Decarbonizing transportation in India

Policy Framework, Charging Infrastructure, and Impact of Electric Vehicles on the Grid by 2030

THE ENERGY AND RESOURCES INSTITUTE
Creating Innovative Solutions for a Sustainable Future
CHILDREN'S INVESTMENT FUND FOUNDATION

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1. **BAU (business-as-usual) Scenario:**

   The BAU scenario, assumes that current EV deployment trends will continue until 2030, however with limited horizon on low carbon growth. Therefore, the number of EVs will increase considerably, but their load and charging patterns will remain mostly uncoordinated.

2. **Smart Charging:**

   Smart charging[1] means adapting the charging cycle of EVs to both the conditions of the power system and the needs of vehicle users. This facilitates the integration of EVs while meeting mobility needs. Smart charging allows a certain level of control over the charging process. It includes different pricing and technical charging options. The simplest form of incentive – time-of-use pricing – encourages consumers to move their charging from peak to off-peak periods. This involves the charging of an EV controlled by bidirectional communication between two or more actors to optimise all customer requirements, as well as grid management, and energy production including renewables with respect to system costs, limitations, reliability, security and safety

3. **Bidirectional Charging (V2G):**

   V2G[2] technology can be defined as a system in which there is capability of controllable, bi-directional electrical energy flow between a vehicle and the electrical grid. The electrical energy flows from the grid to the vehicle in order to charge the battery. It flows in the other direction hen the grid requires the energy. This technology will enable the user to transfer power back to the home (V2H) or back into the grid (V2G), when called upon for reliability reasons

4. **Time of Day (TOD) Tariff:**

   TOD tariff is a tariff structure in which different rates are applicable for use of electricity at different time of the day. It means that cost of using 1 unit of electricity will be different in mornings, noon, evenings and nights.

5. **State of Charge (SoC):**

   State of charge is the level of charge of an electric battery relative to its capacity. The units of SoC are percentage points.

6. **Uncoordinated Charging:**

   In an uncoordinated charging scheme, the batteries of the EVs either start charging immediately after arriving at home/ a public charging station and, or after a short delay (usually due to a limited number of chargers or a limit on the sanctioned load). this type of charging could potentially increase the peak load.

7. **Coordinated Charging:**

   EV integration in the distribution system can be improved when charging at the off-peak period which is called coordinated charging. This can be achieved when a central charging aggregator sends signals to the connected EVs to start, stop, delay or reduce the rate of charging.

8. **Total Cost of Ownership (TCO):**

   Total cost of ownership is a financial estimate intended to help buyers to determine the purchase price of a vehicle plus the estimated costs of operation.

9. **Demand Response:**

   Demand response is a change in the power consumption of an electric utility customer to better match the demand for power with the supply.

10. **Level of Control:**

    The percentage participation of Electric fleet in coordinated charge scheduling i.e. Optimization of charging constrained by utility pricing signal or Network loading.

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[1] Details available at https://irena.org//media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_EV_smart_charging_2019.pdf?la=en&hash=E77FAB7422226D29931E8469698C709EFC13EDB2#:~:text=Smart%20charging%20means%20adapting%20the,the%20needs%20of%20vehicle%20users.

[2] Details available at https://www.energy.gov/sites/prod/files/2014/02/f8/v2g_power_flow_rpt.pdf

ACRONYMS

AC	Alternating current
BAU	Business as usual
B2B	Business-to-business
B2C	Business-to-customer
BEV	Battery electric vehicle
C-rate	Cycling rate
CAGR	Compound annual growth rate
CAPEX	Capital expenditure
DC	Direct current
DHI	Department of Heavy Industry
DoD	Depth of discharge
DISCOM	Power utility
EoL	End of life
EV (LEM)	Electric Vehicle Load Estimation Model
EVCI	Electric vehicle charging infrastructure
EVSE	Electric vehicle supply equipment
GoI	Government of India
ICE	Internal combustion engine
IEC	International Electro Technical Commission
ISO	International Organization for Standardization
LDV	Light Duty Vehicle
MoP	Ministry of Power
MoRTH	Ministry of Road, Transport and Highway
MoH&UA	Ministry of Housing and Urban Affairs
MW	Megawatt
km	Kilometre
kV	Kilovolt
kW	Kilowatt
kWh	Kilowatt-hour
Rs	Rupees
SoC	State of Charge
TOD	Time of day
TOU	Time of use
V2G	Vehicle to grid

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All opinions expressed, as well as omissions and eventual errors are the responsibility of the authors alone.

1. INTRODUCTION AND BACKGROUND OF EV IN INDIA

1.1 Overview of Electric Mobility in India

In recent years electric mobility has gained traction in India with concerted focus towards incentives on vehicle and charging infrastructure, demand creation, and an enabling policy and regulatory framework. India launched the National Electric Mobility Mission Plan (NEMMP) in 2012, a national-level electric mobility programme, which aims to provide the vision and the road map for faster adoption of EVs in the country including their manufacturing. The Department of Heavy Industry (DHI), Government of India is the nodal department of the NEMMP. The national plan has been proficiently supplemented by the Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME India) Scheme, which was launched under the NEMMP in 2015. The FAME India Scheme, currently in its Phase 2, puts a strong and direct focus towards demand creation and supporting charging infrastructure implementation. Electrification of public transportation fleet, especially buses, was the prime focus of the scheme during Phase-I; however, there is considerable stress on passenger vehicles and of late, a significant number of models have been supported by the subsidy earmarked under the FAME India Scheme.

On March 7, 2019, the Government of India (GoI) launched National Mission on Transformative Mobility and Battery Storage to promote clean, connected, shared, and holistic mobility initiatives. Apart from providing the required push to the manufacturing of batteries for EVs, many states have also drafted policies to support the EV eco-system by announcing various incentives, subsidies, and tax benefits in addition to announcing EV charging tariffs. Till date, 15 states have published the final or draft policies while regulatory commissions of 20 states and UTs have notified tariffs. Many central government ministries are involved at the policy-making and regulatory level to support all the aspects related to E-Mobility. The segment-wise EV sales[3] in India are shown in Figure 1. Although electrification of public transportation is underway as part of the central and state governments' efforts under FAME procurement models, the penetration of electric models at the passenger level has been limited.

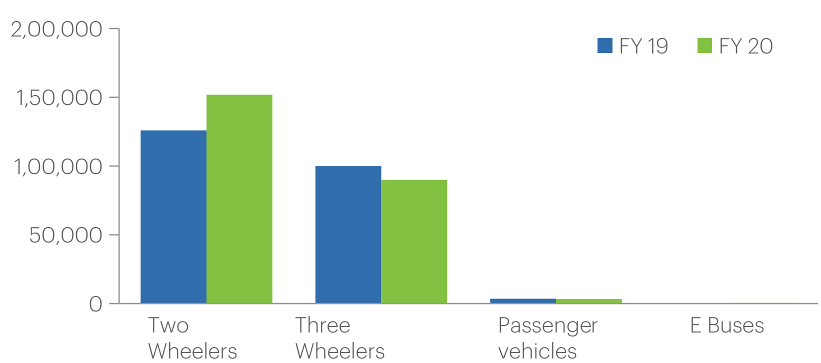

Figure 1: Segment wise EV sales in India (FY 19 and FY 20)

[3] 'Electric mobility in India,' by Intersearch worldwide organization of executive search firms.

1.2 Growth of EV in the National Capital – A Grid Integration Case study

Electric mobility has remained an important priority for the NCT of Delhi as is evident through the various policy-level efforts. The government of NCT Delhi has launched Delhi EV Policy in August 2020 to promote the adoption of electric vehicles at the state level, under which the government has set up targets such as 25% of all new vehicle registrations to be electric by 2024, all delivery services will convert 50% of their fleet to electric by 2023 and 100% by 2025, and induction of 1000 new electric buses will replace CNG buses in the state. Under the same initiative, a campaign called 'Switch Delhi' has been launched which helps people to understand the benefits of EV and urge them to make a switch to EVs. Henceforward, such kind of awareness campaigns will help the state to reduce vehicular pollution level as well as fasten up the process to achieve policy targets. Under this study, TERI has estimated the increase in stock[4] of EVs in Delhi till 2030. Further, we use this incremental growth of EV stock to model the EV charging load and thus draw various interventions to manage the peak demand with a detailed analysis in the final chapter.

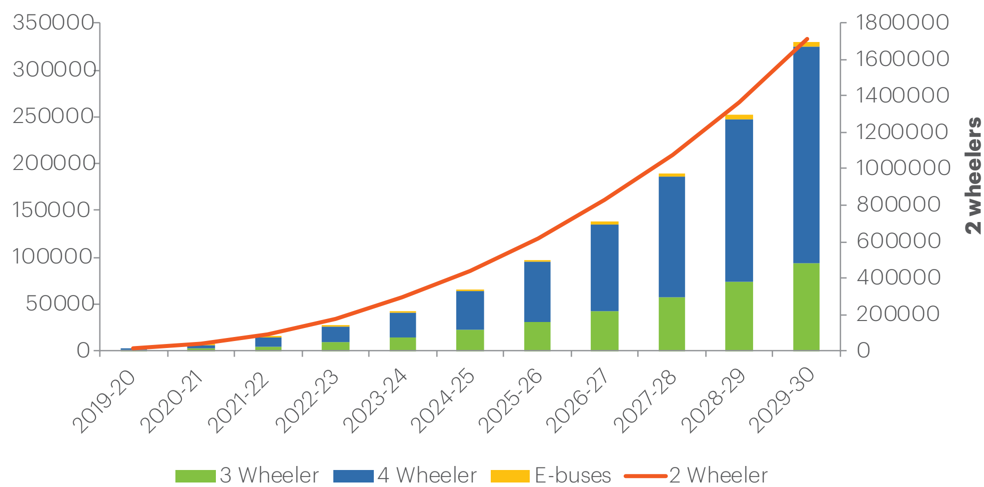

Figure 2: Estimated Growth of Electric vehicle stock in Delhi

The objective of this study is to provide a vision for the decarbonisation of transportation sector in India and the need for essential driving policies and regulations for readying this transition by studying existing policies, India's growth trajectories, and comprehensive load modelling studies. To this end, the report is structured into three chapters. Chapter 2 covers a comprehensive study on global and Indian charging standards. Chapter 3takes the perspective of national- and state-level policies in respect to charging infrastructure deployment and Chapter 4 focuses on EV load estimation modelling case study of Delhi and grid impact of EV Integration on system level and overall recommendations.

[4] TERI Analysis "TERI Transport Modeling"

2. INTRODUCTION TO EV CHARGING INFRASTRUCTURE AND CHARGING STANDARDS

Electric vehicle (EV) charging infrastructure comprises electricity supply infrastructure consisting of distribution transformer(s), energy meters, cables and distribution panels, which provide reliable input power supply to Electric Vehicle Supply Equipment (EVSE). For efficient EV charging, proper networking and communication among DISCOM/grid operators, EVSE and EV should be enabled for charging, monitoring and management as a grid resource.

2.1 Classification of Electric Vehicle Supply Equipment

Electric vehicless are charged from the utility grid through EVSE. The classification of EVSE depends on different aspects and parameters such as power supply, power rating, charging speed and communication protocols, and connector types. This section will briefly cover each of these types of EVSEs.

2.1.1 EVSE Types

The supply equipment for charging EVs is generally categorized based on the type of charging technology used. Accordingly, the EVSE types can be broadly classified based on the following charging technologies:

Slow charging: Slow charging is typically used for overnight charging through chargers rated between 3 kW and 6 kW. It typically takes about 6-8 h for charging an EV through a slow charger rated around 3 kW. Slow chargers make use of an on-board charger, which is sized based on input voltage from the grid.

Fast charging: This technology uses chargers having high power output that are capable of charging an EV in minimum 15 minutes up to 80% of battery state of charge (SoC). These types of chargers are in the range of 20–100kW power rating. Fast charging is generally required for EVs to support ongoing trips, such as major road networks, highways. Fast charging is also known as DC charging because power rectification and voltage regulation are performed in an off-board unit that directly provides DC supply to the vehicle on-board controller for charging the battery. Fast charging is normally used for four-wheelers, e-buses and trucks.

Battery swapping: This form of charging technology involves replacement of a depleted EV battery by a fully charged new battery, instead of re-charging the depleted on-board battery. Accordingly, the EVSE used in such a charging paradigm is typically in the form of a battery swapping station having either a centralized battery charger or separate charging docks. There are separate spaces for keeping and maintaining a stock of extra batteries and for monitoring depleted batteries that need to be connected to the station charger/ charging docks. There is a dedicated battery-state monitoring and control unit to take care of the charging process and facilitates easy replacement of incoming-depleted batteries by pre-charged ones. Since in this case, the battery is separated from the EVs, such a scheme reduces the time for charging, and if optimized well for a segment of vehicles, can reduce the upfront EV cost.

In battery swapping, EV users swap their empty batteries with charged batteries at swapping station. So the EV user does need not buy battery during purchase of EV.The swapping station master charges these batteries and leases it to the EV owners at suitable prices. Therefore, the EVs do not need to be fast charged or carry larger batteries as waiting time get significantly reduced due to the swapping operation.

Wireless charging: The EVSE in such a charging scheme consists of systems capable of transferring power with the help of an electric field or a magnetic field. Such a technological intervention can act as a viable solution to support full autonomy. Wireless charging has emerged as a potential solution to provide longer service hours with smaller battery packs and autonomous solutions. Qualcomm Technologies Inc. introduced Halo™ Wireless Electric Vehicle Charging (WEVC) system, enabling quick charging with high power WEVC, supporting wireless power transfers at 3.7 kW, 7.4 kW, 11 kW, and 22 kW with a single primary base pad and wireless power transfer efficiency of above 90%.

Currently, the issues in wireless charging include EV charger alignment and electromagnetic interference due to foreign objects causing unexpected losses in power transfer. Future roads can be built with embedded charging pads enabling charging on transit and a few pilot trails are already underway.

2.1.2 EVSE Power Ratings

For both AC and DC charging, multiple plug designs and charging modes have been developed and deployed throughout the world. Table 1 summarizes the power-rating levels of AC and DC chargers.

Table 1: AC and DC charging power levels

	AC Charger	DC Charger
Level 1	<3.7 kW	200-450 V DC up to 36 kW (up to 80 A)
Level 2	>3.7 kW and <22 kW	200-450 V DC up to 90 kW (up to 200 A)
Level 3	>22 kW and <43.5 kw	200-600 V DC up to 240 kW (up to 400 A)

2.1.3 Communication Protocols and Connectors

The EV battery and the charger need to communicate with each other throughout the charging process. A communication protocol is needed for this purpose as the EVSE (charger) is external to the EV. These are known as EV–EVSE protocols that are associated with EV charging standards which define the connectors to be used, power rating of connections, and communication link/protocols being used during the charging process.

The three main EVSE characteristics that differentiate chargers from one another include:

- **Level:** power output range of the EVSE outlet
- **Type:** socket and connector used for charging
- **Mode:** communication protocol between the vehicle and the charger

There are three prominent commercially available EV charging standards: i) Charge de Move (CHAdeMO), a DC fast charging standard, ii) combined charging system (CCS), and iii) Guobiao standard (GB/T) in addition to the European IEC type-2 and the American SAE standards. Table 2 provides an overview of these charging standards (with details on level, current, power rating and types, i.e. sockets and connectors) for various global regions. Figure 3 shows the different EV charging connector types for CCS, Gb/T, and ChAdeMO chargers.

Table 2 Summary of global charging standards

	CCS	GB/T	CHAdeMO
Country	Globally	China	Globally
Charging standard	SAE J1722	GB/T-20234	IEC 62196-4
Physical layers for communication	PLCC	CAN	CAN
Communication protocols	CCS	GB/T	CHAdeMO
Charging type	AC and DC	AC and DC	DC
Charging limit	1000 V 350 A 350 kW	750 V 200 A 150 kW	500 V 125 A 400 kW

Figure 3: Different EV charging connectors' types

Source: Details available at https://evcharging.enelx.com/resources/blog/552-ev-charging-connector-types

Figure 4 shows the geographical spread and characteristics of EV chargers used across different regions of the world.

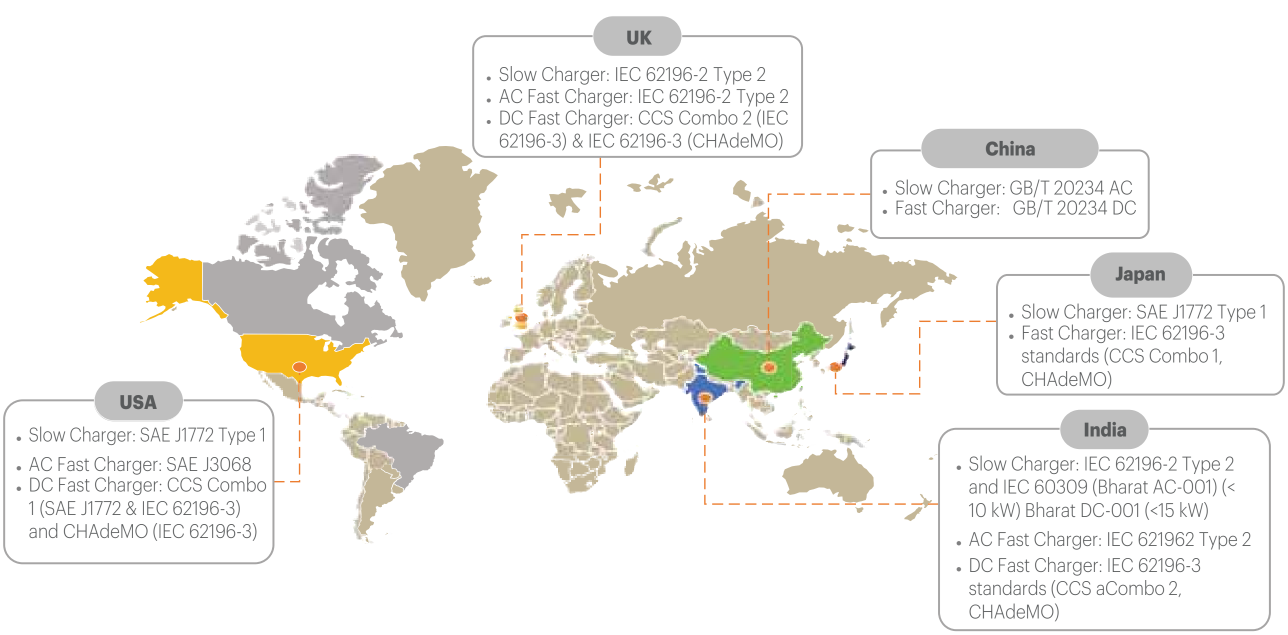

Figure 4: Global overview of EV charger characteristics in key regions

2.2 EVSE-related standards in India

In India, standards for EVSE are being developed by the ETD-51 committee of the Bureau of Indian Standards (BIS), which was set up in 2016. Since the EVSEs need to be connected to the electric grid for charging the battery, they must comply with electricity grid codes like other electrical equipment need to. In India, BIS has published the drafted Indian National Standard IS 15886 for standardization of electric and hybrid vehicles and their components.

The IS: 17017-1 published by BIS in August 2018 recommends both CCS-2 and CHAdeMO. In 2017, a Committee constituted by the Department of Heavy Industries (DHI) issued Bharat Charger Specifications for AC and DC chargers which follow GB/T, the Chinese standards. These standards are as follows:

- For AC: Bharat EV Charger AC001
- For DC: Bharat EV Charger DC001

Brief details about the Indian standards for EV/EVSE are mentioned in Table 3.

Table 3: Details on Indian EV charging standards

Indian Standards	Description	Equivalent Standard
IS:17017 Series of Standards	Primarily based on IEC 61851; IEC 62196 and ISO 15118 series of Standards	
IS:17017-1	General Requirements and Definitions of EVSE	IEC-61851-1
IS:17017-21	EV requirements for connection to AC/DC Supply	IEC 91851-21
IS:17017-22	AC EVSE	IEC 61851-22
IS:17017-23	DC EVSE	IEC 61851-23
IS:17017-24	Control Communication between DC EVSE and EV	IEC 61851-24
IS: 17017 – Part 2*	Standards for the plugs, socket outlet, vehicle couplers and vehicle inlets. These are being adapted as IS:17017 Part 2 – A, B and C*	IEC 62196 Part-1, Part-2, Part-3
IS/ISO:15118*	ISO 15118 series for communication between the EV and the EVSE.	
AC-001	It presents the specifications of a public metered AC outlet (PMAO) which is used to provide AC input to the vehicle that has on-board chargers. This document applies to electric road vehicles for charging at 230 V standard single-phase AC supply with a maximum output of 15A and at a maximum output power of 3.3 kW. PMAO is a slow charger for low-power vehicles (equivalent to IS 12360; IEC 60309)	
DC-001	It prescribes the definition, requirements and specifications for low voltage DC electric vehicle (EV) charging stations in India, herein also referred to as 'DC charger', for conductive connection to the vehicle, with an AC input voltage of 3-phase, 415 V. It also specifies the requirements for digital communication between DC EV charging station and electric vehicle for control of DC charging. (Equivalent to IEC 61851 Part 1,23; GB/T 20234.3)	

Indian Standards	Description	Equivalent Standard
AIS 138 (Part 1)	For charging electric road vehicles at standard AC supply voltages (as per IS 12360/IEC 60038) up to 1000 V and for providing electrical power for any additional services on the vehicle if required when connected to the supply network. Applicable for 1) AC slow charging (230 V, 1 Phase, 15 A outlet with connector IEC 60309) and 2) AC fast charging (415 V, 3 Phase, 63 A outlet with connector IEC 62196). Global: IEC 61851 Part 1, 22; SAE J1772; GB/T 18487 Part 1,2,3	
AIS 138 (Part 2)	For DC EV charging stations for conductive connection and digital communication to the vehicle, with an AC or DC input voltage up to 1000 V AC and up to 1500 V DC (as per IS 12360/IEC 60038). Global: IEC 61851 Part 1, 23, 24	

2.3 Electric Vehicles and Charging Infrastructure: global review

The transportation sector has immensely contributed to GHG emissions mainly through vehicular exhaust. Thus, transitioning towards EVs can be a significant step in the direction of reducing global GHG emissions and bringing-in green transportation and sustainable mobility. Globally, the prices of lithium-Ion Battery rapidly declined from US$1,100 per kWh in 2010 to US$156 kWh in 2019. The reduction in average battery pack prices is projected to reach up to US$87/kWh in 2025 and US$62/kWh in 2030[5].

2.3.1 EV Charging Infrastructure: global status

Rolling-out electric vehicle charging infrastructure (EVCI) or electric vehicle supply equipment (EVSE) mainly depends on the vehicle stock, charging equipment usage, and charging pattern and technical capabilities of EVs. By the end of 2019, there were 7.3 million EV chargers installed worldwide of which 6.5 million chargers were private light-duty vehicle (LDV) slow or normal chargers. The stock of chargers increased by 40% from 5.2 million in 2018.

Public & Private charging

In many EV markets, the most preferred EV charging locations were found to be private homes and workplaces. Workplace charging emerged to be the second-most preferred charging location. In 2019, LDVs mostly charged by private chargers, accounted for about 6.5 million units across the world. In European Union, United Kingdom and the USA, the combined share of EVs charged at home and workplace was observed to be more than 85%. In an EVCIPA report and survey, the access of private chargers in China was estimated to be about 70%[6]. China accounts for 80% of publicly accessible fast chargers compared to 47% of the world's electric light-duty vehicle stock. Figure 5 shows the distribution of publicly accessible fast and slow chargers and private slow chargers across major EV markets in the world.

[5] Bloomberg NEF: Energy and Mobility Transition 2019

[6] Chinabaogao (2019), China's charging infrastructure market, details available at http://news.chinabaogao.com/dianzi/201901/01163934L2019.html

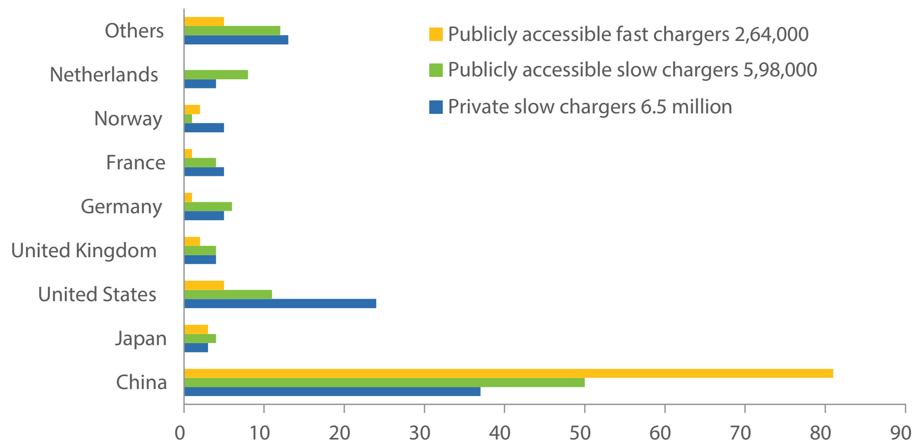

Figure 5: Private and publicly accessible chargers by country (2019)

For LDVs, publicly accessible chargers accounted for 12% of global LDV chargers in 2019, out of which 598,000 (8%), 263,000 (4%) were slow and fast chargers, respectively. The global number of publicly accessible chargers per electric LDV slightly decreased from 0.13 in 2018 to 0.12 at the end of 2019 with the expanding electric LDV stock. Globally, the number of publicly accessible charging points (slow and fast charging) increased by 60% in 2019 compared with the previous year. Most of these public chargers increased in China, accounting for nearly 60% of worldwide public chargers installed in the year 2019.

The global e-buses charger stock increased by 17% in 2019 (184,000 units) as compared to previous year of 2018 (157,000 units). China continues to be holding the first position in electrifying its buses and its chargers, having 98% and 95% of the global e-buses stock and global buses chargers' stock, respectively. In the European Union, Sweden leads in the number of bus chargers installed in 2019.

The need for e-buses charging infrastructure depends on the frequency and dwelling times of the bus fleet, occupancy, and charging strategy. Based on these parameters relating to the number of chargers and capacity/rated power of chargers, the locations of charging infrastructure are decided. Charging strategies for e-buses fleet include overnight charging at depots and on-route opportunity charging in many cities. There are three main technology options in the commercial use for charging: plug-in charging at 150–250 kW rating, that is deployed in China, up to 400 kW for overnight depot charging, pantograph charging which is best suited for on-route opportunity charging and is being used in the United States and European Union, and inductive or wireless charging. High power chargers are especially important for heavy-duty fleet electrification.

2.3.2 Policies and Strategie to Deploy EVCI

This section briefs about the policy landscape for EV charging infrastructure in different EV markets such as Canada, China, European Union, India, Japan, and the US.

Canada:

The federal government allocated CAD 180 million (US$ 130 million) in the 2016–17 budget to install fast-charging EVCI network along the national highway system, natural gas re-fuelling stations along freight corridors, hydrogen refuelling stations in metropolitan areas alongside demonstration of next-generation charging technologies.

In 2019, CAD 130 million (US$ 97 million) was allocated in the new Zero-Emission Vehicle Infrastructure Programme to support the deployment of charging in public places, multi-unit residential buildings, workplaces and commercial areas, as well as for fleets and transit applications.

China:

In March 2019, China set out an aim to shift from subsidizing local vehicle purchases to supporting infrastructure roll-out. China is promoting the following three types of EV charging infrastructure:

- Publicly accessible charging in cities
- Private charging in residences
- Enterprise/company-based charging

Charging infrastructure subsidies provided by local governments, like in Shenzhen, propose to give 400 CNY per kW for DC charging facilities and 200 CYN/kW for AC charging facilities over 40 kW and 100 CYN/kW under 40 kW. The State Grid has announced plans to increase investment in charging stations. Beijing City has outlined a policy to provide up to CNY 200,000 in subsidies per station for operators.

European Union:

Alternative fuels infrastructure directive (AFID) and the Trans-European Network for Transport (TEN-T) regulation will be reviewed for upgrading the EV charging infrastructure in 2021. Furthermore, AFID has set deployment targets for publicly accessible chargers for 2020, 2025 and 2030, with an indicative ratio of 1 charger per 10 electric cars. As of 2020, the EU has 165,000 publicly accessible charging points and by 2025, it is projected to fulfil the need of 1 million charging points to support accelerated EV deployment according to the new policies in the European Green Deal.

India:

The Indian government has made some remarkable decisions towards expanding their charging infrastructure network including policy-level and regulatory guidelines. In October 2019, the Ministry of Power's guidelines and standards for EV charging infrastructure were revised to include all commercially available charging standards to provide choice to consumers at public charging stations among other amendments. The guidelines have set out targets for the installation of at least 1 publicly accessible charger within a 3 3 km grid in cities, and 1 charging station every 25 km on both sides of highways and one fast charging station on every 100 km on highways. Further, under FAME II, about INR 10 billion (US$ 130 million) has been allocated to deploy networks of charging stations, with incentives that range from 50–100% of the cost of a charger based on its location and access.

In addition to aggregating demand for vehicles, the Energy Efficiency Services Limited (EESL) is also deploying 498 publicly accessible chargers in government offices along with 68 publicly accessible chargers across the country. The 2020, 21 target is to deploy 1500 additional publicly accessible chargers in and around major metro rail systems and government offices. Further details on the Indian policies and regulatory interventions related to EV charging infrastructure are discussed in Chapter 3 of this report.

Japan:

The government supports EVCI installation by providing half to two-third of the cost. Japan is also supportive of the development of new international charging standards. The CHAdeMO Association and the China Electricity Council are working jointly on a next-generation ultra-high power charging standard (up to 900 kW), dubbed 'ChaoJi'. ChaoJi will be currently proposed to the International Electro Technical Commission (IEC)/International Organization for Standardization (ISO) committees to be added to the DC fast charging systems. CHAdeMO 3.0 was released in April 2020 as the first publication of ChaoJi. This latest charging protocol proposed a brand new DC fast charging plug compatible with GB/T.

United States of America:

The US Congress extended the federal charging infrastructure tax credit in 2019, which covers up to 30% of the installation cost of new EVSE (limited to US$1000) through fiscal year 2020. The International Code Council (ICC) approved a new voluntary guideline to make all new homes built in the United States EV-ready (EV-Ready Buildings Code).

The state of Michigan recently passed a legislative package intended to increase access to EV charging infrastructure at state-owned properties, businesses, multi-unit buildings, and workplaces. Legislation in Colorado allows electric public utilities to install EV charging. Hawaii has launched a two-stage rebate programme to support the near-term installation of EV-charging stations.

In 2020, New Jersey approved an ambitious EV deployment programme that set a target of 330,000 EVs on the road by 2025 and 2 million EVs by 2035, in addition to the charging infrastructure required to meet the goal. California introduced a programme for EV charging infrastructure funded by the California Energy Commission and implemented by the Center for Sustainable Energy. The programme budget is US$71 million with a potential for up to US$200 million.

2.3.3 Business Models: Supporting EV Charging

Business models adopted to deploy EVCI ascertain its usability and ease of scaling it across the value chain. Hence, it becomes necessary to understand the viability of EVCI. Table 4 shows some of the business models adopted in different countries.

Table 4: Types of business models for EVCI implementation in a few countries

Business Models	China	Norway	USA	United Kingdom	Japan
Free public charging from CPO	✓	✓	✓	✓	✓
Pay per click model	✓	✓	✓	✓	✓
Subscription model	✓		✓	✓	✓
Pay per minute charging model		✓		✓	
CPO provides charging at utility rates			✓		
Free charging but fixed parking fee			✓		

Some of the business models applicable for India are listed here:

Distribution licensee-owned EV charging infrastructure

- Distribution licensee will have the responsibility to provide electricity to the EV owner.
- The retail supply tariff for supplying electricity to the vehicle owners will be decided by the SERC of that respective state.

Distribution licensee franchised EV charging infrastructure

- If the utility is disinterested in investing in charging infrastructure due to funding constraints, it can authorize a third party to install and operate charging stations within its license area after suitable locational planning. The third party and utility can also enter into a public–private partnership (PPP).
- The charging stations can receive electricity at a single point of delivery as bulk power or could purchase power from open access if allowed.

Privately owned battery-swapping stations

- Utility with its franchisee or a third-party can aggregate the demand for batteries and set up battery swapping stations.
- The third party can set up battery swapping stations with prior intimation to the utility to avail the special category tariff since a swapping station does not resell electricity.
- The swapping station can receive electricity at a single point as bulk power from the utility or buy from open access to charge its batteries as per the provisions of the Electricity Act, 2003.

3. NATIONAL AND STATE-LEVEL POLICY INITIATIVES AND REGULATORY FRAMEWORK FOR EV CHARGING IN INDIA

3.1 Background

India is stepping towards low emission transport, which is one of the essential factors in transforming into a green economy. Globally, over 75% of the fuel used for transportation is petroleum based, which primarily includes gasoline and diesel. As per TERI study on Green Growth and Air Pollution in India 2015, 31% of NOx emissions were contributed by transport sector followed by the power sector and industries in the country. In response to these concerns, India is taking rapid actions on electrifying the current private and public fleet and reducing dependency on petroleum-based fuels.

By adopting low-emission vehicles, many countries such as the USA, Norway, UK, China are taking preventive measures to reduce the emissions caused by the road transportation sector. These countries are providing various incentives to scale-up EVs and charging infrastructure, while sourcing power from renewables. Other stakeholders such as equipment manufacturers, electricity distribution companies, fleet operators are also participating to achieve this common goal towards decarbonizing the transportation sector. For example, China is currently dominating the EV market owing to aggressive policy supported-push at both the national and the regional levels to decarbonize its transport-related emissions. In the case of the United States, subsidies are given at both federal level and state level on the basis of the income of the EV user. Norway and the United Kingdom have well-established charging infrastructure and give substantial purchase incentives on buying an EV.

The Government of India (GoI) launched National Mission on Transformative Mobility and Battery Storage on 7 March 2019 to promote clean, connected, shared, and holistic mobility initiatives. The mission aims at creation of a Phased Manufacturing Programme (PMP) to support setting up of large-scale industries for battery and cell manufacturing, and localize production of EV value chain in India. The steering committee under the programme will comprise of secretaries from the Ministry of Road Transport and Highway, Ministry of Power, Ministry of New and Renewable Energy, Department of Science and Technology, Department of Heavy Industry, Ministry of Finance and Bureau of Industrial Standards. This in itself highlights the breadth of participation required across stakeholder types in supporting electric mobility at the national level.

3.2 EV Policy Planning and Structure in India

The NITI Aayog, a national-level policy think-tank, has been given the responsibility to anchor the EV policy roadmap for India in consultation with several relevant ministries as shown in Figure 6.

7 Details available at https://www.eia.gov/outlooks/ieo/pdf/transportation.pdf

8 Details available at https://www.teriin.org/projects/green/pdf/National-Air-Pollution.pdf

Key Ministries

Department of Heavy Industry	Ministry of Road Transport and Highways	Ministry of Power	Ministry of Housing and Urban Affairs	Ministry of Finance	Ministry of Petroleum and Natural Gas
• DHI leading India's electric mobility mission since 2013 • Also playing an important role to install public charging stations and distribution of financial incentives under FAME-2	• MoRTH is currently helping to promote the concept of Electric Vehicle as Green Transport • Green Transport MoRTH will play a significant role in providing febate to EV usersin terms of toll tax, parking fee etc • Green number plate scheme is already announced	• MoP declared guidelines and standards for setting up EVCI as Public Charging options • CEA came up with safety and connectivity standards for EV charging stations. • Setting up EV charging station will be a delicensing activity	• MoHUA has made amendments to the Model Building Byelaws & Urban Regional • Development Plans Formulation and Implementation Guidelines making provisions for establishing EVCIs	• MoF reduced GST rates on electric vehicles from 12% to 5% • Additional income tax deduction of INR 1.5 lakh • Customs duty rates revised on EVCI	• As per the 'New Retail Fuel Policy Guidelines' the retail outlets (RO) to have at-least one new generation alternate fuels like electric vehicle charging points

Figure 6: Role of key ministries for deployment of EV ecosystem in India

3.3 Policy-level Landscape at National Level

At the central level, notable policy-level initiatives have been taken by relevant ministries and central agencies to address various issues relating to E-mobility. These initiatives have been highlighted in Figure 7. Details of the national-level policies are discussed here

Figure 7 Central-level EV policy-initiatives

1. **Faster Adoption and Manufacturing of (Hybrid) and Electric Vehicles (FAME)**

   The FAME scheme was launched in April 2015 with the agenda to ramp up and meet the goals of National Electric Mobility Mission 2020. Phase II of FAME[9] was initiated on 1 April 2019 based on the outcomes and experience gained during Phase I from stakeholders for implementation along with appropriate allocation of funds. The scheme proposed to implement interventions, such as demand incentives, establish charging stations and create awareness on EVs. The incentives under FAME-II are given in Figure 8.

[7] Details available at https://dhi.nic.in/writereaddata/UploadFile/publicationNotificationFAME%20II%208March2019.pdf

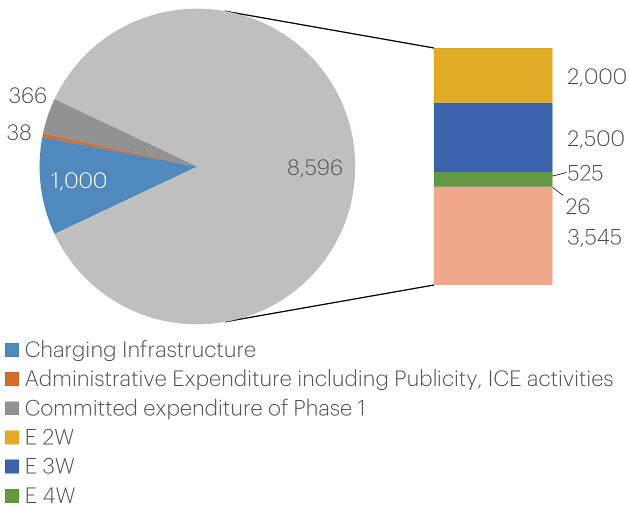

Figure 8 Total fund allocation (INR Crore)

The DHI came up with an EoI[10] on 28 August 2019 for availing incentives under FAME-II for deployment of EV charging infrastructure in various cities. Initially 1000 EV charging stations (slow and fast) were earmarked for deployment. These chargers are to be deployed in different states/cities/entities on the evaluation of proposal received by DHI. Table 5 lists categories of charging stations.

Under this expression of interest, the following categories of EV charging stations got the support:

Category A:

Charging stations at public places for commercial purpose to charge (e.g., EV charging stations at municipal parking, petrol stations, malls, markets, airport, metro stations, bus stops). These charging stations can claim maximum demand incentive of 70% on the cost of EVSE from DHI FAME-II.

Category B:

Charging stations within the premises of state or central government office, government hospitals, government educational institutes (e.g., EV charging station established in Shram Shakti Bhawan, PSU Office Complex). Under FAME-II, 100% of incentive can be availed on the cost of EVSE from DHI.

Category C:

Charging stations established within the semi-restricted premises for commercial or non-commercial purpose for charging of EVs (e.g., charging stations established for

Table 5 Various categories of charging stations introduced under FAME-II

Type of Charging Stations	Minimum Number of Charging Guns	Minimum Number of EVs to be Charged at a Single Time	Types of Chargers Mandatory	Optional Charger Types
Slow Charging Stations	10	10	Bharat AC 001 10 kW (3 guns of 3.3kW each)	Bharat DC 001 (15 kW) 1 Gun; Type 2 AC charger
Fast Charging Stations	6	6	CCS II &CHAdeMO 50 kW or higher capacity	Bharat DC 001 (15 kW) 1 Gun; Type 2 AC 22kW or higher capacity

[10] Details available at https://dhi.nic.in/writereaddata/UploadFile/Revised-%20Expression%20of%20Interest.pdf

Taxy Aggregators, Co-operative Housing Societies). They can avail 50% of the cost of EVSE from DHI under FAME-II.

The Department of Heavy Industry sanctioned 2636 charging stations in 62 cities across 24 states/UTs under FAME-II. About 106 proposals from public/private entities for the deployment of about 7000 EV charging stations were received. Out of these, 2636 charging stations were approved by DHI of which 1633 will be fast charging stations and 1003 will be slow charging stations. The allocations of EV charging stations are shown in Figure 9.

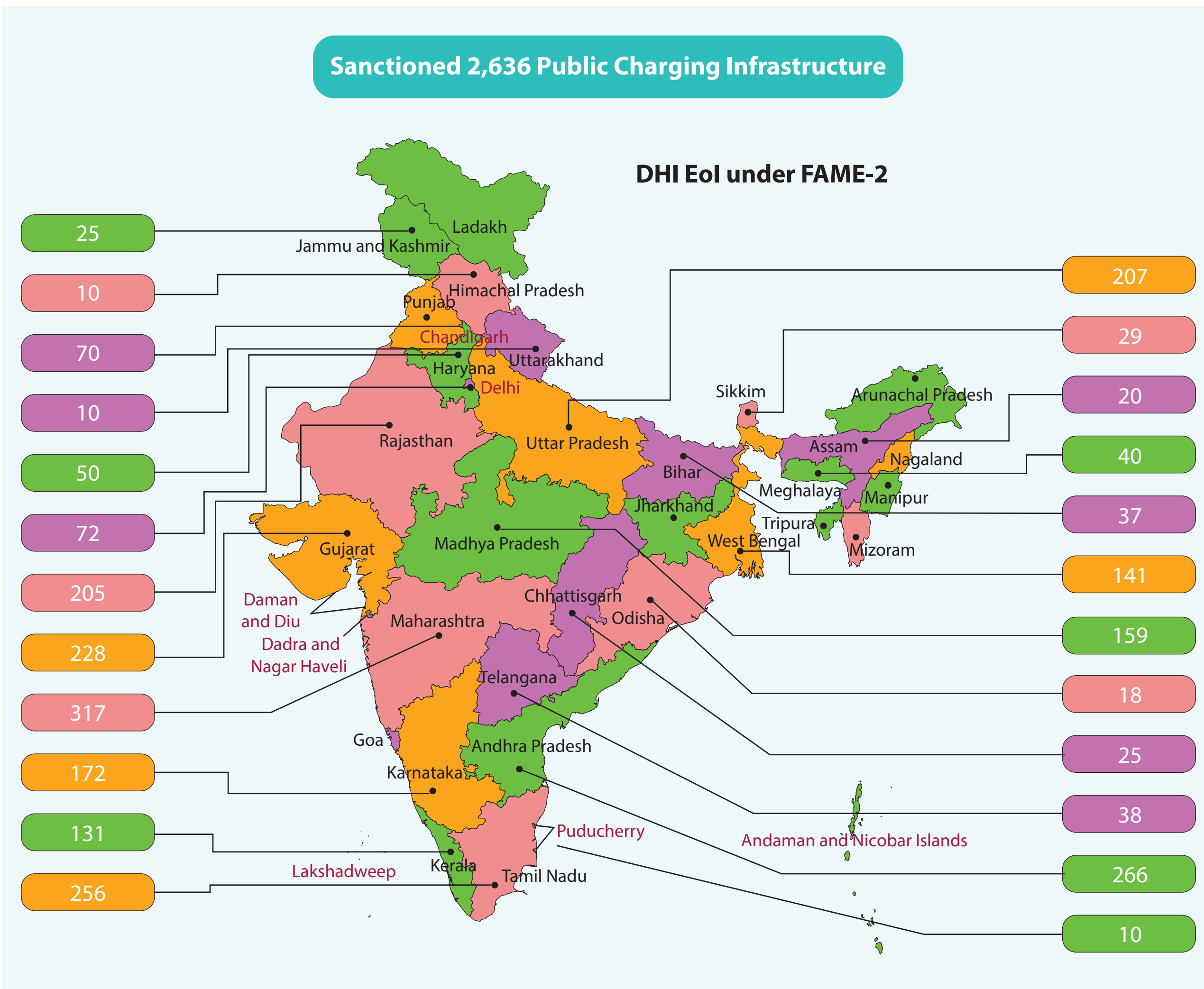

Figure 9 Allocation of EV public charging stations under the EoI issued by DHI

Source: TERI analysis based on data from current EoI from DHI

As per the EoI released by DHI on 12 October 2020, the minimum number of charging stations sectioned for 9 expressways and 25 highways are 174 and 1370, respectively. These stations include one fast charger (50 kW) based on CCS/CHAdeMO and one DC 001 (15 kW) charger at every 25 km including one heavy duty charger of 100 kW at every 100 km range.

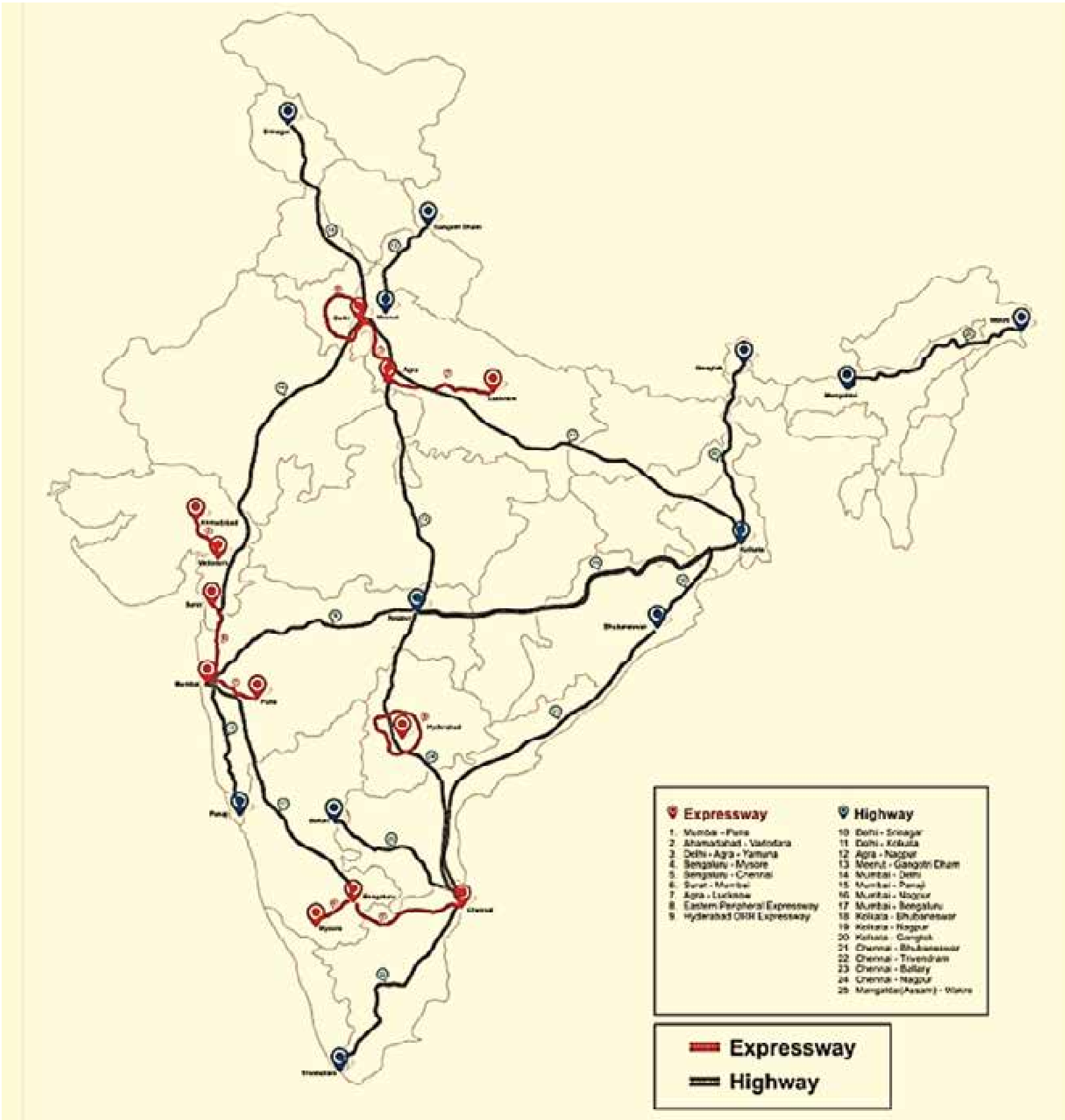

Figure 10 Locations of public charging stations on expressways and highways

2. Business Models Adopted by Energy Efficiency Service Limited

Energy Efficiency Service Limited (EESL) came up with three business models, i.e. wet lease, dry lease, and outright purchase of electric four-wheelers for various Central and State Government departments/ offices. EESL also floated a tender for 10,000 electric cars. EESL-procured vehicles are compatible with Bharat EV Charger AC-001 and DC-001 specifications. However, CHAdeMO and CCS are also being opted for future purchase.

Wet Lease (Car with chauffer)

- Lease rental INR 40,000 (First Year) per car per month excluding statutory charges subject to escalation of 10% per annum
- For vehicle running more than 2400 km per month, extra charges of INR 3/ km shall apply

Dry Lease (Car w/o chauffer)

- The lease rental would in INR 22,500 per month per E-Car excluding statutory charges subject to escalation of 10% per annum.
- Toll Tax, Parking charges, and Octroi (Municipal) would be paid by your organization directly at the collection points

Outright Purchase of Cars

- The cars would be purchased directly by paying upfront cost. Taxes and statutory charge would be extra as per actuals.

Figure 11 EESL's Business models for electric vehicles

3. EV Charging Infrastructure: Guidelines and Standards by Ministry of Power, Government of India

The Ministry of Power (MoP) order dated 13 April 2018 provided clarification[11] on de-licensing of setting up Electric Vehicles Charging Infrastructure (EVCI), invoking the relevant provision in the Electricity Act, 2003. The matter of whether setting up EVCI would be considered as a licensing activity was discussed in the context of Section 12 of the act. As per the definitions under Section 2, the consumer is any person who is supplied with electricity for his own use and trading is defined as the procurement of electricity for resale. It was argued that charging of batteries essentially involves utilization of electrical energy for its conversion to chemical energy, which ultimately gets stored in the battery. Thus, this service cannot be considered as re-sale of electricity. Accordingly, EV charging stations were deemed not requiring any license, as per the relevant provision of Electricity Act, 2003.

The MoP introduced a set of guidelines[12] for Electric Vehicle Charging Infrastructure on 14 December 2018 which was revised on 1 October 2019. The objectives behind this policy are as follows:

a) To enable faster adoption of electric vehicles in India by ensuring safe, reliable, accessible, and affordable charging infrastructure and eco-system

b) To promote affordable tariff chargeable from EV owners and charging station operators/owners

c) To generate employment/income opportunities for small entrepreneurs

d) To proactively support creation of EV-charging infrastructure in the initial phase and eventually create market for EV-charging business

e) To encourage preparedness of the electrical distribution system to adopt EV-charging infrastructure

According to the guidelines, every public-charging station should have an exclusive transformer, 33/11-kV lines with associated equipment, and the adequate space for charging of vehicles including their entry/exit. The charger combinations are given in Table 6.

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[11] Details available at https://powermin.nic.in/sites/default/files/webform/notices/Clarification_on_charging_infrastructure_for_Electric_Vehicles_with_reference_to_the_provisions_of_the_Electrcity_Act_2003.pdf

[12] Details available at https://powermin.nic.in/sites/default/files/webform/notices/Charging_Infrastructure_for_Electric_Vehicles%20_Revised_Guidelines_Standards.pdf

Table 6 Combinations of EV chargers as introduced by Ministry of Power

Charger Type	S No.	Charger Connectors*	Rated Output Voltage (V)	No. of Connector Guns (CG)	Charging Vehicle Type (W = wheeler)
Fast	1	Combined Charging System (CCS) (min 50 kW)	200–750 or higher	1 CG	4 W
	2	CHArge de Move (CHAdeMO) (min 50 kW)	200–500 or higher	1CG	4W
	3	Type-2 AC (min 22 kW)	380–415	1CG	4W, 3W, 2W
Slow/ Moderate	4	Bharat DC-001 (15 kW)	48	1CG	4W, 3W, 2W
	5	Bharat DC-001 (15 kW)	72 or higher	1 CG	4W
	6	Bharat AC-001 (10 kW)	230	3 CG of each 3.3 kW each	4W, 3W, 2W

For public charging for long-range EVs, fast chargers should meet the criteria of having at least two chargers of minimum 100 kW (200–750 V or higher) with different specification (CCS/ CHAdeMO/ any other fast charger approved by DST/BIS). Also the system should have appropriate Liquid Cooled Cables for providing high speed charging. As per the guidelines, one public charging station should be available in a grid of 3 x 3 Sq-Km range and one charging station on both sides of highways at every 25 km. The priority for rollout of EV public charging infrastructure is categorized in two phases. During Phase 1 (1-3 Years) all mega cities with population of more than 4 million, all existing expressways connected to Mega Cities and important highways will be targeted. Phase II (3-5 Years) will be rolled out in big cities like state capitals and UT headquarters for distributed and demonstrative effect. Utilities should make a proper database of public charging stations, conforming to appropriate protocols, which will be finally accessed by the Central Electricity Authority (CEA) and the Ministry of Power. The domestic tariff will be applicable for domestic EV charging. For public charging, separate metering arrangement will be applicable and separate EV category tariff will be determined by the commission in accordance with the tariff policy issued under Section 3 of Electricity Act 2003. The Bureau of Energy Efficiency (BEE) will be the central nodal agency to act as the key facilitator in installing charging infrastructure. Till date, 26 State Nodal Agencies[13] have been appointed in various states/ UTs which include mostly state-owned DISCOMs (refer to Table 7).

Table 7 State nodal agencies appointed under 'Charging Infrastructure for EVs' by MOP

S. No.	State	State Nodal Agency (SNA)
1.	Andhra Pradesh	New and Renewable Energy Development Corporation of Andhra Pradesh (NREDCAP)
2.	Gujarat	Gujarat Energy Development Agency (GEDA)
3.	Himachal Pradesh	Himachal Pradesh State Electricity Board Limited (HPSEBL)
4.	Karnataka	Bengaluru Electricity Supply Company Limited (BESCOM)
5.	Meghalaya	Meghalaya Power Distribution Corporation Limited (Me-PDCL)
6.	Mizoram	Power & Energy Department, Government of Mizoram

[13] Details available at https://beeindia.gov.in/press-releases/state-nodal-agencies-under-provision-%E2%80%9Ccharging-infrastructure-electric-vehicles

S. No.	State	State Nodal Agency (SNA)
7.	Odisha	E.I.C (Elect.)-cum PCEI Odisha, Bhubaneswar
8.	Punjab	Punjab State Power Corporation Limited (PSPCL)
9.	Rajasthan	Jaipur Vidyut Vitran Nigam Limited (JVVNL)
10.	Uttarakhand	Uttarakhand Power Corporation Limited (UPCL)
11.	Telangana	Telangana State Renewable Energy Development Corporation Ltd (TSREDCO)
12.	West Bengal	West Bengal State Electricity Distribution Company Limited (WBSEDCL)
13.	Delhi	Delhi Transco Limited (DTL)
14.	Lakshadweep	Lakshadweep Energy Development Agency (LEDA)
15.	Jammu & Kashmir	EM&RE Wing Jammu as "Nodal Agency for Jammu Division", Kashmir "Nodal Agency for Kashmir Division" and Ladakh "Nodal Agency for Ladakh"
16.	Kerala	Kerala State Electricity Board Ltd (KSEB)
17.	Madhya Pradesh	M.P. Power Management Co. Ltd (MPPMCL)
18.	Haryana	Uttar Haryana Bijli Vitran Nigam Limited (UHBVN)
19.	Andaman & Nicobar	Director of Transport
20.	Sikkim	Power Department, Sikkim
21.	Arunachal Pradesh	Central Electrical Zone, Dept. Of Power, Itanagar
22.	Bihar	Transport Department, Patna
23.	Tamil Nadu	Tamil Nadu Generation and Distribution Corporation Limited
24.	Puducherry	Electricity Department
25.	Chhattisgarh	Transport Department, Raipur
26.	Chandigarh	Electricity Wing, Engineering Department

On 8 June 2020, further amendment in guidelines and standards of charging infrastructure, MoP stated that under Electricity Act 2003 Section 3 (National Electricity Policy and Plan), Para 7.1, the tariff of EV public charging station shall be determined by the appropriate commission and not exceed more than the average cost of supply plus 15 (fifteen) percent.

4. Safety and Connectivity Standards for EV Charging Stations by Central Electricity Authority of India

The MoP guidelines for EV charging infrastructure majorly focusses on building an ecosystem of charging infrastructure that can be easily accessible, safe, and reliable for a user. Simultaneously, the CEA made timely amendments in its existing relevant connectivity and safety regulations to include EVs. CEA had proposed amendments to two of its existing regulations and proposed to include various provisions relating to EV charging and relevant safety standards. The amended regulations were notified in 2019.

On 6 February, 2019, the Central Electricity Authority (Technical Standards for Connectivity of the Distributed Generation Resources) Amendment Regulations, 2019[14], amending the regulations of 2013,

[14] Details available at http://cea.nic.in/reports/others/god/gm/notified_regulations.pdf

were notified. These amended regulations included definitions for 'charging points' and 'charging stations' as applicable to EVs based on voltage-levels and nature of usage, respectively. Certain standards for charging stations were also added: these were connectivity rules and prescribing compliance to certain international standards relating to power quality. Figure 12 provides some of these provisions included in the amended regulations of 2019 for seeking connectivity of EV charging stations to the electricity system.

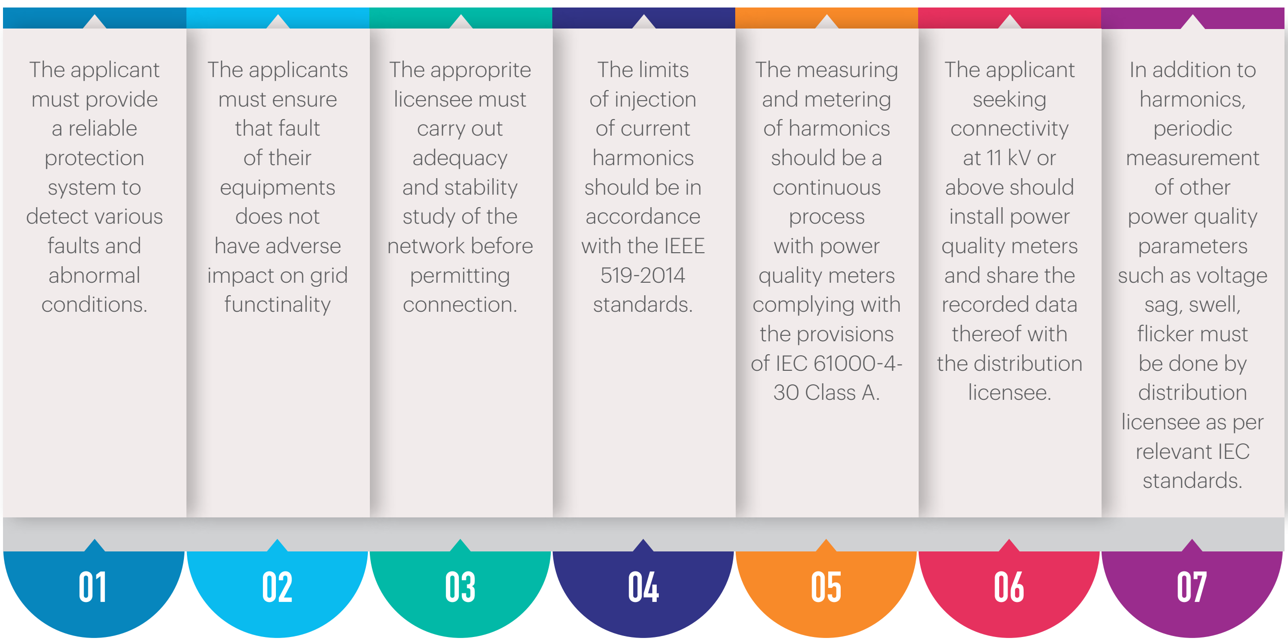

Figure 12 Salient points of the amended regulations for EV charging stations seeking connectivity to the grid

On 28 June 2019, the Central Electricity Authority (Measures relating to Safety and Electric Supply) (Amendment) Regulations, 2019[15] were notified, amending regulations on the subject notified in 2010. The amendment introduced safety provisions for EVCS including general safety requirements, earth-protection system, and fire-protection requirements for EVCS. The amended regulations also mandated testing, inspection, and periodic assessment of charging stations apart from maintenance of records. This amendment to the 2010 regulation also added the definitions for charging point, charging stations, EVs, EVSE, socket outlet, and supply lead with the above-mentioned safety provisions. These safety provisions were introduced in the form of a new chapter titled 'Safety Provisions for Electric Vehicle Charging Stations' and mentioned the various aspects related to EV charging stations such as testing, inspection, maintenance, safety and fire protection measures. The safety requirements (electrical and fire safety) along-side standards related to testing and maintenance of EV charging stations have been summarized in Table 8.

[15] Details available at http://www.cea.nic.in/reports/regulation/measures_safety_2019.pdf

Table 8 Safety provisions for EV charging stations as defined in the CEA (Measures relating to Safety and Electric Supply) (Amendment) Regulations, 2019

S. No	Basic Requirements for EVCS	Recommendations
1.	General Safety Requirements	i. EV charging stations should provide protection against the overload of input supply ii. Socket-outlet should be at least 800 mm above ground level iii. Parking place should be within five meters of connection on the vehicle iv. The station should also be equipped with protective device against reverse power flow v. Charging stations should follow Indian Standards Code IS/ IEC 62305 for lightning protection
2.	Earth protection system	i. Residual current devices for the protection should have a performance equal to Type A in conformity with IS 732-2018. ii. Residual current should not exceed above 30mA iii. Earthing of an EV charging stations should be as per IS 732
3.	Requirements to prevent fire	i. Enclosure of charging stations should be made of fire-retardant material with self-extinguishing property ii. The charging stations must be equipped with fire detection, alarm and free from Halogen. iii. Power supply cables used in charging station should follow IEC 62893-1 and its relevant parts.
4.	Testing of charging stations	i. Apparatus of charging stations should have the insulation resistance value as stipulated in IEC 61851-1.
5.	Inspection and periodic assessment	i. Every charging station must be tested and inspected by the owner every year in the initial period of first three years.
6.	Maintenance of records	i. The owner should keep records in regard of design, construction and labelling to be compatible with a supply of standard voltage at a frequency of 50Hz. ii. The owner of the charging station shall keep records of the relevant test certificate as per IEC 61851.
7.	International Standard for charging stations	i. Charging stations should follow safety provisions for AC charging stations as per IEC 61851-1, IEC 61851-21 and IEC 61851-22 standards ii. DC charging stations should follow safety provisions as per IEC 61851-1, IEC 61851-21, IEC 61851-23 and IEC 61851-24 standards

5. 'Model Building Bye-Laws' for EV Charging Infrastructure, MoH&UA

On 15 February 2019, the MoH&UA came up with an amendment[16] required for charging infrastructure provisions in Development Control Regulations and enabling provisions for installing 'Charging Infrastructure' in the building premises and core urban areas of the cities. Based on the occupancy pattern and the total parking provisions in the premises of the various building types, charging infrastructures shall be provided only for EVs, which is currently assumed to be 20% of all vehicle holding capacity or 'parking capacity' at the premises.

For residential buildings (plotted houses), a minimum one AC slow charger is to be installed compulsorily on the premises

[16] Details available at https://pib.gov.in/newsite/PrintRelease.aspx?relid=188638

with a domestic meter connection. As per minimum requirement specified by MOP for all other buildings (including housing groups) one 1-FC and1-SC on each 10 and 3 four-wheeler EVs, 1-SC on each three-wheeler EV, 1 SC on each 2 two-wheeler EVs with commercial metered connection needs to be installed in every premises. Under this policy, the fuel filling stations (including COCO outlets) shall also conform to specifications and safety norms as per the amendment in the Petroleum Explosives Safety Organization (PESO) Act and obtain clearances from the 'Competent Authority' for adding PCS to fuel filling stations.

6. Guidelines by Ministry of Road Transport and Highway (MoRTH) for Promotion of Electric Vehicles in India

In the Central Motor Vehicles (10th Amendment) Rules, 2018 for battery operated vehicles, the registration mark is to be exhibited in yellow colour on green background for transport vehicles and for all the other cases, in white colour on green background.[17] The amendment also proposes to exempt battery-operated vehicles from renewal of registration certificate and assignment of new registration mark. This means that EVs would be exempted from such registration charges.

7. Guidelines of New Retail Fuel Policy by Ministry of Petroleum & Natural Gas

According to the 'New Retail Fuel Policy Guidelines[18], oil marketing companies have to install at least one new generation alternative fuels like Compressed Natural Gas (CNG), biofuels, Liquefied Natural Gas (LNG), EV charging points at their retail outlets within three years of operationalization, complying with other statutory guidelines.

8. Union Budget Envisions India as a Global Hub for Manufacturing Electric Vehicles

The Union Budget 2019-20[19] had outlined various proposals to give boost to electric vehicle manufacturing and developing India as a global hub for the same. The government has lowered the GST on electric vehicles from 12% to 5%. The union budget also provided additional income tax deduction of INR 1.5 Lakh for an individual on interest paid on loans taken to purchase electric vehicles. This amounts to a benefit of around INR 2.5 lakh over the loan period to the taxpayers who take loans to purchase electric vehicle. As a further incentive to e-mobility, customs duty was exempted on certain parts of electric vehicles.

The Union Budget 2020-21[20] released during the lockdown due to the spread of COVID-19 did not have too many incentives for the stakeholders that could drive the demand of electric vehicle. The government has allocated ₹6.93 billion (~$96.8 million) for the Faster Adoption and Manufacturing of (Hybrid) and Electric Vehicles in India (FAME-India) programme for the financial year 2020-21. In addition, the government has increased the number of EVs to be supported in fiscal year 2020-21 by increasing demand incentives for e-buses 5000 as compared to 1650, electric four- wheeler 3000 as compared to 1650, electric three-wheeler 15,000 as compared to 16,500. The demand incentives on electric two-wheelers has been increased to 40,000 from 33,000 announced in the last budget. As per the budget announcements, 2600 charging stations will be put up on different highways.

[17] Details available at https://pib.gov.in/newsite/PrintRelease.aspx?relid=181837

[18] Details available at https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1601706

[19] "Union Budget 2019-20", details available at https://pib.gov.in/newsite/PrintRelease.aspx?relid=191292

[20] Union Budget 2020-21, details available at https://mercomindia.com/not-lot-ev-sector-in-the-budget/

3.4 State-level Initiatives

Electric vehicles promise zero tailpipe emissions and a reduction in air pollution in cities. The Government of India has created enough momentum through its FAME schemes which encourages, and in some segments, mandates adoption of EVs, with a stated goal of reaching 30% EV penetration by 2030. To scale the deployment of EVs, state government and local transport bodies have been collaborating with each other. Almost 15 States/UTs have published draft or final EV policies that are shown in Figure 13.

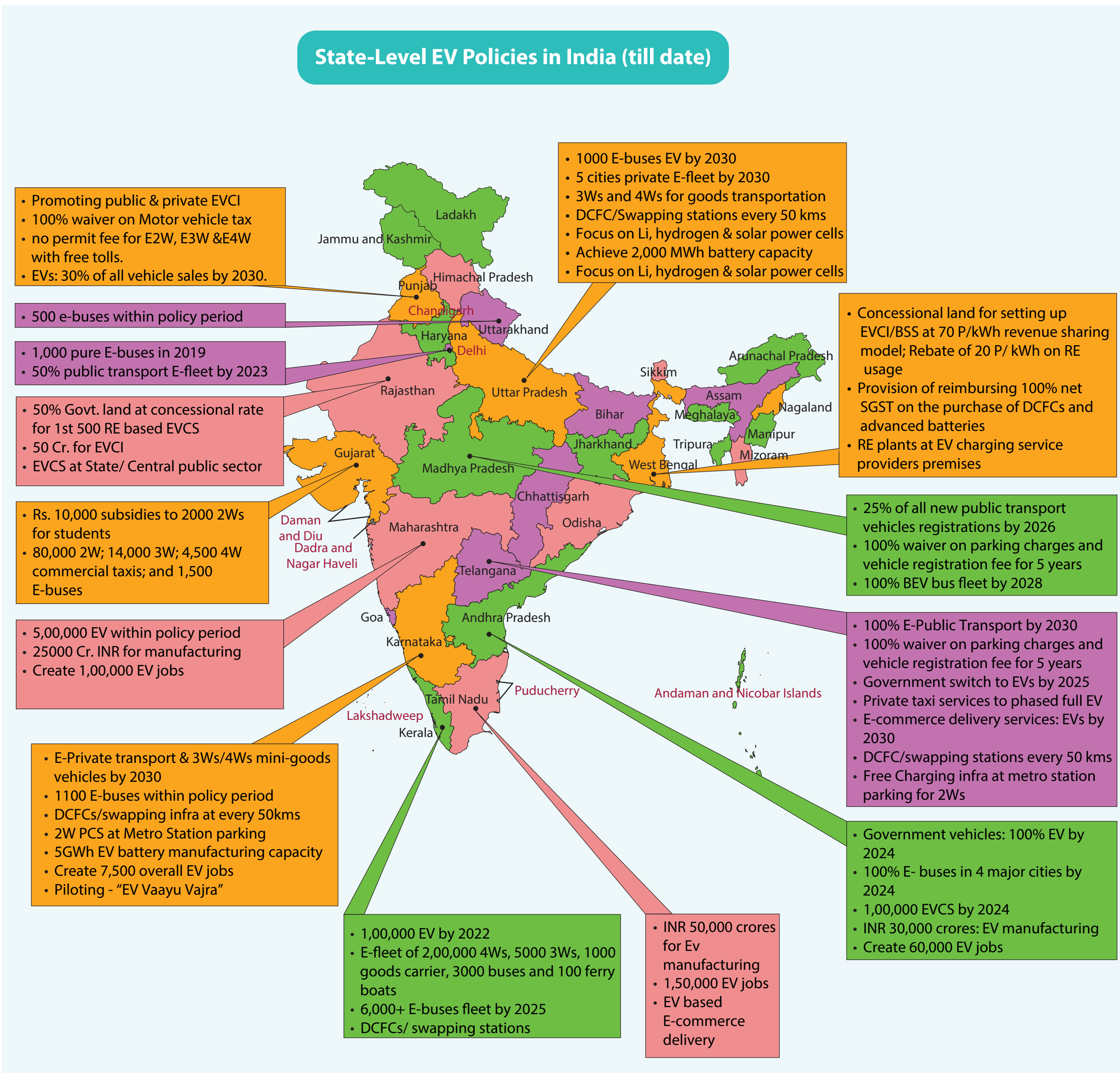

Figure 13 State electric vehicle policies at a glance

3.5 State/Union Territory-specific EV Charging Tariff at a Glance

In addition, 20 States/UTs have so far issued tariff orders for EV charging (refer to Figure 14 and Figure 15). The energy charges in some states like Himachal are based upon the contracted demand, i.e. Contract Demand≤ 20 kVA: INR 5.00/kWh; Contract Demand >20kVA: INR 4.70 kWh. Also, in some states like Delhi, Maharashtra, Telangana and Uttar Pradesh, time of day (ToD) tariff is applicable on energy charges.

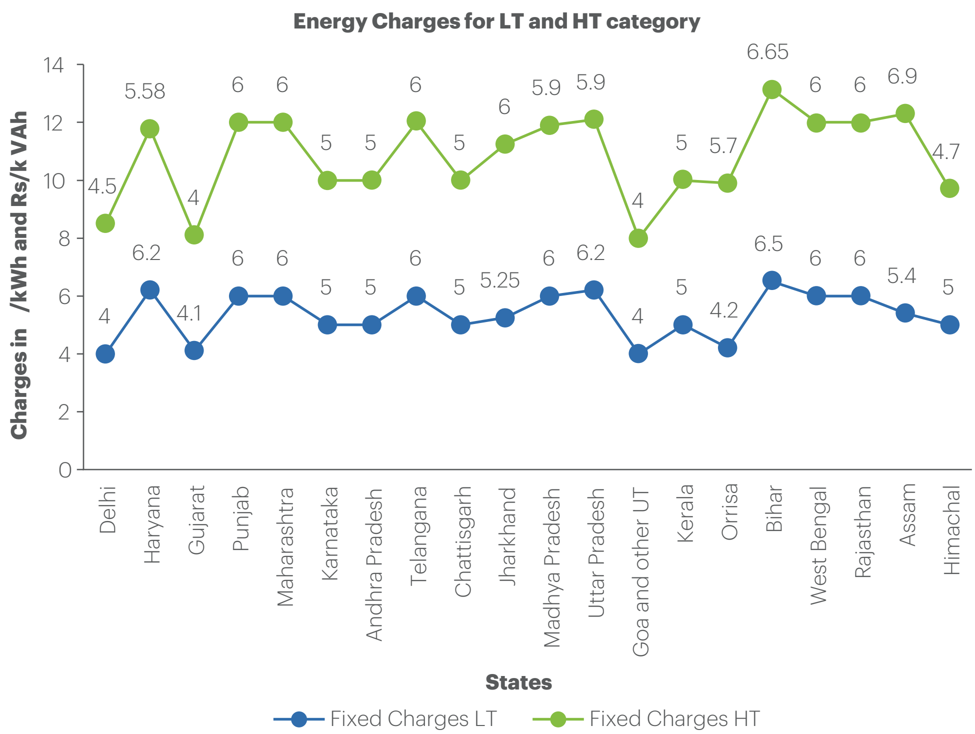

Figure 14 Energy charges in various states for EV chargin

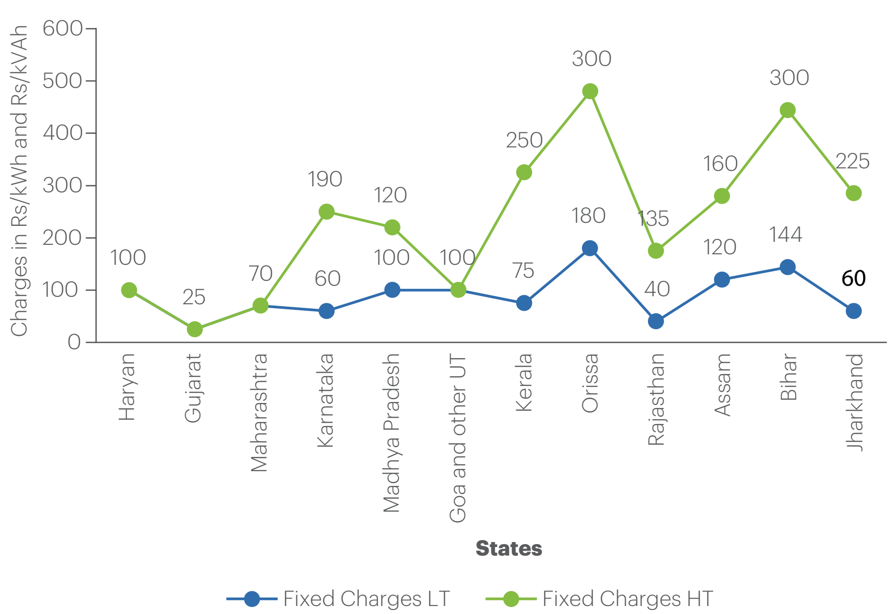

Figure 15 Demand charges in various states for EV charging

4. EV CHARGING LOAD ESTIMATION WITH EV-LOAD ESTIMATION MODEL (EV-LEM)

4.1 Background

Adoption of EVs is essential to meet India's energy and environmental goals. However, integration of EVs could lead to many techno-economic challenges, especially to the power distribution utilities. The impact on the distribution utility owing to an increase in EV penetration includes increase in system peak demand and subsequent increase in peak power purchase, distribution network congestion, and a consequent increase in network augmentation. By 2030, it is estimated that EVs in India will account for about 3–5% of the total electricity requirement[21]. The study also suggests that the energy requirement can be fairly managed; however, if the charging of EV is not well distributed temporally and spatially, it can lead to an increase in peak demand non-uniformly in the distribution network and eventually hamper the peak power purchase of the utilities.

EVs have some level of flexibility in terms of time, duration, and power of charging. This flexibility varies based on the vehicle-use characteristics as well as the battery size and charger rating. The associated parameters for these such as distance travelled in a day, battery capacity, charger rating, can be stochastically modelled for different categories of vehicles. Quantifying their benefits is complex as EVs pose specific challenges in terms of timescale, cross-sectoral coordination, infrastructure adequacy, and optimal utilization. Quantifying the benefits accrued because of EV adoption will play a pivotal role in defining the road map for EV penetration in India. In this regard, it is necessary to develop insights on the potential impact of EV charging on the distribution system, and particularly the load curve, considering the charging load across various fleet segments.

This chapter deliberates the important findings of the study on estimating the additional load as a result of EV addition for NCT of Delhi in the year 2030. Various scenarios for different electric vehicle fleet have been modelled and its impact on the city's power distribution system has been simulated. The modelling and simulation study results are expected to provide some insights on operational planning for EV integration in city distribution networks. The recommendations that emerge may be useful for cities to assess the adequacy of electricity distribution network and for scientific planning of EV charging stations to facilitate this transition towards electric mobility.

The analysis presented focuses on buses, four-wheelers and three-wheelers to gauge the impact of their charging on the city-level load curve for the future year of 2030. These three modes of transportation are important from the point of view of private ownership, fleet of public transportation, and last-mile connectivity services. It is also Massive growth in public transport can lead to scattered charging load, hence it is crucial to optimize the charging load across the day to manage the system peak. Accordingly, this chapter has been divided into sections detailing the objectives of the study, modelling methodology and workflow, insights from the study, and policy recommendations emerging from the EV-LEM.

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[21] Details available at https://www.brookings.edu/wp-content/uploads/2018/05/20180528_impact-series_ev_web.pdf

4.2 Objectives of the EV Load Estimation Modelling Study

In this section, we elucidate the objectives of the developed EV-LEM model and its outcomes based on the considered case study of New Delhi and the essential policy outcomes. The overall objectives of the modelling study are discussed here.

4.2.1 To understand the characteristics of the EV Load Curve

The purpose and hence the load curve characteristics of different types of EVs vary significantly. Therefore, it is important to map the parameters that influence the EV charging pattern. These parameters usually differ for different categories of EVs. Understanding these parameters and their influence on the EV load curve is essential. In this study, we develop estimates of electric load due to EV charging for three vehicle categories: electric buses, four-wheelers, and three-wheelers using EV-LEM.

4.2.2 To Realize the Impact of EV Charging

An increase in EV penetration will lead to energy producers and distributors understand the potential impact of EVs on electricity demand. The most profound impact could be on the distribution utilities in terms of an increase in the peak power purchase and augmentation of the distribution network equipment.

4.2.3 To Assess the Potential of Various Coordinated Charging Strategies

To accommodate an increase in load, DISCOMs conventionally need to invest in the augmentation of the distribution network, and procurement of peak power to ensure adequacy at any time and location of consumption. However, this adds an investment burden on the existing strained finances of Indian utilities. A range of ready options with varying degrees of complexity can be tapped to reduce electric vehicle charging at peak system demand, thereby diluting the need for upgrades to generation, transmission, and distribution assets. While off-peak charging at night through simple end-user programming and/or night-time tariffs would more than halve the contribution of electric vehicles to peak demand, coordinated charging in response to real-time price signals from utilities (V1G) could further exploit synergies with variable renewable electricity generation and expand the range of services electric vehicles offer to the grid.

Uncoordinated EV charging (for each category of vehicles) is usually concentrated in certain hours of the day and the use of fast chargers in an uncoordinated manner leads to further concentration of EV charging during these hours. This means that the load due to EV charging (uncoordinated) would have a low load factor, leading to the aforementioned increase in network augmentation and peak power purchase. However there are control strategies to manage this uncoordinated load. We discuss a few of them here:

1. **Time of day tariff/Static EV charging tariff:** Utilities use ToD tariff to charge the bulk consumers to manage their peak demand. However, for EV charging, a few states like Uttar Pradesh and Maharashtra have introduced a static ToD tariff including a surcharge for averting evening peak. However, if only a few EV users responded to the price signals, the desired reduction in peak would be marginal. On the other hand, if majority of the EV users respond to these signals, it could potentially lead to local network congestion, and hence real-time pricing that considers network load subject to the technical complexity in implementation.
2. **Real-time pricing (RTP)/Dynamic EV charging tariff:** RTP is an approach where the prices that apply for each time block are not predetermined as in the case of static ToD tariff, but the wholesale electricity prices are passed on directly to

the final consumer. This is quite beneficial as it determines the real grid condition and, hence, the price signals are directly indicative of the actual cost of electricity as well as congestion in the network. It may face low acceptability due to the price risk and issues in implementation. Coordinated charging can be managed with more accurate smart metering and telematics.

3. **Active charge control strategies,** also known as 'smart charging', is a system in which advanced charging infrastructure, usually in buildings, is actively used by utilities or other third parties to control when charging occurs, similar to traditional demand response programmes. Through managed charging, EV load can be decreased, increased, shifted, and curtailed. This approach can help avoid or reduce load spikes and potentially enable EV customers to take advantage of renewable power when it is at its highest generating levels, avoiding curtailments.

4.3 EV-LEM Description and Assumptions

EV-Load Estimation model is an optimization framework-based model developed by TERI. It assesses the impact of spatio-temporal EV charging load on the grid at system level. By the coming decade, as the share of EV in the total fleet increases, uncertainty over charging patterns and impact due to its grid integration will prevail. To investigate this stochasticity, TERI developed a comprehensive load estimation model framework to derive overall impact of EV charging on the city-level system load. A workflow of the EV-LEM is mentioned in Figure 16. The model is a linear least cost optimization problem which optimizes the charging of EV fleet across the temporal and spatial boundary. Annexure A, B and C details the problem formulation and methodology used for optimization in each of the fleet as modelled in this study. For each of the vehicle segment, there are unique set of assumptions.

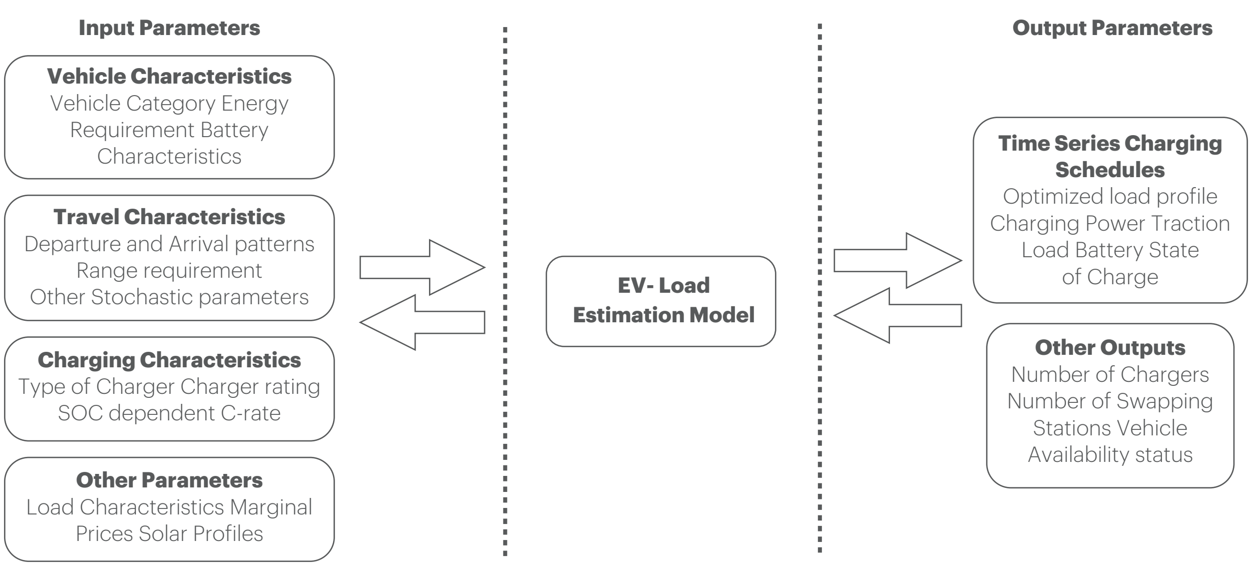

Figure 16 EV-LEM model workflow

Electric buses: EV-LEM derives the impact because of electric bus charging during the operational and non-operational hours of the bus charging at the depot. We estimate the number of electric buses by 2030 and assign them to the existing bus depots of DTC in Delhi. Each depot calculates the number of fast and slow chargers required based on the route length, frequency of bus routes, and the number of buses originating from that depot. The model optimizes the charging schedules of the buses w.r.t to their daily operating schedules. The output results from the LP optimization for each bus depot provide temporal availability of bus at the depot, chargers availability, traction load, and EV charging load. A few assumptions related to bus operation and technical characteristics have been mentioned in Table 10. Detailed modelling results and assumptions regarding electric buses have been listed in Annexure A.

Four-wheelers: To estimate the impact on load curve owing to privately owned four-wheelers, we stochastically derive the travel patterns based on a survey of four-wheelers and their range requirements across the city. This ensures fair distribution of travel patterns on departure and arrival of four-wheelers. This has been discussed in detail along with the results in Annexure B. Further, we consider home, office, and public charging as charging options to ensure charging based on the range requirements. The model thus optimizes the charging schedules for the cars respecting the travel characteristics based upon the time varying charging tariff available for the end consumer. A few assumptions considered in this study are specified in Table 10.

Three-Wheelers: Delhi has a vast network of electric three-wheelers known as e-rickshaws that mostly provide last-mile connectivity to passengers of public transport services like DTC and DMRC. However, this segment is largely unorganized and, hence, battery swapping has been envisaged as a possible solution to cater to near metro stations and retail fuel outlet premises and public places. To model the battery swapping operation, we stochastically model the routes and travel range for required stock of vehicles with their technical characteristics as mentioned in Table 9. Detailed methodology and modelling results for battery swapping are discussed in Annexure C.

Two Wheelers: The two-wheeler vehicle category is divided into two segments, commercial and private vehicles. In this study, we are assuming that most of the private two wheelers will charge at home and commercial two wheelers will charge at parking spots in the captive premises. Henceforward, the home charging of two-wheeler will occur mostly in the night time and its impact can't be monitored until power utilities install separate meter connection. On the other hand, commercial two wheelers charging pattern will vary based upon number of rides, initial state of charge, and routes. Therefore, a separate study can be conducted to monitor behavior of charging of **two wheelers** and their impact on grid.

Table 9 Modelling assumptions across different EV fleets

Vehicle Type	Sub-Category	Total Stock in 2030	Battery Size (kWh)		Type of Charger	Rating of Charger (kW)	Energy Consumption (kWh/km)	Operating hours
			Min	Max				
Buses	9 m	4661	100	120	Level 3 AC	80	1.2	16
	12 m		250	280	DC Fast	150	1.3	16
Three Wheelers	E-rickshaw	94120	1.5	3	AC Slow	1.5	0.075	16
	E-auto		4.5	6	AC Slow	3.3	0.083	24
Four Wheeler	Private cars	230,901	15	40	AC Bharat and CCS	3.3 to 50	0.18	8 to 12

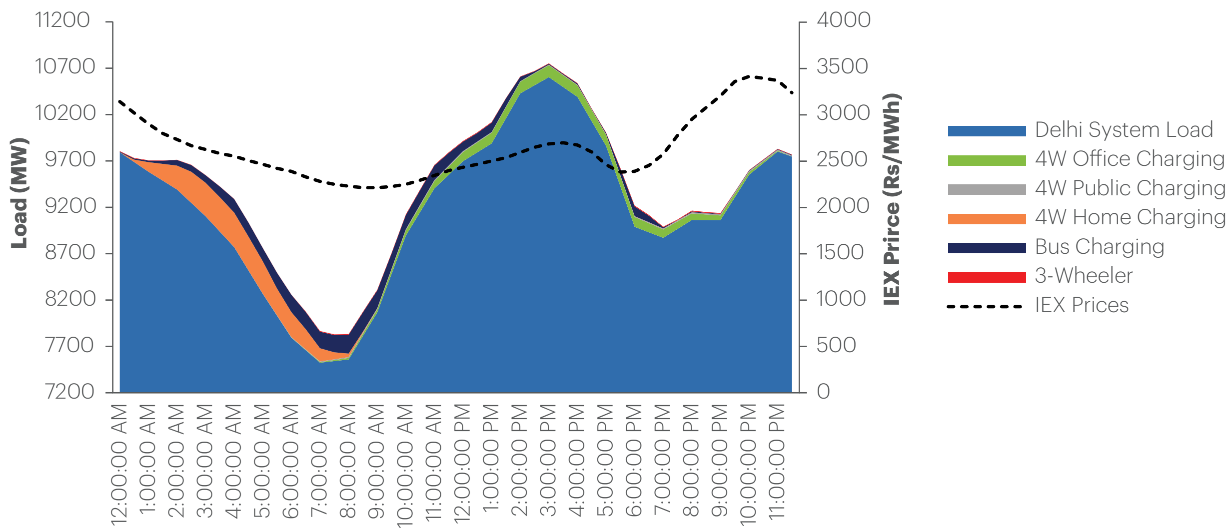

Figure 17 Aggregate system load on peak demand day (coordinated case)

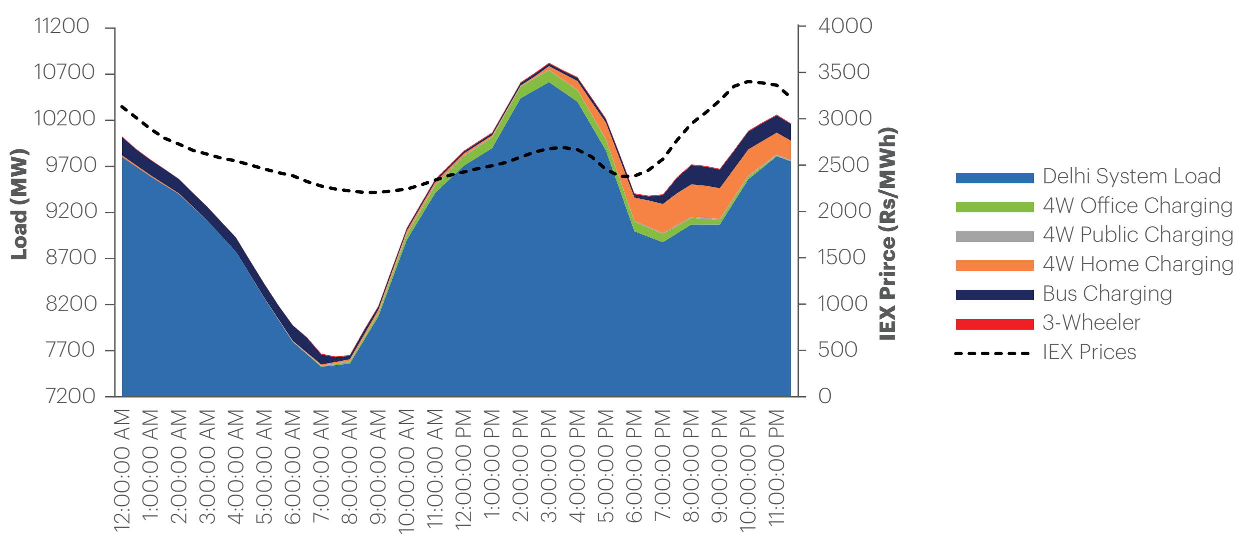

Figure 18 Aggregate system load on peak demand day (uncoordinated case)

4.4 Modelling Outcomes from Selected Charge Scheduling Scenarios

As discussed in previous sections, the main objective of the study was to estimate the EV load from various vehicle segments. In this section we concisely discuss the impact of both coordinated and uncoordinated charge scheduling and its impact on the overall system load. All the scenarios have not been discussed in detail in this section, but we have listed out the detailed methodologies and relevant scenario results and their insights in Annexures A, B, and C.

Figure 17 and Figure 18 show the overall system load in Delhi on the peak demand day in 2030. Both the figures show a comparison of load with the utility marginal price as the control, in this case, is optimized on the cost of charging wherein a time-varying utility marginal price is assumed to be applicable. It can be observed that there is little impact on the overall electricity requirement that has to be met even during a peak demand day.

In the uncoordinated charging case, where the charging pattern is independent of the pricing signals of the utility, the overall charging is concentrated in periods of peak marginal prices, i.e. in the evening. Home charging (4W) and bus charging seem to be contributing most of the charging load. In Figure 17, in the coordinated charging scenario, the pricing signals optimizes the charging and shifts the loads to morning hours where the prices are lower.

The charging seems to be relatively less impacted during the solar hours owing to the charging requirements and travel pattern but can impact hugely once public charging increases as discussed in Annexure A. With the advent of more renewable energy penetration in the grid, the marginal price will decrease and hence there would be higher incentive to charge during solar hours.

Figure 19 and Figure 20 show the temporal share of EV charging and consumer load as a percentage of the overall electricity demand. As stated earlier, the overall impact due to EV l on the utility demand is marginal, but several periods of peak load can surge the utility demand. Moreover, since the distribution of EV charging may not be uniform across the entire distribution network, it could potentially lead to overload of distribution network equipment.

Figure 20 shows that the overall share due to EV at peak durations reaches almost 6% of the overall demand, which coincides with high utility prices in the uncoordinated charging scenario and occurs during wee hours in the coordinated charging scenario. Privately owned four-wheelers and electric bus have a major contribution in the charging load in any scenario, whereas battery swapping contributes slightly to the overall demand and can be managed swiftly.

Despite high marginal prices observed in the evening, the EV fleet mostly contributed by home charging finds it optimal to charge during such periods in the uncoordinated charging case. Such charging patterns in evening hours can overload the local distribution system and thus force the utility to buy costlier power. We observe that charging in certain time blocks can be deferred through measures like dynamic time of use tariffs, and can defer charging, in the coordinated charging scenario by almost 90% of the charging

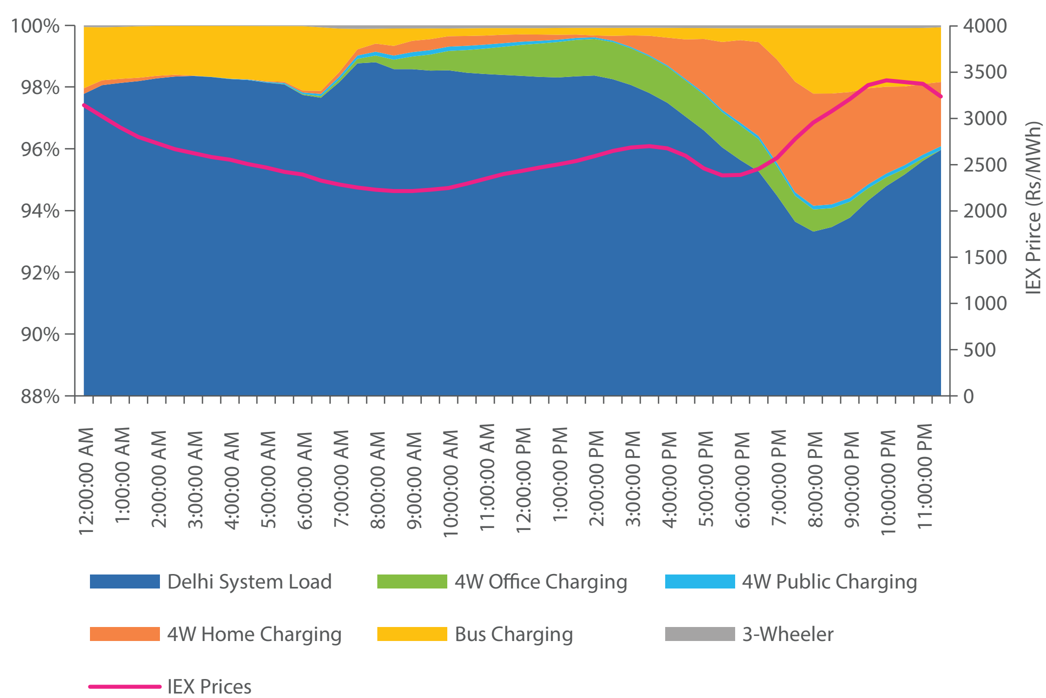

Figure 19 Share of energy requirements in uncoordinated scenario

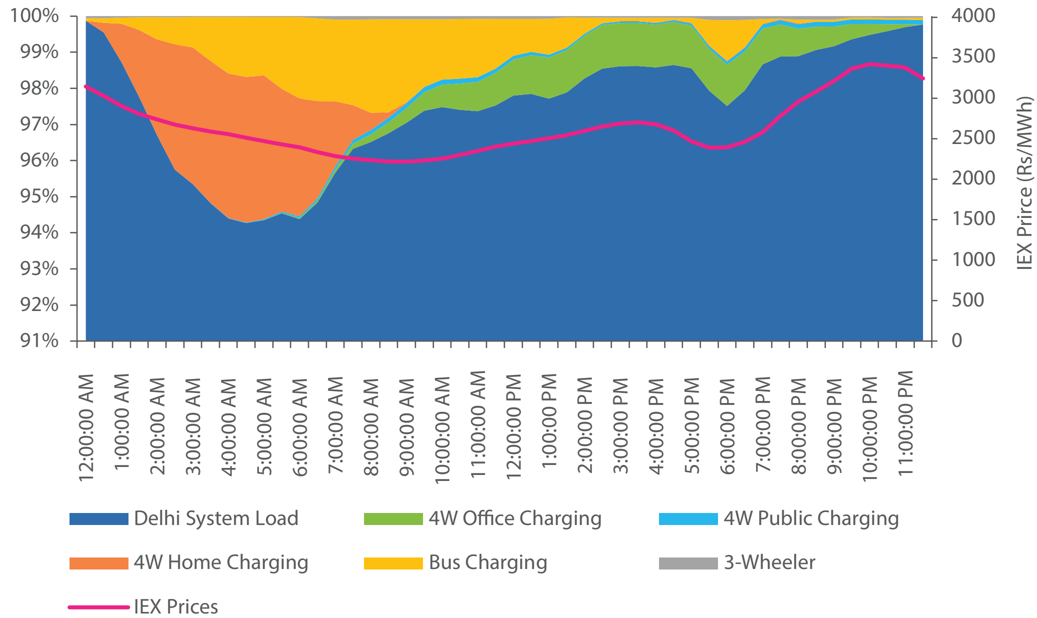

Figure 20 Share of energy requirements in coordinated scenario

load from public transport and home charging to early hours in the morning and solar hours. This can be a win-win situation for both consumers and the utility. Apart from price arbitrage, the public depot operators and battery swapping stations can utilize onsite distributed renewables to charge EVs and, hence, improve the economics of the charging services provided.

Overall, the coordinated charging/smart charging scheme shows the benefit to EV fleet owners to charge their vehicles as per the utility pricing signals in the next decade. Individual results have been discussed in the annexure sections where one can evaluate the different charging behaviour and their overall impact on utility load.

4.5 Key Insights and Recommendations from the Modelling Study

Key Insight 1. Addition of EVs has a marginal impact on the utility level peak load

TERI EV-LEM analysis suggests that the projected growth in e-mobility will not drive a substantial increase in the total electrical-grid peak demand and energy requirements in the coming decade. The total EV stock in 2030 would represent a marginal 6% of the total electricity requirement. The corresponding peak load contribution from EV charging reaches a maximum of 4.8% of system peak on the peak demand day while the total electricity demand could increase by around 2.5% of the total electricity consumption. This increase in electricity demand would be favourable to distribution utilities where the year on-year growth rate in electricity consumption has saturated if the corresponding increase in peak is appropriately managed.

Key Insight 2. Addition of privately owned EVs could increase local network congestion

Privately owned EV (two-wheelers or four-wheelers) penetration will not be uniformly distributed across Delhi in 2030. Therefore, although the system-level peak power demand is not projected to significantly increase due to EVs, an increase in penetration in this segment could lead to an increase in network congestion. This results in not only an increase in peak power purchase but also an increase in network augmentation. TERI's study[20] on Impacts of EV Charging on the Distribution

[22] Details available at http://dufindia.com/electric-vehicles-perspective.html

Network suggests that a non-uniform distribution of EVs across Delhi could lead to overloading of some sections of the distribution network, particularly at the distribution transformer level.

Key Insight 3. Identifying the most effective control strategy for EV charging is critical

The potential of various coordinated charging strategies has to be evaluated to identify the most appropriate strategy. Passive control strategies such as static time-of-use electricity tariffs can influence EV charging behaviour by incentivizing users to charge during off-peak hours. Static time-of-use electricity tariffs could also result in the shifting of the peak to other hours of the day as many EV users inadvertently set their chargers at the same time. This could be avoided by implementing dynamic pricing for EV charging based on real-time network loading. In this way, it is possible to react to changes in the operating conditions (for example, to increase the charging prices during periods of high electricity prices or local network congestion). The aforementioned control strategies provide different levels of control over EV charging and are subject to consumer behaviour and tariff design. TERI's EV-LEM model estimates that adopting dynamic pricing can be a win-win for both utility and consumer while managing peak demand as well optimizing revenue.

Key Insight 4: EV charging can help increase the load factor of distribution system equipment if coordinated charging is implemented

An uncoordinated and majorly home charging regime could lead to utility-level reduction in the load factor of up to 1.1%, while no change or a slight improvement can be observed if any form of control (sufficient adoption) is implemented. Moreover, the load factor change will not be evenly spread as the adoption of EVs in different areas will not be uniform. This could lead to a more drastic load factor reduction at lower voltage level equipment such as DTs, conductors, and cables. A geospatial assessment through power flow study can help evaluate the same at different levels.

Key Insight 5: A two-part tariff could reduce peak contribution due to EV charging

An electricity bill usually consists of two components: a fixed charge, which depends on the maximum instantaneous power (i.e., maximum power absorbed from the grid at any instant of time) and energy charge, which is calculated depending on consumption. Fixed charges in Delhi vary from 50 Rs/kW/month to 250 Rs/kVA/month depending on the consumer category. EV charging does not currently entail a fixed charge in Delhi. An increase in the fixed charge would deter consumers who own multiple EVs from charging simultaneously, especially during peak hours. Group housing societies/offices with common parking areas would also limit the number of charging sockets or the number of fast chargers so as to reduce the fixed charge component of their electricity bill.

Key Insight 6: Promoting office and public charging for privately owned EVs could help increase the adoption of solar PV

We estimate that as the share of public and office charging increases, there is a shift in consumers charging their vehicles during the daytime while commuting or at commercial office spaces. Likewise, there is improvement in utility load factor, as the charging is spatially distributed throughout the day; the evening charging peak drastically reduces from 348 MW to 262 MW as home owners prefer to charge less during the evening peak hours. Promoting office and public charging would make EVs available for charging during solar hours, thereby reducing the integration cost (due to storage) of solar PV. Hence, it is important to note that utilities need to plan for more public charging stations so as to reduce the evening peak demand.

Key Insight 7: Cost effective deployment of Electric buses requires proper planning:

The characteristics of a bus route determine the battery and charger rating for e-buses. Initially e-buses could be deployed on routes that require lower investment. Proper planning should be done to identify the type and number of e-buses and chargers. The operational planning of e-buses should be done considering trip length, time spent between trips at the bus depot, power/RE procurement strategy, range of different types of e-buses, chargers, and the associated capital and O&M cost. Although it is beyond the scope of the study to determine the financial benefits of EV adoption, the benefits of EV charging using coordinated charge scheduling can be estimated as charging follows pricing signals. Around 94% of evening peak charging shifts to operational hours of bus terminals i.e. during the daytime in case of a coordinated charging scenario when the marginal prices are less, thus providing an opportunity for significant savings to bus depot operators.

Key Insight 8: Distributed solar viability increases with coordinated charge scheduling

A coordinated charging scheme can be beneficial to utilize distributed solar in bus terminals and public charging stations. As shown in Table 11 in Annexure A, as the share of participation of fleet in coordinated charging increases, there is an increase in the number of buses charging during the solar hours. Hence, this gives better avenues for bus operators to go for solar rooftop installation.

Key Insight 9: Battery swapping for electric three-wheelers will play a central role in achieving 'shared, connected, and electric' mobility in India

As 80% of electric vehicles in India today are e-rickshaws, it becomes essential to ensure seamless charging given the current charging methods. Battery as a service (BAAS) for the three-wheeler segment can be beneficial in cases where upfront investment is relatively high; rickshaw owners can get the depleted battery replaced at a swapping station and reduce lead-time while increasing revenue. This means battery ownership, high battery purchase cost, battery standardization, safety issues, and charging SOPs need to be enforced in concurrence with e-rickshaw vehicle manufacturers.

The level of control on the load due to the battery swapping scheme depends on the ratio of batteries to the number of vehicles availing this scheme. An increase in this ratio could increase the flexibility of charging, and also reduce the wait time, but it can increase the cost of the service too.

ANNEXURES A.

MODELLING THE PUBLIC ELECTRIC BUSES

1. Background and Scope

Public transportation plays an important role in the mobility mix of India; with decarbonization targets envisioned by the states, the rate of transport electrification is bound to increase with advancement in technology, decrease in price of battery packs, which represents the highest upfront investments. At present private bus operators may hesitate to migrate to electric technology; however, in view of the declining cost of EV batteries, which would improve the bus TCO further, it is a matter of time this segment of public bus fleet would gradually shift to electric. Despite the environment-friendly characteristics of E-buses, their charging requirements have to be planned meticulously, which is mostly dependent on travel patterns and the operation from its terminus stations. Buses bound to multiple routes and arriving at the same time to get charged also would directly impact the electricity load at the depot.[23] Further, discrete charging pattern may leave a haphazard impact on EVCI utilization rate and, in turn, stress the revenue. Therefore, utilities need to be prepared to address the aspects of power purchase and reliability of the utility grid. Since 70–75% of the expenses of electricity distribution companies comprise the power purchase cost, this should encourage utilities to adopt coordinated-charge scheduling schemes for EVs in order to maximize their revenues.

2. Modelling Description and Assumptions

2.1 Technical Parameters

This study presents a case study for the city of New Delhi for the year 2030 to evaluate the aggregated charging load added by the electric buses. Delhi Transport Corporation (DTC) and Delhi Integrated Multi-Modal Transit System (DIMTS) are the bus operators in the city and they have been operating around 8010 CNG buses till date. The study considers coordinated charge scheduling for 4430 number of electric buses that are planned to be inducted in the DTC fleet up to 2030. The mix of electric and CNG buses till 2030 can be seen in Figure 21.As the addition of new electric fleet to the DTC depots is not concretely planned, the study considers existing bus depots for the operation. Data related to existing bus routes is fetched from an opensource dataset.[24] The consolidated dataset consists of information pertaining to departures and arrivals at depot, frequency of buses, distance, and the number of trips per day for each of the bus routes. The Root Mean Square (RMS) route length for the bus routes covered in the city is 27.5 km. Considering this, the study has excluded long routes with more than 42 km of one-way travel. Accordingly, a total of 113 out of 176 bus routes available have been taken from the existing dataset. Buses has considered as per the existing number of buses at each depot and their route frequency.

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[23] S. Das, C. Sasidharan, and A. Ray, "Charging India's bus transport," Alliance for an Energy Efficient Economy, Tech. Rep., 2019.

[24] IIIT-Delhi. (2020) Open transit data. [Online]. Available: https://opendata.iiitd.edu.in/

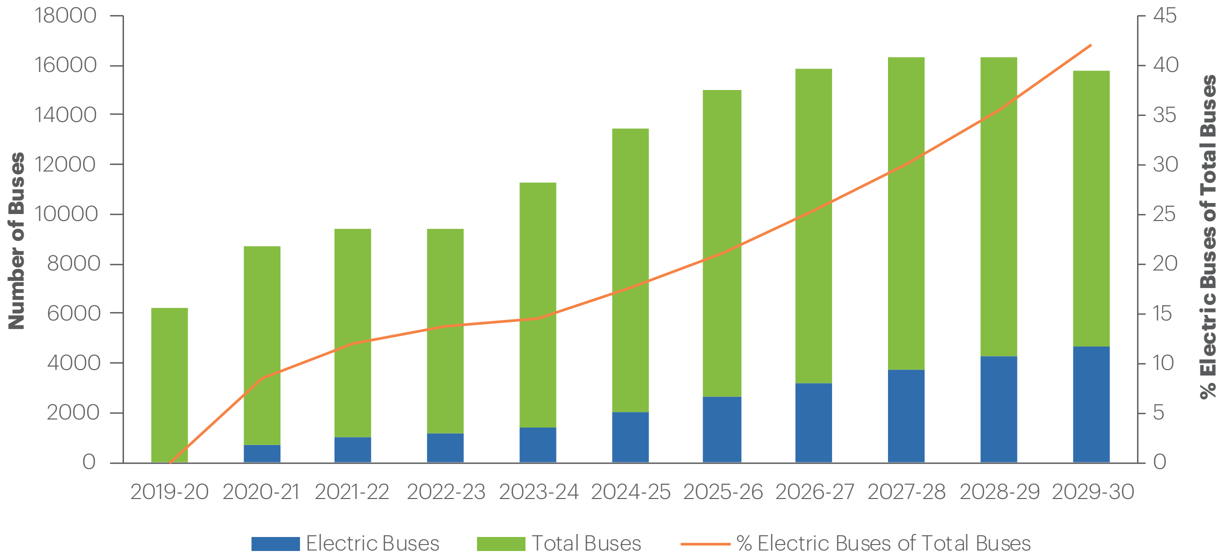

Figure 21 Stock of Electric buses in Delhi

2.2 Operational Parameters

Based upon the current operating buses across the globe and the FAME-India specifications, the two most viable bus types (specifically 9 m and 12 m length buses) have been considered in the study. The battery size for the 9-m variant has been taken in the range of 100-120 kWh while for the 12-m variant, the size range is 250-280 kWh. Energy consumption for the buses is considered to be 1.1-1.3 kWh/km from literature review on existing bus manufacturers in India.[25] For setting up chargers at bus depots and to encourage opportunity charging during operating hours, AC Level III and DC plug in chargers with ratings between 80-150 kW have been considered. To estimate the electric bus charging load on the aggregated load of Delhi, the time series load has been forecast for the year 2030 using CAGR method considering the base year (2018) data from existing TERI study.[26] To capture the feature of deferring charging and availing the opportunity of price arbitrage, a day capturing 24 hours. of load values for the month of April for N2 region in India as specified in The Indian Energy Exchange (IEX) database has been considered. To avoid any arbitrary price at a time stamp, values for different days were normalized in a month and devised to generate a price curve as shown in Figure 22.

[25] S. Das, C. Sasidharan, and A. Ray, "Charging India's bus transport," Alliance for an Energy Efficient Economy, Tech. Rep., 2019.

[26] T. Spencer, N. Rodrigues, R. Pachouri, S. Thakre, and G. Renjith, "Renewable power pathways: modelling the integration of wind and solar in India by 2030," The Energy and Resources Institute, Tech. Rep., 2020.

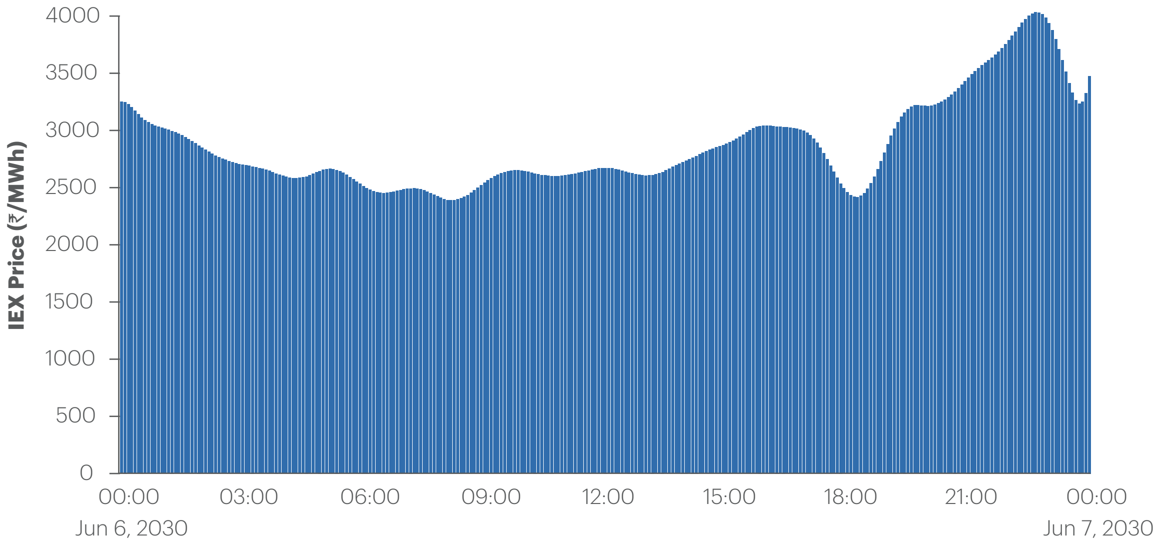

Figure 22 IEX Price for N2 region (INR/MWh)

3. Modelling Framework

Optimized charge scheduling for public buses is developed through a framework, which is established upon various inputs provided to the model. Figure 23 shows the interaction between various input modules, which then simulate the bus schedules during the day in five-minute intervals. The bus depot module pools useful information related to each of the bus routes within the depot and develops an availability matrix of travel for the bus operation. This availability matrix provides the status for each of the bus route at time slot t stating availability at depot. Output module results from the LP optimization for each bus depot provide time-series State of Charge (SoC) of the bus, traction load, and charging power. It also gives the status of each bus charging at individual charger and status of bus travel. The estimated number of chargers N is such that it ensures that each electric bus in a given route has a charger available for at least two times the frequency of departure of a particular route and a maximum of three times the frequency of departure. This means that the time spent between trips at the bus depot for an electric bus would be two to three times that of a CNG bus. This is done to ensure a more aggressive daytime charging while integrating more electric buses into the existing fleet.

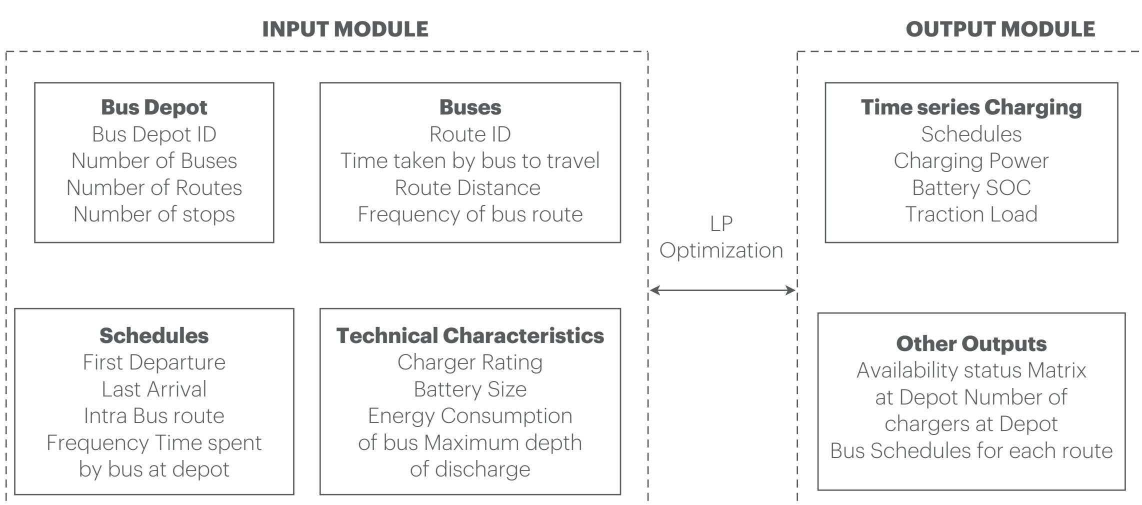

Figure 23 Modelling framework for E-buses

As seen in Figure 24, the time spent at the depot for CNG buses is assumed to be equal to the frequency of departure so as to simplify the schedule. A box diagram has been shown to represent the position of a bus. Green-coloured boxes signify bus at depot while a blue box shows that a bus is on a duty enroute. It is worthwhile to mention at this point that the underlying objective of this report is not to obtain an optimized schedule but to evaluate and assess the load addition owing to electric bus charging.

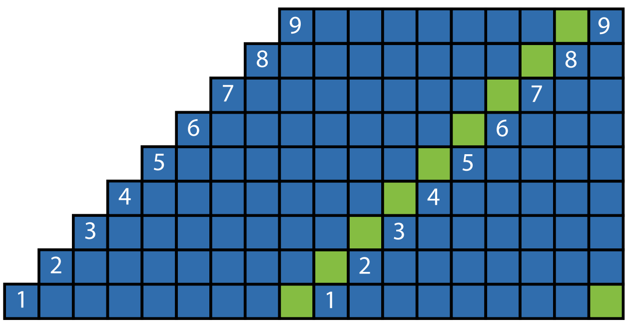

Figure 24 Bus schedules

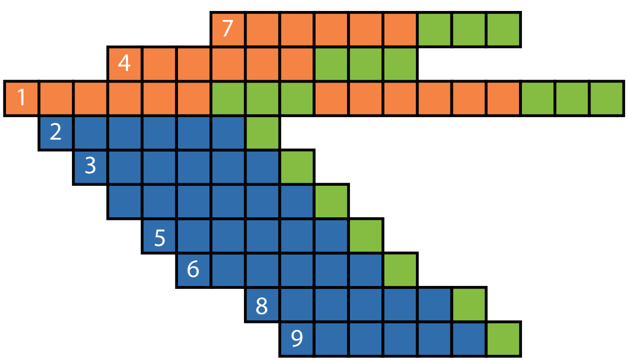

Figure 25 Bus schedules CNG + E-buses

Accordingly, the first departure and last arrival time have been considered from the publicly available dataset while scheduling electric buses on DTC routes. A schedule for electric buses accounts for the fact that these buses will ply along with the existing CNG buses and the schedule for the existing CNG buses headways will be slotted between the departures of two electric buses and the later departures of only CNG ones. The time at the depot is assumed to be minimum three-time blocks if the number of CNG buses added is less than half of the existing number of buses as shown in Figure 25. The orange box on the top signifies electric bus plying with existing CNG buses as seen in the bottom blue boxes. This order represents dual operation of CNG as well as electric buses.

4. Scenarios Modelled

Figure 26 shows a schematic of scenarios modelled for E-bus section. The overall objective of the load modelling study is to explore strategies to manage peak load attributed to EV charging loads in the grid. Hence to understand behaviours in different cases, we have divided the scenarios in three varying conditions: the coordinated, partially coordinated, and uncoordinated charge scheduling. Unlike the uncoordinated charge scheduling scenario, the other scenarios consider a price sensitivity to charging based upon the marginal prices identified in the electricity market as mentioned in the previous section.

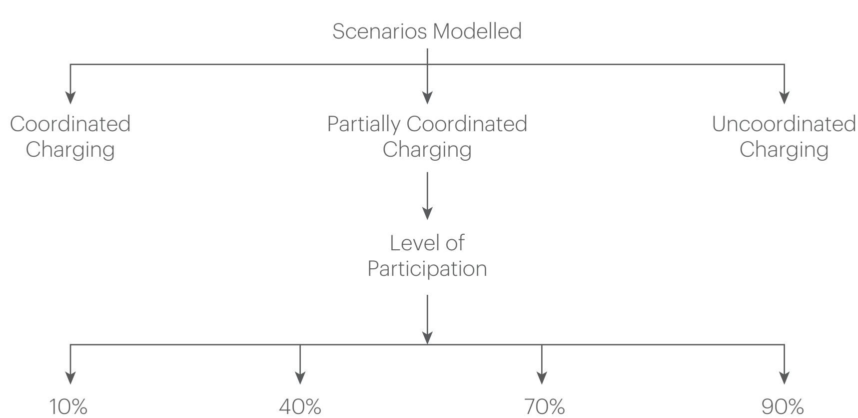

Figure 26 Scenarios modelled for electric buses

5. Key Results from the Modelling Study

The results for the developed charge scheduling model have been evaluated for the scenarios as mentioned in Section 4 to analyse the impact of depot charging on the system load. As per the optimization problem, the constraints have been ensured to adhere to the daily bus operations and the required charging levels considering the least cost incurred. The perfectly coordinated charging scenario improves the load factor in the system from 39% to 54% as mentioned in Table I. Improvement in the load factor signifies the uniform distribution of load across the day; this increases with more participation of fleet in coordinated charge scheduling as we see this in the next sub-section.

There is also a reduction in peak load due to charging in all cases of coordinated charging indicating uniform temporal distribution of load across the day. Peak load due to bus charging reduces from 208 MW in the uncoordinated charging case to 177 MW in the partially coordinated scenario. Apart from improvement in the load factor, coordinated charging also ensures that charging occurs during the operational hours of the depot in the daytime. It can be seen from Table 10 that there is a 300% improvement in charging during the daytime in the case of perfectly coordinated charging as compared to an uncoordinated charging case and similar improvements can be seen in the the case of partially coordinated charging.

5.1 Impact of EV Charging on System Load Curve

In the previous section, we looked into major insights evolving from the modelling study. However, it is not very clear as to which hours of the day are critical and how it can affect the charging characteristics. In this section, we delve more into the temporal aspects to find the impact of coordinated and uncoordinated charging and their temporal behaviour. Figure 27 presents the electric bus charging load superimposed upon the Delhi system load on peak day in year 2030. Although from Figure 27 (a) it is not clear the impact due to coordinated charging scheduling, we note the key impact on certain hours of the day especially the bus operational hours and the evening peak time. It is much clearer in Figure 27(b) that during the operational hours of the depot, there is uniform distribution of load. This ensures that the buses charge when the marginal prices of electricity are lower in the market and also thereby maintaining the operating schedules. Further in Figure 27(c) one can note that the charging starts reducing in the evening owing to the high electricity prices. Hence, most of the charging is ensured either in wee hours or during the operational hours.

Table 10 Aggregate results from the E-Bus modelling study

Level of Control (%)	Load Factor	% of Energy Charged in Solar Hours
100%	54.80%	58.8%
90%	52.60%	53.5%
70%	52.50%	43.6%
40%	47.70%	30.4%
10%	43.10%	18.8%
0% (Uncoordinated)	39.50%	15.2%

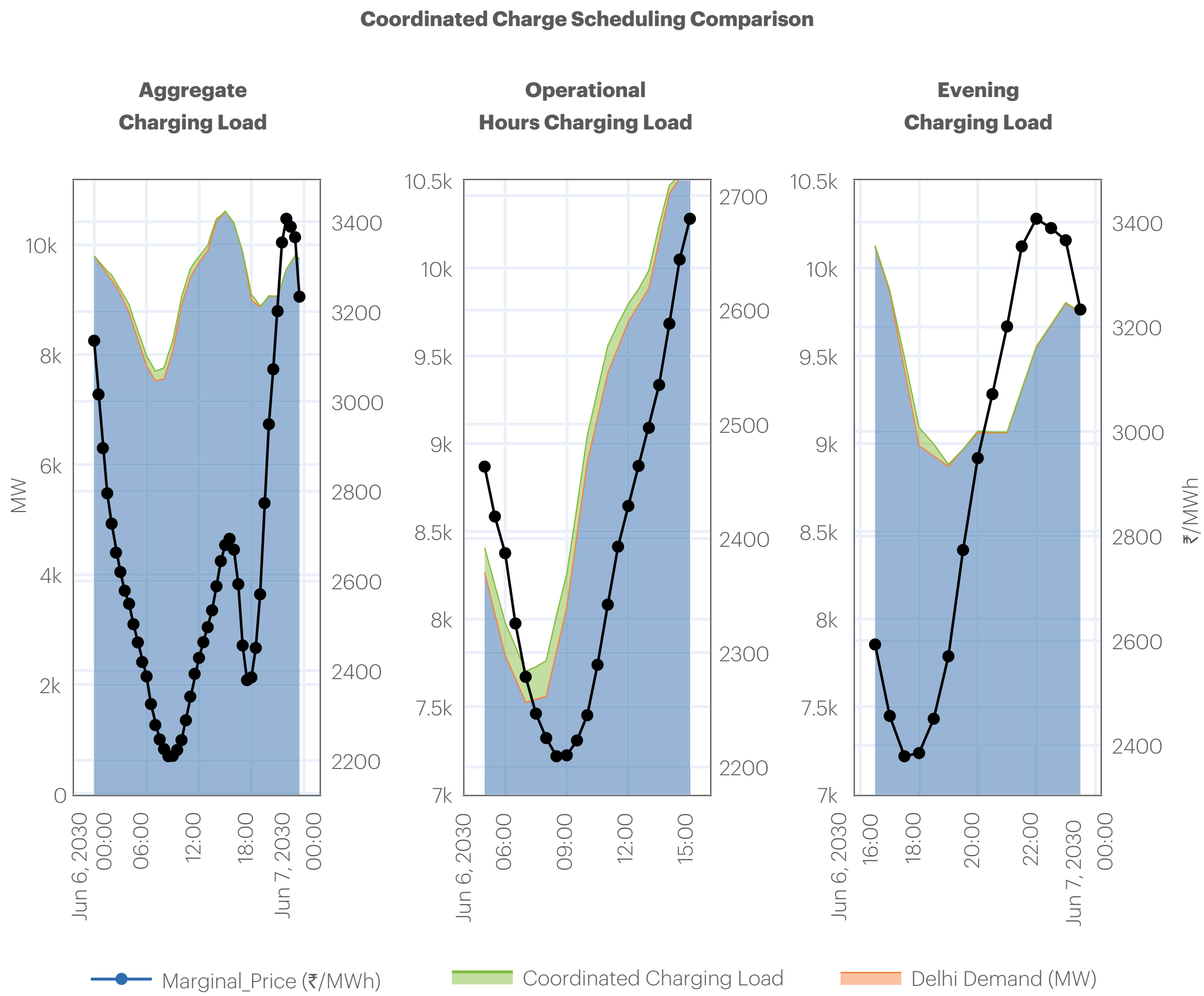

Figure 27 Coordinated charging: (a) aggregate charging load, (b) operational hour charging load, (c) evening charging load

Figure 28 shows a temporal distribution of charging load in the uncoordinated charge scheduling scenario. From Figure 28(a), it can be observed that majority of the charging is either concentrated at evening or morning hours before the scheduled departure of the buses. Figure 28(b) and Figure 28(c) give a comprehensive insight into charging load during operational and evening hours, respectively. As this scenario is insensitive to the marginal prices, charging during operational hours is neglected even when the prices might be low. Further in Figure 28(c) one can see from the effect of the underlying effect of price insensitivity, Delhi has experienced an evening peak trend and further load addition can not only congest the distribution downstream but also increase the peak power procurement for the utility.

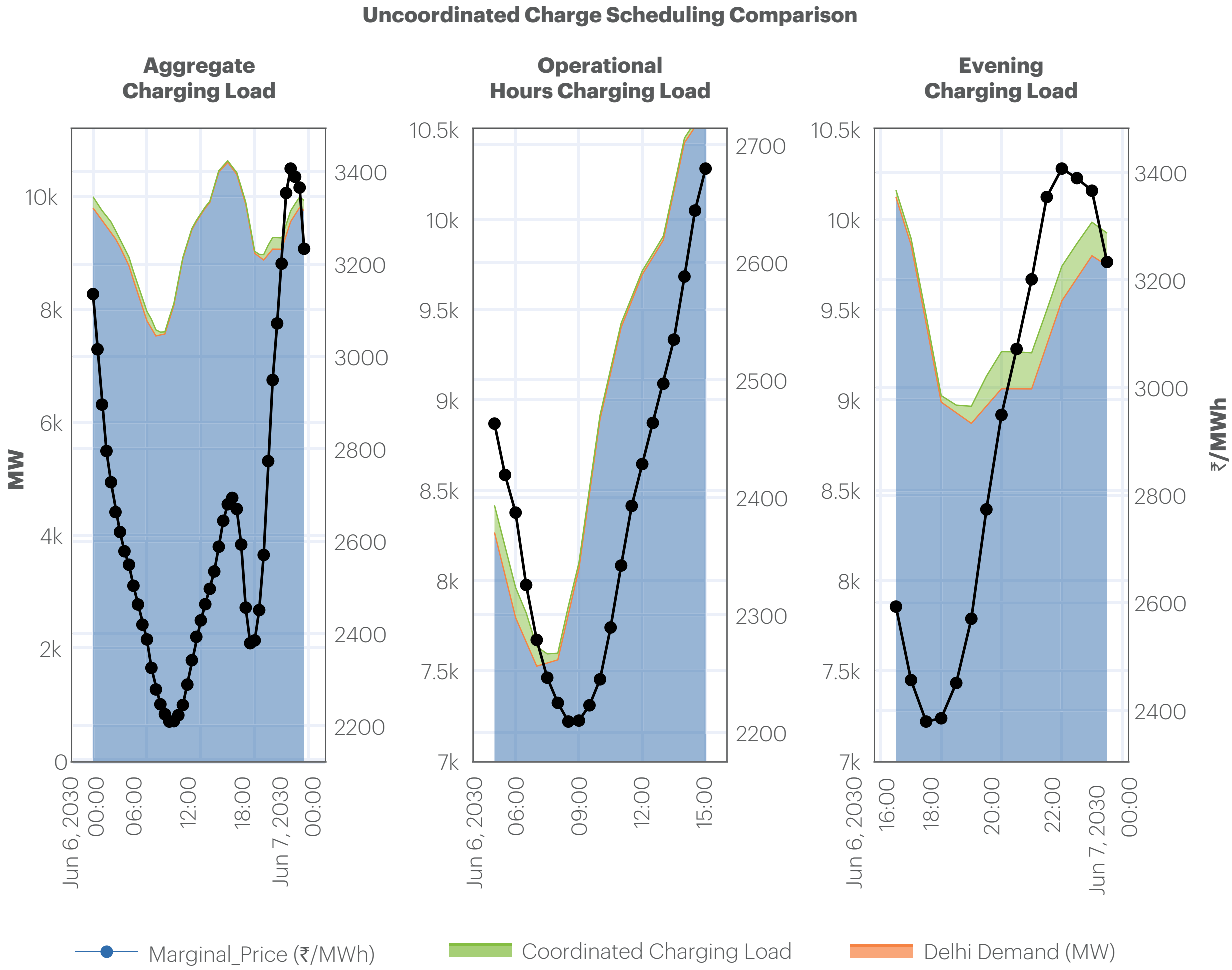

Figure 28 Uncoordinated charging (a) aggregate charging load, (b) operational hour charging load, (c) evening charging load

5.2 Comprehensive Insight into Charging Load Duration:

In this section, we discuss the impact of temporal distribution of charging load across the day for the analysis period. Figure 29 shows the load duration curve for both coordinated and uncoordinated charging. It is seen that in the case of uncoordinated charging, load clustering occurs at 2 locations and a sudden drop can be seen from 150 MW. Load in coordinated charging remains well below that in the uncoordinated charging case showing drop in loading and uniform distribution of load for the time intervals. This change can be attributed to the price sensitivity to the regional load. Hence, in the case of coordinated charging, the charging load is optimized throughout operational as well as non-operational hours.

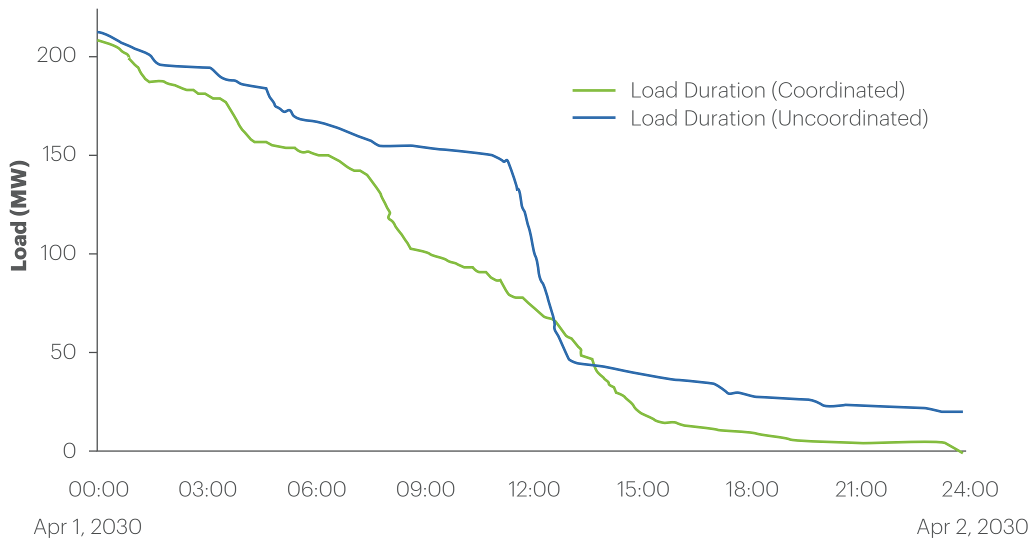

Figure 29 Charging load duration curve

Coordinated/Uncoordinated /Partially Controlled Charging Load

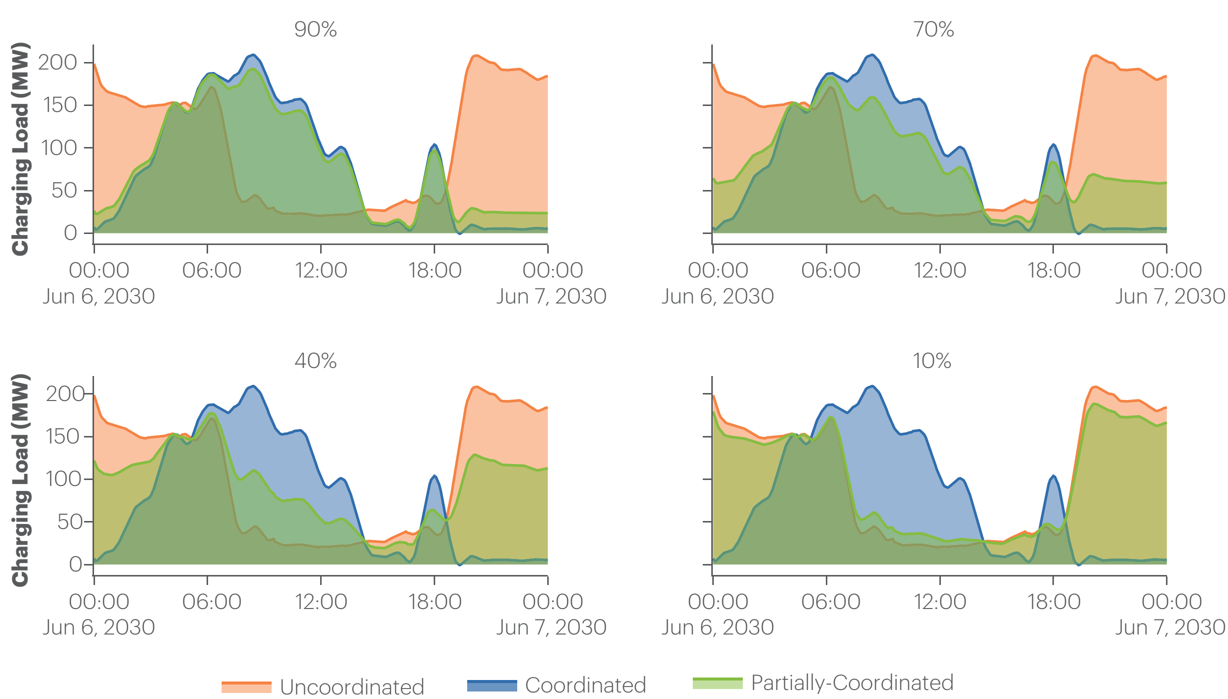

Figure 30 Coordinated/uncoordinated/partially coordinated charging load

From Figure 30, one can further conclude where majority of the charging in the uncoordinated scenario occurs post-operational hours or early morning showing insensitivity to system loading parameters. Figure 30 shows comparison between 3 distinct scenarios cases considering coordinated, uncoordinated and partially coordinated charging case. These scenarios encompass price sensitivity to EV charging variation during the day by considering the level of participation amongst the bus fleet.

An ideal case will be 100% coordinated charge scheduling but this level of participation is not possible. So here those cases have been taken into consideration that have different charging strategies with the percentage of level of control in the fleet towards coordinated charging. As the percentage of control or participation of fleet in coordinated scheduling increases, the charging in lean price period increases. The results show an optimistic view for state bus operators to opt for such interventions due to the practical benefits in term of monetary savings over power purchase costs and to comply with the environmental goals to opt in for more zero carbon public transport.

ANNEXURES B.

LOAD CURVE ESTIMATION FOR PRIVATELY OWNED FOUR-WHEELERS

BACKGROUND AND CONTEXT

An immediate challenge is to make EVs correspond to society-driven mobility needs supplied by personal cars (e.g. the pattern of individual trips required during a set of typical days by each electric vehicle in a fleet). A better understanding of how the mobility needs correspond to the availability of variable power generation and the distribution infrastructure requirement arw thus essential. It is also significant to understand various charging options available with respect to private and public charging of 4-wheeler EVs and their utilisation, indirectly affecting the system-level load.

While the uptake in EVs is unlikely to cause a significant increase in the total power demand, it will most likely to reshape the electricity load curve. The most pronounced effect will be an increase in evening peak loads when people will plug in their electric cars after returning to home from work. However, at a system level, this effect will represent a relatively small percentage at the most. All these anticipated possibilities were in the context of random or uncoordinated charging.

In the case of coordinated charging, control over charging is possible through either direct or indirect interventions, which is beyond the scope of this study. The effects of coordinated and uncoordinated charging are being analysed as a part of this study.

We stochastically model the travel behaviour for privately owned cars in terms of vehicle availability (either at home or office), range requirement, etc. Vehicle characteristics such as the battery, charger rating, and the ratio of vehicles to chargers have also been considered. The minimum amount of charge required in the battery before it leaves either office or home depends on the distance to its next destination (home or office). The range requirement, charger rating, battery capacity, and availability at different charger sites are formulated as constraints that have to be satisfied.

INPUT DATA

1. Travel Characteristics

To estimate the resultant load curve due to the addition of privately owned electric four wheelers, it is imperative to know when a certain EV is available (either at home, office or in transit in between). For this purpose, an availability matrix was developed to model the availability of a privately owned four-wheeler at home and office. It is assumed that the commercial four-wheelers would also be charged at captive places like offices or fleet originating zones.

To develop this matrix, the vehicle travel pattern for a privately owned four-wheeler was considered. This includes the vehicle arrival and departure probabilities. Figure 31 shows the probability of arrival and departure assumed for a privately owned electric four-wheeler. This data may not be truly representative for Delhi. The distribution was obtained through a survey of 50 people in Delhi. The data is indicative of a whole weekday travel pattern. As can be seen from Figure 31, vehicles leave (orange) home in the morning and arrive (reach) in the evening, giving opportunity for charging either in the evening or in the overnight.

The probability distribution curve in Figure 31 depicts the leave (departure from home) and reaches probability (arrival at home). The duration of a vehicle's availability in the office is estimated assuming an average travel speed and the range requirement.

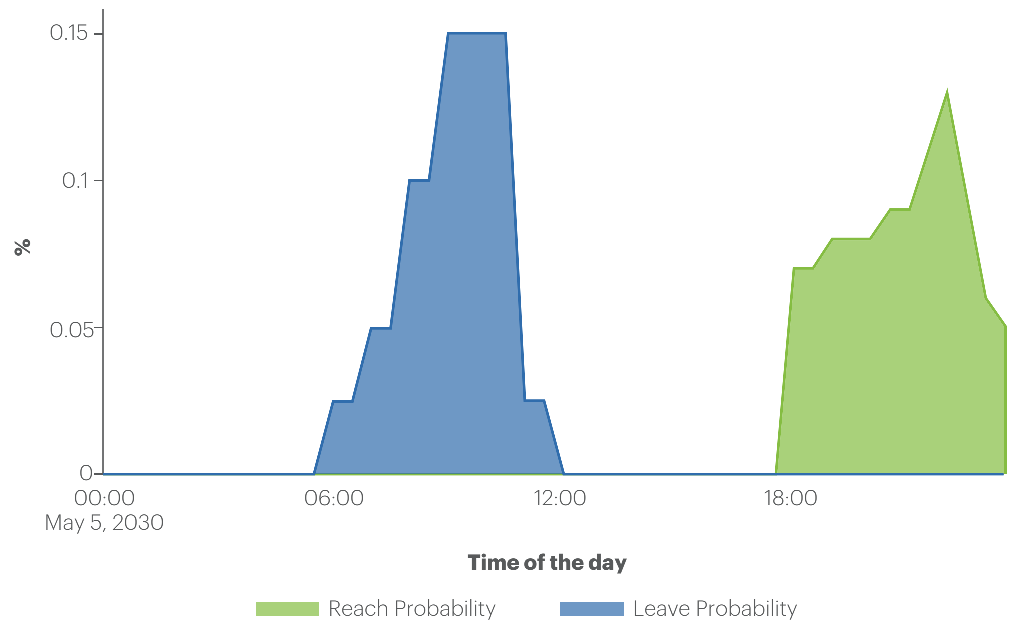

Figure 31 Probability distribution curve of arrival and departure

2. Range Requirement

The minimum amount of charge required in the battery before it leaves either office or home depends on the distance to its next destination (home or office). The range requirement, charger rating, battery capacity, and availability at different charger sites are formulated as constraints that have to be satisfied. The percentage of charging at each of the possible locations (home, office/public) is assumed, as per the scenario assumption. This would influence the level of charging at different time stamps. A range requirement of 30–50 km with a step size of 5 km was assumed, each with equal probability.

3. Charger/Battery Rating Battery Characteristics

The charging power at any instant is significantly influenced by the availability matrix and the range requirement of an EV. Another set of parameters that constrain the level of charging power are the battery characteristics, such as battery capacity, SOC-dependent C-rate and charger rating. The charger rating will also limit the charging power at any timestamp. Table 11 shows the different types of chargers considered in this study and the probability of occurrence. Each battery size, as depicted in Table 12, has an equal probability of occurrence, indicating a uniform distribution of vehicle types in the sample size for simulation. The battery size and charger rating assumptions are as per our interaction with various stakeholders.

Table 11 Chargers selection and their probability

Charger	kVA/ kW	Probability for home charging
Type 1	4.5-5	90%
Type 2	22	10%

Table 12 Vehicle types and battery size

Vehicle	Battery size (kWh)
Vehicle A	20
Vehicle B	35
Vehicle C	40

Time-based electricity tariff coordinated charging is achieved when EV charging can be shifted to a more suitable time of the day while ensuring that the aforementioned conditions such as range requirement, availability at the charging point, are satisfied. In this study, IEX (an Indian electronic system-based power trading exchange), a time-based tariff, was used to model a practical parameter that can trigger the charging to defer from a timestamp wherein the cost of electricity is high to a time wherein the cost of electricity is relatively cheaper. The IEX rate for any region is usually reflective of the marginal cost of electricity for any distribution utility in that region, although a perfect forecast for any given day, as assumed here for simplicity is not usually possible. The average IEX price for May 2019 for the Northern Region (Figure 32) was assumed.

4. Development of Vehicle Dataset

The Monte Carlo method was used to attain a dataset for travel behaviour and vehicle characteristics (considering input data 1, 2, and 3) for 500 vehicles as shown in Table 13. The results for this sample size were extrapolated for the projected EV stock in 2030, i.e. 230,900 vehicles.

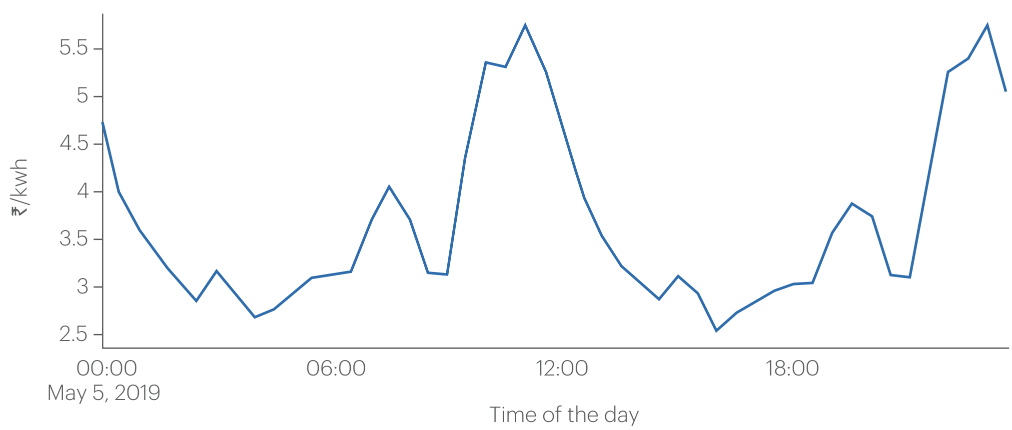

Figure 32 IEX price for region N2

Table 13 Monte Carlo method for travel behaviour

Vehicle ID	Leave time	Reach time	Range requirement (km)	Battery capacity (kWh)	Charger rating (kW)
Vehicle_1	09:00	19:00	30	20	4.5
Vehicle_2	08:00	22:00	45	35	4.5
Vehicle_3	11:00	20:00	50	40	4.5
Vehicle_500	12:00	23:00	25	35	22

SCENARIO FORMULATION

Scenarios were formulated around parameters or variables that strongly affect the output. These include the following:

1. Percentage of Home /Office / Public charging

Privately owned non-commercial electric cars can be charged either at home, office or public charging stations. The proportion of EV charging at any of these locations can be influenced by policies. The assumption around the percentage of charging (that is the percentage of total charge requirement at different location) can directly influence the overall loading at distribution downstream and eventually the system load. A set combination of distributions for charging at different locations has been assumed to assess the impact of this parameter on the load curve.

2. Number of vehicles

The total number of vehicles in all scenarios is assumed to be 230,900 for the year 2030. This is kept uniform across all scenarios.

3. Ratio of EVs to chargers

Most electric car users prefer to start charging as soon as they reach home or office. If the number of chargers is limited, the number of cars that start charging simultaneously decreases. Even though most EV user have a slow charger or an on-board charger, the maximum number of chargers that can be connected at a time (either at any residential area/home or office) is limited by the maximum load sanctioned to each consumer of a DISCOM or the maximum load sanctioned for each EV-charging meter/sun-meter. The ratio of EVs to chargers can be interpreted as the number of chargers allowed to simultaneously charge at a time to the number of electric cars. The two different ratios of chargers to EVs assumed for the purpose of this study are 4:1 and 10:1.

4. Percentage of control

Different control charging strategies, degrees of complexity in implementation, and effectiveness have been briefly discussed in Section 4.3.3. As discussed, different control strategies have varied levels of effectiveness. Moreover, 100% participation in either direct or indirect control schemes will not be possible in different proposed schemes. To account for this, an additional parameter, percentage control, adjusts the volume of users that participate in any control scheme. To understand the level of influence of this parameter, varied levels of controls are assessed (30%, 40%, and 50%). This parameter is used to influence the number of EV users that participate in various coordinated charging schemes.

RESULTS

Base Scenario

Percentage of Home /Office /Public charging: 70%:25%:5%

Ratio of chargers to EVs: 1:4

Percentage of Control: 0%

The base case represents the effects of uncoordinated charging. As can be seen in Figure 33, the peak power demand is projected to increase by 3% while the electricity consumption is estimated to increase by less than 2%, and the overall load factor reduces by 1%.

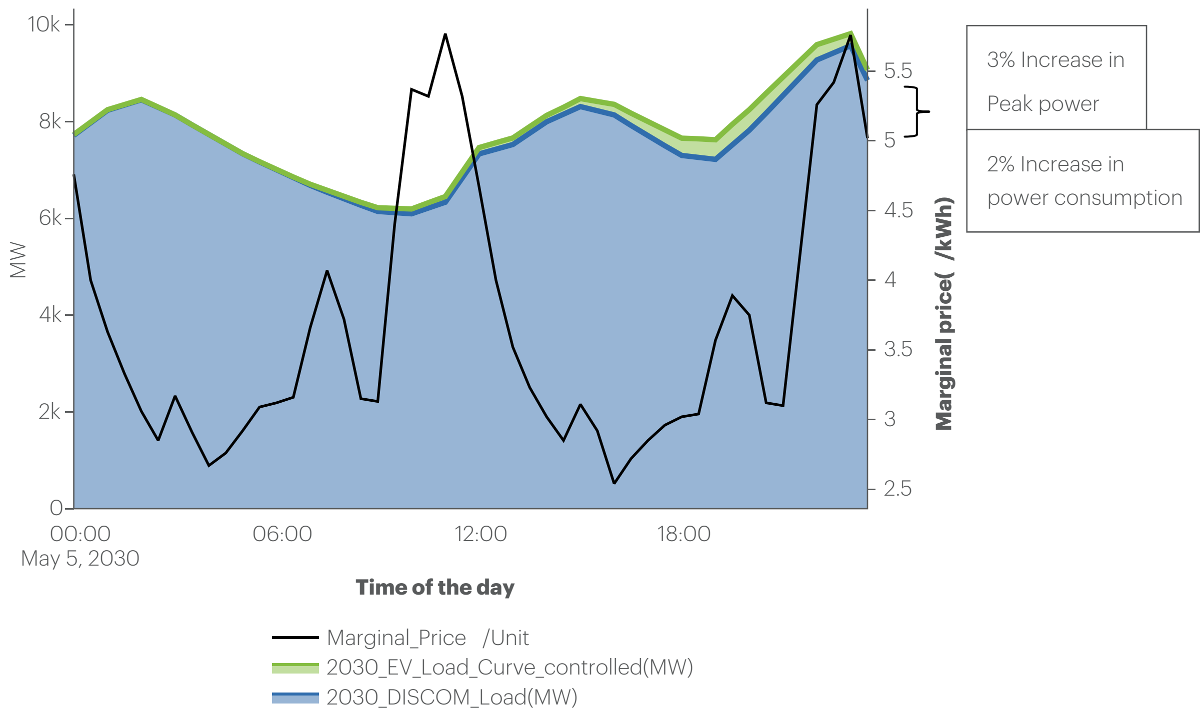

Figure 33 Aggregate EV and system load in BAU

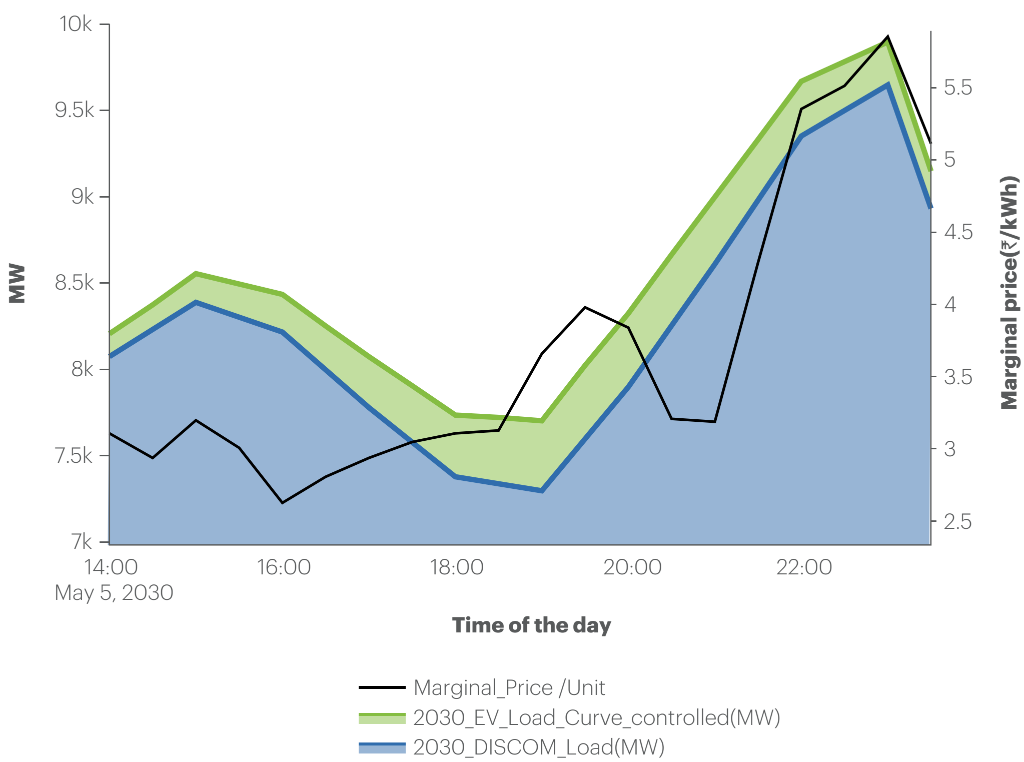

Figure 34 Increase in peak load in the base case scenario

Scenario2: Increase in the level of control

Percentage of Home /Office /Public charging: 70%:25%:5%

Ratio of chargers to EVs: 1:4

Percentage of Control: 40%

A change in the percentage of control to 40% or an increase in participation by this level would reduce the increase in peak from 3% to 1.7%. But, the load factor will remain unchanged due to the addition of EV load. In a coordinated charging scheme, some amount of charging is deferred to early morning hours as the cost of electricity is cheaper during these hours of the day. This helps to control the charging time of some of the customers subject to cost of electricity at different hours of the day (IEX price).

Scenario3: Number of Chargers

Percentage of Home /Office /Public charging: 70%:25%:5%

Ratio of chargers to EVs: 1:10

Percentage of Control: 0%

Limiting the number of chargers simultaneously charging in the EV ecosystem provides an inbuilt distribution of EV charging across the plausible hours of the day. A change in the ratio of EVs to chargers from 4:1 to 10:1 is analysed in this scenario.

Figure 36 shows uncoordinated charging with the ratio of EVs to chargers assumed to be 4:1. The number of chargers limits the number of vehicles that can charge at any instant, hence spreading out EV charging to later hours of the day. Figure 36 shows the same with the ratio increased to 10:1.

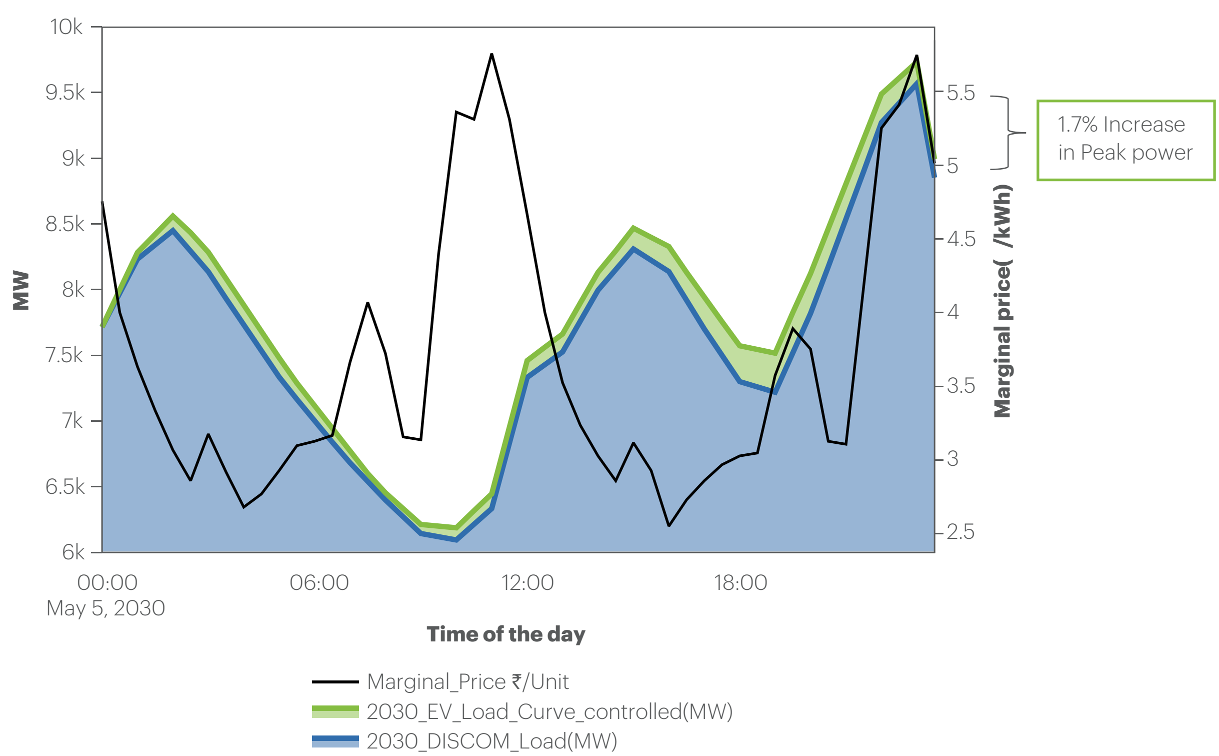

Figure 35 Impact of level of control in reducing the system peak

The increase in this ratio, as observed in Figure 36 and Figure 37, shows that the reduction in the number of chargers simultaneous being used results in EV users delaying EV charging to late night or early morning hours of the day, thereby reducing the peak by slightly less than 40 MW.

Scenario 4:

The percentage of the total EV charging that takes place at the public charging stations and commercial spaces like offices can significantly influence the load shape due to EV charging. In this section, two scenarios are analysed and compared to assess the potential in promoting both public and office charging.

Scenario 4a: Prominent home charging

Percentage of Home /Office /Public charging: 90%:5%:5%

Ratio of chargers to EVs: 1:4

Percentage of Control: 40%

This is an extreme case where negligible charging takes place during office hours which loosely corresponds to hours with solar PV generation available and the charging concentrates in the early hours or during evening peak hours. Figure 38 shows the results for the same.

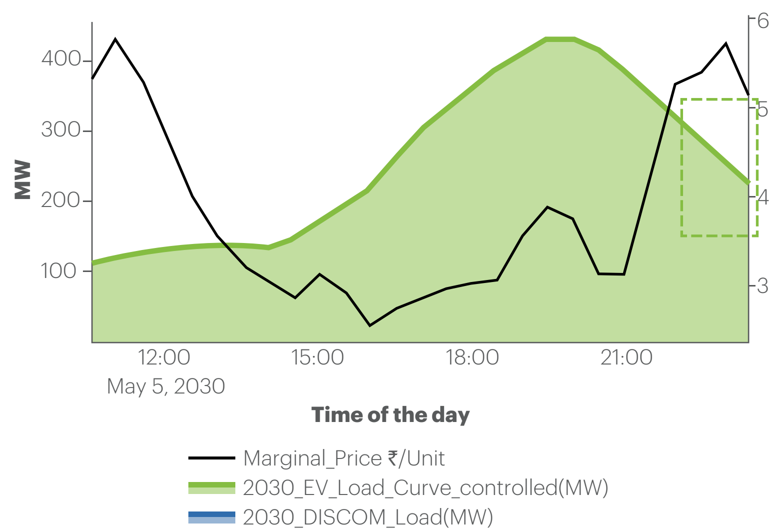

Figure 36 Aggregate EV charging load with 4:1 EV to charger ratio

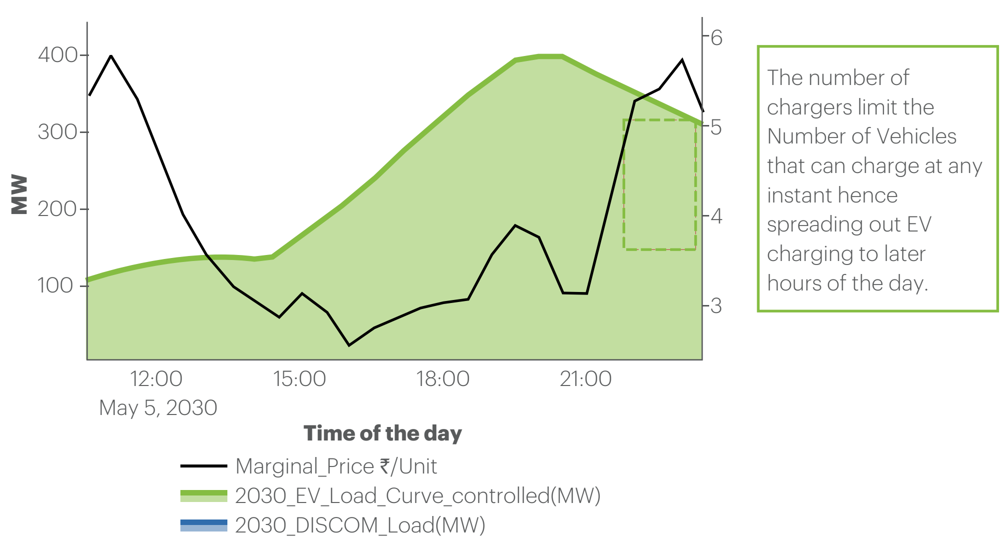

Figure 37 Aggregate EV charging load with 10:1 EV to charger ratio

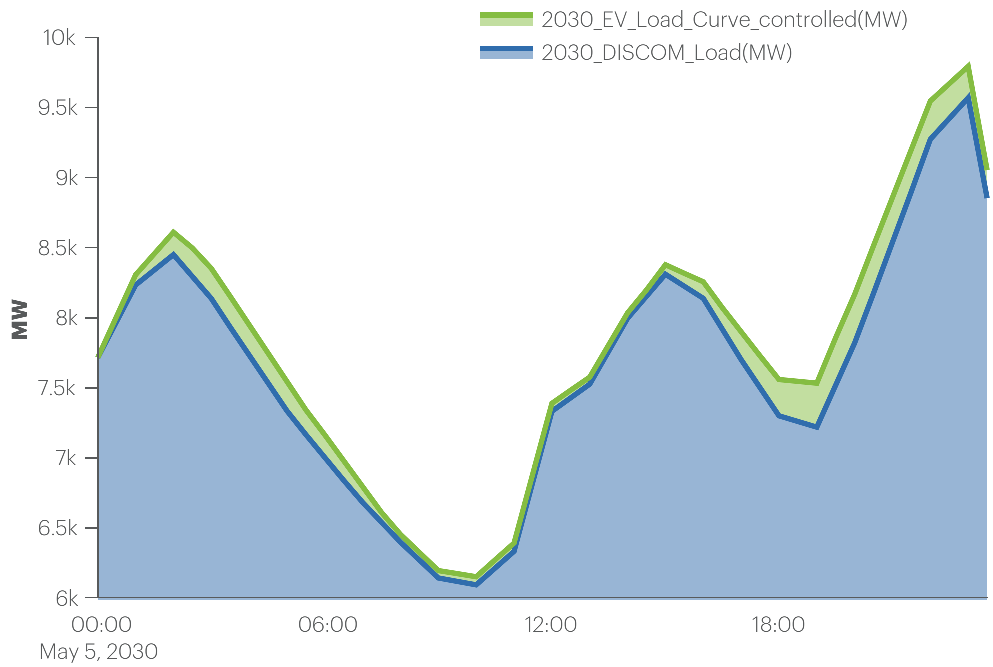

Figure 38 Aggregate EV and system load with predominant home charging

Scenario 4b: Promoting public charging

Percentage of Home /Office /Public charging: 40%:40%:20%

Ratio of chargers to EVs: 1:4

Percentage of Control: 40%

The approximate percentage of charging taking place during solar hours in this scenario is approximately 42%. In this scenario, the load factor also improved as compared to the previous case. Figure 39 shows the results for the same.

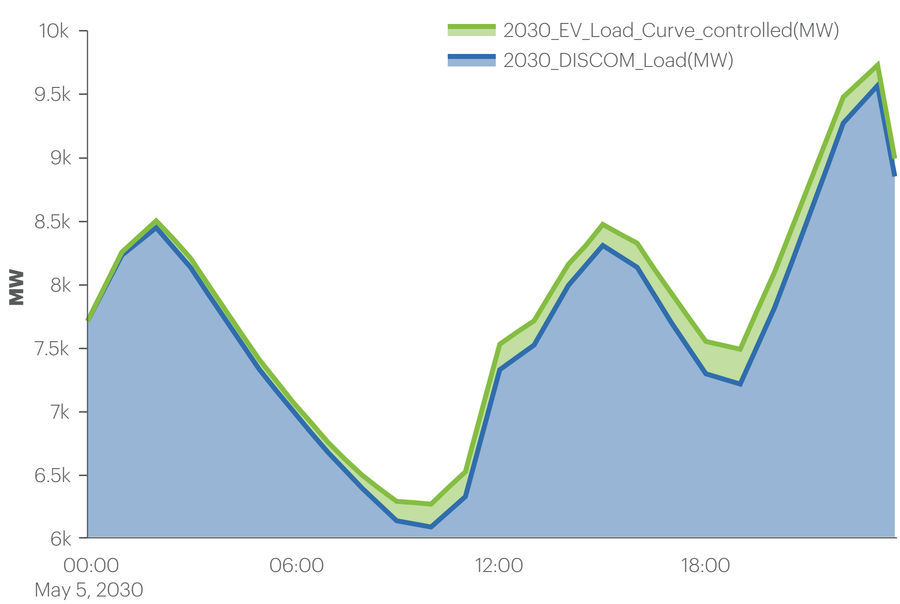

Figure 39 Aggregate EV and system load with predominant public/office charging

ANNEXURES C.

FRAMEWORK FOR MODELLING THREE-WHEELER OPERATION (USING BATTERY SWAPPING)

1. Background

Delhi has a huge network of electric three-wheelers known as E-Rickshaws that mostly provide last mile connectivity to passengers of public transport services such as DTC buses and DMRC metro railway. However, this segment of vehicles is rather unorganized leading to erratic charging pattern. These type of vehicles – CNG and electric rickshaws – operate largely around public places like DTC bus stops and metro stations and, hence, battery swapping system maybe relevant for this segment. The MoP has also recognized battery swapping as one of the charging methods. As per a notification released on 8 June 2020[27], the MoP highlighted the role of Battery Swapping Stations (BSS) where any electric vehicle can get its discharged battery or partially charged battery replaced by a charged battery as part of the said amendment in the revised 'Guidelines and Standards for Charging Infrastructure for Electric Vehicles'. Also, as per the 'New Retail Fuel Policy Guidelines'[28], the new retail outlets should have one alternate fuel-generation station like EV-charging or swapping station. However, the operation of a BSS and the impact of charging its batteries on the distribution network need to be studied. With insufficient insights available on battery swapping models in India, this study attempts to showcase possible impacts of the same on the city distribution network level.

2. Modeling and Simulation Approach for Battery Swapping Stations

2.1 Modelling Framework

In the first phase, prospective vehicle types which would be catered by Battery Swapping Station (BSS) are identified and their specifications such as range, battery size, average speed and mileage have been taken from manufacturer datasheets. The technological advancements till the future year have been considered and the specifications have been taken accordingly.

As part of the modeling assumptions, each battery in a swapping station can have only three possible states: fully charged, partially charged, and discharged. Only one battery of capacity depending on the vehicle type was involved for each swapping operation for modeling convenience. It is assumed that each swapping operation takes 3 minutes on average. Also two different combinations of chargers to battery has been assumed in this simulation study a) 1:2 C/B b) 1:3 C/B. These scenarios would identify which operation would show business as use (BAU) for charge point operator while showing less impact on distribution network.

27 Details available at https://powermin.nic.in/sites/default/files/webform/notices/Amendment%20in%20Revised%20Guidelines.pdf

28 Details available at https://pib.gov.in/PressReleasePage.aspx?PRID=1601706

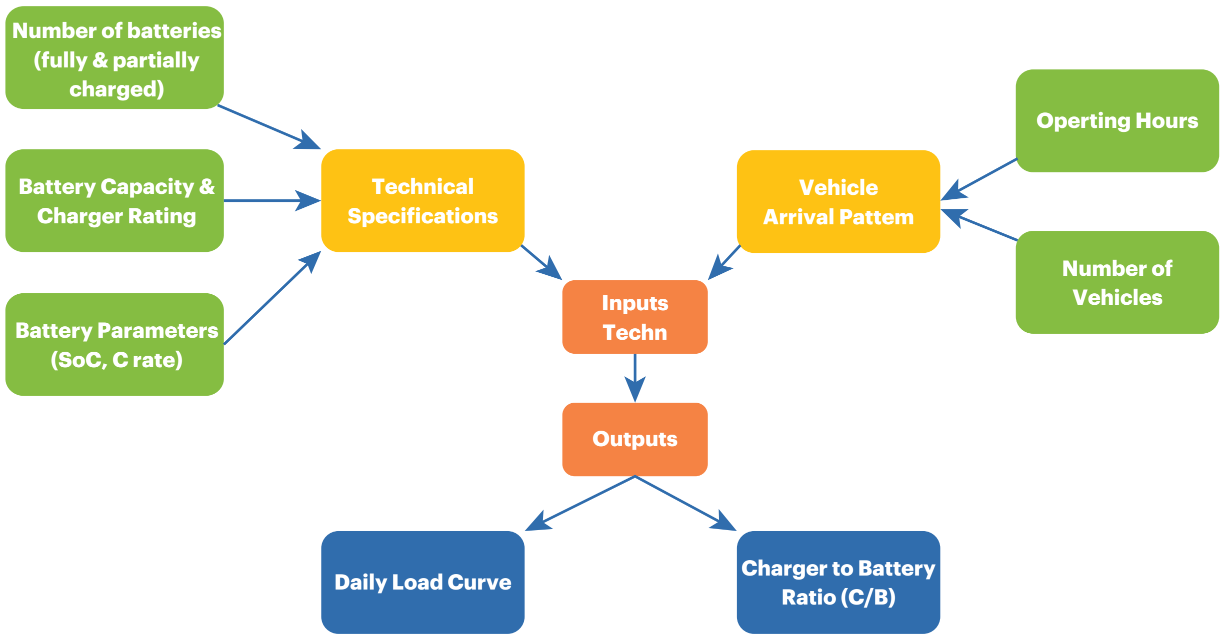

Figure 40 Input assumptions and outputs results of modeling framework

We consider two vehicle categories: electric rickshaw (E-rickshaws) and electric autos (3W) and only 60% of them will undergo battery swapping operation in 2030. The following assumptions are taken in account while creating vehicle pattern for the simulation:

a) E-rickshaws are daily-bound vehicles that run commercial operations on a fixed route having a fixed trip length and almost a fixed number of trips; hence, their source and destination points are fixed.

b) For E-autos, the source may be fixed but the destination depends on the route they take, the range left, and the time of the day.

The capacity of batteries considered is based on vehicle type such as 2.8 kWh for E-rickshaw and 4.5 kWh for E-auto. The bulk chargers have multiple charging slots to charge the batteries kept at a station and the number of charging slots will be less than the number of batteries. Each swapping station has one dock for all vehicle types, so a sequential operation will occur where all the vehicle types will line-up in a queue and one swapping operation will involve only one vehicle at a time. Parallel swapping operations are also possible; however, there are limited cases presently. The assumptions given in Table 14 shows the details used during simulation.

Table 14 Assumptions for Battery Swapping System (BSS) Operation in Modelling study

Technical Specification	E-rickshaw	E-auto (3W)
Number of total batteries (at each station)	60	60
Battery capacity (kWh)	2.8	4.5
Charger rating (kW for each batteries)	1.5	4.5
Number of fully charged	40	40
Number of partially charged	20	20
Chargers to battery ratio (Scenario 1)	1: 2	1:2
Chargers to battery ratio (Scenario 2)	1:3	1:3
C rate	0.5C	0.5C
SOC initial	0.25	0.25
SoC final	0.95	0.95
Average Trip Length (km)	10	20

The daily operation at each battery swapping station and their vehicle arrival follows as probability distribution curves using Monte Carlo simulation method. In the case of E-rickshaws, they are expected to operate for 16 hours, in parallel to DMRC operational hours, and the running time will last for 5 hours after each swapping operation. The E-autos are expected to operate for 24 hours but the probability of arrival at a swapping station will be less during the night time. E-autos operate in three shifts of 8 hours each and would cross the swapping station at least once in a day.

2.2 Generation of Load Curve Patterns from Battery Swapping (BS) Operation

The battery swapping operational model framework has been depicted as a sequential-operation diagram in Figure 41. The most important objective of a BSS is to keep batteries fully charged whenever required for swapping and accordingly the number of batteries to be kept in reserve and the total number of batteries and chargers have to be defined judiciously in view of the number of vehicles expected to be served by a BSS. The proposed model for BSS operation has been divided into one-day operation, split into half-hourly interval operation.

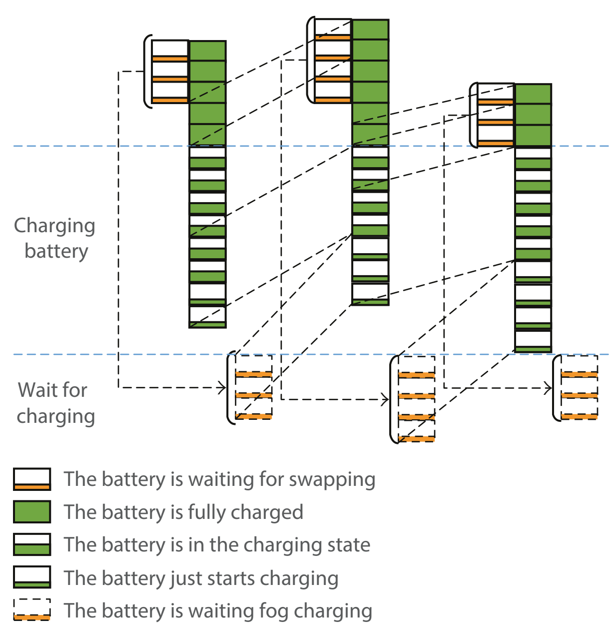

Figure 41 Schematic of battery swapping station operational model

3. Results

In this section, we discuss the results from the battery swapping modelling framework as discussed in the previous section. Figures 42 and 43 show the power demand due to coordinated/uncoordinated charging of batteries for e-rickshaws and e-autos for Delhi in 2030 for different chargers to battery ratios: 1:2 (Scenario 1) and 1:3 (Scenario 2). The simulation results show that coordinated charging reduces the load on distribution system during peak hours, load shifted to off-peak hours, and the overall charging cost reduced for BSS owners. The results show that with Scenario 2 (with less number of chargers), energy requirement is reduced and the peak demand is reduced by approx. 20% with coordinated charging. The coordinated charging is done in day-ahead scheduling based on the time of the day (ToD) tariff (DERC tariff order) (assuming there will be same peak/off-peak time slots in 2030 similar to current peak/off-peak timings).

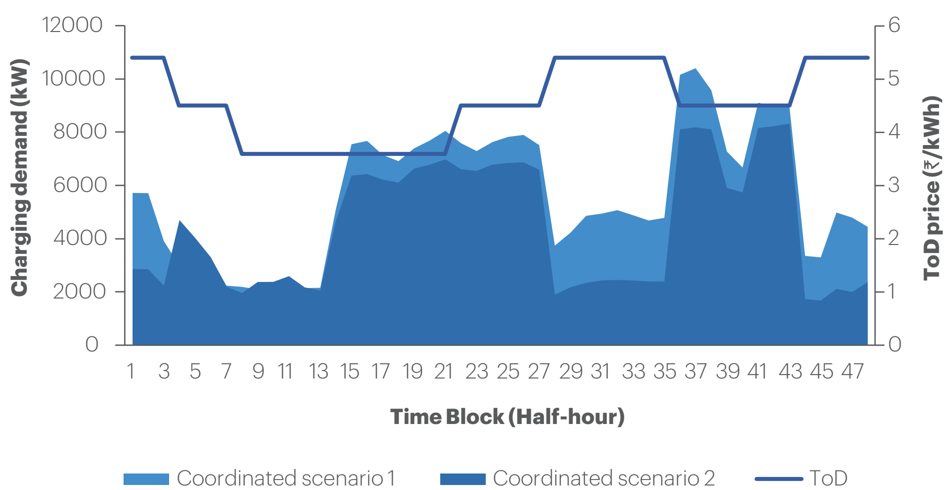

Figure 42 Power demand due to coordinated charging

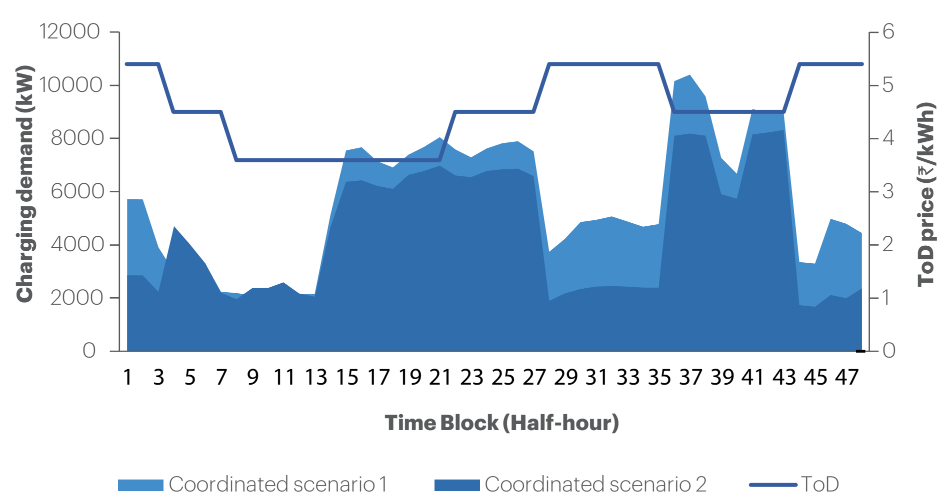

Figure 43 Power demand due to uncoordinated charging

ANNEXURES D.

CHARGING PROTOCOL AND COMMUNICATION STANDARDS

Standardization is the key to updating the EV technology as per evolving features and requirements and to benchmark functionalities as per specific electricity systems in various geographical regions. The key global standards are recognized by various standardization or standard-making organizations/ groups for overall safety of charging stations, EVSE safety, connectors, communication between EV–EVSE, and vehicle to grid (V2G) functionality. The details on all these EV–EVSE-related standards are listed in Table 15.

Table 15 Major EV charging standards description

Category	Standard name	Description	Coverage
EVCS	IEC 61851-1	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.	Power supply input and output characteristics, environment conditions, protection against electric shock, description of charging modes and their functions, communication between EVSE and EV, communication between EVSE and management system, conductive electrical interface requirements, requirements for adaptors, cable assembly requirement, EV supply equipment constructional requirements and tests, overload and short-circuit protection, automatic reclosing of protective devices, etc.
	IEC 61851-21-1	Electric vehicle conductive charging system - Part 21-1 electric vehicle onboard charger EMC requirements for conductive connection to AC/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).	General test conditions, test methods and requirements, immunity of vehicles, immunity of electromagnetic radiated RF-fields and pulses on supply lines, emission test conditions, emission of harmonics and voltage changes, high frequency conducted and radiated disturbances, etc.

Category	Standard name	Description	Coverage
	IEC 61851-23	Electric vehicle conductive charging system - Part 23: DC electric vehicle charging station It 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 1000 V AC and up to 1500 V DC according to IEC 60038.	Rating of the supply AC voltage, general system requirements and interface, protection against electric shock, connection between power supply and the EV, specific requirements for vehicle coupler, charging cable assembly requirements, EVSE requirements, specific requirements for DC EV charging station, communication between EV and DC EV charging station, etc.
	IEC 61851-24	Electric vehicle conductive charging system – Part 24: digital communication between a DC EV charging station and an electric vehicle for control of DC charging This part together with IEC 61851-23, applies to digital communication between a DC EV charging station and an electric vehicle (EV) for the control of DC charging, with an AC or DC input voltage up to 1000 V AC and up to 1500 V DC for the conductive charging procedure.	System configuration, digital communication architecture, charging control process, overview of charging control, exchanged information for DC charging control, etc.
	GB/T 18487.1- 2015	Electric vehicle conductive charging system. Part 1: general requirements	Charging system general requirements, communication protection against electric shock, vehicle and power supply interface, EVSE construction and performance requirements, overload and short circuit protection, etc.
	GB/T 18487.2- 2001	Electric vehicle conductive charging system AC/DC electric vehicle charging Station	Standard conditions for operation in service and for installation, rating of AC input and DC output voltages and current, general test requirements, functions, electrical safety, dielectric insulation test, environment tests, specific connector requirements, communication between EV and DC charging stations, etc.

Category	Standard name	Description	Coverage
	ISO 17409	Electrically propelled road vehicles - connection to an external electric power supply - safety requirements	Environment conditions, requirement for protection of persons against electric shock, protection against thermal incident, specific requirements for the vehicle inlet, plug and cable; additional requirement for AC electric power supply; additional requirement for DC electric power supply, operational requirements and test procedures.
EVSE	IEC 61140	Protection against electric shock - common aspects for installation and equipment	Protection against electric shock, elements of protective measures, provisions for basic protection, fault protection, enhanced protective, protective measures, coordination between electrical equipment and protective provisions within an electrical installation, special operating and servicing conditions, etc.
	IEC 61000-6-2	Electromagnetic compatibility (EMC) – Part 6-2: generic standards - immunity standard for industrial environment	Performance criteria, conditions during testing, product documentation, applicability, measurement, uncertainty, immunity test requirements, etc
	IEC 61000-6-3	Electromagnetic compatibility (EMC) – Part 6-3: generic standards - emission standard for residential, commercial and light-industrial environments.	Conditions during testing, product documentation, applicability, emission requirements, measurement uncertainty, application of limits in tests for conformity of equipment in series production, compliance with this standard, emission test requirements, etc
AC charging and connectors	IEC-62196-2 (normal + high power)	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 It applies to plugs, socket outlets, vehicle connectors and vehicle inlets with pins and contact-tubes of standardized configurations, herein referred to as accessories	provisions, resistance to ageing of rubber and thermoplastic material, construction of socket outlets, connectors and vehicle inlets, insulation resistance, temperature rise, breaking capacity, flexible cables and their connection, mechanical strength, current carrying parts and connections, creep-age distances, resistance to heat and fire, corrosion and resistance to rusting, conditional short circuit current withstand test, EMC, resistor coding, etc.

Category	Standard name	Description	Coverage
	IEC 60309-1	Plugs, socket-outlets and couplers for industrial purposes - Part 1: general Requirements It applies to plugs and socket-outlets, cable couplers and appliance couplers, with a rated operating voltage not exceeding 690 V DC or AC and 500 Hz AC, and a rated current not exceeding 250 A. It is primarily intended for industrial use, either indoors or outdoors.	Standard rating, marking and dimensions, electric shock protection, earthing provisions, resistance to ageing of rubber and thermoplastic material, construction of outlets, plugs, connectors and inlets, insulation resistance, temperature rise, breaking capacity, flexible cables and their connection, mechanical strength, current carrying parts and connections, creepage distances, resistance to heat and fire, corrosion and resistance to rusting, conditional short-circuit current withstand test, electromagnetic compatibility, etc.
	IEC 60309-2	Plugs, socket-outlets and couplers for industrial purposes — Part 2: dimensional interchangeability requirements for pin and contact-tube accessories. It applies to plugs and socket-outlets, cable couplers and appliance couplers with a rated operating voltage not exceeding 1000 V, 500 Hz and a rated current not exceeding 125 A.	Standard rating, marking and dimensions, electric shock protection, earthing provisions, resistance to ageing of rubber and thermoplastic material, construction of outlets, plugs, connectors and inlets, insulation resistance, temperature rise, flexible cables and their connection, mechanical strength, current carrying parts and connections, creepage distances, resistance to heat and fire, corrosion and resistance to rusting, conditional short-circuit current withstand test, electromagnetic compatibility, etc.
	SAE J 1772 (Type 1)	SAE Electric Vehicle Conductive Charge Coupler It is also known as a "J plug", is a North American standard for electrical connectors for electric vehicles maintained by the SAE International.	General conductive charging system description, control and data, general EV and EVSE requirements, coupler requirements, etc.
	GB/T 20234.2- 2015 AC	Connection set for conductive charging of electric vehicles - Part 2: AC charging coupler Electric vehicle connection set - AC charging coupler	General requirements, function definitions, rated values of AC charging coupler, functions of charging coupler, parameters and dimensions of AC charging coupler for conductive charging of electric vehicles, etc.

Category	Standard name	Description	Coverage
DC charging and connectors	IEC-62196-3 (normal + high power)	Dimensional compatibility and interchangeability requirements for DC and AC/DC pin and contact-tube vehicle couplers Intended for use in electric vehicle conductive charging systems which incorporate control means, with rated operating voltage up to 1500 V DC and rated current up to 250 A, and 1000 V AC and rated current up to 250 A.	Connection between EVSE and EV, design and construction of socket outlets, plugs, vehicle connectors, vehicle inlets, interlocks, earthing, protection against shock; insulation, resistance, normal operations, temperature rise, breaking capacity, cables and connections, distances, EMC, short circuit test, etc.
	GB/T 20234.3-2015	Connection set for conductive charging of electric vehicles - Part 3: DC charging coupler This part is applicable to vehicle coupler in charging mode 4 and connection mode C, of which the rated voltage shall not exceed 1,000 V (DC) and the rated current shall not exceed 250 A (DC).	General requirements, function definitions, rated values of DC charging coupler, functions of vehicle coupler, parameters and dimensions of DC charging coupler for conductive charging of electric vehicles, etc.
Vehicle to grid Standard	ISO 15118-1	Road vehicles – vehicle to grid communication interface - Part 1: general information and use-case definition It specifies terms and definitions, general requirements and use cases as the basis for the other parts of ISO 15118. It provides a general overview and a common understanding of aspects influencing the charge process, payment and load levelling	Requirements for communication concept, user specific, OEM specific, utility specific, start of charging process, communication set-up target setting and charging scheduling, end of charging process, etc.

Category	Standard name	Description	Coverage
	ISO 15118-2	Road vehicles – Vehicle to grid communication interface - Part 2: network and application protocol requirements	Basic requirement for V2G communication, service primitive concept of OSI layered architecture, security concept, V2G communication states and data link handling, data, network and transport layer, V2G transfer protocol, V2G message definition, V2G communication session and body element definitions, V2G communication timing, message sequencing and error handling, etc.
	ISO 15118-3	Road vehicles – vehicle to grid communication interface - Part 3: physical and data link layer requirements	System architecture, EV and EVSE system requirements, connection coordination, plug-in phase for EV and EVSE side, loss of communication for EV and EVSE side, plug-out phase, timings and constants, EV – EVSE matching process, EMC requirements, signal coupling, Layer 2 interfaces, etc.
	ISO 15118-4	Road vehicles – Vehicle to grid communication interface - Part 4: network and application protocol conformance test	Test architecture reference model, platform and SUT adapter interfaces, test suite conventions, test case descriptions for 15118-2 V2GTP, SDP messages and V2G application layer messages
Other Vehicles related safety	ISO 6469-4	Electrically propelled road vehicles – Safety specifications - Part 4: post-crash electrical safety It specifies safety requirements for the electric propulsion systems and conductively connected auxiliary electric systems of electrically propelled road vehicles for the protection of persons inside and outside the vehicle.	Applied crash test procedures, electrical safety requirements, electric shock protection, protection against overcurrent, RESS electrolyte spillage, test conditions, test procedures for electrical safety, test procedures for RESS electrolyte spillage, etc.
	ISO 26262	Road vehicles – functional safety It is intended to be applied to electrical and/or electronic systems installed in "series production passenger cars" with a maximum gross weight of 3500 kg. It aims to address possible hazards caused by the malfunctioning of electronic and electrical systems.	It is a risk-based safety standard where the risk of hazardous operational situations is qualitatively assessed and safety measures are defined to avoid or control systematic failures and to detect or control random hardware failures or mitigate their effects.

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