mid and long-term e-bus implementation plans. The procurement and deployment of e-buses should be done in stages. This will not only mitigate the risks associated with implementing new EV technology, but also provide BMTC with the flexibility to absorb future technology breakthroughs. We have identified currently operational BMTC routes that are feasible from a transport and electrical network perspective (requiring no changes in the bus schedules or grid upgradation). These routes can be prioritised for implementing the operations of the e-bus fleet. All types of current BMTC services, namely, Vayu Vajra, Vajra, Metro-feeder routes and ordinary non-AC diesel bus routes, were considered for the analysis. We have used load data from 11 kV BESCOM feeders to analyse the impact of e-bus deployment on the existing electrical infrastructure along given routes.

The report concludes with recommendations on significant (up to 50%) e-bus deployment by 2022 and 100% e-bus deployment by 2030 in Bengaluru, which is in-line with GoI's all-electric plans for public transportation by 2030.

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1. Introduction

India is one of the fastest growing automobile markets in the world. Today, while vehicular emission may not be the only source of air pollution in major Indian cities, it does significantly contribute to the deteriorating air quality. Automobiles alone contribute 25-30% of the emissions, globally. As per 2010 estimates, the total amount of CO_2e emissions from India's transport sector was 188 Million Tonnes (MT), out of which 87% was contributed by road transport (Ministry of Forest Environment and Climate Change, 2015). Urbanisation, motorisation and increase in travel demand over the years have played a substantial role in shaping the current trends in fuel consumption and emission intensity. Many cities in India have exceeded the permissible levels of Particulate Matter (PM) and CO_2 emissions, which contribute to increased health-related risks (Central Pollution Control Board, GoI, 2012). A shift to electric vehicles (EVs) would, thus, provide an opportunity to move towards a clean and low-carbon transport ecosystem.

The Government of India (GoI) recently announced its plans for all-electric public transportation by 2030. Earlier, under the National Electric Mobility Mission Plan (NEMMP 2013), 6-7 million EV/hybrid vehicles were envisioned to be deployed on Indian roads by 2020, the majority being two-wheelers. To further the adoption of EVs, the Faster Adoption and Manufacturing of hybrid and Electric vehicles policy (FAME 2015) has allocated funds to subsidise EV purchases. Through these schemes, the government aims to promote hybrid vehicles and EVs as the preferred choice of vehicle to consumers. Accelerated adoption of these modes of transport would help in reducing emissions, which would support India's Nationally Determined Contribution (NDC) targets along with providing major health benefits in the urban setting. In addition to lowering emissions, EVs can also be expected to offer huge opportunities for investments, manufacturing and job creation.

Major Indian cities are striving to adopt stringent environmental measures in matters of air quality. For example, in the last decade, all public transit buses and public light duty vehicles in Delhi were mandated to convert to Compressed Natural Gas (CNG) fuelled engines. A new supply chain for fuelling was established in record time, with similar initiatives being adopted by some other cities as well. The Himachal Road Transport Corporation (HSTRC) and Mumbai Metropolitan Region Development Authority (MMRDA) are also taking measure to reduce pollution by introducing pure electric buses (e-buses) and hybrid e-buses, respectively. Recently, Karnataka became the first Indian state to announce a state EV policy.

However, EV deployment in India has been slow, so far. This is due to the high cost of the vehicles and a lack of EV-related infrastructure and technology awareness among users. Large-scale penetration of EVs will require coordinated planning among three sectors, namely, transport, urban planning and power grid. Further, India has set a target of achieving 175 GW of renewable energy (RE) by 2022. With a commitment of installing 40% of fossil-free capacity in the electricity mix by 2030, under its NDCs, the share of renewables in the country is set to increase. The synergy between NEMMP and RE targets will help develop a robust and clean transport roadmap.

In the present study, we have chosen Bengaluru for preparing an e-bus implementation plan. Out of the total amount of emissions from the transport sector in Bengaluru, NOx accounts for 68% and PM10 accounts for 42% of the total amount of road dust. As the bus fleet has a significant share (27%) in the transport system of Bengaluru, converting public bus fleets to e-bus fleets could be a progressive step towards establishing a clean transport system.

The Bangalore Metropolitan Transport Corporation (BMTC) operates the public transport bus service in the Bruhat Bangalore Mahanagara Palike (BBMP) area and in parts of the Bangalore Metropolitan Region (BMR). At present, BMTC is among the more efficient State Transport Units (STUs) in the country. It operates approximately 2,400 routes, with a fleet of about 6,400 buses, catering to approximately 45-50 lakh passenger trips per day. It is expected that by 2021, at least 67 lakh passenger trips per day will be served by buses only[1].

The Bangalore Electricity Supply Company (BESCOM) is the power distribution provider for the Bengaluru zone. It serves 207 lakh consumers, with a mix of residential, commercial and industrial customers. BESCOM is envisioning high penetration of solar installations in the coming years as Karnataka has set significant RE targets. It anticipates an installation of 6 GW of solar capacity, by 2020, including approximately 1 GW of Rooftop Solar Photovoltaic (RTPV) installations. The upgradation of the city's grid in the future will be aligned with the state's RE and EV targets.

This project identifies key barriers to large-scale EV penetration and prepares a long-term implementation plan for public e-bus transportation in Bengaluru. The detailed assessment and framework presented in this report serves as a template across major cities for planning a future e-bus transport ecosystem. In this project, we have analysed the transport and electricity distribution infrastructure in Bengaluru, by working closely with BMTC and BESCOM. This study includes the development of a detailed implementation plan for BMTC's buses, which would help the agency transition to an EV fleet at the most efficient and economical terms. We have also carried out a bus route analysis using various criteria, and identified BMTC routes which could be prioritised for electrification. This could serve as a reference database, since BMTC has announced plans to introduce a significant volume of e-buses in the near future. We have developed a Geographic Information System (GIS) based computational platform, which provides visualisations of the results. We have also carried out a cost-benefit analysis, comparing diesel buses with different variants of e-buses.

The project outcome is an e-bus fleet implementation plan that includes: (1) identification of suitable BMTC routes for installing Electric Vehicle Supply Equipment (EVSE) or charging infrastructure; (2) an integrated planning and visualisation tool for EV fleet implementation and operation, which could be used by the Department of Heavy Industry, Ministry of New and Renewable Energy, Ministry of Power, NITI Aayog, Ministry of Urban Development, and STUs; (3) a cost-benefit framework for e-bus variants (which includes fully electric and hybrid buses); (4) a plan for awareness generation among consumers/STUs regarding clean energy based public transport and its benefits.

[1] P. Anantha Lakshmi, *et al*. "Need for Government Support for Public Bus Transport", Center for Study of Science, Technology and Policy (2015).

2. Global Overview of Electric Vehicle Adoption

Adoption of EVs has been rapidly increasing over the last decade. A 2013 McKinsey research report[2] reveals that primarily high-income, well-educated consumers and industry players with a concern for the environment were early adopters of EVs. This is especially in cities like Shanghai, New York and Paris. Key aspects fuelling the adoption of EVs, across the globe, include:

1. Scope for reduction of carbon emissions

Adoption of EVs will contribute towards a reduction in CO_2 [and other Green House Gas (GHG)] emissions, and thus help in decreasing the effects of global warming. With this focus, the European Union (EU) has set ambitious CO_2 reduction targets of achieving 95 g CO_2/km by 2020 in the transport sector[3]. As of 2014, the average emission from the overall transport sector stood at 123.3 g CO_2/km[4]. Nevertheless, the EU is expected to further tighten its regulatory standards beyond 2020.

2. Government support

Governments across the globe are offering lucrative incentives to EV consumers. For instance, Amsterdam (The Netherlands) is offering parking permits in dense urban areas, whereas Oslo and Drammen, Norway have a free parking policy for zero-emission vehicles[5].

2.1 Steps taken by Governments towards increased EV Mobility

Some of the major global initiatives[6,7] to encourage the adoption of EVs are mentioned below.

- The United States of America (US): Citizens enjoy tax credits of up to USD 7,500 for certain listed vehicles (Chevrolet Volt, Nissan Leaf, Coda Sedan, Tesla Roadster, etc.). Moreover, states such as California offer additional incentives of up to USD 2,500, whereas Colorado provides an income tax credit of up to USD 6,000.
- Canada: The Canadian Government expects to have 1 EV for every 20 vehicles driven in Ontario by 2020. On the other hand, Quebec offers rebates of up to USD 8,000 per EV purchased or leased[8].
- The United Kingdom (UK): UK offers a purchase incentive of up to £4,500 for electric cars and £8,000 for light commercial vehicles. Also, a one-time premium of £4,000–7,000 (based on purchase price) is disbursed for vehicles that emit less than 75 g of CO_2 per km.
- France: France began offering purchase incentives of up to €6,300 on EVs from 2013. Furthermore, scrapping diesel vehicles allows an additional bonus of €10,000.

[2] McKinsey & Company, "Electric vehicles in Europe: gearing up for a new phase?" (2014)
[3] Ibid.
[4] The International Council on Clean Transportation," CO_2 emissions from new passenger cars in the EU: Car manufacturers' performance in 2014" (2015)
[5] McKinsey & Company, "Electric vehicles in Europe: gearing up for a new phase?" (2014)
[6] Ibid.
[7] International Energy Agency, "Global EV outlook 2016: Beyond one million electric cars" (2016)
[8] Global News, "Electric car subsidies in Ontario and Quebec costly and inefficient," http://globalnews.ca/news/3547509/electric-car-subsidies-ontario-quebec/

- Germany: Germany had set a goal of reaching 1 lakh EVs by 2014 and offered up to €5,000 for each unit. In addition to that, a budget of €500 million is allocated for EV-related incentives, technology and infrastructure. However, as of December 2016, the total EV volume in Germany was 75,000, far behind its 2014 targets[9,10].
- Japan: The Japanese government aims to have 1 EV for every 5 vehicles driven, by 2020. A budget of ¥106 billion has been allocated for this.
- Norway: In Norway, exemption from purchase taxes as well as VAT is offered for EVs. A very attractive package of subsidies amounting to USD 12,000 is provided.
- Portugal: In Portugal, EVs are exempt from vehicle registration and circulation taxes. Moreover, scrapping an existing vehicle and replacing it with an EV brings in a bonus of USD 5,000.
- Estonia: Estonia has installed fast chargers all over the country (165 in total) and has ensured that all cities with a minimum of 5,000 inhabitants host at least one station[11].
- The Netherlands: In the Netherlands, the income tax imposed on full electric cars was 0% in 2013, and 4% in 2014 (versus 14-20% for Internal Combustion Engine cars)[12].
- China: EV owners in China are exempted from acquisition tax and excise tax, which are normally based on the engine size being replaced. The subsidy provided for EVs was between 35,000 and 60,000 CNY in 2013[13].

A summary of the policy instruments for adoption of EVs is provided in Table 30, Appendix 1. In an attempt to reduce traffic congestion and pollution in major European metropolises, their respective governments have provided specific schemes. A summary of some of these incentives (in major cities) has been captured in Table 31 in Appendix 1.

2.2 EV Fleet: Market Overview

According to the Global EV Outlook 2017[14], it is estimated that the global stock of e-buses reached 3,45,000 in 2016. China stood out as the world leader in the e-bus segment. Currently, China possesses 3.4 lakh e-buses, out of which 3 lakh are pure e-buses[14]. Table 1 shows the global stock of all types of e-buses.

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[9] ARAI, "Policies & Implementation Status of EVs in India," http://www.jari.or.jp/Portals/0/resource/pdf/AAI%20Summit/H25/2.%20EV%20ARAI.pdf
[10] HybridCARS, "The World Just Bought Its Two Millionth Plug-in Car," http://www.hybridcars.com/the-world-just-bought-its-two-millionth-plug-in-car/
[11] Forbes, "Estonia Launches Nationwide Electric Vehicle Fast-Charging Network," https://www.forbes.com/sites/justingerdes/2013/02/26/estonia-launches-nationwide-electric-vehicle-fast-charging-network/#58b7015c2610
[12] McKinsey & Company, "Electric vehicles in Europe: gearing up for a new phase?" (2014)
[13] Forbes, "China's New Electric Vehicle Subsidies: Winners and Losers," https://www.forbes.com/sites/tomkonrad/2013/09/18/chinas-new-electric-vehicle-subsidies-winners-and-losers/#3cc399554bc2
[14] International Energy Agency, "Global EV outlook 2017" (2017)

Table 1: Global stock of all types of electric buses at the end of 2016

Country	All types of EV stock, 2016
Europe	1,273
U.S.	200
China	343,500
India	100*
Japan	21*

Source: Global EV Outlook 2016/2017
*As of year 2015

2.3 Key EV Developments in India

India too has demonstrated its intention of reducing its overall tail-pipe emissions. The government introduced a mobility transition mission[15], which aimed to deploy 6–7 million EVs on the roads by 2020. According to 2007 estimates, the transport sector was responsible for 7.5% of the total GHG emissions in India.[16] It is estimated that if the objective of deploying 6–7 million EVs is achieved, then the country can achieve an annual GHG emission savings of approximately 2 MT.

NEMMP plays an important role in the fuel security of the nation. India imported 83% of its crude oil in 2015–16, spending around INR 4,160 billion[17]. As per the all India study report submitted to the Petroleum Planning and Analysis Cell (PPAC), 70% and 99.6% of all diesel and petrol, respectively, was consumed by the transport sector in the year 2014[18].

Besides NEMMP, GoI has formulated various policies to provide financial support to EV buyers. Some of these are:

1. The Auto Fuel Vision & Policy was formulated in 2014 to convert Bharat Stage (BS) III emission standard engines to BS IV emission standard. This mandated conversion resulted in the reduction of sulphur and PM 2.5 emissions. Further, due to high air pollution warnings, the Ministry of Road Transport and Highways announced a transition to BS VI standards directly in 2016, skipping BS V.
2. Under the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) policy, INR 1 lakh crore will be spent in a planned and structured manner, from 2014 to 2019, to replace conventional public transport buses with e-buses.
3. The Faster Adoption and Manufacturing of Electric Vehicles (FAME) was launched in 2015 to support the EV manufacturing ecosystem and sales. It incentivises electrification of all vehicle segments and covers several variants of hybrid and pure EV technologies. Under this scheme, EV buyers are provided purchase incentives of up to INR 66 lakh for each e-bus and 1.38 lakh for each four wheeler. The FAME scheme will be active for 6 years, focusing on four areas, namely, technology development, charging infrastructure, demand creation and pilot projects.

[15] Department of Heavy Industry, Government of India, "National Electric Mobility Mission Plan 2020" (2012)
[16] Ministry of Environment and Forests, Government of India, India, "Greenhouse Gas Emissions 2007" (2010)
[17] Ministry of Petroleum and Natural Gas, Government of India, "Indian petroleum & natural gas statistics 2015-2016" (2016)
[18] Press Information Bureau, Government of India – Ministry of Petroleum and Natural Gas, http://pib.nic.in/newsite/PrintRelease.aspx?relid=102799

In May 2017, the Nagpur local authority launched the country's first multi-modal EV project. This project plans to bring in 200 EVs into the city, including cars (taxis), rickshaws and buses. The fleet is expected to include 100 new Mahindra e2o Plus cars, buses from Tata Motors and BYD, and Kinetic Safar rickshaws.

GoI is taking steps to create dedicated low-cost funds to encourage the adoption of EVs in the country. Discussions are underway between GoI and Softbank to arrange low interest-rate loans for green mobility projects. The government wants to deploy 2 lakh e-buses for public transportation[19]. Further, the Maharashtra Government has waived VAT, road tax and registration charges for all EVs in the state, to incentivise this sector[20].

Recently, the taxi aggregator Ola committed over INR 50 crore for EVs and charging infrastructure. As part of its initial steps towards promoting green mobility, it intends to install more than 50 charging points across four locations in Nagpur[21].

2.4 EV Status in Bengaluru

- Among all Indian cities, Bengaluru ranks first in the total number of buses and two-wheelers and second in the total number of vehicles and car ownership.
- Ola (ANI Technologies Ltd.) plans to deploy 1 million electric cars in the country within the next 5 years, with specific focus on Bengaluru.
- Bengaluru currently has only 16 public charging stations, which are maintained by Mahindra for its electric cars.
- Lithium Technologies India R&D Pvt. Ltd. operates more than 200 corporate e-taxis in the city today.

Ola handles one of India's largest online transportation networks. Going forward, it plans to pursue its EV initiative proactively. Table 2 illustrates key specifications of its electric car service.

Table 2: Charging specifications for four-wheeler cabs (Courtesy: Ola, Bengaluru)

Parameters	**Vehicle: Mahindra e_2O Plus**
Charging Time	
Normal charging (hours)	6-10
Fast charging (hours)	1.5-3
Charging Infrastructure	
Cost per charging station (INR, lakh)	4.5-16
Energy requirement per vehicle (kWh)	16.5
Information about connectors and standards	GBT[22] Standard
Battery Specifications	
Battery cost (USD/kWh)	280-375 (INR 18,205 – 24,382)[23]
Charging power (kW)	48 or 72

[19] The Indian Express, "Nagpur becomes first city with electric mass mobility system," http://indianexpress.com/article/india/nagpur-becomes-first-city-with-electric-mass-mobility-system-ola-mahindra-e-vehicle4676750/
[20] Ibid.
[21] The Hindustan Times, "Nagpur gets 200 e-vehicles," http://www.hindustantimes.com/india-news/nagpur-becomes-first-city-with-electric-mass-mobility-gets-200-e-vehicles/story-hwPoGHvv8eNxVoDTHQrzaM.html
[22] GBT – Guobiao Tuijian (Chinese standard naming convention)
[23] Exchange rate: US$ 1–INR 65.02 as of October 2017

Chemistry	Lithium-ion battery (LIB)
Capacity (Ah)	210
Battery range (km)	80-125
Battery life (cycles)	2,000
Operational Information	
Daily average distance covered (km)	120-200

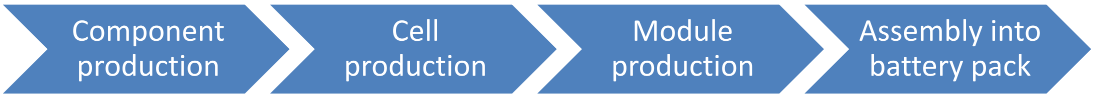
E-bus Trials in Bengaluru

BMTC used an e-bus from BYD Co. Ltd. (leading Chinese e-bus manufacturer) in 2014, to run trials. The bus was expected to cost around INR 2.7 crore and was operated on the Kempegowda Bus Station (KBS)–Kadugodi and KBS–ITPL routes.

On an average, the bus completed six trips a day and covered approximately 60-65 km per trip[24]. These buses were powered by BYD's non-toxic lithium iron-phosphate batteries. At the end of the pilot, BYD claimed the buses to be capable of travelling over 250 km on a single charge, irrespective of traffic. However, the cost of these buses vis-à-vis conventional diesel buses was seen as a major bottleneck for large-scale adoption at that time, regardless of the mileage efficiency.

2.5 Prominent Battery Technologies for EV Application

The Boston Consulting Group has predicted that by 2020, the global market for EV batteries will reach an astronomical figure of USD 25 billion[25]. In a bid to refine existing research and development (R&D) initiatives, the US Council for Automotive Research (USCAR) and the US Advanced Battery Consortium (USABC) have set goals for improving battery characteristics. The supply chain of batteries for EV application follows several steps, as shown below, before the batteries are integrated with an EV[26].



Among different battery technologies, the LIB is a promising alternative for EV applications, over the conventional lead-acid batteries. It has high power density, a high depth of discharge (DOD) and includes a wide range of battery chemistries, which have different combinations of anode and cathode materials. While anodes used for Lithium-ion batteries are mainly graphite and Lithium titanate (LTO), prominent and well-known battery cathodes are Lithium-Nickel-Cobalt-Aluminium (NCA), Lithium-Nickel-Manganese-Cobalt (NMC), Lithium-Manganese spinel (LMO) and Lithium iron phosphate (LFP).

Table 3 shows the different kinds of battery technologies used by major e-bus manufacturers and their battery suppliers.

[24] The Indian Express, "BMTC urges extension of electric bus trial period," http://indianexpress.com/article/cities/bangalore/bmtc-urges-extension-of-electric-bus-trial-period/
[25] The Boston Consulting Group, "Batteries for Electric Cars: Challenges, Opportunities, and the Outlook to 2020" (2010)
[26] Clean Energy Manufacturing Analysis Center, "Automotive Lithium-ion Battery (LIB) Supply Chain and U.S. Competitiveness Considerations" (2015)

Table 3: Battery technologies along with suppliers and battery management systems (BMS)

EV Bus Model	Battery Chemistry	Capacity (kWh)	Range (km)	Charging Time	Battery Supplier	BMS Supplier
BYD-k9	LFP	324	≥250	5 hr	BYD	BYD
Yutong-E12	LFP	295	320, at 20°C without AC	5 hr	ATL, Tianjin Lishen and Samsung SDI	Yutong
Proterra-FC (35 foot catalyst)	LTO	79-105	80-100	10-13 min	Toshiba	Proterra
Proterra-XR (35 foot catalyst)	NMC	220-330	220-310	<3 hr	LG Chem	Proterra
Wuzhoulong-FDG6113EVG	LFP				Optimum Nano	Optimum Nano
EBUSCO-YTP 1	LFP	242-311	250-300	2.5 hr	EBUSCO	EBUSCO

2.6 EV Battery Management System (BMS)

Safety and reliability are two important aspects to be considered while expanding the market share of EVs. In this respect, battery technology and BMS play a key role. In a battery pack, some batteries may get overcharged, while some may remain undercharged, during operation. This affects the battery's performance. A BMS addresses this by equalising all batteries in a pack at the same voltage. This process involves voltage transfer from the battery at a higher level to those at a lower charge. To ensure safe and reliable vehicle operation, a BMS should be able to:

- Measure individual cell and pack voltage
- Measure the current flowing into (charging) or out (during discharge) of the battery
- Monitor cell temperature
- Disconnect the battery when maximum/minimum permissible temperature, voltage, etc. are exceeded
- Charge balance among cells in a stack
- Estimate the state of charge (SOC), state of function (SOF) and state of health (SOH) of the battery.

Although available in a wide-range of portable electronics, such as laptops, computers and mobile phones, the BMS used in EVs are significantly more complex. This is because the number of cells required for a vehicle's battery is much greater than those required in portable electronics. The BMS of an EV should therefore be designed such that it can manage the enormous amount of data generated by each cell, and simultaneously monitor each battery cell continuously. According to the "Global and China Power Battery Management System (BMS) Industry Report, 2016-20"[27], the market size of BMS is expected to reach USD 7.25 billion by 2022, from USD 1.98 billion in 2015, at a Compound Annual Growth Rate (CAGR) of 20.5%.

2.7 Electric Vehicle Supply Equipment (EVSE)

The ecosystem for publicly accessible Electric Vehicle Supply Equipment (EVSE) and charging stations is generally created in collaboration with a city's EV and EVSE programmes. In the

[27] PR Newswire, "Global and China Power Battery Management System (BMS) industry Report, 2006 – 2020," http://www.prnewswire.com/news-releases/global-and-china-power-battery-management-system-bms-industry-report-2016-2020-300319644.html

recent past, some countries (China, Denmark, France, Germany, Japan, the Netherlands, Norway, Portugal, Sweden, the UK and the US)[7] have launched national EV programmes offering subsidies or fiscal credits for EVSE to favour the deployment of a publicly accessible network. Some key initiatives taken by major markets are listed below [7].

- In Denmark, the government offers a tax rebate of up to DKK 18,000 (USD 2,700).
- The UK supports electric car home chargers by covering 75% of the installation costs (GBP 500 or USD 700) for the charging points.
- France requires all newly built residential and corporate establishments to include EV charging spots. Further, fiscal deductions are provided to private operators who opt to maintain charging stations in public spaces.
- In the US, the government launched a federal-funded programme, which resulted in the installation of 36,500 publicly accessible charging stations in 2015.
- In Japan, a landmark initiative was launched, in collaboration with a leading retailer, to install 500 fast chargers and 650 standard chargers in all stores across the country. The government provided 60% of the funding.

Table 4 shows a compilation of publicly accessible, slow-charging stations in various countries from 2005 to 2015 (number of units)[7]. As can be seen, China deployed the highest number of slow-charging stations up to 2015, followed by the US and the Netherlands. The earliest adopter of slow-charging stations was, however, the US.

Table 4: Global installations of slow-charging stations between 2005 and 2015

Country	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Canada							144	1,172	1,172	2,266	3,360
China										21,000	46,657
France						26	253	800	1,700	1,700	10,122
Germany						60	573	1,500	2,400	2,606	4,787
India						72	108	225	256	328	328
Italy						614	728	1,350	1,350	1,350	1,679
Japan										8,640	16,120
Korea						57	321	640	833	1,170	1,170
The Netherlands						400	1,826	3,611	5,770	11,860	17,786
Norway						2,800	3,105	3,688	4,511	5,471	6,357
Portugal						88	1,080	1,128	1,154	1,172	1,192
South Africa											10
Spain						25	216	400	800	800	1,479
Sweden						76	146	500	1,000	1,070	1,350
U.K.						318	1,503	2,804	5,515	7,431	8,716
U.S.A			333	339	373	482	3,903	11,695	14,990	20,115	28,150
Others*						1	49	2,190	3,525	6,810	12,539
Total			333	339	373	5,018	13,957	31,253	44,976	93,789	1,61,802

*Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Iceland, Ireland, Latvia, Liechtenstein, Lithuania, Luxemburg, Malta, Poland, Romania, Slovak Republic, Slovenia, Switzerland, Turkey.

Slow chargers include AC level-1 (≤3.7 kW) and AC level-2 chargers (>3.7 kW and ≤22 kW, respectively).

Table 5 presents a compilation of publicly accessible, fast-charging stations in various countries between 2005 and 2015 (number of units)[6]. As can be seen, China had the highest number of stations installed, followed by Japan and the US. India had no fast-charging stations till 2015.

Table 5: Global installations of fast-charging stations between 2005 and 2015

Country	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Canada								2	7	55	153
China						123	558	1,407	9,000	9,000	12,101
France							3	9	127	127	543
Germany						3	28	75	317	317	784
India											
Italy						2	2	4	10	10	70
Japan					95	312	801	1,381	2,877	2,877	5,990
Korea						6	33	85	60	60	100
The Netherlands						4	15	63	262	262	465
Norway						6	23	58	200	200	698
Portugal							6	8	9	9	14
South Africa											
Spain						2	21	39	118	118	186
Sweden						1	1	5	135	135	350
U.K.						3	13	36	470	470	1,158
U.S.A			42	42	47	60	489	1,464	2,518	2,518	3,524
Others*						3	25	241	790	790	1,571
Total			42	42	142	524	2,018	4,876	16,948	16,948	27,707

*Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Iceland, Ireland, Latvia, Liechtenstein, Lithuania, Luxemburg, Malta, Poland, Romania, Slovak Republic, Slovenia, Switzerland, Turkey.

Fast chargers include AC 43 kW chargers, DC chargers, Tesla Superchargers and inductive chargers.

2.8 Business Models of Charging Service Providers

Based on global experience, especially in the US and Europe, selling power alone is not a profitable exercise as an EV charging service provider.

Some charging service providers, such as Charge Point in the US and the New Motion in Europe, have therefore adopted a unique approach. They provide both charging stations as well as backend services, such as payment and billing services, in exchange for a subscription fee, which includes a profit margin.

The charging station companies in these regions have primarily targeted retailers, municipalities and businesses with parking lots. EV drivers subscribe for the services by paying a subscription fee and in return receive a Radio Frequency Identification (RFID) card, which allows them to access a network of publicly accessible stations.

Municipalities and business clients pay these companies for using their EV charging services (including charging station hardware) and later structure the payment options based on their needs. Depending on their broad goals, companies provide varied offers, such as subsidised charging tariffs and free charging hour[25] benefits.

2.9 Ultrafast Public Electric Bus Charging in China

Xiaoying Public Transit Bus Terminal, a new ultrafast EV charging station, became operational in Beijing in December 2015[28]. The Xiaoying Public Transit Bus Terminal in Chaoyang district possesses 25 EV chargers, operating at a total of 360 kW, and five additional chargers operating at 90 kW[28]. It is possible for all 30 chargers to operate simultaneously.

At this terminal, each bus requires only 10–15 minutes to be charged completely, with a requirement of 2–3 charges per day. A battery-swapping system was also installed in Beijing to experiment and improve the slow-charge battery buses. This effort was made to improve the overall operating efficiency and reduce the charge time for the buses. With the ultrafast charging system now in place, there is no need for investment in large battery packs, or on high-cost automated robotic battery-pack-swapping infrastructure. Future fast-charging point expansion plans have already been drafted for the period 2016–20. More charging stations like the Xiaoying Terminal Charge station can fulfil public bus charging needs in the future.

2.10 Overview of Total Cost of Ownership for Electric Vehicles

The term Total Cost of Ownership (TCO) was coined by Ellram in 1995 for understanding the actual cost of buying a good from a supplier[29]; it is a combination of different costs. According to estimates, the TCO of an EV can be lower than that of an internal combustion engine vehicle (ICEV), in the near future[30].

For a pure EV, the battery pack alone constitutes 40% of the total cost of the vehicle[30], which is declining gradually. In the near future, battery costs (large-format LIB packs) are estimated to reduce to around USD 150 per kWh from the present value of USD 227 per kWh[31], owing to advancements in battery technology.

Various government incentive programmes in the US, China, Japan, Canada and EU are expected to bring about a reduction in the TCOs of EVs, as compared to those of ICEVs, by 2020. According to the Boston Consulting Group, in the coming years, consumers in the US will buy an EV at an even higher cost, on account of its lower operating cost[32]. In order for a greater shift towards EVs, the following conditions will need to be fulfilled: oil price increase from USD 100 per barrel to USD 300 per barrel and a further increase in existing tax rebates with no change or improvement in the currently available government incentives.

The most influential factors, which can affect TCO, are the initial capital investment, total distance covered in the entire lifetime of the vehicle, years in operation, energy cost and maintenance cost.

[28] Clean Technica, "Ultra-fast Electric Bus Charging in China," https://cleantechnica.com/2015/12/15/ultra-fast-electric-bus-charging-in-china/

[29] Lisa M. Ellram (1995), "Total cost of ownership: an analysis approach for purchasing", International Journal of Physical Distribution & Logistics Management, 25(8), 4–23

[30] J. Hagman, S. Ritzén, J.J. Stier & Y. Susilo (2016), "Total cost of ownership and its potential implications for battery electric vehicle diffusion", Research in Transportation Business & Management, 18, 11–17.

[31] Electrek, "Electric vehicle battery cost dropped 80% in 6 years down to $ 227/kWh – Tesla claims to be below $190/kWh," https://electrek.co/2017/01/30/electric-vehicle-battery-cost-dropped-80-6-years-227kwh-tesla-190kwh/

[32] The Boston Consulting Group, "Batteries for electric cars" (2010)

2.11 Observations and Insights

Most countries worldwide are taking positive strides towards creating a greener ecosystem for the future. European countries have taken the lead in this respect by rolling out attractive incentives and setting bold targets for net GHG emission reduction. India has responded positively to this momentum and proposed substantial goals under policies like NEMMP, AMRUT and FAME. Successful completion of the NEMMP goals will help reduce approximately 2 MT of GHG emissions annually and India's dependence on fossil fuels.

To achieve India's target of 100% electric mobility by 2030, the regulatory bodies at the centre as well as state levels need to work in close collaboration with industry to create an attractive electric mobility ecosystem. Companies should be able to provide robust charging infrastructure (both slow and fast charging options), which could be used with all available digital payment gateways. Some learnings in this respect should be taken from the successful ventures in the US and Europe.

Charging infrastructure is vital for the success of any EV implementation programme. Globally, there has been a steady increase in EV uptake and charging infrastructure. India should initiate mass awareness campaigns and deliver mandates that motivate citizens to move towards electric mobility, along with a simultaneous increase in power generation, grid connectivity and charging infrastructure.

Indian states could launch dedicated deployment plans in their tier-1 and tier-2 cities after thoroughly examining the outcomes of successful plans such as the ZEV action plan launched by California and those launched in other countries.

Going forward, rapid innovation is expected in the domain of battery chemistry. Currently, LIBs are a promising alternative to the conventional lead-acid batteries and are the frontrunners in all types of EV applications. However, extensive research is being conducted on phosphate-based batteries, although upcoming LIBs like Lithium-rich Cobalt-Manganese-Nickel, Lithium-air and Lithium-Sulphur are expected to outperform the phosphate-based batteries in the near future. In the short term, India might have to import BMS. However, going forward, developing a BMS suitable for Indian conditions will be key for safe operations and higher adoption of EVs.

The cost of batteries will eventually come down, as explained under the sub-section "Overview of Total Cost of Ownership for Electric Vehicles". Economies of scale will help bring down other EV-infrastructure related costs. Further, the higher capital expenditures will eventually get offset by savings from expenditure on fossil fuels.

Today, China is the most successful country in the electric mobility sphere. They have demonstrated a strong intention of embracing electric mobility with rapid vehicle deployment. With the help of mature indigenous manufacturing capabilities, they are emerging as the leaders of the EV market. Europe has also pioneered the EV shift and been successful in rolling out attractive incentives and schemes for accelerated electric mobility.

India is currently on the cusp of its own alternate energy revolution. The various national targets related to climate control, clean energy and transportation will enable the nation to meet its EV implementation goals, under NEMMP.

3. Existing Public Transport and Electricity Infrastructure in Bengaluru

3.1 Transportation Sector Landscape: Public Buses

Bengaluru is spread over 741 sq. km and has a population of 8.52 million[33]. BMTC provides bus services in and around Bengaluru city. The city also has a Metro rail service in operation, the Bengaluru Metropolitan Railway Corporation Limited (BMRCL), and 21 Metro-feeder BMTC bus routes cater to the last mile connectivity needs of the people.

Bengaluru Metropolitan Transport Corporation (BMTC)

BMTC was formed as an independent corporation, with effect from August 15, 1997. It caters to the transport requirements of the city and suburban areas of Bengaluru, covering a radius of about 40.4 km. BMTC's mission is to provide affordable, reliable, safe, efficient, comfortable and self-sustaining public transportation to all the sections of society in and around Bengaluru Metropolis, with the support and cooperation of its patrons and the public.

BMTC runs the second largest bus fleet in the country. Table 6 shows the operational details of BMTC. The fleet[34] has approximately 6,300 buses with 11.89 lakh service kilometres. This service carries around 39.7 lakh passengers daily, generating a revenue of INR 3.81 crore per day. BMTC has 2,400 (broken into 6,335 schedules) routes in Bengaluru and has adopted a destination-oriented network model, with an aim to provide last-mile connectivity.

Table 6: Operational details of BMTC

No. of vehicles	6,310
No. of schedules	6,335
No. of Volvo buses	801
No. of Metro-feeder routes	21
Service kilometres (lakh)	11.89
No. of bus trips per day	74,697
Daily passenger carried around (lakh)	39.7
No. of depots	43
No. of bus stations	53

Bengaluru Metropolitan Rail Corporation Limited

Bengaluru Metro, or Namma Metro, is India's second largest Metro system, in terms of both length as well as number of stations, after the Delhi Metro. The Metro network consists of two colour-coded lines, with a total length of 42.42 km, serving 41 stations. The Purple Line of Phase I connects Baiyyappanahalli in the East to Mysore Road in the West, covering a distance of 18.22 km and serving 24 stations. The Green Line is the second line of the Metro, connecting Nagasandra in the North to Puttennahalli in the South, covering a distance of 24.2km and serving 24 stations. The network includes a mix of underground, at-grade and

[33] www.censusindia.gov.in
[34] www.mybmtc.com. Updated on July 15, 2017

elevated stations, using standard-gauge tracks. Bengaluru Metro has an average daily ridership of 1,75,000 passengers and the service operates daily, between 06:00 and 22:00, running with a headway varying between 4 and 15 minutes[35].

3.2 Electricity Sector Landscape

BESCOM is the largest distribution company in Karnataka. It covers a contiguous area of 41,092 km^2 and serves approximately 101.46 lakh consumers, spread across eight districts. There are around 1,500 feeders and 2,36,672 Distribution Transformers (DTs) in the BESCOM region[36].

A map of Karnataka showing the various districts and BESCOM's jurisdiction are represented in Figure 1.

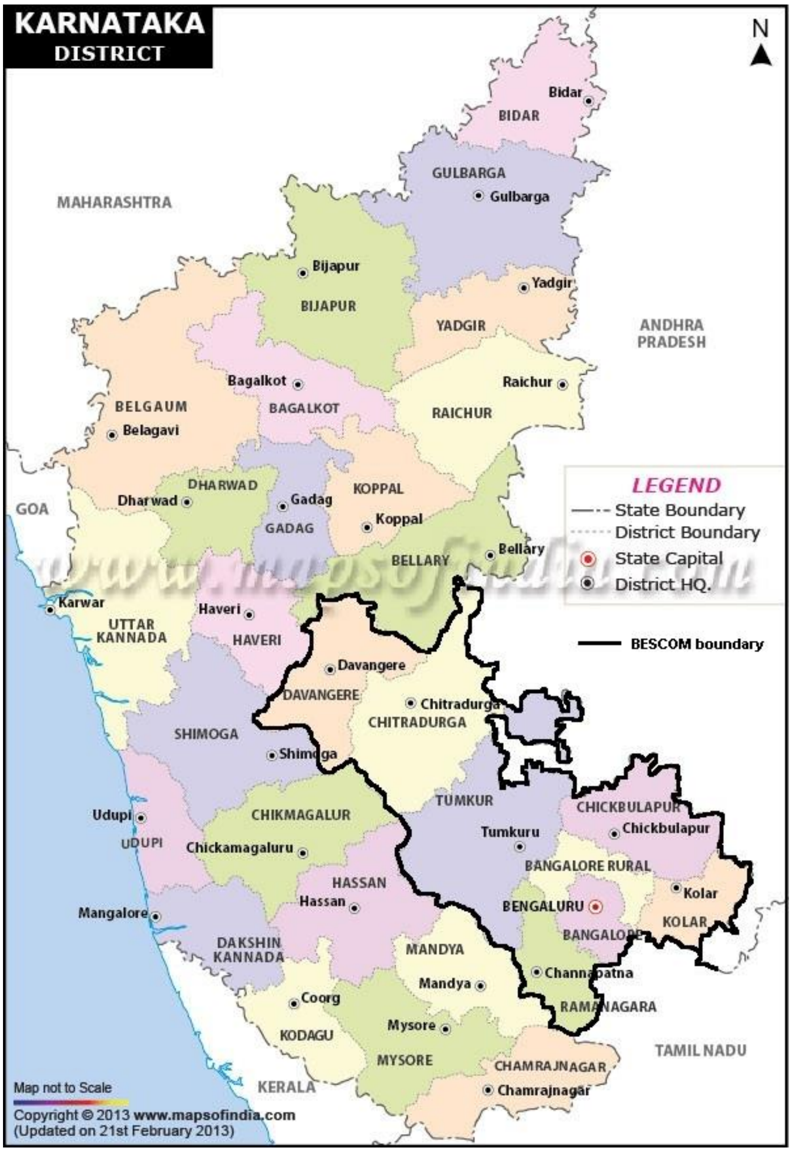


Figure 1: Karnataka district map and BESCOM jurisdiction boundary[37]

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[35] www.bmrc.co.in
[36] https://bescom.org/en/know-your-station-code-and-feeder-code/
[37] Original content sourced from www.mapsofindia.com

The number of consumers in each category under BESCOM's jurisdiction is summarised in Table 7[38].

Table 7: Category-wise consumer break-up

Category	No. of Consumers (as on 31-03-2016)
Bhagya Jyothi	7,72,458
Domestic Lighting	68,08,445
Commercial Lighting	9,44,611
Low-Tension (LT) Power	1,89,452
High-Tension (HT) Power	13,624
Irrigation Pump Sets	8,11,331
Street Light and Others	1,21,505
Temporary Power	4,85,141
Total	101,46,567

As of May 2017, the contribution of installed capacity from thermal units in Karnataka was 9,561 MW (45%). Renewables (solar, wind, small hydro and biomass) contributed 7,458 MW (35%) and hydro and nuclear had contributions of 3,600 MW (17%) and 698 MW (3%), respectively. BESCOM's share in the overall energy mix of the state is 47% (i.e., 65,576 Million Units [MUs]). Out of this, 73% (22,734 MU) is contributed by state-owned thermal power plants, including procurement from central generating stations. Contributions from renewables stood at 12% (3,629 MU) and hydel projects at 9% (2889 MU). For energy procurement, BESCOM enters into long-term and short-term power-purchase agreements with these sources based on allocation by the government and competitive bidding. The average approved power purchase cost for 2017-18 stood at INR 4.41/unit. Karnataka plans to have 6.3 GW of solar capacity and 4.75 GW of wind capacity installed by 2022. Specifically, BESCOM has a solar Roof Top Photovoltaic (RTPV) target of 1.3 GW to be achieved by 2022.

In FY 2015-16, BESCOM distributed approximately 24,538 MUs under the metered category and 6,190 MUs under the unmetered category, via 89,298 circuit kilometres of HT lines and 163,045 circuit kilometres of LT lines. The revenue collected was INR 14,049 crore, against a revenue demand of INR 14,218 crore. Distribution losses stood at around 12%, whereas the maximum peak load ranged from 3,676 to 4,931 MW, during this period.

CSTEP analysed the BESCOM feeder network in detail for mapping the state's EV charging infrastructure. The power requirement for an e-bus, with a range of 250 km (as well as an e-bus with 100 km), is approximately 60 kW. Details of BESCOM's infrastructure are provided in Appendix 2.

[38] BESCOM Tariff Order 2015-16, http://www.karnataka.gov.in/kercold/Downloads/COURT-ORDERS-2015/TARIFF%202015-16/BESCOM-TARIFF-2015-16.pdf

4. GIS-based Transportation Platform for Bengaluru

4.1 Compilation of Transportation and Electricity Distribution Information

The data required for performing the transport and electrical network analysis have been collected, combined and represented in the form of layers of geospatial information. These datasets include:

- Administrative boundaries (Bengaluru, BMTC's areas of operation, BESCOM's areas of operation)
- BMTC's routes and schedules
- Location of BMTC's depots, bus stands, bus stops
- BMTC's passenger density and revenue for routes over select intervals
- Location of BESCOM's DTs
- BESCOM's 11 kV feeder load data for 24 hours[39].

Details of each dataset are available in Appendix 4 and important operational details of the BESCOM network are available in Appendix 2.

4.2 Route Analysis

The BMTC fleet consists of diesel buses, which are known to contribute significantly to GHG emissions and local air pollution. E-buses are zero emission vehicles and they are expected to have lower GHG emissions even if they are charged through the thermal power grid. Therefore, transforming the current fleet to e-buses could result in a drastic reduction of emissions and local air pollution within the city. This section of the analysis focuses on the identification of the most feasible routes for replacing a percentage of BMTC's existing diesel buses, with e-buses.

The route identification process is based on a number of criteria, including route length, per day distance travelled by each bus, availability of sufficient stop-time to charge the battery, location of crew halts and e-bus specifications. To determine whether a route is feasible, the following criteria are applied:

1. Include routes that have a high passenger density (so as to maintain the same revenues for the operating utility).
2. Include routes that have a (minimum) length or more: The total distance covered by an e-bus is the route length times the number of schedules it runs. Since the goal is to ensure full utilisation of the battery and no disruption of any schedule on that route, the route length is an important criterion.
3. Include routes with higher number of scheduled stops per km. Studies have shown that EVs are more energy efficient than diesel/petrol vehicles under "stop-and-go" conditions. Hence, replacing diesel buses on routes that have higher "stop-and-go" incidences would be more beneficial.

[39] The feeder data are collected for April when the electricity demand in Bengaluru is the highest due to peak summer period. For each feeder, the highest load value seen by that feeder during every hour interval (0-24) in April is recorded and used for the analysis.

4. Include routes that are converging at a common origin and/or destination point. This is to achieve economies of scale in utilising the existing charging infrastructure available at these origin and destination points.
5. Waiting time for the bus during (or at the end of) its daily run: The e-bus variant considered in this analysis had a battery that can power a 250 km journey on a full charge, under charging constraints specified later in this chapter. Hence a minimum waiting time is to be considered so as to enable enough charge for the bus for its next run.

The criteria mentioned here form the core of the methodology, but can be applied selectively and with variations based on the local requirements and datasets. To analyse BMTC's services, the methodology is divided into two parts: the General Methodology, which is applied to predefined route categories, namely the Vayu Vajra Services (airport buses), Vajra Services [routes starting from International Tech Park Ltd (ITPL)], and Metro-feeder routes; and the Ordinary Route methodology that is applied only to ordinary routes.

For the route categories considered under the general methodology, the key determinants discovered are as follows:

1. Routes that have a high passenger density.
   An examination of the weekly BMTC data leads to passenger densities in each route category as specified in Figure 2. Since a large number of routes within each category have high passenger density, the median value of passenger density is chosen as a filter within each route category so as to reduce the number of routes to be examined. This is because the mandate given by BMTC was to identify the best 150 routes across all route categories.
2. Waiting time >= 5 hours.
   To ensure no changes in the schedule, the battery of the e-bus variant considered needs appx. 300~330 minutes for a full charge. Hence, the waiting time considered is in that range.

All other criteria ae not part of this specific analysis due to the routes lengths, stops, locations being pre-determined.

Vayu Vajra Services

For airport services, BMTC has a fleet of comfortable air-conditioned Volvo buses known as Vayu Vajra, which connect the airport with the city, through 161 schedules. Each bus completes an average of 12 trips per day, covering approximately 350 km. This analysis aims to identify feasible Vayu Vajra routes for the implementation of electric mobility.

Table 8 provides details of the number of vehicles that are feasible for electrification, their route length and average daily run, and identifies charging locations for feasible routes, total kilometres to be charged (night charging and top-up charging in-between trips) at each location and the corresponding energy requirement. For example, a bus on the KIAS-8 route (represented by KIAS-8/1) would need to go to the Electronic City location to charge its battery fully (night charging) and to Depot 28 for in-transit top-up charging. Likewise, some buses on this route can halt at BTM Layout for charging. Figure 2 shows a schematic of the various airport routes and their specific origin and destination points.

Table 8: Feasible Airport routes with charging locations and requirement details

Route No. (Origin–Destination)	Total Schedule (No. of Buses)	Route Length (km)	Average Daily Run (km)	Charging Locations	Charge Provision (Total km)[40]	Energy Required (kWh)
KIAS*-8 (Airport–Electronic City)	3	66	303.6	Electronic City	500	650
				Depot 28	154.1	200.3
				BTM Layout	250	324
KIAS-7A (Airport–HSR Layout)	3	50	353.3	Depot 25	291.2	378.6
				HSR Layout	500	650
				Airport	250	324
KIAS-9 (Airport–KBS**)	2	49.7	366.4	Depot 07	143	185.7
				KBS	411	533.9
				Airport	250	324
KIAS-5A (Airport–Jambusavari Dinne)	2	50.75	308	Airport	408.4	530.9
				Depot 13	301.2	391.6
KIAS-5B (Airport–Bannerughatta)	2	56.15	321	Airport	446.4	580.3
				Depot 07	285.7	371.4

*KIAS, Kempegowda International Airport Services
**KBS, Kempegowda Bus Station

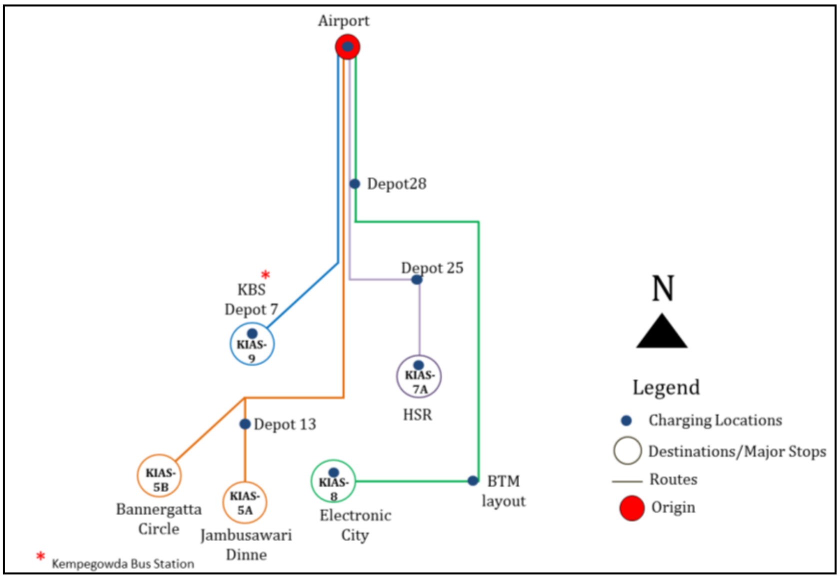

Figure 2: Feasible Airport routes with charging locations (Vayu Vajra Buses)

[40] The data are to be interpreted as follows:
Buses (over a 24-hour period) make various "charging halts" at the locations mentioned under the column "Charging Locations". The cumulative energy requirement at a location, for all the buses that stop at that location, is given under the column titled "Energy Required (kWh)" and the cumulative number of kilometres that the charging will provide is given under the column titled "Charge Provision (Total km)". The energy provided to each bus at various times and locations is based on the energy each bus will require as it goes about completing its daily run without changing any timings.
Illustrative example: As per row 1, some (if not all) of the 3 buses on route KIAS-8 will make stops at Electronic City during a 24-hour period. The total amount of energy needed at that depot (to serve the buses that stop there) will be 650 kWh and will enable the buses to run a total of 500 km.

ITPL Vajra Services

ITPL Vajra services are Volvo buses originating from ITPL, a technology park located in Whitefield, 18 km from the city centre. The service comprises of 18 routes, originating from ITPL to different parts of the city. The buses on this route cumulatively complete 150 trips per day, with an average daily run of 230 km.

Table 9 provides details of the number of vehicles that are feasible for electrification, their route length and average daily run, and identifies charging locations for feasible routes, total kilometres to be charged (night charging and top-up charging in between trips) at each location and the corresponding energy requirement. Figure 3 illustrates the feasible ITPL routes considered for this exercise.

Table 9: Feasible ITPL routes with charging location and energy requirement details

Route No. (Origin–Destination)	Total Schedule (No. of Vehicles)	Route Length (km)	Average Daily Run (km)	Charging Locations	Charge Provision for (Total km)	Energy Required (kWh)
V-500CA (ITPL–Banashankari)	42	25.2	243	Depot 18	975	1,267.7
				Depot 25	2,681	3,486
				Banashankari	975.2	1,267.7
				ITPL	975.2	1,267.7
				Depot 13	3,169	4,120.2
				Depot 28	1,219	1,584.7
				Hebbala	243.8	316.9
V-500BM (ITPL–Brigade Millennium)	4	28.4	222.8	Depot 18	222.8	289.64
				Depot -7	222.8	289.64
				KBS	222.8	289.64
				Banashankari	222.8	289.64
V-500CH (ITPL–Vidyanagar)	6	33.73	203.3	Banashankari	406.6	528.5
				Depot 13	813.2	1,057.16
V-500DF (ITPL–Hebbala)	4	28.5	214.3	Depot 28	571	743.3
				Hebbala	190	247.7
V-500K (ITPL–Vijayanagara)	30	41.6	220	Depot 13	3,740	4,862
				ITPL	880	1,144
				Banashankari	220	286
				Depot 25	1,760	2,288
V-500KE (ITPL–Kengeri)	7	42.7	227.3	Depot 18	681	886.4
				Depot 25	681	886.4
				ITPL	909	1,181.9
				Depot 13	227	295.5
V-500KR (ITPL–Kechanahalli)	5	38.62	218.4	Depot 13	1,310	1,703.5
				ITPL	436	567.8
V-500P (ITPL–Chikkalasandra)	4	29.9	183.6	Depot 13	367	477.3
				Depot 25	550	716.04

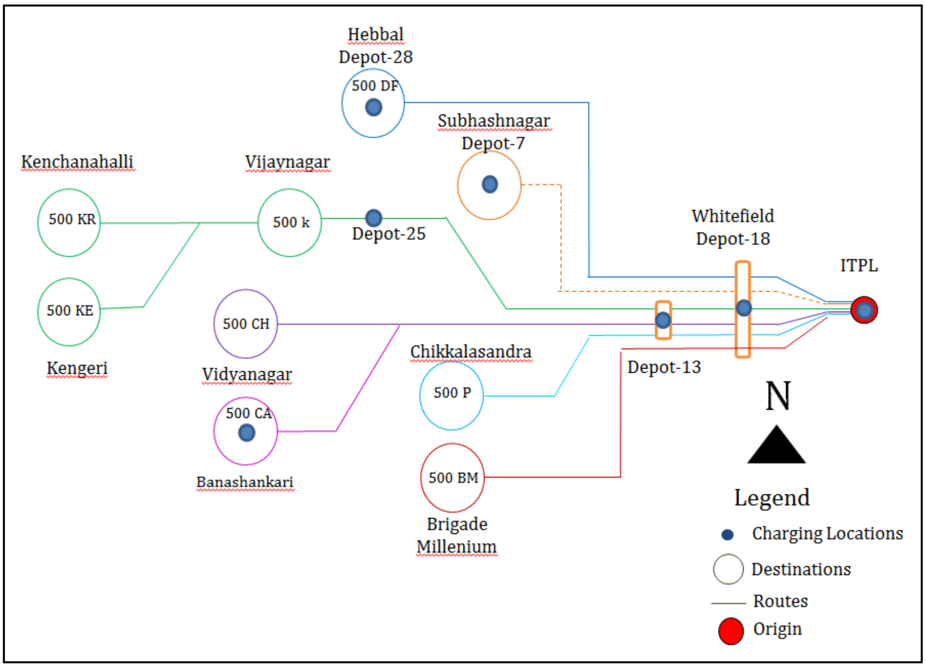

Figure 3: Feasible ITPL routes with charging locations (Vajra Buses)

Metro-feeder Services

BMTC has introduced feeder bus services to provide last and first mile connectivity to Metro users. 141 Metro-feeder buses are operated along the Purple line (East-West) Metro corridor. The route length of the Metro-feeder buses ranges from 2 km to 30 km (average of 15 km) and each bus covers around 140 km per day. Table 10 shows the number of routes, which fall (approximately) within the 250 km average daily run. Figure 4 shows an illustration of the feasible Metro-feeder routes considered for this exercise.

Table 10: Feasible Metro-feeder routes with charging location & energy requirement

Route No. (Origin–Destination)	Total Schedule (No. of Vehicles)	Route Length (km)	Average Daily Run (km)	Charging Locations	Charge Provision for (Total km)	Energy Required (kWh)
MF-6 (SV Metro Station–Silk Board)	9	10.2	190	SV Metro Station	570	741
				Depot 6	760	988
				Central Silk Board	190	247
MF-13 (Vijayanagara Metro Station–Vijayanagara Metro Station)	2	21	263	Vijayanagara	526	683
MF-12 (Vijayanagara–Banashankari TTMC)	7	10.6	171	Banashankari	171	222
				Depot 16	171	222
				Vijayanagara	342	444
				Depot 17	513	666.9
MF-1 (KBS–Mantri Square)	1	29.3	171.6	Depot 2	171.6	223
MF-2 (Baiyyappanahalli Metro Station–HAL Main Gate)	3	14.5	259	Depot 6	259	336.7
				Depot 29	518	673

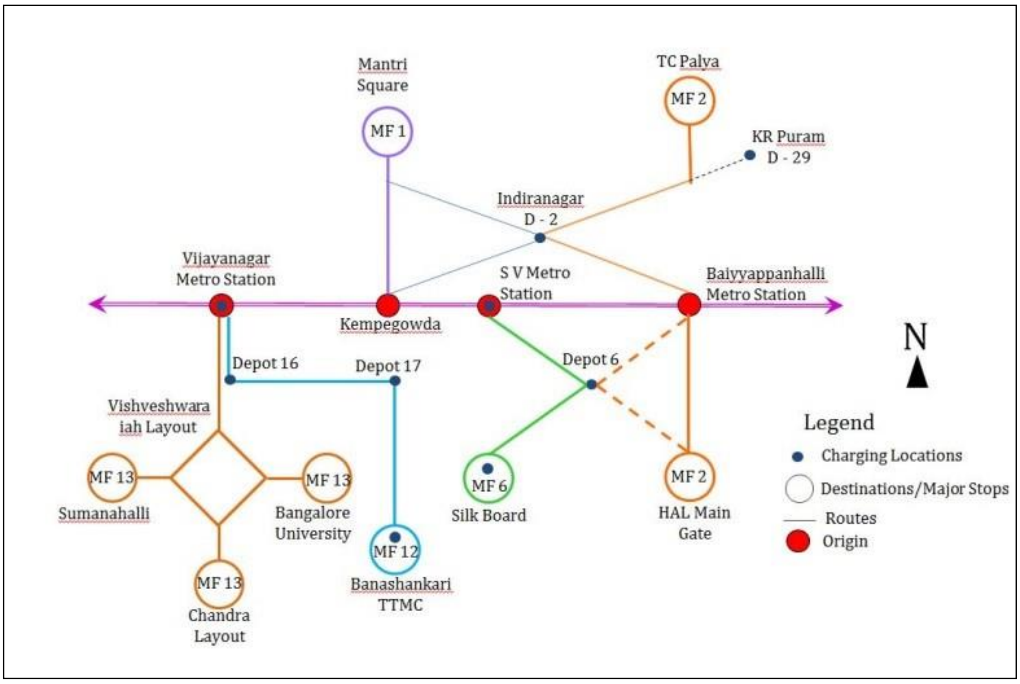

Figure 4: Feasible Metro-feeder routes with charging locations

Ordinary Routes

Ordinary routes are the mainstay of BMTC's services. There are around 2,500 routes under this category, of which approximately 70% are less than 30 km in length. The methodology adopted for analysing this category of buses is slightly different from the methodology used for the other services. The ordinary routes have been selected based on the route length, passenger density, number of bus stops per kilometre and maximum common origin/destination. The number of bus stops per kilometre and common origin/destination were not considered for the other services. Figure 5 explains the process of identifying the feasible routes for the ordinary services and the results of the analysis are shown in Table 11. Figure 6 shows the schematic of the results for the ordinary routes.

Table 11: Feasible Ordinary High-Range routes with charging locations & energy requirement

Route No.	No. of Buses	Route Length (km)	Average Daily Run (km)	Charging Location	Charge Provision for (Total km)	Energy Required (kWh)
KBS-1I	11	26.7	245.2	Depot 06	583	757.9
				KBS	2,706	3,517.8
KBS-1K	4	24.5	230	Depot 06	212	275.6
				KBS	920	1196
SBS-1K	13	22	240	Shivajinagar Bus Station	165	214.5
				Depot 06	3,120	4,056

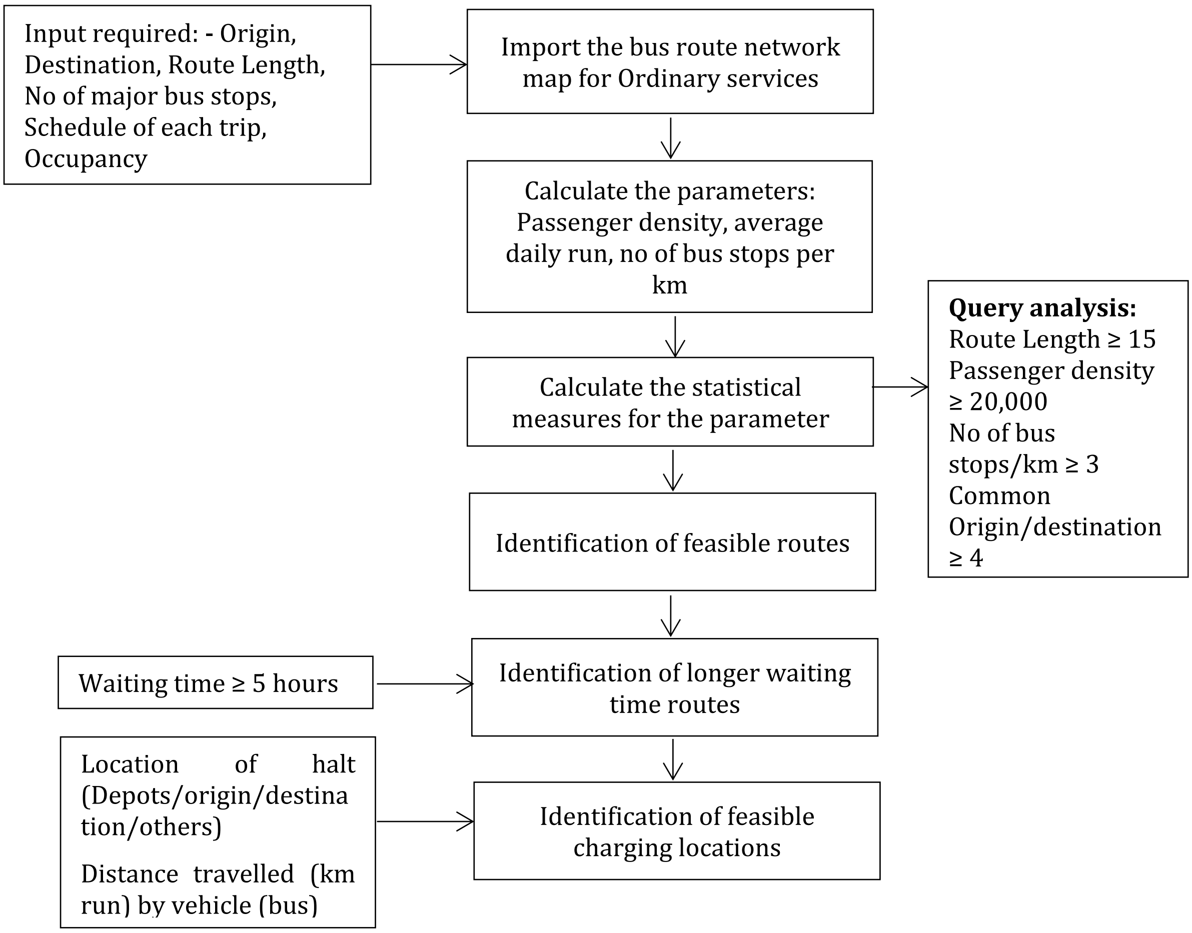

Figure 5: Methodology - Ordinary route selection

For the route categories considered under the ordinary route methodology, the key determinants discovered are as follows:

1. Routes that have a high passenger density.
   A large number of routes within the ordinary category have high passenger density, and so the median value (passenger density >= 20,000 passengers travelling on that route per week) is chosen so as to reduce the number of routes to be examined.
2. Routes that have a (minimum) length or more.
   An examination of the dataset reveals that schedules may not be consistent across different days. However, the route length is more or less constant as is the distance a bus covers during its daily run. Hence, after some iterations through the data, route length of 15 km or more be found to be an adequate filter. This choice provides a sufficient number of routes for further analysis as well as ensures that the bus covers enough distance daily so as to fully utilise the battery.
3. Routes with higher number of scheduled stops per km.
   The median number of stops is 3 stops per km.
4. Routes that are converging at a common origin and/or destination point.
   The median number of routes at these kinds of common locations is 4.
5. Waiting time for the bus during (or at the end of) its daily run.
   As described in Section 4.2, the waiting time >= 5 hours is considered for the analysis.

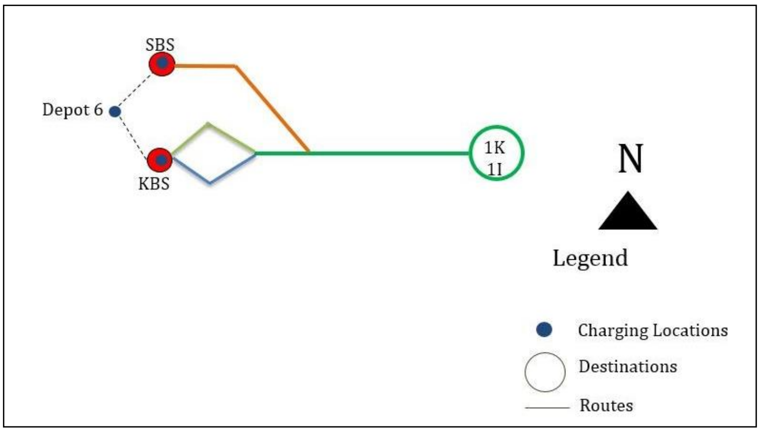

Figure 6: Feasible Ordinary high-range routes (250 km) with charging locations

Table 12 gives an overall summary of all four bus services, including the feasible routes under each category, average kilometre travelled and charging locations. Since *en route* charging is not considered here, charging locations have been identified wherever enough halt time is available. The charging locations are either at depots or destination points.

Table 12: Summary of all four bus service categories (Vayu Vajra, Vajra, Metro-feeder and Ordinary routes)

Service Name	Feasible Routes	Feasible No. of Schedule	Average Daily Run (km)	Common Charging Locations
Airport Routes	5 routes (out of 16 routes)	12 (out of 100 schedules)	333	• Airport • Electronic City • Banashankari • ITPL • Central Silk Board • Shivajinagar Bus Station • KBS • Yeshwanthpur Bus Station • Depot 7, 13, 25, 28, 18
ITPL Routes	8 routes (out of 18 routes)	102 (out of 150 schedules)	220	
Metro Feeders	5 routes (out of 14 routes)	21 (out of 100 schedules)	210	
Ordinary Routes	5 routes (out of 2,500 routes)	38 (out of around 6,000 schedules)	214	

4.3 Visualisation Platform

Electricity load data from 11 kV feeders have been used to analyse the effects of electrification of the BMTC fleet on the existing electrical infrastructure. The feeders have been identified by the proximity of DTs to bus depots. Further, the required battery size is estimated based on the range of the bus route, as determined by the route analysis. The battery size is estimated to have a power requirement of 60 kW[41]. The energy rating of the battery would be 324 kWh, with a maximum charging time of approximately 330 minutes. Next, the closest DTs and feeder tapping points need to be identified. This is done because the DT feeding a particular depot might already be significantly loaded. Assuming the nearest feeder to the depot as a source is deemed appropriate in such a case. Extending the feeder to the depot would be an added cost, but this would enable effective utilisation of available resources in close proximity. Also, a dedicated transformer with appropriate protection devices would serve as a preferred set-up from both maintenance and metering standpoints.

[41] Roughly the capacity of 12 average houses in the BESCOM region

Case Study

Battery details:
324 kWh, 60 kW (380/400 AC, 3-phase), charging time ~ 330 minutes.
(This estimate has been arrived at post analysis of BMTC's e-bus trial run data for 2014.)
Route/Depot/Substation details:
Airport route; Depot: HSR Layout, Depot 25; Substation: HSR Layout 220 kV.

Table 13 and Table 14 show the feeders considered for analysis and the depot schedules, respectively.

Table 13: Feeders of interest

Substation	Operating Voltage (kV)	Feeder No.	Feeder Name	Feeder Type	Near Dist. (m)
HSR Layout_220	11	Blr_hsr_f05	F05-Somasunderapalya	Urban	2,056
		Blr_hsr_f07	F07-Jakkasandra-sector	Urban	2,054
		Blr_hsr_f13	F13-Venkatapura	Urban	2,047

Table 14: Depot schedule

Bus No.	Night Charging Start Time	Night Charging Stop Time	Day Charging Start Time	Day Charging Stop Time
KIAS-7A/3	22:45 pm	4:15 am	10:50 am	14:45 pm
KIAS-7A/4	00:10 am	5:40 am	11:55 am	15:45 pm
KIAS-8/11	-	-	12:40 pm	14:10 pm
KIAS-8/12	-	-	15:00 pm	16:20 pm
KIAS-8D/1	-	-	11:25 am	14:55 pm
KIAS-12/5	22:35 pm	4:05 am	11:05 am	13:30 pm
KIAS-12/6	00:00	5:30 am	11:15 am	14:50 pm

Source: KIAS, Kempegowda International Airport Services

The input information is then analysed by a decision-support framework (please refer to the next section). This framework also provides the ability to visualise and query data, and form an implementation roadmap for BMTC. The roadmap can list various routes that are feasible for electrification with no change in BMTC's operations (timings, depot infrastructure, etc.) or in BESCOM's operations (other than minor strengthening of equipment). Further, the outputs can be used to create policy decisions for new routes and design new tariffs.

The framework can be accessed at http://darpan.cstep.in/ev/

The homepage of the framework (shown in Figure 7) has relevant information represented as data layers. This information includes the range of routes, location of important bus depots and location of DTs near the bus depots. Figure 8 shows details of a selected airport route, whereas Figure 9 shows a particular BMTC bus depot (Hebbala Bridge) and the nearest BESCOM DT.

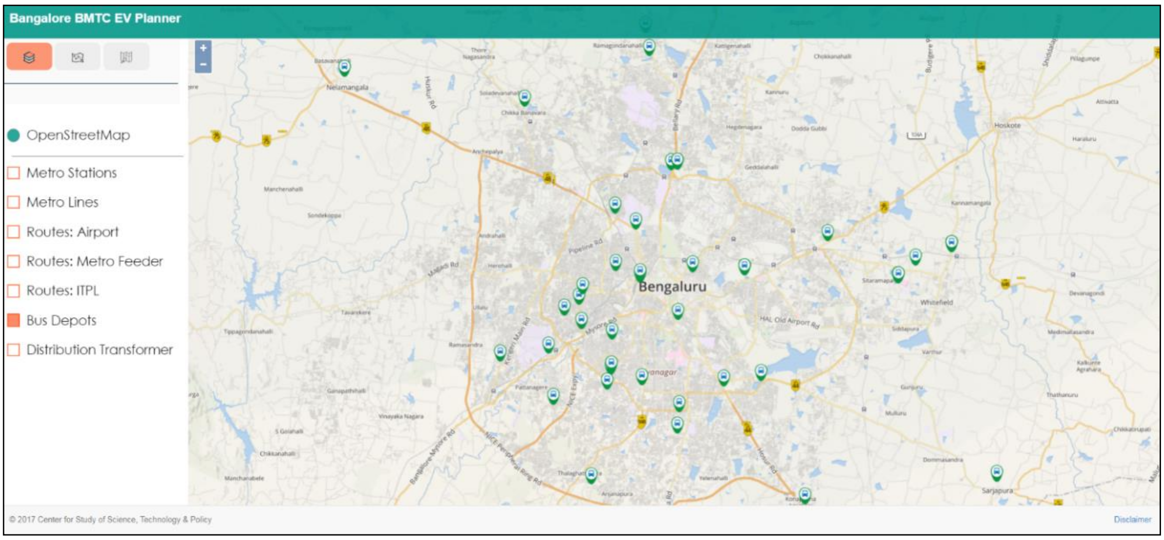

Figure 7: EV Planner homepage

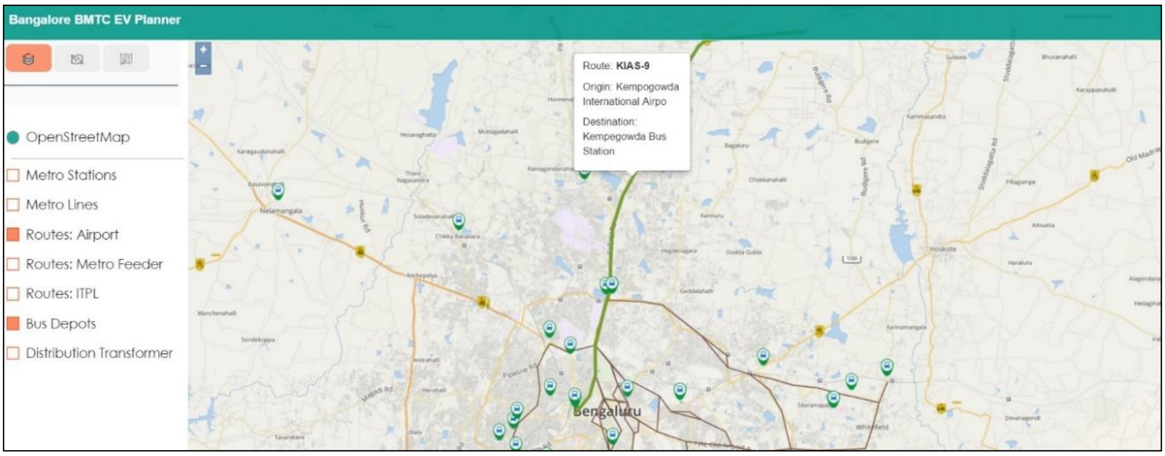

Figure 8: Sample Airport route

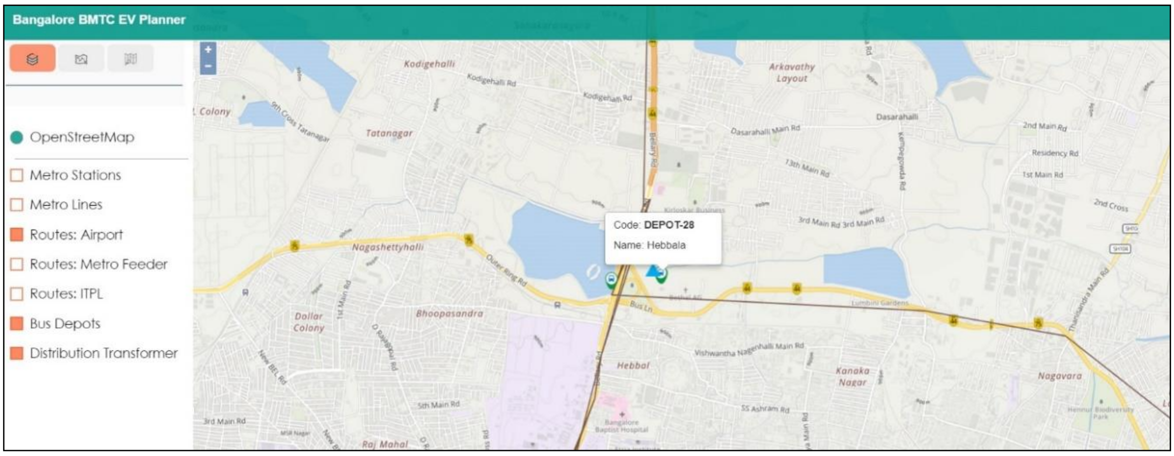

Figure 9: Depot and nearest DT

To view the impact of EV charging on a particular route category, a user can select "Route Type", "Bus Depot" and "Feeder" as shown in Figure 10. For this case study, the selection would be Route Type = "Airport" and Depot = "Depot-25". The possible feeders for this selection are F05, F07 and F13. The system returns a list of bus numbers and their optimal charging schedules along with the electrical load for the feeder connected to the nearest DT (Figure 11); this is followed by an increase in load at the feeder due to charging (Figure 12). A user can also assess the impact on each feeder at the charging location by comparing the details of electrical load and change in load due to charging of e-buses at each of the feeders (Figure 13).

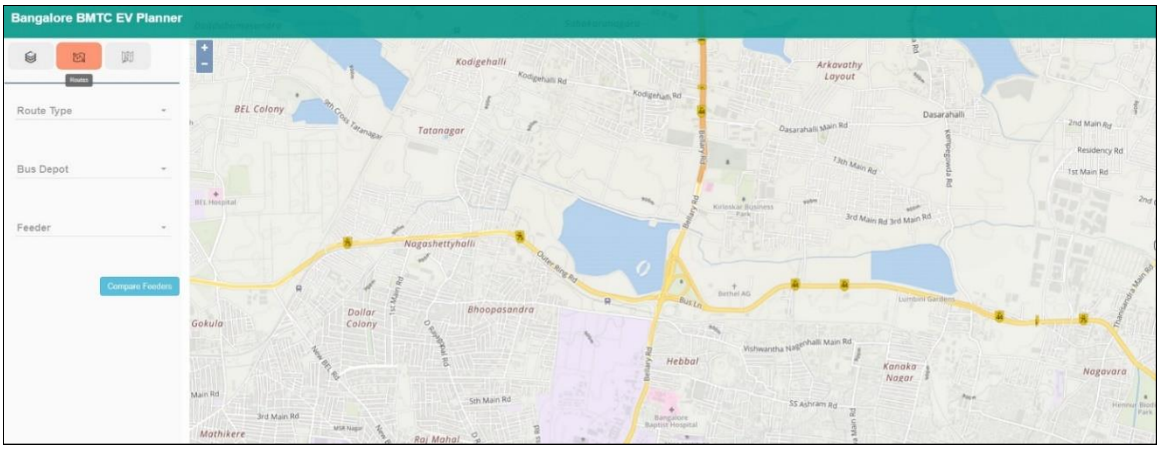

Figure 10: Route selection screen

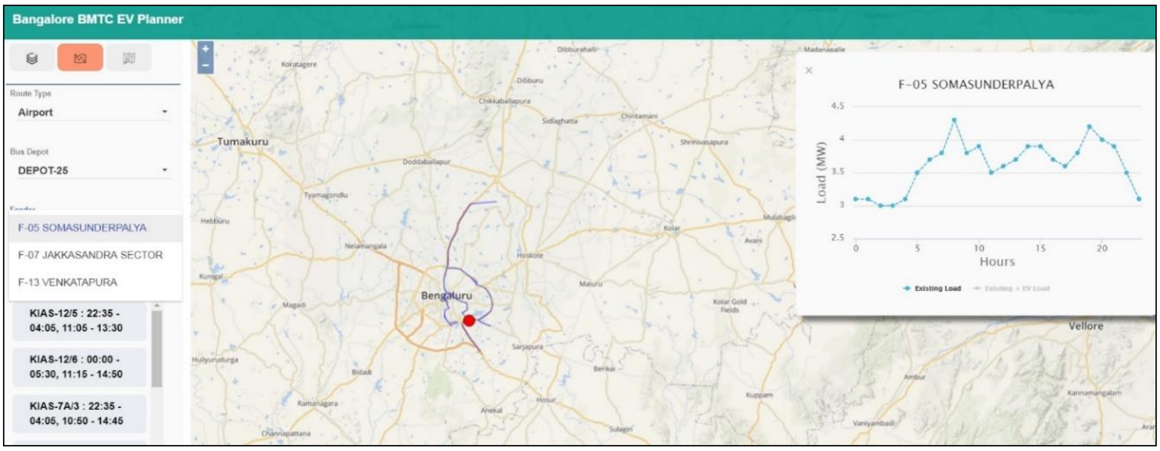

Figure 11: Airport Route and Feeder F05, Somasunderpalya, load (Depot 25)

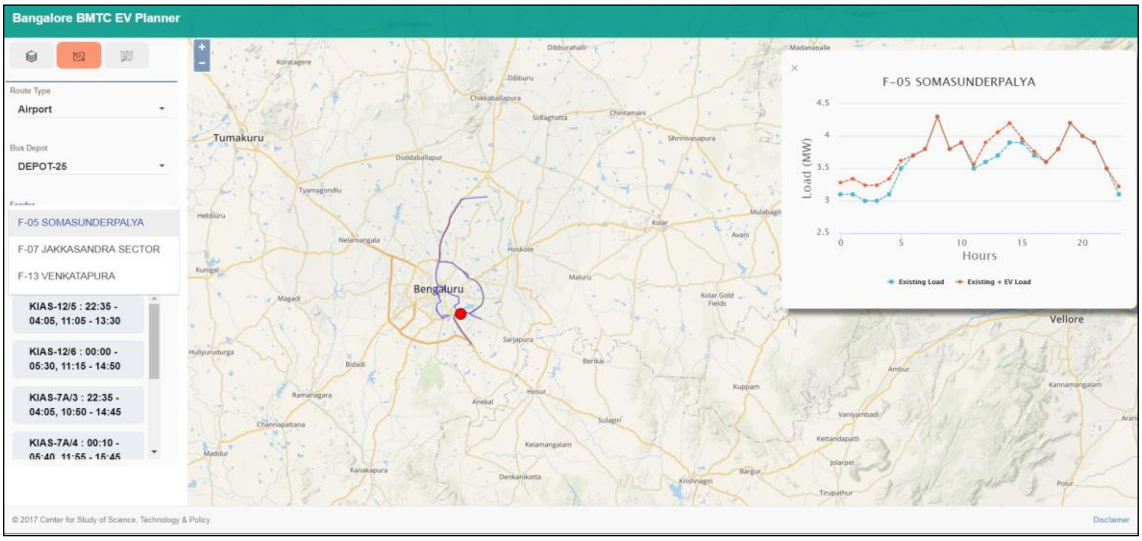

Figure 12: Change in feeder (F05 Somasunderpalya) load with EV charging

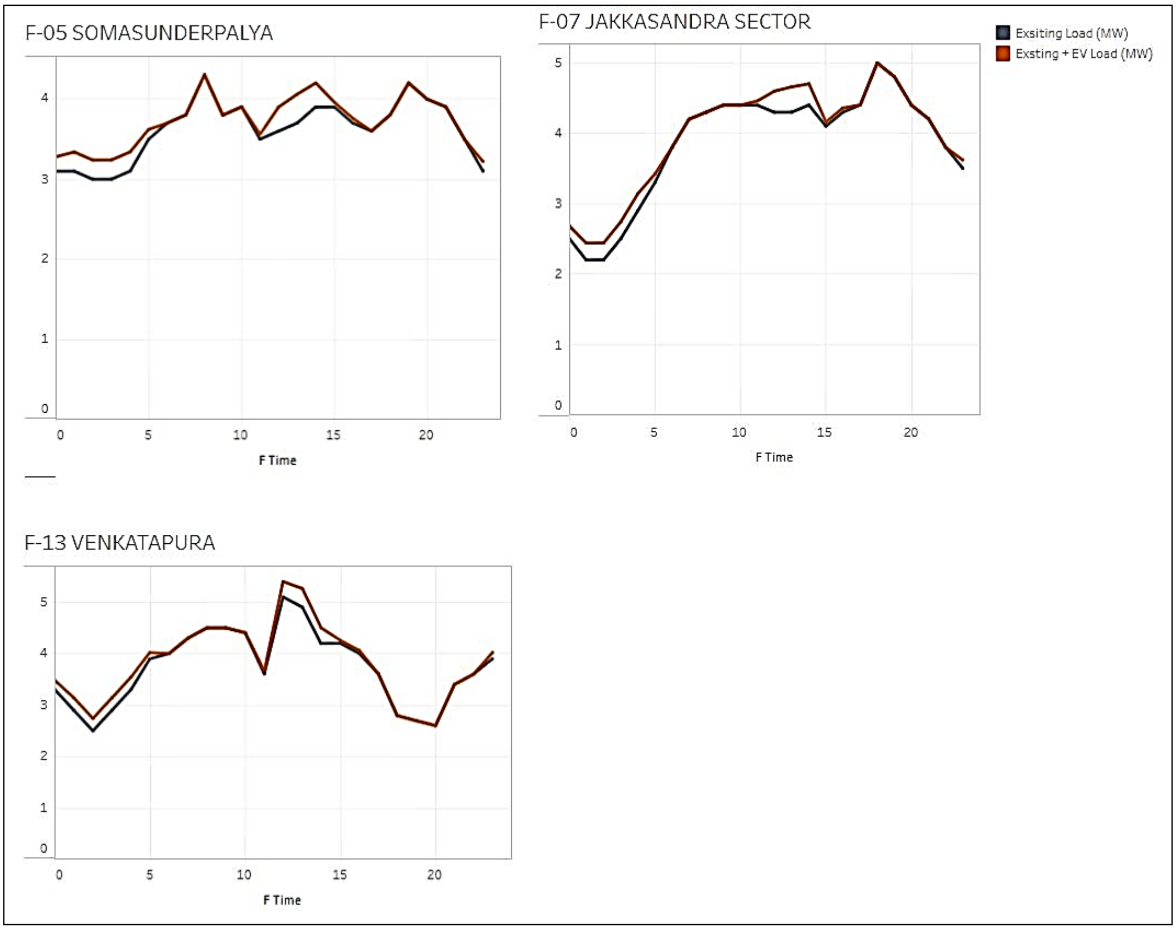

Figure 13: Feeder load comparison

In Figure 13, the graphs display feeder load trends with and without EV charging for three different feeders, namely, F05, F07 and F13. The *X*-axis shows the time in hours and *Y*-axis shows the load at the feeder in MW.

5. Analysis of the Viability of Short-range Battery Buses

The cost of the battery is a major component of the cost of an EV. Reducing the battery size reduces the vehicle's range, and its weight and cost. This chapter presents an analysis of the feasibility of operating buses with a battery range of 100 km in Bengaluru.

BMTC operates approximately 2,800 routes under the Ordinary category, with the majority (approximately 70%) of them being less than 30 km in length. The mean route length is 45 km, but the median route length is approximately 20 km. Each bus operates an average of 15–20 trips per day, with an average daily run of 200 km. Table 15 provides details of the number of Ordinary bus routes based on their route length.

Table 15: BMTC Ordinary bus route length

Route Length Range (km)	No. of Routes
1-10	350
10-20	972
20-30	711
30-40	519
40-50	220
50-60	52
>60	45

The specifications of a short-range battery for an e-bus (Proterra) are given in Table 16.

Table 16: Specifications of an EV with a short-range battery[42]

Specification	Value
Dimension	12 m x 2.5 m x 3.5 m
Seating capacity	40
Top speed	104 (kmph)
Total energy available from one full charge	79 (kWh)
Standard charging time	10 (min)
Charging – in depot	60 (kW)

General Methodology

The methodology of this analysis is explained in Figure 14.

[42] Source: https://www.proterra.com/products/catalyst-40ft/

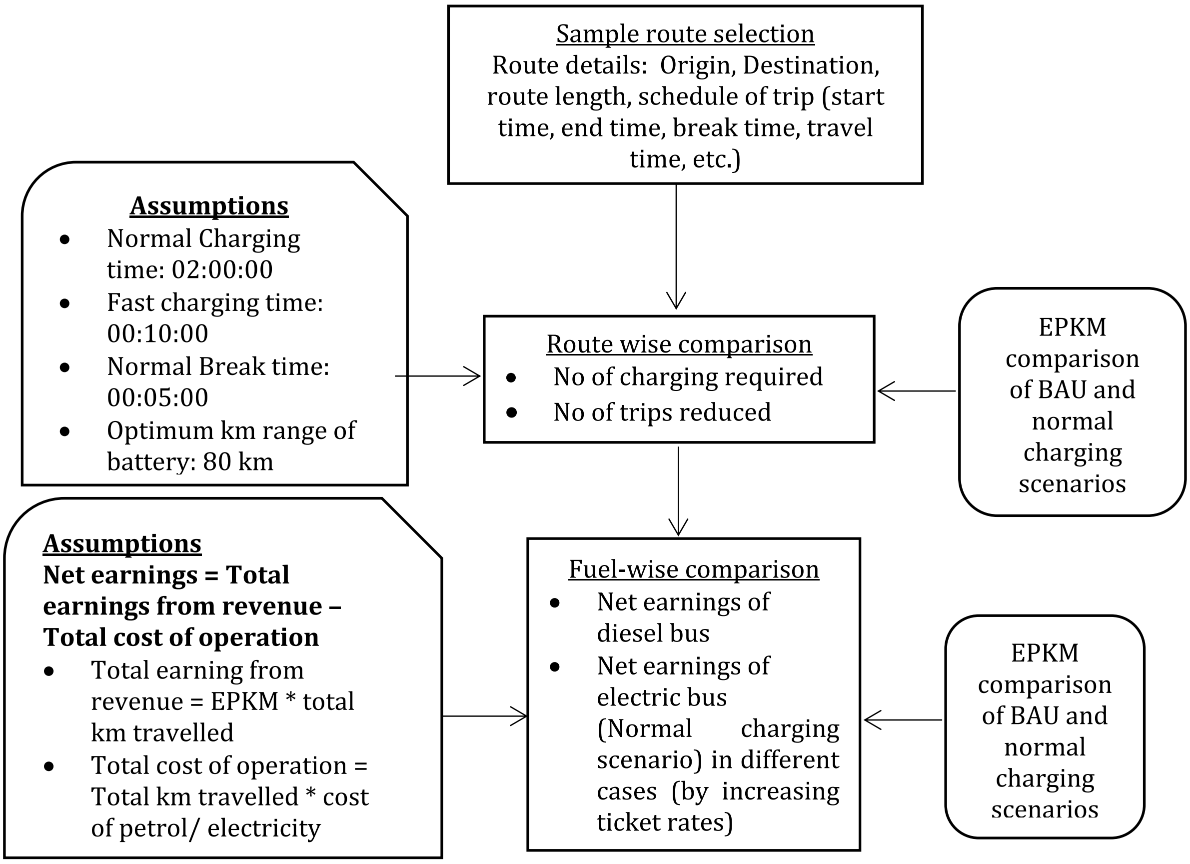

Figure 14: General methodology for the viability study of short-range battery buses

*EPKM, earnings per kilometre

The BMTC route considered for the analysis is 215-C, which extends from K.R. Market to Jambusavari Dinne. This route was chosen as it meets the criteria for a typical BMTC Ordinary route, which are:

- Lies within a 10–20 km route length
- Has approximately 15 buses servicing the route
- Has a high passenger density
- Has a large number of bus stops.

The bus route's details are provided in Table 17, while it is represented in Figure 15.

Table 17: Route details of BMTC bus number 215-C

Route No.	215-C
Origin	K. R. Market
Destination	Jambusavari Dinne
Route length (km), Round-trip length (km)	13.5, 27
No. of bus stops (per route)	34
No. of bus stops/km	3
Passenger density[43] (per week)	3,250
Start time of daily trip schedule	14:15:00
End time of daily trip schedule	22:35:00
Travel time of one-way trip	45 minutes

[43] Passenger density = Number of passengers per route

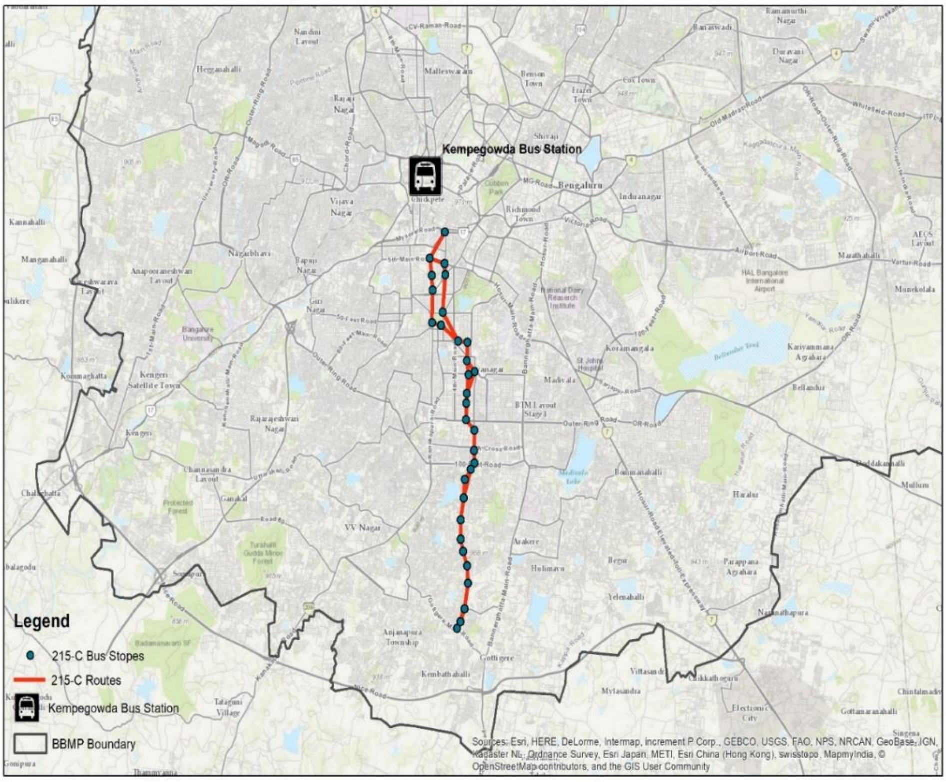

Figure 15: Route map of BMTC bus number 215-C (K.R. Market to Jambusavari Dinne)

A comparative analysis of the replacement of a conventional diesel bus with a short-range e-bus (for a typical daily schedule) on route 215-C shows a reduction of round trips, with the use of the latter. This is because the practical range of the battery is approximately 80 km, hence the bus on this route will be able to complete only three round trips (totalling 81 km) before it needs charging. Under normal charging conditions, the time taken to charge will be less than 2 hours[44]. This time is equivalent to the time taken to complete one round trip on this route. Hence, the total number of round trips completed by the bus on this route will reduce to four (as opposed to five roundtrips completed by the diesel variant). Thus, the revenue earned will reduce by 20%, as shown in Table 18.

Table 18: Route-wise comparison of diesel and EV bus

No. of round trips made by diesel variant	5
Total distance travelled per day (km) by diesel variant	135 (27 x 5)
No. of charging halts required by short-range EV bus	1 night charge + 1 during service time
No. of trips reduced for 2 hour charging[45]	1
Total km travelled by short-range battery e-bus per day	108
% reduction in revenue by the reduction of no. of trips[45]	20%

Revenue and expense calculations comparing the diesel and e-buses show (Table 19) that the latter earns lower revenue if the ticket costs are kept the same as those of the former. Further, even if the electricity tariff is reduced to the tariff applied for Bengaluru Metro, the e-bus still

[44] Assuming the power rating of the battery to be 60 kW
[45] Revenue reduction is calculated by considering the EPKM value (EPKM, Earning per km = Revenue/total km travelled)

earn a lower revenue. However, it can match the revenue of the diesel bus provided ticket prices are increased by 15% and the electricity tariff for Bengaluru Metro is applied.

These are, however, conservative estimates. If the low maintenance cost of EVs are factored in, the revenue from the e-bus is likely to be comparable to that of a diesel bus. Moreover, the schedule and revenue will remain the same for the e-bus if a 'standard'[38] charging facility is available, as the charging time required for a short-range battery is only about 10 min (Table 16). While the infrastructure cost could be much higher as compared to normal charging, which takes up to 2 hours to charge the same battery, this increase in cost could be offset by an increase in the bus fares.

Table 19: Revenue comparison of diesel and electric vehicle

	Diesel Bus (INR)	**E-Bus (INR), Based on Commercial Tariff**	**E-Bus (INR), Based on Metro Supply Electricity Tariff**	**Remarks**
Total earning from revenue (a) per route per day	6,750	4,320	4,320	
Total cost of operation (b) per route per day	2,025*	902**	567***	
Net earnings (a-b)	4,725	3,418	3,753	Bus fare for EV bus kept the same as diesel bus
		3,850	4,185	Bus fare for EV bus increased by 10% per ticket
		4,563	4,897	Bus fare for EV bus increased by 15% per ticket
		5,656	5,990	Bus fare for EV bus increased by 20% per ticket

**cost of diesel – INR 60/l.*
***cost of electricity - INR 8.35/unit.*[46]
****cost of electricity - INR 5.25/unit.*[47]

In addition, the standard charging infrastructure could also be made viable through new models of operation for the transport utility, such as infrastructure being provided and/or operated by municipalities, public-private partnerships and vehicle/equipment manufacturers. This analysis clearly indicates that there is an opportunity for using innovative models to derive a viable business case for short-range e-buses in Bengaluru.

[46] http://bescom.org/wp-content/uploads/2016/05/Electricity-Tariff-for-FY-17-pdf.pdf
[47] www.cescmysore.org

6. Cost-Benefit Analysis of Hybrid and All Electric Buses

Challenges to the adoption of e-buses include their high upfront cost and lack of supporting infrastructure. However, e-buses offer benefits, including climate change mitigation, health of citizens, better quality of life, etc., through a reduction of emission intensity, improvement of air quality and promotion of sustainable urban mobility. Thus, there is a need for a Cost Benefit Analysis (CBA) framework, which looks beyond the total upfront costs of e-buses technologies and also addresses the benefits to society, at large.

The analysis compares e-bus technologies with conventional diesel buses, and largely focuses on the variants that are currently run, or are being considered for trial runs and large-scale procurement by State Road Transport Undertakings (SRTUs). Trial runs conducted so far by SRTUs in India have shown a positive indication in the direction of implementation of e-buses. The status of e-buses in various Indian SRTU fleets is given, in detail, in Appendix 5.

The CBA was worked out using the Total Cost of Ownership (TCO) approach. In this analysis, TCO refers to the cost incurred by the operator to run a bus over its lifetime, which includes various components such as the procurement cost, staff cost, energy cost, operation and maintenance costs, etc. For the convenience of comparison, all costs were calculated as Net Present Value (NPV) per km. It was observed that some parameters, namely, subsidy, interest rate, average daily run, fuel price, battery replacement cost and battery capacity, have a notable effect on the TCO of different bus types. Based on a sensitivity analysis, various scenarios were generated to understand the impact of different parameters on the TCO per km for different bus variants.

This analysis provides a framework to understand the implications of different parameters on the costs and benefits, once they are contextualised for a certain city. It also gives directions for policy design and roadmap development for large-scale adoption of e-buses.

6.1 Current Policy Incentives for EVs

The NEMMP estimates a total investment of INR 1,100–1,300 crore in the e-bus segment, including demand-side incentives, manufacturing incentives, R&D and infrastructure support. It draws up a four-phase approach for building India's EV manufacturing capabilities, including developing R&D capacities, strengthening domestic capabilities and initiating localisation. The later phases focus on creating high capabilities across the value chain, developing indigenised products (like localised plan, sourcing components locally, etc.), creating an EV component ecosystem, generating investments to enhance capabilities and preparing production plans for exports. The four above-mentioned areas of intervention, according to NEMMP, are explained in the subsequent sections.

Demand-side Incentive

The aim of this incentive is to promote the initial sales of EVs. NEMMP has estimated an investment of INR 500–550 crore for demand-side incentives, with a target of ensuring the penetration of 3,000 e-buses by 2020. The incentives proposed for low-floor urban buses are as follows (all decreasing annually):

- INR 5–20 lakh for Hybrid Electric Vehicles (HEVs)

- INR 18–34 lakh for Plug-in Hybrid Electric Vehicles (PHEVs)
- INR 20–37 lakh for Battery Electric Vehicles (BEVs, i.e., fully e-buses).

Under the FAME scheme, the incentive range for hybrid and fully e-buses is INR 30 lakh (minimum) to INR 66 lakh (maximum).

Manufacturing Incentives

NEMMP, with the help of Original Equipment Manufacturers (OEMs), estimated that demand-side incentives for 3,000 buses would provide sufficient economies of scale for OEMs to bring down their costs by 20–25%. NEMMP also specified a minimum threshold percentage of localised components, with an annual increase of 5% for the next five years.

Other benefits of localisation include job creation. NEMMP estimates approximately 60,000–65,000 direct job generation, According to the Policy document, an additional 1,80,000–2,00,000 jobs can be created in EV-related (allied) services, through local manufacturing of hybrid and EVs, respectively, by 2020.

R&D Incentives

This type of incentive promotes indigenous research in battery and powertrain. An investment of INR 500–600 crore has been estimated for R&D in the bus segment.

Infrastructure Support

According to NEMMP, 2–4 MW of extra power generation will be required to meet the energy needs of the e-bus segment. However, when the NEMMP was announced, the majority of the EV fleet to be introduced by 2020 was expected to come from the two-wheeler segment. The corresponding charging infrastructure would include 300–500 charging terminals, which would require an additional investment of INR 10–20 crore. Out of these, 70% would be normal chargers (6–8 hours), 20% would be fast chargers (3–4 hours) and 10% would be rapid chargers (less than 30 minutes).

6.2 Need for Cost-Benefit Analysis

Cities such as Mumbai, and states such as Himachal Pradesh, have been in the process of procuring hybrid and pure e-buses, respectively. In this context, it becomes important for city bus corporations to understand the technology, policy landscape and operational realities to assess the benefits and costs involved in the adoption of e-bus technologies. This report, with inputs from select SRTUs, documents the operational drive cycle of e-buses and provides a cost-benefit framework, which can be shared with other SRTUs as a reference document for the adoption of pure electric and hybrid buses.

One of the objectives of this study was to formulate a CBA framework for fully electric and hybrid buses, and to compare them with diesel buses. The framework takes into consideration the various incentives currently available for the adoption of e-buses. This framework could form the basis for justification of investment in new technologies. Key stakeholders in this project included bus procurers and operators (SRTUs), electric and hybrid bus vendors, utility department, pollution control board and environmental departments.

6.3 Methodology

The bus variants and associated data selected for the study are the non-AC (henceforth, referred to as Ordinary diesel bus) and AC diesel buses of BMTC (the AC diesel bus is considered as the base variant for comparison with e-bus); the Tata series diesel hybrid (henceforth, referred to as hybrid e-bus) procured by the Mumbai Metropolitan Regional Development Authority (MMRDA); and the BYD e-bus (henceforth, referred to as e-bus) used for trial run in Bengaluru in 2014.

The methodology for the CBA is described below.

Workshop

An initial set of interactions with bus operators and manufacturers gave an overview of the intended project and helped gain their support for the project. A stakeholder workshop was conducted in September 2016, in Bengaluru. This workshop brought together operators, manufacturers and researchers on one platform, where they discussed the need, challenges and suggestions for implementation of EVs and appropriate charging infrastructure. The stakeholders also put forth their challenges and assessments of the potential for EV penetration. Support from the stakeholders was solicited towards the study, for data and assumptions, to ensure that the analysis is robust and captures ground realities.

Data from Trial Runs (MMRDA and BMTC)

Electric and hybrid e-bus variants were selected for comparison with AC and Ordinary diesel buses, based on the current proposals for procuring hybrid electric and e-buses by MMRDA, BMTC and HRTC, and results from trial runs. As data from HRTC was not available, data on vehicle characteristics, such as passenger carrying capacity, trip profile and technical specifications, were obtained from the trial runs by BMTC (BYD e-bus) and MMRDA (Tata series diesel hybrid e-bus). The specifications of the bus variants are given in Appendix 5.

Public Transport Data from Bengaluru

Operational data (passenger volume, drive cycle, trip schedule, etc.) were procured from BMTC and bus manufacturers. The input data for the CBA are given in Appendix 5.

Total Cost of Ownership (TCO) Approach

This methodology involved the estimation of direct financial costs with the TCO approach, which includes capital costs, O&M costs, etc., of Ordinary diesel and e-bus variants (Figure 16). This is in addition to the estimation of socio-economic benefits and environmental impacts such as reductions in energy consumption, GHG emissions and noise.

Monetising Benefits

The CBA framework includes monetising the benefits mentioned above for the convenience of comparison in the CBA.

Sensitivity Analysis

A sensitivity analysis was carried out to assess uncertainties such as subsidies, interest rates, fuel prices, average daily run, battery cost and battery capacity, and the costs associated with these dynamic parameters.

6.4 Total Cost of Ownership (TCO)

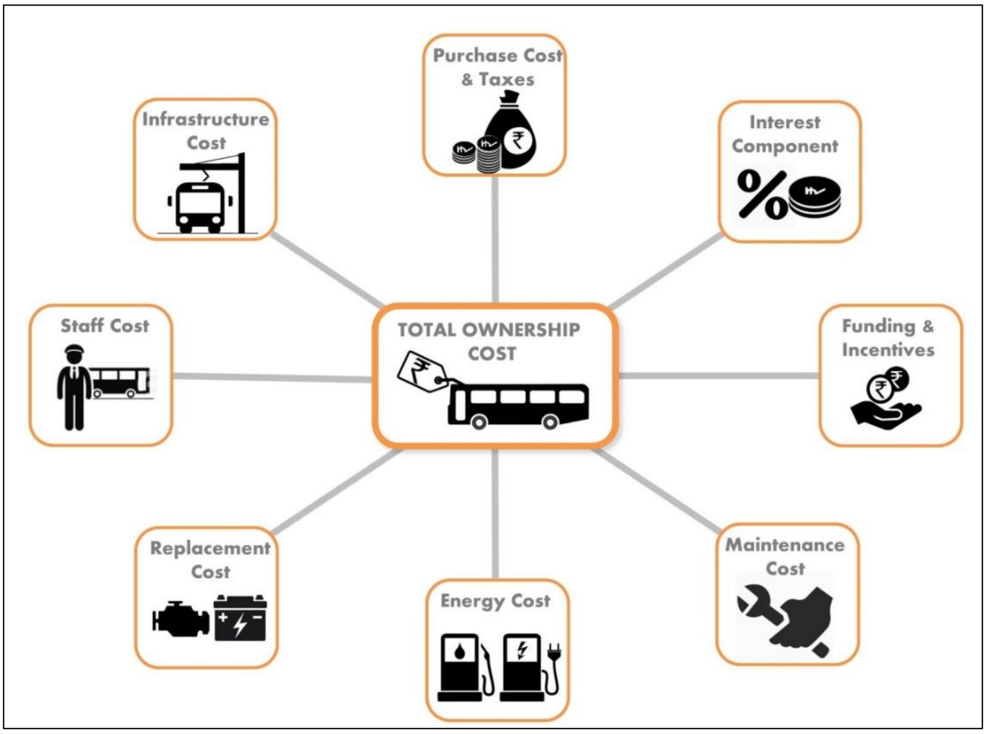

Figure 16: Total Cost of Ownership (TCO) framework

As per its definition, TCO is an "estimation of the expenses associated with purchasing, deploying, using and retiring a product or piece of equipment" ('Total Cost of Ownership', 2015). In this analysis, TCO refers to the total cost incurred by an operator to run a bus through its total lifespan. The main components of TCO considered for the assessment of public transport bus technologies were capital cost (purchase cost, taxes, etc.), interest amount, funding and incentives, and costs related to maintenance, energy, component replacements, man power and infrastructure (Figure 16). For the purpose of this study, the lifespan of all bus variants has been kept at a constant of 10 years. The total cost of the vehicle that the operator will incur in these 10 years has been estimated and the NPV of this cost per kilometre has been calculated.

Major TCO Components and Definitions

- Purchase cost of the vehicle ($PC_{Vehicle}$): This is the price quoted by the manufacturer for the bus (based on current specifications of available bus variants).
- Taxes ($TA_{Vehicle}$): This component includes the taxes and duties levied by the government on the SRTUs for procuring and operating the bus.
- Interest Amount ($IA_{Vehicle}$): This amount refers to the interest on the loan availed for procuring the bus.
- Funding and incentives ($FI_{Vehicle}$): This is the financial aid from state and central governments, and private or corporate agencies, to address the viability gap for procurement of buses (based on current policies).
- Maintenance Cost ($MC_{Vehicle}$): Maintenance cost is expressed as the sum of per km cost incurred for spare parts, lubricants, tyre replacements, brake pads, air suspensions, etc., required during the lifespan of the bus:

- ($MC_{Vehicle}$) = (Maintenance cost per km * Vehicle km run).

- Energy Cost ($EC_{Vehicle}$): The energy cost is the cost of fuel (diesel/electricity or both) incurred by the bus for its operation (per day, per year or for lifetime):
  - ($EC_{Vehicle}$) = (Average vehicle km run * Fuel cost per unit / Fuel efficiency)
- Replacement Cost ($RC_{Vehicle}$): This cost includes the cost of battery replacement for an e-bus and engine replacement for an Internal Combustion Engine (ICE) diesel bus during the operational life of the bus:
  - ($RC_{Vehicle}$) = (Replacement cost of battery or engine * No. of replacements)
- Staff Cost ($SC_{Vehicle}$): This cost includes the salaries, incentives and benefits to the driver, conductor and admin staff:
  - ($SC_{Vehicle}$) = (Staff cost per vehicle km * Vehicle km run)
- Infrastructure Cost ($IC_{Vehicle}$): This cost includes the cost that the operator has to bear for the charging and fuelling infrastructure. Currently, operators are not bearing any fuelling infrastructure cost as it is borne by the fuel-supplying companies. Same has been considered for e-bus.

$$TCO_{Vehicle} = [PC_{Vehicle} + TA_{Vehicle} + IA_{Vehicle} - FI_{Vehicle} + MC_{Vehicle} + EC_{Vehicle} + RC_{Vehicle} + SC_{Vehicle} + IC_{Vehicle}]$$

The assumptions for the CBA related to social and environmental damage, fuel consumption, noise levels and emission factors are given in Appendix 5.

6.5 Analysis

This study analyses the TCO of all the variants as per the Business as Usual (BAU) scenario and identifies the major cost components. It quantifies the social and environmental benefits[48] of hybrid electric and fully e-bus over AC diesel buses. To understand the importance of the different parameters, a sensitivity analysis has been carried out. In addition to the sensitivity analysis, different scenarios have been developed based on the different values of select parameters. The benefits in all the scenarios do not change significantly, except for a slight variation due to changes in average daily run and, hence emissions. Even though the benefits remain more or less similar for all the scenarios, the share of benefits is different due to the varying TCO estimates. Table 20 shows the assumptions for the TCO and estimation of societal costs[49] are given in Appendix 5.

Table 20: Business as Usual scenario

Parameter	Units	Value
Subsidy for Hybrid Electric Bus	INR	30,00,000
Subsidy for Electric Bus	INR	66,00,000
Interest rate	%	10.50
Average daily run	km	195
Fuel cost	INR/litre	60
Battery replacement cost (% of present cost)	%	50
Battery capacity	kWh	324
Battery cost associated with capacity (% of current cost)	%	100

[48] Since all benefits like Quality of life cannot be monetised, the estimates are conservative
[49] Societal cost refers to the damage cost of carbon and noise-related health cost

TCO Assessment

Figure 17 below shows the TCO components of all four bus variants as per the BAU scenario. This scenario considers:

- A FAME subsidy of INR 30 lakh for a hybrid e-bus and INR 66 lakh for a fully e-bus
- Present interest rate of 10.50% paid by the SRTUs
- Average daily run of 195 km
- Battery offered by BYD, which is of 324 kWh capacity, and battery price during replacement to be 50% of the current battery price.

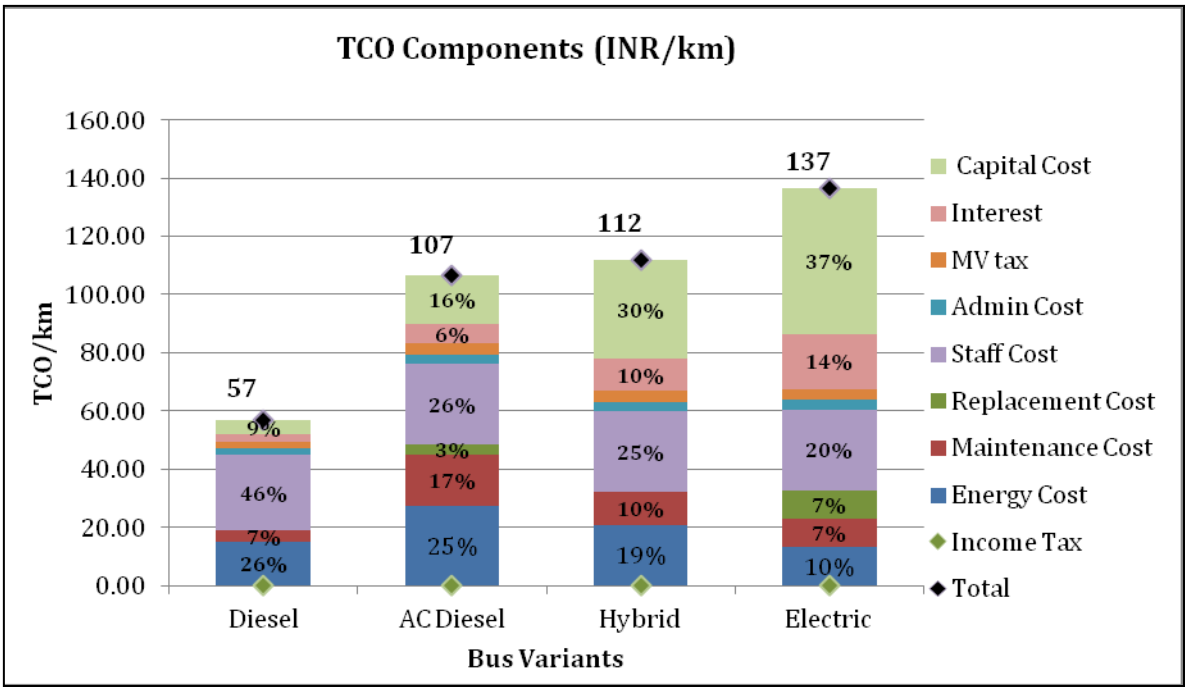

Figure 17: TCO components and their percentage shares

It is to be noted that:

- The staff cost, maintenance cost and energy cost may reduce for an e-bus
- Inflation and staff cost increments have not been considered in this analysis.

The major TCO component for hybrid and fully e-buses is the capital cost (30% and 37%, respectively). For Ordinary diesel and AC diesel buses, however, the staff cost is the major TCO component (46% and 26%, respectively). Some of the reasons for the high capital cost of the hybrid electric and e-buses in India include lack of bulk manufacturing and high import costs. The energy cost for Ordinary diesel and AC diesel buses contributes about 25% to the total cost of operation per kilometre, whereas this share reduces to 19% and 10% for hybrid electric and e-buses, respectively. Under the current policy regime, the TCO/km of an e-bus is 28% higher than that of an AC diesel bus, whereas the TCO/km of a hybrid electric bus and an AC diesel bus are quite comparable. Comparing the TCOs of all four variants for the duration of their lifetime, it can be seen that the TCO of e-bus remains higher throughout (even though it decreases over the years) (refer to Figure 18 for details). The TCOs of an e-bus and an AC diesel bus can be seen to increase remarkably in the fifth year due to inclusion of battery and engine replacement costs, respectively. The decrease in the TCO is because of the interest component, which reduces every year. The capital costs for electric and hybrid buses are higher than that of the Ordinary and AC diesel bus. Hence, the rate of decrease of TCO/km for the electric and hybrid e-buses is higher than those of Ordinary diesel and AC diesel buses.

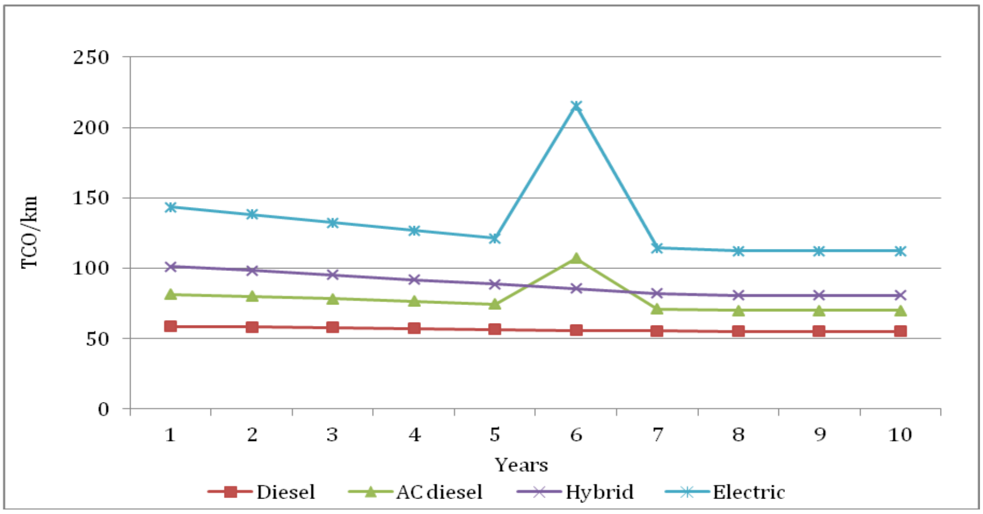

Figure 18: Year-wise TCO/km for the lifetime of a bus

Benefit Assessment

The benefit assessment in this analysis takes into consideration the economic, environmental and social benefits. The benefits have been calculated based on the AC diesel bus. Due to the lack of availability of contextual data, this analysis depends upon secondary data obtained from literature (Appendix 5). Input data from the operators, secondary data and assumptions have been given in Appendix 5. A health benefit assessment is, however, a challenge as no reliable data is available for monetising the health related cost-benefits with respect to emissions.

Note: The benefits assessed are conservative as many parameters, such as health and quality of life impacts, are not accounted for.

Parameters for assessing benefits are as follows:

- Emissions (damage cost of carbon or cost of carbon pollution)
- Noise (noise-related health cost)
- Energy savings (alternative energy costs).

Table 21 shows the benefits of all variants over the AC diesel bus.

Table 21: Benefits of Ordinary diesel, hybrid electric and e-buses over AC diesel bus

Bus Variant	**Noise-related Health Cost Benefit (INR/km)**	**Damage Cost of Carbon Benefit (INR/km)**	**Energy Cost Benefit (INR/km)**	**Total Benefits (INR/km)**
Ordinary diesel bus	0.00	1.31	13.51	14.82
Hybrid electric bus	6.50	0.61	6.27	13.38
Electric bus	11.64	2.64	13.68	27.96

- The total benefits over the AC diesel bus are the highest in the case of e-buses, at INR 27.96/km.
- Noise-related benefit over the AC diesel bus is the highest for e-buses, at INR 11.64/km, followed by that for hybrid e-bus (INR 6.50/km).
- The benefit for the damage cost of carbon is the least for hybrid e-buses (INR 0.61/km) and the maximum for e-buses (INR 2.64/km).
- For the energy cost aspect, the benefits of the hybrid electric and e-buses are INR 6.27/km and INR 13.68/km, respectively, as compared with the AC diesel bus.

6.6 Key Observations from the Analysis

- The TCO/km for the AC diesel and hybrid e-buses are comparable. Capital costs contribute the major share of TCO/km in hybrid electric and e-bus and staff cost and energy cost have the major share in the case of the AC diesel bus.
- The share of energy cost in the TCO/km of Ordinary diesel and AC diesel buses is 25%, whereas this share reduces to 19% and 10% for hybrid electric and e-buses, respectively.
- E-bus has the maximum benefit (INR/km) over the AC diesel bus; the benefits are significantly higher when compared with the hybrid electric bus.
- The current FAME subsidy of INR 30 lakh for a hybrid electric bus is adequate for its TCO/km, to compete with the AC diesel bus. However, with the INR 66 lakh FAME subsidy for an e-bus, the TCO/km of the e-bus remains 23% higher than that of the AC diesel bus.

Sensitivity Analysis

A sensitivity analysis for Ordinary diesel, AC diesel, hybrid electric and e-buses was carried out by identifying the significant factors that influence the TCO. The major cost component in the TCO analysis for hybrid electric and e-buses is the capital cost. In this context, the sensitivity analysis considers the parameters that have a greater impact on the capital cost. The second criteria involved parameters that are subject to change contextually (nation-wide for this analysis). Sensitive parameters considered for this study included:

- Subsidy
- Interest rate
- Average daily run
- Fuel price
- Battery price during replacement
- Battery capacity[50]

A brief description of the factors and the TCO component(s) they impact is given in Table 22.

[50] Currently available battery size for the trial run in Bengaluru is 324 kWh, which allows the bus to run 250 km in one charge

Table 22: Sensitive parameters, their descriptions and ranges

No.	Factors	Description	Range	TCO Impact
1	Subsidies/incentives (INR)	Maximum FAME subsidies for hybrid-electric and e-buses have been assumed, and the impact of a higher subsidy has also been considered	0 30,00,000[51] 66,00,000[52] 1,08,00,000[53]	Capital cost
2	Interest rate (%)	Depends on the type of loan or scheme if any	6 8 10.50 14	Capital cost
3	Average distance per day (km)	The average distance per day depends on the existing traffic conditions, city average trips lengths, schedules, charging time, etc.	170 195 250	Operational and maintenance cost
4	Fuel cost (INR/litre)	Constantly fluctuating fuel prices mostly dominated by increasing trends	50 60 70 80	Operational cost
5	Battery replacement cost (% of present cost)	The battery replacement cost depends on the technical advancement at the time of replacement, size of the battery, import cost (if imported), etc.	25 50 100	Replacement cost
6	Battery cost as per capacity (kWh)	The battery cost depends on the size of the battery required to cover the daily distance run	220 252 324	Capital cost

The sensitivity analysis involved an understanding of the impact of each parameter on the TCO/km. Based on this, three scenarios, namely, Best, Pragmatic and Pragmatic with tax exemption for an e-bus were developed. While analysing the impact of each parameter on the TCO/km individually, the rest of the parameter values had been retained as per the BAU scenario. The values for the BAU scenario are given in Table 20.

Figure 19 represents the impact of each parameter independently on the TCO/km. It shows that a high subsidy and a high average daily run of a bus are the two major parameters that affect the TCO/km of the bus. These two are followed by the battery replacement costs and rate of interest. Fuel price has no impact on the TCO of an e-bus, but it inversely impacts the TCO gap. The TCOs of an Ordinary diesel and AC diesel bus are independent of subsidy, battery price and battery range.

[51] FAME subsidy for hybrid bus
[52] FAME subsidy for electric bus
[53] Assumed subsidy of 40% of purchase price

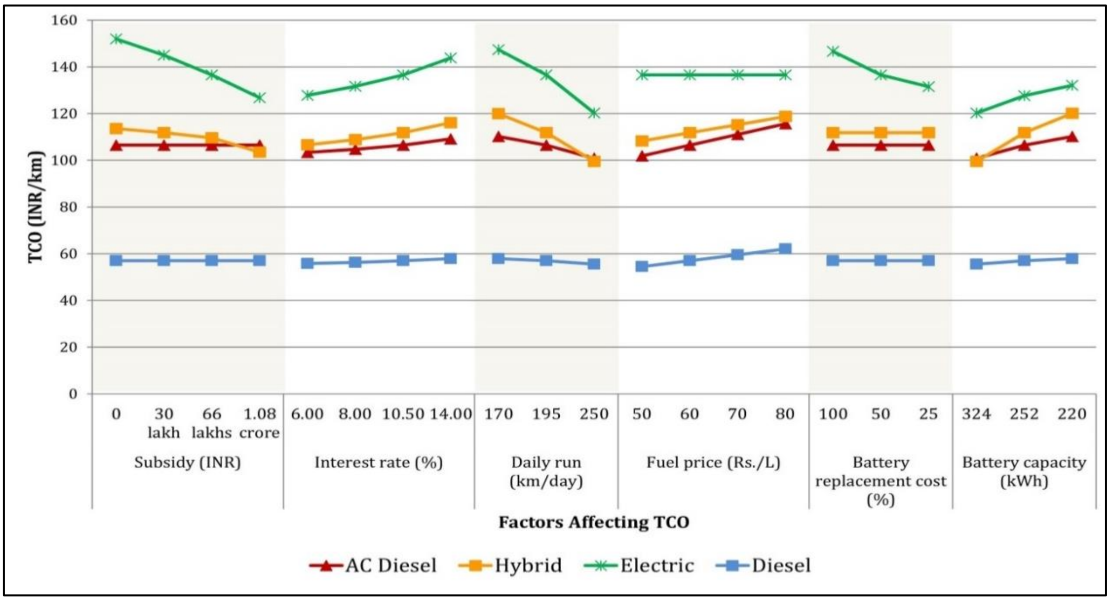

Figure 19: Summary of effects of individual parameters on TCO

To summarise:

Subsidy: With higher FAME subsidy for hybrid electric and e-buses, the TCO gap between AC diesel and hybrid e-buses can be eliminated. However, the TCO/km for e-buses remains 28% higher than that of an AC diesel bus. Additional subsidy is thus required for e-buses to compete with AC diesel buses.

Interest rate: Generally, the interest rate for the SRTUs in India is found to be 10.50%. Delhi Transport Corporation (DTC) is the only SRTU paying the highest interest rate of 14% (State Transport Undertakings Profile & Performance 2013-14, 2016). This study considers an incentivised interest rate of 8% and 6% for hybrid electric and e-buses, respectively. With an incentivised interest rate of 6%, the TCO/km of a hybrid e-bus is seen to almost equal that of an AC diesel bus, whereas the TCO/km of an e-bus is 20% higher than that of an AC diesel bus.

Average daily run: This is the third parameter considered for the sensitivity analysis. For this analysis, an e-bus with a battery range of 250 km has been considered. Thus, when the bus runs less than 250 km, the battery is not being utilised optimally. This parameter is seen to be inversely proportional to the TCO/km. The TCO/km of a hybrid e-bus is seen to be more than that of an AC diesel bus, or a minimum run of 170 km. This equalises when the daily run increases to 250 km. The TCO/km of an e-bus is 34% more than that of an AC diesel bus for 170 km, whereas this gap reduces to 19% when the daily run increases to 250 km.

Fuel price: This is the most sensitive parameter as fuel (diesel) prices are constantly fluctuating. Fuel (diesel) inflation impacts the estimation of the TCO/km of Ordinary diesel, AC diesel and hybrid e-buses. The TCO/km gap between an AC diesel and an e-bus is seen to reduce when diesel prices increase. The TCO of the e-bus is, however, independent of this parameter. For a reduced diesel price of INR 50/km, the TCO gap between a hybrid e-bus and an AC diesel bus is 6%; this gap reduces to 2.7% if diesel prices increase to INR 80/km. Similarly the TCO/km gap between an e-bus and an AC diesel bus is 34% for a low diesel price of INR 50/litre; however, this gap reduces to 18% for a fuel price of INR 80/km.

Battery capacity: For this study, a battery with a range of 250 km/charge has been considered. However, the average daily distance covered by a bus per day is 195 km. Hence, for the sensitivity analysis, we considered three average daily runs of 170 km, 195 km and 250 km, which would influence the battery capacity and cost accordingly. This study shows that the TCO gap between an e-bus and an AC diesel bus is maximum (20%) when minimum battery capacity (220 kWh) is considered. With maximum battery capacity (324 kWh), this gap reduces to 19%. This shows that this parameter has no remarkable effect on the TCO gap.

Battery replacement cost: Battery replacement cost is an important parameter, which influences the sensitivity analysis. The life of a battery is considered to be 2,000 cycles as per BYD specifications. The average price of EV batteries dropped by 14% from 2011 to 2012, and 30% from 2009 to 2012 (Shahan, 2016). Hence, the battery price assumed, at the time of replacement, may further drop to 50% of the current price (of the BAU scenario). This study considered two additional cases: where the battery price remained the same, and where it falls to 25% of the current price, at the time of replacement. The TCO/km of an e-bus is seen to be 37.5% more than that of an AC diesel bus when the battery price is assumed to remain the same as today. However, this gap reduces to 24% if the battery price comes down to 25% of the current price, at the time of replacement.

Scenario Analysis

For understanding the effect of each parameter on the TCO, the following three scenarios have been considered in this study:

1. Best Case Scenario: High subsidy, low interest rate, low fuel price, adequate battery size
2. Pragmatic Scenario: Moderate subsidy, regular interest rate, adequate battery size
3. Tax-exempt Scenario: Moderate subsidy, regular interest rate, adequate battery size, all taxes exempt for e-buses.

The values considered for each scenario are given in detail, in Table 23.

Table 23: Values of sensitive parameters for different scenarios

	Variants	Factors					
		Subsidy (INR)	**Interest Rate (%)**	**Average km per Day (km)**	**Fuel Price (INR/ litre)**	**Battery Replacement Cost (% of Current Price)**	**Battery Capacity (kWh)**
Scenario 1 (Best Case)	Ordinary Diesel	0	14	250	80	NA	NA
	AC Diesel	0	14	250	80	NA	NA
	Hybrid Electric	66 Cr	6	250	80	NA	NA
	Electric	1.08 Cr	6	250	NA	25	100
Scenario 2 (Pragmatic Case)	Ordinary Diesel	0	10.50	250	60	NA	NA
	AC Diesel	0	10.50	250	60	NA	NA
	Hybrid Electric	30 lakh	10.50	250	60	NA	NA
	Electric	66 lakh	10.50	250	NA	50	100
Scenario 3 (Pragmatic Case with Tax Exemption)				Same as "Pragmatic Scenario", along with all the taxes exempted for e-buses.			

Best Case Scenario

This scenario considers favourable conditions for hybrid electric and e-buses. After several iterations, it was found that the TCO/km for hybrid electric and e-buses is the least, considering:

- The lowest interest rate of 6%
- Average daily run of 250 km (full battery capacity utilisation and more revenue)
- High diesel price of INR 80/litre and electricity tariff equal to that of Metro rail (INR 5.35/unit)
- 25% battery price at the time of replacement
- Subsidy of INR 66 lakh and INR 1.08 crore for hybrid e-bus and e-bus, respectively (INR 66 lakh is the maximum FAME subsidy and INR 1.08 crore is the assumed subsidy of 40% on purchase price of an e-bus).

With all these conditions, the analysis results showed:

- The TCO/km of a hybrid e-bus is 12% lesser than that of an AC diesel bus
- The TCO/km of an e-bus is 16% lesser than that of an AC diesel bus and 4% lesser than that of a hybrid e-bus.

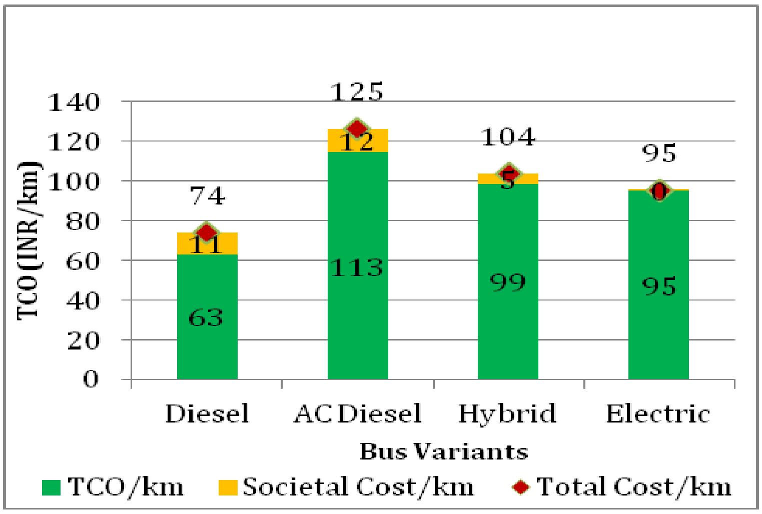

Figure 20: Best Case Scenario

Considering the damage cost of carbon and noise-related health cost, the gross cost of an AC diesel bus is seen to be much higher than that of all the other variants. With the societal cost added to the TCO, the gross cost/km of a hybrid electric and an e-bus is lesser than that of an AC diesel bus by 16.8% and 24%, respectively. Figure 20 illustrates the Best Case Scenario.

Pragmatic Case Scenario

This scenario considers all the parameters similar to the BAU scenario, but assumes full battery utilisation. The average daily run is assumed to be 250 km (BYD battery capacity). Figure 21 illustrates the Pragmatic Case Scenario.

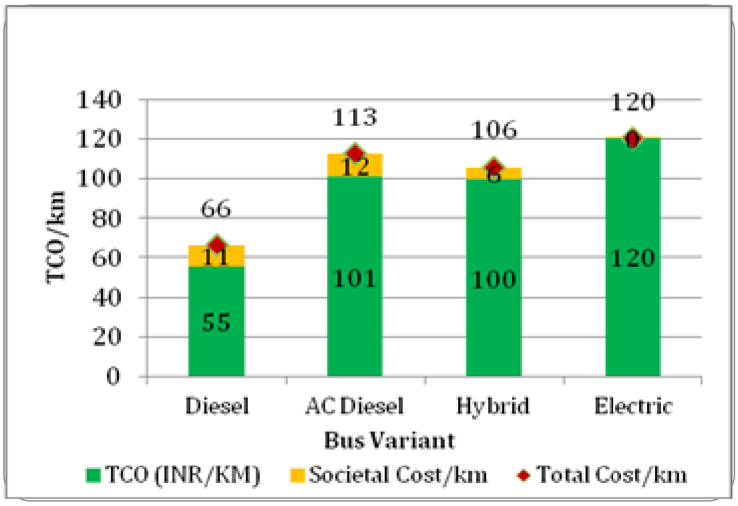

Figure 21: Pragmatic Case Scenario

The following observations have been made regarding the Pragmatic Case Scenario:

- The TCO/km of an e-bus is 19% higher than that of an AC diesel bus, whereas the TCO/km of a hybrid electric bus is comparable to that of an AC diesel bus
- Considering the societal costs, the gross cost/km of a hybrid electric is 6% lesser than that of an AC diesel bus, and that of an e-bus is 6% higher than that of an AC diesel bus.

Pragmatic Case Scenario with Tax Exemption for Electric Bus

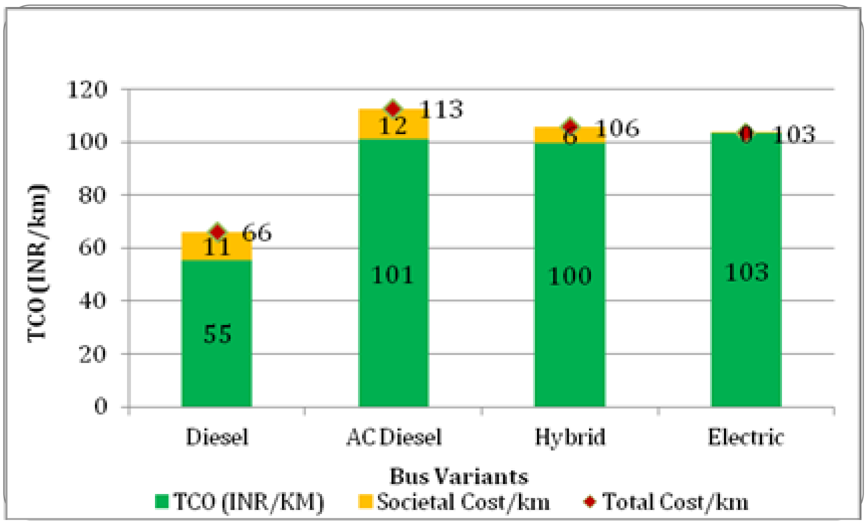

Figure 22: Pragmatic Case Scenario with tax exemption

This scenario considers tax exemption for e-bus, while keeping all the other parameters as per the Pragmatic Scenario. Figure 22 illustrates the Pragmatic Case Scenario with Tax Exemption.

The following observations have been made:

- The TCO/km of an e-bus is almost equal to that of an AC diesel bus
- Considering the societal cost, the total cost/km of an e-bus is 8% lesser than the total cost/km of an AC diesel bus.

6.7 Policy Implications

The challenges facing e-bus penetration in India are not unique. It is evident from the analysis that EVs are not yet competitive, given the current price range offered by manufacturers like Ashok Leyland (INR 1.5–3.5 crore) (Rakshit, 2016). In the short term, government incentives will be required to achieve financial viability and breakeven volumes/prices for users to shift to EVs. For a large part of this decade, hybrids will continue to provide a better Return on Investment (ROI) to customers than EVs (under the current conditions). One of the key enablers for the cost competiveness of EVs is upfront cost reductions, while the prices of other bus variants remain relatively constant. Costs of ownership will be a central issue in fleet electrification throughout the decade. With government subsidies and incentives likely to be stopped in the long run, costs will have to reduce significantly.

Battery costs today, in many cases, add as much as 50% to the cost of a vehicle. Though there is much debate, the emerging consensus is that the cost of a LIB should be reduced by as much as 50–70%, within the next decade. Experience in the photovoltaic sector for solar applications can support this claim. With scaling-up of volumes, photovoltaic technology costs have come down by about 70% in the last 20 years, with about 45% of the cost reductions happening in the first decade itself (PRTM, 2011).

Identifying suitable technology solutions for specific local operational contexts will be important to further reduce this cost. It is thus crucial to match the battery size of a fleet to the daily driving range. Currently, imported buses (250 km range) cost about INR 3 crore each, with a battery cost of INR 1.2–1.3 crore per bus. Although batteries for short ranges, for example, 100–150 km, would require accessibility to charging infrastructure at all times, the battery costs may decrease by 50% of the current price, to INR 65,000. The costs may reduce further by removing air-conditioning and other non-essential components. With the current level of subsidies, the cost of e-buses can be made competitive with that of AC diesel buses. Localised specifications with standardisation can enhance the cost reduction through scaling-up of production, production optimisation, material improvement design (to increase energy density, etc.) and standardisation (standard cell sizes, less product complexity), etc. Further, the development of batteries with longer life also becomes imperative for reducing their lifetime costs. A secondary market for batteries can further this even more. There is thus a need to develop an ecosystem (upstream and downstream battery manufacturers), which includes OEMs, who build strong supply relationships/partnerships to combine resources and fast-track their development timelines.

The cost reduction will thus come from a combination of interventions, including global trends in battery price, localisation and design standardisation, with improvements in production processes, materials and supply chain actions, and provision of adequate charging infrastructure. Some imperatives that emerge from the current challenges related to the high upfront costs are:

- Role of scale: The central role of scale in vehicle electrification is crucial to electrification of buses. Low cost is only achieved in large-volume, highly automated manufacturing units.
- Shorter battery range: 90% of intra-city buses have trip lengths measuring less than 30 km. In this context, batteries sized to relevant driving cycles become important; this

also has a positive impact on the cost of the battery, which ultimately impacts the cost of the bus. However, one should be cognisant of the charging infrastructure needs and challenges, whether it be fast-charging or battery swapping.

- Government incentives and investments: These are needed in the short term to propel demand from SRTUs, growth and scaling-up of the new industry. Leapfrogging to e-buses will need incentives—for example, tax holiday for SRTUs for procurement of e-buses during the initial years, for building up demand for creation of localised manufacturing units, etc.
- R&D and manufacturing of battery systems: Large investments will be required in new R&D, industries and facilities (for example, Lithium ion cell components such as cathodes, anodes, separators and electrolyte solution; cells using diverse chemistries; pack assembly facilities; and also game changing technology like using nanoparticles instead of conventional graphite anodes, etc.).
- Creating new institutions and markets: There is a need for establishing solutions for battery second-life use, to reduce the battery life-cycle cost (higher salvage costs). For example, retired EV batteries could be used in the solar sector.
- Commercial models/financial instruments: Helping build commercially viable systems/solutions that serve the customers' needs and propel growth once subsidies are discontinued.

7. Implementation Plan for BMTC's Electric Bus Fleet in Bengaluru

7.1 Route Prioritisation

Procurement and deployment of e-buses should be done in stages, as described below. Doing so will not only mitigate the risks associated with implementing new EV technology, but also provide BMTC the flexibility to absorb future technology and policy breakthroughs.

Stage 1: Procure and Deploy 150 Buses by June 2018

Table 24 provides a list of the airport routes that are feasible from a transport and electrical network perspective (no. schedule changes or upgradation required) and should, therefore, be prioritised for operating e-buses (please refer to the section "GIS-based Transportation Platform for Bengaluru City" for details).

Table 24: Stage 1 Airport e-bus routes

Route No. (Origin–Destination)	Total Schedule (No. of Vehicles)	Route Length (km)	Average Daily Run (km)	Charging Locations	Charge Provision for (Total km)[54]	Energy Required (kWh)
KIAS*-8 (Airport–Electronic city)	3	66	303.6	Electronic city	500	650
				Depot 28	154.1	200.3
				BTM Layout	250	324
KIAS-7A (Airport–HSR Layout)	3	50	353.3	Depot 25	291.2	378.6
				HSR layout	500	650
				Airport	250	324
KIAS-9 (Airport–KBS**)	2	49.7	366.4	Depot 07	143	185.7
				KBS	411	533.9
				Airport	250	324
KIAS-5A (Airport–Jambusavari Dinne)	2	50.75	308	Airport	408.4	530.9
				Depot 13	301.2	391.6
KIAS-5B (Airport–Bannerughatta)	2	56.15	321	Airport	446.4	580.3
				Depot 07	285.7	371.4
Total	**12**					**5,445**

**Kempegowda International Airport Services*
***Kempegowda Bus Station*

[54] Please refer to Chapter 4 for detailed explanation of calculations

Figure 23 shows the exact path taken by a vehicle along Airport route KIAS-8.

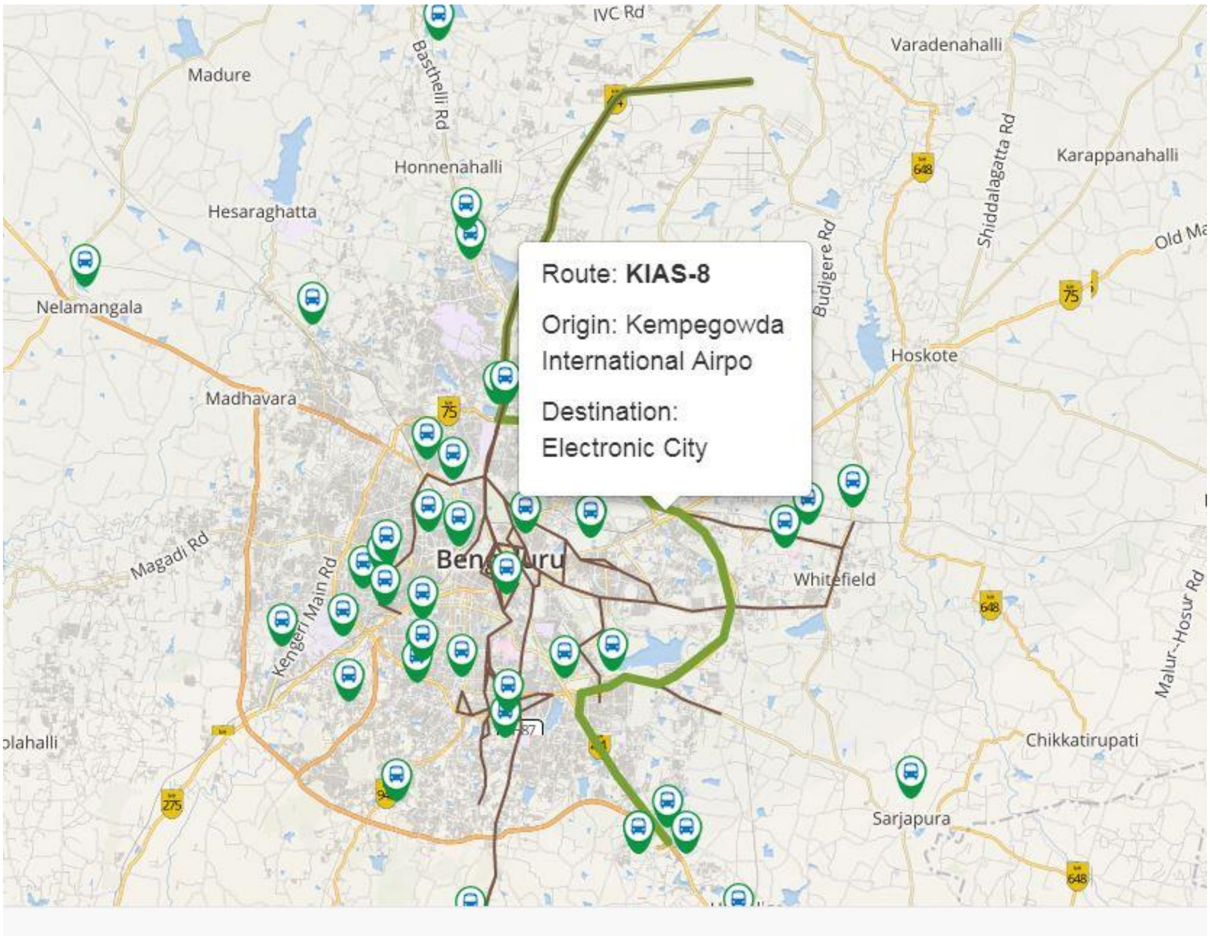

Figure 23: Sample Airport route (KIAS-8)

Table 25 lists the details of the Vajra routes that should be prioritised for operating e-buses.

Table 25: Stage 1 Vajra e-bus routes

Route No. (Origin–Destination)	Total Schedule (No. of Vehicles)	Route Length (km)	Average Daily Run (km)	Charging Locations	Charge Provision for (Total km)	Energy Required (kWh)
V-500CA (ITPL–Banashankari)	42	25.2	243	Depot 18	975	1,267.7
				Depot 25	2,681	3,486
				Banashankari	975.2	1,267.7
				ITPL	975.2	1,267.7
				Depot 13	3,169	4,120.2
				Depot 28	1,219	1,584.7
				Hebbala	243.8	316.9
V-500BM (ITPL–Brigade Millennium)	4	28.4	222.8	Depot 18	222.8	289.64
				Depot -7	222.8	289.64
				KBS	222.8	289.64
				Banashankari	222.8	289.64
V-500CH (ITPL-Vidhyanagar)	6	33.73	203.3	Banashankari	406.6	528.5
				Depot 13	813.2	1,057.16
V-500DF (ITPL–Hebbala)	4	28.5	214.3	Depot 28	571	743.3
				Hebbala	190	247.7
V-500K (ITP–Vijayanagara)	30	41.6	220	Depot 13	3,740	4,862
				ITPL	880	1,144
				Banashankari	220	286
				Depot 25	1,760	2,288
V-500KE (ITPL–Kengeri)	7	42.7	227.3	Depot 18	681	886.4
				Depot 25	681	886.4
				ITPL	909	1,181.9
				Depot 13	227	295.5
V-500KR (ITPL–Kechanahalli)	5	38.62	218.4	Depot 13	1,310	1,703.5
				ITPL	436	567.8
V-500P (ITPL–Chikkalasandra)	4	29.9	183.6	Depot 13	367	477.3
				Depot 25	550	716.04
Total	**102**					**32,341**

Figure 24 shows the exact path taken by a bus along a Vajra route (V-500CH).

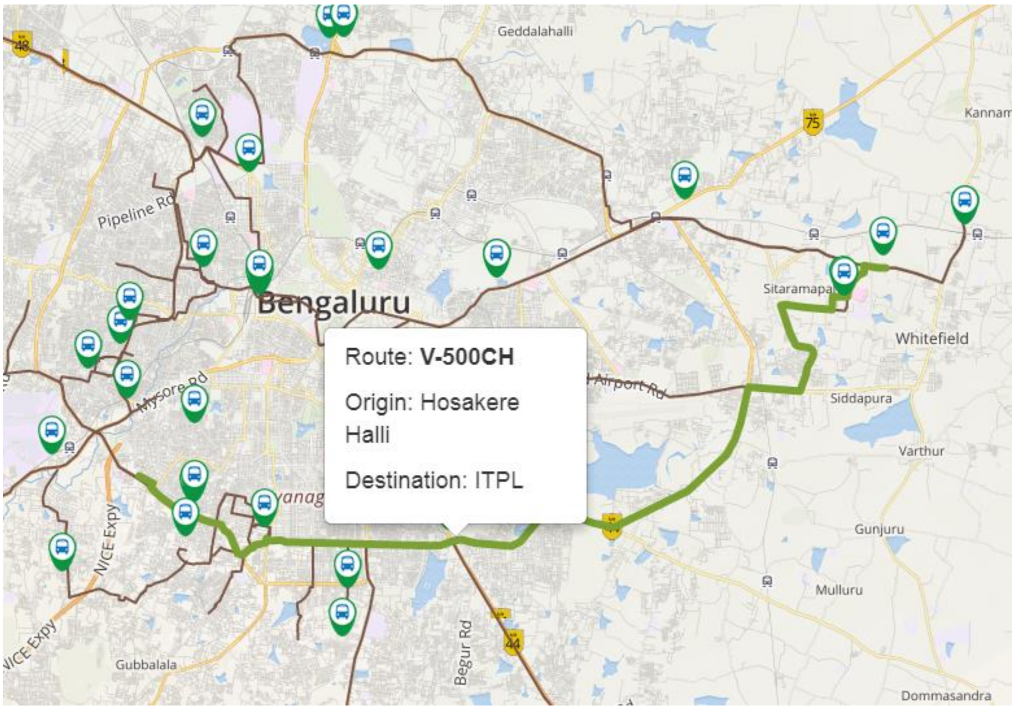

Figure 24: Sample Vajra route (V-500CH)

Table 26 lists the details of the Metro-feeder routes that should be prioritised for operating e-buses.

Table 26: Stage 1 Metro-feeder e-bus routes

Route No. (Origin – Destination)	Total Schedule (No. of Vehicles)	Route Length (km)	Average Daily Run (km)	Charging Locations	Charge Provision for (Total Km)	Energy Required (kWh)
MF-6 (SV Metro Station–Silk Board)				SV Metro Station	570	741
				Depot 6	760	988
	9	10.2	190	Central Silk Board	190	247
MF-13 (Vijayanagara Metro Station–Vijayanagara Metro Station)	2	21	263	Viajayanagara	526	683
MF-12 (Vijayanagara–Banashankari TTMC)				Banashankari	171	222
				Depot 16	171	222
				Vijayanagara	342	444
	7	10.6	171	Depot 17	513	666.9
MF-1 (KBS–Mantri Square)	1	29.3	171.6	Depot 2	171.6	223
MF-2 (Baiyyappanahalli Metro Station–HAL Main Gate)				Depot 6	259	336.7
	3	14.5	259	Depot 29	518	673
Total	**22**					**5447**

Figure 25 shows the exact path taken by a bus along a Metro-feeder route (MF-1).

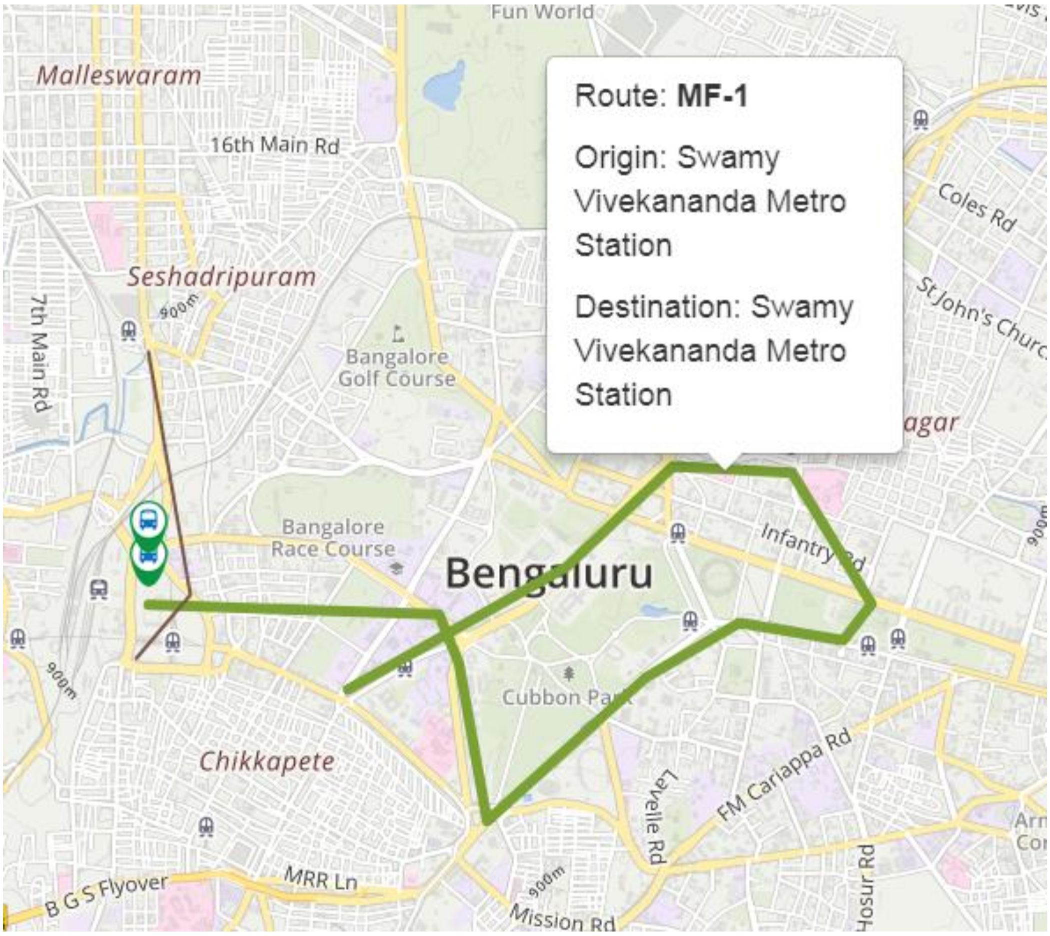

Figure 25: Sample Metro-feeder route (MF-1)

Table 27 lists the details of Ordinary (non-AC bus) routes that should be prioritised for operating e-buses.

Table 27: Stage 1 Ordinary (non-AC) bus routes identified for operating e-buses

Route No.	No. of Buses	Route Length	Average Daily Run	Charging Location	Charge Provision for (Total km)	Energy Requirement (kWh)
KBS-1I	11	26.7	245.2	Depot 06	583	757.9
				KBS	2,706	3,517.8
KBS-1K	4	24.5	230	Depot 06	212	275.6
				KBS	920	1196
SBS-1K	13	22	240	Shivajinagar Bus Station	165	214.5
				Depot 06	3,120	4,056
Total	**28**					**10,018**

Table 28 provides a summary of the assessments for each type of BMTC bus routes.

Table 28: Stage 1 - Overall assessment for initial fleet of e-buses

Route Type	No. of Buses	Energy Requirement (kWh[55])
Airport	12	5,445
Vajra	102	32,341
Metro Feeder	22	5,447
Ordinary	28	10,018
Total	**164**	**53,251**

7.2 Electrical Load Analysis

BMTC has common depots for all its buses, regardless of the category. Hence, a sample analysis of the electrical infrastructure at a depot, which hosts buses of various categories at different times, is presented below.

Illustration: If Depot 7 were to host the following e-buses, as per the analysis, the details are shown in Table 29.

Table 29: Schedules utilising Depot 7 for charging

Route Type	Route Number and Schedule
Airport	KIAS 9/1
Airport	KIAS 5B/1
Airport	KIAS 5B/2
Vajra	V-500BM/4

Depot 7 has two feasible feeders, namely F-6 and F-26[56]. As shown in Figure 30, feeder F-6 can easily absorb the extra load generated by the four e-buses mentioned in Table 29.

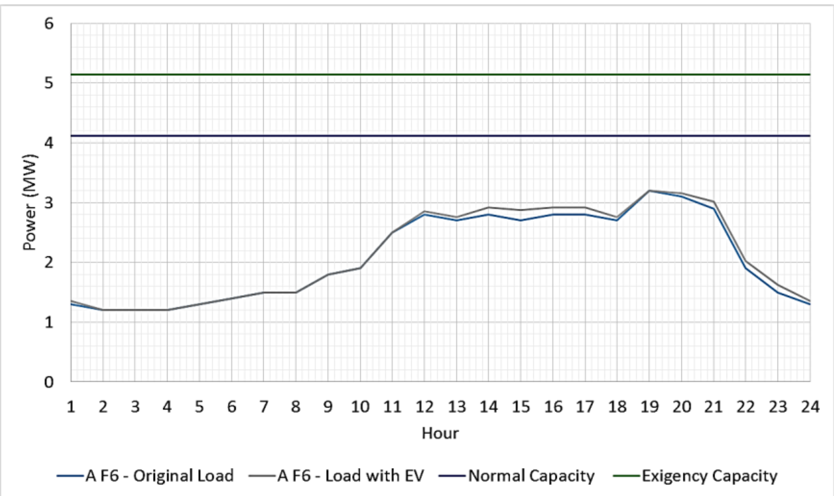

Figure 26: Electrical load on feeder F-6 (at Depot 7) caused by e-buses

[55] Please refer to previous sections for details on calculations of energy requirement
[56] Feasible feeders are those feeders that are running under capacity for all of a 24 hour period. Some exceptions may be considered in the analysis.

The discussion in this section can be useful for immediate procurement and deployment of 150 e-buses for Bengaluru. A similar analysis coupled with the points mentioned in Stage 2 (described in the next section) can be used to procure and deploy more e-buses by 2022.

Stage 2: Significant (up to 50%) e-bus deployment by 2022 and 100% e-bus deployment by 2030

The above-mentioned results cater to the current adoption plan of 150 EV buses. In view of increased adoption of EVs, in Stage 2 and beyond, the following aspects would be recommended for effective planning:

- Integrated planning between state transport and distribution utilities, capturing the intricacies of route details, such as length between stops and sufficient halt time for charging, would be imperative. Availability of fast-charging options for midday top-up charging and appropriate planning of power distribution infrastructure to support this should be considered.
- The role of RE sources such as RTPV systems could be successfully used by optimising the charging schedule of e-buses along with the availability of solar energy.
- Major adoption and hence charging of EVs is expected in the residential and commercial segments in the future; this would add stress on the electricity distribution grid, further. Considering the nature and quantum of power requirement, there is strong merit in developing a revised distribution grid infrastructure planning framework to accommodate the uptake of EVs. A possible way could be by streamlining the planning process using the “connected/sanctioned load” parameter as reference.
- A structured plan must be formulated for transitioning from diesel buses to e-buses. This would include not only the replacement of the vehicle, but also building of the entire support ecosystem to facilitate the EV infrastructure. This ecosystem includes charging stations, vehicle parts (motors, batteries, etc.) and spares for EV support equipment (EVSE), along with both slow-charging and fast-charging options.
- An assessment of EV-related equipment (both EV and EVSE) and a clear EV ecosystem roadmap is needed to cater to the needs of manufacturers.

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9. Appendix 1

Table 30: Summary of policy support mechanisms in a few countries - 2015

	EV Purchase Incentives				EV Use and Circulation Incentives				Waivers on Access Restrictions			Tail pipe Emission Standards		Market Share of Electric Cars in 2015
	Rebates at registration/sale	Sales tax exemptions (exd. VAT)	VAT exemptions	Tax credits	Calculation tax exemptions	Waivers on fees (e.g., tolls, parking ferries)	Electricity supply Reductions/exemptions	Tax credits (company cars)	Access to bus lanes	Access to HOV lanes	Access to restricted traffic zones*	Fuel economy standards/regulations including elements	Road vehicles tail pipe pollutant emissions standards	
Canada	Widespread					Targeted				Targeted		Nationwide	Tier 2	0.4%
China	Nationwide	Nationwide			Nationwide	Targeted	Targeted				Targeted	Nationwide	China 5	1.0%
Denmark		Nationwide				Widespread						Nationwide	Euro 6	2.2%
France	Nationwide	Nationwide				Targeted		Nationwide	Targeted		Targeted	Nationwide	Euro 6	1.2%
Germany					Nationwide	Nationwide		Nationwide	Targeted		Targeted	Nationwide	Euro 6	0.7%
India	Nationwide	Widespread	Widespread		Targeted							General fuel economy standard	Bharat 3	0.1%
Italy	Nationwide				Nationwide							Nationwide	Euro 6	0.1%
Japan	Nationwide	Nationwide			Widespread	Targeted	Nationwide					General fuel economy standard	JPN 2009	0.6%
The Netherlands		Nationwide			Nationwide			Nationwide			Targeted	Nationwide	Euro 6	9.7%
Norway		Nationwide	Nationwide			Nationwide	Targeted		Nationwide			Nationwide	Euro 6	23.3%
Portugal	Nationwide	Nationwide			Nationwide	Targeted	Targeted					Nationwide	Euro 6	0.7%
South Korea	Nationwide	Nationwide			Nationwide	Widespread	Nationwide					General fuel economy standard	Kor 3	0.2%
Spain	Nationwide	Nationwide			Targeted	Nationwide		Nationwide		Nationwide		Nationwide	Euro 6	0.2%
Sweden	Nationwide			Nationwide	Nationwide	Targeted		Nationwide				Nationwide	Euro 6	2.4%
UK	Nationwide	Nationwide			Nationwide	Targeted	Targeted	Nationwide	Targeted			Nationwide	Euro 6	1.0%
US	Targeted	Targeted		Nationwide	Targeted	Targeted	Targeted			Targeted		Nationwide	Tier 2	0.7%

Legend		
No Policy	Widespread Policy***	General fuel economy standard, indirectly favouring EV deployment
Targeted Policy**	Nationwide Policy	Pollutant emissions standard in place in 2015

*Such as environmental/low-emission zones.

**Policy implemented in certain geographical areas (e.g., specific states/regions/municipalities), affecting less than 50% of the country's inhabitants.

***Policy implemented in certain geographical areas (e.g., specific states/regions/municipalities), affecting more than 50% of the country's inhabitants.

Table 31: Incentivising EV uptake in cities

	Amsterdam	Paris	Barcelona	London	Oslo
Subsidy per EV (on purchase price)	EUR 5,000/10,000/40,000 for passenger car/taxi[1]/truck	EUR 4,000–7,000 premium (one-time grant)	25% (up to EUR 6,000) off	25% (up to GBP 5,000) off	Exempt from 25% VAT and purchase tax
EV benefits	- No waiting list for parking permits - Four parking garages with free charging - Exempt from registration tax and annual circulation tax	- Reduced toll and parking fees - For Autolib: free parking, exempt from road and registration tax, access to bus lanes	- Up to 75% road tax reduction - Free parking in regulated areas - Free charging at road-side stations, hotels and university (for e-bikes)	Exempt from congestion charge and road tax	- Exempt from all non-recurring vehicle fees, including road tax - No parking fees or toll payments - Access to bus and taxi lanes
EV car sharing service	Launched Car2Go in 2011; 300 vehicles (135 km range)	Launched Autolib in 2011; 2,000 vehicles (250 km urban range), e-scooter sharing service (2011)	Launched in 2013 with Madrid; 23 vehicles (200 km range), e-scooter sharing service (2013)	Launched E-Car Club in 2013 (145–200 km range)	Launched Move About in 2009

10. Appendix 2

BESCOM: Operational Information

Based on Section 6.2.3 (c) of [1][57], the following assumptions were considered for the analysis to evaluate the impact of charging an EV bus on the feeder:

1. ACSR Coyote conductor was considered as a reference for Overhead (OH) lines.
2. The thermal limit is specified in POM-code 3; the transmission system planning and security standard [1] are stated as 323 A (at an ambient temperature of 40ºC). The Mega Volt Ampere (MVA) rating of this conductor for an 11 kV feeder line is 6.14 MVA.
3. As an exercise, a Lumino "Coyote" conductor [2] was considered; the reference conductor temperature was chosen to be 75ºC for an ACSR conductor (as per definition of thermal limit in [1]). The reference current rating indicated is 367 A and the MVA rating of this conductor is 6.99 MVA. Similar exercise was conducted for underground cables.

As per stakeholder consultation with BESCOM experts, a typical 11 kV feeder cable is a three-core, 400 mm^2, aluminium or copper conductor. It is XLPE insulated, armoured and ground-mounted. A Havells 11/11 kV aluminium/copper conductor cable of similar configuration [3] was considered. The normal current rating specified was 400 A for the aluminium and 500 A for the copper conductor, and the corresponding power ratings work out to be 7.62 MVA and 9.53 MVA, respectively.

Considering the norms stated under section 3.19.C (Security standards) and 3.11 (Service area of distribution network) in the Karnataka Electricity Distribution Code [4][58], the normal available capacity of a feeder would be restricted to 60% of its capacity. In case of exigency, the available capacity could be raised to 75%. Some indicative ratings are illustrated in Table 32 below.

Table 32: Indicative ratings for conductors

Type	60% of MVA cap.	75% of MVA cap.	100 % of MVA cap.
OH line [1], [2]	3.7–4.2	4.62–5.24	6.15–7
UG cable – Al conductor [3]	4.6	5.72	7.62
UG cable – Cu conductor [3]	5.72	7.14	9.53

Factoring the power factor specification as per Section 2.1.12 (the definition of "connected load") and Section 4.11.2 (Voltage and power factor monitoring and control) in [4], the power factor for this analysis is considered as 0.9 lagging. This further reduces the available capacity of the feeder in MW, as shown in Table 33.

Table 33: Recalculated ratings of conductors

Type	60% of MVA cap. at 0.9 pf* (MW)	75% of MVA cap. at 0.9 pf (MW)
OH line [1], [2]	3.32–3.78	4.15–4.72
UG cable – Al conductor [3]	4.12	5.14
UG cable – Cu conductor [3]	5.14	6.43

**pf: power factor*

[57] Details in Notes: 1
[58] Details in Notes: 2

Since most 11 kV feeders in the BESCOM jurisdiction are underground (UG) cables, as indicated by BESCOM officials, the reference feeder rating considered here is an 11/11 kV, three-core, 400 mm^2, aluminium conductor, which is an XLPE insulated, armoured and ground-mounted cable with maximum available capacity of 4.12 MW.

References

[1] Karnataka Electricity Regulatory Commission (KERC), "Grid Code, Distribution Code, Standards for Transmission System and Distribution System." KERC, Bangalore, India.

[2] Lumino Industries Ltd, "Lumino ACSR conductor products," *Lumino Industries website*. [Online]. Available at http://www.luminoindustries.com/acsr.html. [Accessed: 31-Mar-2017].

[3] Havells India Ltd., "LT/HT Power & Control Cables," *Havells Website*, 2016. [Online]. Available at http://www.havells.com/content/dam/havells/brouchers/Industrial Cable/Cable Catalogue-2016.pdf. [Accessed: 31-Mar-2017].

[4] Karnataka Electricity Regulatory Commission (KERC), "Karnataka Electricity Distribution Code (KEDC)," Bangalore, 2015.

Notes

Under DPCOM-1, Section 6.2.3 (c) of [1],

> *The maximum length of LT lines shall not exceed 0.5 KM and that of 11 KV lines shall not exceed 20 KM and the total length of a HT line with spur lines shall not exceed 50 KM subject to voltage regulation limits. Irrespective of the size of the conductor used, the normal span between the supports shall be suitable for the highest size of conductor adopted in the Distribution System for the particular voltage. (At present "ACSR Rabbit" is the highest size of power conductor used on LT and HT Lines in rural areas. The highest size of power conductors used in urban areas is "ACSR Coyote" for HT Lines and "ACSR Rabbit" for LT Lines. Till such time any other higher size of conductor is introduced from techno-economic considerations, the maximum spans applicable for these conductors shall be adopted irrespective of the size of conductor used.)*

As per [4], under "Security standards", Section 3.19.C,

> *Loading in any current carrying component of the distribution system (e.g. conductors, joints, transformers, switchgear, cables and other apparatus) shall not exceed 75% of their respective thermal limit in case of radial feeding and 60% of their respective thermal limit in ring main feeding system.*

Also as per norms under "Service area of distribution network", Section 3.11,

> *11 kV feeders taken from a Sub-Station shall to the extent possible linked to another feeder extended from another Sub-Station to enhance reliability. Disconnecting switches (Group Operating Switches) shall be installed at appropriate locations to facilitate opening of the faulty sections and enable continuity of power supply to the maximum number of consumers in the healthy section. The sizes of conductors shall be so chosen to enable supply of electricity from either end of the feeder i.e., normally each line shall be loaded up to 60% of line capacity to facilitate changeover of the loads from either side in case of exigency.*
>
> *For UG cable power distribution system, the Ring Main concept of connecting the feeders between the same Sub-Station bus with separate switchgear or between two Sub-Stations, it is preferable to connect between two separate Sub-Stations to improve power supply reliability. The loads on any section of the U.G. cable shall be limited to 60% of its capacity by proper designing of the size of the UG cable to facilitate changeover of loads in case of exigencies.*

11. Appendix 3

EV Action Plan: California Case Study

The Governor of California, in 2012, issued an order directing certain government agencies to formulate benchmarks, which would result in 1.5 million Zero-Emission Vehicles (ZEVs) on California's roads by 2025. In-line with the objectives of the 2012 order, the Governor's Office has been publishing a ZEV action plan every year, since 2013. The 2016 ZEV Action Plan lists specific strategies and directives for achieving the goals and identifies the concerned state agencies who are charged with implementing these plans/strategies[59].

The 2016 ZEV action plan lists six broad objectives:

- Spreading mass consumer awareness of ZEV options and benefits
- Making ZEVs affordable and an appealing option for citizens
- Ensuring the provision of convenient charging and overall infrastructure for a large fleet of ZEVs
- Supporting and encouraging the growth of the ZEV market outside California
- Leading by example, integrating ZEVs into the State's government fleet
- Creating employment opportunities.

California is one of the most active markets for light-duty ZEVs. As of summer 2016, Californians drove 47% of all ZEVs in the US. Ownership of Plug-in Electric Vehicles (PEVs) in the state has exceeded 2.3 lakhs; as of mid-2016, 5 lakh such vehicles had been sold[14], and today, more than 20 PEV variants are available in California. Among these, the Nissan Leaf, Chevrolet Volt, Tesla Model S and Ford Fusion Energi were the highest selling variants in the US, in 2015. On the e-bus front, as of mid-2016, 61 pure e-buses delivered services to eight distinct transit regions[60].

In-line with its overall agenda of reducing GHG emissions, the State of California has also announced some proactive climate goals for 2030; these include 50% reduction in petroleum usage levels against 2015, and 40% reduction in GHG levels against 1990[61].

PEV Charging Network: Expansion Plan

The Government of California has made great strides in EV penetration by deploying numerous charging stations in the state. However, many more stations are needed in order to achieve the 2025 target of 1.5 million ZEVs on its roads. The decision to buy a ZEV relies heavily on the availability of adequate charging infrastructure. A wide network of charging stations is needed to address any concerns regarding usage feasibility for long ranges.

An analysis conducted in 2014, to estimate the overall charging station requirements, suggested a need for approximately 10 lakh charging points at homes, workplaces and public locations, by 2020[14]. Excluding home charging, there are approximately 11,000 charging points in California at present, supporting more than 2.3 lakh PEVs on the road[62].

[59] ARAI, "Policies & Implementation Status of EVs in India," http://www.jari.or.jp/Portals/0/resource/pdf/AAI%20Summit/H25/2.%20EV%20ARAI.pdf
[60] Ibid.
[61] Governor's Interagency Working Group on Zero-Emission Vehicles, "ZEV Action Plan, 2016"; https://www.gov.ca.gov/docs/2016_ZEV_Action_Plan.pdf
[62] ARAI, "Policies & Implementation Status of EVs in India," http://www.jari.or.jp/Portals/0/resource/pdf/AAI%20Summit/H25/2.%20EV%20ARAI.pdf

Plans to Bolster the ZEV Market Growth outside California

In 2013, California made a landmark announcement to sign a MoU with seven other US states, to initiate a multi-state ZEV Action Plan, to reach a target of 3.3 million ZEVs by 2025. California is also part of an International ZEV Alliance, a collaboration of leading jurisdictions, to accelerate the global deployment of ZEVs. The ZEV Alliance includes the Netherlands, Norway, the UK, Germany, British Columbia, Quebec, California and the seven states who are signatories of the Multi-State ZEV Action Plan.

In parallel, in the UN Climate Conference in December 2015, the ZEV Alliance members promoted the implementation of ZEVs and laid out a plan for a sizable representation of EVs by 2050.

Such dedicated action plans could be customised and adopted by each state in India, thus feeding into the national EV targets.

Electric Cars

Table 34 presents the stock of electric cars in a few countries, as of 2015, and EV sales targets for 2020[6]. Based on EV adoption missions, China seems to demonstrate the most ambitious outlook.

Table 34: Global electric car scenario - existing and planned fleet volume commitments

Countries with Targets Announced for 2020 or Later	2015 EV Stock (Thousand Vehicles)	2020 EV Target (Million Vehicles)
Austria	5.3	0.2
China*	312.3	4.6
Denmark	8.1	0.2
France	54.3	2
Germany	49.2	1
India	6	0.3
Ireland	2	0.1
Japan	126.4	1
The Netherlands	87.5	0.3
Portugal	2.0	0.2
South Korea	4.3	0.2
Spain	6	0.2
United Kingdom	49.7	1.6
United States of America**	101	1.2
Total of all markets listed above	814.1	12.9

Source: IEA, 2016

* Represents a vision of deploying 4.3 million cars and 0.3 million taxis. This planned fleet introduction is being carried out as part of an overall deployment target by 2020[7].
**Estimate represents the fleet as of 2015. This estimate is part of the overall target of achieving 3.3 million EVs in eight US states by 2025. The estimate in this table is representative of eight US states. The share of these eight states are assumed to account for 25% of the total US car market and fleet.

The adoption of electric cars quickened towards the end of the last decade and it has been increasing gradually since then. Table 35 shows the increase in the uptake of electric cars in all major markets. New registration of electric cars (including fully electric and plug-in hybrids) increased by 70% from 2014 to 2015. More than 550,000 vehicles were sold worldwide in 2015[7]. The US surpassed China's sales, with over 2 lakh new registrations, in 2015. Though the US closed the gap with China on the whole, the latter continued to hold the higher global market share of EVs at 1%, as compared to US' share of 0.7%.

In the overall global sales for 2015, 90% of car sales took place in eight key markets: China, US, the Netherlands, Norway, the UK, Japan, Germany and France. Sales of electric cars more than doubled in the Netherlands in 2015 and took the overall market share of electric cars close to 10%, the second highest in the EU, only after Norway (23%) [7].

The year-on-year sales of electric cars grew by almost 75% in France, Germany, Korea, Norway, Sweden, the UK and India, in 2015[7].

Table 35: Global all-electric and plug-in hybrid car market share from 2005 to 2015

Country	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Canada							0.0%	0.1%	0.2%	0.3%	0.4%
China						0.0%	0.0%	0.1%	0.1%	0.4%	1.0%
France							0.1%	0.3%	0.55	0.7%	1.2%
Germany							0.1%	0.1%	0.2%	0.4%	1.2%
India						0.0%	0.0%	0.1%	0.0%	0.0%	0.7%
Italy								0.0%	0.1%	0.1%	0.1%
Japan					0.0%	0.1%	0.4%	0.5%	0.6%	0.7%	0.6%
Korea							0.0%	0.1%	0.1%	0.1%	0.2%
The Netherlands						0.0%	0.2%	1.0%	2.5%	3.9%	9.7%
Norway				0.2%	0.1%	0.3%	1.5%	3.2%	5.8%	13.7%	23.3%
Portugal							0.1%	0.1%	0.2%	0.25	0.7%
South Africa											0.1%
Spain							0.1%	0.1%	0.1%	0.2%	0.2%
Sweden							0.1%	0.3%	0.5%	1.4%	2.4%
UK							0.1%	0.1%	0.2%	0.6%	1.0%
US						0.0%	0.1%	0.4%	0.6%	0.7%	0.7%
Others*							0.0%	0.1%	0.1%	0.3%	0.7%
World**				0.0%	0.0%	0.0%	0.1%	0.2%	0.3%	0.5%	0.9%

*Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Iceland, Ireland, Latvia, Liechtenstein, Lithuania, Luxemburg, Malta, Poland, Romania, Slovak Republic, Slovenia, Switzerland, Turkey.
**Total: represents the share of EVs in the overall passenger car segment.

Ningbo Case Study

China is well known for setting up one of the fastest charging stations in the world. The world's fastest charging public e-bus is currently being operated in Ningbo[63]. According to concerned authorities, this bus, which takes as few as 10 seconds to be fully charged, operates along a route containing 24 stops, spanning 11 km. This 10-second charge however allows the bus to run for only a short distance of 5 km[26]. While this short-interval charging practice may only deliver enough power for short distances, the prospect of shrinking the idle charging time seems attractive. Public transport vehicles generally run along fixed routes, which means that a bus can charge whenever it is stationary for short periods at designated bus stops.

[63] EV Obsession, "Chinese Electric Bus Charges in 10 Seconds, Fastest in World," https://evobsession.com/chinese-electric-bus-charges-in-10-seconds-fastest-in-world/

In addition to its capacity to charge rapidly, the bus is also equipped with a mechanism to use its energy more efficiently during its operations. While braking, the bus has the ability to harness over 80% of its potential energy. This allows the bus to reduce its energy consumption by around 30–50% as compared to conventional buses.

The e-bus operated in Ningbo uses a super-capacitor technology. The super-capacitor is made of special carbon material, which functions well in the temperature range of -40°C to 60°C. These super-capacitors are also extremely durable and capable of charging and discharging a million times[64]. This gives the e-bus the ability to operate for up to 12 years.

Using only one-tenth of the energy of a standard diesel bus, this bus helps to add fuel savings worth USD 200,000 over its entire lifetime. Ningbo now plans to add 1,200 more such buses to its public transportation fleet by 2018.

Foreseen Challenges in Battery Swapping: Case Study - Aleees

Aleees is the leading brand of e-buses in Taiwan and the developer of the world's first parallel power module and swapping system. They have entered into a collaboration with Japan's SONY to manufacture LIBs and Germany's Siemens to manufacture e-buses.

Aleees' Operation Model

The battery module is swapped to save charging time. This also eliminates the requirement of premium real estate for charging stations for large electric cars.

Unlike other commercially available e-buses, which require a charging time of more than 8 hours, Aleees' battery "exchange-type" e-buses can switch their batteries in 6–10 minutes. As this is the same time taken to completely refuel a diesel bus, the swapping mechanism seems feasible. Owing to the heavy batteries handled at the stations, the swapping is done by a mechanised structure with robotic arms, with no manual intervention involved.

[64] EV Obsession, "Chinese Electric Bus Charges in 10 Seconds, Fastest in World," https://evobsession.com/chinese-electric-bus-charges-in-10-seconds-fastest-in-world/

12. Appendix 4

The following datasets have been collected and used in the preparation of this report:

1. Administrative boundaries (Bangalore city, BESCOM's areas of operation)

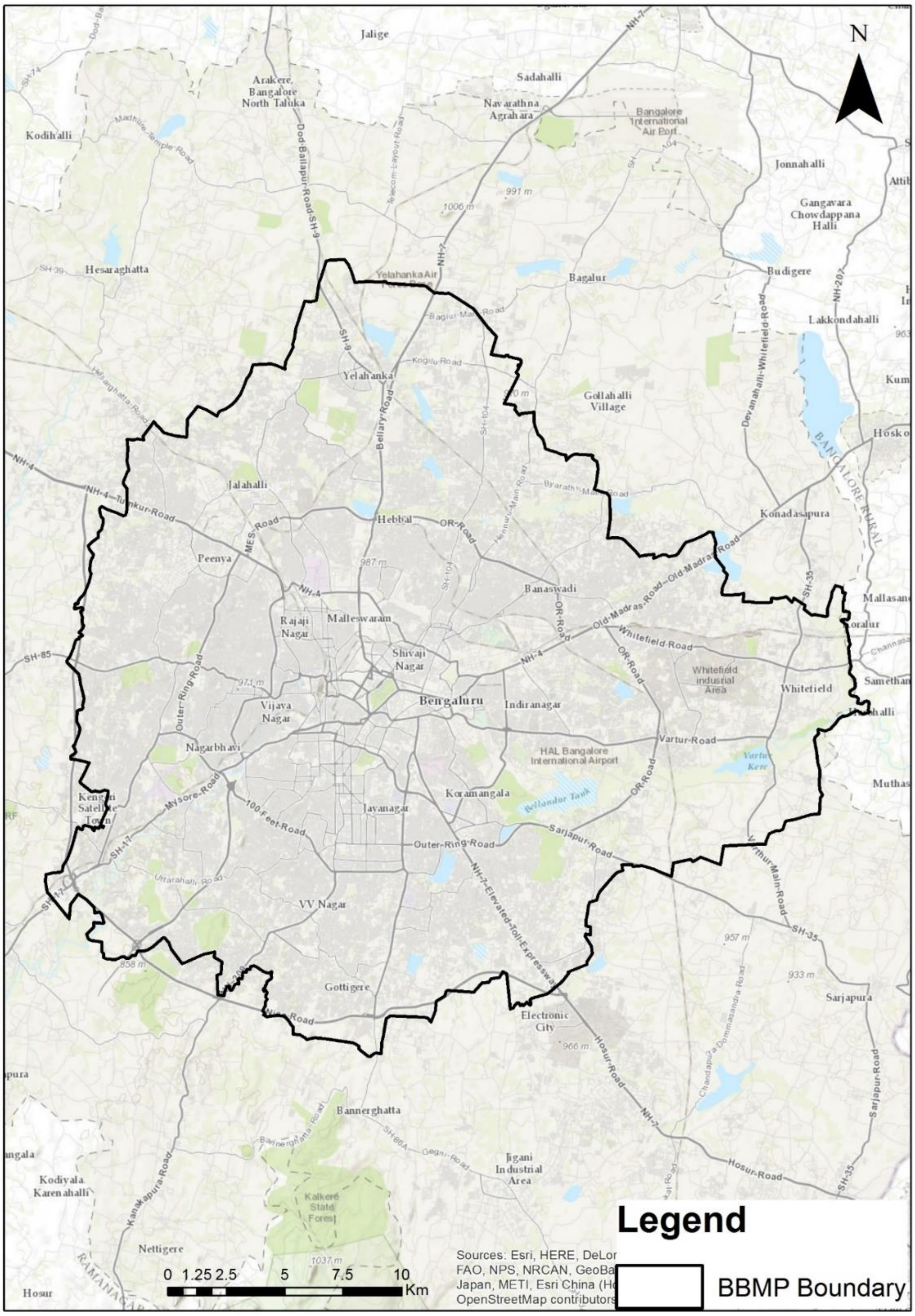

Figure 27: Bengaluru city and surrounding areas

Source: BBMP

Figure 27 shows the Bengaluru metropolitan area along with the administrative boundaries of the local municipality, namely, Bruhat Bengaluru Mahanagara Palike (BBMP).

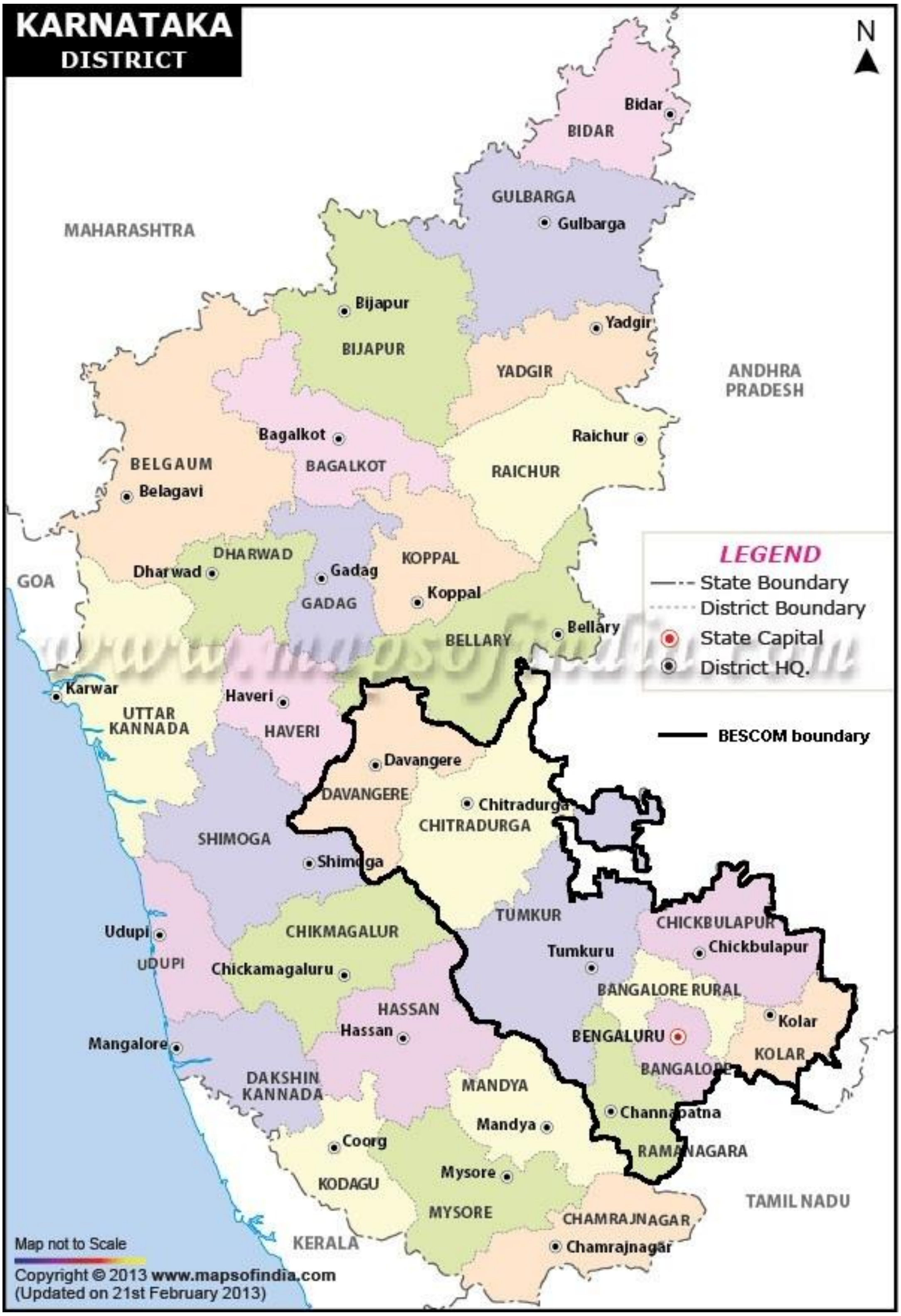

Figure 28: BESCOM areas of operation

Source: BESCOM

Figure 28 is the Karnataka state map showing all districts, along with the administrative boundaries of BESCOM.

2. BMTC's routes and schedules

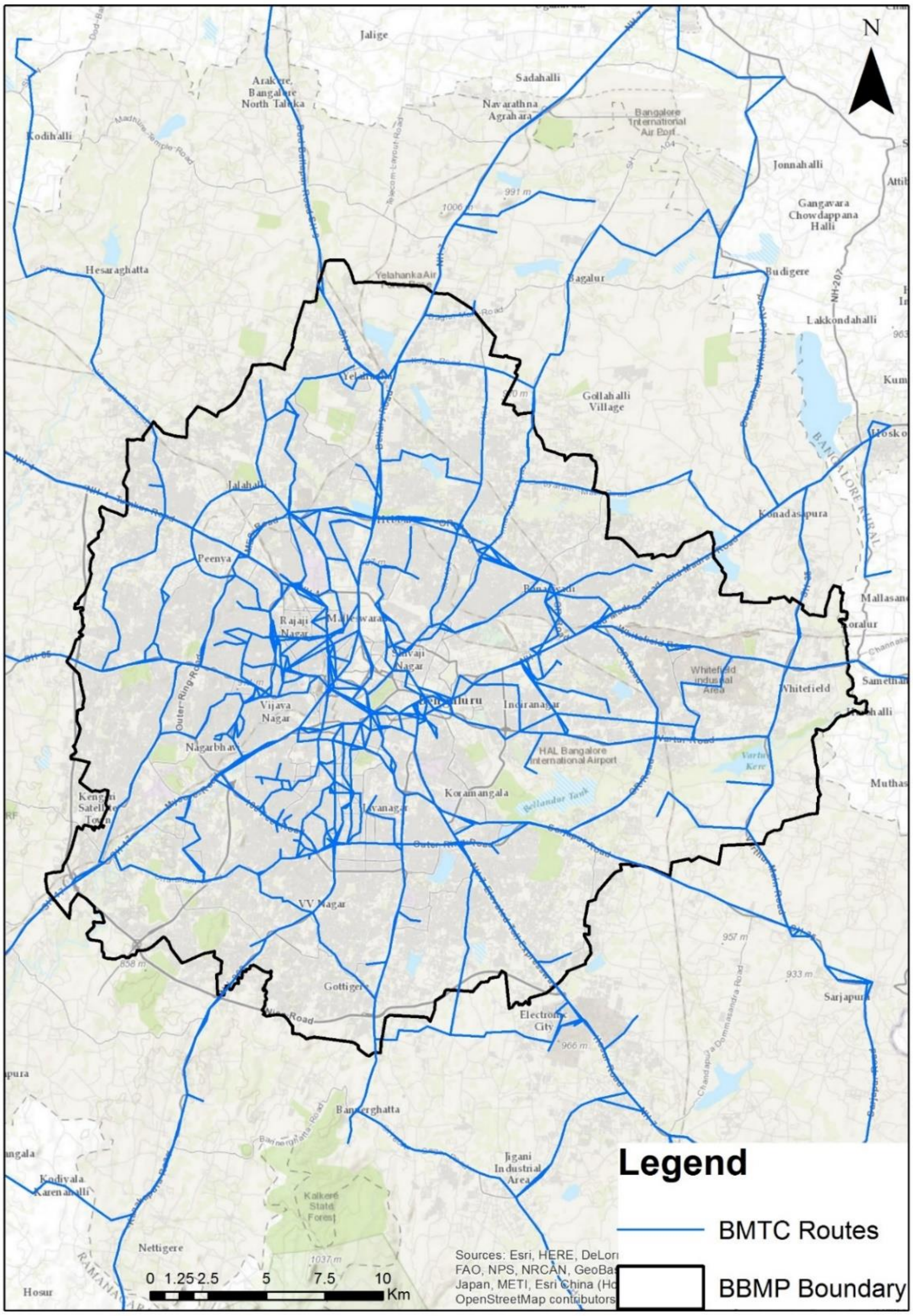

Figure 29: Select BMTC route map

Source: BMTC

Figure 29 shows select BMTC bus routes, including a mix of airport routes, AC routes, Metro-feeder routes and Ordinary routes.

CENTRAL OFFICE:SHANTHINAGAR : BANGALORE-27

SERVICE	**A/C VAYU**	**FORM-IV**	**DIVISION:CENTRAL**
BRAND	**VAJRA**	**KEMPEGOWDA INTERNATIONAL AIRPORT**	**DEPOT-25**
ROUTE	**KIAS-7A**	**HSR BDA COMPLEX**	**NIGHT OUT**
SCHEDULE	**KIAS-7A/4**	**VAYU VAJRA SERVICE**	**W.E.F: 01.11.2013**

TRIP NO.	**PLACE ORIGIN**	**DEST.**	**ROUTE LENGTH**	**TIMINGS FROM**	**TO**	**JOURNEY TIME**	**REMARKS**
1	HSRB	KIAL	50.0	07:40	09:40	2:00	
2	KIAL	HSRB	50.0	09:45	11:45	2:00	
3	HSRB	BMT-25	1.0	11:50	11:55	0:05	
			101.0				
CREW CHANGE, FUELLING & MAINTENANCE AT DEPOT							
4	BMT-25	HSRB	1.0	15:45	15:50	0:05	
5	HSRB	KIAL	50.0	15:50	**17:45**	1:55	
6	KIAL	HSRB	50.0	**18:00**	19:55	1:55	
7	HSRB	KIAL	50.0	20:20	22:15	1:55	
8	KIAL	HSRB	50.0	22:25	24:10	1:45	
			201.0				

VEHICLE UTILISATION			**CREW DUTY HOURS**			**REST FOR CREW**
SCH.KM.	101.0	201.0	SPREAD	415	840	1745-1800
DEAD KM.	1	1	STEERING	415	800	1955-2020
TOTAL KMS.	**300.0**					

KIAL:KEMPEGOWDA INTERNATIONAL AIRPORT

FARE STRUCTURE

SL No.	**BUS STOPS**	**TO**	**VAJRA FARE (IN RS)**
1	Jakkasandra, Koramangala, Sony World signal, 80FT road, Dell, Domalur	**KIAL**	**220.00**
2	M.G. Road, BRV, Shivajinagar Bus Station Indian Express, Chalukya Hotel, Windsor Manner RM Guttahalli	**KIAL**	**210.00**
3	Mekhri Circle Veterinary Collage	**KIAL**	**190.00**
4	Hebbala, Esteem Mall	**KIAL**	**170.00**

Figure 30: Sample BMTC schedule (Form 4)
Source: BMTC

Figure 30 shows a sample BMTC schedule document for a particular bus (also called Form 4). It includes all the details necessary to understand the operation of a particular bus (KIAS-7A/4) on a particular route (KIAS-7A), its route category/type (A/C Vayu Vajra), etc. The form also highlights the origin, destination, depot, timings, halts/stops, ticket tariffs and division for this bus.

3. Locations of BMTC's depots and bus stands

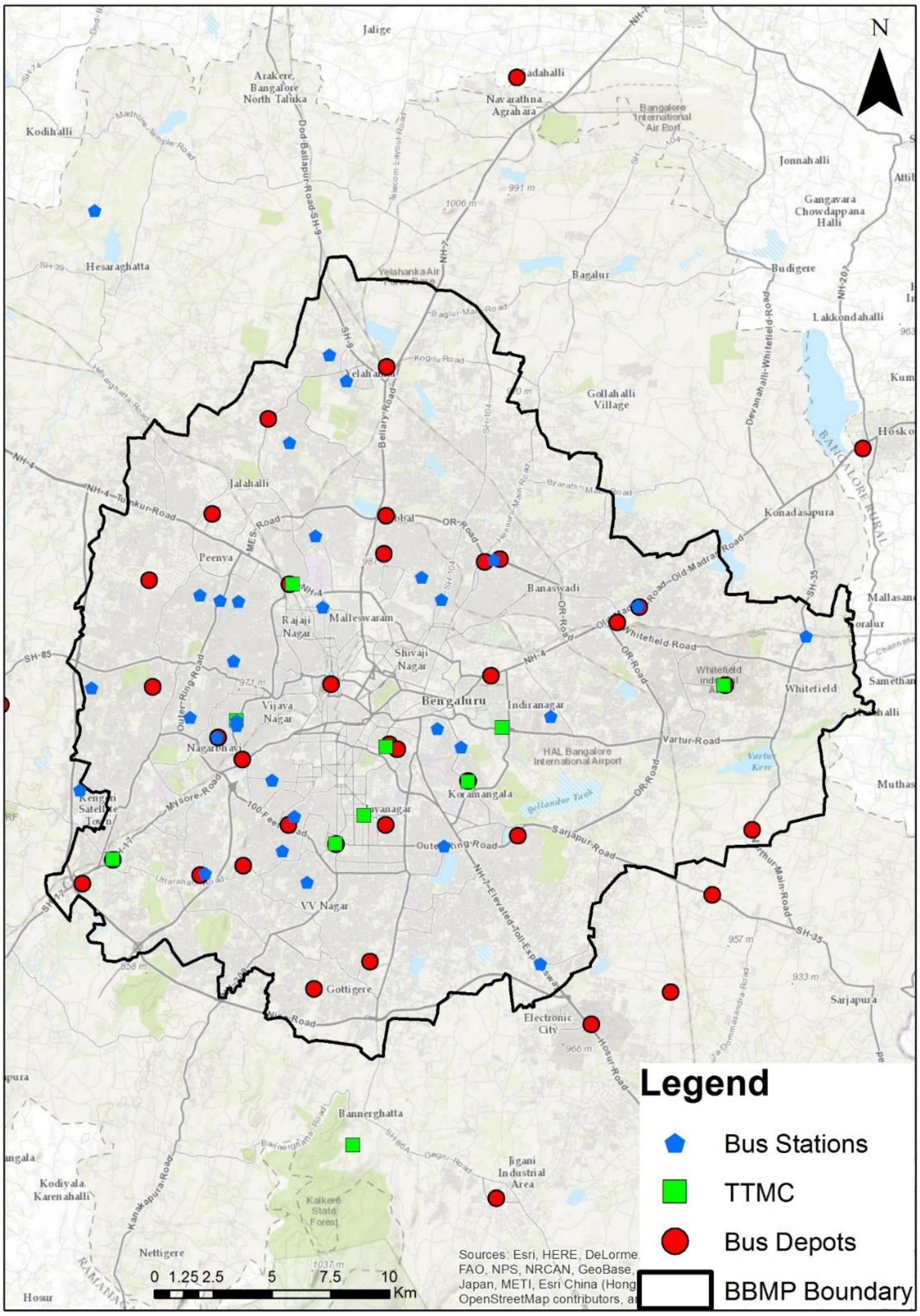

Figure 31: Key BMTC locations

Figure 31 shows key BMTC locations in and around the Bengaluru metropolitan areas (including a mix of depots, bus stations and Traffic Transit Management Centres).

4. BMTC passenger density and revenue for routes, over select intervals

route_no	schedule_no	origin	dest	service_type_name	shift_type_name	route_lenth	no_bus_stop	no_buses	start_time	end_time	trip_no	occupancy	Revenue
10-JDN	10J/1	Avalahalli BDA Park Girinagara	Kempegowda Bus Station	Ordinary	Day 1	7.857	18	1	20:10:00	20:45:00	10	31	335
10-JDN	10J/1	Avalahalli BDA Park Girinagara	Kempegowda Bus Station	Ordinary	Day 1	7.857	18	1	16:10:00	16:45:00	4	77	890
10-JDN	10J/1	Avalahalli BDA Park Girinagara	Kempegowda Bus Station	Ordinary	Day 1	7.857	18	1	17:30:00	18:05:00	6	101	1291
10-JDN	10J/1	Avalahalli BDA Park Girinagara	Kempegowda Bus Station	Ordinary	Day 1	7.857	18	1	18:50:00	19:25:00	8	107	1257
10-JDN	10J/1	Avalahalli BDA Park Girinagara	Kempegowda Bus Station	Ordinary	Day 2	7.857	18	1	11:45:00	12:20:00	10	209	2621
10-JDN	10J/1	Avalahalli BDA Park Girinagara	Kempegowda Bus Station	Ordinary	Day 2	7.857	18	1	06:00:00	06:35:00	2	31	433
10-JDN	10J/1	Avalahalli BDA Park Girinagara	Kempegowda Bus Station	Ordinary	Day 2	7.857	18	1	07:20:00	07:55:00	4	102	1331
10-JDN	10J/1	Avalahalli BDA Park Girinagara	Kempegowda Bus Station	Ordinary	Day 2	7.857	18	1	08:40:00	09:15:00	6	164	1917
10-JDN	10J/1	Avalahalli BDA Park Girinagara	Kempegowda Bus Station	Ordinary	Day 2	7.857	18	1	10:25:00	11:00:00	8	152	1851
10-JDN	10J/2	Avalahalli BDA Park Girinagara	Kempegowda Bus Station	Ordinary	General Shift	7.857	18	1	13:30:00	14:05:00	10	215	2776
10-JDN	10J/2	Avalahalli BDA Park Girinagara	Kempegowda Bus Station	Ordinary	General Shift	7.857	18	1	14:50:00	15:25:00	12	119	1553
10-JDN	10J/2	Avalahalli BDA Park Girinagara	Kempegowda Bus Station	Ordinary	General Shift	7.857	18	1	16:35:00	17:10:00	14	113	1460
10-JDN	10J/2	Avalahalli BDA Park Girinagara	Kempegowda Bus Station	Ordinary	General Shift	7.857	18	1	17:55:00	18:30:00	16	135	1745
10-JDN	10J/2	Avalahalli BDA Park Girinagara	Kempegowda Bus Station	Ordinary	General Shift	7.857	18	1	09:05:00	09:40:00	4	219	2441
10-JDN	10J/2	Avalahalli BDA Park Girinagara	Kempegowda Bus Station	Ordinary	General Shift	7.857	18	1	10:50:00	11:25:00	6	175	2100
10-JDN	10J/2	Avalahalli BDA Park Girinagara	Kempegowda Bus Station	Ordinary	General Shift	7.857	18	1	12:10:00	12:45:00	8	173	2237
10-JDN	36A/1	Avalahalli BDA Park Girinagara	Kempegowda Bus Station	Ordinary	Day 1	7.857	18	1	20:50:00	21:25:00	10	64	791
10-JUP	10J/1	Kempegowda Bus Station	Avalahalli BDA Park Girinagara	Ordinary	Day 1	6.839	18	1	20:50:00	21:25:00	11	53	680
10-JUP	10J/1	Kempegowda Bus Station	Avalahalli BDA Park Girinagara	Ordinary	Day 1	6.839	18	1	15:05:00	15:40:00	3	74	983
10-JUP	10J/1	Kempegowda Bus Station	Avalahalli BDA Park Girinagara	Ordinary	Day 1	6.839	18	1	16:50:00	17:25:00	5	98	1153
10-JUP	10J/1	Kempegowda Bus Station	Avalahalli BDA Park Girinagara	Ordinary	Day 1	6.839	18	1	18:10:00	18:45:00	7	208	2478
10-JUP	10J/1	Kempegowda Bus Station	Avalahalli BDA Park Girinagara	Ordinary	Day 1	6.839	18	1	19:30:00	20:05:00	9	111	1428
10-JUP	10J/1	Kempegowda Bus Station	Avalahalli BDA Park Girinagara	Ordinary	Day 2	6.839	18	1	06:40:00	07:15:00	3	44	669
10-JUP	10J/1	Kempegowda Bus Station	Avalahalli BDA Park Girinagara	Ordinary	Day 2	6.839	18	1	08:00:00	08:35:00	5	42	490
10-JUP	10J/1	Kempegowda Bus Station	Avalahalli BDA Park Girinagara	Ordinary	Day 2	6.839	18	1	09:20:00	09:55:00	7	75	933
10-JUP	10J/1	Kempegowda Bus Station	Avalahalli BDA Park Girinagara	Ordinary	Day 2	6.839	18	1	11:05:00	11:40:00	9	58	717
10-JUP	10J/2	Kempegowda Bus Station	Avalahalli BDA Park Girinagara	Ordinary	General Shift	6.839	18	1	14:10:00	14:45:00	11	120	1538
10-JUP	10J/2	Kempegowda Bus Station	Avalahalli BDA Park Girinagara	Ordinary	General Shift	6.839	18	1	15:30:00	16:05:00	13	67	891

Figure 32: Sample BMTC operation data (weekly)

Source: BMTC

Figure 32 shows a sample of BMTC's operational data for a week. Performance of specific buses, on particular routes (including parameters such as occupancy and revenue), can be determined from this data.

5. Location of BESCOM's distribution transformers

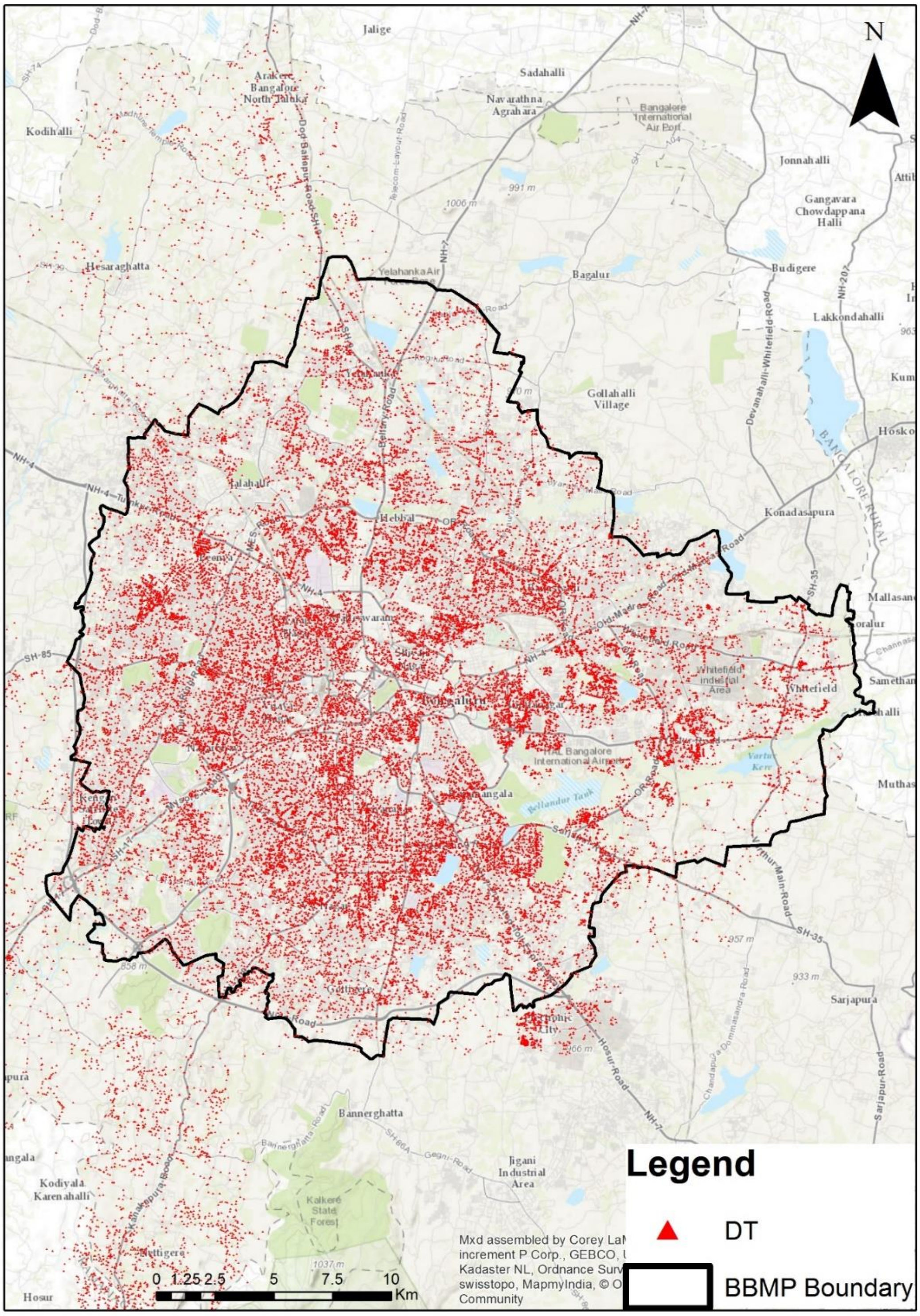

Figure 33: Locations of BESCOM's distribution transformers
Source: BESCOM

Figure 33 shows BESCOM's distribution transformers in and around Bengaluru.

6. BESCOM feeder load data for 24 hours

Data for BESCOM feeders in the Bangalore Metropolitan Area Zone (BMAZ) were collected as described below.

The feeder data was collected for that specific time of the year when the feeder is the most loaded. For each feeder, the highest load value experienced during every hourly interval (0-24) in the peak month (April) of the year (2016) was recorded and used for the analysis. The table below gives the categories and total number of feeders that were available for analysis.

Feeder Category	Total No. of Feeders
Commercial	179
Industrial	247
Domestic	189
Residential-mixed	345

Sample loading data in each category of feeder mentioned above are provided in Figures 34 through 36.

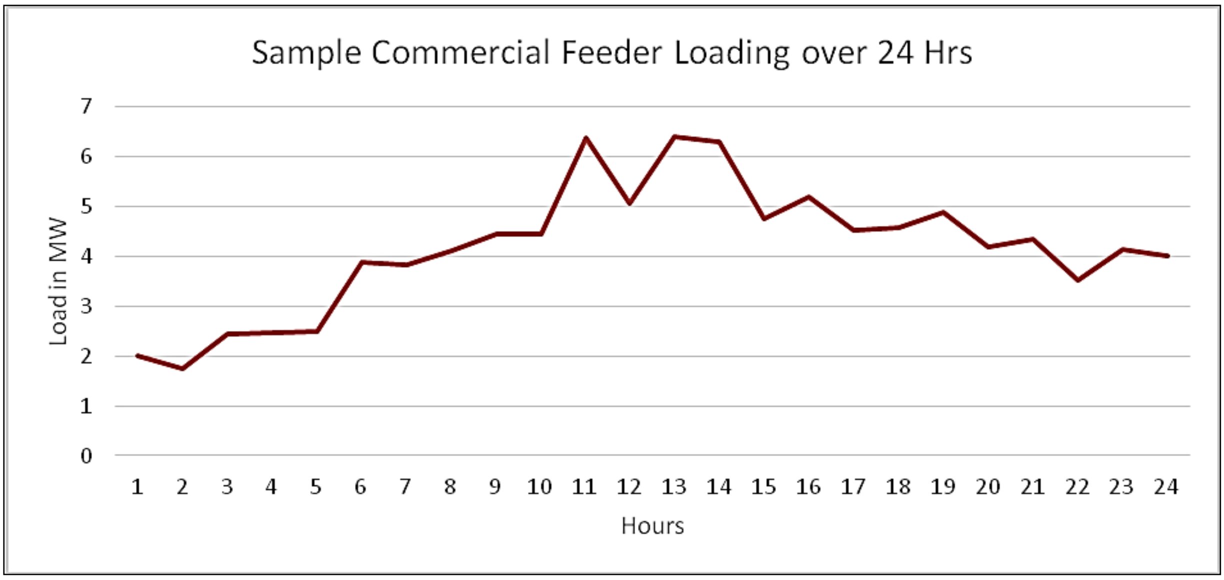

Figure 34: Electrical loading of a commercial feeder (24 hours)

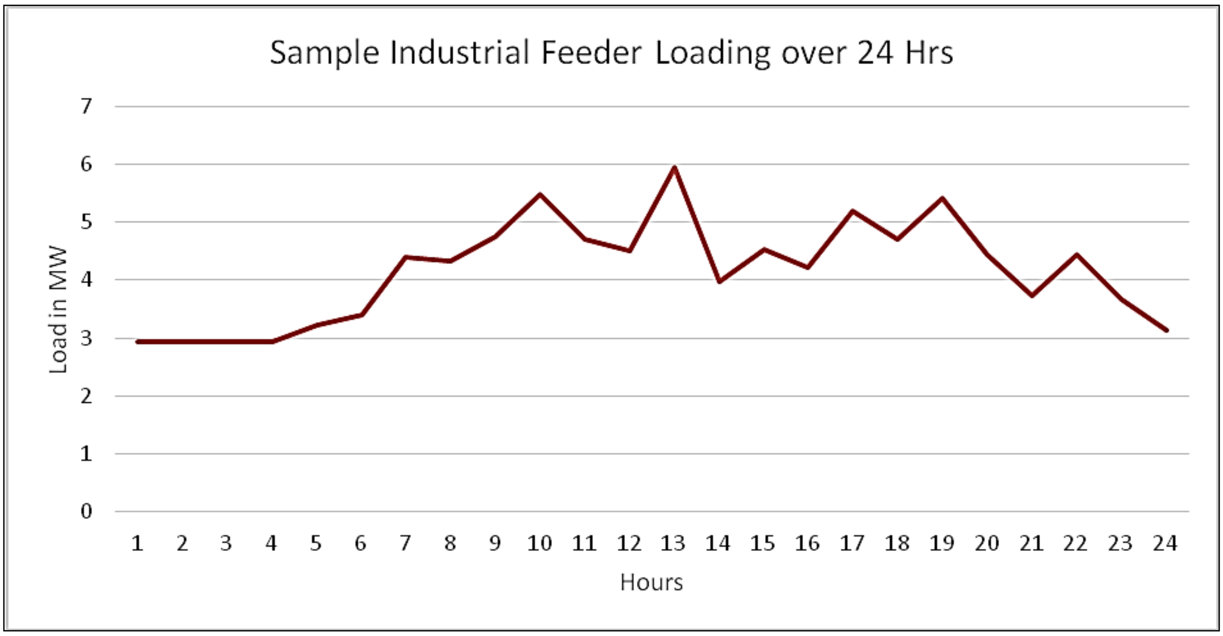

Figure 35: Electrical loading of an industrial feeder (24 hours)

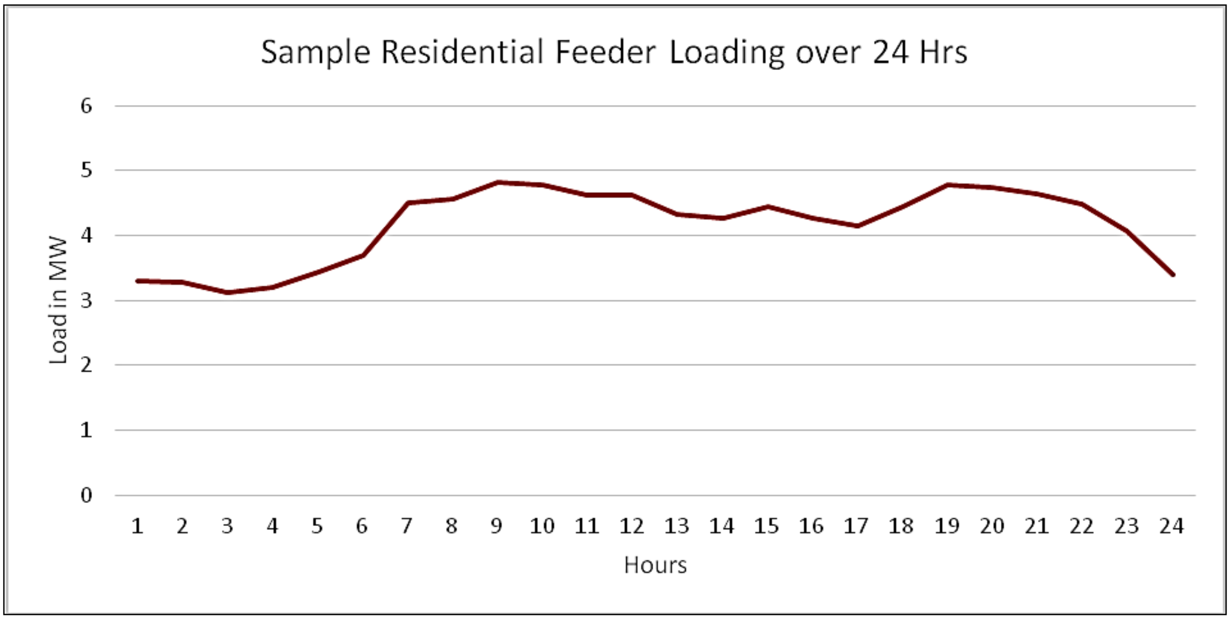

Figure 36: Electrical loading of a residential feeder (24 hours)

13. Appendix 5

Table 36: City-wise initiatives

No.	State/City /National	Type: CNG/ Hybrid/ Electric	Fleet Size	Organisation	Implementation Status	Description	Source
1.	Delhi	CNG	DTC: 5,000 DIMTS: 1,157 Metro feeder: 117 Total: 6,274	DTC, DIMTS	Implemented on 1 April 2001 till date	Operational cost per km: INR 18	(M. Goyal & Bezbaruah, n.d.) (Mehta, 2004)
2.	Bengaluru	BYD full electric	Single bus	BMTC	Trial run for three months	Cost: INR 2.7 Cr Min. fare: INR 10 Route: Kempegowda bus stand–Kadugodi Average daily run: 170 km Daily electricity consumption: 269.84 kWh Trips per day: 6	(Sharma, 2014), ("Country's First Electric Bus Launched in Bangalore", 2014), (Basu, 2016) (Adheesh, Vasistha, & Ramasesha, 2016)
2.	Delhi	BYD full electric	Single bus		6 months trial run from 11 March 2016	Cost: INR 2.7 Cr Min. fare: INR 10 Route: Delhi secretariat–central Secretariat Per km electricity cost: INR 10.66 Operational cost: INR 17.54 Trips/day: 22	("Capital gets its 1st electric bus for DTC trial", 2016)
3.	Mumbai	Tata Starbus: Low-floor Diesel Hybrid Bus	25	MMRDA	Full-fledged operation from 2017	Route: BKC–Sion/Bandra/Kurla railway stations 5 years maintenance from Tata	(Tata motors, 2016) (MMRDA, 2016)
4	Navi Mumbai	Volvo Hybrid bus	5	NMMT	Manufacturing starts mid 2016	Buses to be manufactured in Bengaluru and transported to Navi Mumbai	(Singh, 2015)
5	Ludhiana	Electric bus	10	LSCL	Proposal in progress	70-75% additional subsidy over the Smart City fund for e-buses	("Proposal to run electric buses", 2016)

Table 37: Specifications of bus variants considered in the study

Parameters	Units	Diesel Bus	AC Diesel (Volvo 8400)	Hybrid Bus (Tata Series Diesel Hybrid)	Electric Bus (BYD K-9)
Source		BMTC	BMTC	MMRDA, Tata Motors	BMTC
Length	metres	12.00	12.00	12.00	12.26
Width	metres	2.55	2.54		2.55
Height	metres	3.00	3.30		3.48
Seating capacity	Nos.	42+1	38+3+1		41+1
Top speed	km/hr	Restricted at 60		60	90 with 90 A motor
Turning radius	metres	11.83	10.25	10.50	12.78
Ground clearance	mm				265
Fuel efficiency	km/litre km/kWh	4.71	2.21	2.873	0.62
Battery range	km				250
Battery type		NA	NA	NA	Lithium iron phosphate battery
Battery capacity	kWh/Ah	NA	NA	NA	324

Table 38: Input data

Parameters	Units	Diesel Bus	AC Volvo Diesel	Hybrid Bus	Electric Bus
Purchase price	INR	27,04,500	80,00,000	1,67,00,000	2,86,53,750
Taxes					
Total taxes	INR	9,92,675	17,52,113	31,90,114	72,67,225
Capital cost	INR	36,97,175	97,52,205	2,00,26,328	3,59,20,975
Funding Structure					
Share of funding in capital cost	%	0.00	0.00	14.98	18.37
Purchase obligation	INR	36,97,175	97,52,205	1,70,26,328	2,93,20,975
Loan share	%	75	75	75	75
Operator share	%	25	25	25	25
Rate of interest per year	Years	10.50	10.50	10.50	10.50
Loan tenure	INR	7	7	7	7
Weighted Average Capital Cost (WACC)	%	12.88	12.88	12.88	12.88
Operational Cost					
Average kilometres per day	km	195	195	195	195
Operational days in a year	Days	300	300	300	300
Operational years	Years	10	10	10	10
Lifetime kilometres	km	5,85,000	5,85,000	5,85,000	5,85,000
Staff Cost					
Employee cost per vehicle km	INR	26.06	27.67	27.67	27.67
Energy Cost					
Annual diesel consumption	Litres	13,295	26,471	20,362	-
Annual electricity consumption	kWh				94,355
Annual energy cost	INR	7,97,727	15,88,235	12,21,719	7,87,863

Maintenance Cost					
Maintenance cost per km	INR	3.90	17.86	11.28	9.34
Engine life	Years	10	5	10	NA
No. of engine replacement	No	0	1	0	NA
Engine replacement cost each time	INR	0	20,00,000	0	NA
Battery life	Years	NA	NA	NA	5
No. of battery replacements	No	NA	NA	NA	1
Battery replacement cost each time	INR	NA	NA	NA	1,16,64,000
Supporting Infrastructure Cost					
Charging stations	No	0	0	0	0
Fuelling infrastructure	INR	0	0	0	0
Revenue					
Earning per Kilometre (EPKM)	INR	35	66.51	66.51	66.51
Average daily traffic revenue	INR	6,825	12,969	12,969	12,969
Annual traffic revenue	INR	20,47,500	38,90,835	38,90,835	38,90,835
Benefits over AC diesel bus					
Social and Environmental Benefits					
Noise levels	dB	73.56	73.56	64.89	50.79
Annual carbon emissions	Tonnes	39.33	71.19	54.76	22.86
Noise-related health cost benefit	INR/km	0.00	-	6.50	11.64
Damage cost of carbon benefit	INR/km	1.18	-	0.61	2.64
Fuel consumption benefit	Litres	1,03,269	-	53,254	-
Economic Benefits			-		
Fuel cost saving	INR/km	10.12	-	5.22	9.16

Assumptions			
Social and environmental damage			
Pollutant		**Damage Cost**	
GHG CO_{2equi} (Funk & Rabl, 1999)	Euro/kg	0.029	
Bus noise levels (Global Green Growth Institute, 2015)	dB	**Electric bus**	**Diesel bus**
		60	70
Cost of noise from road traffic per person per year (SEK_{2014}) (Bangman, 2016)		**Level of noise (dB)**	**Total cost SEK per person per year (2014)**
		60	11,439
		70	41,845
Noise-related health cost per household (*Kapitel 20 English summary of ASEK Guidelines,* 2016)	INR	**Level of noise (dB)**	**Total cost per household (INR)**
		50	256
		65	3,490
		75	7,808
Salvage value (Pihlatie et al., 2014)		Zero for both vehicle and battery	

To carry out the CBA of e-buses and hybrid buses versus diesel buses, the following data was obtained (Table 39).

Table 39: Data from the manufacturers of all three types of buses

Data Required	From Manufacturer	From Operator	From Market
Total manufacturing cost			
Major components of manufacturing cost			
Potential cost cutting component			
AMC and contract period			
Infrastructure requirement and cost			
Vehicle specifications			
Battery specifications			
Battery range	(Expected)	(Actual)	
Battery replacement cost and interval			
Fuel efficiency	(Expected)	(Actual)	
Emissions			
Purchase price			
Financial model for procurement and operation			
Taxes for operation			
Taxes exempted			
Subsidy on oil and electricity tariff			
Total staff cost per km (all variants)			
Staff training cost			
Funding and incentives (type and share)			
Operating cost per km and major components			
Average daily km run per bus			

14. Appendix 6

The EV online framework is a web application hosted on CSTEP's DARPAN (Decision Analysis for Research and Planning) platform. It has been developed using open-source software components and public datasets, as much as possible.

System Architecture

The standard Model–View–Controller (MVC) architecture used in the development of the application is shown in Figure 37.

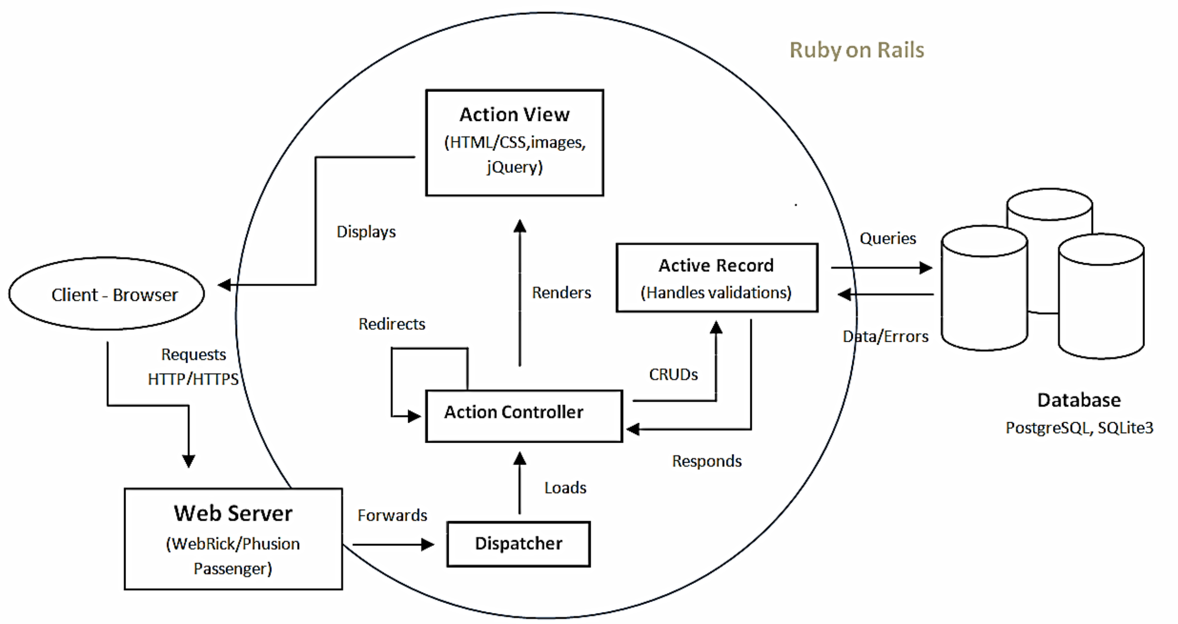

Figure 37: General system architecture

Development of Models and Tools

MVC is an object-oriented design pattern, which attempts to divide an application into three components, namely, the Model, View and Controller. The three components are described below.

- Model: Model contains the application's business logic, represents the information (data) of the application and the rules to manipulate the data.
- View: The user interface is represented by the View. In a web-based application, the View is implemented as a template, which renders an HTML page.
- Controller: The communication between the model and the view occurs via the Controller. Incoming requests from the web browser are associated with Controller actions, which interact with the Model for data and pass them on to the View for presentation.

Ruby on Rails

Ruby on Rails is a web application framework for developing "database-driven" web applications. It uses the "Convention over Configuration" concept, which is well-suited for "agile" development. Ruby on Rails was chosen over other frameworks because, unlike other frameworks, it:

- Is open-source
- Is suited for building new code bases from scratch
- Has a quick turnaround time between development and testing
- Works well for iterative projects, especially when developing early prototypes.

AngularJS and HighCharts.js

HighCharts.js has been used to develop the front-end of the tool. It is a fast and lightweight JavaScript library, which aids in rapid web development. The main advantages of using HighCharts.js are:

- Ease of use
- A large code library powered by a strong open-source community
- Ajax support
- Comprehensive documentation.

AngularJS is a structural framework for dynamic web apps. It allows HTML as the template language and extends HTML's syntax to clearly and succinctly express the components of an application. AngularJS's data binding and dependency injection eliminate much of the code and work within web browsers, making it an ideal partner with any server technology. It handles the Document Object Model (DOM) and AJAX code.

Further, AngularJS attempts to minimise the impedance mismatch between document-centric HTML and what an application needs by creating new HTML constructs. The primary features of AngularJS include:

- Two-way data binding
- DOM control structures for repeating, showing and hiding DOM fragments
- Support for forms and form validation
- Attaching new behaviour to DOM elements, such as DOM event handling
- Grouping of HTML into reusable components.

Database

The tool was developed and tested using PostgreSQL as the back-end. The project went through multiple iterations with the Extreme Programming (XP) methodology.

Datasets

The datasets used to develop the application are listed below:

- Land Use–Land Cover (source: National Remote Sensing Centre, India)
- Slope and elevation of land (source: USGS EarthExplorer)
- Solar insolation via India annual average GHI and DNI (source: NREL)
- Wind power density and wind speed (source: NREL; data extrapolated to 80, 100, 120 m hub heights)
- Road network (source: Divagis)

- Protected areas (source: UNEP Protected Planet database)
- Electric substations (source: Power Grid Corporation of India Ltd).

Development of Web Application

The process for developing the application was as follows:

- A database was created in PostgreSQL
- The database was spatially enabled by installing the PostGIS spatial database extender
- The projections of the shapefiles were changed to WGS84 projection and imported into the Postgres database using the shp2pgsql-gui plugin
- The back-end of the web app was built using the Ruby on Rails web application framework
- The front-end of the application was built using HTML/CSS + jQuery. OpenLayers has been used for display and rendering of maps/GIS data
- The parameters for calculating parcel potential are GHI/DNI values, area, choice of technology and packing density (in case of photovoltaic)
- The application is hosted using the Phusion Passenger server and can be accessed using a web browser over the internet.

Software Versions

Programming Languages

- Ruby v2.2.4
- Rails v4.2.6

Database and GIS

- PostgreSQL v9.4
- PostGIS v2

Front-end UI/UX

- HTML/CSS
- AngularJS

Visualisation/Map-rendering libraries

- OpenLayers v3

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