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SHAKTI SUSTAINABLE ENERGY FOUNDATION

ISGF India Smart Grid Forum

Implementation Plan for ELECTRIFICATION OF PUBLIC TRANSPORTATION IN KOLKATA

OCTOBER 2017

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To
Sri Reji Kumar Pillai,
President,
India Smart Grid Forum,
CBIP Building, Malcha Marg,
Chanakyapuri, New Delhi – 110021.

Sub: Report on Implementation Plan for Electrification of Public Transportation in Kolkata.

Sir,

I am extremely thankful to India Smart Grid Forum supported by Shakti Sustainable Energy Foundation and World Bank for preparing an Implementation Plan for Electrification of Public Transportation in Kolkata City. Kolkata Metropolitan Area caters to a population of 2.0 crores and around 1.0 crore people every day move to and from major commercial centres of the city. Kolkata is the only city in the country having functional Tram system. Further, major addition (around 100 Kms) to Metro Network is already going on at fast pace. Hence, present study to work out an Implementation Plan for Electrification of Public Transportation in Kolkata City is a need of the hour. I am sure this study will provide us a platform for further implementation of electrical mobility in public transport in Kolkata.

Yours sincerely,

11/x/2017

Managing Director,
West Bengal Transport Corporation.

The World Bank
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October 26, 2017

Sri Reji Kumar Pillai
President
India Smart Grid Forum
CBIP Building, Malcha Marg
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New Delhi – 110021

Dear Mr. Pillai :

Sub: Report on Implementation Plan for Electrification of Public Transportation in Kolkata

World Bank is pleased to be part of this first-of-a-kind study on electric transportation planning undertaken by India Smart Grid Forum in Kolkata by sharing data from our previous projects in Kolkata. The findings and recommendations from this study are very innovative and relevant to other cities in developing countries.

We are examining the feasibility of implementing the recommendations from this study in Kolkata. We compliment India smart Grid Forum for this timely report.

Yours sincerely,

Rakhi Basu
Transport Specialist & Task Team Leader
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SHAKTI
SUSTAINABLE ENERGY
FOUNDATION

Krishan Dhawan
Chief Executive Officer

To,
Mr. Reji Kumar Pillai
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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. No doubt the road to electric vehicles must be bridged with appropriate measures to facilitate the transition required to meet the EV targets.

The study, undertaken by India Smart Grid Forum (ISGF) with support from Shakti Sustainable Energy Foundation, is particularly relevant in this context. A first of its kind study, it lays out a comprehensive implementation plan to electrify public transport in Kolkata. The plan will assist city authorities in electrifying public transport, evaluate technology choices, assess the impact on distribution grids and analyse infrastructure requirements. It also provides policy recommendations for scaling-up the public transport electrification programme at the state and national level.

While this roadmap is specific to Kolkata, it holds immense potential for replication by cities and states across India to facilitate electrification of public transport fleet.

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 be translated into action.

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

Krishan Dhawan
Chief Executive Officer
Shakti Sustainable Energy Foundation

PREFACE

INDIA SMART GRID FORUM October 2017

In India, transportation sector emissions is a significant contributor to the deteriorating air quality and human health in cities. Transportation accounts for 20% of global energy use and it contributes 25% to 30% of the emissions. With the rapid acceleration of the Indian automobile markets, battery powered electric vehicles (EVs) represent a promising pathway towards improving air-quality, energy security (avoiding oil imports) and economic opportunities. The gradually increasing momentum behind EV adoption – both from the side of the Government and the Automotive Industry – will ensure that electrification of transport sector will play an important role in Indian mobility going forward nurtured by policy support from Government.

To accelerate adoption of EVs, this study qualitatively and quantitatively assessed the potential for electrification of public transport in Kolkata. Leveraging the best practices, empirical analysis, stakeholder reviews, optimal charging infrastructure operation models for grid integration of different types of EVs and the distribution grid capacities were analysed in detail to arrive at the recommendations.

The study proposes prioritized EV and charging infrastructure deployment plans to for electrification of public transport under most efficient and economical terms. Finally, the study prescribes policy changes to scale the deployment of EVs. The report recommends consideration of an integrated transportation, electrification, and charging infrastructure, and a prioritized roadmap for buses, 3-wheelers, and ferries. The analysis framework and results in this study can be adopted, as a model to deploy EVs in other Indian cities, to create new business and manufacturing opportunities, and improve energy security and air-quality.

India Smart Grid Forum (ISGF) would like to take this opportunity to thank Shakti Sustainable Energy Foundation (SSEF) for supporting this study and we wish to dedicate our strong commitment to work towards making transport electrification targets of Government of India a reality. I also take this opportunity to thank all the stakeholders for their valuable contribution in preparation of this implementation plan, particularly Mr. Narayan Nigam and his team at WBTC and Ms. Rakhi Basu at World Bank and Mr. Aniruddha Basu at CESC and Mr. Sanjoy Chatterjee at Ideation Technologies who have provided valuable inputs for this study.

Reji Kumar Pillai
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Chairman, Global Smart Grid Federation

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Acknowledgments

India Smart Grid Forum (ISGF) would like to express our sincere gratitude to Shakti Sustainable Energy Foundation (SSEF) who has extended this opportunity to ISGF for undertaking first of its kind project in the country to prepare an ***Implementation Plan for Electrification of Public Transportation in Kolkata City***. SSEF works to strengthen the energy security of India by aiding the design and implementation of policies that support energy efficiency, renewable energy and sustainable urban transport.

We would like to thank Mr. Narayan Swaroop Nigam, MD, Calcutta Tramways Company and his team for providing all the necessary guidance and support required to undertake the study for preparation of this report.

We would also like to thank Ms. Rakhi Basu from World Bank and Mr. Sanjoy Chatterjee and his team from Ideation Technologies for extending the support by providing the relevant data collected by them as well as help in the analysis.

We would also like to thank Mr. Aniruddha Basu, MD, CESC Kolkata and his team for providing all the necessary inputs related to electricity infrastructure in Kolkata.

Our appreciation to Biosirus Inc., Canada for their Cost-Benefit model/analysis and electrical charging/power system infrastructure calculations.

We also like to extend our sincere gratitude to all the stakeholders whom we consulted during the course of this study for their cooperation and relevant inputs which were valuable for this study. List of all the stakeholders consulted is provided in the Annexure A.

About India Smart Grid Forum

India Smart Grid Forum (ISGF) is a Public Private Partnership initiative of Ministry of Power (MoP), Government of India for accelerated development of smart grid technologies in the Indian power sector. Mandate of ISGF is to advise government on policies and programs for promotion of Smart Grids in India, work with national and international agencies in standards development and to help utilities, regulators and the Industry in technology selection, training and capacity building.

About Shakti Sustainable Energy Foundation

Shakti Sustainable Energy Foundation was established in 2009 to facilitate India's transition to a sustainable energy future by promoting policies that encourage energy efficiency as well as the increased generation of renewable energy. The energy choices that India makes in the coming years will be of profound importance. Meaningful policy action on India's energy challenges will strengthen national security, stimulate economic and social development and keep our environment clean.

Table of Contents

LIST OF FIGURES

List of Tables

EXECUTIVE SUMMARY

Electric Vehicles (EVs) and supporting technologies and services represent new economic pathways in India to increase energy security (avoid oil imports), reduce carbon emissions (reduce greenhouse gas emissions) and improve air quality (better human health). Indian cities represent a large unrealized economic, energy security, and decarbonisation opportunity among the rapidly accelerating automobile markets in world. India is home to 53 cities that has population of greater than a million. These prerogatives compel India to look at electric mobility options in its urban city core from a different perspective. While the challenges to transition towards electrification (policy, technology, infrastructure, and business models) from the existing internal combustion engine-centric (ICE) vehicles may seem daunting, the realized financial savings in imported fossil-based fuel, noise reduction, and air-quality improvements in inner cities can be significant.

In support of various national missions, this study seeks to address the following distinct priorities related to the Indian imperatives and electrification of public transportation in Kolkata:

a.	**Evaluate options to reduce cost of EVs for public transportation to increase affordability and faster adoption**
b.	**Consider lack of domestic lithium-ion battery and charging station manufacturers**
c.	**Emphasis on the value of "Make in India" solutions for domestic requirements**
d.	**Demonstrate social/health, energy/carbon/environmental, and economic impacts**
e.	**Elucidate inextricable links between transportation electrification and electric grid**

With motives to leapfrog India's adoption of zero emission vehicles , this study focuses on battery-based EVs (henceforth referred to, as EVs) and prioritizes them for public transportation sector—a sector where an accelerated early-stage adoption of EVs can be fostered through public-sector intervention and, axiomatically, set the trend for large-scale EV adoption. Having a large consumer base dependent on public transport, a shift to EVs provide an opportunity to move towards a clean low carbon sustainable transport system.

With these macro- and micro-level motivators, the study proposes an integrated implementation guide for the electrification of public transportation in the Kolkata city. The main objectives of this study were:

- Identify global best practices and standards for EV charging and communication infrastructure to accelerate the deployment of electric buses, and review potential for electric rickshaws, electric taxis and electric ferries
- Analyse existing public transport and electricity distribution infrastructure to enable an accelerated transition at most efficient and economical terms
- Review and propose an integrated approach comprising of electric vehicle supply equipment (EVSE) or charging station infrastructure technologies and services, electric grid infrastructure, existing transportation considerations, and operation models to ensure maximum interoperability for different types of vehicles in congruence with the electric grid infrastructure
- Understand the applications for an integrated approach in meeting India's city level, state level and national level policy objectives considering that EV benefits span multiple national missions, policy objectives, and ministries

- Prepare implementation guide to electrify public transportation and common analysis frameworks, which can be applied to other cities

The study conducted a bottom-up analysis to recommend potential viable business models for public transportation (buses, 3 wheelers and ferries) that can be adopted without huge investment in infrastructure upgrades or subsidies to accommodate this electric mobility transformation. The report reviews global best practices, compares options in selecting key business and technical parameters (in each of the buses, 3-wheelers and ferries segment), to leverage "Made in India" solutions.[1] This exercise challenged not only many status quo concepts, but also questioned the need for India to summarily adopt western automotive designs and budgets, often resulting in a higher investment.

The stakeholder consultation (over the course of this year-long project), with transport operators, OEMs, government agencies, and public policy think tanks in India gave valuable inputs. While specific recommendations are directed towards the study of Kolkata, some of the findings can be applied across other cities in India.

HIGHLIGHTS: ELECTRIFICATION OF PUBLIC TRANSPORTATION IN KOLKATA

A. ELECTRIC 3-WHEELERS

In the 3-Wheeler electric rickshaw segment, a battery swapping arrangement using Lithium Ion batteries has been considered, which can presumably create a new private sector service industry such as a battery leasing agency (BLA).

The transition to Lithium Ion battery leasing model will ensure better environmental motive for the 3-Wheelers than the conventional lead acid batteries, while keeping the upfront vehicle and battery costs lower. In a reference business model scenario, the vehicle operators can pay a rental fee for the use of the batteries or leverage pay-per-use models. This model also eliminates Lead Acid batteries from poor performance and careless recycling.

B. ELECTRIC FERRIES

No TCO analysis was performed on the ferry service routes due to lack of quality technical and operational data.

A simple pathway to a potential electrification of a two short ferry routes with heavy traffic (involving a maximum of 6 boats) are proposed with some technical cost estimates for charging infrastructure.

[1] The analysis of taxi-fleets was not conducted due to the lack of credible data.

C. ELECTRIC BUSES*

1. A shift in focus away from high costs associated with larger (>300 kWh) battery size adopted in imported buses, to lower cost 100 kWh and 200 kWh battery size is better for Kolkata's conditions. This capacity meets about 70% of the inner city slower speed bus routes. This lowers the bus cost from INR 3 crores to less than INR1.5 crores.
2. The Total Cost of Ownership (TCO) for a bus with 100 kWh battery is cheaper than diesel buses on Net Present Value (NPV) considerations. The bus with 200 kWh battery is almost at par, while the bus with 300 kWh battery is more expensive than diesel bus equivalents on NPV of TCO. While no subsidies are required on a TCO basis, innovative financing mechanisms may be required to bridge the initial purchase cost of electric buses.
3. For charging infrastructure, all buses on the shorter, inner city route (100 km or less per day), shall be charged overnight at the bus depots where there is available electrical infrastructure for fast and slow charging stations. This results in a significant reduction of dispersed charging infrastructure locations and better utilization of investments. The selection of a maximum fast charging rate of 5C (12 minutes for the 100 kWh bus models), allows charging of up to 4 buses per hour (or 32 buses per overnight or 96 buses per 24-hour day), and axiomatically better utilization of the charging infrastructure. This charging infrastructure can be owned and operated by the WBTC/CTC or CESC in Kolkata.
4. A low-cost electrical infrastructure using 600 kVA distribution transformer has been considered at major bus depots to allow for 415 V power supply feeds at 500 kW for 5C fast chargers. This eliminates significant costs associated with demand charges and allows for the lowest industrial energy tariff rate. A faster charging rate (greater than 5C) together with a higher battery size of 200 kWh, would push this requirement to 11KV (or 33KV supply for 300kWh).
5. The cost and operational assumptions for CBA were estimated from the inputs from stakeholder consultations and global best practices. The fixed cost apportionment of the fast chargers is included in the TCO models. Similarly on the energy costs, we have included the demand charge as well as the electricity rate tariff noted by the CESC, for 415 V and 11 kV. The cost assumptions are pessimistically loaded to compensate for the lack of a DPR quality cost details. No changes are considered for bus fare revenue model and bus routes that are operational today. Thus, the fare collections should essentially be the same with no route change recommendations in the immediate term.
6. Kolkata has an unique overhead 550 V DC distribution system that feeds its existing electric tram network. This infrastructure is not effectively utilized due to both legacy (age) issues as well as declining use of trams, as a choice mode of transport. Some capital expenditures are needed to upgrade the AC/DC converters and to make this asset purposeful towards distributed charging of buses (e.g., pantograph chargers). This will potentially eliminate or lower the number of depot-based chargers along these routes and can be useful for operations in "outer Kolkata" routes.

* Due to its large volumes and significant costs associated with this segment, additional details have been examined to recommend a viable business model for adoption.

CONCLUSIONS AND NEXT STEPS

Further to implementation plan and recommendations, to accelerate EV adoption (public or private), the Indian policy makers and regulators must consider global practices, while examining the local requirements such as cost, electricity network, and customer charging behaviour. India must develop specific EV needs based on the Indian conditions and work with global and local OEMs and experts to meet the government goals on electric mobility and local manufacturing. Specific policy recommendations must also consider applications at state-level and national-level objectives with specific local needs. To engage cost-sensitive customers, the Indian national-level and state-level regulations must consider total cost of ownership (TCO) and social-cost based incentives to lower EV and EVSE ownership costs passenger ticket fare. This should consider mechanisms such as customer tax credits, local production by OEMs, reduced sales taxes, etc., which can be funded from oil subsidy and import savings, CO_2 reduction, and innovative financing mechanisms. EVs also provide other non-tangible societal benefits such, as urban air-quality improvements and better health for citizens.

In Kolkata, the Government of West Bengal and the key state agencies—WBTC, WBSEDCL, CESC, WBERC etc.—must be enlightened on the study findings. This will ensure that the electrification plans for public transportation in Kolkata are aligned with the interests of the public and private sectors. These agencies should be convened to undertake a detailed project report (DPR) to firm up technical and cost estimates using market based tender offers from major OEMs within the automotive, charging infrastructure, and battery technology sectors. The recommendations on battery technologies, sizing, policy changes, and integrated vehicle and grid considerations can be expanded for procurement of EVs and field evaluation programs may be conducted to apply lessons for cost-effective and accelerated electrification of the entire public transportation sector in next 8 years (up to 2025) and pathways to electrify private transportation. Capacity building, consumer education and engagement relative to charging infrastructure, TCO models, and vehicle choices foster stakeholder acceptance of EVs and transition towards electric transportation. The recommendations also represent a priority to transition India's ICE-vehicles for full electrification considering the recent plans for sale of only EVs starting 2030.

IMPLEMENTATION ROADMAP

The following tables, 1, 2, and 3, proposes an implementation roadmap and immediate, near-term, and long-term recommendations for full electrification of buses, 3-wheelers, and ferries for five key priority determinant considerations—social and environmental, policy and electricity rate tariff design, charging standards, business models for operations, and vehicle-grid integration (VGI).

Table 1: Priority Deterministic Areas and Implementation Roadmap: Buses

Priority Determinant	Implementation Roadmap: Buses		
	Immediate (up to 2 years)	**Near-Term (3-5 years)**	**Long-Term (6-8 years)**
Proposed Deployment	119 buses in 10 selected routes	All 1,866 buses operated by the State government agencies on 376 routes	100% of the buses operating in Kolkata (includes school, private, PSU buses)
Social and Environmental*	• Monetize diesel savings of 32,500 litres/bus/year x 119 buses = 3.9 Million Litres/year for electrification • Monetize CO_2 savings of 87 Tons/bus/year x 119 buses = 10,350 Tons/year for electrification	• Monetize diesel savings of 32,500 litres/bus/year x 1,866 buses = 60 Million Litres/year for electrification • Monetize CO_2 savings of 87 Tons/bus/year x 1,866 buses = 162,350 Tons/year for electrification	• Monetize diesel savings of 32,500 litres/bus/year x 15,000 buses = 490 Million Litres/year for electrification • Monetize CO_2 savings of 87 Tons/bus/year x 15,000 buses = 1.3 Million Tons/year for electrification
Policy and Electricity Rate Tariff Design	• Finalize specifications for 9 meter buses and with battery size of 100 kWh capacity • WBERC to issue enabling regulations for WBTC and/or CESC to own and operate charging infrastructure • Ease the import duties for lithium ion batteries and	• Finalize specifications for 9 meter buses and with battery size of 200 kWh capacity for longer routes and inter-city operations • Promote local manufacturing and/or assembly of EVs, batteries and components, and charging stations • WBERC to issue	• Large scale local manufacturing and import of EVs, batteries and components, and charging stations • Enabling electricity market redesign to use EV, as grid resources

* The CO_2 savings can vary, depending on the source of the electricity generation. The site CO_2 savings consider a renewable generation source.

	chargers • Train O&M personnel on the EV infrastructure.	regulations to allow franchisees to set up charging stations • WBERC to notify separate tariff for EVs • Creation of a large pool of trained O&M personnel on the use and maintenance of EVs • Conduct education and outreach to raise awareness among public to adopt EVs	
Charging Standards	• Mandate BIS recommended standards for EV and charging infrastructure. Consider both power and communications, including grid • In case, the release of BIS standards is delayed and Kolkata has to rollout EVs prior to that, the choice of EVSE should be careful to avoid lock-in with proprietary technologies and protocols.		
Business Models for Operations	• WBTC shall own and operate this first batch • WBTC to own and operate appropriate chargers in their bus depots	• Bus operators to set up appropriate charging stations in their bus depots • DISCOM/Franchisees to set up charging stations at bus terminus/bus interchanges	• Third party operators to set up public charging infrastructure at highways and other strategic locations
Vehicle Grid Integration	• None	• Enabling regulations and dynamic tariffs for VGI • Infrastructure upgrade plans to facilitate VGI	• Infrastructure upgrade to facilitate VGI

Table 2: Priority Deterministic Areas and Implementation Roadmap: 3-Wheelers

Priority Determinant	**Implementation Roadmap: 3-Wheelers**		
	Immediate (up to 2 years)	Near-Term (3-5 years)	Long-Term (6-8 years)
Proposed Deployment	2,715 auto rickshaws along seven select routes	Approximately 100,000 e-Rickshaws, which use lead acid batteries to be converted to lithium ion; 50% or 4,300 of the remaining auto-rickshaws	Remaining 4,300 auto rickshaws
Social and Environmental*	• Monetize diesel savings of 2,030 litres/rickshaw/year x 2715 rickshaws = 5.5 Million Litres/year for electrification • Monetize CO_2 savings of 3.8 Tons/rickshaw/year x 2715 rickshaws = 10,370 Tons/year for electrification	• Monetize diesel savings of 2,030 litres/rickshaw/year x 4300 rickshaws = 8.7 Million Litres/year for electrification • Monetize CO_2 savings of 3.8 Tons/rickshaw/year x 4300 rickshaws = 16,340 Tons/year for electrification • Impose taxes to mitigate environmental and health impacts of lead acid recycling, disposal	• Monetize diesel savings of 2,030 litres/rickshaw/year x 4300 rickshaws = 8.7 Million Litres/year for electrification • Monetize CO_2 savings of 3.8 Tons/rickshaw/year x 4300 rickshaws = 16,340 Tons/year for electrification
Policy and Electricity	• Promote battery leasing agencies (BLA) by	• Promote local manufacturing and/or	• Enable large scale local manufacturing and import

* The CO_2 savings can vary, depending on the source of the electricity generation. The site CO_2 savings consider a renewable generation source.

Rate Tariff Design	providing incentives so that electric auto rickshaws can be sold without batteries • Allocate business permits and locations to set up battery charging and swapping stations • Ease import duties for Lithium-ion batteries, chargers • Conduct public education and outreach to raise awareness to use electric rickshaws	assembly of EVs, batteries and components, and charging stations • WBERC to notify separate tariff for BLAs, including enabling VGI services. • Stop issuing permits for internal combustion engine (ICE) based auto rickshaws • Complete phase-out of e-Rickshaws with lead-acid batteries	of EVs, batteries and components, and charging stations • Enable electricity market redesign to use BLA's charging infrastructure, as grid resources
Charging Standards	BLAs may choose most efficient and economic technologies and standards for charging infrastructures		
Business Models for Operations	• Enable market mechanisms for electric auto rickshaws to be sold without batteries to lower the first cost • Require BLAs to establish battery leasing contracts with electric auto rickshaws owners • Require BLAs to swap charged batteries to electric auto rickshaws owners or operators	Enable market competition for more BLAs to operate	Consider secondary use of retired batteries for stationary and grid applications
Vehicle Grid Integration	None	Enabling regulations and dynamic tariffs for VGI	

Table 3: Priority Deterministic Areas and Implementation Roadmap: Ferries

Priority Determinant	**Implementation Roadmap: Ferries**		
	Immediate (up to 2 years)	**Near-Term (3-5 years)**	**Long-Term (6-8 years)**
Proposed Deployment	Six ferries along two routes	All the remaining ferries	Explore potential for additional ferry services
Social and Environmental	• Monetize diesel savings for electrification • Monetize CO_2 savings for electrification • Monetize avoided environmental degradation from oil spills		
Policy and Electricity Rate Tariff Design	• WBSTC must engage an experienced agency to prepare DPR to electrify existing boats • WBSTC must engage CESC to create charging facilities at Howrah jetty • Ease the import duties for lithium ion batteries and chargers	• WBERC to notify separate tariff for charging of ferries • WBSTC must stop buying diesel ferries	• None
Charging Standards	• WBSTC/CESC/WBSEDCL may choose most efficient and economic technologies and standards for charging infrastructure		

Business Models for Operations	• WBSTC shall continue to own and operate electric ferries
Vehicle Grid Integration	• To be evaluated in the DPR

CHAPTER 1 INTRODUCTION AND BACKGROUND

In India, electric vehicles (EVs), and supporting technologies and services could open up new economic opportunities and pathways to increase energy security (avoid oil imports), reduce carbon emissions (reduce greenhouse gas emissions) and improve air quality (better human health). The Indian cities represent a large unrealized economic, energy security, and decarbonisation opportunity among rapidly accelerating automobile markets in world. India is home to 53 cities that has population of greater than a million.[2] These prerogatives compel India to examine electric mobility options in its urban city core from a critical perspective. While the challenges to transition toward electrification (policy, technology, infrastructure, and business models) from the existing internal combustion engine-centric (ICE) vehicles may seem daunting, the realized financial savings in imported fossil-based fuel, noise reduction, and air-quality improvements in inner cities can be significant.

India's decarbonisation policies to address greenhouse gas (GHG) emissions and drive new economic opportunities, while improving the quality of life of the citizens in the cities, will be based on the three key prioritized decarbonisation pathways for energy–generation, energy-utilization, and transportation sectors, as shown in Figure 1-1. All these three sectors will influence significant rise in city-level carbon emissions in next five to ten years, primarily driven by India's accelerated urbanization and economic growth. India has significant policy imperatives to reduce the GHG emissions from the generation and utilization sectors with aggressive renewable generation and energy efficiency deployment goals. The 175 Gigawatt (GW) renewable generation program by 2022 with 40 GW of that from roof-top PVs is a step in the right direction that also requires addressing integration challenges and efficient use of the generation.[3] The Energy Conservation Building Code (ECBC) adoption by the Indian states has the potential to significantly reduce the energy use in utilization sector by at least 25% to 50% from current levels.[4]

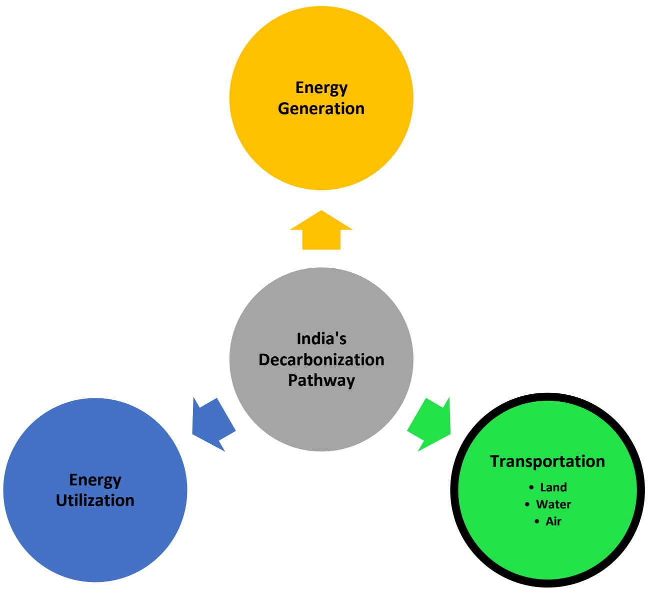

Figure 1-1: Prioritized Approaches for India's Decarbonisation Pathway (emphasis on Transportation)

Studies that emphasize the city-level challenges, have shown that the rapid urbanization is the key

[2] Press Information Bureau, Government of India (http://pibmumbai.gov.in/scripts/detail.asp?releaseId=E2011IS3)
[3] Press Information Bureau, Government of India (http://pib.nic.in/newsite/PrintRelease.aspx?relid=155612)
[4] Singh, R; D. Sartor, and Ghatikar, G, Practices Guide for High- Performance Indian Office Buildings; LBNL. April 2013

contributor to the rising energy use and GHG emissions. An equivalent of the entire United States' population or 315 million people will be added to the Indian cities by 2040.[5] In addition, India is experiencing sustained economic growth with a high annual gross-domestic growth (GDP) of 7.9% in 2015, whereas, the world-average was 2.7%.[6] This has axiomatic energy-use cause-and-effect to the urban population health through rise in GHG emissions from increased energy consumption, infrastructure development, and vehicle ownership.

With focus on the transportation sector, 80% of crude oil imports in India drive 30% of primary energy, and majority of this is used by the transportation sector leading to oil-dependency.[7] India imported 80.9% of its oil in 2015–16, up from 77.6% in 2013–14.[8]. India's crude oil consumption in 2015 was 4.1 million barrels per day[9] and is estimated to be 10 million barrel per day by 2040[10]. However, India's oil-import is anticipated to skyrocket to USD 230 billion by 2023.[11] At the same time, the transportation sector is expected to expand driven by the economic development, low oil-prices, government policies to develop highway and road infrastructure, and make in India programs that promote local manufacturing.[12] In the business as usual scenario by 2040, India is expected to add more than 250 million passenger cars, 185 million two- and three-wheelers and 30 million trucks and vans.[13] India's drivers for transportation and new infrastructure underlies strong demand for the rise in oil demand, energy-intensive goods, while the rising level of vehicle ownership keeps the transport demand on an even steeper upward curve.

Emissions from vehicles is a key contributor to urban air pollution and impact on human health. As a reference case, the United States (U.S) transportation sector uses 28% of the total energy, mostly from petroleum-based sources.[14] In 2012, this sector contributed 28% of the total greenhouse gas (GHG) emissions, whereas the electricity generation sector's share is 31%.[15, 16] GHG emissions also deteriorate air quality, impacts human health, and leads to premature deaths.[17] To address the resulting socio-economic impacts from the transportation sector, India's clean energy pathway must be characterized by accelerated transition to decarbonize the electricity infrastructure and to significantly lower the GHG emissions with focus on the city infrastructure. Electric transportation can be the strategic path to decouple the energy generation source from vehicle fuel and the location of the generation source through energy storage. Electric Vehicles (EVs) can be charged from non-fossil based sources and also from the distributed generation with utility, community, and customer-based generation sources (e.g., roof-top PVs, micro wind turbines and energy storage).

Battery powered EVs derive all power from battery packs and thus have no internal combustion engine but instead have electric motors to drive the wheels. Electric vehicles typically use chemical-based batteries (e.g., like Lithium-ion), which powers electric motors and motor controllers for propulsion unlike

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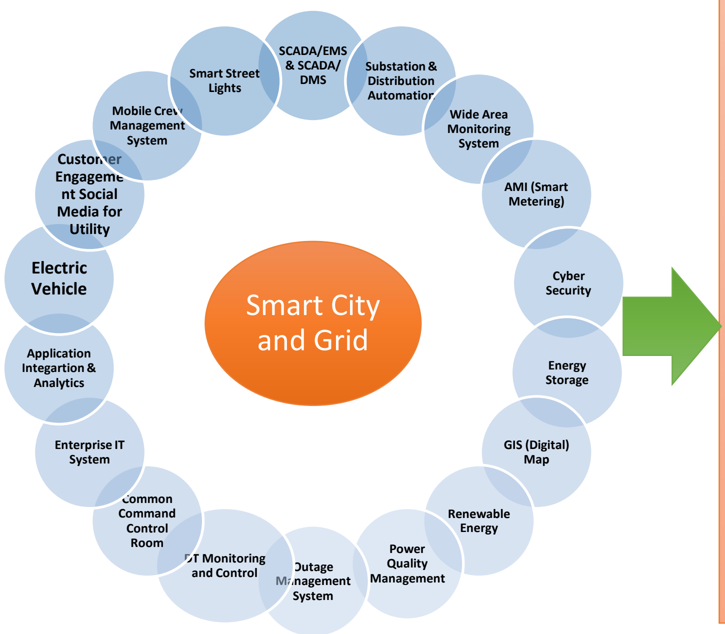
5 Reference: IEA India Energy Outlook 2015
6 World Bank Data, http://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG (accessed June 2017)
7 All India Study Report to Petroleum Planning and Analysis Cell on Sale of Diesel and Petrol, Press Information Bureau, Government of India, January 2014. Accessible at http://pib.nic.in/newsite/PrintRelease.aspx?relid=102799
8 India Leaps Ahead: Transformative Mobility Solutions For All, NITI Aayog and RMI, May 2017
9 BP Statistical Review of World Energy, June 2016
10 The Economic Times, India's oil demand to more than double to 10 million bpd by 2040, http://economictimes.indiatimes.com/industry/energy/oil-gas/indias-oil-demand-to-more-than-double-to-10-milliom-bpd-by-2040/articleshow/55815017.cms
11 Goldman Sachs, India: How Much Energy? Asia Economics Analyst, Issue No: 14/25. June 2014.
12 U.S. Energy Information Administration (EIA), Country Analysis Brief: India, June 2016.
13 Reference: IEA India Energy Outlook 2015
14 U.S. Energy Information Administration (EIA), Annual Energy Outlook 2014, DOE/EIA-0383.
15 U.S. Environmental Protection Agency (EPA); Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2012, EPA 430-R-14-003
16 U.S. Department of State (DOS); U.S. Climate Action Report 2014
17 Lelieveld J, et al; The Contribution of Outdoor Air Pollution Sources to Premature Mortality on a Global Scale, Nature 525, September 2015.

an internal combustion engine (ICE) vehicle, which uses fossil fuel like petrol, diesel, or natural gas for its propulsion. Electric motors are also inherently more energy-efficient than gasoline or diesel engines as the losses in case of motors are less, especially when the motors are brushless direct current (DC) as batteries also store DC power and does not need power conversion. Battery electric cars have the added benefit of home recharging. A 240 Volt (V) outlet, similar to those used for air conditioners or clothes dryers, can be used to charge a battery powered EV, albeit at a slow charge rate. Once fully-charged, most EVs can meet consumer's day-to-day driving range requirements depending upon battery size, terrain, weather conditions, and usage pattern. With constantly falling cost of lithium-ion batteries, the market trend is toward higher battery capacity, which extends the EV range. Additional charging stations at public-places, highways, and workplaces will provide added charging opportunity, as and when needed.

As shown in figure 1-2, the push for battery powered zero emission vehicle (ZEV) deployment can not only lower carbon emissions and improve air-quality, but also has the potential to advance technological innovation and economy through "Start-up India" and "Make-in-India" programs. The prioritization on ZEV can be a key contributor to advance smart city with integrated smart grid infrastructure that can provide needed energy source and can also leverage demand flexibility through vehicle-grid integration (VGI) services such as smart charging and better address variability caused by renewable generation.



Zero Emission Vehicles (ZEV) are key to smart city infrastructure:

- Low carbon emission
- Improved air quality
- Enable new business services
- Improved quality of life for citizen

ZEVs are:

- Battery powered EV is one of the types of zero emission vehicles with no tail pipe emissions
- Hydrogen fuel cell-based vehicles is another popular type of ZEV.

Study Focus: Battery powered EV and its link with smart grid

Figure 1-2: Integrating Zero Emission Vehicles for Smart City and Smart Grid Framework

1.1 RELATED HISTORICAL ACTIVITY: INDIA AND REFERENCE COUNTRIES

After China and the United States (U.S.), India is the third-largest energy consumer in the world.[18] India's 2040 projected share will be 25% of the total global energy demand, which is still 40% below the world average in terms of per-capita energy consumption. This will also make India the third-largest country for volume of carbon (CO_2) emissions.[19] India's coal-centric fossil fuel accounted for 81% of the total electricity generation of 1,208 terawatt-hours (TWh) in 2014.[20] However during the year 2016-17, capacity addition of renewable energy sources (18438.72 MW) exceeded conventional power plants (7654.84 MW) for the first time; and this trend is expected to continue according to government policies and programs.[21]

With a large deposit of fossil fuel-based resources for electricity generation, the transportation sector continues to rely on oil imports. This is primarily due to the inextricable link between oil and energy source for the automobiles powered by internal combustion engines. Of the 4.1 million barrels per day (Mbpd) of oil consumed by India in 2015, 40% was used for the transportation sector.[22] Figure 1-3 from 2013 data shows fossil-based fuels dominating India's energy demand. Petroleum and other fossil-based liquids contribute 23% of India's energy source. India with over 1.3 billion population in 2016 and steadily growing at the rate of 1.4% per year, will likely result in increased oil dependence based on current trends.[23]

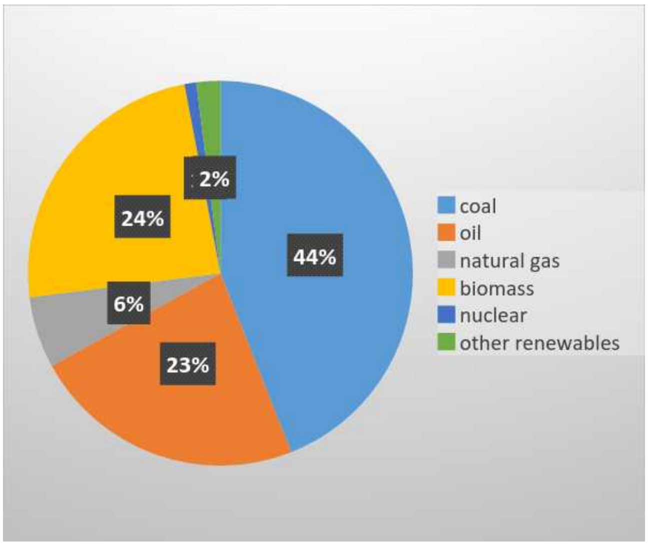


Figure 1-3: Fossil Fuels Dominate India's Energy Demand

The 2040 projections shows that India's thirst for oil will be accelerating to 10 mbpd, which is higher than any other country. The vehicle ownership is expected to continue to rise driven by the economic growth and axiomatic links to improved road infrastructure, urban migration, and public transit.[24] With increasing oil dependency, India lacks an intrinsic strategy to alleviate or disassociate the axiomatic linkages between: (a) indigenous economic growth and dependence on foreign energy sources; and (b) fossil

[18] U.S. Energy Information Administration: Country Analysis Brief, India, June 2016
[19] International Energy Agency, World Energy Outlook Special Report: India Energy Outlook, 2015
[20] Energy Information Administration, derived 2014 data using growth rates of BP Statistical Review of World Energy 2015
[21] Executive Summary March 2016 and March 2017, Central Electricity Authority (CEA)
[22] IEA India Energy Outlook 2015
[23] The World Bank, http://data.worldbank.org/indicator/SP.POP.TOTL
[24] IEA India Energy Outlook 2015

energy sources and automobiles. India requires integrated policies to address both these challenges by transitioning toward EVs for transportation and renewable resources for electricity generation.

India's National Electric Mobility Mission (NEMM) envisages about 6-7 million electric/hybrid vehicles in India - a shift from traditional Internal Combustion Engine (ICE) vehicles to electric vehicles- by the year 2020. The Government of India (GoI) has set targets of about 4.8 million Two Wheelers (2W) EVs and 1.5 million Four Wheelers (4W) EVs to be deployed on the road by 2020. Having a large consumer base dependent on public transport or vehicles for commuting, a shift to EVs provide an opportunity to move towards a clean low carbon sustainable transport system. Further, India has recently revised renewable energy targets to 160 GW (solar and wind combined) by 2022. In support, the GOI has allocated INR 1,000 crores or USD 150 million for faster adoption and manufacturing of (hybrid and) electric vehicles scheme (FAME) for the financial years, April 2015-16 and 2016-17.[25] The FAME scheme has been extended by 6 months and is applicable till September 30th 2017 or till approval of phase 2 of the scheme whichever is earlier[26]. The budget for the FAME scheme is allocated for the following components: demand incentives, technology platform, pilot projects, charging infrastructure, and program operations. The large share for demand incentive lowers the retail price of the vehicle. The synergy between NEMM, and renewable energy targets will help develop a robust clean transport roadmap.

Some major cities are no stranger to adopting public policy on matters of air pollution. For example, in last decade, all public transit buses and public light vehicles in Delhi were converted to CNG and a new supply chain for fuelling was established in record time of a few years and similar initiatives have been taken by some other cities as well. Other initiatives to improve air quality are being experimented by Mumbai Metropolitan Region Development Authority (MMRDA) and Himachal Road Transport Corporation (HRTC), through the introduction of hybrid-electric buses and pure electric buses, respectively.

Converting large fleet of taxis, three wheelers and buses to EVs in a planned manner as per NEMM would be very beneficial for India, which can reduce air pollution significantly. With the addition of EVs to the system, NEMM has estimated that about 1 GW of additional electricity generation capacity will be required to match the demand, if India is to achieve the proposed targets. Though, the pan India demand may not look very high due to EVs, but it is important to analyse the demand due to these non-static loads or EVs on the distribution grids as a whole and at the feeder level where the concentration of the EVs are going to be high as it may cause overloading of the distribution system and hence it becomes an important task for the electricity distribution companies in India to plan their system in a proper way in order to accommodate EVs and use them as an asset.

In this context, it becomes important for city bus corporations and electricity distribution companies to understand the barriers, technology choices, policy landscape and operational realities in adoption of EVs. A detailed implementation plan to analyse the infrastructure requirements and impact of EV adoption on distribution network is critical since the EV sector is still at infancy in India.

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[25] The Hindu Business Online, Accessible at http://www.thehindubusinessline.com/news/govt-earmarks-rs-1000-cr-to-boost-electric-vehicle-sales/article6792232.ece
[26] http://dhi.nic.in/writereaddata/UploadFile/continuationFAMEscheme0001.pdf

1.2 THE INDIAN IMPERATIVES

In India, the introduction of EVs that began a decade ago, as hybrids, is now rapidly transforming to battery powered vehicles. This “pure electric” transformation allows for a much simpler drive-train, better torque, better efficiencies and takes away the complexity of the “dual-mode” hybrid models. However, since most of the technology developments took place in the western economies (United States, Canada, European Union, United Kingdom and Japan), the requirements and designs of such EVs are largely influenced by their needs. Recently, new entrants such as China, Taiwan and South Korea have introduced smaller and lighter EVs (cars, delivery vans, 3-Wheelers, 2 wheelers) with battery types, which are more suited for Indian cities and environmental conditions.

The evolution of any such new industry in a country raises questions on domestic challenges, such as, affordability, local manufacturing, availability of spare parts, and the servicing of these vehicles. The answers are often difficult in such “make v/s. buy” as often a roadmap has to be created (and executed) to attain the stated national objectives. A large country like India with its thrust for transformation to a cleaner transport options , has the potential to rapidly develop the EV manufacturing and related ecosystem as the second largest globally (China being the largest). In the case of EVs there are a few distinct challenges that make the Indian imperative distinctly different from other countries. The GoI is expected to launch a new mission housed in NITI Aayog under the supervision of an inter-ministerial committee soon that will look into these challenges. These distinctions are highlighted below:

a. Emphasis on Cost Reduction to Increase Affordability and Faster Adoption

While the market scale potential is huge in India, the affordability for such increased adoption by its general masses is a critical one. This applies not only to passenger-owned vehicles but also to fleet vehicles, as the operators would need to recover such costs from fare-paying ridership. In this context, the size of the battery in city public transit e-buses (developed in the West), with distance ranges of 300 km, speeds of 120 km/h, air-conditioning, etc., all contribute to an enormous cost increase that India does not need. The Indian cities have average bus routes of less than 25 km, speeds of 30-50 km/h with majority of buses non-air-conditioned. The assumption that a bus needs a large battery (to be charged daily at night) and then run during the entire day needs to be revisited in the Indian context.

Currently an air conditioned 12 meter diesel bus in India costs about US dollars (USD) 131,000 (INR 85 lakhs) while an imported electric bus of similar size is almost 3.5 times at USD 460,000 (INR 3.0 crores). The main difference in cost is the size of the battery (324 kWh). For most Indian driving conditions (noted above), it is possible to bring down the battery size to about 75-90 kWh pack. This drops the electric bus price to about USD 231,000 (INR 1.5 crores).[27] India needs to make such discerning optimization on costs in order to increase e-mobility adoption. The cost reduction over a 1000 bus fleet is significant and could justify the use of fast charger investment that can be shared by several buses in the depot or at strategic locations on key routes.

[27] This price was indicated by OEMs/STU in 2016 which we have used for the Cost Benefit Analysis in Chapter 6; however, this price may be less when procured in large numbers.

b. Consider Lack of Domestic Lithium-ion Battery and Charging Station Manufacturers

India plans to abolish the use of lead-acid battery in EVs for reasons of “irresponsible recycling” practices and environmental contamination by the small-scale industry. Further, the lead-acid battery (often deployed in e-Rickshaws) carries almost a third of its payload in lead-acid battery weight alone. Replacing lead acid with Lithium batteries not only decreases the weight by 40% but also increases the battery life and power-range of the vehicle due to a better and more powerful battery source.

However, India does not make Lithium cells or Lithium Ion battery packs so far. Since the introduction of an electric car model and few e-bus models, a year ago, some original equipment manufacturers (OEM) have started to “assemble” Lithium battery packs for their e-vehicles from imported cells. While the physical assembly of such battery packs does not appear difficult, but the thermal design, cooling and certification may prove daunting and arduous for many third-party battery packers. Further, India currently, does not have any published standards for Lithium batteries. All these could easily add a few years in ensuring the manufacturing of Lithium batteries. The same is true for domestic manufacturing (or lack thereof) of chargers/charging stations. Currently, all EV charging stations are imported to India.

c. Emphasis on the Value of “Make in India” Solutions for Domestic Requirements

All of the above calls for indigenous manufacturing or “Make in India” imperative (bus size, batteries, chargers, etc.). India has a thriving bus-body manufacturing capability (build from chassis) and e-bus market should be channelized through this to the extent possible. Such a make in India policy will not only increase India’s capability in the aftermarket spares and services, but will spawn even more economic benefits if EVs are exported from India.

However, in order to achieve and start this new industry, a lot of other inputs such as requisite skills, training and specialty materials need to be made available.

d. Demonstrate Social/Health, Energy/Carbon/Environmental, and Economic Impacts

Most urban cities have a few common locations where air quality is monitored. These are generally logged every hour and uploaded to a central city server for reporting and alerts. Typical variables include Nitrogen Oxides (NOx), Sulphur Oxides (SOx), Particulate Matter (PM) 10, Particulate Matter (PM) 2.5, Particulate Matter (PM) 100, Carbon Dioxide (CO_2), etc. apart from ambient environment conditions such as temperature, humidity, etc.

India does not monitor air quality at its meso-scale (neighbourhood/local) level in inner city cores and hence there is a potential such meso-scale readings could be much higher (in some cases lower as well) than the few aggregate points monitored at the city level. A good example of this could be inner city roads where there is high vehicle traffic along with stop-and-go congestion, could result in much higher air-pollution readings for the residents in that local area. Further, such air pollution levels could be dynamic during the time of day or night. Certain studies have looked at early-stage air quality collection and analysis at mico-levels.[28] In such instances, air-quality measurement sensors are fitted on to street view data collection cars. Such vehicular-based real time air-quality data collection and analysis can be explored in the Indian scenarios.

[28] Joshua S. Apte,Kyle P. Messier, Shahzad Gani, Michael Brauer, Thomas W. Kirchstetter, Melissa M. Lunden, Julian D. Marshall, Christopher J. Portier, Roel C.H. Vermeulen, and Steven P. Hamburg; High-Resolution Air Pollution Mapping with Google Street View Cars: Exploiting Big Data. Environmental Science and Technology, June 2017

It is clear that vehicle tailpipe emissions is a cause for not only GHG and particulate emissions but a concern for health effects as well. Different neighbourhoods could be subject to differing levels of air-pollution causing differing levels of health effects in residents.

The use of battery electric vehicles in such inner city congested corridors, alleviates this health hazard. Public fleets (buses, taxis and 3 wheelers) become prime consideration for conversion. In many advanced nations, the health effects of air-pollution is considered significant enough for corrective action as it impacts economic outputs as well.

e. Elucidate Inextricable Links Between Transportation Electrification and Electric Grid

Considering that battery powered EVs require a charging infrastructure at various levels (public and private), this has clear implications to the state of the electric grid and its modernization initiatives in India. The full-scale adoption of EVs require a careful analysis of electric grid infrastructure (at transmission and distribution levels) and planning of charging infrastructure.

With India's plans for aggressive de-carbonization of electricity generation, EVs provide an unique flexibility resource for vehicle-grid-integration (VGI) capabilities that can be used to address variability from renewable generation resources.

1.3 PURPOSE OF THE STUDY

To leapfrog India's roadmap to extend policy objectives toward accelerated deployment of EVs, this study qualitatively and quantitatively assesses the feasibility of electrification of public transportation for the city of Kolkata with emphasis on buses, 3-Wheelers (3W), and ferries. The high-level feasibility analysis of electrification of publicly managed taxi fleets, shared vehicles, and trams was also conducted. The electricity distribution system and urban transport practices for Kolkata were reviewed to propose an accelerated and practical implementation plan to deploy EVs into Kolkata's public fleets.

In the context of public transport, the study focuses on the accelerated advancement of EVs in the urban cities for the public transportation sector. While the public transportation can be in the form of road, rail, air, and water, the primary focus is on the road transport that represents immediate opportunity for electrification. The energy demand from the road transport is 90% of the transportation sector, highlighting the priority for electrification. Effective public transportation presents an opportunity to alleviate the trend towards individual vehicle ownerships and limiting city-level pollution. In particular, within the road transport, buses are primarily targeted for quantitative analysis due to their fixed schedules, routes, operation models, and an ability to optimally plan the charging infrastructure. Additionally, 3-wheelers were targeted since they have fixed routes in Kolkata and also offer immediate and low-cost opportunity for electrification. Ferries are also proposed for electrification since oil leakages from their engines to water bodies is more harmful to the environment than their emissions. The other forms of road public transport—taxi fleets and shared vehicles—and other strategically prioritized public transportation (e.g., trams) are qualitatively assessed.

1.4 WHY KOLKATA?

Kolkata has been chosen for the study, as it was the first city in India that introduced public transportation system running on electricity and represents a unique opportunity to leverage the electricity infrastructure for accelerated and cost-effective EV deployment. The city also has taken steps to prepare a roadmap for transitioning the city to low-carbon future.[29] The erstwhile capital of India, the trams in Kolkata started in the year 1902 are still being used by millions of people. CESC Kolkata, the first electric utility in the country is successfully supporting the tram system network with supply of power through 6 kV alternate current (AC), which Calcutta Tramways Company (CTC) converts to 550 volt (V) direct current (DC) at their receiving points and 550 V DC (approx. 400 Amps during peak load) is fed on the tram network. From 1899 until 2008, CESC also used to supply DC power to several residential and Low Tension (LT) industrial customers at 225 V and 450 V through a 3-wire DC distribution system, which has now been phased out. With expansion of the city over the years, the lion share of public transportation has moved from the trams to buses, 3 wheelers and cars. According to the World Health Organization. Kolkata is also the twentieth most populated city in the world, and lists third among the Indian urban cities.[30] Electrification of public transport will represent one of the most promising pathways to increased energy security and improved air quality in the city that retains Kolkata's spirit of electrification of public transportation.

Since Kolkata has a unique situation where DC power is available, it is easier to set up DC Fast Charging (DCFC) stations for public transport vehicles. DCFCs are more conducive for fleet operations as it can also support taxi and mini-bus fleets efficiently. Currently in India most of them are on low voltage platforms; and this contributes to the uniqueness that DCFC has with respect to low voltage vehicle platforms which perhaps has no parallel anywhere.

Fast-tracked rollout of charging infrastructure for fleet operations will prompt the automotive companies to come out with many variants of the 1-ton load carrier/ passenger vehicles which are currently being developed/ prototyped or commercially launched by at least half dozen Indian companies. Charging station network in Kolkata which can be made scalable by utilizing the existing tram lines, gives serious potential for commercial/taxi/passenger vehicle fleets to develop over a short period as an economical proposition. This technology intervention can change the paradigm, and EV introduction can jump-start. One aligned strategy could be to reduce the size of Lithium ion battery packs for electric buses which can give a range of 50 – 60 km in single charge and rely on this DC charging network extensively, by design.

Converting taxis/autos and buses to EVs in a planned (and organized) way would be the approach for this transition. This would potentially reduce about 50% of the pollution generated by these vehicles, which for the most part are idling in stop-and-go traffic in their daily routines. Also, the distance travelled in a given day is not that large which makes the conversion of public taxi fleet to EVs much more attractive.

[29] PwC; Roadmap for Low Carbon and Climate Resilient Kolkata. 2016
[30] PwC; Roadmap for Low Carbon and Climate Resilient Kolkata. 2016

1.5 STUDY GOALS AND OBJECTIVES

The goal of the study is to propose an integrated implementation guide for the electrification of public transportation in Kolkata city. The main objectives of this study are:

1. Identify global best practices and standardization practices for power and communication infrastructure to accelerate the deployment of electric buses, and review potential for electric rickshaws, electric taxis and electric ferries
2. Analyse existing public transport and electricity distribution infrastructure to enable an accelerated transition at most efficient and economical terms
3. Review and propose an integrated approach comprising of electric vehicle supply equipment (EVSE) or charging station infrastructure technologies and services, electric grid infrastructure, existing transportation considerations, and operation models to ensure maximum interoperability for different types of vehicles in congruence with the electric grid infrastructure
4. Understand the applications of an integrated approach in meeting India's city level, state level and national level policy objectives considering that EV benefits span multiple national missions, policy objectives, and ministries
5. Prepare implementation guide to electrify public transportation and common analysis frameworks, which can be applied to other cities

While specific recommendations are made considering the potential changes to the electricity sector in next 5 to 10 years, this implementation plan is a set of recommendations for electrification of the existing public transportation network, as a base scenario. For example, the benefit and cost assessment of electrification of existing ICE bus fleets and 3-wheelers, and their routes in Kolkata.

1.6 STUDY METHODOLOGY AND STAKEHOLDER INCLUSIVENESS

Electricity distribution and urban transport practices of Kolkata were reviewed to propose an accelerated implementation plan to deploy EVs into the public fleets. The study proposes charging infrastructure to help transition of the public transportation to electric fleet under most efficient and economical terms. Through empirical analysis and stakeholder engagements, the study recommends an optimal number of electric vehicle supply equipment (EVSE) and their strategic placements. Finally, the study prescribes policy and regulatory challenges for implementation of EVs for public transportation to accelerate and scale the EV adoption.

Figure 1-4 provides an overview of the methodology adopted for the preparation of implementation plan. The team from M/s Ideation Technologies who had surveyed and collected data for all 925 bus routes in Kolkata and mapped it onto GIS under the project funded by the World Bank, helped the project team in doing the route analysis after which top 10 routes were selected on the basis of passenger volumes; route lengths, overlap with trams and congestion. After the top 10 routes were selected, CESC who is responsible for supply of electricity in most part of the Kolkata were approached to get the details of existing distribution transformers (DTs) on the selected routes and in the bus depots which comes in the purview of these top 10 selected routes. Once the data for DTs was collected, then the availability of head room to accommodate additional load of EVs was analysed on those DTs.

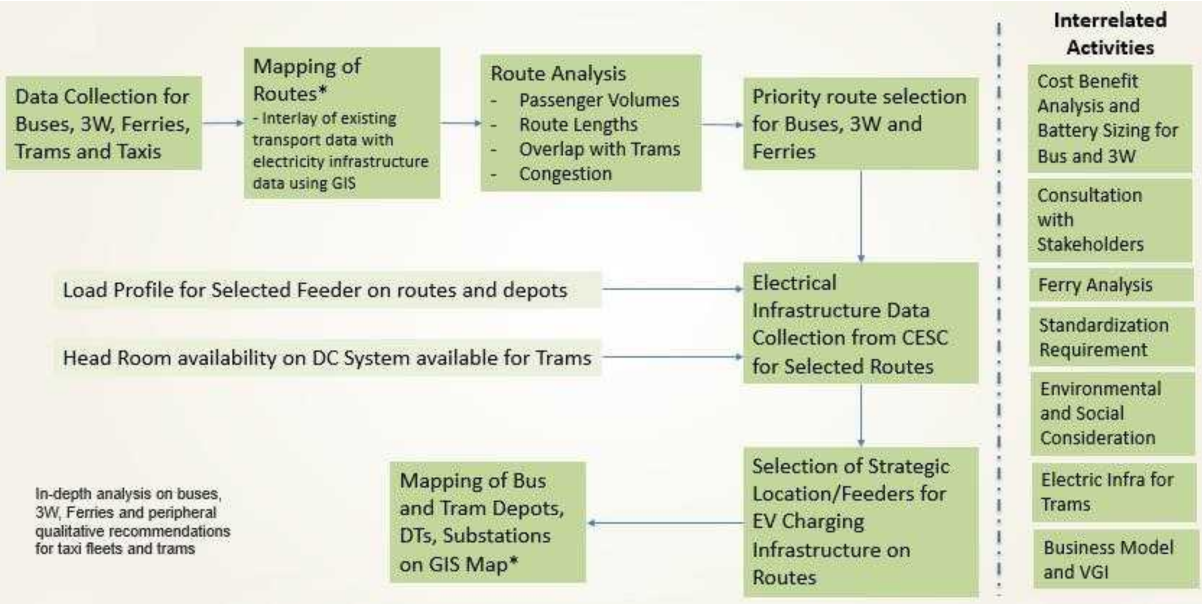

Figure 1-4: Methodology used in the Study to Derive the Recommendations

** Conducted by M/s Ideation Technologies, India.*

All the bus routes along with the bus depots, trams intersection points and DTs were plotted on the GIS platform for the visualisation purpose. The project team also calculated Total Cost of Ownership (TCO) for the electric bus v/s diesel bus where the cost numbers were taken from various sources in India. To ensure pragmatic recommendations and success of the project, multitude of stakeholders meetings and workshops were conducted during the course of this assignment. The names of the stakeholders consulted and their underlying engagement are described in the Table 1-1 below:

Table 1-1: Stakeholders Engagement

Stakeholder (and Sector)	Areas of Engagement
West Bengal Transport Corporation	West Bengal Transport Corporation (WBTC) is the entity responsible for operating the buses in the city of Kolkata. Though many routes are operated by private bus operators but they are also monitored by WBTC. The Transport Department of Govt Of West Bengal (GoWB), have envisaged on a programme of upgrading existing public transport infrastructure services in Kolkata to provide a safer, more comfortable and faster journey on the urban road network of Kolkata Metropolitan Area. The World Bank has decided to provide financial and technical assistance to the GoWB for the same. To achieve the above endeavour, the Transport Department of GoWB decided to carry out "Listing and Mapping of Public Transport infrastructure and routes in Kolkata Metropolitan Area" for which World Bank appointed Ideation Technologies who helped in providing the relevant data for the buses.
World Bank	
CESC	The erstwhile, Calcutta Electric Supply Corporation, now CESC, the electric utility is the responsible entity for distributing electricity in most part of Kolkata. Meetings with CESC officials were conducted to obtain the data for

	the study and to evaluate study recommendations.
Mahindra Electric	Since, Mahindra Electric is the only company in India which manufactures electric cars, it was necessary to take their views on the study.
Lithium Cabs	Lithium cabs is a start-up company which runs electric cars for corporates in the city of Bangalore and some of the relevant operational data was received from them was very helpful. Lithium cabs has investment from Mahindra and use their cars, as electric taxi fleets.
Infosys	Infosys has deployed bus fleets in partnerships with Bangalore Metropolitan Transport Corporation (BMTC). Data on the routes, travel distance, fuel and operational costs, etc., received form Infosys was helpful in determining the optimal battery sizing of buses and for effective benefit-cost analysis. The team met Infosys to get good understanding of their operations.
Ashok Leyland	Ashok Leyland is one of the bus manufacturer in India who has demonstrated fully electric bus. Intention was to get bus specifications and get to know the challenges/opportunities being observed by a manufacturer. Ashok Leyland shared relevant points which were useful in carrying out the study.
TATA Motors	Intension was to get bus specifications and get to know the challenges/opportunities being observed by a manufacturer. TATA Motors has shared relevant points which were useful in carrying out these study.
JBM Group	JBM group also manufacturers the electric buses and gave valuable inputs.
Delhi Integrated Multi-Modal Transit System Ltd (DIMTS)	DIMTS operates 3000+ buses in Delhi and operational data from them was very helpful
Society of Indian Automobile Manufacturers (SIAM)	SIAM is an important channel of communication for the Automobile Industry with the Government, National and International organisations. The Society works closely with all the concerned stake holders and actively participates in formulation of rules, regulations and policies related to the Automobile Industry. SIAM gave important inputs for the study
Robert Bosch	Robert Bosch was consulted for the charging infrastructure

Detailed list of stakeholder consultation and key points discussed are given in Annexure A.

Directionally, the outreach with the various stakeholders (mentioned above) helped build a consensus for the following:

- Smaller battery for the buses to reduce capital expenditures (capex) cost and reduce overall TCO (to better compare with the current diesel buses). This could change some of the strategy around the charging infrastructure and route optimization
- Challenges in swapping batteries in buses (at least for now)
- Some "notional" agreement on battery sizing and two/three variants on bus size and route operations assumptions
- Choices for the battery chemistry for India considering high ambient temperatures in most parts of the country Potential battery rental and swapping business model for 3W e-Rickshaws (but

using more expensive and better suited Lithium batteries than Lead Acid batteries). This reduces the capex of the vehicle

- Potential advantage of leveraging the overhead DC wires of Kolkata Tramways for EV bus charging
- Need for domestic manufacturing of DC fast chargers and other EVSE ecosystem
- Evoked interest in the utilities and other government departments for initiating policies and programs for setting up charging infrastructure.

CHAPTER 2 GLOBAL BEST PRACTICES: STATE OF ELECTRIC MOBILITY

This section reviews global best practices for EV adoption and recommends appropriate practices for India that are aligned with the latest technology trends and practices from the global context. Global EV adoption practices and the resulting impacts on the grid could provide guidance to design appropriate policies to accelerate and scale India's EV adoption. This is axiomatically important considering India's aggressive EV deployment plans through NEMM and FAME program. While the EV adoption rates in India have a long road ahead to meet the NEMM goals, the global adoption practices show that the readiness of the charging infrastructure and other supporting eco-system programs are key to influence consumer's decision to own EVs. For EVs, the deployment of charging infrastructure is determined by the extant electricity supply and the state of the grid.

Several countries have set targets for EV adoption. While some countries are proceeding aggressively by favourable environment for policies and incentives, others are at a nascent stage. The United States (U.S.) represents one of the largest EV markets in the world, have aggressive plans to deploy EVs with tangible incentives at both state- and federal-level, public investment and loan programs for the deployment of charging infrastructure, and aggressive R&D investment in the key areas of grid modernization, vehicle-grid-integration, and power systems interoperability. For example, as one of the leading state in the U.S., California's Zero Emission Vehicle (ZEV) mandate requires 1.5 million EVs by 2025 with over USD 1.1 billion public investments in the charging infrastructure with the bulk system operators and distribution utilities playing a key role in accelerating their adoption. Beginning 2015, California's building codes also required all new residential and non-residential buildings to install electricity infrastructure for EV charging stations.

The building codes and enforcement will lead to pervasive EV charging stations and enable customers to buy electric cars. Overall in 2016, 609,629 Alternate Fuel Vehicle or non-ICE vehicles were registered in the European Union, up 4.1% compared to 2015. The hybrid electric vehicles (+27.3%) followed by the pure electric vehicle (EV) segment, which saw more modest growth (+4.8%), drove the increase. Among the big five markets, Spain (+49.4%), Germany (+21.9%) and the United Kingdom (+14.9%) recorded substantial increases in non-ICE vehicle registrations. Growth in these countries was fully driven by demand for electric and hybrid electric vehicles[31]. Similar to California, France plans for aggressive EV deployment through new building codes requiring new apartment and commercial buildings to be ready for charging infrastructure[32]. At a macro-level, to promote the EVs, Europe is planning initiatives to accelerate the deployment of EV charging infrastructure[33]. In 2016, China sold 351,000 electric passenger cars, which makes it by far the largest market for plug-ins (termed, as New Energy Vehicles or NEVs in China). The increase of NEVs in 2016, over 2015, was staggering 85%.

The following subsections summarize global best practices for EVs in the context of market share, incentives, power and communication standardization, ownership and operational models for vehicle-grid

[31] European Automobile Manufacturers Association, alternate fuel vehicle registration, in press
[32] French building code, decree no 2016-968 of 13 July 2016
[33] Platform for Electric Mobility, Accelerating Electric Infrastructure Deployment in Europe, Position Paper of the Platform for Electro-Mobility, Brussels; November 2016

integration (VGI) programs to manage grid impacts from EV demand.

2.1 GLOBAL PRACTICES FOR ELECTRIC VEHICLE ADOPTION

Several countries have set targets for EV adoption. While some countries are proceeding aggressively by favourable environment for policies and incentives, others are at a nascent stage. The global EV adoption rates are primarily driven by strong state- and/or country-level policies, which are targeted at the higher market share of 4 wheelers.

Table 2-1 provides the 4 wheeler EV sales for the American, European, and Asian countries[34 35 36]. The global electric car adoption crossed the million-mark barrier to 1.26 million in 2015 and exceeded 2 million mark in 2016.[37,38] India has the least per-capita EV adoption among the countries studied.

Table 2-1: Global Sales of Electric Vehicles

Country	Sales in 2016
United States	84,850
Canada	4,160
European Union	155273
India	~1,000
China	2,66,000

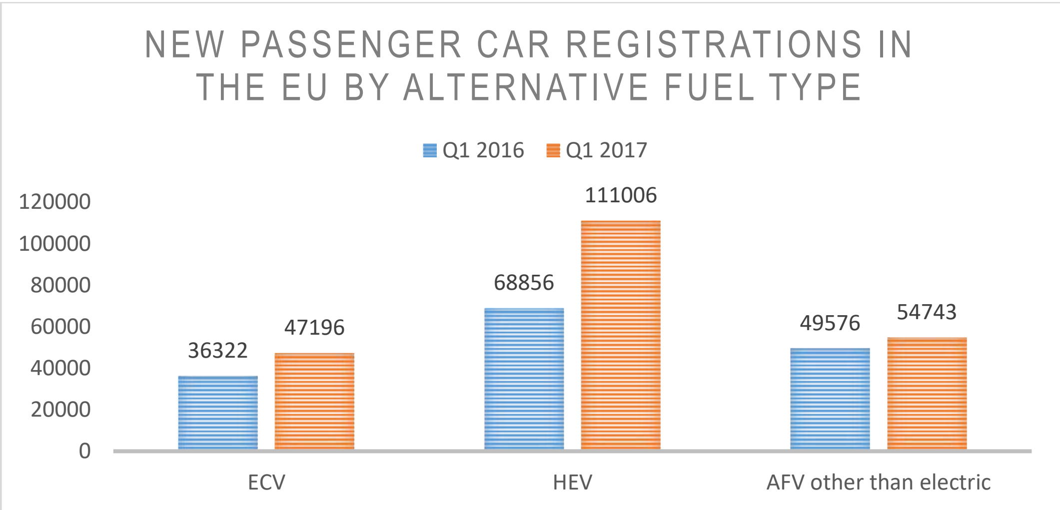

Figure 2-1: EV Registration in EU (2016)

ECV: Electrically Chargeable Vehicle; HEV: Hybrid Electric Vehicle; AFV: Alternate Fuel Vehicle

Chinese brands and market are responsible for more than 95% of the global EV Buses and Batteries. Government initiatives are playing a pivotal role in facilitating the growth of the electric bus market. In

[34] Bloomberg New Energy Finance, New Energy Outlook 2016, Long-term projects of the global energy sector. June 2016
[35] European Automobile Manufacturers Association, Alternate fuel vehicle registration, in press
[36] EV-Volumes, Global plug-in sales for 2016, in press
[37] Organization for Economic Cooperation and Development (OECD) and International Energy Agency (IEA), Global EV Outlook 2016: Beyond 1 million electric cars, 2016
[38] International Energy Agency (IEA), Global EV Outlook 2017: Two million and counting, 2017

China, for example, the Ministry of Transport provides subsidies and tax benefits to manufacturers of low-emission buses, including subsidies of USD 81,600 per bus for the purchase of electric buses in 2016. [39] [40]

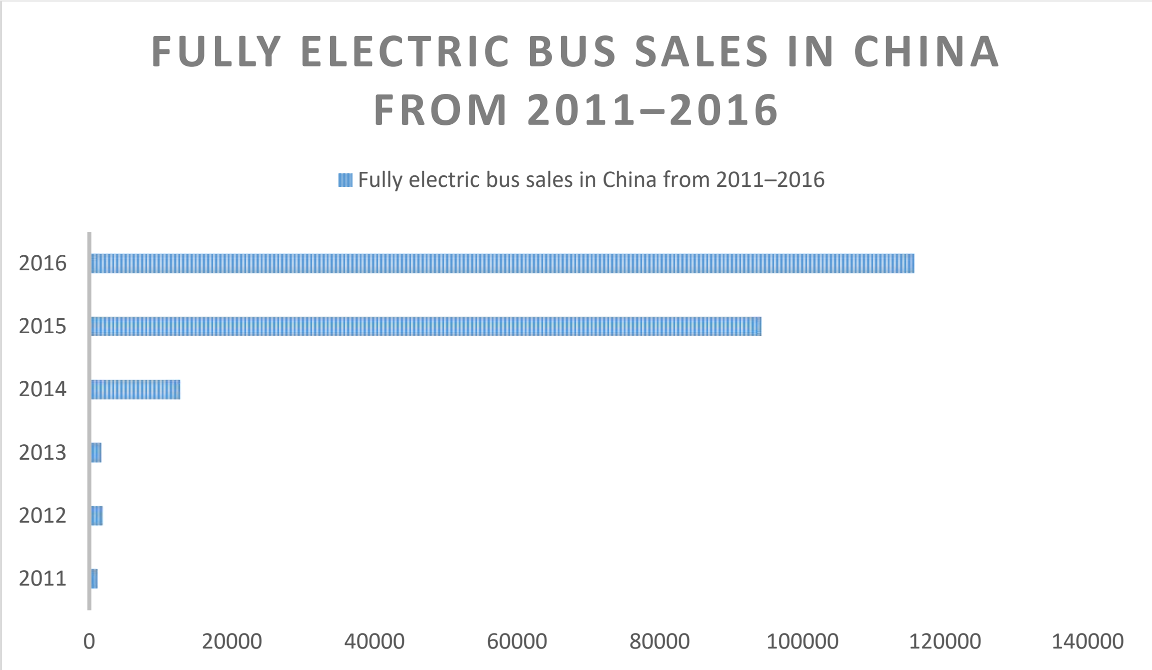

Figure 2-2: Electric Bus Sale in China 2011-2016

In Europe, electric bus sale numbers are in the hundreds, with over 1300 buses delivered. The European OEMs are betting more on plug-in hybrid EVs (PHEVs).

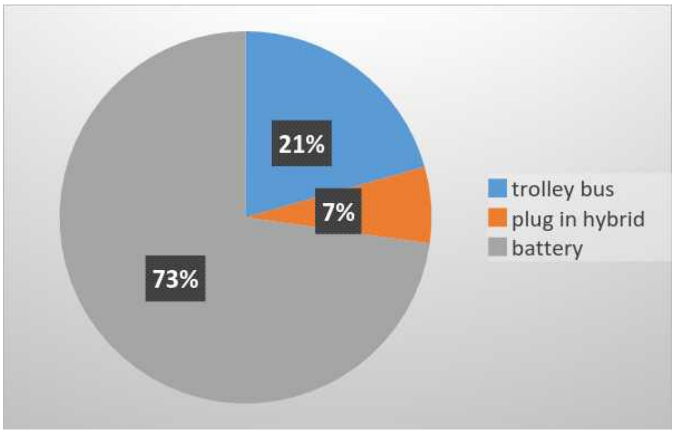

Figure 2-3: Types of Electric Buses in Europe[41]

The greatest number of electric buses of the above types can be seen in the United Kingdom, with over 18% of the total European fleet, followed by the Netherlands, Switzerland, Poland and Germany, with around 10% each. South Korea has also launched a wirelessly charged electric bus called 'on-line electric vehicle' (only e-bus) to test induction charging for buses.

Approximately 200 full battery electric buses were delivered in the USA in 2016, with the largest number

[39] http://zeeus.eu/uploads/publications/documents/zeeus-ebus-report-internet.pdf
[40] https://cleantechnicACom/2017/02/03/china-100-electric-bus-sales-grew-115700-2016/
[41] http://zeeus.eu/uploads/publications/documents/zeeus-ebus-report-internet.pdf

currently operated in the Los Angeles region (California). The North American market is also characterised by the presence of both an American and a Chinese OEMs. Last year, the US Department of Transportation announced USD 55 million in competitive grants to deploy more zero-emission buses across the country.[42]

2.2 POLICIES, BUSINESS MODELS, CHARGING INFRASTRUCTURE

The global EV adoption rates are primarily driven by strong state- and/or country-level policies, which are targeted at the higher market share of 4 wheelers. As stated already, India has the least per-capita EV adoption among the countries studied which opens the opportunity for new EV deployments.

While the availability of and access to the charging infrastructure is a determinant in nudging the consumer adoption of EVs, initial interviews with market makers in India have revealed that the capital expenditure costs of EVs represent a key decision influencer for consumer adoption. Albeit the EV costs globally are falling precipitously, it still remains a key decision factor for consumers. Most policies incentivize the early adopters for EV purchase. Table 2-2 summarizes the incentives available for EVs and their charging infrastructure.[43]

Table 2-2: EV and EVSE Purchase Incentives Available in Different Countries

United States	
o	EV purchased during or after 2010 is eligible for a federal income tax credit of up to USD 7,500.
o	Many states offer cash and non-cash incentives, such as carpool lane access and free parking. Some examples are, as follows: o **Arizona:** Reduced Vehicle License Tax, Carpool lane access and reduced electricity rates for EV charging o **California:** Up to USD 2,500 income state tax credit rebate o **Colorado**: USD 5,000 tax credit o **Hawaii:** Carpool lane access and reduced electricity rates for EV charging o **Nevada:** Carpool lane access and reduced electricity rates for EV charging o **New Jersey:** Sales tax exemption o **Washington DC:** Excise tax exemption
France	
o	Regions have the option to provide an exemption from the registration tax (either total or 50%) for alternative or clean fuel vehicles. Under a bonus system, starting 2016, a premium is granted for the purchase of a new electric or hybrid electric vehicle, as follows: (1) car that emits between 61 and 110g CO_2/km, the amount of the bonus is Euro 750; (2) for a car or commercial vehicle emitting between 21 and 60g CO_2/km, the bonus amounts to Euro 1,000; (3) for a car or commercial vehicle emitting 20g CO_2/km or less, the bonus amounts to Euro 6,300. EVs are also exempt from the company car tax. Hybrid vehicles emitting less than 110g CO_2/km are exempt from the tax during the first two years after registration.
Italy	
o	In many regions, electric vehicles are exempt from the annual circulation tax (ownership tax) for a period of five years from the date of the first registration. After this five-year

[42] http://zeeus.eu/uploads/publications/documents/zeeus-ebus-report-internet.pdf
[43] Ghatikar G, A. Ahuja, and R. Pillai; Battery Electric Vehicle Global Adoption Practices & Distribution Grid Impacts: Preliminary Case Study for Delhi, Proceedings of India Smart Grid Week, March 2017.

period, they benefit from a 75% reduction of the tax rate applied to equivalent gasoline vehicles

Denmark

- Electric cars and vans are exempt from registration tax. Hydrogen and fuel cell-powered vehicles are exempt from registration tax until the end of 2018.

United Kingdom

- Electric vehicles (with CO_2 emissions below 100g/km) are exempt from the annual circulation tax, while other alternative fuel cars receive a GBP 10 discount on the paid rates.
- From 1 April 2010, pure electric cars are exempt from the company car tax, while all cars with CO_2 emissions lower than 50g/km pay 5% for the tax year 2015/2016.

Spain

- Main city councils (e.g., Madrid, Barcelona, Zaragoza, Valencia, etc.) are reducing the annual circulation tax (ownership tax) for electric and fuel-efficient vehicles by 75%.

China

- Exemption from acquisition and excise tax for electric cars, which range from CNY 35,000 to 60,000 and are based on the engine displacement and price. Under new planned scheme until 2020, owners of "new-energy vehicles," or 4 wheeler EVs, owners will receive subsidies of up to CNY 55,000. Indigenous electric buses are eligible for up to CNY 500,000 in subsidies
- State Grid Corporation of China, which is the operator and the supplier of EVSEs, has deployed a significant number of charging stations. By mid-2016, China had approximately 81,000 public charging stations.

a. Charger Type and Standards

The type and power levels for the charging standards determine the cost of charging stations. Information regarding the location of charging stations and charging time alleviates the driver's range and charging anxiety. Charging station standards may be selected in a manner to enable interoperability (charging of different makes of vehicles) so that third-party service providers can set up charging stations catering to all types of EVs.

Table 2-3: Power Charging Standards in Frontrunner Countries

Country	Power Standards
Americas	SAE J1772 Level 1 and 2 for Alternate Current (AC) SAE J1772 Combo Coupler Standard (CCS), CHAdeMO, and Tesla Supercharger for Direct Current (DC) fast chargers (DCFC).
Europe	SAE J1772 Level 1 and 2 for AC SAE J1772 CCS, CHAdeMO, and Tesla Supercharger for DCFC IEC 61851 for AC/DCFC
China	GB/T for AC/DC IEC 61851 for AC/DCFC
Japan	SAE J1772 Level 1 and 2 for AC CHAdeMO for DCFC

b. Charging Stations and Ownership Models

To increase EV adoption, innovative operational and ownership models and electricity tariffs are proposed to ensure customer and grid preparedness. Table 2-4 summarizes ownership models and installations for charging infrastructure, and electricity tariffs, as proposed by the major distribution system utilities in the U.S..

Table 2-4: EV Charging Infrastructure and Ownership Models in the United States

<table>
<tr><th>Ownership Models</th><th>Description</th><th>Installations</th><th>Electricity Rate Tariffs</th></tr>
<tr><td>Customer</td><td>Most widely used business model with any available 120V outlets</td><td>Residential and Commercial Buildings, Campuses, etc.</td><td rowspan="3">Three type of tariffs common in USA:
1. Dynamic day-ahead VGI rate to driver or charging station owner
2. Time of use (TOU) rates to driver or charging station owner
3. TOU rates to charging station owner</td></tr>
<tr><td>Third-Party</td><td>Increasingly popular business model in public spaces. These are AC and DC fast chargers operating at 240V or higher</td><td>Public spaces, Highway corridors, etc.</td></tr>
<tr><td>Electric Utility</td><td>Evolving business model to deploy AC and DC fast chargers operating at 240V or higher</td><td>Public spaces, highway corridors, and disadvantaged communities</td></tr>
</table>

Studies show vehicle grid integration (VGI) opportunities (e.g., demand response), challenges, and multi-level benefits. VGI is increasingly accepted through pilot projects and has shown positive grid impacts. The EV battery is used for voltage and frequency regulation to balance supply and demand. With the increase in penetration of wind and solar energy into the Indian grid, voltage and frequency stability will soon be a major concern. During unpredictable peak demands, VGI can be a resource where EV batteries can also provide emergency backup services during power outages and address electricity reliability. For example, Consolidated Edison's project in the U.S. opts for demand-side resources—batteries and thermostats—to defer USD 1 billion substation and infrastructure upgrades in congested urban centres at 50% lower cost.

Contextual lessons from global experiences can be applied in India and targeted urban centres to develop policies to foster new technologies, programs, and alleviate the grid impacts to accelerate large-scale adoption of EVs.

CHAPTER 3 STANDARDS FOR ELECTRIC MOBILITY

Understanding the electric mobility systems and their interface standards represent an opportunity to provide cost-effective and secure interoperability with a diverse set of technologies and business models. Standards are key enablers for open interoperable systems and encourage innovation because it enables new business models and services. The benefits of interoperability standards for customer-side transactions are well studied and deployed in commercial programs in many countries. EV batteries as distributed energy resource (DER) systems, requires integration among all three power-flow domains: grid operators, electricity service providers, and customers. The standards can be de-facto, which are uniformly adopted by the industry, or de-jure, which are developed by an accredited standards development organization (SDO) and adopted by the industry. The standards can also be at various levels—for data models, transport mechanisms, and physical communications. This chapter lists the SDO-supported data model standards for EV charging infrastructure that includes EV supply equipment (EVSE) or charging stations, EVs, and grid interconnection at the key interfaces, as shown in Figure 3-1. Open standards refers publicly available standards with no intellectual property (IP) or pre-agreed IP terms. The chapter also lists power standards for different EVSE types.[44]

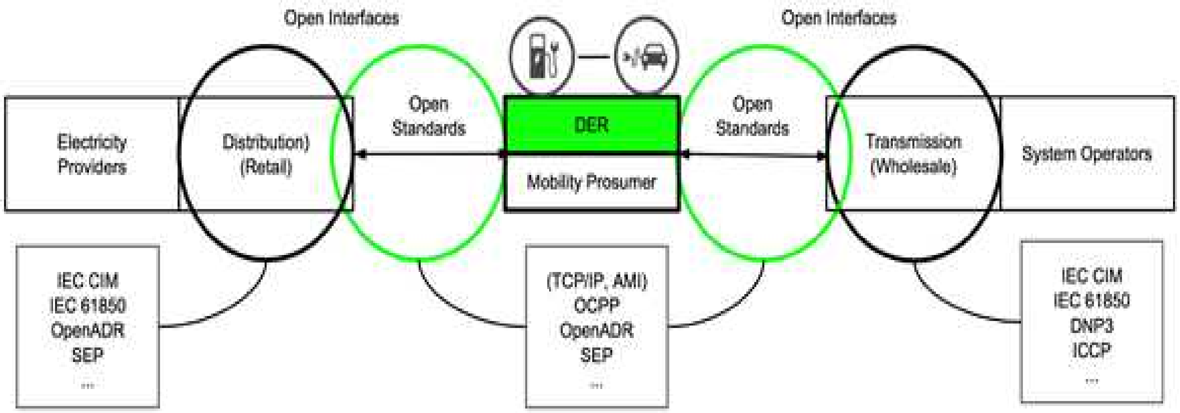

Figure 3-1: Electric Mobility Interoperability with Power Systems and Electricity Markets

3.1 ELECTRIC VEHICLE CHARGING INFRASTRUCTURE

The standards governing low voltage AC and DC systems are quite different. The established Low Voltage AC (LVAC) standard voltage limit is 1000V AC internationally, while the IEC Low Voltage DC (LVDC) standard voltage limit is 1500V DC[45]. The Bureau of Indian Standards (BIS) has embarked upon its own LVDC standards with two collaborations: a Memorandum of Understanding (MoU) with IEEE for LVDC micro grids and with IEC as a part of their membership in LVDC SEG4 and LVDC Sys Committees; The BIS has also set up two technical committees: ETD-50 (LVDC Power Distribution Systems) and ETD-51 (Electro Technology in Mobility), however work is still under progress in these BIS committees. Further, the BIS has standards for various batteries but none for Lithium Ion chemistry variants. Thus, in the short-term, the standards governing EVSE and/or the EV batteries in India will likely be governed by

[44] Ghatikar G; Decoding Power Systems' Integration for Clean Transportation and Decarbonized Electric Grid, Proceedings of the ISGW 2016. New Delhi, India.
[45] Note that the various national standards as it exists today limit the DC voltage between 400V – 1000V

major international standards such as the IEC or the IEEE.

The EV charging infrastructure comprises of the following:

1. Electricity supply infrastructure - transformers, meters, panels, conduits and wires that is required to provide reliable electricity supply to the vehicle chargers. This activity is outside the scope of this study
2. Electric Vehicle Supply Equipment networking requirements to enable efficient EV charging and other services among EVSE owners and EV drivers
3. EVSE and EV integration for automated communications and EV identification
4. EVSE/EV communication with electricity service provider and/or grid operators for effective monitoring and management of EV, as a grid resource

There are two basic EVSE options for charging an electric vehicle: wired or conductive charging and wireless or inductive charging. Considering that the wireless charging is still in early stages of development and widespread acceptance, the focus is on wired charging. Wired charging is primary option wherein commercially ready solutions are widely available for EVs and EVSEs. The EVSEs are classified into several types and categorized by the current flows and the power ratings at which the EV batteries are charged.

The EVSE current follows are categorized, as alternate current (AC) and direct current (DC) charging. Charging with AC is used for low- and medium-power charging at homes and offices or workplaces, and at public spaces. Charging with DC is used for fast-power and are called DC Fast Charging (DCFCs), while AC Pulse Charging (ACPC) is enabled through the deployment of Ultra Capacitors. The global deployments of public charging infrastructure are dominated by AC chargers and DCFCs. The advantage of Pulse Charging is that the grid power supply intake is much less even though the DC pulse charge (often less than a second) can be twice as much as DCFC levels.

Considering that all EV batteries require DC power to be charged, the grid-supplied AC power has to be converted to DC. An AC/DC convertor is needed to charge the battery using grid power. In the AC EVSEs the converter is on-board the EV, while the DC EVSEs (DCFC) and the ACPC (AC Pulse Chargers) have integrated converters. At higher power DC charging levels, a more expensive converter is needed that is not a standard practice by majority of the car manufacturers. These converters are therefore incorporated in the EVSEs and DC power is delivered to the EV. The same is true of Pulse Chargers as well.

Table 3-1: Different EVSE types for AC and DC, their typical voltage and current levels

Power Levels	Grid Voltage/Current (in Amperes) Input	DC Power to Battery (kW)	Applicable Vehicles
AC Level 1	108-120/15-20	~1.4 to 2.4	2W, 3W, 4W
AC Level 2	208-240//≥30	~7.2 to 19	3W, 4W
DC Level 3 (DCFC)	400-800/≥120	≥50 (up to 150)	4W, LDV, HDV
AC Level (ACPC)	400/60	450-600	HDV

HDV: Heavy Duty Vehicle; LDV: Light Duty Vehicle

The EVSE types vary for each type of EVs for example, 4 wheelers primarily use dedicated EVSEs in non-residential charging, while buses can be charged with overhead (pantograph based) charging. While the power standards for EVSEs are mature for 3W, 4W and LDVs, the same is not true for bus charging infrastructure.

It may be noted that battery chemistry variant dictates the limitations to the type of charging method (and hence chargers) that can be used. While this is taken care in the case of the AC Level-1 and AC Level-2 chargers (being on board the vehicle), in all other cases where the charger converter is external to the vehicle, the selection of third party chargers needs careful consideration of battery chemistry[46] used in different types of EVs.

AC Pulse Chargers cannot typically adjust their outputs to respect Demand Response (DR) signals nor VGI signals due to their internal pulse booster circuitry designs which keep the battery “off-circuit” from the grid. These type of chargers are not widely used.

3.2 EVSE POWER STANDARDS

For both AC and DC charging, multiple plug designs and charging modes have been developed and have been deployed throughout the world. Some of the major charging standards followed around the world are described below:

a. MODES

The charging mode refers to power levels that charger and its connectors are rated for. IEC 61851-1 Committee on “Electric vehicle conductive charging system” has defined 4 Modes of chargers, concerning:

- Mode 1: slow charging from a household-type socket-outlet in AC
- Mode 2: slow charging from a household-type socket-outlet with an in-cable protection device in AC
- Mode 3: slow or fast charging using a specific EV socket outlet with control and protection function installed in AC
- Mode 4: fast charging using an external charger in DC

b. PLUG TYPE

i. AC Charging Stations:

Both 3 and 4 wheelers can primarily use the AC EVSEs, depending on the EV manufacturers’ preferences.

The IEC committee has defined three types of socket outlets:

- **IEC 62196-2 "Type 1"** - single phase vehicle coupler - reflecting the SAE J1772/2009 automotive plug specifications
- **IEC 62196-2 "Type 2"** - single and three phase vehicle coupler - reflecting the VDE-AR-E 2623-2-2 plug specifications
- **IEC 62196-2 "Type 3"** - single and three phase vehicle coupler with shutters - reflecting the EV Plug

[46] Popular battery chemistry for EV batteries and its properties are Lithium Titanate Oxide (LTO); Lithium Manganese Cobalt (LMNC); Lithium Phosphate Oxide (LFP); Lithium Polymer (LP). Each one has its own charging and discharging advantages and limitations. While some of them can be fast charged up to 10C, others are at 5C or below. (1C denotes 1 hour of charging to 100% State of Charge; therefore, a 10C rating would full charge in 6 minutes; this would apply equally for discharge rate as well).

Alliance proposal

ii. DC Charging Stations:

Both 3 and 4 wheelers, and buses can primarily use the DC EVSEs,[47] depending on the EV manufacturer's preferences, based on the battery chemistry. There are four different standards for DCFCs in practice today as briefed below:

CHAdeMO

To define a standard for DC charging, Japan set up the CHAdeMO association (Charge de Move) in 2010. CHAdeMO charging station can only be used for cars with a matching CHAdeMO inlet and that it is not possible to use alternative cables such as for AC charging. The plug design is however not (yet) recognized as such by the IEC even though its power and safety ratings comply with the IEC 62196 norms. A major drawback of the CHAdeMO standard is that it prescribes a separate vehicle inlet that is used for DC charging exclusively. The CHAdeMO equipment is typically rated for 125 A and 500 V DC, which translates to 62.5 kW, albeit recent updates allow the peak power charging upwards of 125 kW.

Combined Charging System (CCS)

The Combined Charging System (CCS) or Combo was developed by the Society of Automotive Engineers (SAE) for EVs with DC charging requirements. Similar to CHAdeMO, the CCS-supported EVSE can only be used for cars with a matching CCS inlet. There are two versions of the CCS connector: (1) The U.S. version combines the Type 1 Yazaki AC design with the additional DC pins, and (2) The European version combines the DC pins with the Type 2 Mennekes AC design. Type 1 is available for sale rated up to 200 A and 600 V on the DC lines, which translates to 120 kW peak power at best. European Type 2 seems much more capable with 200 A and 850 V, which in theory gives 170 kW peak power.

GB/T

GB/T is a Chinese standard (20234), which can run up to 250 A and 750 V, which means that it is actually the most powerful DC fast-charger in the world with 187.5 kW capacity. This standard is yet to be accredited by the international standards development organisations.

Tesla SuperCharger

Tesla began its adventure from 90 kW level, then increased to 120 kW in North America. The connector in North America is unique. Tesla SuperChargers in Europe have a different connector which looks like Level 2 AC connector.

Table 3-2: Popular EVs and their DCFC Standards

EV Models	DCFC Standards
Nissan LEAF, Mitsubishi,	CHAdeMO
Chevy Volt, BMW, Ford, Mercedes	CCS
Tesla	SuperCharger
BYD	GB/T

[47] http://archive.northsearegion.eu/files/repository/20140805153226_StandardizationofEVRecharginginfrastructure.pdf

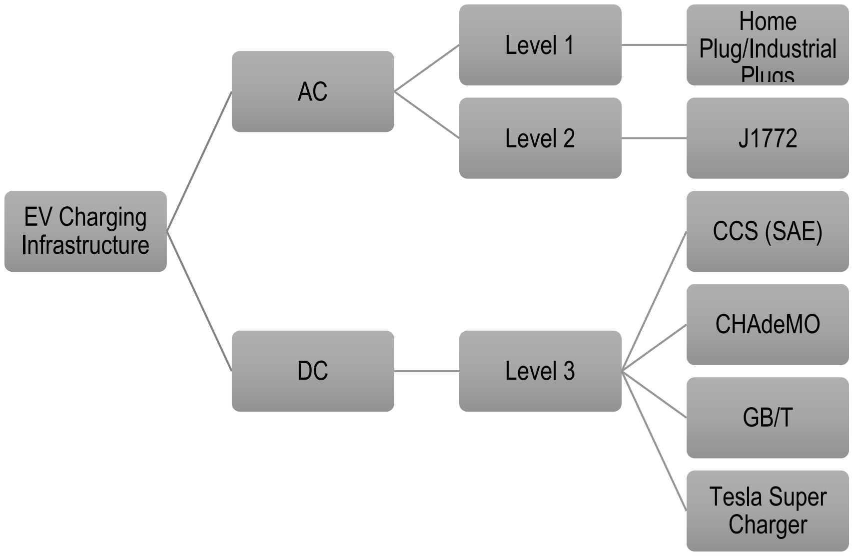

Figure 3-2: Charging Standards for Alternate and Direct Current Charging Infrastructure

For buses, the EVSE types can also be overhead or pantograph based. Considering that the battery capacities for buses are typically much larger than those of 3 or 4 wheelers, a significantly higher level of charging will be required. The U.S. Society of Automotive Engineers (SAE) is considering charging voltage (V) limits in the range of 500 V to 1000 V and current ampere (A) limits from 200 A to 350 A, which provides a maximum 350 kW DC charge. For buses, the following standards are under consideration[48]:

1. Manual 3 phase AC at high power—SAE J-3068
2. Manual DC connection at high power—SAE J-1772
3. Overhead or pantograph connection at high power—SAE J-3105

iii. AC Pulse Charging Stations:

These chargers are typically deployed on heavy duty vehicles (buses and trucks) mostly through the use of pantograph style connectors due to the heavy pulsed charging currents involved. This method allows for charging en-route (and not just at depots) as well due to its short duration. The cost of the charger is high due to its use of Ultra Capacitors and DC-DC pulse boosting converters.

3.3 EVSE COMMUNICATION STANDARDS

While power standards are key to determine interoperability to charge different makes of EVs, with different makes of EVSEs, their management and use for services to respective owners is the key function of the standardization of communication standards. Figure 3-3 shows the communication requirements between EV and EVSE and EVSE/EV with the electric grid through electric utilities and EVSE service providers (EVSP). These communication standards are further described below.

[48] EPRI IWC Bus and Truck Charging WG

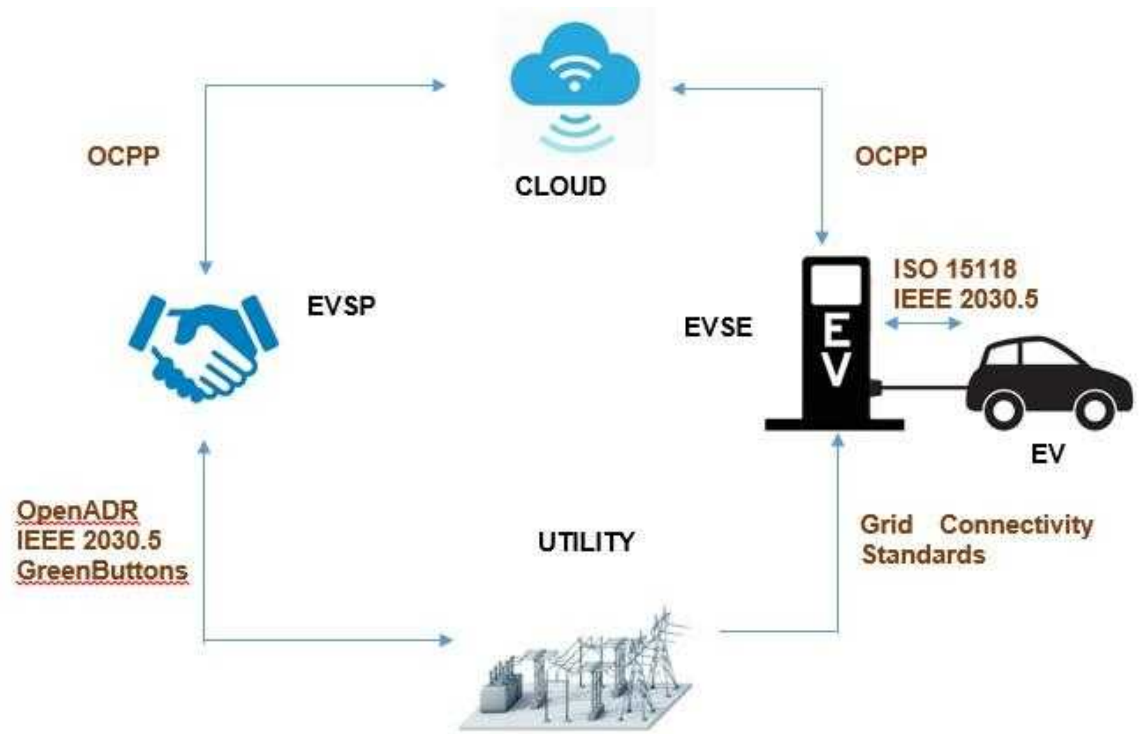

Figure 3-3: Few Globally Available Information Exchange Standard

EVSP: EVSE Service Provider; EVSE: Electric Vehicle Supply Equipment; OCPP: Open Charge Point Protocol

a. Open Charge Point Protocol (OCPP)

EVSE communicate through the internet to management software for the purposes of operating and controlling the charging stations. The Open Charge Point Protocol (OCPP) is an internationally established open protocol for the communication between EV charging stations and charging station networks (akin to a cell phone service provider). OCPP tells the charging station to communicate and send data to a particular EVSE service provider (EVSP) or operating company's charging station management software. That charging station management software is the major component of an EV charging "network".

An EV charging station network is necessary to monitor charging station up-time, control access to charging, enable payment processing, capture driver and usage data for reporting, and to integrate with enterprise software systems beyond the charging station network – including utilities, building management systems, HR systems, customer loyalty programs, and other charging station networks.

b. ISO 15118

ISO 15118 specifies the communication between Electric Vehicles (EV) and the Electric Vehicle Supply Equipment (EVSE). As the communication parts of this generic equipment are the Electric Vehicle Communication Controller (EVCC) and the Supply Equipment Communication Controller (SECC), ISO 15118 describes the communication between these components. The ISO 15118 can be applied to any vehicles that wishes to communicate with the supporting EVSE in a standardized fashion.

ISO 15118 does not specify the vehicle internal communication between battery and charging equipment and the communication of the SECC to other actors and equipment (beside some dedicated message elements related to the charging). All connections beyond the SECC, and the method of message exchanging are considered to be out of the scope as specific use cases.

c. OASIS Energy Interoperation (or OpenADR 2.0)

OpenADR is commonly being used in peak load management programs in electric utilities. The last few years have seen an increasing uptake of this standard for fast demand response (DR) programs and auxiliary service which deploy DR resources within seconds to balance inconsistent generation from renewables. Distributed energy resources (DER) management and electric vehicle charging are also key aspects in many recent trials. OpenADR 2.0 can communicate event messages, reports, registration services, and availability schedules for price- and energy usage-based programs[49].

d. IEEE 2030.5 (or Smart Energy Profile)

IEEE 2030.5 is a standard for communications between the smart grid and electricity customers. The standard is built using Internet of Things (IoT) concepts and gives consumers a variety of means to manage their energy usage and generation. Information exchanged using the standard includes pricing, demand response, and energy usage, enabling the integration of devices such as smart thermostats, meters, plug-in electric vehicles, smart inverters, and smart appliances.

e. Energy Services Provider Interface (or GreenButton)

The GreenButton initiative is an industry-led effort that responds to a White House call-to-action to provide utility customers with easy and secure access to their energy usage information in a consumer-friendly and computer-friendly format. Customers are able to securely download their own detailed energy usage with a simple click of a literal "Green Button" on electric utilities' websites.

The GreenButton initiative was officially launched in January 2012. This ensures homes and businesses to securely access their own energy information in a standard common, machine-readable format.

3.4 EVSE COSTS

The costs of EVSEs are one of the critical component that needs to be considered to support scaled deployment of EVs. For Level 2 and DCFCs, which are widely deployed using CHAdeMO and CCS standards, the following are the early 2017 costs for the United States market. While the costs may be higher, the federal-, state-, and city-level incentives and funding allocation have reduced their costs significantly. A large component of the EVSE costs is the cost-recovery through innovative operational business models. Table 3-3 shows typical costs in the United States for Level 2 and DCFC EVSE up to 100 kW. [50]

Table 3-3: Total Costs for Level 2 and DC Fast Chargers in the United States

Charger Type	Cost (in USD)
Level 2 AC Wall Mount (~7 kW)	900
Level 2 AC Ground Mount (~7 kW)	1,350
Level 2 AC Ground Mount (~25 kW)	2,410
DCFC Ground Mount (~50 kW)	31,000

[49] https://openadr.memberclicks.net/assets/using%20openadr%20with%20ocpp.pdf

[50] Present standards cover EVSE up to 150 kW only. Standards for higher capacity are in progress

Level 3 DCFC ~75 kW	56,000
Level 3 DCFC ~100 kW	78,000
Level 3 DCFC ~150 kW	>95,000

(These are indicative prices of various makes available in the market in 2016)

The hardware constitute the majority of the EVSE costs and are in the range of 45% to 65% of the total costs, depending on the type and peak charging power level. The other costs include communications, installation, commissioning, and annual operation. Figure 3-4 below shows the breakdown of these costs.

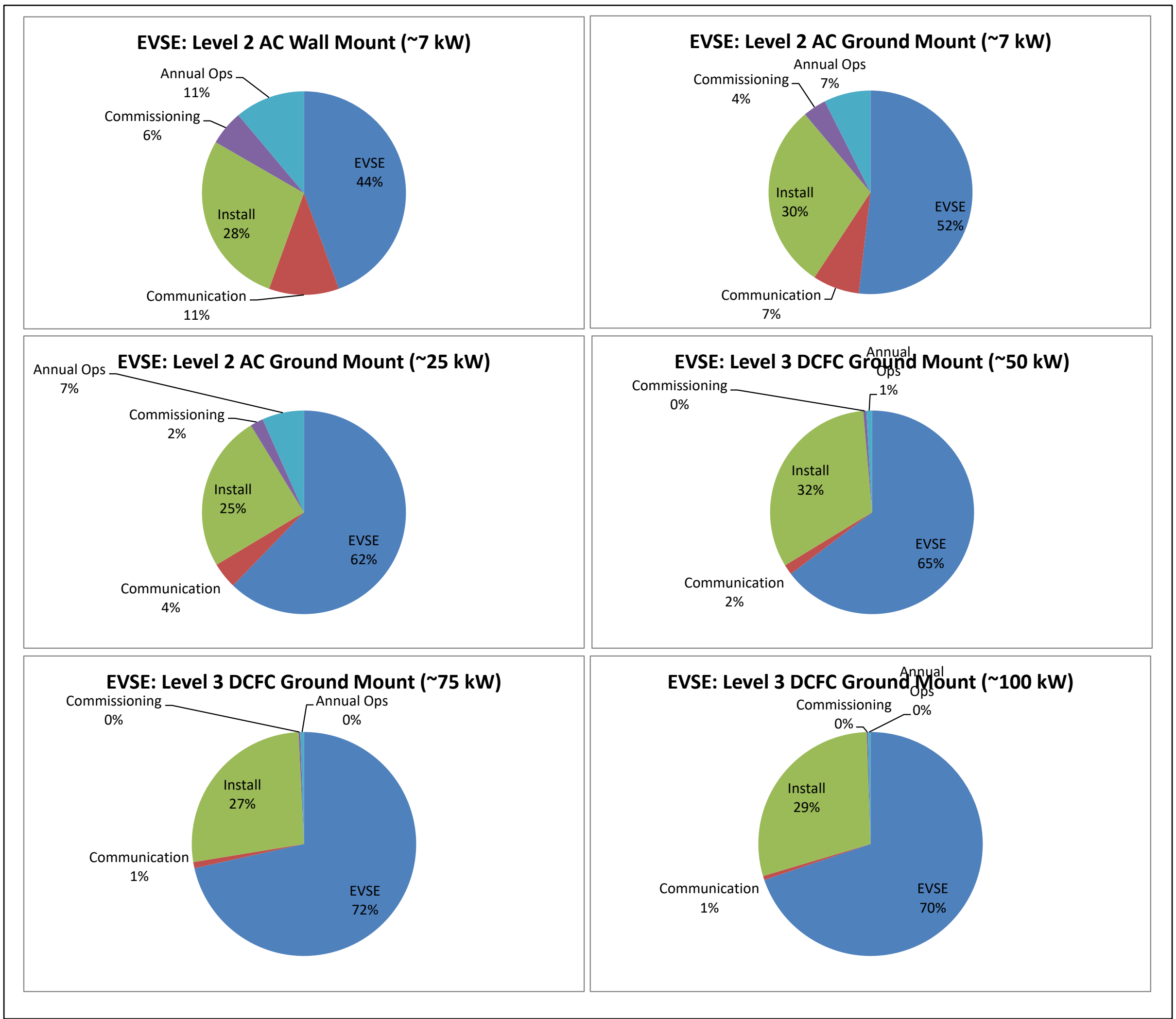

Figure 3-4: Percentage Cost Breakdown of Main EVSE Types

The EVSE costs continue to fall and not necessarily represent the true costs in India, which can be lower considering local manufacturing, scaling, and lower labour cost for installation and maintenance.

The Indian Context for EVSE Standards: Aggressive electric mobility adoption has potential for grid services, using the framework for electric mobility infrastructure and electric power systems integration. To best integrate EVs, Regulators should mandate grid interoperability using open standards that have been adopted by the electric grid participants and technology providers in other countries. This will address industry issues with vendor lock-in, and cost-effectively connect EVs with all charging network types, metering, and Smart Grid domains, to encourage innovation and advance the industry/customer experience.

List of globally available standards for Electric Vehicles are provided in Annexure B

3.5 EV CHARGER STANDARDS IN INDIA

Automobile Industry Standards (AIS) 0138 was prepared by the Automotive Research Association of India (ARAI) in 2016. This covers charger standards for both AC (Part 1) and DC (Part 2).[51]

In May 2017, a committee appointed by Department of Heavy Industries, GoI prepared charger specifications for EVs (do not cover buses).[52] These specifications includes following type of chargers:

- AC Chargers
- AC Public off-board Chargers up to a maximum charging rate of 2.5 kW or 3 kW.
- DC Public off-board Chargers
    - Level 1 DC Chargers
    - Level 2 DC Chargers

Bureau of Indian Standards (BIS), the national standards body has constituted a technical Committee (ETD-51) which is presently preparing standards for EVSEs for India.

3.6 CHARGING AND GRID CONNECTIVITY GUIDELINES

The electrical code in India provides connectivity guidelines (both Low Tension (LT) and High Tension (HT) connections). It also articulates the technical details of the load connection to be submitted to the local Distribution Companies (DISCOMs) for review. The DISCOM reviews these details primarily for determining electrical capacity requirement to feed the stated load as well as impact on power quality aspects. It then selects the rate class under which the applicant would be billed (demand charges and energy tariff).

All charging infrastructure (AC, DCFC, ACPC) falls under the electrical code purview. If the charging infrastructure is a HT connection (11 kV or higher) the captive substation design details must be submitted to the DISCOM for review (location, public safety, electrical protection/relaying, etc.) and approval. Substations that are located in proximity of public spaces require other municipal clearances like fire, water, noise, fence clearance surroundings, underground, etc. These approvals are required for each location of a charger to be installed by a third party (other than DISCOM). To the extent such charging infrastructure is drawn from an existing source point (e.g. DT), then such process is much simpler. Addition of new captive DT (415V application) is much like a new application and will go through the DISCOM approval process.

Typically, capacity requirements under 600 kVA could be delivered either through an existing DT or through the provision of a captive DT. All load capacity requirements above 600 kVA and up to 1500 kVA

[51] Electric vehicle conductive DC charging system, ARAI; https://araiindiACom/hmr/Control/AIS/922201652239PMAIS-138_Part_2_EVSEDC.pdf
[52] Committee Report on Standardization of Public EV Chargers; DHI, GoI http://dhi.nic.in/writereaddata/UploadFile/Standardization%20of%20protocol.pdf

will require an 11 kV connection with the applicant providing necessary voltage step down transformers and a functioning substation that interfaces with the charging equipment. The impulse characteristics of fast chargers (typically 3C and above) are to be studied for power quality impact and if significant, the charging station may be connected to 33 kV (instead of 11 kV) or require customer-owned mitigation equipment to reduce impact from impulse.

The fleet operator (or third party operator) who owns and operates charging facilities will be given an electrical licence to operate under the requirements of the electrical code. The code stipulates ongoing upkeep and safe operations of such charging facilities.

a. Necessary Regulatory Provisions

As a customer connected to the LT or HT grid, and duly supplied by a DISCOM, the state regulatory provisions and approved codes shall apply. The DISCOM has no powers of waivers over regulatory matters, imposed tariff structure or rates. The DISCOM merely administers the regulatory codes and regulations. The regulatory powers are in turn delivered through state or central legislation via the Electricity Act or other legislative directives.

Since the charging infrastructure for public bus fleets is a monopoly asset for the public good, the DISCOMs themselves may agree to own and operate these assets. To do this, they need to apply to the regulatory process for such acquisitions and an approved a rate recovery. If approved, a new rate class may be prescribed by the regulator or merely directed under an existing rate class.

b. Connectivity Norms/Standards—Charging Management, Batteries, and Demand Response

All charging equipment in India shall be either covered/certified to relevant standards set by the Bureau of Indian Standards (BIS). These include the following subsystems of a typical charging infrastructure:

1. Battery type, enclosure, battery management system (BMS) and all DC connection gear /equipment
2. The AC/DC power converter, associated control and protection equipment
3. Drivetrain controls, motor and all AC and DC electrical equipment such as substation that feeds the power converter
4. Others such as fire protection, anti-flooding, public safety, etc.

All batteries require a select methodology of charging to ensure its internal chemistry as well as physical parameters (thermal, mechanical, etc.) are not damaged due to an aggressive charging process. The BMS acts as safeguard here.

All batteries have a stated depth of discharge (DOD) beyond which its life is reduced. For most Lithium Ion batteries the DOD is 70% (max). The various states of charge (SOC) between 100% full charge and the maximum DOD (70%) governs the battery performance and this function is not linear. For example, a 100 kWh battery should not be discharged below a residual 30 kWh level. As the residual power in the battery decreases towards the DOD levels, the stress on the battery increases. Suitable third-party fast chargers are typically recommended by the battery vendor (through EV OEM) for suitability as otherwise it may be detrimental to the battery employed. Also, the drivetrain is also mated with a particular battery type and size for optimum performance.

Smart chargers may have communications connectivity at the grid side to DISCOMs to be able to reduce charging power levels under voluntary /subscription based participation in a Demand Response program. The charging power levels set by the fleet operator to optimize the charging process may be given precedence over participation in the DR program.

CHAPTER 4 EXISTING PUBLIC TRANSPORT AND ELECTRICITY INFRASTRUCTURE IN KOLKATA

As emphasized in the introduction, Kolkata represents a unique opportunity for electrification of public transportation. In addition to the strong reliance on electric-based transportations (Trams) and existing electricity distribution network, the progressive public officials and relevant state agencies are supportive of city's transition to electric mobility. In this chapter we dive into micro-level focus and reviews the existing infrastructure for: (1) public transport infrastructure for railways, metros, trams, buses, 3 wheelers (all land), and ferries (water) and their routes; and (2) electricity distribution infrastructure at sub-station and distribution transformer (DT) levels, to prioritize the electrification of public transport.

4.1 EXISTING PUBLIC TRANSPORT INFRASTRUCTURE

Kolkata Metropolitan Area (KMA) has an extensive network of public transport system consisting of Railways, Metros, Trams, Ferries and Buses. Existing Intermediate Public Transport (IPT) modes such as Auto-Rickshaw, Cycle Rickshaw and Hand-Rickshaw serve the last mile connectivity in the city. In this section, the details of existing rail, metro, tram, bus, 3 wheeler and ferry services are presented as adopted from the report prepared by RITES for World Bank in 2016.

a. Rail Infrastructure

The KMA has a total of 145 railway stations and is served by sub-urban rail system of the Indian Railways, along with the main trunk railway network which provides much frequent trains and connects the surrounding areas of Kolkata. The extent of sub-urban rail system is not restricted till KMA boundary, but it caters the entire Southern region of the West Bengal state. This includes the entire six administrative districts of Kolkata, Howrah, Hooghly, North24 Parganas, South24 Parganas and Nadia. The sub-urban rail along with main railway system is operated and maintained under three divisions of railways in KMA, namely Howrah, Sealdah and Kharagpur. This entire rail network including the sub-urban system is already electrified.

b. Metro Corridor

Presently Kolkata city has a 27.22 km long Metro Railway line with 24 stations in operation from Dum Dum in the North to Kavi Subhash in the South of the city. A metro corridor on the east-west urban area for an approximate length of 14.67 km is under construction. The figure 4-1 below shows the Kolkata metro system. This map also shows future lines under planning stage.

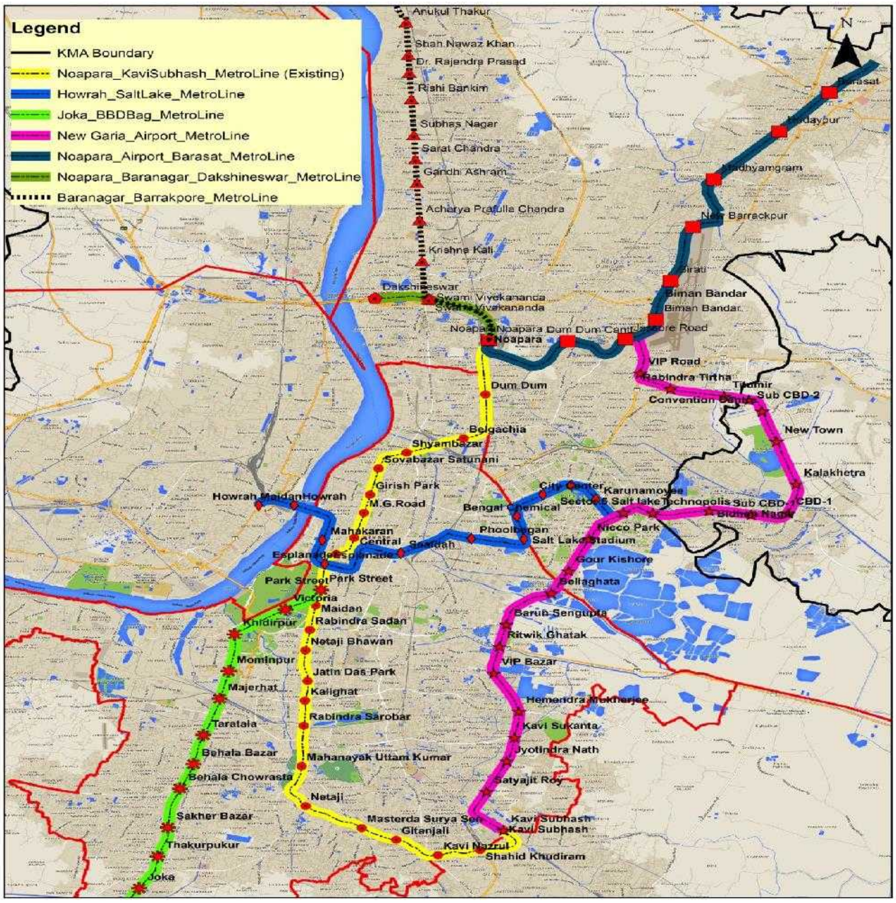

Figure 4-1: Kolkata Metro Map

c. Trams

Trams are in operation in Kolkata since 1902 and are managed by the Calcutta Tramways Company (CTC). Currently, 151 trams are running on 24 routes daily. The trams are operated on 550 V DC overhead electric network. Tram network extends over 57 km with double tracks within the city limits. Out of the total track length, about 3.2 km is reserved for tram movement only; and in the remaining length of the tram route other vehicles also ply. The figure 4-2 shows the tram network along with the 10 substations that feed the 550 V DC network.

Figure 4-2: Kolkata Tram Map with 6kV/415V Substation

d. Buses

Kolkata Metropolitan Area has a well-established bus system with multiple government and private operators. There are 5 STU's and a number of private operators providing bus services. The 5 STUs mentioned below have now been merged under West Bengal Transport Corporation (WBTC)

1. Calcutta State Transport Corporation (CSTC)
2. Calcutta Tramway Company (CTC)
3. West Bengal Surface Transport Corporation (WBSTC)
4. South Bengal State Transport Corporation (SBSTC)
5. North Bengal State Transport Corporation (NBSTC)

There are 925 bus routes operating in KMA, out which 242 routes (26%) are run by city bus operators like CSTC, CTC, WBSTC, and STA. A total of 134 bus routes (14%) are long distance routes (operated by SBSTC and NBSTC), which either originate in Kolkata or pass through Kolkata as one of the intermediate station. Remaining 549 routes (60%) are operated by private operators in KMA. Table 4-1 presents the details of all agencies, number of routes and buses.

Table 4-1: Bus operators and Number of Bus operated in Kolkata

S.No.	Agency	Bus Operator	Total No. of Routes	Total No. of Buses
1	CSTC	Government	110	808
2	CTC		84	345
3	WBSTC		40	313
4	NBSTC		30	79
5	SBSTC		104	241
6	Kolkata RTA	Private	303	5583
7	Howrah RTA		111	1672
8	North 24 Parganas RTA		53	1150
9	South 24 Parganas RTA		27	356
10	Nadia RTA		6	112
11	Hooghly RTA		49	882
12	STA (West Bengal)	Government	8	80
	Total		**925**	**11621**

Representative route maps for CTC, WBSTC, and private network are shown in figures 4-3, 4-4, and 4-5.

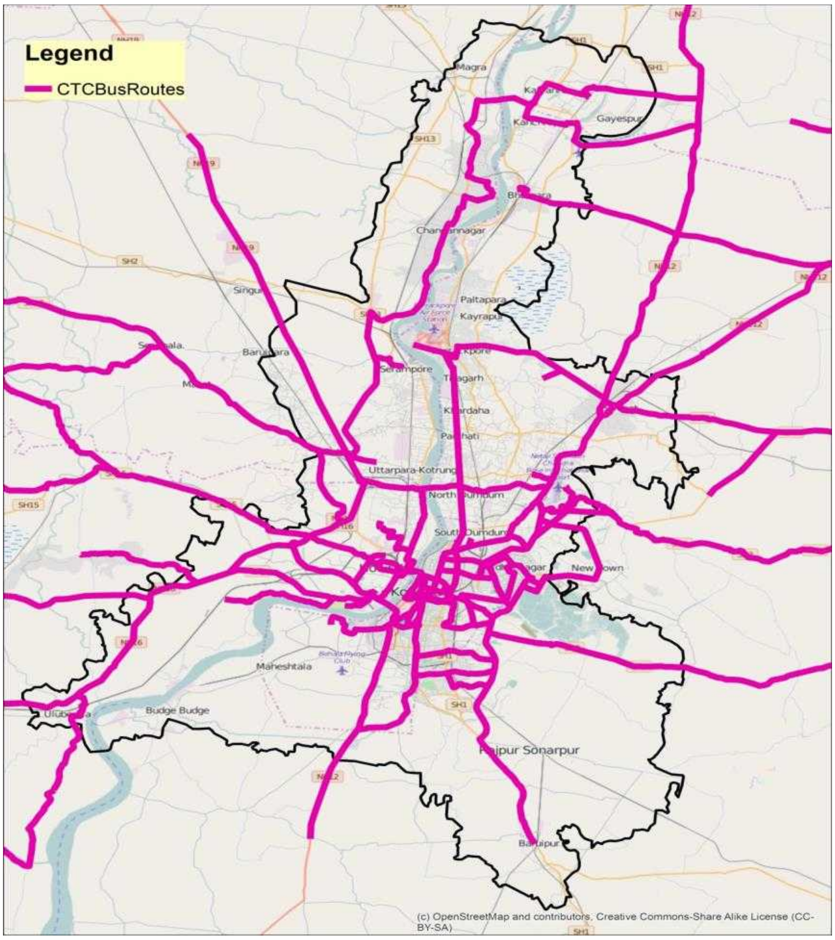

Figure 4-3: CTC bus routes

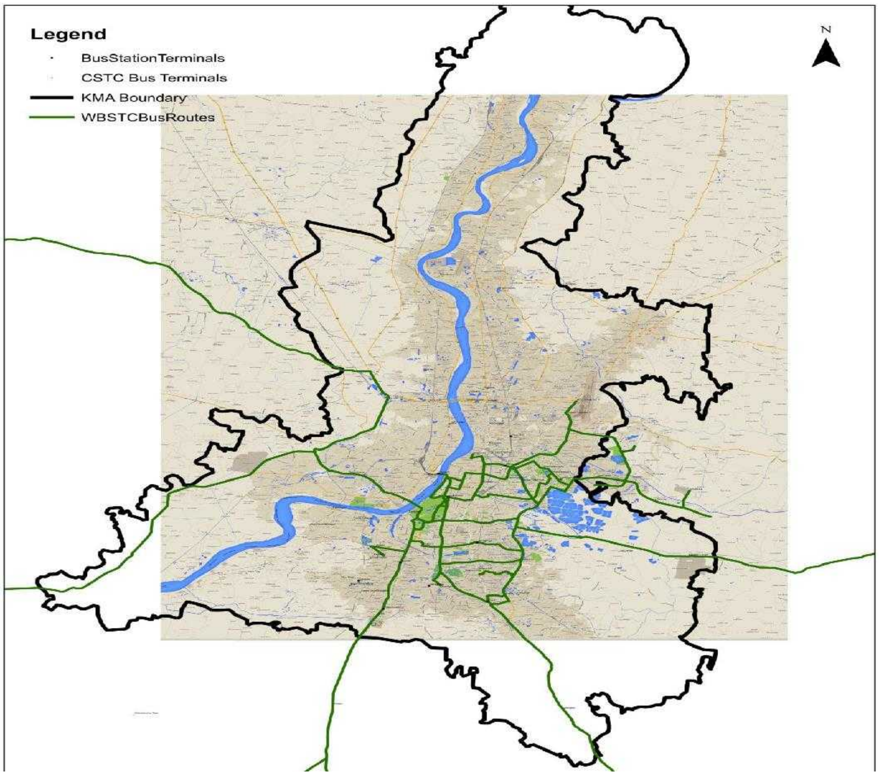

Figure 4-4: WBSTC Bus network

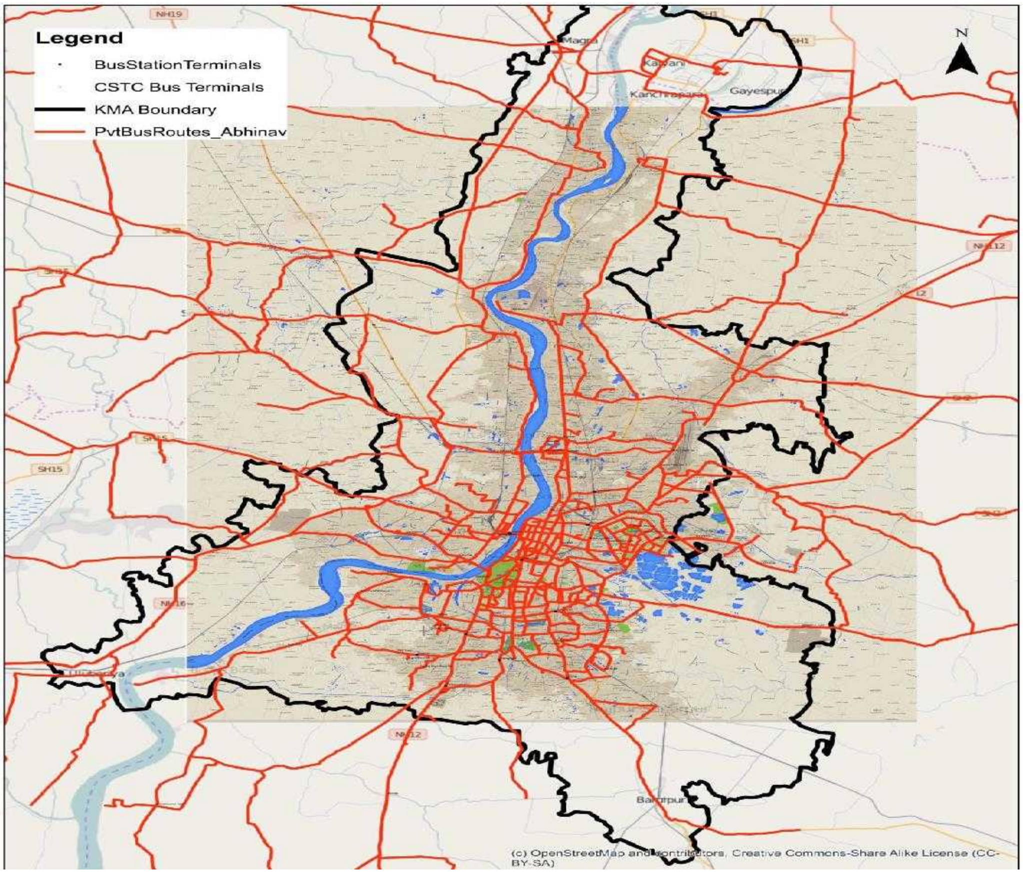

Figure 4-5: Private Bus network

e. 3 Wheelers (Auto-rickshaws and e-Rickshaws)

Kolkata city has a very good network of 3 Wheelers operated by independent owners/operators. Unlike other cities, auto-rickshaw in Kolkata run on fixed routes, not from any point to another point. From a regulatory perspective, the West Bengal state transport department regulates auto-rickshaws in Kolkata through regional transport authority (RTA) that function at the district level, issuing route-based permits and other documents like fitness certificates, pollution under control certificates, etc. There are 125 routes for which permits are issued by RTA. The total number of permits issued to auto-rickshaw by RTA was 11,315 (2017).[53] Auto-rickshaws run on LPG/CNG are only permitted in Kolkata. E-Rickshaws (locally knows as TOTOs) that operate in the outskirts of the city are estimated to be over 100,000.

In 2016, Centre for Policy Research (CPR) conducted a study sponsored by Shakti Sustainable Energy Foundation (SSEF) on 3 wheelers in Kolkata. [54] The study used GIS mapping to determine the routes and functioning of the 3 wheeler routes in the city. Some of the key findings of the study are summarised below:

- In the peripheral areas of Kolkata, the battery-operated e-rickshaw or 'toto' thrives due to low costs and negligible regulation. Presently, totos are not allowed in Kolkata Metropolitan Corporation (KMC) area. With the recent inclusion of e-rickshaws under the mandate of the Motor Vehicles Act, 1988 in 2015, 'totos' are expected to become more accessible forms in Kolkata city under

[53] http://transport.wb.gov.in/wp-content/uploads/2017/04/2017-03-31-notification-on-auto-routes-n-maximum-permits-in-Kolkata-1276.pdf

[54] Research Study, Dec 2016 – "Integrating Intermediate Public Transport Within Transport Regulation in a Megacity: A Kolkata Case Study" by Centre for Policy Research and Shakti Foundation

registration and other regulatory compliance

- The study found that about 72% of the city's municipal area is only half a kilometer away from an auto route. About 70% of the respondents (to a survey) in the city, preferred auto-rickshaws as convenient, affordable and faster mode of transport for both last mile connections and multiple legs of their daily commute
- The convenience of autos is also underscored by their intense usage even by those who own private vehicles. Interestingly, the study finds that 58% and 48% of daily auto users own four-wheelers and two-wheelers respectively. The emissions savings achieved by this set of users opting for a shared mode of transport over private vehicles is substantial (cleaner LPG/CNG fuel and utilizing less road space).
- Auto rickshaws are also perceived as safe, even by women who use them for a variety of trips through the day as well as to commute to work
- The report suggests that the auto rickshaw system be strengthened by rationalizing permits and routes based on robust data collection systems; improving regulatory efficiency and eliminating daily cash transactions

Figure 4-6 shows the map of auto-rickshaw routes.

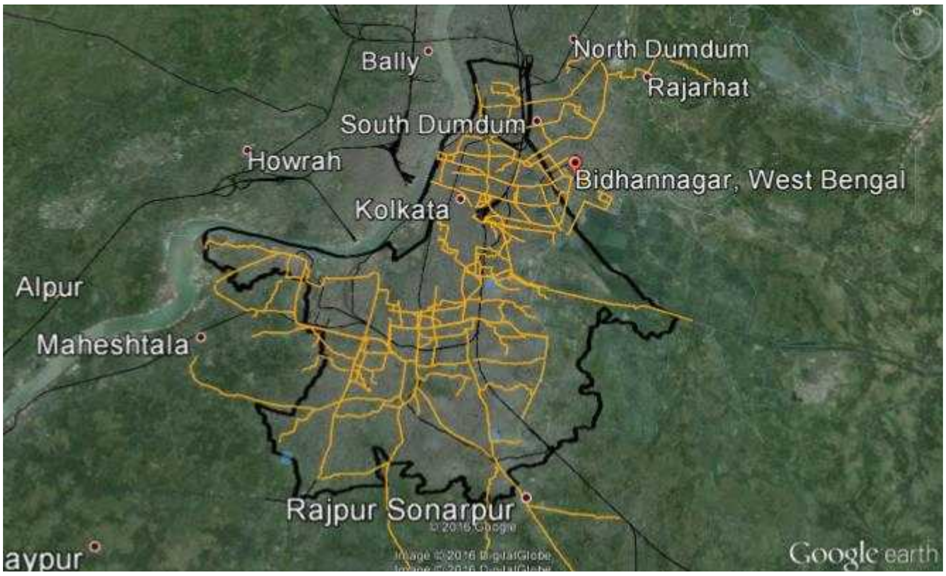

Figure 4-6: 3W Route Map of Kolkata

f. Taxi Cars

Limited information could be collected about taxis in Kolkata for this study. As per city government data, Kolkata had 41,393 licenced taxis operating in 2015[55]. But as per our secondary research and from publicly available data, it is estimated that Kolkata has some 14,000 conventional taxis and 30,000 vehicles running under Ola and Uber[56].

[55] West Bengal Statistical Book 2015
[56] http://www.thehindubusinessline.com/economy/logistics/kolkatas-yellow-cabs-to-roar-on-tygr-app/article9640379.ece

g. Ferries

Kolkata has a good network of passenger and/or vehicular ferries across the Hooghly River that runs through the Howrah-Central Kolkata area. Crossing the Hooghly River is generally faster and more convenient by ferries than by using the clogged road bridges (especially during rush hour). Ferries depart about every 7 to 20 minutes from Howrah to jetties in central Kolkata.

These ferries transport both passenger loads as well as vehicular/goods loads.

Ferry services in the city are operated by:

1. West Bengal State Transport Corporation (WBSTC) [57]: operates 26 number of ferries on 6 routes
2. Hooghly Nadi Jalapath Paribahan Samabay Samity (HNJPSS): operates 24 number of ferries on 8 routes
3. Municipality: operates ferries on 2 routes (Bandhghat – Ahiritola and Uttarpara – Ariadaha)

Based on the data obtained from WBSTC, the following are the highlights:

- Number of daily passengers on these routes varies across from mere 59 – 8,934 on an average daily basis. A typical passenger ferry has a capacity of about 400 passengers and/or 300 vehicles. Few boats are slightly smaller (150/112 and 250/187)
- Most of the boats are about 26 years old although there a few recent models (less than 5 years old) as well
- Most of these ferries have an average power of 102 HP x 2 (78 kW x 2). The biggest ones are rated at 140x2 HP (107x2 kW) and 180x1 HP (137x1 kW). The average consumption of diesel by these ferries is 13 litres per hour

The following are the passenger ferry service routes operated by WBSTC:

Table 4-2: Passenger Ferry Routes Details

Passenger Routes	Daily Average Passenger Service	Average Daily Frequency	Average Travel Time	Number of boats plied
Howrah - Shipping	6,976	10 min	10 min	3
Howrah – Farlie	6,376	10 min	8 min	3
Belur - Dakshineswar	1,666	30 min	30 min	3
Farlie - Bichalighat	59	3 hours	60 min	1
Ariada – Shipping (via Dakshineswar/Belur/Kutighat/Ratanbaurghat/Baghbazaar/ Howrah/Farlie)	05	12 hours	30 min	1
Lot – 8 – Kachuberia	8,934	No Data	45 min	5

[57] Listing And Mapping Of Public Transport Infrastructure And Routes In Kolkata Metropolitan Area (KMA) by RITES under World Bank Project

The following are the vehicular ferry service routes of WBSTC:

Table 4-3: Vehicular Ferry Routes Details

Vehicular Routes	Average Travel Time	Number of Boats Plied
Namkhana - Naraynpur	10 min	2
Hasnabad – Par-Hasnabad	10 min	1
NebuKhali - Dulduli	15 min	1

The following are the passenger ferry service routes operated by HNJPSS:

Sl. No.	Route	Frequency (Peak Hr) min	Frequency(Lean Hr 1 to 4pm) min
1.	Howrah - Chandpal	10	15
2.	Howrah - Fairley	10	15
3.	Howrah - Armenian	10	15
4.	Howrah - Bagbazar	15	15
5.	Chandpal - Ramkrishnapur	10	-
6.	Metiaburuj - Nazirgunj	10	-
7.	Bauria - Bujbuj	15	-
8.	Bagbazar - Cossipore	30	-

Figure 4-7 shows the map of existing ferry routes.

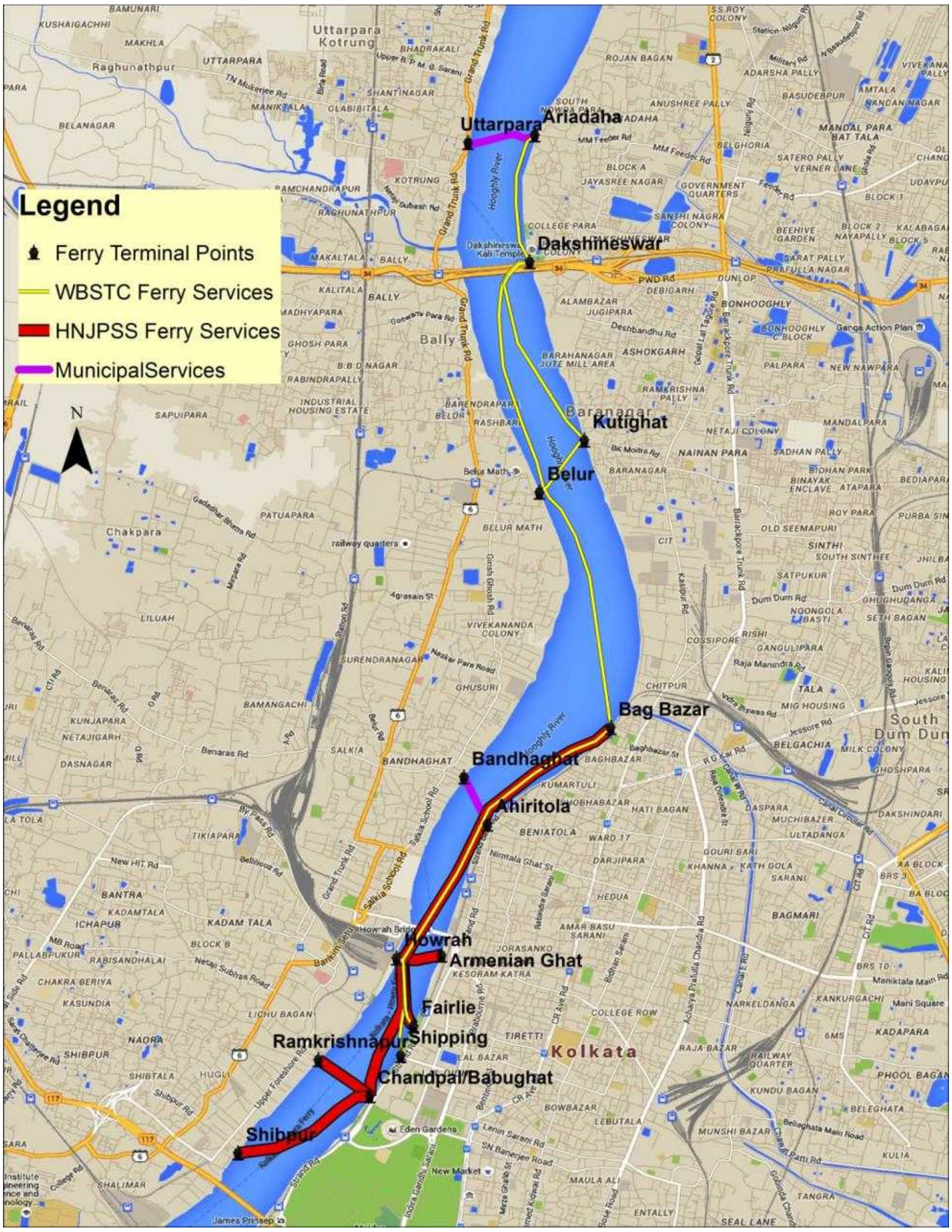

Figure 4-7: Ferry Route Network

Details on ferry service operated by municipality are still awaited.

4.2 ELECTRICITY DISTRIBUTION INFRASTRUCTURE

In India, electricity distribution is relatively the same across the country. The DISCOMs own and operate the distribution systems and supply power to customers on its captive wires. These DISCOMS inherently being monopolies, are regulated in each state by respective State Electricity Regulatory Commissions. The City of Kolkata is fed by two DISCOMs i.e. Calcutta Electric Supply Company (CESC) which is privately owned and West Bengal State Electricity Distribution Company (WBSEDCL) which is a State Government-owned entity. In Kolkata, in addition to its AC distribution network, there is an existing overhead 550V DC system that feeds the tram network. The asset is relatively old and in need of some upgrades, but could be a leveraged for fast DC charging of bus fleet.[58] This DC network is owned and operated by CTC with AC feeds from CESC.

Although parts of Kolkata city is serviced by WBSEDCL, this study focuses on the distribution system of the city core which is serviced by CESC.

Typical distribution networks receive bulk power at 33 kV stations and then get distributed on 11 kV lines. They are further stepped down from 11 kV to secondary voltages at 415 V using DTs to retail customers, residential, commercial, and industrial centres. Large load customers such as industrial plants are fed at 11 kV or 33 kV directly.

The EV charging infrastructure will need to be accommodated (as a load point) within the network. Smaller L2 chargers (>30 Amps) could be fed at 415V but power supply for most fast chargers have rating between 600-1500 kW that would need to be fed at 11 kV (with the charger location having its own step-down transformer). Thus, a network of such charging stations for public fleet charging (both small and big) requires a careful study of existing daily load patterns, seasonal load patterns to determine "headroom" capacity in DT and on the 11 kV feeders. This determination needs to be worked out with local DISCOMs.

4.3 TYPICAL OBSERVATION ON POWER AVAILABILITY FOR EV CHARGING

The following table 4-4 (given by CESC) provides a good insight into hourly "headroom" availability on DTs for EV charging. The table shows hourly DT loading data collected from 4 representative DTs (residential, commercial, industrial, and commercial cum residential) for a typical summer and a winter day.

Table 4-4: Hourly Headroom Availability in Kolkata DTs in a Selected Area

	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Kasba Ind DT 400KVA	I	N	D	U	S	T	R	I	A	L														
04/2016	60	60	60	60	60	60	90	90	180	310	325	340	300	320	270	270	270	240	150	120	60	60	60	60
11/2016	50	50	50	50	50	75	75	100	200	250	250	225	200	220	220	225	225	225	175	125	75	75	75	60
Jadavpore DT 400KVA	C	O	M	M	E	R	C	I	A	L		+		R	E	S	I	D	E	N	T	I	A	L
04/2016	40	40	40	30	30	30	30	30	50	75	125	150	135	125	120	120	175	260	260	275	250	200	75	50
11/2016	15	15	15	15	15	15	15	15	15	20	60	60	60	45	45	75	135	135	120	120	105	60	15	15
Kalagachia DT315 KVA	I	N	D	U	S	T	R	I	A	L		+		R	E	S	I	D	E	N	T	I	A	L
04/2016	260	240	210	240	210	240	270	270	270	270	260	250	270	300	315	315	315	325	325	325	310	270	270	270
11/2016	170	160	140	140	140	150	160	180	190	200	220	210	180	180	210	220	220	220	210	220	210	220	190	180
Ezra St T/H DT 600KVA	C	O	M	M	E	R	C	I	A	L														
05/2016	25	25	25	25	25	25	25	25	45	100	350	425	425	456	430	430	425	420	175	125	40	25	25	25
12/2016	15	15	15	15	15	15	15	15	30	60	210	240	240	240	240	247	247	235	75	50	20	15	15	15

An enlarged version of this table is shown in Annexure C

The key findings from this DT load analysis are:

1. Typical sample load patterns to show where EV charging is possible - during the day/night, and summer/winter
2. Each DT sample case has varying name-plate capacities (kVA)

[58] Considering the focus of the study on the public transportation, buses have been proposed. Depending on the ownership and operation models that the state determines, this infrastructure can be accessed by others (e.g., cars).

3. The colored bars denote capacity availability on that specific DT, relative to the load already present at that time
    a. Red denotes little or no capacity available for EV charging
    b. Yellow denotes about 40-50% DT capacity is availability for EV charging
    c. Green denotes about 80% of DT capacity is available for EV charging

It is observed that 315 kVA rsidential DTs have headroom for charging only during 4 months in winter.

The CESC electrical network diagram in Kolkata is depicted in figure 4-8.[59]

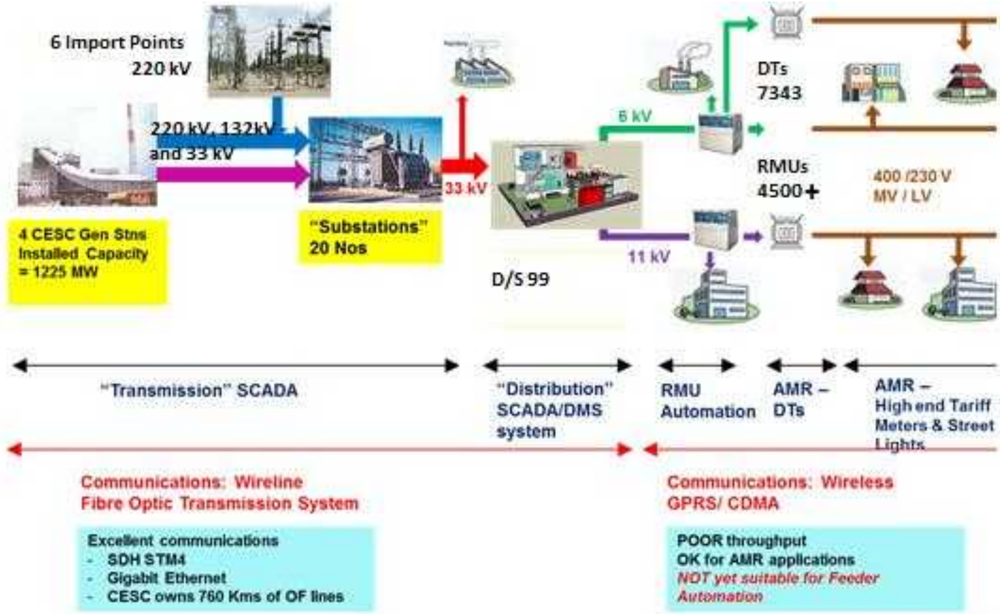

Figure 4-8: CESC Network Diagram *(Figure Source: Tetra Tech ES and ESTA International)*

Next Chapter analyses the above traffic and electrical data to identify priority routes (buses, 3 wheelers and ferries) for electrification and assess the capability of the electrical network to support charging infrastructure for the same.

[59] Tetra Tech ES, and ESTA International, Feasibility Study for the CESC Smart Grid Project, 2013

CHAPTER 5 ROUTE ANALYSIS AND PRIORITIZATION FOR ELECTRIFICATION

This chapter presents the analysis of public transport traffic data compiled from different sources and the electrical infrastructure, as provided by the Calcutta Electric Supply Company (CESC). Based on the study and analysis of their data, priority action plan for electrification of public transportation is proposed here.

a. Buses

As briefed in previous chapter there are 11,621 public buses operating on 925 routes in Kolkata. Leveraging the traffic study conducted by World Bank together with their associate, M/s Ideation Technologies, we have conducted additional detailed analysis to identify priority routes and charging infrastructure models for electrification of buses; and have selected top 10 priority bus routes for immediate electrification based on the following selection criteria:

- **Route Congestion:** Most congested routes contribute to higher fuel consumption and higher emission
- **Route Distance:** Shorter routes opted to optimize lower battery size and hence lower cost of EVs
- **Overlap with Electric Tram Infrastructure**: Access the existing DC infrastructure for EV charging and avoid potential infrastructure cost for fast charging

Our analyses resulted in the selection of nine bus routes operated by CSTC and one route (VS1) operated by WBSTC, as shown in Table 5-1. It can be seen most of the routes have maximum length of about 20 km, which overlap with the electric tram network with varying percentages.

Table 5-1 Kolkata Top 10 Bus Routes Selected for Electrification

S.No	Route Name	Source to Destination	Average Passengers/bus/trip	Route Length (km)	Overlap with Tram network (%)
1	E-01	Jadavpur 8B Bus Stand – Howrah	41.03	13.5	14.29
2	S-03A	Sealdah (Jagat Cinema) - Thakurpukur 3a Bus Stand	33.87	17	43.47
3	S-03B	Behala 14 No – Kankurgachi	35.26	14.5	51.71
4	S-05	Garia Bus Stand – Howrah	42.95	17.5	21.74
5	S-07	Garia Bus Stand – Howrah	35.46	16.5	26.47
6	S-12D	Howrah -	45.26	17	9.38

		Thakurpukur 3A Bus Stand			
7	S-12	Howrah - Newtown Bus Depot	34.30	20.5	17.24
8	S-22	Sakuntala Park - Karunamoyee (Salt Lake)	32.51	16.5	12.5
9	S-47A	Behala Airport – Howrah	35.62	15	36.36
10	VS-1	Airport 2 No Gate – Esplanade	37.41	20	21.88

Brief details and maps of each of the above routes are presented below.

1. ROUTE E1: JADAVPUR 8B BUS STAND – HOWRAH

STOPS: DHAKURIA / ANWAR SHAH ROAD / RASHBIHARI MORE / KALIGHAT / HAZRA / RABINDRA SADAN / PARK STREET / ESPLANADE / B B D BAG / BARABAZAR

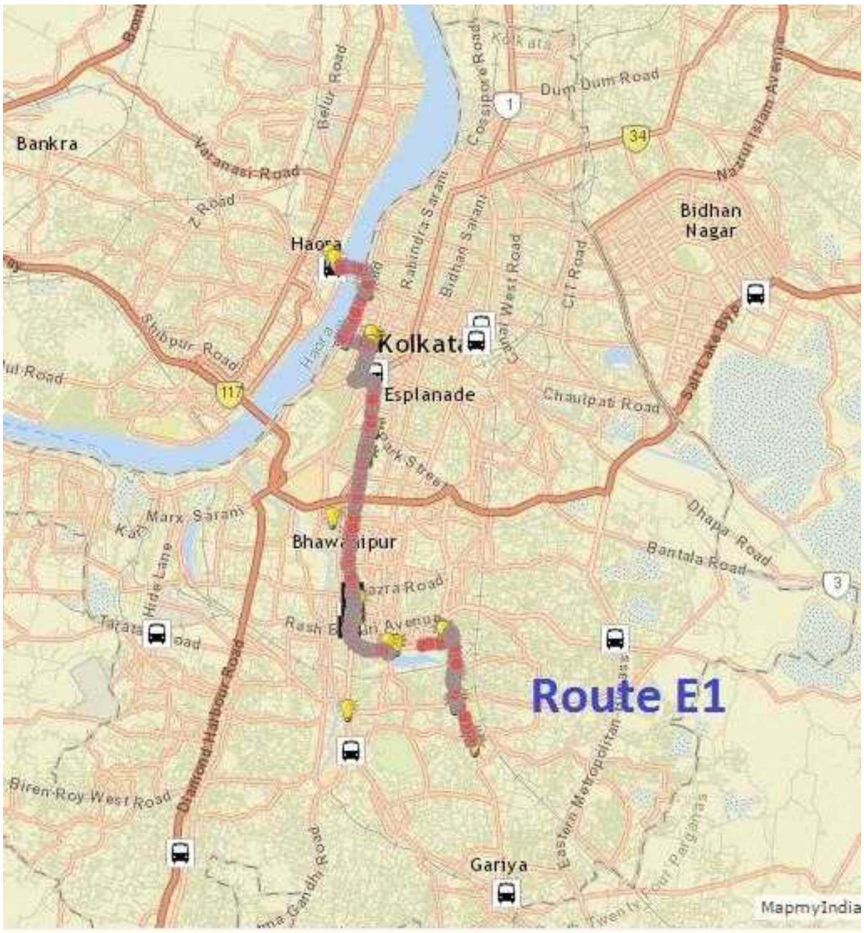

Figure 5-1: E1 Route Map

Peak Hour Frequency	Average Number of Passenger/day/Journey	Number of buses operated	Bus trips/day/bus	Number of Bus Depots (Start – On route – End)
5 Mins	41.03	19	3	2

Bus Depots on this route and the available electrical infrastructure there are:

Bus Depot Name	Substation	Transformer Capacities (kVA)	Peak Load (Amp)	
			Day	Night
Howrah	Mukhram Kanoria Rd O/T	315	168	204
Esplanande	Esplanade (S) P/T	315	204	300

2. ROUTE S3-A: SEALDAH (JAGAT CINEMA) - THAKURPUKUR 3A BUS STAND

TOPS: BEHALA / TARATALA / MOMINPUR / KHIDIRPUR / FORT WILLIAM / ESPLANADE / B B D BAG / LALBAZAR / BOWBAZAR / GOENKA COLLEGE / AMHERST STREET

Figure 5-2: S3A Route Map

Peak Hour Frequency	Average Number of Passenger/day/Journey	Number of bus operated	Bus trips/day/bus	Number of Bus Depots (Start – On route – End)
15 Mins	33.87	13	3	4

Bus Depots on this route and the available electrical infrastructure there are:

Bus Depot Name	Substation	Transformer Capacities (kVA)	Peak Load (Amp)	
			Day	Night
Sealdah (Jagat cinema)	A. P. C. RD (E) O/T NO.9	315	96	96
Silpara	SAKHER BAZAR (N) O/T	315KVA	180	216
Esplanade	Esplanade (S) P/T	315	204	300
Raja Bazar	RAJABAZAR P/T	400	384	348

3. ROUTE S3 B: BEHALA 14 NO - KANKURGACHI

STOPS: TARATALA / MOMINPUR / KHIDIRPUR / KHIDIRPUR / FORT WILLIAM / BABU GHAT / B B D BAG / B B GANGULI ST / SEALDAH / RAJA BAZAR / PHOOLBAGAN

Figure 5-3: S3 B Route Map

Peak Hour Frequency	Average Number of Passenger/day/Journey	Number of bus operated	Bus trips/day/bus	Number of Bus Depots (Start – On route – End)
15 Mins	35.26	16	3	3

Bus Depots on this route and the available electrical infrastructure there are:

Bus Depot Name	Substation	Transformer Capacities (kVA)	Peak Load (Amp)	
			Day	Night
Raja Bazar	Raja Bazar P/T	400	384	348
Sealdah(Jagat Cinema)	APC Rd (E) O/T No.9	315	96	96
Esplanade	Esplanade (S) P/T	315	204	300

<u>4. ROUTE S5: GARIA BUS STAND - HOWRAH</u>

STOPS: BAGHAJATIN / JADAVPUR / DHAKURIA / GOLPARK / SOUTHERN AVENUE / DESHAPRIYA PARK / RASHBIHARI MORE / KALIGHAT / HAZRA / RABINDRA SADAN / PARK STREET / ESPLANADE

Figure 5-4: S5 Route Map

Peak Hour Frequency	Average Number of Passenger/day/Journey	Number of bus operated	Bus trips/day/bus	Number of Bus Depots (Start – On route – End)
15 Mins	45.26	10	3	4

Bus Depots on this route and the available electrical infrastructure there are:

Bus Depot Name	Substation	Transformer Capacities (kVA)	Peak Load (Amp)	
			Day	Night
Howarah	Mukhram Kanoria Rd O/T	315	168	204
Kalighat	Apurba Mitra Road O/T	400	480	465
Garia Bus Stand	Garia O/T	315	360	348
Esplanade	Esplanade (S) P/T	315	204	300

5. ROUTE S7: GARIA BUS STAND - HOWRAH

STOPS: NAKTALA / RANIKUTHI / TOLLYGUNJ / RASHBIHARI MORE / KALIGHAT / HAZRA / RABINDRA SADAN / PARK STREET / ESPLANADE / B B D BAG

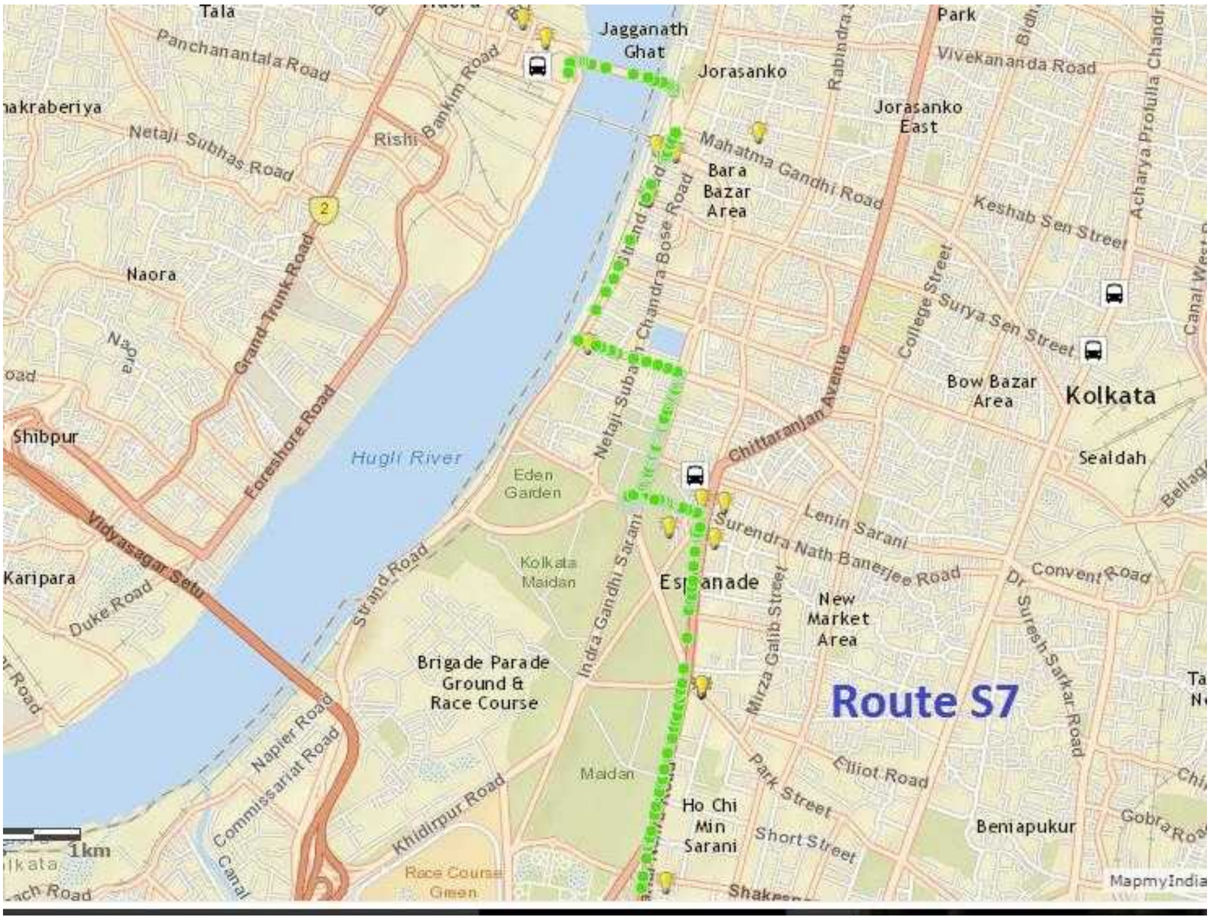

Figure 5-5: S7 Route Map

Peak Hour Frequency	Average Number of Passenger/day/Journey	Number of bus operated	Bus trips/day/bus	Number of Bus Depots (Start – On route – End)
15 Mins	35.46	10	3	5

Bus Depots on this route and the available electrical infrastructure there are:

Bus Depot Name	Substation	Transformer Capacities (kVA)	Peak Load (Amp)	
			Day	Night
Kalighat	Apurba Mitra Road O/T	400	480	456
Tollygunge Metro	DESHAPRAN SASMAL RD (S) T/H	315	48	132
Garia Bus stand	Garia Bus Stand O/T	315	384	360
Esplanade	Esplanade (S) P/T	315	204	300
Howarah	Mukhram Kanoria Rd O/T	315	168	204

6. ROUTE S 12D: HOWRAH - THAKURPUKUR 3A BUS STAND

STOPS: B B D BAG / ESPLANADE / FORT WILLIAM / KHIDIRPUR / MOMINPUR / TARATALA / BEHALA

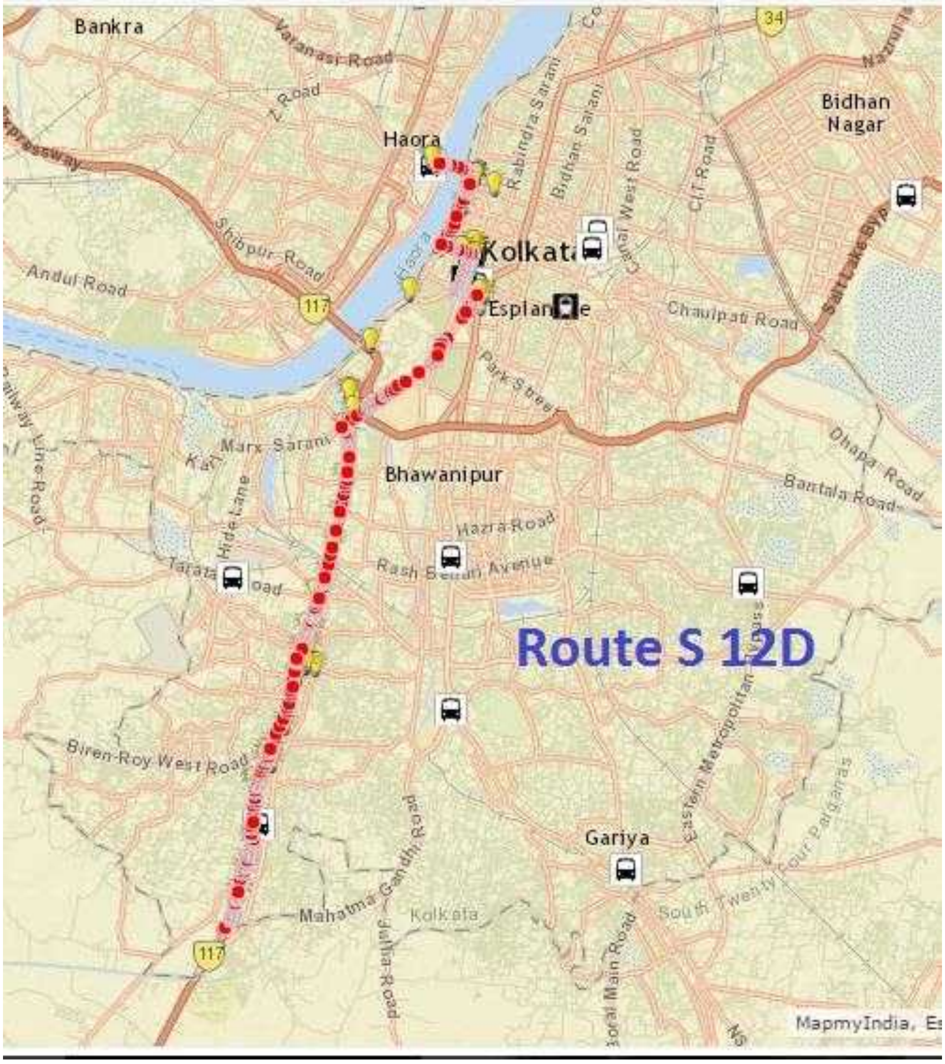

Figure 5-6: S 12D Route Map

Peak Hour Frequency	Average Number of Passenger/day/Journey	Number of bus operated	Bus trips/day/bus	Number of Bus Depots (Start – On route – End)
10 Mins	45.26	10	3	3

Bus Depots on this route and the available electrical infrastructure there are:

Bus Depot Name	Substation	Transformer Capacities (kVA)	Peak Load (Amp)	
			Day	Night
Howrah	MUKHRAM KANORIA RD O/T	315	168	204
Esplanade	ESPLANADE (S) P/T	315	204	300
Silapara	SAKHER BAZAR (N) O/T	315KVA	180	216

7. ROUTE S 12: HOWRAH - THAKURPUKUR 3A BUS STAND

STOPS: TECHNOPOLIS / COLLEGE MORE / NICCO PARK / CHINGRI GHATA / BELIAGHATATA ID / C I T MORE / URIA BAGAN / SALES TAX / MOULALI / SUBODH MALLICK SN / ESPLANADE / B B D BAG

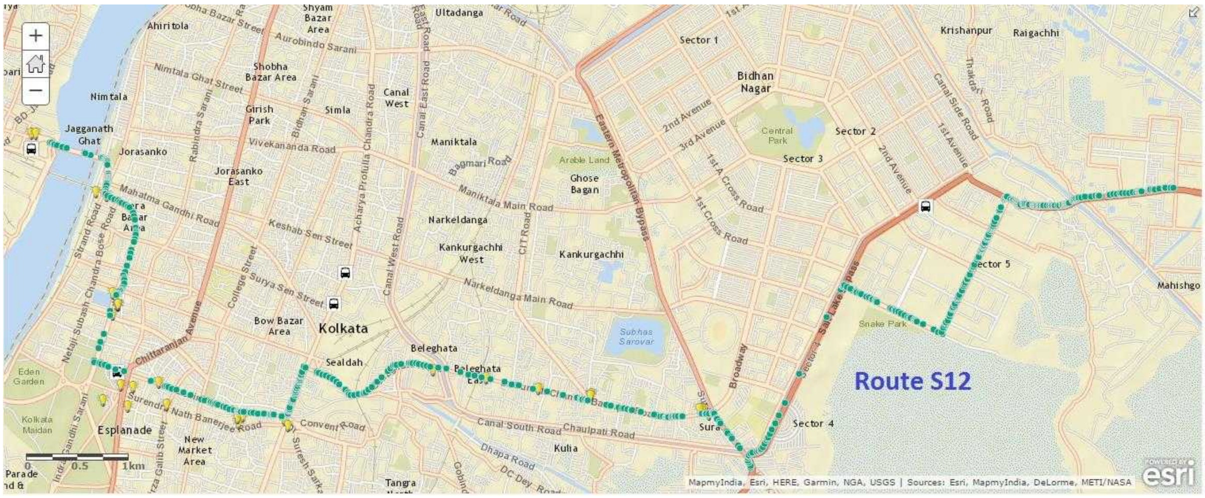

Figure 5-7: S12 Route Map

Peak Hour Frequency	Average Number of Passenger/day/Journey	Number of bus operated	Bus trips/day/bus	Number of Bus Depots (Start – On route – End)
10 Mins	34.3	13	3	2

Bus Depots on this route and the available electrical infrastructure there are:

Bus Depot Name	Substation	Transformer Capacities (kVA)	Peak Load (Amp)	
			Day	Night
Howarh	Mukhram Kanoria RD O/T	315	168	204
Esplanade	Esplanade (S) P/T	315	204	300

8. ROUTE S 22: SAKUNTALA PARK - KARUNAMOYEE (SALT LAKE)

STOPS: SARSUNA / BEHALA / TARATALA / MOMINPUR / GOPALNAGAR / HAZRA / RABINDRA SADAN / PARK STREET / ESPLANADE / MOULALI / SEALDAH / MANICKTALA

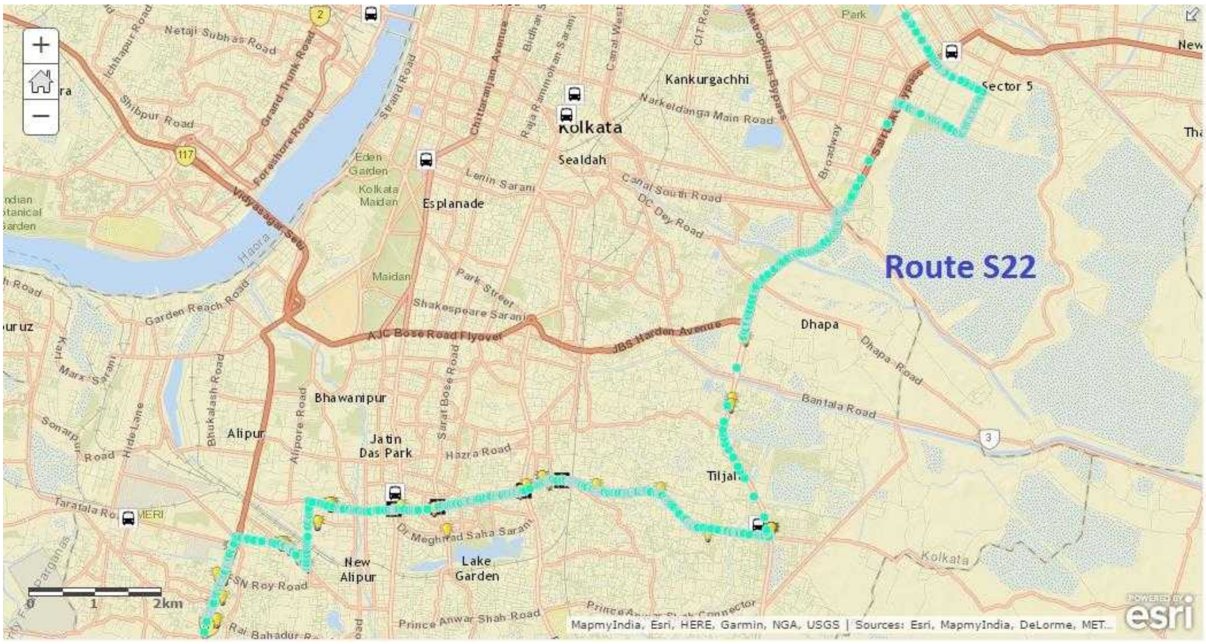

Figure 5-8: S22 Route Map

Peak Hour Frequency	Average Number of Passenger/day/Journey	Number of bus operated	Bus trips/day/bus	Number of Bus Depots (Start – On route – End)
20 Mins	32.51	15	3	3

Bus Depots on this route and the available electrical infrastructure there are:

Bus Depot Name	Substation	Transformer Capacities (kVA)	Peak Load (Amp)	
			Day	Night
Ruby More	ANANDAPUR (S) O/T NO.5	400	348	264
Kali Ghat	APURBA MITRA ROAD O/T	400	480	456
10 No. Tank	Not in CESC Area of Supply			

9. ROUTE S 47A: BEHALA AIRPORT - HOWRAH

STOPS: B B D BAG / ESPLANADE / FORT WILLIAM / KHIDIRPUR / MOMINPUR / TARATALA / PARNASREE

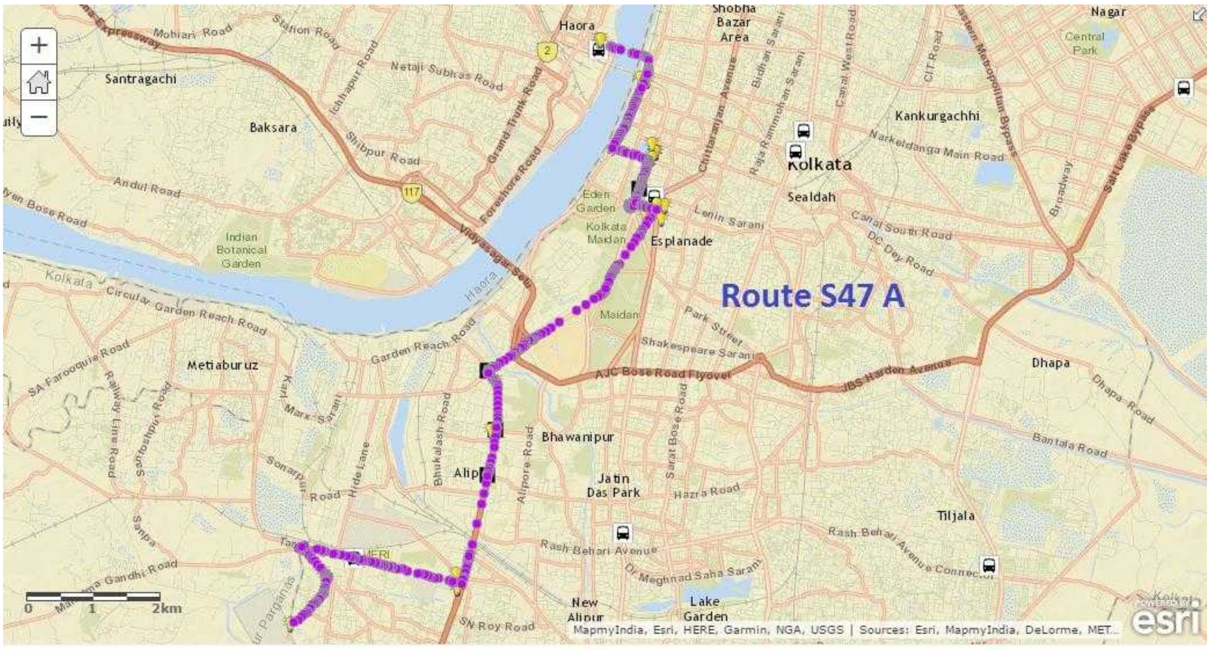

Figure 5-9: S47 A Route Map

Peak Hour Frequency	Average Number of Passenger/day/Journey	Number of bus operated	Bus trips/day/bus	Number of Bus Depots (Start – On route – End)
10 Mins	35.62	5	3	3

Bus Depots on this route and the available electrical infrastructure there are:

Bus Depot Name	Substation	Transformer Capacities (kVA)	Peak Load (Amp)	
			Day	Night
Howrah	Mukhram Kanoria RD O/T	315	168	204
Taratala	S.W.R.O. O/T	315	372	240
Esplanade	Esplanade (S) P/T	315	204	300

10. ROUTE VS 1: AIRPORT GATE No.2 - ESPLANADE

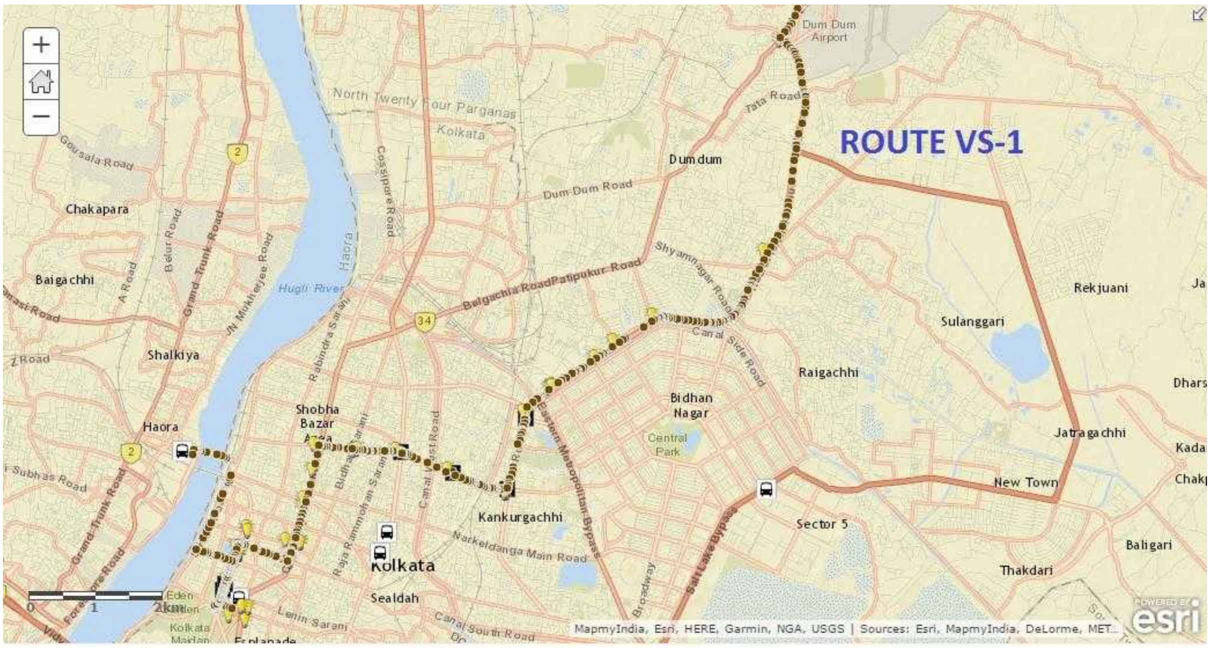

Figure 5-10: VS 1 Route Map

Peak Hour Frequency	Average Number of Passenger/day/Journey	Number of bus operated	Bus trips/day/bus	Number of Bus Depots (Start – On route – End)
10 Mins	37.41	8	4	3 (start from the Airport)

Bus Depots on this route and the available electrical infrastructure there are:

Bus Depot Name	Substation	Transformer Capacities (kVA)	Peak Load (Amp)	
			Day	Night
AIRPORT 2 NO GATE	Airport Sub-Station O/T	400	180	252
Howrah	Mukhram Kanoria RD O/T	315	168	204
Esplanade	Esplanade (S) P/T	315	204	300

b. 3 Wheelers

The 11,315 auto-rickshaws operate in following routes as shown in figure 5-11. [60]

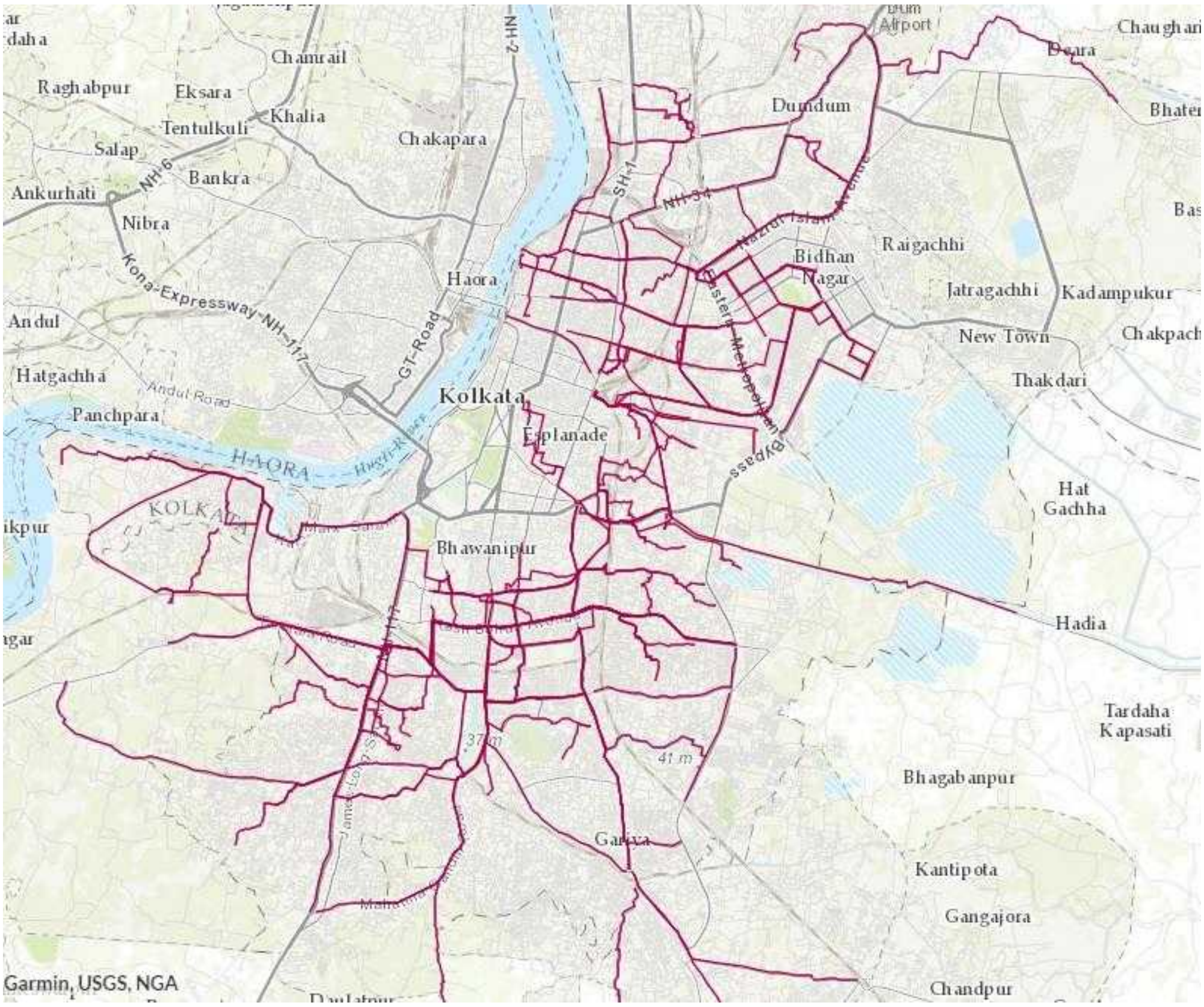

Figure 5-11: Autos Route Map in Kolkata

60 Live map http://ideationts.maps.arcgis.com/apps/Directions/index.html?appid=94726c1658b942eca28f115af6c82594

Figures 5-12 and 5-13 illustrate the route density and licensed auto-rickshaw density

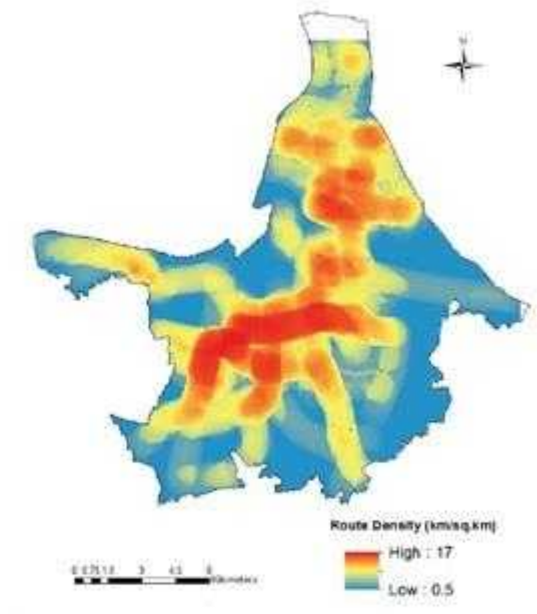

Figure 5-12: Licensed Auto Density

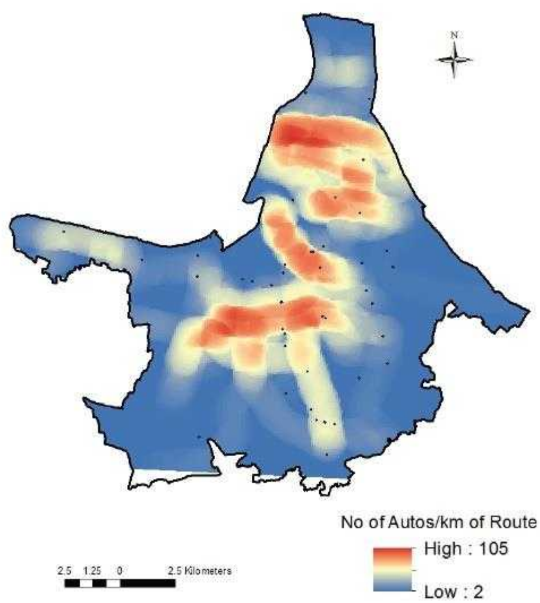

Figure 5-13: Route Density

Source: CPR Study Report

Out of 125 permitted routes for auto-rickshaws, the following 7 routes have been selected for introduction of electric auto-rickshaws as they offer a substantial vehicle population for conversion (above 300 per route). These maximum vehicle density routes are chosen to provide maximum impact of electrification and also increase the throughput of the proposed charging infrastructure.

Table 5-2: Auto-rickshaw Routes Recommended for Electrification

Sl No	Location Name	Number of Auto-rickshaws
1	Golpark – Gariahat	525
2	Ganesh talkies to Phoolbagan	420
3	Ultadanga Station to Jora Bagan Power House	390
4	Lohapool to Dharmatala	375
5	Dharmatala - Orient Row	355
6	Kimber Street (Park Circus) to Topsia	335
7	Sealdah Court Complex to CIT Building	315
	TOTAL	2,715

These are the locations where battery charging infrastructure may be established.

Note that there are substantial e-rickshaws already present in the outskirts of KMA which operate on lead acid batteries. These are also candidates for conversion to Lithium batteries and battery swapping opportunity.

c. Taxi Cars

Since no authentic data could be collected regarding taxi car routes and points of concentration, no analysis and route selection is presented here. However, it is recommended that popular locations such as Kolkata Airport, Howrah Railway Station, Sealdah Railway Station, Park Street Bus Stand, Writers Building, large Public Sector Undertakings (PSU) Offices, University Campuses, etc., could be potential locations for establishment of charging infrastructure for taxi car and other public and private 4 wheelers.

Also, ride sharing services and fleet operators such as OLA, UBER etc., may establish EV charging station at their hubs.

d. Ferries

Ferry services connect many regions of Kolkata with central parts of the city via Hooghly River. Several thousand people use daily ferry services operated by the West Bengal Surface Transport Corporation (WBSTC) and HNJPSS.

Cities in different parts of the world have initiated the process of converting existing diesel engine driven ferries to electric ferries and Solar Boats or introducing brand new electric ferries. This is a latest trend and experiences of cities in Sweden, Finland, Norway etc., are encouraging.

Based on the data received from WBSTC, the following 2 ferry routes in Kolkata have been selected for e-ferry conversion as these 2 routes carry maximum passengers daily.

Table 5-3 Shortlisted Ferry Routes

Passenger Routes	Daily Average Passenger Service	Average Daily Frequency	Number of boats plied
Howrah - Shipping	6,976	10 min	3
Howrah - Farlie	6,376	10 min	3

The map of the route selected are shown below in figure 5-14 and 5-15.

ROUTE 1: Howrah – Shipping

Passenger Routes	Daily Average Passenger Service	Distance (KM)	Number of boats plied
Howrah – Shipping	6,976	1.05	3

ROUTE 2: Howrah - Fairlie

Passenger Routes	Daily Average Passenger Service	Distance (KM)	Number of boats plied
Howrah - Fairlie	6,376	0.7	3

The total number of boats for e-ferry conversion (or new build) would be 6 ferry boats. This offers a substantial incentive to the creation of an e-ferry industry. Older boats are better for electric conversion, as old engines consume more fuel and require frequent maintenance. From the safety perspectives also, older boats may be taken up for conversion first. If all boats in a route are to be converted to electric to take full advantage of the charging infrastructure, then newer diesel boats operating in that route may be deployed on other routes.

e. Trams

As explained in Chapter 4, CTC operates trams in 24 routes in Kolkata. In some of the tram routes, goods are also transported by local vendors. However there are no dedicated tram services for goods. While passengers are moving away from trams to buses and other modes owing to slow speed of trams, the goods transporters find trams much cheaper and convenient to transport their goods. For example, coconuts and mangoes brought to Sealdah railway station are transported by tempos (mini trucks) to different city locations by vendors which is not only very expensive for them, but also congest the city roads and contributes to emissions.

It is proposed to start a dedicated goods tram service between Sealdah and Howrah during the night on experimental basis to assess the viability of this option before expanding to other routes.

Summary of the findings from this chapter is given in the table 5-4

Table 5-4: Summary Findings from Route and Electricity Infrastructure Analysis

Transport Type	Findings	Remarks
Buses	Opportunities for electrification of top 10 routes involving 119 buses in the city core having significant overlap with the tram network.	7 bus depots for the select 10 routes are ideal locations for establishment of charging infrastructure. Four out of this 7 depots are in close proximity to 550 V DC network of CTC. The CTC's DC network is under-utilised and can be leveraged with capital investment for establishing fast charging stations.
3-Wheelers	Top 7 of 125 permitted auto-rickshaw routes are recommended for introduction of electric auto-rickshaws. These routes represent approximately 25% of the total 11,315 auto-rickshaws	There is a bigger opportunity for conversion of lead acid batteries to lithium ion batteries in 100,000 plus e-rickshaws (totos) operating in the outskirts of Kolkata
Taxis	No specific routes identified owing to lack of accessible authentic data.	Opportunity exist for approximately 40000 taxis and shared cars to be electrified
Ferries	Top 2 routes out of 6 passenger routes recommended for conversion to electric ferries	There are 6 boats operating in the select two routes which can be serviced from single charging station at Howrah Jetty.
Trams	Dedicated Goods Tram service during the night between Sealdah and Howrah	This will help local vendors transport goods brought to Sealdah railway station to different locations within the city at cheaper rates and also de-congest the city roads

CHAPTER 6 COST BENEFIT ANALYSIS FOR EV AND BATTERY SIZING

Besides the availability of charging infrastructure, the present cost of EV is another key factor that determines the customer's EV ownership decision. While the first-cost is important for ownership, other tangible benefits such as continued cost savings through fuel costs and operation and maintenance should be considered. These benefits can be supplemented by the quantification of other axiomatic benefits such as, lower oil imports, improvement in energy security and electric grid reliability, and better quality of life for citizens through improvement in air-quality and noise reduction leading to health improvements. This chapter focuses on the total cost of ownership (TCO) model, which considers these factors, and net present value (NPV) for first-cost investment in EVs. The cost benefit analysis (CBA) model is based on the life-cycle cost of EV ownership.

6.1 ELECTRIC BUSES

a. Cost Benefit Analysis (CBA)

A CBA model was developed to compare the TCO and the NPV of a diesel bus and different variants of the electric buses. Three models of electric buses with different sizes of on-board batteries are considered i.e. 100 kWh, 200 kWh and 300 kWh battery packs to reflect operations from the route analysis. Proportionate to the battery sizes, the charging infrastructure models vary and costs for these have been considered.

In the absence of any meso-scale emissions data,[61] two attributes of diesel bus tailpipe emissions are considered and costed in the CBA model: (1) carbon pricing of carbon dioxide (CO_2) emissions from burnt fuel from tail-pipe at USD 20 per ton and (2) the health-effect of emissions to the immediate neighbourhood at USD 100 per ton.[62] No finer data on PM2.5 and PM10 emissions models were available for Kolkata and hence the cost impacts due to particulate matters and noise reductions are not taken into consideration in the CBA. The salvage value of used battery is also not taken into consideration in the CBA. If these parameters are added, the TCO for electric buses will be more attractive.

Table 6-1: Cost Benefit Analysis Framework for Electric Buses with Different Battery Sizes

Serial no.	Parameters	Diesel Bus	EV1 (100 kWh)	EV2 (200 kWh)	EV3 (300 kWh)
1.	Cost of Bus (INR Crores)	0.85	1.5	2.25	3.2
2.	Engine/Battery Replacement Cost (INR Crores)	0.20	0.75	1.5	2.4
3.	Life of Bus (Years)	10			

[61] No meso-scale data related to emissions is available in India, as these are monitored at the city-level at select locations

[62] A nominal rate of USD 100 per ton of CO_2 has been considered for the health impact to the human beings. This is miniscule compared to USD 152,429 per ton of CO_2 derived from the combined economic loss of USD 5.33 trillion in 2013 from 35 billion tons of CO_2 emission in that year (http://www.worldbank.org/en/news/press-release/2016/09/08/air-pollution-deaths-cost-global-economy-225-billion, http://data.worldbank.org/indicator/EN.ATM.CO2E.PC?end=2013&start=1960)

4.	Financial Interest Rate and Discount Rate (%)	10.5			
5.	Financing of Vehicle	100%			
6.	Financing Amortization Period (Years)	7			
7.	Linear Asset Depreciation (Years)	7			
8.	Average Bus Round trip (km) [63]	50			
9.	No. of Trips Daily[64]	4			
10.	Daily Travel (km) [65]	200			
11.	Days per Year in Operation (Days)	325			
12.	Yearly Travel (km)	65,000			
13.	Diesel Mileage Rate (km/litre) [66]	2	-	-	-
14.	Diesel Fuel Cost (INR/litre)	60	-	-	-
15.	Diesel Fuel Cost (INR/km)	30	-	-	-
16.	Annual Diesel Consumed (litres)	32,500	-	-	-
17.	Rate of CO_2 Emissions/L (kg)	2.68	-	-	-
18.	Annual CO_2 Emissions (tons)	87.1	-	-	-
19.	Carbon Cost of CO_2 Emissions (INR/ton) @ USD 20/ton	1,300	-	-	-
20.	Emissions Health Impact at USD 100 per ton of CO_2 (INR/ton)	6,500	-	-	-
21.	Cost of Diesel Engine Replacement after 200,000 km – after every 4 years (INR Lakhs)	20	-	-	-
22.	Operation and Maintenance (O&M) Costs (INR/km)	46	10		
23.	EV Charging Cost – Demand + Energy Tariff (INR/km)	-	22	34	34
24.	Battery Fast Charging Rate (C) [67]	-	5		
25.	Fast Charging Infrastructure Cost (INR Lakhs)	-	100 (415V)	500 (11kV)	750 (11kV)
26.	Fast Charging Infra Annual Cost Apportionment per bus charge @ 20 buses/day @ 325 days/year (INR Lakhs)	-	0.015	0.077	0.115
27.	Battery Life Cycle (Years)	-	10		
28.	Battery Upgrade Costs (INR Lakhs)	-	0.75	1.5	2.4

[63] The average bus roundtrip in the first top priority recommended routes are less at 35 KM each).
[64] The average number of trips daily in the top priority recommended routes are only 3 round trips/bus/day.
[65] The model uses an average daily travel of 200 KM, whereas the top priority recommended routes are less at 100 KM (3x35 KM)
[66] This estimate based on discussions, appears to be a range for both A/C and non- A/C buses. The value adopted is for a A/C bus which seems to be preferred mode going forward as well as evaluating the higher parasitic load for the electric bus.
[67] The battery life-cycle has been assumed conservatively as 3700 cycles, as daily charge will not be from a 100% Depth of Discharge (or a dead-flat battery).

The summary of the CBA for buses is given below:

Table 6-2: Cost Benefit Analysis Summary for Buses

	Diesel Bus	EV1 (100 kWh)	EV2 (200 kWh)	EV3 (300 kWh)
TCO (INR Crores)	7.91	5.02	7.63	9.79
NPV (INR Crores)	4.43	3.1	4.63	5.99

The analysis show that for EV1 and EV2 categories, the TCO is lower than the diesel bus variant, and additionally, EV1 with a 100 kWh battery has high cost-effectiveness to own and operate over a span of 10 years. There is a net savings of 70 lakhs (or almost a full cost of diesel bus) in current INR (based on NPV). In another look, one can afford 3 numbers of EV1 100 kWh buses for the price of two diesel buses over the span of 10 years. Even the EV2 200 kWh bus gets a close parity to a diesel bus on both a TCO as well as on NPV. The EV3 300 kWh bus, however appears to be 25% more expensive.

b. Recommendations for Bus Sizes and Driving Range

Given that Kolkata has a good existing public-private ownership and operator model for buses, it is recommended that the electric bus sizes be kept the same as its diesel fleet today. The common bus lengths in Kolkata are 7 meters and 9 meters. The bus length of 9 meters is common in most parts of India and hence, this would offer larger volumes for electric bus manufacturing industry, which would reduce the overall prices of the electric buses. Maintaining existing bus length allows business-as-usual for transport operators. If the OEMs cannot meet the 9 meters bus length and seating capacity criteria in their new EV design, then a decision may have to be made regarding altering the passenger parameters in terms of seating and standing capacity.

Most of the Kolkata bus fleet route patterns in the city-core, seem to have a daily round trip range of less than 200 km. The top ten routes recommended in this report for electrification (employing about 119 buses) has average daily round-trip of 100 km per bus, which increases the potential of modular battery sizing, resulting in further reduced battery sizes and charging costs.

A few suburban routes from Kolkata core to nearby Salt Lake, Dum Dum, etc., may still fit the 200 km daily round trip range, due to longer travel times and lesser round trips per day. To be on the safer side, we have considered the highest driving range for all buses in our CBA model.

c. Battery Chemistry and Sizing for Buses

This study has considered the characteristics and cost of Lithium Ferrous Phosphate (LFP) type batteries for cost benefit analysis. Given India's high ambient temperature (55 degree C), high humidity (above 90% relative humidity) and harsh dust environments, it is suggested to choose appropriate battery chemistry in consultation with electric bus manufacturers and battery OEMs to suit the above environmental conditions. . New generation of LFP batteries are capable of 5C charging limit whereas Lithium Titanium Oxide (LTO) batteries can be charged at 10C. . We did not conduct analysis for other battery storage technologies types to understand the levelized cost impacts against higher costs and other parameters.

Based on the bus fleet operations and travel patterns, 100 kWh battery buses will likely be the most widely required in the inner city-core routes.

d. Use of Overhead DC Tram Circuit for Electric Bus Charging

A unique option available in Kolkata, is to explore the use of the overhead wires of the 550V DC used by trams to charge electric buses. This may involve some capital investments to upgrade the existing AC-DC converters that feed the DC loop. This may be well worth the investment, as it provides both (1) flexibility in charging infrastructure (the whole DC loop is available for charging) and (2) having to optimize the fixed charger station locations and real estate requirements. Such buses will of course need to be fitted with overhead pantograph style of terminals. However, there are challenges with the pantograph charging since they're not standardized and need reliance on the manufacturer for all services. This and consideration of strategic DCFC spots opens many possible flexible ways of fast-charging buses within the city core, as well lateral routes away from the tram route loops.

6.2 THREE WHEELERS

a. Cost Benefit Analysis (CBA)

The basic assumptions in the CBA model are applicable for 3-wheelers, as well and are shown in table 6-3. These CBA models consider existing auto-rickshaw replacements with e-Rickshaws. The cost of LFP batteries has been considered in this CBA.

Table 6-3: Cost Benefit Analysis Framework for 3-Wheelers with Different Battery Technologies

Serial No.	Parameter	Auto Rickshaw (CNG/LPG/ Petrol)	E-Rickshaw (Lead Acid Battery)	E-Rickshaw (Li-ON Battery)	E-Rickshaw (Without Battery)
1.	Cost of Vehicle (INR)	90,000	60,000 (without battery)		
2.	Cost of 5 kWh Battery (INR)[68]	-	40,000	125,000	Battery on Rental
3.	Total Cost of 3-Wheeler (INR)	90,000	100,000	185,000	60,000
4.	Life of Vehicle (Years)	10			
5.	Financing Interest and Discount Rate (%)	10.5			
6.	Financing of Vehicle	100%			
7.	Financial Amortization Period (Years)	7			
8.	Linear Asset Depreciation (Years)	7			
9.	Average trip (km)	5			
10.	Number of Trips Daily	25	25	25	25
11.	Daily Travel (km)[69]	125	125	125	125
12.	Days per Year in Operation (Days)	325	325	325	325

[68] Lead Acid battery at USD 123/kWh at 24 V and LFP at USD 385/kWh at 48V (new standard); Heavier loads may need two sets of 10 kWh battery capacity

[69] Typical travel per day is between 100 – 150 km depending on the route

13.	Yearly Travel (km)	40,625	40,625	40,625	40,625
14.	Fuel Mileage Rate (km/litre)[70]	20	-	-	-
15.	Fuel Cost (INR/Lakhs) [71]	60	-	-	-
16.	Fuel Cost (INR/km)[72]	1.84	-	-	-
17.	Annual Fuel Consumed (litre)	2,030	-	-	-
18.	Daily Fuel Cost (INR)[73]	230	-	-	-
19.	Annual Fuel Cost (INR)	74,750	-	-	-
20.	Rate of CO_2 Emissions/litre (kg)[74]	2.68	-	-	-
21.	Annual CO_2 Emissions (tons)[75]	3.81	-	-	-
22.	Carbon Cost of CO_2 Emissions at USD 20/ton (INR/ton)	1,300	-	-	-
23.	Health Impact at USD 100/ton of CO_2 (INR/ton)	6,500	-	-	-
24.	Engine Replacement Cost After 120,000 km - 3 years (INR)	10,000	-	-	-
25.	O&M Costs (INR/km)[76]	0.5	0.1		
26.	Charging Rate (C)	-	0.2C	3C-5C	
27.	415 V/50 kVA Maximum Charging Infrastructure Cost (INR)[77]	-	227,500		
28.	Charging Infra Annual Cost Apportionment per charge at 20 EV /day at 325 days/year (INR)	-	7		
29.	Annual apportionment of charger fixed cost for 10 years use (INR)	-	1138		
30.	EV Charging Cost – Energy Tariff (INR/ 5 kWh charge)[78]	-	34.65		
31.	Annual Charging Cost (INR)	-	11,261		
32.	EV Charging Cost – Demand and Energy Tariff (INR/km)	-	0.28		
33.	Battery Replacement (Years)[79]	-	1	10	10
34.	Battery Replacement Costs (INR Lakhs)	-	40,000	125,000	Rental

[70] Assumed at 20 km/L

[71] Cost of fuel: CNG INR 45/kg; Diesel INR 59/L; Petrol INR 79/L

[72] Cost/km is Petrol INR 3.5/km; CNG INR 1.84/km; Diesel 3.0/km

[73] Institute for Urban Transport 2016 study data for CNG auto rickshaw and e-rickshaw ownership/rental costs

[74] Emissions rate for Diesel fuel

[75] Assumed at 70% of diesel fuel emissions rate for same fuel weight

[76] No engine maintenance for EV

[77] 415V LT 50 kVA Max. Supply: The above costs have been assumed at the higher level to include unknowns such as import duties, GST, telecom, & installation and includes some parts of the balance of systems (USD 3,500).

[78] CESC rate: Fixed Demand charge of INR 42 up to 50 kVA max + energy charge of INR 6.93/kWh

[79] The Battery life-cycle for LFP has been assumed conservatively as 3700 cycles, as daily charge will not be from a 100% Depth of Discharge (or a dead-flat battery). Deep cycle Lead Acid battery is 1,200 cycles lifetime, but the LA batteries used in e-rickshaws currently are cheap car batteries

35.	Battery Rental Rate (INR/day)[80]	-	-	-	96.00
36.	Battery Rental Rate (INR/km)	-	-	-	1.03

The TCO and NPV for each case is shown in table 6-4.

Table 6-4: Cost Benefit Analysis Summary for 3-Wheelers

	Auto Rickshaw (CNG/LPG/Petrol)	e-Rickshaw (Lead Acid Battery)	e-Rickshaw (Li-ON Battery)	e-Rickshaw (Rent Li-ON Battery)
TCO (INR Lakhs)	15.12	7.00	5.51	6.04
NPV (INR Lakhs)	8.26	3.91	3.41	3.40

The above TCO and NPV calculations for each of the options (over a span of 10 years), points to some interesting business observations. The following is the summary:

1. All battery storage technology options are significantly cost-effective than a CNG/LPG/Petrol variants with a savings of about 50% to 60% on TCO and NPV
2. The e-Rickshaw with a LFP battery purchase option is the cheapest
3. The e-Rickshaw with a LFP battery rental option is 15% cheaper than Lead Acid battery option, but slightly more expensive than LFP purchase option (due to return on investment of the battery rental business). However, the capex required for the e-Rickshaw owner/operator is the lowest
4. At a strategic level, one can afford almost 2.5 to 3 times e-rickshaws (with LFP batteries) than a single CNG auto-rickshaw over the 10 year period

The cost impacts due to noise levels and particulate matters have not taken into consideration in the CBA. If these parameters are added, the TCO for e-Rickshaws will be more attractive.

b. Recommendations for Battery Types and Battery Sizing

A typical e-Rickshaw in India uses deep-discharge lead acid batteries rated at 12V or 24V, 50Ah (i.e., 0.6 kWh or 1.2 kWh). As India is adopting 48V DC standard, the latest e-rickshaw models (being mooted) may adopt deep-discharge lead acid batteries of 48V, 50 AH (or 100Ah) ratings (i.e., 2.4 kWh or 4.8 kWh).

Regardless of the size and applications, lead acid batteries as a class, suffer from the following problems:

1. Extremely low life-cycles (about 300 cycles) which barely makes it to a single-year useful life. Many get changed in 6 months
2. These batteries cannot be typically be discharged below 40%, but regularly are, due to revenue generation imperatives
3. Lead acid batteries are slow to charge typically at 0.1C rate (need 8 to 10 hours to charge) and hence pose a limitation to business opportunity for a quick mid-day charge
4. Very low energy density and hence high dead weight. Typically, a 350 kg e-Rickshaw could often have as much as 125 kg (or 33% of total weight) in lead acid battery weight alone

[80] Assuming accelerated cost recovery over 4 years (@325 days/year) to include theft, damage, abuse, wear and tear

5. These batteries are often recycled in small shops, which do not cater to safe environmental practices for disposal. This is a more severe environmental problem than tailpipe emissions vehicles.

The move to a more expensive LFP batteries (or other types of lithium chemistry battery) alleviates most of the above concerns i.e., 3,700 cycles, 80% DOD, 5C charging rates, a lower battery weight of 70 kg, and a potential secondary use for stationary applications. However, the cost of the LFP battery (48V, 50Ah) can be as expensive as the rest of the e-Rickshaw itself when considered on first-cost alone.

The longer life of the lithium batteries and its high power-energy ratio, more energy, and lower weight all contribute to a much better TCO to the e-Rickshaw owner with little or no interruptions to business during the day.

It is recommended that a unit size of 48V, 50Ah be selected with the provision of connecting two batteries in parallel for a 100Ah requirement if needed (heavier payload applications, longer routes, hilly terrains, etc.).

6.3 FERRIES

The six boats selected for electric conversion running on two routes have engine capacity of 2x102 HP. Based on this engine capacity, the battery size is estimated at 2x150 kWh (300 kWh battery) for conversion to electric ferry (e-Ferry). Since the duration of ferry stop is about 10 minutes, a fast charging rate of 10C is required (6-minute charging time). At present, only LTO batteries are capable of charging at 10C rate. The electrical capacity to support such a charging rate would need to be about 3.5 MVA substation capacity likely supplied at 11 kV.

In the absence of detailed cost data of the existing diesel boats and the accurate cost of conversion to e-Ferries, no analysis on the TCO or NPV could be done. The capex cost for the battery and the charging station is estimated below:

Table 6-5: Cost Benefit Analysis Summary for Ferries: Option 1

	300 kWh Battery (LTO)	Ultra-fast Onshore Charger
Total Capex Cost (INR Crores)	1.95[81]	12.9[82]

Note: The capex of the onshore charger is a common asset for all ferries that dock at the port.

An alternative solution is to setup an onshore charging infrastructure to charge a larger battery onshore and "dump" the charge from the onshore battery to the on-board battery when the ferry docks at the port. The benefits of this option, would be that the charge rate of the onshore battery (albeit bigger in size) would not be at 10C (6 min) but slower 2C (30 min) or 3C (20 min) charge rate albeit being capable of discharging at a higher rate. This allows for significant cost reduction in the charging infrastructure, as

[81] The LTO battery plus BMS plus Auxiliaries cost estimated at USD 1,000 per kWh

[82] 11 kV DC Ultra-Fast Charging Station plus substation at USD 2.0 million. The above costs have been assumed at the higher level to include unknowns such as import duties, GST, telecom, installation, and includes some parts of the balance of systems of the 11 kV substation

well as less expensive battery chemistries for the onshore battery.[83]

For this method, the onshore battery should be of higher capacity than the on-board ferry battery (proportional to its own SOC levels) and be able to (a) charge in 20 minutes between the ferry arrivals; and (b) a discharge to the on-board battery during the 10-minute ferry docking stay. Selecting the onshore battery at 500 kWh would ensure that at its full capacity, it charges at 3C (20 min; 500 kWh) and discharges to the ferry battery at 6C (10 min; 300 kWh). The ferry battery would still get at the 10C rate for its own battery rating. The electrical substation capacity would be rated lower at 1.75 MVA at 11 kV.

In practice, the onshore battery system will not be stretched to its full capacity, as the ferry battery would have a residual charge (minimum 20% for on-board LTO batteries and 30% for onshore battery). Hence, the above operating parameters could be comfortably maintained. Table 6-6 shows the cost estimation for this option.

Table 6-6: Cost Benefit Analysis Summary for Ferries: Option 2

	300 kWh Ferry Battery (LTO)	Onshore 500 kWh (Li-Ion) Battery	Onshore Charger DCFC
Total Capex Cost (INR Crores)	1.95[84]	1.3[85]	7.50[86]

Note: The capex of the onshore battery systems and its captive charger is a common asset for all ferries

[83] A detailed study needs to be conducted for preparing a detailed project report (DPR) for conversion of diesel boats to e-ferries
[84] LTO battery plus BMS plus Auxiliaries cost estimated at USD 1,000 per kWh
[85] Li-Ion battery plus BMS plus Auxiliaries cost estimated at USD 500 per kWh
[86] 11 kV DC Fast Charging Station plus substation at USD 1.15 million. The above costs have been assumed at the higher side to include unknowns such as import duties, GST, telecom, installation, and includes some parts of the balance of systems of the 11 kV substation

CHAPTER 7 POLICY AND TARIFF DESIGN RECOMMENDATIONS

The policy and tariff design recommendations presented in this section though written for Kolkata, but it is conceptually relevant for other cities in India. Creating a conducive ecosystem for electrification of private and public transportation in the country requires a strong policy and regulatory support, as explained in the section. If appropriate policies are in place, the sector could attract investments and the shift towards electrification will be faster.

1. Standardization of Bus Sizes, Define Ideal Driving Range for Electric Bus, Battery Technologies, and Battery Pack Size to Lower Costs and Accelerate Manufacturing

There is an immediate need for a policy on appropriate bus sizes and battery type (chemistry) and battery pack sizes to be adopted for cities in India. The standardization of these parameters would drive volumes for a particular set of products that the industry can concentrate on manufacturing and assembling in the country. The imported buses presently offered have battery capacities above 300 kWh (which itself is >6 MT in weight) offering >300 km driving distances and costing over INR 3 Crore. As elaborated in the previous sections, buses in the Indian cities are driven 50 km to 70 km per shift of 8 hours by a driver. If we consider 9 meter buses with 30 to 35 people seating capacity (and additional 10 people standing) and that the bus batteries will be charged at the end of each shift for one hour, the battery packs can be 50 to 60 kWh capacity for Non A/C buses and 90 to 100 kWh for AC buses. This will reduce the cost of electric buses comparable to that of diesel buses. Hence it is recommended to standardize following specifications for electric buses for intra-city use in India:

a. Bus structure: 9 meter bus with 3 steps (low floor electric buses in Indian cities prone to flooding are not advisable; for wheel chair passengers, appropriate ramps may be constructed at bus stops). Some cities with wider roads may opt for 12 meter buses
b. Driving distances per shift: 50-70 km (initially electric buses may be introduced in smaller and most congested routes; and longer routes may be rationalized to bring down the per shift driving distance to these limits in a phased manner)
c. Battery chemistry: Most widely used battery chemistries for buses are LFP which is also incidentally the cheapest and reliable in hot and humid weather conditions. The choice of battery chemistry and final sizing may be left to the bus manufacturer as several other parameters need to be considered to arrive at the final choice
d. Battery pack size:
    - **Non AC Buses:** 50 kWh - can be optimized between 50-60 kWh after discussions with potential OEMs
    - **AC Buses:** 100 kWh - can be optimized between 90-100 kWh after discussions with potential OEMs
    - **Three Wheelers:** 2.5 to 5 kWh - this may be able to give a range of 50 to 100 km with 5 passengers and the battery (weighing approximately 40 kg each) can be swapped by 1 person.

The CBA in Chapter-6 has considered LFP battery which can be charged up to 5C with 600kVA, 415V supply. This seems adequate for most of Kolkata. LTO battery can be charged at 10C would require 11kV connection which will increase the cost for electrical network upgradation that would significantly increase the TCO.

2. Power and Communication Standardization for EVs and Charging Stations

In February 2017, Department of Heavy Industries (DHI) has setup a Committee of Experts to prepare the appropriate standards for EV Charging Stations for India. This committee has submitted the ***"Bharat EV Charger Specifications"*** in May 2017 (which has been updated in July 2017 by the same Committee). The ARAI has prepared AIS 138 standards for AC and DC charging infrastructure. The Bureau of Indian Standards (BIS) has constituted a Technical Committee (ETD-51) to formulate standards for EVSEs.

The BIS ETD-51 technical committee is expected to review Bharat EV charger specifications, AIS 138 standards and inputs from various stakeholders to finalize EVSE power and communication standards. This BIS standard may be issued expeditiously by early 2018.

3. Regulations for Franchisees to Own and Operate EV Charging Stations

Per existing Indian Electricity Act, distribution licence is required to buy electricity from a utility and sell to a third party. So a non-utility charging station owner cannot buy electricity from a DISCOM and sell to an EV owner. This should ideally be addressed in the Electricity Act itself. But an Amendment to the Electricity Act is in the Parliament which may be passed in the near future. Hence it is recommended to request the Forum of Regulators (FOR) to issue appropriate regulations enabling third parties to set up charging stations at strategic locations and buy electricity from DISCOMs and sell to EV owners at tariffs set by respective state electricity regulatory commissions (SERC). In Kolkata's case, West Bengal Electricity Regulatory Commission (WBERC) may take the leadership to formulate appropriate regulations to initiate e-mobility.

Presently in many states regulators have taken the view that third party EVSE services with electricity resale may be allowed from any commercial connection given by a DISCOM. However, these are adhoc decisions and subject to interpretations. In the absence of a clear policy, large investment for setting up of chains of charging stations may not come forward.

4. Electricity Tariff for EV Charging and Payment Settlement Mechanisms

Use of electricity for mobility applications can be interpreted as commercial use and could attract commercial tariff prevailing in the state. But tariffs for EV charging may be viewed from a different perspective. The battery in the EV can be a load as well as a distributed generation resource on the edge of the grid. With rapid proliferation of rooftop PV systems connected to the distribution grid, the stability of the low voltage system is seriously affected. In order to integrate the renewable resources (solar PV and micro wind turbines) the electric grid needs flexibility in both supply and demand. EV batteries can be an excellent resource that could help stabilize the low voltage grid.

Concessional EV charging tariff at off-peak hours could promote EV rollout as well as help improve the plant load factor (PLF) of power stations. A separate tariff for EVs may be introduced that promotes faster adoption of EVs. Also such tariffs for EVs must have time of use or real time pricing such that whenever there is surplus generation, the EVs should charge from the grid and whenever there is surplus demand, the EVs should sell power to the grid (possible with VGI technologies). However, to implement time of use (TOU) tariff, metering systems and billing and settlement systems need upgrades.

Monetization of electricity used by EVs needs to be understood better. This means that the charging and billing of services and the software that takes care of bill-to-cash management for electro-mobility are key elements which will ensure that the amount of electricity used by the EVs will be invoiced and payments accounted. It needs meticulous planning as to how a charging infrastructure will be created and the customers invoiced for the electricity consumed. This process should use a proper system of customer identification and authorization. So all EV charge related details need to be collected and posted to contracts accounts of the DISCOMs. Customer inquiries also need to be managed. When the EV is connected for charging, a hand-shake between the EV and EVSE takes place and that should generate a contract between the EV/Customer and the DISCOM or their Franchisee. This handshake and identification needs to be standardized. This process avoids the need for making payment at the charging stations and also facilitate roaming of EVs across different DISCOM's service areas. The billing process should have a flexible pricing engine including prepaid and real-time pricing options so that EVs can avail concessional tariffs during off-peak hours. More sophisticated solutions (e.g., via consumer interface apps) can allow for staggered/delayed charging as per customer requirements of actual charging time slots and quantum. It is recommended that all charging stations (AC Slow Charging, AC Fast Charging, DCFC) may be connected to the DISCOMS control room and the unique ID of the EV/Customer (who can avail a charge card) may be authenticated when hand-shake between the EV and the charging station is established. The EV owner/Driver may be able to view the charge status and charging rate and other related info on a mobile app/EV dashboard and authorize the charging. Either the cost of electricity is billed to EV Owner/Driver in a post-paid regime or deducted from the prepaid charge card/authorized credit card, or payment gateways/platforms.

However to begin with, a standard hourly-fee for the usage of the third party EVSE by all categories of EVs is recommended as regulatory changes, revenue metering and modification of DISCOM's billing engines would take time. For example, in the case of Kolkata, (a) for the STUs that will own and operate the EVSEs in their depots, it will be an internal cost; (b) in the case of Franchisee operator it shall be a "parking fee"; and (c) in the case of battery swapping a simple rent per each battery swap.

When DISCOMS will be directly billing and collecting the cost of electricity from EV Owners, the third parties who are owners and/operators of charging stations may be incentivized by the DISCOMS as a percentage of the EV charging revenue.

Also, locations, capacities and availability of all charging stations in the city should be available to EV drivers including real time status of charging, reservation of charging slot, up time / breakdown status of charging infrastructure etc. This can be made available through suitable mobile Apps.

The EV charging stations can also offer grid balancing and ancillary services to the DISCOMs which can also be compensated to the charging stations owners/operators. EV charging stations may opt on subscription basis to facilitate: (a) Load Balancing; (b) Ancillary Services; (c) Demand Response; and (d) Other Load Time Shifting Requirements that the DISCOMs would prefer. Such innovative VGI activities could be considered at the time of large roll-outs in consultation with local DISCOMs. All these issues need to be spelt out in the policies for EVs.

Electricity tariff structure in all jurisdictions is built on a fixed delivery charge and an energy consumption charge (based on regulated tariff per kWh). For larger consumers (typically above 50 kVA) the delivery charge is substituted with a demand charge (on a per kVA basis) and an energy consumption charge with an optional time-of-day (TOD) three-part tariff. As the voltage connection of the load rises (11 kV or 33 kV), the demand charge rises substantially compared to 415 V connection. This is due to the fact that connections at higher voltages, typically have a higher power need and this capacity is allocated in the 11 kV or 33 kV line capacity. There are often severe penalties (as high as 200% of the demand charge) for violating the stated maximum demand of a load connection. These are triggered if the violation occurs three times in a calendar month.

An example based on Kolkata tariff for different load is summarized in table 7-1.

Table 7-1: Kolkata Tariff for Different Load

Customer Class	Maximum Demand	Energy Consumption	Demand Charge per kVA (INR)	Energy Charge (INR)	Monthly Total (INR)	Average cost per kWh (INR)
415 V "C1"	50 kVA	20,000 kWh	42.00 (Fixed)	6.93/kWh	138,642	6.93
415 V "C1"	75 kVA	20,000 kWh	3,150 (75x42)	6.93/kWh	141,750	7.09
415 V " C1"	400 kVA	144,000 kWh	16,800 (400x42)	6.93/kWh	1,014,720	7.05
11 kV "A"	800 kVA	288,000 kWh	307,200 (800x384)	6.95/kWh	2,308,800	8.01
33 kV "A1"	1200 kVA	432,000 kWh	460,800 (1200x384)	6.95/kWh	3,463,200	8.01
33 kV "A1"	1300 kVA (violation)	432,000 kWh	921,600 (1200x384x2)	6.95/kWh	3,924,000	9.08

For the fast chargers requiring 800 kW and above it would typically mean a dedicated 11 kV connection per charging station, which would attract higher demand charge.

5. Vehicle-Grid-Integration Services Mandatory for All EVs Sold in India

Vehicle-Grid-Integration (VGI) technologies have been successfully tested in several research labs and universities and are commercially deployed in the United States and Europe extensively. But most EV manufacturers are apprehensive of the effect of specific VGI methodologies on battery life and battery warrantees. The life of a battery is based on the number of charge-discharge cycles and in certain VGI methods such as vehicle-to-grid (V2G) operations, where battery is discharged to feed electricity to the grid, it can cause issue with battery warranties and degradation lifetime.[87] So theoretically for V2G services, the life of the battery can reduce in terms of years of service. Many V2G trials have shown that if the DOD is kept above 50% of the battery capacity, the effect of V2G operations on battery life will be minimal. However, other alternatives such as V1G, where battery is managed smartly to charge based on the grid conditions or real-time prices has no adverse impacts on the batteries and can immediately considered for EVs and charging infrastructure.

[87] V2G refers to 2-way power flow between the vehicle battery and grid, whereas V1G refers to 1-way power flow from grid to vehicle battery

A recent study report "***On the possibility of extending the lifetime of lithium-ion batteries through optimal V2G facilitated by an integrated vehicle and smart-grid system***"[88] talks about the "massaging effect" on the EV batteries through partial charge-discharge cycles that could extend the life of lithium-ion batteries.

From the future proofing context, it is recommended that by regulation VGI services should be enabled in all EVs sold in the country. This will be a great support for the grid with increasing share of renewable energy, though location specific constraints may be considered.

6. Policies on Reuse of EV Batteries

When the capacity of an EV battery drops below 70% (typically after 3-4 years of use in cars and auto-rickshaws), it is replaced with a new battery. The retired battery from an EV can be reused for several years for stationery applications such as storage for solar PV systems, solar PV based street lighting, UPS, energy storage for microgrids, ancillary services and other grid support applications.

Third party agencies may be encouraged setup facilities for providing grid support services to both distribution and transmission grid operators. Such third parties can underwrite the cost of used EV batteries to be given to them after retirement from EVs at mutually agreed terms. This could significantly reduce the entry cost to an EV owner and will drive faster EV adoption. Deploying millions of EV batteries retired every year for grid applications would be the most cost effective route to build GW scale energy storage systems for grid support services in India.

Appropriate norms may also be prescribed in the policy for final disposal of the batteries at end of life.

7. Setting up of EV Charging Stations at Strategic Locations

Large PSUs may be advised to set up charging stations at strategic locations on fast track under their Corporate Social Responsibility (CSR) budget so that the e-mobility plan can be started immediately. Visibility of EV charging stations in parking lots, malls, railway stations, office complexes, hospitals, metro stations, government offices, highways etc., gives people comfort to buy EVs.

8. Approvals to Setup EV Charging Stations near Fuel Stations

For setting up an electric vehicle charging station at high voltage (11 kV and above) inside or next to a petrol pump require special approval under the Indian Explosives Act. In many places it would be strategically advantageous to locate EV charging stations next to an existing fuel pump, particularly on highways. This may be examined and appropriate regulatory provisions be issued with required safety norms.

9. Optimization of Modern Bus Transit Stations

With introduction of electric buses, route optimization may be undertaken in many cities so that route length is adjusted to the battery capacity of the buses which the bus operators may choose. This can be achieved through creation of interchange points or transit stations very much like the metro rail stations where passengers change from one line to another. Such interchange bus stations can be made either by the roadside itself or underground or over ground depending on the space availability in cities. These

[88] http://www.sciencedirect.com/science/article/pii/S0360544217306825?via%3Dihub#

stations should have EV charging stations, toilets, cafes, and other convenience stores.

10. Setting up Facilities for Testing and Certification

New electric vehicles need to be tested and certified which requires facilities to be created in the country on fast track.

11. Operating strategies for mass transit EVs in power markets

The tariff structure (mentioned in point 4) poses some interesting viewpoints for transport operators of EV fleets who would have to pay for electricity usage for charging of their vehicles. The following examples highlight the impact of various battery sizes and charging methods on potential electricity charges:

Table 7-2: Rate of Charging, Demand Charges and Energy Charge

Chargers Type	Rate of charging (C)/Demand	Battery size/Energy Consumption (kWh)	Demand Charge per kVA (INR)	Energy Charge (INR)	Total (INR)	Average cost per kWh (INR)
a. Charging Through Shared DT for 100 kWh Battery						
L2 (415V) (share DT)	0.25C (4 hrs) 25 kW	100 kWh	42.00 (Fixed)	6.93/kWh	735	7.35
L2 (415V) (share DT)	0.5C (2 hrs) 50 kW	100 kWh	42.00 (Fixed)	6.93/kWh	735	7.35
DCFC/415V (share DT)	1C (1 hrs) 100 kW	100 kWh	4,200 (100x42)	6.93/kWh	4,893	48.93
DCFC/415V (share DT)	2C (30 mins) 200 kW	100 kWh	8,400 (200x42)	6.93/kWh	9,093	90.93
b. Charging Through Captive DT for 100 kWh Battery						
DCFC/415V (sole DT)	5C (12 mins) 500 kW	100 kWh	21,000 (500x42)	6.93/kWh	21,693	216.93
DCFC/415V (sole DT)	5C (12 mins) 500 kW	100 kWh x 10 buses (2 hr use)	21,000 (500x42)	6.93/kWh	27,930	27.93
DCFC/415V (sole DT)	5C (12 mins) 500 kW	100 kWh x 20 buses (4 hr use)	21,000 (500x42)	6.93/kWh	34,860	17.43
DCFC/415V (sole DT)	5C (12 mins) 500 kW	100 kWh x 50 buses (10 hr use)	21,000 (500x42)	6.93/kWh	55,650	11.13
c. Charging Through 11 kV for 200 kWh Battery						
DCFC/11 kV (sole S/S)	5C (12 mins) 1000 kW	200 kWh (12 min use)	384,000 (1000x384)	6.95/kWh	383,390	1,926.95
DCFC/11 kV (sole S/S)	5C (12 mins) 1000 kW	200 kWh x 10 buses (2 hrs use)	384,000 (1000x384)	6.95/kWh	397,900	198.95

DCFC/11 kV (sole S/S)	5C (12 mins) 1000 kW	200 kWh x 20 buses (4 hrs use)	384,000 (1000x384)	6.95/kWh	411,800	102.95
DCFC/11 kV (sole S/S)	5C (12 mins) 1000 kW	200 kWh x 50 buses (10 hrs use)	384,000 (1000x384)	6.95/kWh	453,500	45.35
d. Charging Through 11 kV for 300 kWh Battery at 5C						
DCFC/11 kV (sole S/S)	5C (12 mins) 1500 kW	300 kWh (12 min use)	576,000 (1500x384)	6.95/kWh	578,085	1,926.95
DCFC/11 kV (sole S/S)	5C (12 mins) 1500 kW	300 kWh x 10 buses (2 hrs use)	576,000 (1500x384)	6.95/kWh	596,850	198.95
DCFC/11 kV (sole S/S)	5C (12 mins) 1500 kW	300 kWh x 20 buses (4 hrs use)	576,000 (1500x384)	6.95/kWh	617,700	102.95
DCFC/11 kV (sole S/S)	5C (12 mins) 1500 kW	300 kWh x 50 buses (10 hrs use)	576,000 (1500x384)	6.95/kWh	680,250	45.35
e. Charging Through 11 kV for 300 kWh Battery at 8C						
DCFC/11 kV (sole S/S)	8C (8 mins) 2400 kW	300 kWh (8 min use)	921,600 (2400x384)	6.95/kWh	923,685	3,078.95
DCFC/11 kV (sole S/S)	8C (8 mins) 2400 kW	300 kWh x 10 buses (1.3 hr use)	921,600 (2400x384)	6.95/kWh	942,450	314.15
DCFC/11 kV (sole S/S)	8C (8 mins) 2400 kW	300 kWh x 20 buses (2.7 hr use)	921,600 (2400x384)	6.95/kWh	963,300	160.55
DCFC/11 kV (sole S/S)	8C (8 mins) 2400 kW	300 kWh x 50 buses (6.7 hr use)	921,600 (2400x384)	6.95/kWh	1,025,850	68.39
DCFC/11 kV (sole S/S)	8C (8 mins) 2400 kW	300 kWh x 100 buses (13. hr use)	921,600 (2400x384)	6.95/kWh	1,130,100	37.67

S/S: sub station

The above table illustrates the need for charging infrastructure to be prudently selected along with the battery sizing and route optimization. High voltage level chargers utilization factor should be optimized to bring per unit cost of electricity to affordable limits by deploying large number of buses. From a least charging cost and charging infrastructure utilization perspective based on the above table, the following appear to be viable solutions:

- **Bus Battery Size - 100 kWh:** Charging station at 415 V with a dedicated DT of 600 kVA installed in the depot/terminus is the least cost option provided it charges 25-30 buses at night (at the 5C rate) and up to 60 buses during a 24 hour period so that electricity costs for charging is contained within a reasonable limits

- **Bus Battery Size - 200 kWh and 300 kWh:** DCFC at 11 kV installed in the depot/terminus is the least cost option provided it charges 50 buses at night (at the 5C rate) and up to 100 buses (at the 8C rate) during a 24 hour period so that electricity costs for charging is contained within a reasonable limits

Should Time-Of-Use (TOU) tariff be introduced later, electricity cost of daytime charging of buses will become even more expensive with peak daytime tariff being many times twice as much as night time tariff.

12. Policy and Tariff Support for 3 Wheelers

The following policy and tariff support would advance the pace of adoption of e-rickshaws and provide an impetus for creating battery swapping business opportunities in the private sector.

1. Currently the business case for lithium-ion battery rentals stands on its own merit using the current demand and energy tariff prescribed. However, to give this industry a “formative” boost, it may be welcome to offer a fair discount on their monthly energy bills to such businesses
2. Impose a higher Goods and Services Tax (GST) on Lead Acid Batteries and consider eliminating GST on lithium-ion batteries.
3. Create a licensing regime for battery swapping stations along auto-rickshaw routes selected for electrification.

13. Policy and Tariff Support for Ferries

The following policy and tariff support would advance the pace of adoption of e-ferry conversions (or new builds):

1. Marine vessels have the highest of environment footprints in any vehicle class. Even a small amount of fuel spill or contamination affects millions of litres of water. In view of this, a very high disincentive must be placed on diesel fuelled marine vessels
2. While TCO or NPV analysis could not be performed due to absence of data, the high cost of the LTO battery system as well as the high-cost charging infrastructure, may warrant a relook at offering subsidies to the e-ferry operators

14. Policy Decisions for Implementation

It is recommended to immediately take appropriate actions on phase-wise roll-out of EVs in Kolkata, as suggested below:

1. All buses (119 numbers) plying on the selected 10 routes where traffic is moving slowest resulting in most emissions and high fuel use shall be converted to electric buses from April 2018.
2. From April 2018 only electric 3-Wheelers shall be registered in KMA. All existing non-electric 3 Wheelers shall be phased out by 2022
3. All new taxis and fleet vehicles (all categories) shall be electric from April 2018. All existing buses and taxis shall be phased out by 2030
4. Direct Current Fast Charging (DCFC) and Level-2 AC Charging Stations may be installed on fast track in locations such as: bus stations, railway and metro stations, BRT/bus stops, malls, IT

parks, commercial centres, colleges/school campuses, hospitals, courts, petrol pumps, government buildings, parking lots, residential colonies, etc.

5. All electric vehicles (2 Wheelers, 3 Wheelers, cars and buses) shall have lithium ion batteries which can be fast charged. Lead acid batteries to be banned for all categories of EVs immediately
6. Electric 3- Wheelers and electric cars may be allowed to charge only from standard EVSEs
7. Battery Charging cum Swapping stations will be established at strategic locations in the city for 3-Wheelers on fast track
8. For next 5 years all large organizations (both public and private) should allot half of their CSR funds for creation of EV charging stations near their facilities and strategic locations in Kolkata
9. All new commercial buildings and multi-storied residential buildings may be mandated to install EV charging units in their parking spaces
10. Concessional taxes may be levied on EVs and its parts. Several states have already offered lower registration charges and road taxes. This may be relooked and appropriate tax concessions may be offered to promote EVs on fast track. *Refer our recommendations from Global Best Practices in Chapter-3*
11. Other incentives such as free (or concessional) parking, reserved parking lots, free (or concessional) toll fee etc. may be considered
12. Certain exclusive localities in KMA (for example: Esplanade, Park Street, Writers Building etc.) should allow only EVs from 2022
13. Registration number of all EVs should have a clearly recognizable numbering series – for example: WB-EV-1234567. This will make recognition of EVs easier for differential treatment for several incentives
14. For busy districts in the city, a congestion fee may be levied on non-electric vehicles (could have implementation challenges) during peak hours from 2022
15. Duty free import of EVs and lithium-ion batteries may be allowed for a limited time (or limited numbers) for the buses, taxis and government vehicles
16. All cars owned (or leased) by central government, state governments and PSUs in Kolkata shall be replaced with EVs by 2020

CHAPTER 8 BUSINESS MODELS FOR EV OPERATIONS

This Chapter recommends business models based on global experiences, analysis or routes and electricity distribution infrastructure, including suggestions from stakeholders consulted for this study.

Mass rollout of electric vehicles can happen only if the business models for both EVs and the supporting charging infrastructure are cost-effective. The cost effectiveness comes from the optimal planning and use of charging infrastructure to support the electrification needs. While the government grants and tax breaks could help this industry take-off the ground and encourage the early adopters, creation of a functioning supply chain ecosystem through sustainable business models would make EV deployments successful.

The governments should also consider reducing import duties and taxes on EVs, major components, batteries, and EVSE. A few notables would be applicable GST rates (currently proposed 28% for all vehicles). India would initially need to import Lithium batteries and it is not clear what the import duties on such products will be.

In the initial phase charging facilities may be setup through grants from NEMM or through corporate social responsibility (CSR) funds from PSUs. However, to ensure long term sustainability a good integrated market model that supports cost recovery of charging infrastructure could be considered.

8.1 ELECTRIC BUSES

We apply our earlier analysis to the assumption that electric buses will continue to be operated by the same state transport undertakings (STU) and private operators in the city. Per cost benefit analysis (refer Chapter-6), the overall Total Cost of Ownership (TCO) of electric buses are more attractive (particularly at the 100 kWh battery capacity and rises to be about same at the 200 kWh) than diesel buses. While the capex of the electric bus is higher, the operating expenses (opex) of electric buses are much lower than diesel buses.

There should be initial investment to train the drivers and technicians to operate and maintain the electric buses. In the initial phases, the City Governments may come forward to support the training initiatives which in turn may be funded from the National Electric Mobility Mission (NEMM).

a. Charging Infrastructure for Buses:
Countries such as China, South Korea etc. are experimenting the model of battery swapping on buses with robots. A typical lithium-ion battery of 100 kWh weighs around 1.5 - 2 MT or more. Swapping of such a heavy battery and bolting it to correct torque is still an engineering challenge. Until the battery swapping system is matured and safe operation of 2-3 years is observed, it may not be prudent to adopt battery swapping as the only charging model for electric buses.

Once battery swapping system is perfected and adopted, we could look at the model of buses being sold without batteries and a battery leasing agency owning the batteries and maintain a chain of battery charging and swapping stations. This model is explained in detail in the next section on 3-Wheelers.

In the initial phase to kick start electric bus rollout, this study recommends to introduce electric buses with batteries that can be fast charged. Proposed charging station infrastructure models for buses are:

1. **Bus Depot:** Buses that typically get parked overnight may be charged with slower and less expensive AC Type-2 Charges at appropriate voltage in adequate numbers or optimal number of DCFCs. This being a captive use, these chargers may be owned and operated by WBTC in their own bus depot.
2. **Bus Terminus/Bus Interchange Stations:** It is proposed to setup DCFCs in bus terminuses and bus interchange stations. The DCFCs in bus terminuses and bus interchange stations may be operated by franchisees of the electricity distribution companies (DISCOM) or STUs or appropriately licensed third parties.[89] These facilities could offer charging services to all public vehicles (buses, delivery vans, municipal trucks, water tankers, etc.) and appropriate charging rates may be designed ensuring cost recovery on the capex and opex of such stations.
3. **Highways and other Strategic Locations:** For setting up charging stations on highways and other strategic locations, existing petrol fuelling stations can be ideal locations. The DCFCs which can service buses may be established in facilities near (at safe distance) fuel stations. This infrastructure can be leveraged for charging by other electric 4 wheelers for cost recovery. These highway charging stations may be owned and operated by fuel pump station owners or any third parties who could be the franchisee of the local DISCOM.

All the above charging stations can avail lower electricity tariff during periods of surplus power on the grid. In large charging facilities for simultaneous charging of several EVs, they could take advantage of open-access policies and buy electricity from the cheapest source or power exchange. They could also offer grid balancing service to the local grid operators to avail further economic benefits.

8.2 THREE WHEELERS

The recommended business model for 3-Wheelers (3W) is the *battery leasing model (BLA)*. The 3Ws will be sold without batteries and third party BLA will offer batteries on rent per charge.

Today a typical 3W driver buys fuel (petrol or CNG) for INR 250-300/day and drives 100-150 km (vary from city to city) a day.[90] Instead 3W operators will rent a fully charged battery (2.5 kWh or 5 kWh) for a certain amount and drive approx. 100 km. All the batteries will be owned by the BLAs who will setup charging stations at strategic locations within the city where 3Ws can exchange the batteries for fully charged ones. In certain cases BLA may choose to setup large charging stations outside the city (industrial premises) and charged batteries may be trucked to strategic locations in the city. The 3Ws can exchange the batteries at such locations. Such trucks with batteries can move from one location to another within the city based on the traffic density and points of concentration of 3Ws during time of the

[89] Special licenses may be issued a third party vendor to operate these DCFC facilities as opposed to captive own/operate models employed by DISCOMs or STUs
[90] Assuming running cost for a diesel 3W to be Rs 3/Km (20 Km/Ltr, Rs 60/Ltr as diesel cost)

day or day of the week. To protect the battery assets BLAs will deploy mobile apps and GPS trackers. Such mobile apps will also help 3W drivers locate the position and distance of the battery swapping stations (or the trucks with charged batteries) and choose the one nearest. Payment can be settled through prepaid cards or post-paid account authorization.

Battery sizes recommended for 3Ws are:

- Regular Auto-rickshaws/E-Rickshaws: 2.5 to 5 kWh
- Heavy Auto-Rickshaws and 3-Wheeler Delivery Vehicles: 2 units of above battery sizes

Since all batteries for 3Ws will be charged in large charging stations, fast charging is not required and accordingly the appropriate battery chemistry may be chosen. The benefits of using lithium-ion batteries over lead acid batteries are (1) reduced weight of 60 kg per vehicle on the battery weight alone; (2) longer battery life by 5-7 years; (3) faster charging; (4) better acceleration capability; (5) avoided contamination due to local recycling of lead acid batteries; (6) tolerance to higher ambient temperature; and (7) re-use of lithium-ion batteries for stationary applications (at 70 to 80% residual capacity)

Cost of an electric 3W without battery could be around INR 60,000 and the present cost of a 5 kWh LFP battery is also around INR 125,000 which we expect to drop considerably further in coming days based on lowering price trajectory of lithium-ion batteries. In our assumptions for CBA model, a nominal scrap value of INR 10,000 per battery at end of life is considered. With this data points, per km running cost of for an electric 3W will be INR 0.66 against INR 3.5 for petrol; INR 1.84 for CNG and INR 2.6 for diesel 3Ws.[91]

This model will reduce the entry cost of an electric 3W and can also offer lower cost per km of travel to passengers, besides reduced pollution in the city.

8.3 FERRIES

Since the WBSTC operates the ferry services, it is best that this business remains with them. The charging infrastructure at the boat jetties could be owned and operated by the WBSTC much like the tram DC infrastructure operated by CTC or perhaps be owned and operated by CESC through regulatory mandate. Either of these options will be good for long term viability.

[91] Assuming 22 km/litre of Diesel/Petrol or per kg of CNG vehicles. Cost of CNG: INR 45/kg; Diesel: INR 59/litre; Petrol: INR 79/litre

CHAPTER 9 IMPLEMENTATION PLAN AND RECOMMENDATIONS

The city of Kolkata represents a latent opportunity for electric mobility with new economic opportunities, while addressing the energy security objectives and driving the city toward its planned low-carbon future. The improved air-quality and health benefits will provide its citizens a new pathway toward the vision of a clean and smart city. Based on the quantitative and qualitative assessment of public transportation systems and electricity distribution systems, battery technologies and cost, cost benefit analysis, and global best practices and standardization initiatives for EVs across the world, this Chapter describes the implementation plan and propose the prioritized next steps to electrify public transportation in Kolkata. Though the study focuses on public transportation in Kolkata, several of the recommendations are applicable to private transportation, while some policy, technology, and business recommendations are relevant to other Indian cities.

The study recommendations represent the deterministic areas to electrify public transportation categories—buses, and 3-Wheelers (e-Rickshaws), and ferries—to initiate an electrification roadmap. Understanding that electrification of the entire public transportation will take time, these recommendations are phased under immediate, near-term, and long-term deployment roadmap. With strong state and national level initiatives, we propose an aggressive plan to electrify 100% of the public transportation in KMA by 2025. The lessons from this sector can be leveraged in parallel to drive electrification of public and private cars and fleets.

Figure 9-1 shows the proposed implementation roadmap for immediate (up to 2 years), near-term (2-5 years), and long-term (6-8 years). In the immediate term, the electrification prerogatives should consider field evaluation to ensure the lessons learned from early-stage deployments, improve the cost, efficiency, and technology advancements in the next-stages. For example, immediate rollout of existing lithium-ion battery technology for buses can be reviewed for effectiveness to prepare battery specifications that other lithium-ion chemistry can support and enable the markets to determine the most feasible technology option in near- and long-term. The near-term and long-term implementations should also consider lessons learned from the deployment of public transportation to expand it across taxi-fleets and apply them toward electrification of private transportation—eventually phasing out the ICE vehicles.

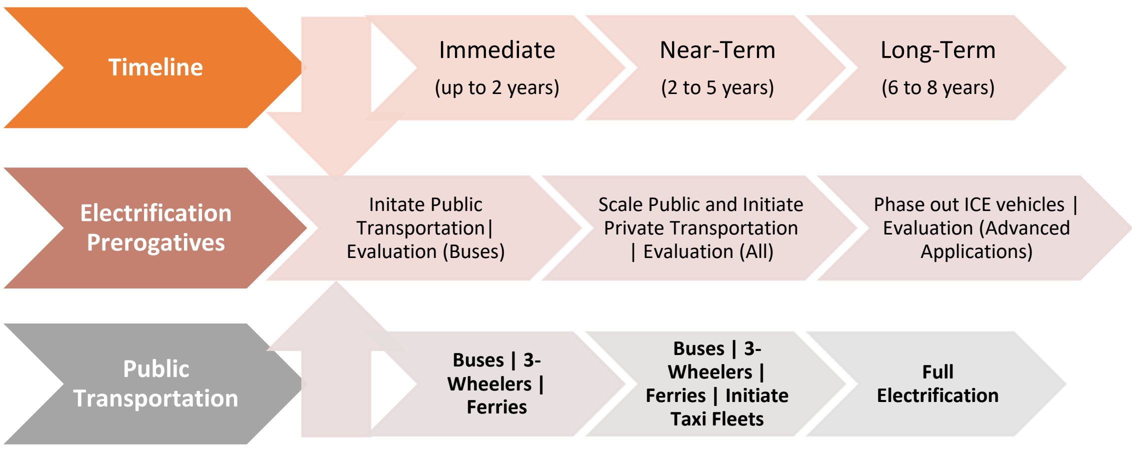

Figure 9-1: Implementation Roadmap of Public Transportation with Links to the Private Sector

While the implementation roadmap is helpful in providing a roadmap for electrification, the tangible recommendations are key to ensure success for electrification. The following priority determinants are identified for recommendations for public transportation.

1. **Social and Environmental:** Addresses the energy security, decarbonisation, and air-quality improvements to leapfrog India toward climate change goals
2. **Policy Tariff and Design:** Changes in the policies and regulations, and appropriate electricity tariffs to accelerate adoption of EVs
3. **Charging Standards:** Application and development of power and communication standards to future-proof electrification investment and open doors for low-cost innovation
4. **Business Models for EV Operations:** Sustainable business models to drive EV ownership and operation of EV charging infrastructure
5. **Vehicle-Grid-Integration:** Consider links of EVs with Smart Grid and Smart City to enable better grid reliability and high penetration of renewable resources

Tables 9-1, 9-2, and 9-3 list the key priority determinants and recommendations for immediate, near-term, and long-term implementation roadmap to electrify public transportation. These recommendations focus on three key transportation types, which were analysed in this study.

Table 9-1 Priority Deterministic Areas and Implementation Roadmap: Buses

Priority Determinant	Implementation Roadmap: Buses		
	Immediate (up to 2 years)	**Near-Term (3-5 years)**	**Long-Term (6-8 years)**
Proposed Deployment	119 buses in 10 selected routes	All 1,866 buses operated by the State government agencies on 376 routes	100% of the buses operating in Kolkata (includes school, private, PSU buses)
Social and Environmental[*]	• Monetize diesel savings of 32,500 litres/bus/year x 119 buses = 3.9 Million Litres/year for electrification • Monetize CO_2 savings of 87 Tons/bus/year x 119 buses = 10,350 Tons/year for electrification	• Monetize diesel savings of 32,500 litres/bus/year x 1,866 buses = 60 Million Litres/year for electrification • Monetize CO_2 savings of 87 Tons/bus/year x 1,866 buses = 162,350 Tons/year for electrification	• Monetize diesel savings of 32,500 litres/bus/year x 15,000 buses = 490 Million Litres/year for electrification • Monetize CO_2 savings of 87 Tons/bus/year x 15,000 buses = 1.3 Million Tons/year for electrification
Policy and Electricity Rate Tariff Design	• Finalize specifications for 9 meter buses and with battery size of 100 kWh capacity • WBERC to issue enabling regulations for WBTC and/or CESC to own and operate charging infrastructure • Ease the import duties for lithium-ion batteries and chargers • Train O&M personnel on the EV infrastructure.	• Finalize specifications for 9 meter buses and with battery size of 200 kWh capacity for larger routes and inter-city operations • Promote local manufacturing and/or assembly of EVs, batteries and components, and charging stations • WBERC to issue regulations to allow franchisees to set up charging stations • WBERC to notify separate tariff for EVs • Creation of a large pool of trained O&M personnel on the use and maintenance of EVs • Conduct education and outreach to raise awareness among public to adopt EVs	• Large scale local manufacturing and import of EVs, batteries and components, and charging stations • Enabling electricity market redesign to use EV, as grid resources
Charging Standards	• Mandate BIS recommended standards for EV and charging infrastructure. Consider both power and communications, including grid • In case, the release of BIS standards is delayed, and Kolkata has to rollout EVs prior to that the choice of EVSE should be careful to avoid lock-in with proprietary standards		
Business Models for Operations	• WBTC shall own and operate this first batch • WBTC to own and operate appropriate chargers in their bus depots	• Bus operators to set up appropriate charging stations in their bus depots • DISCOM/Franchisees to set up charging stations at bus terminus/bus interchanges	• Third party operators to set up public charging infrastructure at highways and other strategic locations

[*] The CO_2 savings can vary, depending on the source of the electricity generation. The site CO_2 savings consider a renewable generation source.

Vehicle Grid Integration	• None	• Enabling regulations and dynamic tariffs for VGI • Infrastructure upgrade plans to facilitate VGI	• Infrastructure upgrade to facilitate VGI

Table 9-2 Priority Deterministic Areas and Implementation Roadmap: 3-Wheelers

Priority Determinant	**Implementation Roadmap: 3-Wheelers**		
	Immediate (up to 2 years)	Near-Term (3-5 years)	Long-Term (6-8 years)
Proposed Deployment	2,715 auto rickshaws along seven select routes	Approximately 100,000 e-Rickshaws, which use lead acid batteries to be converted to lithium ion; 50% or 4,300 of the remaining auto-rickshaws	Remaining 4,300 auto rickshaws
Social and Environmental*	• Monetize diesel savings of 2,030 litres/rickshaw/year x 2715 rickshaws = 5.5 Million Litres/year for electrification • Monetize CO_2 savings of 3.8 Tons/rickshaw/year x 2715 rickshaws = 10,370 Tons/year for electrification	• Monetize diesel savings of 2,030 litres/rickshaw/year x 4300 rickshaws = 8.7 Million Litres/year for electrification • Monetize CO_2 savings of 3.8 Tons/rickshaw/year x 4300 rickshaws = 16,340 Tons/year for electrification • Impose taxes to mitigate environmental and health impacts of lead acid recycling, disposal	• Monetize diesel savings of 2,030 litres/rickshaw/year x 4300 rickshaws = 8.7 Million Litres/year for electrification • Monetize CO_2 savings of 3.8 Tons/rickshaw/year x 4300 rickshaws = 16,340 Tons/year for electrification •
Policy and Electricity Rate Tariff Design	• Promote battery leasing agencies (BLA) by providing incentives so that electric auto rickshaws can be sold without batteries • Allocate business permits and locations to set up battery charging and swapping stations • Ease import duties for lithium-ion batteries, chargers • Conduct public education and outreach to raise awareness to use electric rickshaws	• Promote local manufacturing and/or assembly of EVs, batteries and components, and charging stations • WBERC to notify separate tariff for BLAs, including enabling VGI services. • Stop issuing permits for internal combustion engine (ICE) based auto rickshaws • Complete Phase out of e-Rickshaws with lead-acid batteries	• Enable large scale local manufacturing and import of EVs, batteries and components, and charging stations • Enable electricity market redesign to use BLA's charging infrastructure, as grid resources •
Charging Standards	BLAs may choose most efficient and economic technologies and standards for charging infrastructures		
Business Models for Operations	• Enable market mechanisms for electric auto rickshaws to be sold without batteries to lower the first cost • Require BLAs to establish battery leasing contracts with electric auto rickshaws owners	Enable market competition for more BLAs to operate	Consider secondary use of retired batteries for stationary and grid applications

* The CO_2 savings can vary, depending on the source of the electricity generation. The site CO_2 savings consider a renewable generation source.

	• Require BLAs to swap charged batteries to electric auto rickshaws owners or operators		
Vehicle Grid Integration	None	Enabling regulations and dynamic tariffs for VGI	

Table 9-3 Priority Deterministic Areas and Implementation Roadmap: Ferries

Priority Determinant	Implementation Roadmap: Ferries		
	Immediate (up to 2 years)	**Near-Term (3-5 years)**	**Long-Term (6-8 years)**
Proposed Deployment	Six ferries along two routes	All remaining ferries	Explore potential for additional ferry services
Social and Environmental	• Monetize diesel savings for electrification • Monetize CO_2 savings for electrification • Monetize avoided environmental degradation from oil spills		
Policy and Electricity Rate Tariff Design	• WBSTC must engage an experienced agency to prepare DPR to electrify existing boats • WBSTC must engage CESC to create charging facilities at Howrah jetty • Ease the import duties for lithium ion batteries and chargers	• WBERC to notify separate tariff for charging of ferries • WBSTC must stop buying diesel ferries	• None
Charging Standards	• WBSTC/CESC/WBSEDCL may choose most efficient and economic technologies and standards for charging infrastructure		
Business Models for Operations	• WBSTC shall continue to own and operate electric ferries		
Vehicle Grid Integration	• To be evaluated in the DPR		

9.1 NEXT STEPS

Further to implementation plan and recommendations, to accelerate EV adoption (public or private), the Indian policy makers and regulators should evaluate global practices, while examining the local issues such as cost, impact on electricity network, and customer charging behaviour. India must develop specific EV needs based on the Indian conditions and work with global and local OEMs and experts to meet the government goals on electric mobility and local manufacturing. For example, the lion share for FAME scheme's demand incentive component lacks adequate focus on charging infrastructure and research needs to understand and future-proof unique vehicle and electricity distribution needs in India—all relatively high priority objectives for global practices. Specific policy recommendations must also consider applications at state-level and national-level objectives with localized needs.

To engage cost-sensitive customers and keep passenger fare at par with existing levels, the Indian national-level and state-level regulations must consider total cost of ownership (TCO) and social-cost based incentives to lower EV and EVSE ownership costs. This should consider mechanisms such as customer tax credits, local production by OEMs, reduced sales taxes, etc., which can be funded from oil subsidy and import savings, CO_2 reduction or Climate Funds, and innovative financing mechanisms. EVs also provide other non-tangible societal benefits such, as urban air-quality improvements and better health for citizens.

The TCO model considered in this study is a representative sample to conduct feasibility studies for electrification of transportation. The feasibility studies must consider an integrated transportation, electric grid, and infrastructure development plan to accelerate and futureproof the EV adoption. Regulators, grid operators, and utilities must consider localized and integrated power system impacts of EVs. The VGI has the potential to mitigate or defer system upgrade costs, which can also support higher penetration of renewables. With managed charging technologies, EVs can be charged without any restrictions and electricity tariffs can be designed to offer incentives to modulate customer-charging behaviour, and building codes that mandate residential and workplace charging infrastructure.

In Kolkata, the GoWB and the key state agencies—WBERC, WBTC, WBSEDCL, CESC, etc.— and the OEMs must be enlightened on the study findings and plan for phased rollout must be prepared. This ensures that the electrification plans for public transportation are aligned with the interests of the public and private sectors. The state agencies should convene to prepare a detailed project report (DPR) to finalize technical specifications and cost estimates using market tender offers. This should be inclusive of the major OEMs of the automotive, charging infrastructure, and batteries. The recommendations for battery technologies, sizing, policy changes, and grid integration considerations can be expanded for procurement of EVs and field evaluation programs are conducted to apply lessons for cost-effective and accelerated electrification of the entire public transportation sector in next 8 years (up to 2025). Capacity building and consumer education relative to charging infrastructure, TCO models, and vehicle choices will play a key factor in acceptance of EVs and transitioning Kolkata toward fully electrified transportation. These recommendations represents priorities to transition India's public and private ICE-vehicles for full electrification considering the recent announcements in India that all vehicles sold starting 2030 should be electric.

For Kolkata, we recommend that a pilot rollout of 26 buses on two routes may be undertaken immediately. The routes suggested are:

1. **S-07: Garia Bus Stand – Howrah**

Peak Hour Frequency	Average Number of Passenger/day/Journey	Number of bus operated	Bus trips/day/bus	Number of Bus Depots (Start – On route – End)
15 Mins	35.46	10	3	5

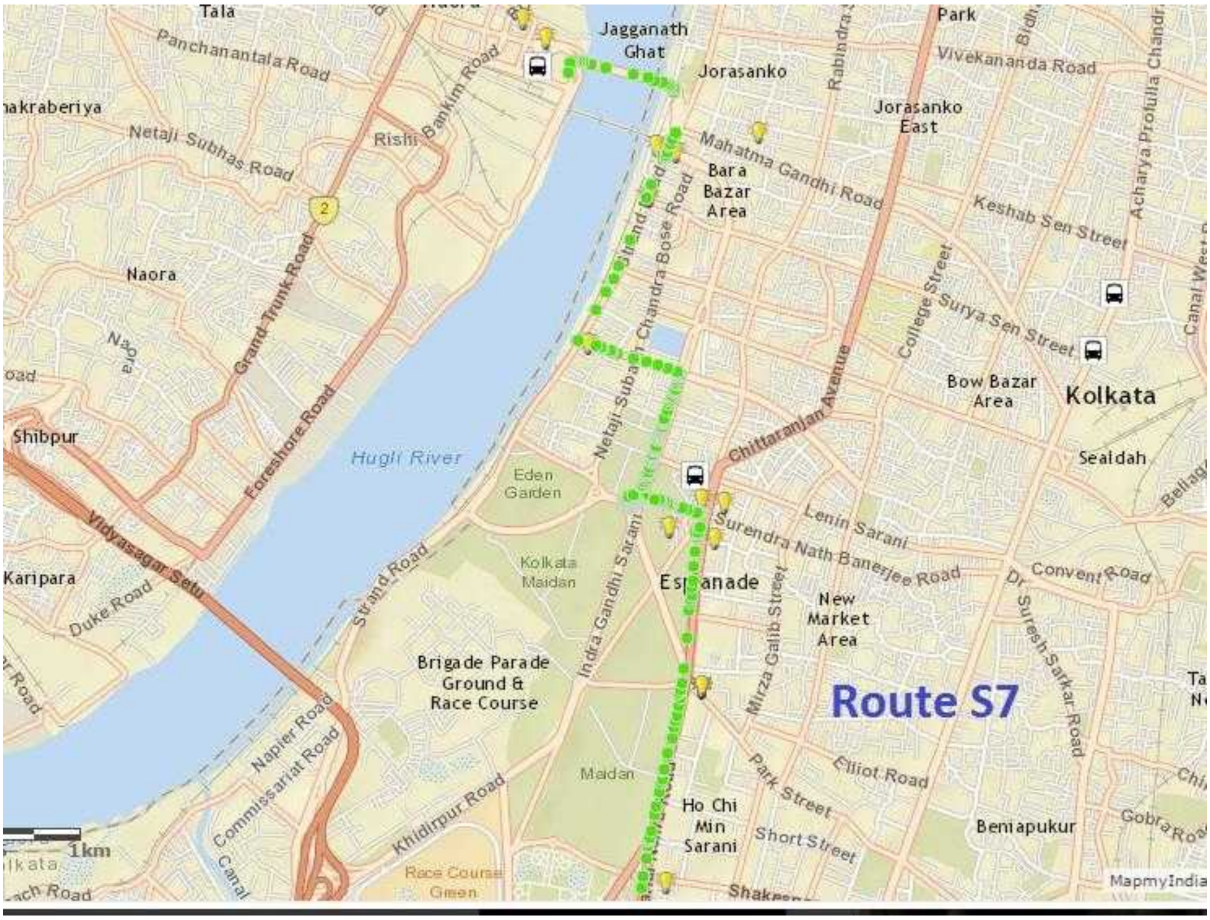

Figure 9-1: S7 Route Map

2. **S-3B: Behala 14 No – Kankurgachi**

Peak Hour Frequency	Average Number of Passenger/day/Journey	Number of bus operated	Bus trips/day/bus	Number of Bus Depots (Start – On route – End)
15 Mins	35.26	16	3	3

Figure 9-2: S3 B Route Map

For this pilot we recommend DC fast chargers installed at any 3 or 4 tram depots/stations among the following:

1. Tollygunj
2. Gariahat
3. Park Circus
4. Raja Bazar
5. Sham Bazar
6. Belgachia

A Detailed Project Report (DPR) and RFP should be prepared which will cover the specifications and technical and operating parameters of the DC Fast Charger and Bus Specifications.

ANNEXURE A

Meeting Notes – Electrification of Public Transport in Kolkata and Bangalore

TATA MOTORS Philip Jose ISGF Akshay Ahuja Ravi Seethapathy Date: 11/01/2017	1. Considerable battery modules can be 48V, 100Ah – 50Ah are also good option 2. 10 years can be considered as useful life for a battery 3. Running cost of a bus are: 0.7-0.8 kWh/Km for 9 meter bus (without AC) 1.3-1.4 kWh/Km for 12 meter bus (without AC) 30-40% more energy consumption in AC buses 4. CAN standards are used as communication protocols 5. Chargers usually operate at PF of 0.98 6. DC trams work at 550V whereas Electric Buses need 650V to operate and DC infrastructure used for trams will require DC-DC convertor 7. 1.5C-2C is the ideal charging and 4C-5C should be used for pulse charging
MINISTRY OF NEW AND RENEWABLE ENERGY Ashok Jhunjhunwala ISGF Reji Kumar Pillai Akshay Ahuja Ravi Seethapathy Date: 11/01/2017	1. BYD bus uses 324kWh, 80kW battery 2. Buses presently uses CNG has 1 tonnes of CNG cylinder on roof of the bus 3. Lithium Titanium Phosphate can be charged 8 times faster than Lithium Phosphate 4. Lithium Phosphate can be charged maximum at 2C rate but has a higher ambient temperature 5. Last 20% of the charging takes more hour to charge 6. Power to energy ratio is better in titanium and manganese cobalt as compared to phosphate batteries 7. No Alcohol electrolyte in phosphate so temp is not much issue 8. Flash or pulse chargers are expensive and need better batteries 9. Depots can be good option for battery swapping 10. Government may put few charging stations 11. Franchisee model may be considered 12. CSR money may be used for putting up charging stations
IDEATION TECHNOLOGIES Sanjoy Chatterjee ISGF Reji Kumar Pillai Akshay Ahuja Ravi Seethapathy	1. Kolkata has 928 routes out of which 768 are private routes and remaining are government operated routes 2. Day population of Kolkata metropolitan area is 1.6 crore per day 3. Highest AC bus fare in Kolkata is INR 75 and average is INR 35 4. 3 operators exist in Kolkata – SBSTC, NBSTC WBTC (CTC, CSTC and WBSTC)

Date: 17/01/2017	
MAHINDRA REVA - Bangalore Kartik Gopalan ISGF Girish Ghatikar Akshay Ahuja Date: 08/12/2016	1. Industries are also looking for alternatives – Bio fuels and Hydro fuels 2. Reva has Lithium-ion Ferrous Phosphate (LiFePO4) batteries which has the best balance between safety and energy density 3. 15-20% of the battery goes into air conditioning 4. Import cells and pack itself 5. Local manufacturing of batteries is important
MAHINDRA REVA - DELHI Pawan Sachdeva ISGF Girish Ghatikar Akshay Ahuja Ravi Seethapathy Date: 14/12/2016	1. CESS on diesel goes to air ambient fund in Delhi which can be used for promoting EVs 2. Charging infrastructure is critical for fleet operators 3. Registration of Electric Vehicles should be permitted as a tourist cab 4. Mini vans for schools and 2W for ecommerce should be made mandatory 5. One of the challenge is lack of options 6. Sales went up in 2011 when MNRE came up with scheme called Alternate Fuels for Surface Transportation Programme (AFSTP)
SIAM Saurabh Rohilla ISGF Girish Ghatikar Akshay Ahuja Ravi Seethapathy Date: 14/12/2016	1. Automotive mission plan is under preparation (2016-2026) 2. Range is important and installation of charging infrastructure is important 3. Specification of buses is under preparation which will include ideal range, charging infrastructure, top speed etc. 4. 70 – 100 km could be ideal range for buses 5. Three type of buses exist: <8 meters; 8-10 meters; >10 meters 6. INR 76/km is O&M cost of a diesel bus which has INR 30 for fuel and INR 46 for maintenance
ASHOK LEYLAND Barath Rajagopalan ISGF Akshay Ahuja Ravi Seethapathy	1. Bus was launched on 17th October 2016 2. Aim is to have 5000 electric buses on road by 2020 3. Bus has centrally located motor with 151 kW capacity 4. Bus uses Lithium Phosphate battery 5. Battery cost 50% of the bus cost 6. Bus has 45kW battery pack and can accommodate maximum of 4 packs 7. Consumption is 1.2-1.3 kWh/km for non-AC and 1.8-1.9 kWh/km on uphill

Date: 20/01/2017	8. With AC 50% more consumption 9. For a 9 meter bus – 32 seats + 16 standing 10. On board charger takes 4-6 hours to charge 11. Mini bus has typically 3 battery packs 12. Battery operate at 35 degree Celsius with cooling and between 55-70 degree Celsius without cooling 13. Battery last for around 7 years with 1C charging 14. 100 kW hour battery pack takes about 2.5 hours to charge – 2 hours for 1 battery pack and 3 hours for 3 battery packs 15. Pulse charging will bring heavy infrastructure 16. Swapping will being safety risk if done manually 17. DC induction motor is used in bus 18. India may go for plug in charging as in case of pantograph investment will have to be from STUs
WEST BENGAL TRANSPORT CORPORATION Narayan Nigam ISGF Reji Kumar Pillai Girish Ghatikar Ravi Seethapathy Date: 05/09/2016	1. The tram (ridership is slipping) system is underutilized and perhaps down to 30% utilization. Main cause is that trams are slow and being on tracks and get stuck in traffic jams. Buses on the other hand can change lanes and go around. 2. The 500-550V DC ring main system is owned and operated by CTC. It is fed by CESC on the AC side. 3. The DC rectifier are very old and may need upgrades depending on the power needed. 4. The use of the DC overhead ring main for e-bus charging will increase revenue and ROI for CTC. 5. CTC may be interesting in upgrading the DC ring main if there is a business case for doing so. 6. The tram depots are fairly big and have sufficient space for bus charging as well. 7. With the merger of the 3 STUs (under one head), there is synergy for route/technology optimization
DIMTS C.K Goyal ISGF Reji Kumar Pillai Akshay Ahuja Ravi Seethapathy Date: 19/01/2017	1. AC low floor standard bus cost – INR 80 lakhs; O&M – CPK (Cost per KM) – INR 60/KM 2. AC entry + 2 steps (900 mm – floor height) – 54 lakhs; O&M - CPK – INR 43/KM (Capacity of 61 – Sitting + Standing) 3. Non-AC low floor bus cost – INR 70 lakhs; O&M – CPK – INR 45/KM (cost is 75% of the AC bus) 4. Non-AC entry + 2 steps (900 mm – floor height) – 32 lakhs; O&M - CPK – INR 32/KM (Capacity of 61 – Sitting + Standing) 5. In case of Diesel buses, Capex is reduced by 10% compared to CNG buses and Opex increases by 8% 6. For AC bus

	CNG fuel average – INR 1.9 km/litre Diesel fuel average- INR 2.6 km/litre 7. O&M is higher in CNG due to extra circuits 8. BYD bus pilot results: AC 12 meter bus – INR 1.6 kWh/km Non-AC 12 meter bus – INR 1.3 kWh/km 9. Distance travelled by Bus in Delhi- a. Bus travels 10km from depot to terminals b. Origin to Destination – 30 km and Destination to Origin – 30 km c. Drivers are given half hour break after one full trip d. One bus drives 260 km on an average per day 10. Depth of discharge of battery should never go down below 90% 11. 324 kWh battery weights about 3.5 Tons 12. Lithium Ion Phosphate of 324 kWh gives around 6000 life cycles
KOLKATA METRO RAIL CORPORATION ISGF Akshay Ahuja Ravi Seethapathy Date: 10/09/2016	1. E-Ricks/Feeder buses are good options last mile connectivity 2. More than 1 lakh E-Ricks already operates in Kolkata 3. Howda Station to Sealdah Station can be good option for electrification covering a range of 4 km 4. East-West metro is planned from Howrah Maidan and goes up to Salt Lake Sector V 5. Kolkata North to South Metro has a span of 23 km
CESC Debasis Gupta ISGF Akshay Ahuja Ravi Seethapathy Date: 10/09/2016	1. Sub-stations can be used for putting up charging infrastructure due to easy power and space availability 2. The summer loads are about twice as much as winter loads at the system level. The summer pattern lasts for about 8 months (Apr-Nov) 3. The average tariff across all load classes is "flat" - Residential (INR 6.5), industrial (INR. 7.0) and Commercial (INR. 7.5) – and there is no TOU tariff except for the large direct demand customers.
WORLD BANK Rakhi Basu ISGF Reji Kumar Pillai Akshay Ahuja Date: 01/2017	1. Transport Department of West Bengal Government has undertaken the study on Route Rationalization in Kolkata (encompassing all public transportation modes) with assistance from World Bank 2. Under this project, digitizing the transport routes and capturing the dynamic information of traffic density and other key parameters are done 3. Electric Ferries could also be considered as part of project 4. World Bank will share the digitized route data with ISGF for the study

ANNEXURE B

List shows few standards which are available for electric vehicles around the globe

Standard Issuing Organisation	Standard Number	Title	Description / Scope
EVSE (Conductive)			
IEC	61851-1:2017 Ed. 3.0	Electric vehicle conductive charging system Part 1: General requirements	Applies to EV supply equipment for charging electric road vehicles, with a rated supply voltage up to 1000 V AC or up to 1500 V DC and a rated output voltage up to 1000 V AC or up to 1500 V DC. Electric road vehicles (EV) cover all road vehicles, including plug-in hybrid road vehicles (PHEV), that derive all or part of their energy from on-board rechargeable energy storage systems (RESS). The aspects covered in this standard include: the characteristics and operating conditions of the EV supply equipment; the specification of the connection between the EV supply equipment and the EV; the requirements for electrical safety for the EV supply equipment.
IEC	61851-3-1 Ed. 1.0	Electric Vehicles conductive power supply system - Part 3-1: General Requirements for Light Electric Vehicles (LEV) AC and DC conductive power supply systems	Will specify the requirements for Light Electric Vehicles (LEV) AC and DC conductive power supply systems including the control communication in a general way. It will make reference to the IEC 61851-1 general requirements standard for electric vehicles
IEC	61851-3-2 Ed. 1.0	Electric Vehicles conductive power supply system - Part 3-2: Requirements for Light Electric Vehicles (LEV) DC off-board conductive power supply systems	Will specify requirements for Light Electric Vehicles (LEV) DC off-board conductive power supply systems
IEC	61851-3-3 Ed. 1.0	Electric Vehicles conductive power supply system - Part 3-3:	Will specify requirements for Light Electric Vehicles (LEV) battery swap systems

		Requirements for Light Electric Vehicles (LEV) battery swap systems	
IEC	61851-3-4 Ed 1.0	Electric Vehicles conductive power supply system - Part 3-4: Requirements for Light Electric Vehicles (LEV) communication	Will specify requirements for the communication
IEC	61851-21 Ed. 1.0	Electric vehicle conductive charging system - Part 21: Electric vehicle requirements for conductive connection to an AC./DC. supply	This part of IEC 61851 together with part 1 gives the electric vehicle requirements for conductive connection to an AC. or DC. supply, for AC. voltages according to IEC 60038 up to 690 V and for DC. voltages up to 1 000 V, when the electric vehicle is connected to the supply network. This standard does not cover class II vehicles. NOTE Class II vehicles are not excluded, but the lack of information on this type of vehicle means that the requirements for the standard are unavailable at present. This standard does not cover all safety aspects related to maintenance. This standard is not applicable to trolley buses, rail vehicles, industrial trucks and vehicles designed primarily to be used off-road. Will be withdrawn and replaced by subparts 1 and 2
IEC	61851-21-1 Ed. 1.0	Electric vehicle conductive charging system - Part 21-1 Electric vehicle on board charger EMC requirements for conductive connection to an AC./DC. supply	This part of IEC 61851 together with Part 1 give requirements for conductive connection of an electric vehicle (EV) to an AC. or DC. supply. It applies only to on board charging units either tested on the complete vehicle or tested on the charging system component level (ESA - electronic sub assembly).
IEC	61851-21-2 Ed. 1.0	Electric vehicle conductive charging system - Part 21-2: EMC requirements for off-board electric vehicle charging systems	This part of IEC 61851, defines the EMC requirements for any off board components or equipment of systems that are used to supply or charge electric vehicles with electric power by conductive power transfer (CPT), with a rated input voltage, according to IEC 60038, up to 1000V AC. or 1500V DC. and an output voltage up to 1000V AC. or 1500V DC., or by wireless power transfer (WPT).

IEC	61851-22 Ed. 1.0	Electric vehicle conductive charging system - Part 22: AC electric vehicle charging station	Together with Part 1, gives the requirements for AC. electric vehicle charging stations for conductive connection to an electric vehicle, with AC. supply voltages according to IEC 60038 up to 690 V. Note: to be withdrawn upon publication of IEC 61851-1, 3rd edition.
IEC	61851-23 Ed. 1.0	Electric vehicle conductive charging system- Part 23: DC electric vehicle charging station	IEC 61851-23:2014, together with IEC 61851-1, gives the requirements for DC. electric vehicle (EV) charging stations, herein also referred to as "DC charger", for conductive connection to the vehicle, with an AC. or DC. input voltage up to 1 000 V AC. and up to 1 500 V DC. according to IEC 60038. It provides the general requirements for the control communication between a DC. EV charging station and an EV. The requirements for digital communication between DC. EV charging station and electric vehicle for control of DC. charging are defined in IEC 61851-24.
IEC	62196-1 Ed. 2.0	Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 1: General requirements	This part of IEC 62196 is applicable to plugs, socket-outlets, vehicle connectors, vehicle inlets and cable assemblies for electric vehicles, herein referred to as “accessories”, intended for use in conductive charging systems which incorporate control means, with a rated operating voltage not exceeding – 690V AC. 50Hz to 60 Hz, at a rated current not exceeding 250 A, –1 500 V DC. at a rated current not exceeding 400 A.
IEC	62196-2 Ed. 1.0	Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 2: Dimensional compatibility and interchangeability requirements for AC. pin and contact-tube accessories	IEC 62196-2:2011 applies to plugs, socket-outlets, vehicle connectors and vehicle inlets with pins and contact-tubes of standardized configurations, herein referred to as accessories. They have a nominal rated operating voltage not exceeding 500 V AC., 50 to 60 Hz, and a rated current not exceeding 63 A three-phase or 70 A single phase, for use in conductive charging of electric vehicles.
IEC	62196-3 Ed. 1.0	Plugs, socket-outlets, vehicle connectors and vehicle inlets -	This part of IEC 62196 is applicable to vehicle couplers with pins and contact tubes of standardized configuration, herein also referred

		Conductive charging of electric vehicles - Part 3: Dimensional compatibility and interchangeability requirements for DC. and AC/DC pin and contact-tube vehicle couplers	to as "accessories", intended for use in electric vehicle conductive charging systems which incorporate control means, with rated operating voltage up to 1500V DC and rated current up to 250 A, and 1000 V AC and rated current up to 250 A.
SAE	J1772	SAE Electric Vehicle and Plug in Hybrid Vehicle Conductive Charge Coupler	This SAE Recommended Practice covers the general physical, electrical, functional and performance requirements to facilitate conductive charging of EV/PHEV vehicles in North America
SAE	J1773	Electric Vehicle Inductively Coupled Charging	Establishes the minimum interface compatibility requirements for electric vehicle (EV) inductively coupled charging for North America.
SAE	J2293/1	Energy Transfer System for Electric Vehicles-Part 1: Functional Requirements and System Architectures	Establishes requirements for Electric Vehicles (EV) and the off- board Electric Vehicle Supply Equipment (EVSE) used to transfer electrical energy to an EV from an Electric Utility Power System (Utility) in North America
SAE	J2953/1 V1	Plug-In Electric Vehicle (PEV) Interoperability with Electric Vehicle Supply Equipment (EVSE)	This SAE Recommended Practice J2953/1 establishes requirements and specification by which a specific Plug-In Electric Vehicle (PEV) and Electric Vehicle Supply Equipment (EVSE) pair can be considered interoperable
SAE	J2953/2 V1	Test Procedure for the Plug-in Electric Vehicle (PEV) Interoperability with Electric Vehicle Supply Equipment (EVSE)	This SAE Recommended Practice SAE J2953/2 establishes the test procedures to ensure the interoperability of Plug-In Vehicles (PEV) and Electric Vehicle Supply Equipment (EVSE) for multiple suppliers.
UL	2202	Safety of Electric Vehicle (EV) Charging System Equipment	Covers charging system equipment, either conductive or inductive, intended for use with electric vehicles.
UL	NMX-J-678ANCE/CSA C22.2 No. 282-13/UL 2251	Standard for Plugs, Receptacles, and Couplers for Electric Vehicles	Covers plugs, receptacles, vehicle inlets, vehicle connectors, and breakaway couplings, rated up to 800 amperes and up to 600 volts ac or dc, intended for conductive connection systems, for use with electric vehicles. These devices are for use in either indoor or outdoor non-hazardous locations in accordance with the

			electrical codes of Canada, Mexico and the United States.
UL	NMX-J-677ANCE/CSA C22.2 NO. 280-13/UL 2594	Standard for Electric Vehicle Supply Equipment	Covers conductive electric vehicle (EV) supply equipment with a primary source voltage of 600 V ac or less, with a frequency of 60 Hz, and intended to provide ac power to an electric vehicle with an on-board charging unit. This Standard covers electric vehicle supply equipment intended for use where ventilation is not required.
IEEE	2030.1.1-2015	IEEE Standard Technical Specifications of a DC Quick Charger for Use with Electric Vehicles	Direct-current (dc) charging is a method of charging that facilitates rapid energy transfer from the electric grid to plug-in vehicles. This method of charging allows significantly more current to be drawn by the vehicle versus lower rated alternating-current (ac) systems. A combination of vehicles that can accept high-current dc charge and the dc supply equipment that provides it has led to the use of terminology such as “fast charging,” “fast charger,” “dc charger,” “quick charger,” etc. DC charging and ac charging vary by the location at which ac current is converted to dc current. For typical dc charging, the current is converted at the off-board charger, which is separate from the vehicle. For ac charging, the current is converted inside the vehicle, by means of an on-board charger. The location of the ac to dc conversion equipment, or converter, shapes the complexity of the equipment design. Regarding ac charging, as previously mentioned, the conversion is on board the vehicle. This allows the original equipment maker (OEM) designed systems to control the charging operation in its entirety. The on-board charger (converter) and battery controller solution is under direct control of the vehicle manufacturer. For dc charging, an entirely new challenge exists for OEMs. The dc charger is now external to the vehicle and requires the vehicle engineers to control an external power device. For the reason of necessary interoperability, standards such as IEEE Standard 2030.1.1 are provided to assist

			developers.
WIRELESS CHARGING			
SAE	J2954	Wireless Charging of Electric and Plug-in Hybrid Vehicles	Establishes minimum performance and safety criteria for wireless charging of electric and plug-in vehicles
UL	2750	Wireless Charging Systems for Electric Vehicles	Covers wireless charging systems consisting of a power unit, a primary coil and a secondary coil (on board)
IEC	61980-1 Ed. 1.0	Electric vehicle wireless power transfer systems (WPT) - Part 1: General requirements	This standard applies to the equipment for the wireless transfer of electric power from the supply network to electric road vehicles for purposes of supplying electric energy to the RESS (Rechargeable energy storage system) and/or other on-board electrical systems in an operational state when connected to the supply network, at standard AC. supply voltages per IEC 60038 up to 1000V AC. and up to 1500 V DC.
IEC	61980-3	Electric vehicle wireless power transfer (WPT) systems - Part 3 specific requirements for the magnetic field power transfer systems	
COMMUNICATION			
IEC	61851-24 Ed. 1.0	Electric vehicle conductive charging system - Part 24: Digital communication between a DC EV charging station and an electric vehicle for control of DC charging	IEC 61851-24:2014, together with IEC 61851-23, applies to digital communication between a DC. EV charging station and an electric road vehicle (EV) for control of DC. charging, with an AC. or DC. input voltage up to 1 000 V AC. and up to 1 500 V DC. for the conductive charging procedure. The EV charging mode is mode 4, according to IEC 61851-23. Annexes A, B, and C give descriptions of digital communications for control of DC. charging specific to DC. EV charging systems A, B and C as defined in Part 23.
IEC	61980-2	Electric vehicle wireless power transfer	

		(WPT) systems - Part 2 specific requirements for communication between electric road vehicle (EV) and infrastructure with respect to wireless power transfer (WPT) systems	
IEEE	802.20	Standard for Local and Metropolitan Area Networks - Standard Air Interface for Mobile Broadband Wireless Access Systems Supporting Vehicular Mobility - Physical and Media Access Control Layer Specification	The technical requirements of this standard form a compatibility standard for mobile broadband wireless access systems. The standard ensures that a compliant access terminal (AT) or user terminal (UT) can obtain service through any access node (AN) or base station (BS) conforming to properly selected modes of this standard, consistent with equipment and operator requirements, thus providing a framework for the rapid development of cost-effective, multivendor mobile broadband wireless access systems.
IEEE	1609.4	IEEE Standard for Wireless Access in Vehicular Environments (WAVE)--Multi-channel Operation	The scope of this standard is the specification of medium access control (MAC) sub-layer functions and services that support multi-channel wireless connectivity between IEEE 802.11 Wireless Access in Vehicular Environments (WAVE) devices.
IEEE	P1609.5	Standard for Wireless Access in Vehicular Environments (WAVE) - Communication Manager	This standard specifies communication management services for Wireless Access in Vehicular Environments (WAVE). This standard defines communication management services in support of wireless connectivity among vehicle-based devices, and between fixed roadside devices and vehicle-based devices for Wireless Access in Vehicular Environments.
IEEE	1609.11	IEEE Standard for Wireless Access in Vehicular Environments (WAVE)--Over-the-Air Electronic Payment Data Exchange Protocol for Intelligent	This standard specifies the application service layer and profile for Payment and Identity authentication, and Payment Data transfer for Dedicated Short Range Communication (DSRC) based applications using IEEE Std. 802.11(TM) and IEEE 1609 protocols in Wireless Access in Vehicular Environments. This standard defines a basic

		Transportation Systems (ITS)	level of technical interoperability for electronic payment equipment.
ISO/IEC	15118-1	Road vehicles — Vehicle to grid communication interface Part 1: General information and use case definition	Specifies the communication between electric vehicles (EV), (this term includes Battery Electric Vehicles as well as Plug-In Hybrid Electric Vehicles) and the electric vehicle supply equipment (EVSE).
ISO/IEC	15118-2	Road vehicles -- Vehicle to grid Communication Interface -- Part 2: Technical protocol description and open systems interconnections (OSI) requirements	Specifies the communication between battery electric vehicles (BEV) or plug-in hybrid electric vehicles (PHEV) and the Electric Vehicle Supply Equipment (EVSE, also known as charge spot). It covers the overall information exchange between all actors involved in the electrical energy exchange. This International Standard is applicable for (manually) connected conductive charging.
ISO/IEC	15118-3	Road vehicles -- Vehicle to grid Communication Interface -- Part 3: Physical and data link layer requirements	Specifies the physical and data link layer for a high level communication, directly between battery electric vehicles (BEV) or plug-in hybrid electric vehicles (PHEV), and the fixed electrical charging installation (Electric Vehicle Supply Equipment (EVSE)), used in addition to the Basic Signalling, as described in IEC 61851. It covers the overall information exchange between all actors involved in the electrical energy exchange.
ISO/IEC	15118-4	Road vehicles -- Vehicle to grid communication interface -- Part 4: Network and application protocol conformance test	Specify test cases to be applied to and correctly handled by EVs (EVCC) and EVSEs (SECC) implementing ISO/IEC15118-2
ISO/IEC	15118-5	Road vehicles -- Vehicle to grid communication interface -- Part 5: Physical layer and data link layer conformance test	Specify test cases to be applied to and correctly handled by EVs (EVCC) and EVSEs (SECC) implementing ISO/IEC15118-3
SAE	J1850	Class B Data Communications	Establishes the requirements for a Class B Data Communication Network Interface applicable to

		Network Interface	all On- and Off-Road Land-Based Vehicles
SAE	J2293/2	Energy Transfer System for Electric Vehicles Part 2: Communication Requirements and Network Architecture	Establishes requirements for Electric Vehicles (EV) and the off-board Electric Vehicle Supply Equipment (EVSE) used to transfer electrical energy to an EV from an electric Utility Power System (Utility) in North America
SAE	J2497	Power Line Carrier Communications for Commercial Vehicles	Defines a method for implementing a bidirectional, serial communications link over the vehicle power supply line among modules containing microcomputers. This document defines those parameters of the serial link that relate primarily to hardware and software compatibility such as interface requirements, system protocol, and message format that pertain to Power Line Communications (PLC) between Tractors and Trailers.
SAE	J2836/1 V1	Use Cases for Communication Between Plug-in Vehicles and the Utility Grid	This SAE Information Report establishes use cases for communication between plug-in electric vehicles and the electric power grid, for energy transfer and other applications.
SAE	J2836/2 V1	Use Cases for Communication between Plug-in Vehicles and the Supply Equipment (EVSE)	This SAE Information Report J2836/2™ establishes use cases and general information for communication between plug-in electric vehicles and the DC Off board charger.
SAE	J2836/3 V1	Use Cases for Plug-in Vehicle Communication as a Distributed Energy Resource	This SAE Information Report establishes use cases for a Plug-in Electric Vehicle (PEV) communicating with an Energy Management System (EMS) as a Distributed Energy Resource (DER).
SAE	J2836/4 V1	Use Cases for Diagnostic Communication for Plug-in Vehicles	This SAE Information Report establishes diagnostic use cases between plug-in electric vehicles and the EV Supply Equipment (EVSE).
SAE	J2836/5 V1	Use Cases for Communication between Plug-in Vehicles and their customers	This SAE Information Report J2836/5™ establishes use cases between Plug-In Vehicles (PEV) and their customer.

SAE	J2836/6™ V1	Use Cases for Wireless Charging Communication for Plug-in Electric Vehicles	This SAE Information Report SAE J2836-6 establishes use cases for communication between plug-in electric vehicles and the EVSE, for wireless energy transfer as specified in SAE J2954.
SAE	J2847/1 V4	Communication for Smart Charging of Plug-in Electric Vehicles using Smart Energy Profile 2.0	This document describes the details of the Smart Energy Profile 2.0 (SEP2.0) communication used to implement the functionality described in the SAE J2836/1Гäó use cases
SAE	J2847/2 V2	Communication between Plug-in Vehicles and Off-Board DC Chargers	This SAE Recommended Practice establishes requirements and specifications for communication between plug-in electric vehicles and the DC Off-board charger.
SAE	J2847/3 V1	Communication for Plug-in Vehicles as a Distributed Energy Resource	This document applies to a Plug-in Electric Vehicle (PEV) which is equipped with an on board inverter and communicates using the Smart Energy Profile 2.0 Application Protocol (SEP2).
SAE	J2847/4 V1	Diagnostic Communication for Plug-in Vehicles	This SAE Recommended Practice J2847/4 establishes the communication requirements for diagnostics between plug-in electric vehicles and the EV Supply Equipment (EVSE) for charge or discharge sessions
SAE	J2847/5 V1	Communication between Plug-in Vehicles and Their Customers	This SAE Recommended Practice J2847/5 establishes the communication requirements between plug-in electric vehicles and their customers for charge or discharge sessions.
SAE	J2847/6 V1	Wireless Charging Communication between Plug-in Electric Vehicles and the Utility Grid	This SAE Recommended Practice J2847/6 establishes signals and messages for communication between plug-in electric vehicles and the electric power grid, for wireless energy transfer.
SAE	J2931/1 V2	Digital Communications for Plug -in Electric	This SAE Information Report SAE J2931 establishes the requirements for digital communication between Plug-in Vehicles (PEV), the Electric Vehicle Supply Equipment (EVSE) and the utility or service provider, Energy Services Interface (ESI), Advanced Metering Infrastructure (AMI) and Home Area Network (HAN).
SAE	J2931/2	Inland Signalling Communication for	Establishes the requirements for physical layer communications using Inland Signalling

		Plug-in Electric Vehicles	between Plug-In Vehicles (PEV) and the EVSE.
SAE	J2931/3	PLC Communication for Plug-in Electric Vehicles	Establishes the requirements for physical layer communications using Power Line Carrier (PLC) between Plug-In Vehicles (PEV) and the EVSE.
SAE	J2931/4 V1	Broadband PLC Communication for Plug-in Electric Vehicles	This SAE Technical Information Report SAE J2931/4 establishes the specifications for physical and data-link layer communications using broadband Power Line Communications (PLC) between the Plug-In Vehicle (PEV) and the Electric Vehicle Supply Equipment (EVSE) DC off-board-charger.
SAE	J2931/5 V1	Telematics Smart Grid Communications between Customers, Plug-In Electric Vehicles (PEV), Energy Service Providers (ESP) and Home Area Networks (HAN)	This SAE Recommended Practice J2931/5 establishes the security requirements for digital communication between Plug-In Electric Vehicles (PEV), the Electric Vehicle Supply Equipment (EVSE) and the utility, ESI, Advanced Metering Infrastructure (AMI) and/or Home Area Network (HAN).
SAE	J2931/6 V1	Digital Communication for Wireless Charging Plug-in Electric Vehicles	This SAE Recommended Practice J2931/6 establishes the digital communication protocol requirements for wireless charging between Plug-In Vehicles (PEV), the Electric Vehicle Supply Equipment (EVSE) and the utility, ESI, Advanced Metering Infrastructure (AMI) and/or Home Area Network (HAN).
BATTERY SWAPPING			
IEC	62840-1 Ed. 1.0	Electric vehicle battery swap system Part 1: System description and general requirements	This standard gives the general requirements for battery swap system, which is for the purposes of swapping batteries of electric vehicles in a non-operational state when the battery swap system connected to the supply network. The power supply is up to 1000V AC. or up to 1500V DC., according to IEC 60038.
IEC	62840-2 Ed. 1.0	Electric Vehicles Battery Swap System - Part 2: Safety requirements	This standard provides the safety requirements for a battery swap system for the purposes of swapping batteries of electric vehicles in a non-operational state, when the battery swap system is connected to the supply network, at standard supply voltages per IEC 60038 is up to 1000V AC. or up to 1500V DC.

SAE	2000-05-0356	Design and Safety Considerations for Automated Battery Exchange Electric Vehicles	The exchange of the energy storage unit from an electric vehicle is considered an alternative to in-vehicle battery charging. If the exchange process is mechanically assisted or automated, the exchange can potentially be accomplished in much less time than that required for in-vehicle charging. Many means for accomplishing battery exchange have been proposed or attempted, with various degrees of success, from the late 1800's through the present. In recent years, battery exchange methods have not been embraced by the electric vehicle industry, in deference to fast in-vehicle battery charging. Only a small number of semi-automated mechanizations have actually been demonstrated.
BATTERY			
ISO	12405-1	Electrically propelled road vehicles — Test specification for lithium-ion traction battery packs and systems — Part 1: High power applications	Specifies test procedures for lithium-ion battery packs and systems, to be used in electrically propelled road vehicles
ISO	12405-2	Electrically propelled road vehicles -- Test specification for lithium-ion traction battery packs and systems -- Part 2: High energy application	Specifies the tests for high energy battery packs and systems.
ISO	12405-3	Electrically propelled road vehicles - Test specification for Lithium-ion traction battery packs and systems -- Part 3: Safety performance requirements	Specifies test procedures and provides acceptable safety criteria for voltage class B lithium-ion battery packs and systems, to be used as traction batteries in electrically propelled road vehicles.

ISO	18300	Electrically propelled road vehicles -- Specifications for lithium-ion cell and battery coupled with other types of battery and capacitor	Specifies classification, definition, designation, test method and requirements for lithium-ion hybrid cell and battery consisted of other type of battery or capacitor for vehicle propulsion. The project defines requirements and test procedures for battery systems in which lithium ion cells are combined with ultra capacitors.
ISO/IEC	PAS 16898	Electrically propelled road vehicles - Dimensions and designation of secondary lithium-ion cells	Specifies a designation system as well as the shapes and dimensions for secondary lithium-ion cells for integration into battery packs and systems used in electrically propelled road vehicles including the position of the terminals and any over-pressure safety device (OPSD). It is related to cylindrical, prismatic and pouch cells.
SAE	J240	Life Test for Automotive Storage Batteries	This life test simulates automotive service when the battery operates in a voltage regulated charging system
SAE	J537	Storage Batteries	Serves as a guide for testing procedures of automotive 12 V storage batteries and as a publication providing information on container hold down configuration and terminal geometry.
SAE	J1797	Recommended Practice for Packaging of Electric Vehicle Battery	Provides for common battery designs through the description of dimensions, termination, retention, venting system, and other features required in an electric vehicle application.
SAE	J1798	Recommended Practice for Performance Rating of Electric Vehicle	Provides for common test and verification methods to determine Electric Vehicle battery module performance.
SAE	J2288	Life Cycle Testing of Electric Vehicle Battery Modules	Defines a standardized test method to determine the expected service life, in cycles, of electric vehicle battery modules.
UL	2271	Batteries and Battery Packs for Use in Light Electric Vehicles	These requirements cover nickel, lithium ion and lithium ion polymer batteries and battery packs for use in light electric vehicles (LEVs) as defined in this standard.
UL	2580	Batteries for Use in Electric Vehicles	This standard evaluates the cells, cell modules and battery pack's ability to safely withstand simulated abuse conditions

ANNEXURE C

	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Kasba Ind DT 400KVA	I	N	D	U	S	T	R	I	A	L														
04/2016	60	60	60	60	60	60	90	90	180	310	325	340	300	320	270	270	270	240	150	120	60	60	60	60
11/2016	50	50	50	50	50	75	75	100	200	250	250	225	200	220	220	225	225	225	175	125	75	75	75	60
Jadavpore DT 400KVA	C	O	M	M	E	R	C	I	A	L		+		R	E	S	I	D	E	N	T	I	A	L
04/2016	40	40	40	30	30	30	30	30	50	75	125	150	135	125	120	120	175	260	260	275	250	200	75	50
11/2016	15	15	15	15	15	15	15	15	15	20	60	60	60	45	45	75	135	135	120	120	105	60	15	15
Kalagachia DT315 KVA	I	N	D	U	S	T	R	I	A	L		+		R	E	S	I	D	E	N	T	I	A	L
04/2016	260	240	210	240	210	240	270	270	270	270	260	250	270	300	315	315	315	325	325	325	310	270	270	270
11/2016	170	160	140	140	140	150	160	180	190	200	220	210	180	180	210	220	220	220	210	220	210	220	190	180
Ezra St T/H DT 600KVA	C	O	M	M	E	R	C	I	A	L														
05/2016	25	25	25	25	25	25	25	25	45	100	350	425	425	456	430	430	425	420	175	125	40	25	25	25
12/2016	15	15	15	15	15	15	15	15	30	60	210	240	240	240	240	247	247	235	75	50	20	15	15	15

NOTES

NOTES

An initiative supported by

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