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NITI Aayog

Report 4

Recommendations for Seamless Adoption of EV Charging Infrastructure in India

Integration of Electric Vehicles Charging Infrastructure with Distribution Grid: Global review, India's Gap Analysis and Way Forward

Led by IIT Bombay

FSR Global Regulatory Knowledge Hub

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Recommendations for Seamless Adoption of EV Charging Infrastructure in India

Integration of Electric Vehicles Charging Infrastructure with Distribution Grid:
Global review, India's Gap Analysis and Way Forward

Acknowledgement

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FOREWORD

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FOREWORD

With the second-largest road network in the world, India's road transport contributes towards nearly 64% of the country's overall goods movement and caters to around 90% of India's total passenger traffic. This provides a huge opportunity to decarbonize the transport sector but there are also challenges. Government of India has taken proactive measures towards fostering a clean, connected, shared and cutting-edge transportation system by providing policy and regulatory support.

As India embarks on this ambitious journey towards sustainable mobility, a robust charging infrastructure will play a pivotal role. It must be understood that sector coupling between the energy and transport sectors is vital for e-mobility. With the growing number of EVs, the need for development of large network of charging infrastructure will only increase in the future. To support deployment of charging infrastructure in the country, the Government of India has allocated a total fund of INR 1000 Crore under the FAME II scheme. Under public procurement, Department of Heavy Industry (DHI) has sanctioned 2,636 EV Charging Stations, in 62 cities across 24 States/UTs and 1,544 such stations on highways under FAME II scheme. EV charging is a delicensed activity in India and the Ministry of Power (MoP) has published revised guidelines for Charging infrastructure for Electric Vehicles to facilitate the deployment of charging infrastructure. Apart from this, several states have announced targets for EV deployment including special EV tariff to incentivize EV charging in India. For the uptake of EV adoption in India, a major challenge of integrating the charging infrastructure with the electrical network needs to be tackled. The continued development of EV charging infrastructure and its integration will depend, among other things, on policy and regulatory environment, which must also account for grid stability.

I am glad to know that the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) has initiated a study focused on EV charging infrastructure, related policy and regulatory measures, grid integration of EVs, critical international review from eight countries, and way forward for smooth integration of EV charging infrastructure with the Indian grid.

I congratulate GIZ for the publication of this report.

(Amitabh Kant)

Place- New Delhi
Dated- July, 2021

FOREWORD

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Subhasis Chaudhuri, Director
शुभाशिस् चौधुरी, निदेशक

FOREWORD

At the COP21 conference in Paris in 2015, India targeted to reduce its carbon footprint for every dollar of economic output by 33 to 35% within 2030 from what it was in 2005. The transportation sector being one of the largest consumers of oil and gas and emitters of greenhouse gases globally, need to be addressed on a priority basis. Fuelled by reducing manufacturing and component prices of equipment and improving the affordability of personal vehicles, India has seen a rise in on-road automobiles. Naturally, the transportation sector in India is one of the largest consumers of crude oil and a significant source of GHG emissions, even from an international standpoint. In 2013, the National Electric Mobility Mission Plan (NEMMP) 2020 was envisioned with a vision and roadmap for faster adoption of hybrid and electric vehicles and boosting indigenous manufacturing to achieve national fuel security and mitigate the adverse environmental impacts of road transport vehicles. Government of India further brought out the ambitious Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme to promote electric mobility in the country. The first phase of the scheme (FAME-I) began in 2015 and was extended till 2019, following which the second phase (FAME-2) began which has recently been extended till 2024. The initiatives being taken also have a broader plan to de-license the charging infrastructure business and mandate specific guidelines and standards for charging infrastructure for electric vehicles. This would further strengthen the market of public charging infrastructure and warrant a roadmap for the development of charging infrastructure. Although the Government has taken decisive steps towards faster adoption of EVs, several challenges and gaps are existing in the Indian EV ecosystem that needs to be addressed.

The Nationally Determined Contribution-Transport Initiative for Asia (NDC-TIA), a joint project of seven organisations, on behalf of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and with the engagement of China, India, and Vietnam is a welcome action. The project aims to promote a comprehensive strategy to decarbonising transport, i.e. a coherent system of effective policies coordinated among various sector ministries, civil society, and the private sector.

IIT Bombay is committed to playing a constructive role in achieving green and sustainable electrified transportation sector in the country. This specific study, "*Integration of Electric Vehicles Charging Infrastructure with Distribution Grid: Global review, India's Gap Analyses and Way Forward*", which is led by IIT Bombay, focuses on EV charging infrastructure, related policy and regulatory measures, grid integration of EVs, and the way forward for smooth EV adaption in the Indian EV ecosystem.

I would like to congratulate the authors, all the stakeholders involved, the reviewers, and the funding agencies contributing to the successful preparation of these reports.

(Subhasis Chaudhuri)

Date: 02.08.2021
Place: Mumbai

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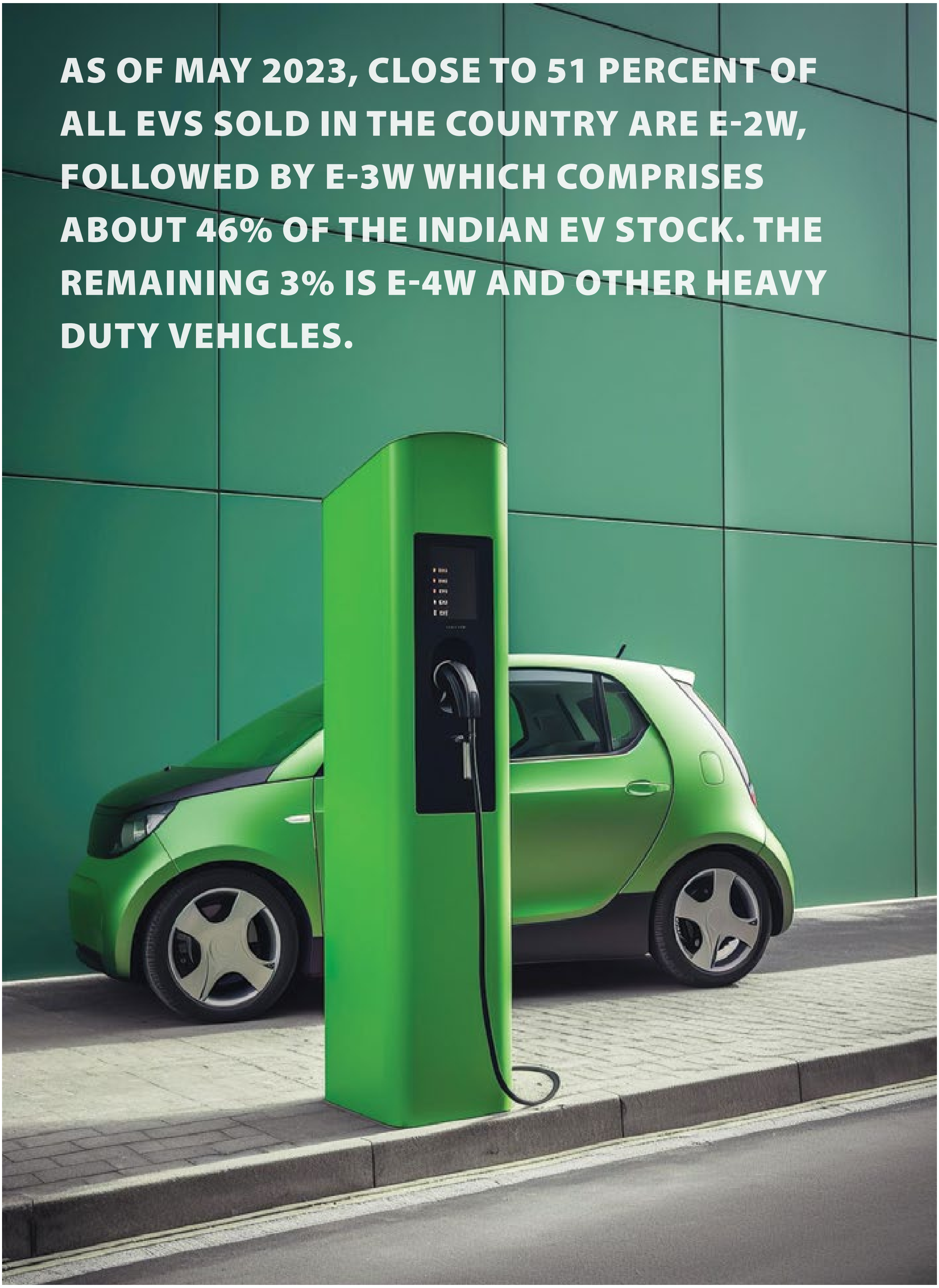

AS OF MAY 2023, CLOSE TO 51 PERCENT OF ALL EVS SOLD IN THE COUNTRY ARE E-2W, FOLLOWED BY E-3W WHICH COMPRISES ABOUT 46% OF THE INDIAN EV STOCK. THE REMAINING 3% IS E-4W AND OTHER HEAVY DUTY VEHICLES.

01 Introduction

In India, EVs represent currently a small share with approximately 25 lakh vehicles by the end of May 2023 (0.75% of the total registered vehicles). However, more than 30% of new vehicles are expected to be electric vehicles by 2030. India by the end of May 2023, has over 340 million vehicles, dominated by 2-wheelers which account for 75% of the total vehicles registered[1]. Amongst the different vehicle segments, public buses, taxi fleets, 2-wheelers and three-wheelers are expected to be the first adopters of EVs. As of May 2023, close to 51 percent of all EVs sold in the country are e-2W, followed by e-3W which comprises about 46% of the Indian EV stock. The remaining 3% is e-4W and other heavy duty vehicles. Since the country is at an early stage of EV adoption, public charging infrastructure is still limited. A number of states have started introducing policies to promote EV adoption and charging infrastructure deployment, and as of May 2023, a total of 25 states/UTs have notified their final EV policies, while 3 States/UTs have released draft EV policies. The rapid growth in EV uptake required to reach India's policy targets will have to address two major challenges. The first challenge is ensuring the deployment of the charging infrastructure required to serve the needs of the ever-growing number of EVs. The second challenge is the integration of the EVs into the power system securely and efficiently. The success of the EV revolution hinges primarily on the timely deployment of effective EV charging infrastructure. However, at the same time, EV adoption is the main driver for the business case of EV charging infrastructure. Policy and regulation, informed by a thorough understanding of the EV charging ecosystem, can offer solutions to this chicken-and-egg problem.

Although the e-mobility plan is developed at the central level, the onus is on the state governments, which have to develop and implement policies and regulatory frameworks to enable the adoption of EVs and deployment of charging infrastructure in their respective states. Thus, considering India's federal structure as well as the wide variance in the social-geographic and economic variances between states, a one-size fits all approach cannot be applied (an example being the use of informal form of transportation in varying social geographies). The development of adequate charging and power system infrastructure to support the uptake of EVs would rest upon state-specific

1 VAHANSEWA, "DASHBOARD," Ministry of Road Transport & Highways, 2021, https://vahan.parivahan.gov.in/vahan4dashboard/vahan/view/reportview.xhtml.

Deployment of adequate EV charging infrastructure, which is one of the most critical factor for seamless adoption of EVs, is limited by various challenges, including technical, policy and regulatory issues. In order to mitigate the challenges, this study identifies the key mitigation measures that can be undertaken to accelerate the growth of EV charging infrastructure in India.

policy, regulatory measures, and effective implementation of such policy and regulatory interventions, with effective support and leadership by the central government.

Deployment of adequate EV charging infrastructure, which is one of the most critical factor for seamless adoption of EVs, is limited by various challenges, including technical, policy and regulatory issues. In order to mitigate the challenges, this study identifies the key mitigation measures that can be undertaken to accelerate the growth of EV charging infrastructure in India. Further using a scientific methodology, the study identifies, ranks in terms of priority, and analyses the key technical and policy/regulatory interventions required for seamless development of EV charging infrastructure in India.

1.1 Study overview

The Nationally Determined Contribution – Transport Initiative for Asia (NDC-TIA) is part of the International Climate Initiative (IKI), which is working under the leadership of the Federal Ministry for Economic Affairs and Climate Action, in close cooperation with its founder, the Federal Ministry of Environment and the Federal Foreign Office. It is a joint project of seven organizations and with the engagement of China, India, and Vietnam. The organizations partnering with GIZ on this project are World Resources Institute (WRI), International Council on Clean Transportation (ICCT), International Transport Forum (ITF), Agora Verkehrswende, REN21 and SLOCAT. For the India component of the NDC-TIA project, the implementing partner is the National Institution for Transforming India (NITI Aayog).

Under the NDC-TIA India Component, we have an ongoing study "Integration of Electric Vehicles charging infrastructure with distribution grid: Global review, India's gap analyses and way forward" which is focused on conducting Indian and International review on overall environment related to EV charging. This study is carried out by consortium led by IIT Bombay along with Florence School of Regulation (FSR), Technical University Denmark (DTU), Cardiff University and Universidad Pontificia Comillas.

This specific study focused on EV charging infrastructure, related policy and regulatory measures, grid integration of EVs, and way forward for smooth EV adaption in Indian EV ecosystem. The study developed a framework along with the inputs from a detailed critical international review on EV charging infrastructure development and its grid integration from different EV rich countries. The developed framework has been used as a basis for identifying gaps and scope for improvement in EV charging infrastructure adoption at the national level and in the states. The study, based on a combination of desk research, surveys, bilateral consultations with stakeholders, and consolation workshops, has been used to identify and recommend national and state specific interventions that can be sandboxed for the use by regulators, policy makers, DISCOMS, and other stakeholders, and later adopted statewide.

1.1.1 Aim of the Study

The aim of this study was to conduct a detailed study with high impact/quality reports that can supplement decision making by the Government of India including State Governments, distribution system operators, transmission system operators, planning and regulatory agencies and other stakeholders (EV industry etc.) to frame, adapt, and/or revise policies, regulations, technical charging standards, communication protocols related to the integration of EV charging infrastructure with distribution and the transmission grid.

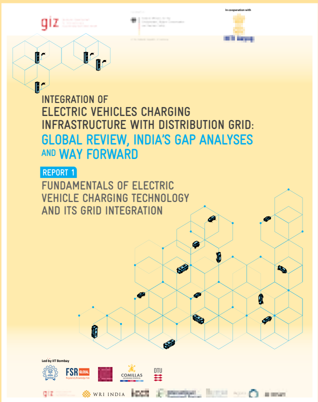
1.1.2 Objectives of the Study

A detailed study was conducted based on critical analysis of international experience on EV charging infrastructure and its grid integration from different EV rich international countries (besides India) with the main thrust on the following points:

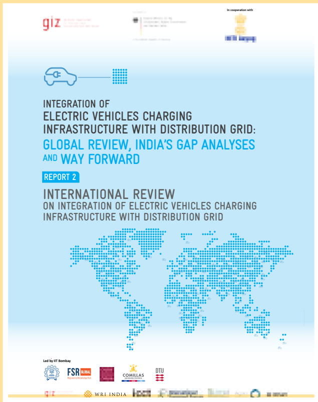
- Planning and operation of distribution grid with integration of EV charging infrastructure
- Grid support services from electric vehicles to facilitate large-scale renewable energy integration
- Technologies and standards for EV charging infrastructure's integration with distribution grid
- Policies and regulations for EV charging infrastructure and integration with distribution grid
- Identifying the key challenges and recommendations for efficient, effective and sustainable integration of EV charging infrastructure in India

1.1.3 Organisation of the Study Reports

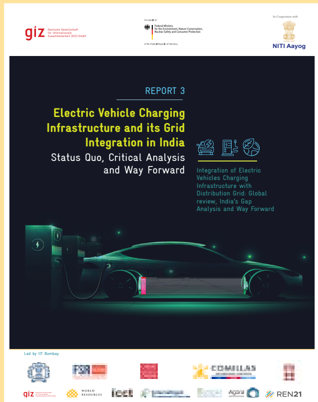
The outcome of this study is documented in a series of four technical reports. The four reports listed below cover different aspects of EV integration in a structured manner for effective, organised, and easy dissemination of the study outcome.



Report-1: Fundamentals of Electric Vehicle Charging Technology and its Grid Integration
(Link to download,
Link to download from NITI Aayog Website)



Report-2: International review of Electric Vehicle Charging Infrastructure and its Grid Integration
(Link to download,
Link to download from NITI Aayog Website)



Report-2: Electric Vehicle Charging Infrastructure and its Grid Integration in India: Status Quo, Critical Analysis and Way Forward
(Link to download,
Link to download from NITI Aayog Website)

Report-4: Recommendations for Seamless Adoption of EV Charging Infrastructure in India

1.1.4 Scope of the Report

This specific report is the fourth and final report of this study, which documents the final outcome of the study. The main focus of this report is on the recommendations for seamless adoption of EV charging infrastructure in India, which includes, technical, regulatory and policy measures for the key stakeholders of Indian EV ecosystem. The methodology adopted in arriving the final set of key recommendations is based on scientific approaches along with the inputs from the key stakeholders and backed by detailed techno-economic analysis of the proposed key interventions. One of the crucial aspects of the recommendations, particularly from the implementation point of view by the implementing agencies, is to adequately identify the order of the key interventions in which they need to be prioritised for effective achievement of the target goal. In this report, the recommended key interventions have been ranked based on multicriteria approach through a robust scientific method while considering realistic factors with the inputs from the field experience obtained through different modes. Different criteria, such as, impact on EV charging infrastructure growth, the effort needed for its execution, its impact on the cost of EV charging and its benefits to the overall EV ecosystem are among various factors considered in the final ranking of the recommended key interventions. Moreover, based on experience and critical analysis of various EV charging tenders floated globally and in India, this report also provides recommendations for the framing Request for Proposals (RfPs) and tenders for EV charging infrastructure development. Since the Indian EV market is presently dominated by electric 2W, 3W and 4W (e-cars), the main focus of this report is on these passenger vehicle segments. E-buses and heavy-duty trucks are not the focus of this report.

02 Challenges and potential counter measures in EV charging infrastructure adoption

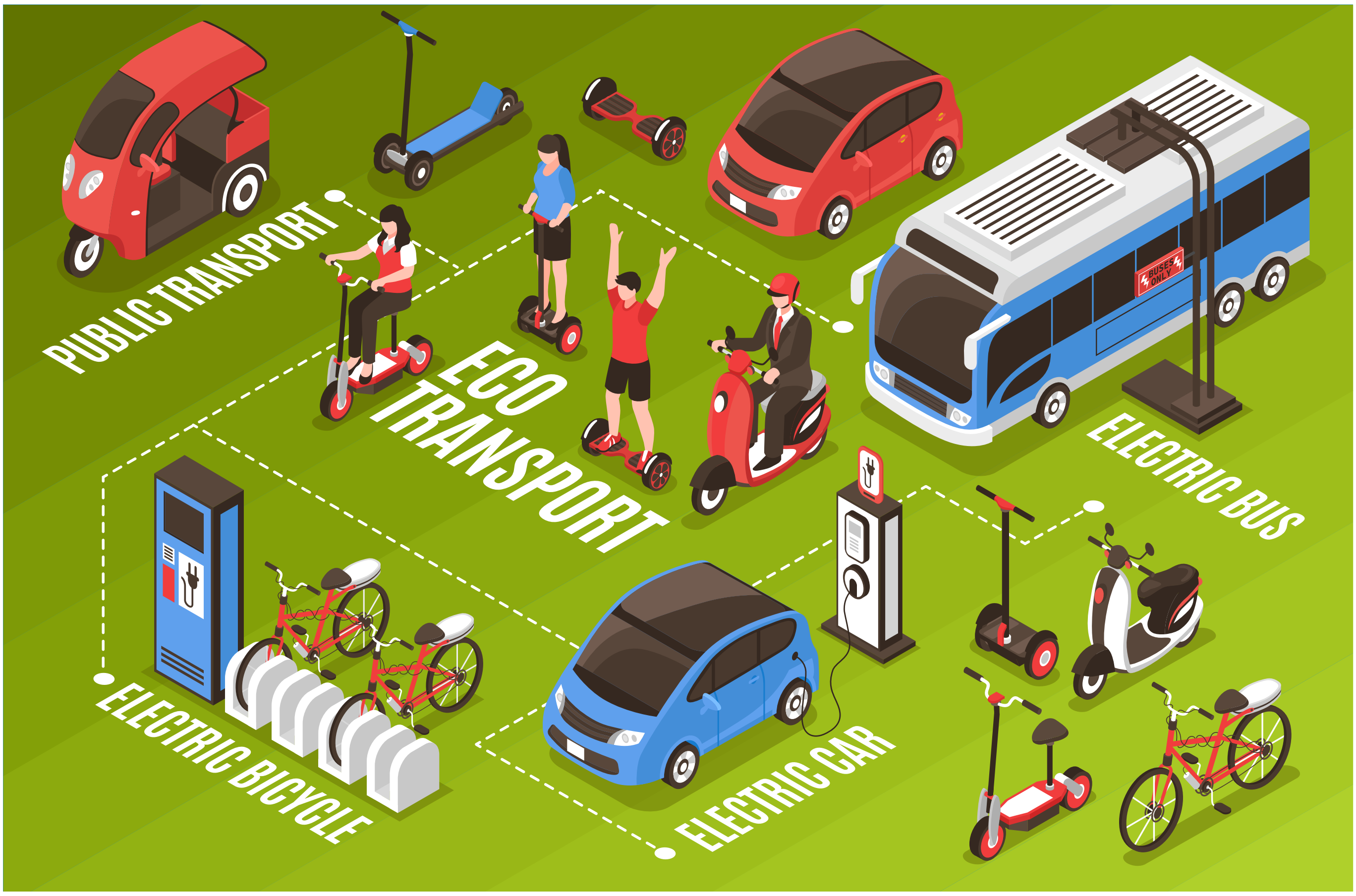
There are multiple key gaps and challenges slowing down the adoption of EV charging infrastructure in the country. While the efforts by the central and state level governments have certainly helped the EV ecosystem to gather a good momentum, there is a need to address various challenges and further develop EV charging infrastructure and improve its grid integration. The detailed analysis of the existing gaps and challenges in the Indian EV Ecosystem have been provided in Chapter 9 of Report-3: Electric Vehicle Charging Infrastructure and its Grid Integration in India: Status Quo, Critical Analysis and Way Forward, here we have provided a summary of the different gaps. This is then followed by potential countermeasures that can address the mentioned gaps and challenges.

2.1 Challenges in EV adoption

2.1.1 Challenges in policies for EV charging infrastructure development

The central and state governments in India have rolled out different schemes and policies to help the growth of EV charging infrastructure in the country. However, the following are critical challenges in this regard.

- While Department of Heavy Industries (DHI), through the FAME scheme have sanctioned 2877 charging stations till June 2021, with subsidies, these were primarily awarded to Public Sector Undertakings (PSU) or other government agencies.
- The allocation of chargers under the FAME scheme were not optimally distributed based on the existing EV market among the different states .
- The subsidies provided for charging infrastructure development is primarily allocated for high powered chargers used for electric 4wheelers, while the subsidy for vehicle purchase are mainly geared towards subsidy for 2W and 3W. There is a mismatch between the subsidies provided for the segment-wise EV demand and the corresponding subsidies for the EV charging infrastructure, which needs to be addressed.
- Residential EV charging is one of the critical requirements to make eMobility a success. However,



for people residing in residential welfare societies and apartments, installation of charging units in the common areas may be opposed by the building management. While the building bye-law amendment guidelines have been in place since 2019, they are yet to be adopted/implemented by the State Governments.

- The lack of financial support to battery swapping is a major challenge, when it comes to developing of the swapping infrastructure in the country.

Potential Countermeasures	Reference Sections
Long-term mobility strategies and effective cooperation between the different ministries, government organizations, municipal and civic bodies along with the private stakeholders would be required.	Section 2.2.1 and Section 2.2.2

2.1.2 Challenges in integration of the EV charging infrastructure with the Distribution Network

As the number of EVs in the country grows, considerable number of EV chargers are expected to be connected to the distribution network, which can introduce different challenges for the grid operator as mentioned in Report-1: Fundamentals of Electric Vehicle Charging Technology and its Grid Integration. Indian distribution networks which are already generally highly loaded with aging infrastructure, high penetration of EV chargers may further reduce the reliability of the network. The IT infrastructure in the DISCOMs also would need significant investment in order to seamlessly integrate the EV charging infrastructure of the future.

In addition to policies, the lack of adequate regulations for EV charging has also hampered the widespread deployment of EV charging infrastructure. Experience on RE integration has proven beyond doubt that adequate grid code regulations introduced at right time played an instrumental role in successful integration of RE in majority of RE rich countries. Therefore, taking an inspiration from the journey of RE integration so far, it is important to plan adequate grid code regulations for EVs for seamless adoption in Indian electricity grid.

Potential Countermeasures	Reference Sections
Careful planning of the charging infrastructure would be needed.	Section 2.2.3 and Section 2.2.7
Funds for grid upgradation should also be allocated in the EV policies	Section 2.2.14

Potential Countermeasures	Reference Sections
Design of adequate grid codes for utilization of EVs for grid support services should be investigated	Section 2.2.5
Adequate tariffs, use of RE for EV charging and implementation of smart charging could also alleviate the issues with grid integration of EVs	Section 2.2.10, 2.2.6 and 2.2.11
EVs could also be used to potentially help support the grid, through different ancillary support services	Section 2.2.13

2.1.3 Challenges in developing adequate charging infrastructure

Majority of the urban population of India, particularly metro cities, reside in multi-unit dwellings with lack of private parking space for every dweller. Even for the limited number of parking spaces in apartments, it will be difficult for the EV users to install an EV charger while supplying electricity from his/her the contracted home electrical connection. Effective planning of charging infrastructure location, the charger technology based on the expected category of EVs is imperative. A significant hurdle in the 2W and 3W segment in India is the lack of standard connector types. Beyond 2W, 3W and 4W EV segments, the charging infrastructure requirement for the buses and heavy duty vehicles (trucks etc.) also needs to be taken into consideration.

Potential Countermeasures	Reference Sections
Proper planning of the charging infrastructure is critical.	Section 2.2.3
Ensuring interoperability among the different chargers can increase the usable charging infrastructure for the EV users while at the same time increasing the revenue earning opportunity for the CPO. This would however require extensive cooperation between the different players involved.	Section 2.2.9

2.1.4 Challenges in communication infrastructure

The effectiveness of the EV ecosystem is highly dependent on the effective communication between the different involved entities. Communication infrastructure is required for smooth integration of EVs with all functionalities like roaming, smart charging etc. The disregard of roaming facilities may be a cause of concern for the EV users owing to the limited choice for charging while travelling. Also, communication between DISCOM and CPO/eMSP is required for smart charging as well as for demand response services. However, the communication infrastructure is largely lacking in India.

Potential Countermeasures	Reference Sections
For effective utilization of the charging infrastructure the presence of communication infrastructure and interoperable hardware is imperative.	Section 2.2.8 and 2.2.9
The grid codes can also play a part here by regulating the requirement of a minimum level of communication between the grid operators with the charging infrastructure.	Section 2.2.5

2.1.5 Challenges in Smart Charging

Under high EV penetration, simultaneous charging of large fleet of electrical vehicles will undeniably put stress on the electrical grid. Smart charging is an innovative technology to reduce the overloading of DTs and defer the network augmentation, and this technology is already in place in many EV rich countries. One of the simple approaches for implementation of smart charging is the utilization of a Time of Use/Time of Day tariff. However, baring a few states, time-based tariffs for EV charging is not present in India. Other active forms of smart charging, such as, charging control due to operating conditions of the distribution grids require more hardware and communication infrastructure. There needs to be smart grid infrastructure, which in some specific applications may need monitoring of the operating conditions, such as voltage levels, loading on transformers and cables, stability limits of voltage and frequency etc.

Potential Countermeasures	Reference Sections
To introduce smart charging in India, the simplest option is to introduce time-based EV tariffs by the different state electricity regulatory bodies.	Section 2.2.10
For implementation of communication based smart charging, the communication standards needs to be developed and implemented.	Section 2.2.8 and 2.2.11

Potential Countermeasures	Reference Sections
Investment needs to be made on the upgradation of the metering and communication of electrical distribution infrastructure and make the system future proof.	Section 2.2.14 and 2.2.12

2.1.6 Limited revenue opportunities and challenges for public EV charging

EV Charging infrastructure in India is in its nascent stage, and the public utilities have taken the lead to expand this network. Though a few private players have entered the market, their current penetration into the EV charging network is still quite limited. One of the issues of private EV charging players in the market is the long breakeven period. Considering the high upfront cost of establishing a charging infrastructure, it restricts the number of able participants competing in the EV charging market. Also, the lack of a single window clearing system, significantly delays the installation process. Getting the necessary approvals is a time-consuming process making it challenging for a private CPOs to make progress.

Potential Countermeasures	Reference Sections
CPOs need to adequately plan their charging infrastructure based on the location and the expected users.	Section 2.2.3 and 2.2.4
By ensuring interoperable chargers and unlocking eRoaming, the CPOs can increase their customer base.	Section 2.2.9
Further to increase the profit margin, the CPOs can also go for increased use of RE, while the electricity regulators can provide custom tariffs and waive off the demand charges and other surcharges for EV charging during the initial growth years	Section 2.2.6, 2.2.10, 2.2.15

2.1.7 Unavailability of land in suitable locations

In Indian urban localities, there is generally a lack of publicly available land. Most of the available land is under the ownership of state-run offices, municipalities and other public authorities. Currently, there is not any specific scheme or procedure through which the private EV charger installers can purchase/lease these spaces.

Potential Countermeasures	Reference Sections
Novel instruments, through which the land owned by the different government organizations could be lent to the CPOs, would go a long way in alleviating the issue of land availability in urban locales.	Section 2.2.16
DISCOMs should provide a publicly available data of headroom available for its distribution assets, which would enable CPOs to properly plan their charging infrastructure.	Section 2.2.7

2.1.8 Limited EV market and lack of training and capacity development for EV workforce

One of the major barriers to the growth of the EV charging infrastructure is the limited EV market. EV charging station owners have a low margin of profitability as they are generally only paid for the energy use which is a low gain revenue stream. To maximize the profitability of EV charging stations, the usage of the EV chargers in the charging stations need to be high, which would only be possible under high EV penetration level. Also, adequate skilled manpower is necessary to bring parity between EV and ICE vehicles in terms of satisfactory service provision.

Potential Countermeasures	Reference Sections
For widespread adoption of EVs, the general public needs to be educated of the different benefits of EVs. This requires extensive knowledge dissemination through different channels including mass communication, incorporation of EV courses in educational institutes etc, and making the public more accepting of sustainable living in general.	Section 2.2.18

2.1.9 Challenges in implementation of V2X

V2X application of EVs has a lot of potential to benefit to the entire EV ecosystem and the energy sector at large. However, in India there are a myriad of challenges for the widespread proliferation of V2X implementation.

- Lack of EV and EV chargers with bidirectional capability
- Absence of regulation grid integration of V2G
- Absence of regulations for aggregation of EVs with DERs

- Metering issues
- Customer trust and preference

Potential Countermeasures	Reference Sections
While EV ecosystem is still at the nascent stage in India, there is need of planning for future EV technologies. This requires framing policies and regulations that appreciate the incorporation of V2X technologies, developing the communication infrastructure, developing an advanced energy market where EVs can act as prosumers and help provide different services to the grid.	Section 2.2.1, 2.2.8, 2.2.12, and 2.2.13

2.1.10 Lack of an advanced energy market

The transition to electrification of transportation sector has been envisaged with the goal of carbon emission reduction. To realize this, the energy used for EV charging should be delivered from clean, renewable energy sources, as the transition would be debatable if the emission is just shifted from the demand side (vehicles) to the generation side (fossil fuel based thermal generating stations). To integrate RE into EV charging, efficient electricity markets can play a key role. In India, energy is still largely traded through long term bilateral Power Purchase Agreements (PPA)s. Only around 6% of total electricity in India is traded in the power exchanges. Also, to integrate higher penetration of RE into the system as a whole, there is need of ancillary services, that can be provided by a range of different players including prosumers such as EVs.

Potential Countermeasures	Reference Sections
Adequate regulations need to be developed by the respective electricity regulatory authorities, that can increase the energy traded through energy markets instead of bilateral long-term contracts. These regulations should also identify EVs as viable resources that can participate in the energy markets	Section 2.2.17
Enabling ancillary services from EV would require regulatory, technical, and administrative interventions. These interventions should clarify the details of implementation of the required services and assign the roles to the different stakeholders involved.	Section 2.2.13

2.2 Potential Countermeasures

2.2.1 Importance of long-term mobility strategies

The responsible agencies should develop a long-term mobility strategy. This strategy should include both the expected growth of EV and also the planned rollout of charging infrastructure. The preparation of such mobility strategy would require forecasting on

1. Urban planning including the amount and types of parking spaces
2. Changes in vehicle fleets
3. Changes in traffic flows
4. Technological developments (e.g. Battery size, charging capabilities etc)

2.2.2 Importance of cooperation

Public authorities should aim at coordinated and possibly uniform strategies at regional/local levels involving different responsible stakeholders/agencies . For example, in Germany there are bi-annual meetings between the representatives of the Federal States organized by the Federal Ministry of transport along with the central transport coordination centre and the National Centre for Recharging Infrastructure to discuss the requirement of charging infrastructure. Similarly, in Netherlands the Dutch Ministry of Infrastructure and Water in collaboration with both public and private stakeholders defined goals and actions for the deployment of the charging infrastructure.

2.2.3 Charging infrastructure

Since most of the residents in metro cities reside in multi-storeyed apartments with limited capacity of installation of residential charging stations, availability of PCS is expected to largely dictate the growth of the EV market. Further, these PCS need to be configured with mostly moderate/fast chargers and rapid DC chargers .

Charging facility can be broadly categorized into four different types of charging stations,

Rapid: These charging stations would be mostly deployed alongside highways, in existing fuel stations and designated rapid charging zones.

Destination: Such type of charging stations would be installed at destination sites, such as office area, market spaces, restaurants, hotels etc. It is expected that the user would spend at least more than 1 hour in these locations.

Residential: These charging station would be installed in the residential areas where the cars may be parked overnight or for significantly long periods. These are particularly important for areas with high density residential buildings.

Private: Private owned chargers that are installed in the property of a private owner.

Charger types recommended for each category of charging station is provided in Table 2.1.

Table 2.1: Categories of charging infrastructure

Charging Station Category	Typical Formats	Charger type	Accessibility
Rapid	❖ Rapid charge hubs ❖ Fuel stations ❖ Public transportation depots	❖ ≥50 kW fast DC chargers with CCS/ CHAdeMO (predominant) ❖ 22 kW fast AC chargers with Type 2 connectors (remaining)	Public
Destination	❖ Office spaces ❖ Public car parks ❖ Urban centres ❖ Leisure areas ❖ Hotels/restaurants	❖ 22 kW fast AC chargers with Type 2 connectors (predominant) ❖ ≥50 kW fast DC chargers with CCS/ CHAdeMO (a small percentage) ❖ AC001 chargers/ Standard 15 A sockets (remaining)	Public/semi public
Residential	❖ Lamp posts ❖ Kerb-side chargers ❖ Dedicated charging zones	❖ ≤22 kW AC chargers with Type 2 connectors (predominant) ❖ Standard 15 A sockets (remaining)	Public
Private	❖ Home ❖ Workplace	As per user requirement	Private

In California, it was found that 20% of EV owners switched back to ICE vehicles from EVs primarily due to the inconvenience of charging. The refuelling of normal ICE vehicles is quick as the entire tank can be filled in roughly 3-5 mins, for a range of around 300 km. However, in an EV, a vehicle charging for an hour using slow chargers would be able to provide around 5 km of range. Of the people who switched back to ICE vehicles in California, it has been found that 70% of them lacked access to fast Level 2 charging [2] .

2.2.4 Location of PCS

Optimal location of PCS is a critical factor for effective and better utilisation of charging infrastructure. It is recommended that for optimization of location of PCS the following factors should taken into consideration,

- Forecast of EV growth in the area- The locations with forecasted high EV demand should be prioritized for scaling up the charging infrastructure
- Forecast of mobility in the area – The areas with higher traffic flow should be given priority.
- Headroom availability in the distribution feeder – The available headroom in the distribution feeder should be considered while selecting the optimal location for placement of PCS
- Presence of nearby utility or activity (like restaurants, market spaces, etc) - Location of PCS nearby to other locations of leisure and activity are preferable.
- Adequate land availability at relatively cheaper prices is expected to play a key role in selection of PCS location

2.2.5 Grid Code Requirements

Grid connection requirements for PCS connection need to be developed adequately for safe, secure and stable grid operation, and to regulate the operation of EV chargers during periods of grid events, which include,

- The regulations should clearly state the normal voltage and frequency operating zones for the charger. Within this zone, the charger cannot be disconnected from the grid. The regulations should also mention the range of power factor that is allowed for the charger to operate within.
- If the voltage/frequency deviates from the normal operating zones, the regulations need to specify requirement of response characteristics of PCS to the grid event.
- The regulations should also state the requirements for active/reactive power support from the charger, along with the permissible delays.
- The frequency of communication for different signals must also be clarified in the regulations.
- Data set and communication requirements need to be specified.

2.2.6 RE integration and Provision of Open Access

The rooftop PV sector has already witnessed a steady growth in the past few decades in India. It is also highly likely that such type of customers would be relatively early adopters of EVs, or vice versa. Therefore, residential energy management systems can be developed for utilization of in-house generation for EV charging.

To promote the use of green energy for EV charging, the PCS can also be provided with commercially viable RE based EV charging specific Open Access to the transmission and the distribution network. This would enable the PCS to purchase green power from any independent supplier or power distribution company, and reduce the cost of energy for the PCS while increasing the utilisation of renewable energy. Each charging station can also be mandated to purchase a minimum number of Renewable Energy Certificates, particularly when the EV charging business matures, to further the transition to green mobility.

2.2.7 Publication of spare capacities of distribution assets in the public domain

In order for CPOs to plan their charging infrastructure installation, the DISCOMs should provide a publicly available data of headroom available for its distribution assets. This would enable CPOs to properly plan their charging infrastructure deployment strategy without having to consult the DISCOM for every identified potential PCS location. The database would also need to be regularly updated.

In UK, the Western Power Distribution has also released a publicly accessible map showing the available margin at each distribution substation under its jurisdiction as shown in Figure 2.1.

2 Dominick Reuter, "1 in 5 Electric Vehicle Owners in California Switched Back to Gas Because Charging Their Cars Is a Hassle, New Research Shows," Business Insider, April 30, 2021, https://www.businessinsider.in/thelife/news/1-in-5-electric-vehicle-owners-in-california-switched-back-to-gas-because-charging-their-cars-is-a-hassle-new-research-shows/articleshow/82332806.cms.

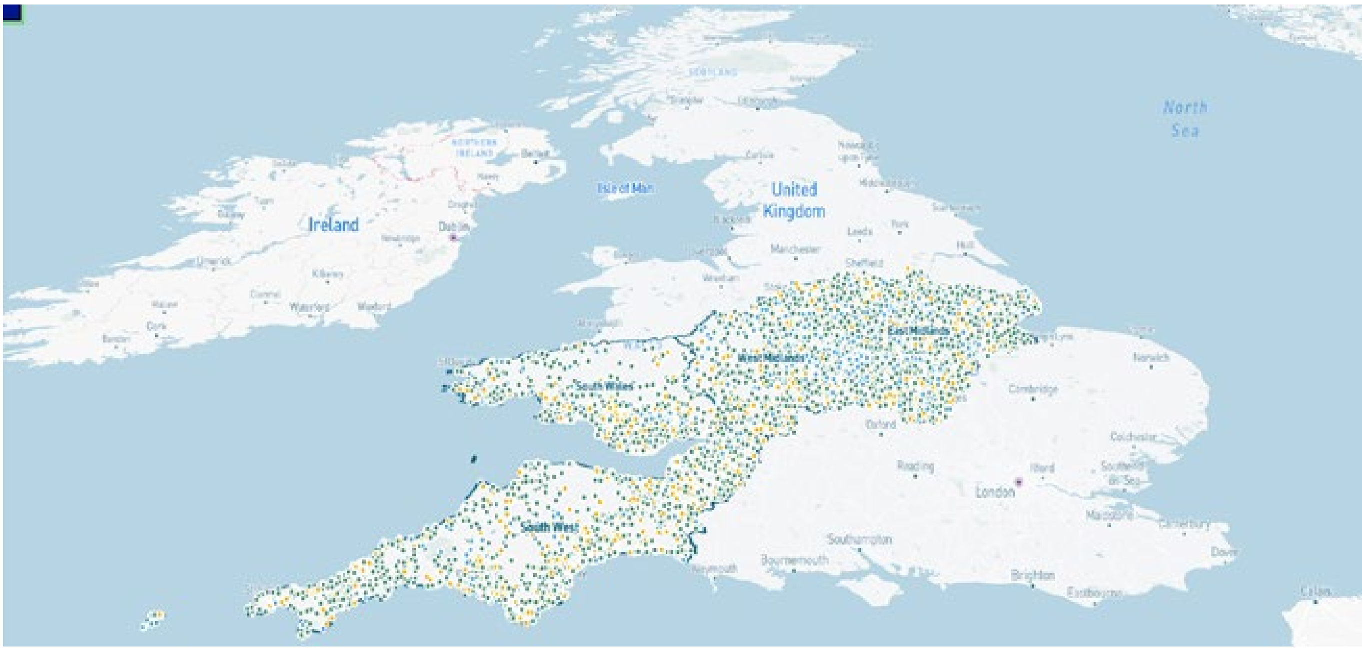


Figure 2.1: Interactive map released by WPD showing the capacity available in each distribution substation for placement of EV chargers [3]

2.2.8 Communication Standards

There should be a standardization of communication protocols to enable the four main communication domains of the EV charging ecosystem for interoperable operation.

EV – Charging point: Currently the IEC 61851 is being followed for communication between the EV and the charger globally. However, it is recommended that to make the ecosystem future proof, the charger should contain the necessary hardware and software elements to support an upgrade to ISO 15118. ISO 15118 would provide the necessary communication between the EV the EVSE to unlock smart charging and bidirectional charging.

Charger – Back-end/ Network Management System: OCPP is currently the dominant protocol for the communication between the charger and the management system in India, however, standardization work is currently ongoing to harmonize OCPP and its functionalities into an IEC 63110 standard. This standard would be backwards compatible to OCPP, the responsible agencies should recommend the use of OCPP with the option to upgrade to IEC 63110.

Roaming – To enable roaming facility, public authorities are may mandate the use of open, platform-independent, non-proprietary protocols, that are free of cost. CPOs should have at least one common communication protocol to enable roaming while not restricting the use of other additional protocols.

Future proofing for grid management – The communication between CPOs, eMSPs, grid operators and other EV aggregators is expected to be harmonized under IEC 61850. So future tenders should require the use of IEC 61850 and allow the use of open data models as per the needs of the CPOs and DISCOMsand DISCOMs.

California has mandated all of its CPOs to at least meet and maintain the “California Open Recharging Point Interface Interim Test Procedures for Networked and Electric Vehicle Supply Equipment for Level 2 and Direct Current Fast Charge Classes”, no later than July 1st, 2021[4].

2.2.9 Interoperability

One of the major challenges in the EV charging ecosystem is the lack of interoperability

2.2.9.1 Hardware interoperability

Hardware interoperability refers to the incompatibility of different charger and connector types. Currently in India, industrial socket as per IEC 60309 is used for Bharat AC001 chargers, GB/T socket is used for DC001 chargers, Mennekes sockets are used for Type 2 chargers, while

3 National grid. “Electric Vehicle Map”, https://www.nationalgrid.co.uk/ev-capacity-map-application

4 CALeVIP, “Guide to California regulations for Electric Vehicle Charging Stations”. https://calevip.org/sites/default/files/docs/calevip/California_EVCS_Regulations_Guide.pdf (Accessed July 2023)

CCS and CHAdeMO also have their own socket types. Of all these, only Mennekes sockets used in Type 2 chargers are compatible with CCS. Such variations in socket types makes it difficult for the CPO's to determine the charger combinations to ensure maximum usability of the charging station. The Alternative Fuels Directive 2014 in the European Union has agreed towards the use of Type 2 connectors for AC charging and use of CCS2 chargers for DC charging[5] .

2.2.9.2 Software interoperability and eRoaming

The standardization of communication between the different actors of the EV ecosystem although facilitates the transactions between them, it does not guarantee their cooperation.. Without such cooperation among CPOs, each EV user may end up with multiple RFID cards for each different EMSP, which will be a nuisance for the EV user, Figure 2.3. In this regard either or both of the following enabling factors can be adopted.

- Mandate CPOs to establish connections with any eMSP who wants to connect to the CPO network, Figure 2.2
- Mandate CPOs to establish a minimum amount of roaming connections (via a clearing house or Peer-to-Peer), Figure 2.2

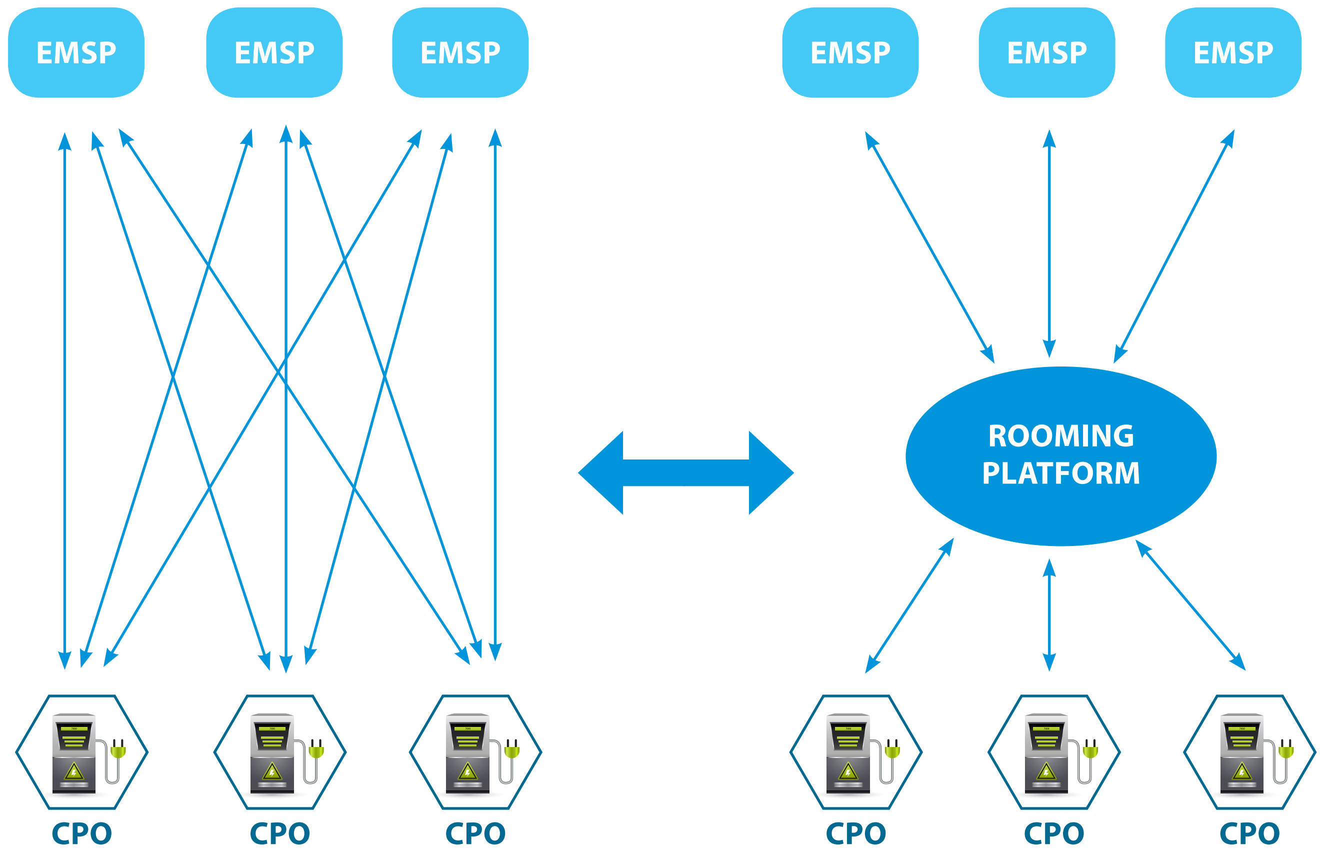


Figure 2.2: Peer-to-peer roaming (left) and roaming via platform (right)

Amsterdam requires a combination of both of the eRoaming types in their tender requirements. The CPO concessionaire must allow third party eMSP access to the charging points to provide services like financial transaction, smart charging etc.

In Berlin, every CPO that operates a recharging point in the public domain must register it in a central authentication platform managed by the city, offering access to the customers of each EMSP under comparable conditions[6].

In Slovakia, within three months of commissioning of a charging point, the CPO must connect to any roaming platform that connect to more than 80 operators[6].

5 Andy Miles, 'Standardization Of EV Charging In The EU', CleanTechnica, Feb 16, 2019. https://cleantechnica.com/2019/02/16/standardization-of-ev-charging-in-the-eu

6 Sustainable Transport Forum, " Recommendations for public authorities on : procuring, awarding concessions, licences and/ or granting support for electric recharginginfrastructure for passenger cars and vans", Dec 2020. https://transport.ec.europa.eu/system/files/2021-06/sustainable_transport_forum_report_-_recommendations_for_public_authorities_on_recharging_infrastructure.pdf

Figure 2.3: Without eRoaming facilities each EV user will have multiple RFID cards for each different vendor which will be highly inconvenient for the EV user[6]

2.2.10 EV tariffs

Most of the states in India have rolled out specialized EV tariffs, but only a few of those tariffs have included a ToD Tariff for EV charging. ToD tariffs can mitigate grid congestion management issues, help in peak shaving, and is one of the simplest methods to enable smart charging. Therefore, it is highly recommended that ToD tariff is implemented for EV charging.

It has also been observed that EV tariffs in a few states lack clarity. For example, the EV tariff for Haryana mentioned a general fixed charge and energy charge without any demarcation on the charges based on whether the charging station is connected to LT supply or HT supply. Further, there are extra hidden charges associated, such as Power Purchase Adjustment Charges (PPAC), Wheeling charge, surcharge etc. The addition of these charges significantly increases the finale price for the CPO, which in turn is reflected in the increased price for the EV users.

Therefore, a consolidated EV charging tariff with clarity regarding the different additional charges incurred is highly recommended.

2.2.10.1 Single-part tariff vs two-part tariff

Another that ned to be considered regarding EV tariffs is the feasibility of single-part tariff over two-part tariff or vice versa. In single-part tariff, the customers are charged based on the energy consumption, while in two-part tariff, the electricity bill comprises of both demand charges and energy charges. The consideration of the type of tariff generally depends on the type of load serviced. For example, for large industrial loads with low load factor[7], the demand charges generally form the bulk of the electricity bill, while for smaller residential loads, the electricity bills are generally based on the electricity consumption. The reasoning behind the higher pricing of demand charges for loads with low load factor is twofold,

- First, the utility needs to set up adequate electrical network infrastructure, which is being highly utilised only during peak periods, however for the other periods, particularly during off peak hours the infrastructure is largely oversized. So, the demand charges to some extent are based on the charges for infrastructure installed by the utility.
- Secondly, low load factor also put added stress on the generation units during peak periods. The higher demand charges, enables the utilities to have extra generation resources securely available to cater to the peak loads.

6 Sustainable Transport Forum, " Recommendations for public authorities on : procuring, awarding concessions, licences and/ or granting support for electric recharginginfrastructure for passenger cars and vans", Dec 2020. https://transport.ec.europa.eu/system/files/2021-06/sustainable_transport_forum_report_-_recommendations_for_public_authorities_on_recharging_infrastructure.pdf

7 Load factor is the ratio of the average load over a period to the maximum demand (peak load). Low load factor implies that the peak demand is much higher than the average demand for the user and vice versa.

Therefore, on long-term basis, the EVs charging stations should be allocated higher demand charges, as their load factors would be typically on the lower side. This would enable the distribution utilities to compensate the added distribution infrastructure, losses etc. needed to cater to the charging load. However, two part tariff with demand charges is likely to impact the business case of CPOs, and result in higher charging prices in the initial phase of EV adoption in the country. Therefore, for the initial few years, to accelerate EV adoption among the masses adoption of single-part tariff is recommended, which should be replaced by two part tariff when the market is matures adequately.

2.2.11 Smart Charging

Smart charging is one of the key enablers to reduce/ potentially avoid/ at least defer the requirement of upgradation of grid infrastructure.

Smart charging capability needs to be mandated/ encouraged/incentivised prior to the rollout of all EV chargers in the market. To enable smart charging, the following functionalities need to be ensured,

- Data storage/handling capacity by CPO
- A meter with the ability to record energy consumption along with synchronised clock based time stamps. This would enable billing as per the time based price. It is preferable that the meter used is a Smart meter specific to EV charging.
- A proportional local load management/control with a calendar feature so that the daily load program can be followed even if the connection to the central charging management service is lost.
- The smart charger should also have the capability of being directly controlled by the relevant distribution network operator. The DISCOM during excessive network demand may use this option as per the contract agreement/regulations to restrict the loading of the smart charger.
- The smart charger should also be capable of adopting a randomized offset to change of load events. This is to ensure that there is no synchronized switching of a large section of customer load in response to a single event.
- As smart charging involves several communication channels, therefore adequate cybersecurity measures needs to be considered.

2.2.12 Future-proof Infrastructure

EV charging technology is relatively a new technology which is rapidly evolving. Since a charging station is likely to be operational for around 10 or more years, charging infrastructure deployment should consider future-proof technologies. This implies, the charging stations should be of the latest possible technology, and it should also be easily configurable to future standards as much as possible, such as

- Higher power chargers to cater to high power capacity and higher energy density batteries.
- Smart charging with bidirectional capabilities
- Grid support services
- In-motion/ electric road charging

2.2.13 Ancillary Services from EV

As EVs are controllable loads with provision for even bidirectional charging, they can technically participate as ancillary service resources. EVs with their fast response times are particularly suited for high power low energy services such as inertial support, primary frequency support, reactive power support etc. Even though they can technically participate in secondary and tertiary reserve markets, the high energy requirement of these services may reduce the energy stored in EV battery, thus impacting the EV user travel needs. EVs are also well suited to provide frequency regulation as they can control their charging current based on the regulation signal from the grid operator.

However, enabling ancillary services from EV would require regulatory, technical, and administrative interventions. These interventions should clarify the details of implementation of the required services and assign the roles to the different stakeholders involved. For example, in order to facilitate ancillary services from EVs, aggregation of EVs would be required to achieve a minimum bid capacity threshold. Smooth functioning of this aggregated EV fleet would require stringent administrative regulations. Further, communication system must be robust to achieve fast relaying of signals for the EVs to respond too, ensuring minimum delays in response time.

As currently being constructed, the only market procured ancillary service in India is the RRAS. In order for EVs, primarily through EV aggregators to provide RRAS service, regulatory interventions are necessary to make

EVs a viable candidate. On 29th May 2021, CERC issued a draft regulation for ancillary services in India. The draft regulation allowed the participation of demand resources, which are connected to inter-state or intra-state transmission system, for provision of ancillary services, specifically Secondary Reserve Ancillary Service (SRAS) and Tertiary Reserve Ancillary Service (TRAS). These resources must, however, be able to provide the required services as per minimum technical requirements set by the system operator. Also, a minimum bid cap has been set at 1 MW. These regulations would open the door for EVs (through aggregators) to provide grid support ancillary services, if allowed to participate at low voltage level.

The requirements for provision of EV participation in ancillary services are given in Table 2.2. Even without V2G provision, EVs can participate in both regulation up and regulation down services by controlling their charging power. With V2G, the available capacity for participation effectively doubles, as shown in Figure 2.4.

Table 2.2: Requirements for EV to participate in ancillary market

Technical requirements	Hardware	Public and private smart charging points
		Smart meters
		Minimum power capacity at aggregator level to participate in market
	Software	Managements software that runs the algorithm to implement smart charging by taking real time inputs from the EVs and the grid condition
	ICT	Interoperable communication protocols for communication across different charger types and entities
		Interoperable standards for communications including hardware requirements
Regulatory requirements	Electricity Market	EVs through aggregators should be allowed to participate in the RRAS
	Financial incentive	Financial benefits to EV users for providing service
EV market structure	Aggregators	Aggregators would be necessary to pool together multiple EV users, thereby increasing the net maximum power capacity.
	VPP	A VPP can also be utilized with EV as a resource and the net VPP can then participate in the electricity market.

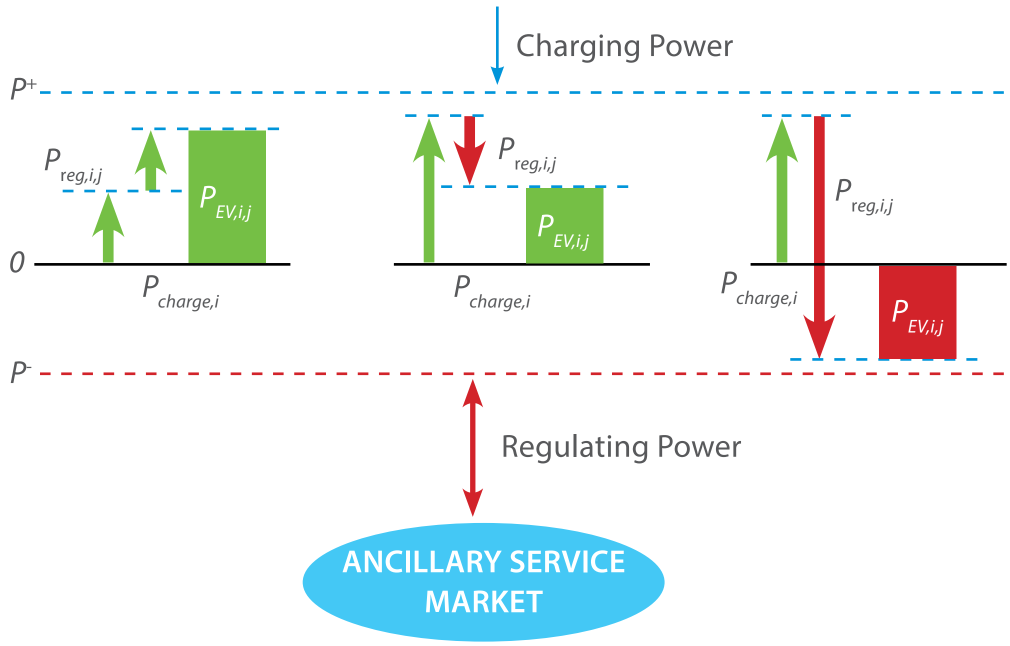


Figure 2.4: Margin availability in EV for provision of ancillary service [8]

8 Zhouyang Wu et al., "Optimal Charging Strategy of an Electric Vehicle Aggregator in Ancillary Service Market," IEEE PES Innovation Smart Grid Technologies Asia, 2019.

EVs can also provide fast response ancillary services such as inertial support and primary frequency reserves, but under current India electricity regulations, inertial support and primary frequency support are mandatory and are not traded in the energy market. In order for EVs to provide these services, regulations are required to make inertial and primary frequency support tradeable in the electricity markets. EVs are also excellent candidates to participate in other ancillary services such as secondary frequency reserve, reactive power support, black start supports etc, but adequate electricity market products are required prior to utilization of EVs into provision of these services.

2.2.14 Allocation of funds in the EV policies for upgradation of grid infrastructure

The FAME II has allocated a total of INR 10,000 crore (1,135.3 million EUR) for development of EV charging infrastructure as well as provide subsidies for purchase of EVs. However, it is recommended that the government should also allot a portion of the budget for development of the distribution network infrastructure. Currently in India any player planning to install a charging station has to generally also pay for distribution grid infrastructure (like transformers, protection devices at the distribution grid side, cables etc) upgradation that would be needed to cater to the EV charging station.

China has redirected its policies towards building of a network of charging stations, while reducing focus on consumer-focused incentives. The state-run grid operator's smart network has already been connected to 90% of all charging stations. China has invested around $300 billion between 2015-2020 for upgradation of the distribution network, which is expected to increase to $900 billion over the next five years. With the investment focus on the distribution network, the cost of installation of chargers has reduced as now the CPO is not expected to pay for added grid upgradation costs. As per a survey in 2019, the cost of installation of an EV charging station in China without subsidies is around $300,000 compared to $600,000 to $1.1 million in the U.S. This reduced cost has attracted more parties to set-up charging stations[9].

2.2.15 Waiving of demand charges and other surcharges for the initial growth periods

The EV tariff that has been set by the different state regulators, have additional charges associated that are generally hidden to a customer, such as wheeling charge, surcharge etc. These charges make the consolidated price

9 Anjani Trivedi, "Biden's EV Infrastructure Plan Should Take a Page From China - Bloomberg," January 16, 2021, https://www.bloomberg.com/opinion/articles/2021-04-15/biden-s-ev-infrastructure-plan-should-take-a-page-from-china?utm_campaign=socialflow-organic&utm_source=facebook&utm_medium=social&utm_content=asia.

of EV charging much higher. In order to make the charging infrastructure business more attractive, the regulators may consider to waive off the demand charges and other charges for the initial stage of EV market growth. This would keep the EV charging price attractive enough for CPOs/investors to install PCS, and the end users in turn will be inclined to charge their EVs in the PCS due to the low cost of charging.

2.2.16 Design of instruments to lease out land occupied by government for setting of charging stations

In India there is a lack of available public spaces, particularly in cities where EVs are likely to grow first. Most of the public spaces are owned by different Government/semi Government offices (for example, state road transport office, Public Works Department, state electricity boards, public sector undertakings etc). An effective instrument needs to be designed that can enable the CPOs to rent these spaces for EV charging infrastructure installation.

2.2.17 Conducive electricity market for EV participation

The participation of EVs in India's power exchanges would be beneficial both from the perspective of the EV user in terms of monetary benefits and from the perspective of the grid operator as it can potentially help in congestion management and load balancing. However, it would not be feasible for individual EVs to participate in the day ahead or balancing markets. So, aggregators of large EV fleets can operate as a VPP and participate in these markets. The necessary regulations would however be needed to be drawn up by the respective regulators. Participation in electricity markets would also be needed to facilitate Demand Side Management from EV fleets.

2.2.17.1 Free Choice of Electricity Supplier

To ensure reduced cost of energy for the end user and bolster the EV market, eventually the end user should have the ability to procure electricity for their EV charging needs based on a supplier of their choice. However, to enable it, adequate regulatory and legal framework would be needed. Further, financial clearing mechanisms through a separate entity from the electricity markets would be needed to balance the electricity supply portfolios as shown in Figure 2.5.

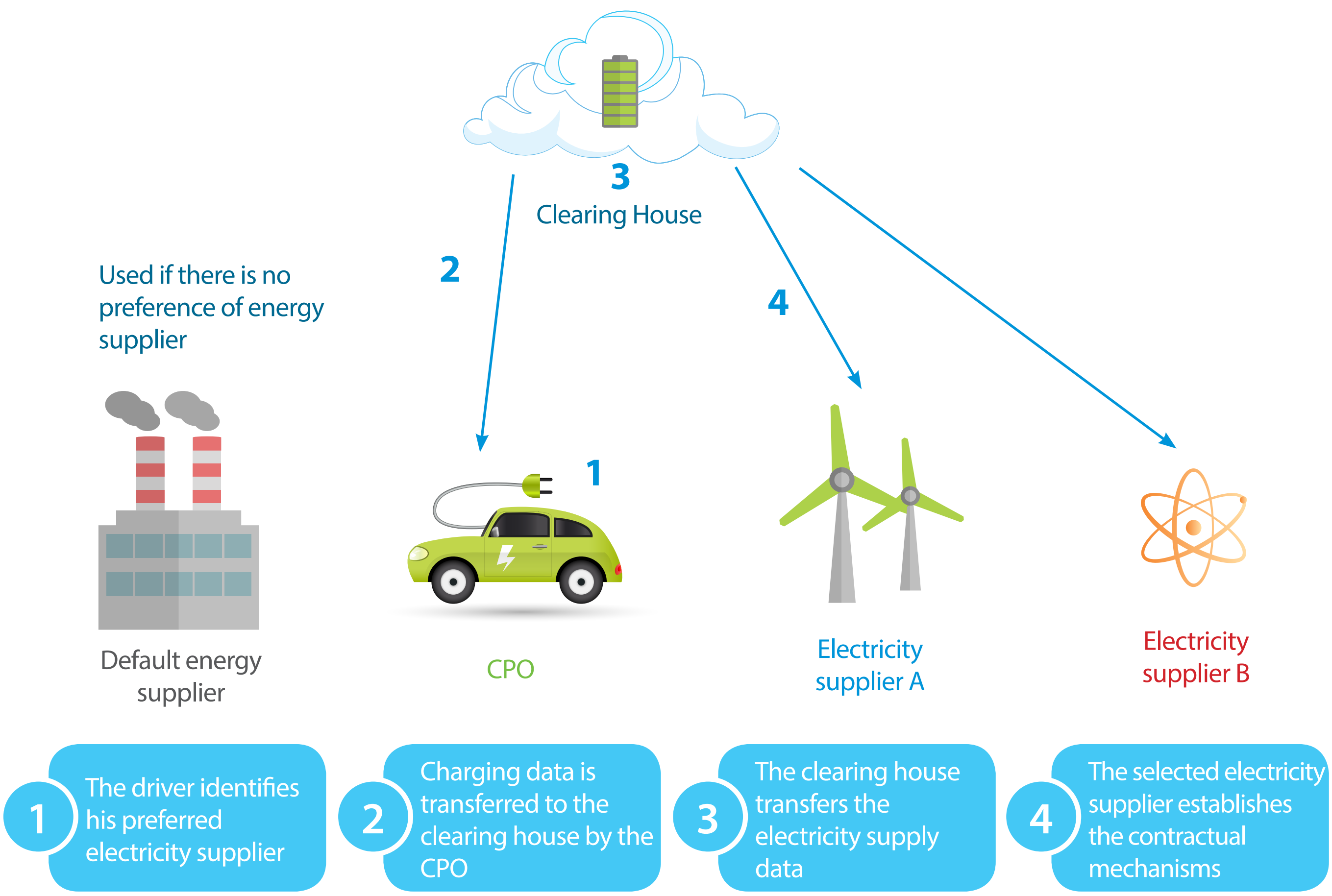


Figure 2.5: Clearing house enabling free choice of electricity supplier to the EV user

2.2.18 Knowledge dissemination

In order to grow the EV market, it is important to create public awareness about different advantages of owning an EV. These awareness campaigns can have different forms as detailed below,

2.2.18.1 Mass Communication

Mass communication includes campaigns targeted for the masses and exposing the general public to the EV ecosystem. Different incentive programs that are currently on offer, can be marketed through these campaigns, so that a larger section of the society is made aware and thus participate in growing the EV market. The impact of EV use on quality of life improvement as well as economic benefits could also be showcased. Different tools such as ad campaigns, posters along highways, parking areas, public websites etc. can be used as a tool for mass communication.

The "Switch Delhi" campaign in Delhi is one such example aimed at creating awareness among the general public about the benefits of electric vehicles, and how it can reduce the air-pollution problem of Delhi. Under the campaign, the Delhi Government has appealed to public to adopt electric vehicles and has also planned various incentives/ subsidy for purchasing electric 2W and 4W, besides waiving off road tax and registration charges for EVs. The Govt. of India and NITI Aayog have also released a portal e-AMRIT to create awareness about electric mobility in India. It serve as a 'one-stop site' to provide all the information related to the adoption of electric vehicles in India.

2.2.18.2 Personal Communication

Here, personalized campaigns are made targeting specific groups of potential buyers such as fleet owners, ride hailing companies, etc. Strategies such as targeted campaigns, electric vehicle demonstrations, EV education etc can be used for this purpose.

2.2.18.3 Education and Skills Training

Awareness can also be raised by providing education and skill-development programs including youth education and advanced degrees on different components of the EV ecosystem. Such skilled labour would strengthen the technology competence in the electric mobility sector. Such training programs can include,

- Developing electric mobility vocational training programs
- Introducing advanced degree and certificate programs
- Introducing electric vehicle driving schools to instruct drivers with the know how to operate advanced electric vehicles.

2.3 Priority of roll-out

Each different measure described above, have their own benefits and challenges. The time frame of incorporation of these measures also vary widely. As such the prioritized list of the measures are given in Table 2.3.

Table 2.3: Priority of deployment of measures

Near Term Priority	❖ Development of long-term mobility strategies ❖ Cooperation among the different Government bodies for decision making on EV charging landscape ❖ Development of charging infrastructure ❖ Enabling interoperability ❖ Knowledge Dissemination ❖ Design of instruments for leasing out of govt. owned land to PCS. ❖ Infrastructure accord given to EV charging infrastructure ❖ Allocation of funds for distribution grid upgradation ❖ Creation of EV tariffs with ToD pricing ❖ Selection of optimal location for PCS
Medium term Priority	❖ ERoaming facilities ❖ Enabling communication based Smart Charging ❖ RE integration for EV charging ❖ Provision of Open Access to PCS ❖ Promotion of shared mobility and mass transit
Long term Priority	❖ Grid support services from EV ❖ Participation of EVs in the Power Market ❖ Free choice of electricity supplier for the EV user ❖ Wireless charging and in-motion charging

03 Tender Recommendations for EV Charging Infrastructure

3.1 Selection of Contract Models

Different contract models can be used to develop the EV charging infrastructure. These contract models are primarily dependent on the maturity of the EV market.

1. The public contract model: In this model the public authority retains control over the charging infrastructure and also takes most of the associated risks. The public authority bears the capital and maintenance cost, and they collect the revenue directly from the customers. For example, the city of Gothenburg in Sweden does not yet have a competitive enough EV market, so as a temporary solution the public authority chose to develop its own infrastructure via a public company. This model in the initial phase of EV adoption, can be useful in providing charging infrastructure to the public and build confidence of CPOs and other players/investors in EV space.

2. The joint-venture model: Under this model both the public and the private sector bear the overall cost of the infrastructure. The associated risks are also shared among all the partners based on their stake in the venture. For example, the City of Oslo in Norway, develops both its own public charging network while also working on a joint-venture structure with private actors to widen the charging infrastructure.

3. The concession model: In the concession model, a private party is given concessions to set up the charging infrastructure. Here, the public authority influences the location and the type of the charging infrastructure that is required to be set up, and interested parties can then bid on the tender. This enables the public authority to ensure that charging infrastructure is rolled out even in less favourable locations. As the private party sets up the infrastructure and collects revenues from the EV users/customer, all associated risks are borne by the concessionaire. For example, Paris city in France generally works on the concession model, with the city administration retaining control and benefit from the royalties paid by the concessionaire while the concessionaire bears the most operational risks.

4. The availability-based model: In the availability-based model, similar to the concession model the public authority allocates the project to a private party. But unlike the concession model, the demand risk, i.e., the risk associated with utilization of the charging infrastructure is borne by the public authority. The public authority collects the revenue and pays the private party the infrastructure cost over the duration of the contract. For example, the City of Rotterdam in Netherlands chose to float a tender for the development and operation of the charging network but maintained the ownership.

5. The license model: In the license model, the authorities permit setting up of charging infrastructure to the private party, which implies that any party which complies with the minimum requirements provided by the public authority has the permission to set up, manage and operate the charging stations as per their design. The private sector has complete control over the infrastructure but also bears the associated risks. The disadvantage of the license model is that as the establishment of the charging infrastructure is completely dependent on the private sector, so the growth of the infrastructure will be governed by the direction of the market. So, the license model is not suitable in the initial stages of market development as the desired deployment levels of the charging infrastructure may not be achieved. For example, the Vestland county in Norway has already made significant investments to building up of the charging network and therefore has chosen to leave further developments to the private sector.

The choice of the contract model depends on the goal of the public authority. Public contracts have the highest associated costs for a public authority; however they also have complete control over the charging infrastructure as shown in Figure 3.1. This contract type is better suited for the initial phase of roll-out of the charging infrastructure. This can then be followed by concession contracts, where the public authority will just notify the requirement of charging infrastructure at a certain location and the interested private players can then construct the required infrastructure. Once the market is matured enough, the license contract type gives the private parties enough freedom to set up their charging infrastructure based on their own judgement. Such open markets would eventually lead to more innovative solutions in the EV charging ecosystem.

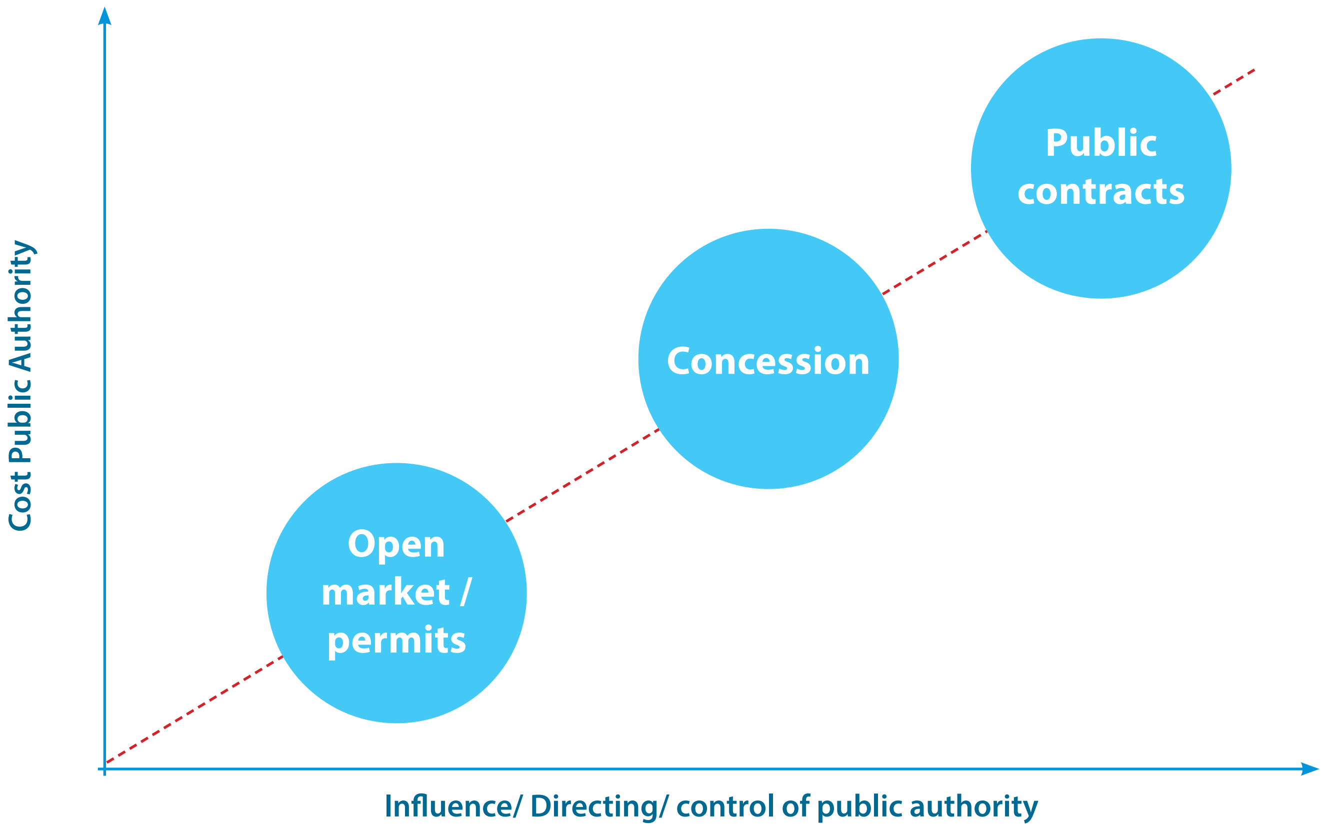


Figure 3.1: Factors affecting choice of contract model[10]

10 Sustainable Transport Forum, " Recommendations for public authorities on : procuring, awarding concessions, licences and/ or granting support for electric recharginginfrastructure for passenger cars and vans", Dec 2020. https://transport.ec.europa.eu/system/files/2021-06/sustainable_transport_forum_report_-_recommendations_for_public_authorities_on_recharging_infrastructure.pdf

3.2 Foster Competition in the Market

Competitive tenders theoretically make it possible for different private parties to enter the EV charging market. However, it is generally seen that it restricts the free market access for non-selected operators. This is because, often, the winning concessionaire obtains the exclusive right to develop the charging infrastructure for a large portion of the area. This can unintentionally impede the innovation in the market leading to higher costs faced by the end users. To counteract this disadvantage, smaller tenders are favourable instead of one large concession. For an example, Malta, Slovakia and Germany often split up the requirements to allow different operators to co-exist. Stuttgart in Germany only grants tenders for two charging points per location in order to make the market as competitive as possible. The City of Oslo has already determined the possible locations for deploying EV charging infrastructure in the city. Interested developer can submit their bids, however, to maintain competition, each private party can are limited by the number of applications that they can send for bidding.

3.3 Price cap

Public authorities can also award their tenders in such a way that it benefits the end users with fair and reasonable charging prices. This can be achieved by awarding the tenders based on the maximum prices that the concessionaire should charge the end user. For example, the region of Vestland includes price requirements in its tender. Similarly, Rotterdam also has a cap on the maximum allowable charging price that can be levied from the end user.

3.4 Physical Dimension

Availability of public space for installing chargers along with required parking space is scarce in most of the Indian cities. Roadside spaces are generally crowded with parked 2W, bicycles, trash cans etc. With the addition of EV charging points, the space on the roadside will get further constrained. Therefore designs, that factor in such constraints should accordingly be acknowledged while awarding the tender. Possible ways to utilize lower public space are,

1. Installation of compact charging points
2. Charging points with multiple connectors that can all be utilized simultaneously.
3. Using existing infrastructure such as lamp posts, telecom boxes etc. for installation of the charging point.

Leuven, mandates the following requirements in its tenders for EV charging stations[11],

- The passage for other traffic like bicycles, pedestrian, wheelchair should not be impeded due to EV charging.
- There should be no obstacles to usage of other street furniture or public greenery.

3.5 Requirements in the Tender

There are also a specific set of important requirements that can be included to the tenders as listed below.

3.5.1 Access hours

End users should be able to charge their vehicle as per their daily schedule. So public charging stations should be accessible to the public 24/7.

Germany provides funding to the charging stations that are open to any indeterminate group of users. These PCS can be either on public highways or on private land.

3.5.2 Safety

One of the essential features that should be mandated in the tenders is the safety of the charging points. These charging points will be installed in public spaces, so it may be in easy reach of many adults, children, the elderly and the disabled. Therefore, these chargers should be designed such that they do not pose any health hazards. The safety designs include both physical safety and electrical safety. In physical safety considerations, the chargers should not possess any sharp ends, and no elements should stick out of the chargers. The connectors should also be adequately designed so that people do not trip over them. In terms of electrical safety, the charging equipment should be properly grounded, and no live parts should be exposed. Also, while in use, the whole infrastructure should be safe with no risk of electroshock.

3.5.3 Efficiency

Public authorities while issuing tenders should also promote energy efficiency. This can be achieved by adding a minimum efficiency requirement for chargers of the participating parties. Specifically for DC charging points, the charger should be able to efficiently convert AC to

11 Sustainable Transport Forum, " Recommendations for public authorities on : procuring, awarding concessions, licenses and/ or granting support for electric recharging infrastructure for passenger cars and vans", Dec 2020. https://transport.ec.europa.eu/system/files/2021-06/sustainable_transport_forum_report_-_recommendations_for_public_authorities_on_recharging_infrastructure.pdf

DC power while limiting energy losses. Another way to promote energy efficiency is by allowing the CPO to charge the EV user solely based on the amount of energy delivered to the EV. Further, as DC chargers are generally high power, the efficiency of charging at different load conditions is also of importance.

3.5.4 Stand-by Power Consumption

With the increasing number of charging stations deployed throughout the nation, the stand-by power consumption of chargers will also become significant. For example, if 500 AC chargers are deployed, each having a stand-by power consumption of 20 W and assuming that these charging points are available 24/7 then it results in an additional consumption of 88 MWh/year. This requirement is more pronounced for a public contracting model, the availability model, or the joint venture model as the cost of energy used would be eventually paid for by the public authority.

3.5.5 Robustness

The charger would be exposed to the elements for multiple years, so the charger has to be robust enough to withstand the various weather conditions as well as possible vandalism. Such requirements can be achieved by demanding maintenance from the concessionaire throughout the contract period.

3.5.6 Metering requirements

The charging stations are provided with a grid certified meter, for accurate metering of the net energy consumption by the charging station. Also, every charger within the charging station typically has a meter to measure the energy transacted during each EV charging session. However, these meters are not generally regulated by any standards, so some questions regarding their accuracy remains. Therefore, standards needs to be created for these meters and such standards should also be notified in the tenders.

3.5.7 Data Communication

Public authorities should include in their tenders, an obligation for the CPOs to transfer a minimum set of data to them, these data include,

- Location
- Operational hours
- Maximum power offered (AC/DC, voltage range, maximum current)
- Real time energy use
- Additional features available (Smart charging/ V2G)
- Real time reservation/ waiting list
- Availability
- Price for charging

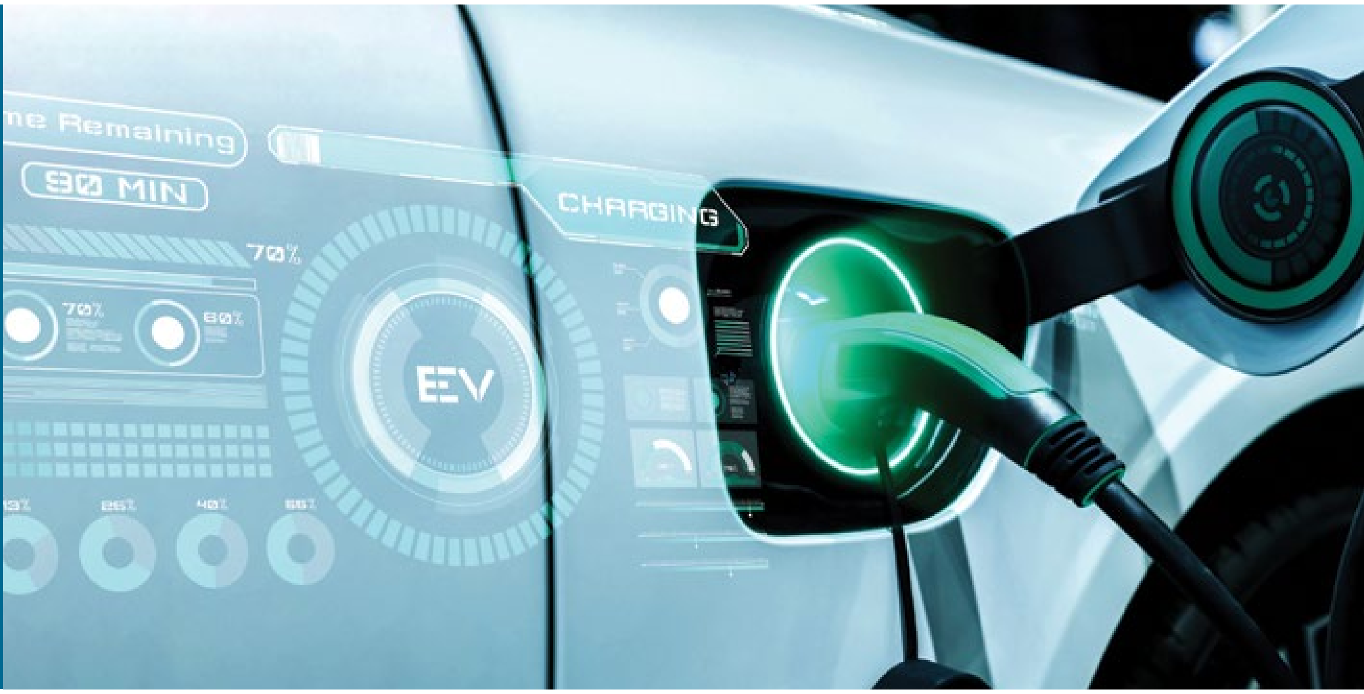
3.5.8 Electricity Supply Requirements

The tender should also make requirements in regard to the electricity supplied to the charging station. The strict use of green electricity should be duly acknowledged and rewarded. The use of green energy can also be regulated by requiring the purchase of a minimum number of Renewable Energy Certificates by each charging station. It is also recommended that the CPO should be allowed to purchase electricity from any supplier irrespective of the distribution network to which the charging station is connected.

In the province of North-Brabant in the Netherlands, in a research project, the consumers are even allowed to choose their own energy supplier at the charging station, including their own home-produced solar energy.

Germany's energy regulator BNetzA is also working on the legal and administrative regulations to facilitate the free choice of electricity supplier by the users at the charging stations.

04 Key Intervention for Seamless Adoption of EV Charging Infrastructure in Indian EV Ecosystem



4.1 Selection of Interventions

It is of critical importance and a challenging task to identify the key interventions for effective and adequate adoption of EV charging infrastructure, as the right interventions will ensure that EV charging infrastructure takes a right direction in India. For policy and regulatory agencies, identifying key interventions, priority of each intervention, and potential way forward to implement the top key interventions will play a critical role in seamless adoption of EV charging infrastructure, and this report aims to provide with these inputs to Indian policy and regulatory agencies, and other key stakeholder.

In order to identify and rank different key interventions, a robust and scientifically advanced framework has been devised in this study as shown in Figure 4.1 as shown in Figure 5.1. Initially, two different sets of recommendations are considered and categorized into technical interventions, and policy and regulatory interventions. The technical interventions include recommendations that implicate the use of technical additions and modification to the EV ecosystem, which can increase the functionality of the EV charging network. The policy and regulatory interventions, include devising policy and regulatory interventions that can lead to widespread deployment of the EV charging network. These recommendations have been provided while considering the existing status of the Indian EV ecosystem. Different interventions that have been considered for analysis are given in Table 4.1.

Table 4.1: List of interventions

Technical interventions	Time based EV tariffs
	Fast Charging Infrastructure
	Slow Charging Infrastructure
	Battery Swapping Infrastructure
	Smart Charging – Unidirectional
	Smart Charging with V2G
	Interoperability
	Energy market participation for EV
	RE integration

Policy and Regulatory interventions	Support for distribution system upgradation for charging infrastructure
	Adequate EV charging infrastructure deployment regulations.
	Mandating EV charging infrastructure in publicly accessible parking locations
	Mandating EV charging infrastructure in building bye-laws
	Easy access of land for setting up PCS
	Support market creation for private investment in public charging infrastructure
	Battery swapping should be subsidized at par with EV chargers
	Grid integration of EV charger regulations (technical)
	Harmonization of EV charging standards
	Grid support services from EV

These recommendations are then scored based on different performance criteria/metrics. These criteria have been discussed in detail in Section 4.21. The ranking of the recommendations is then done by three different multi criteria decision making (MCDM) tools. Each of these tools give out their own sets of rankings for both the technical interventions as well as the policy and regulatory interventions. These rankings are then aggregated to give one set of rankings for each of the technical and policy and regulatory recommendations. An in depth analysis of the top 5 technical recommendations and the top 5 policy and regulatory interventions is then performed and the learnings of this analysis is used for the final combined ranking of interventions.

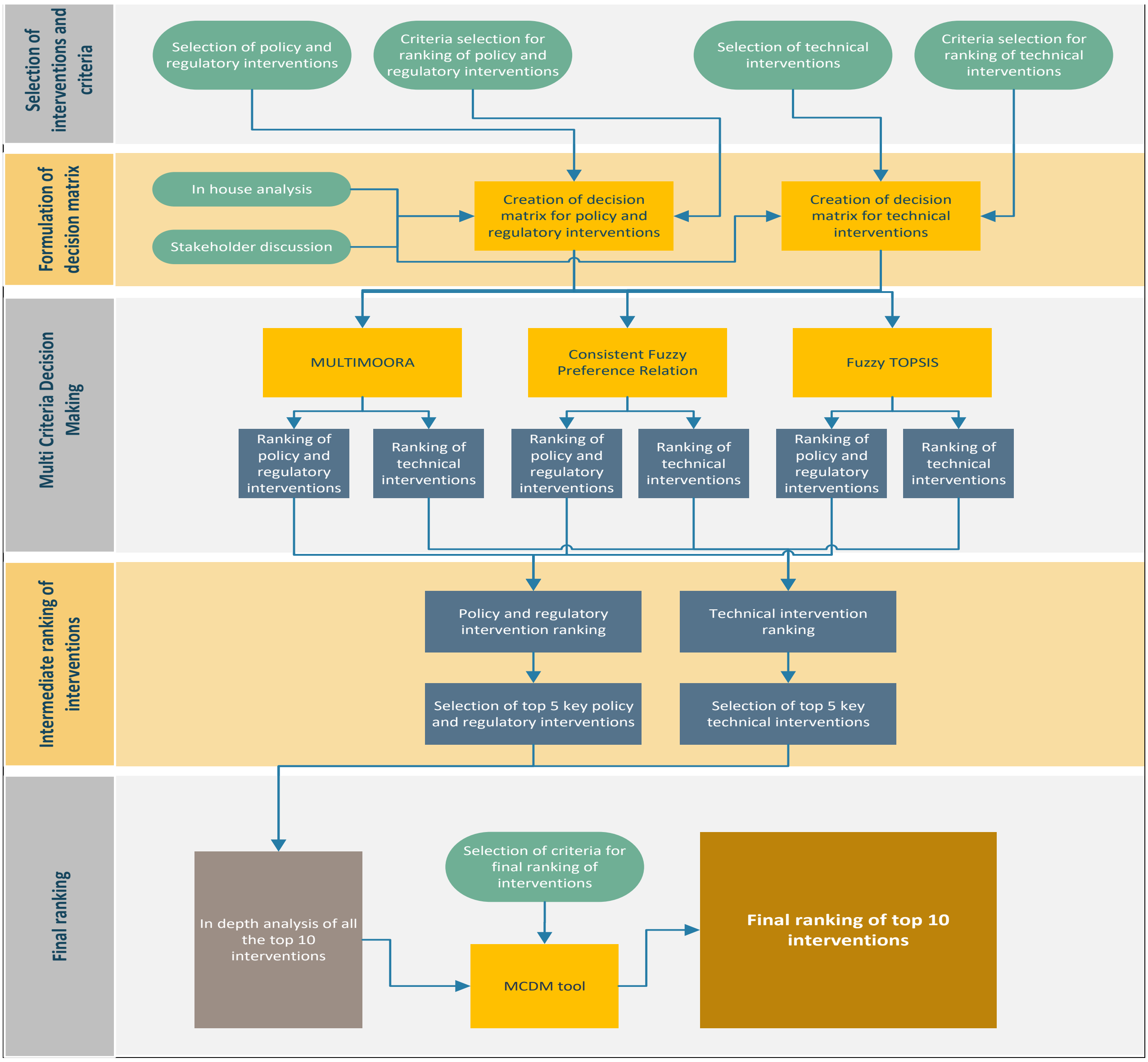


Figure 4.1: Framework for ranking of interventions

4.2 Criteria for Ranking of Interventions

4.2.1 Technical interventions

The ranking of the technical interventions is decided based on the below given criteria. These criteria help in assessing the impact of technical interventions on the growth of EV charging infrastructure in India.

4.2.1.1 Benefits of the intervention

Each intervention would provide benefits to different stakeholder in the EV ecosystem. Therefore, to assess the benefits provided by the different interventions, the interventions are ranked based on the number of beneficiaries that are affected by the intervention. The beneficiaries considered here are,

- Distribution System Operator
- Transmission System Operator
- Charge Point Operators
- EV Users

Each beneficiary has been allotted equal weights except EV user, which has been given double weightage, considering the fact that EV users are the primary customers.

4.2.1.2 Negative Impacts

Similar to benefits, each intervention will also have unwanted negative impacts. Each intervention is penalized dependent on the number of utilities that it negatively impacts on. The stakeholders considered here are,

- Distribution System Operator
- Transmission System Operator
- Charge Point Operators
- EV Users
- Renewable Energy Integration

The weights of the penalty associated to each utility is also equal except EV customer, for which the penalty is doubled.

4.2.1.3 Economic Impact

The economic burden for implementation of the interventions have been considered here for ranking purposes.

4.2.1.4 Stakeholder Involvement

There is a variation in different number of stakeholders that need to cooperate to achieve an intervention. Some interventions can be achieved by actions of a single stakeholder, while the others, such as eRoaming needs the cooperation of multiple stakeholders working in tandem. The involvement of a larger number of stakeholders will also likely complicate the process of achieving the intervention as all the stakeholders involved must be in agreement and need to cooperate and coordinate for effective implementation of such interventions.

4.2.1.5 Technical Maturity

Not all the interventions that have been mentioned in Table 4.1 have the same level of technological maturity. Some interventions have been well developed and are in commercial use, while others are still in demonstration, deployment or pilot phase. The interventions have been ranked based on the following stages of technical maturity,

- Lab-scale research
- Pilot project
- Commercial demonstration
- Introduction to market
- Matured technology

4.2.2 Policy and regulatory interventions

The following objectives/criteria have been utilized for assessing the impact of each policy and regulatory intervention on the growth of EV charging infrastructure.

4.2.2.1 Cost implications

Cost implications refer to the expected costs associated with the implementation of each policy/regulatory intervention over its implementation period. These costs include the budget allocated for funding of a policy; costs associated with development of regulations; costs associated with publicizing the policy/regulation etc.

4.2.2.2 Influence on EV charging adoption

In this objective, the impact of the policy/recommendation on the growth of EV charging infrastructure is analysed, as some policy/regulation would directly influence the growth of charging infrastructure. In contrast, others may not directly influence the growth of charging infrastructure but may increase the value of the infrastructure. As an example, land allocation for setting up of PCS would directly influence the growth of charging infrastructure, however, policies mandating the use of RE for charging of EVs although would no't directly benefit the growth of charging infrastructure, it would increase the value that can be levied by the CPOs from the EV charging stations.

4.2.2.3 Implementation Time Period

As the name suggests, this feature is indicative of the expected time required for complete implementation of the said policy/regulation.

4.2.2.4 Acceptability

Acceptability refers to the acceptability by the authorities/ utilities/ government for implementation of a given policy/ intervention. Some, policies, and regulations although may be favourable for EV charging infrastructure, can be detrimental to some other ways, in which case those policy and regulations would face opposition for implementation.

4.3 Details of the selected Interventions

4.3.1 Technical Interventions

Based on the framework described in Section 4.43, the technical interventions mentioned in Table 4.1 have been ranked. Each intervention and their potential impacts have been considered while ranking the alternatives. The analysis of each intervention has been highlighted below.

4.3.1.1 Time based EV tariffs

Time based EV tariffs is one of the more straightforward methods for passive load shifting. It helps the distribution system operator, transmission system operator in controlling the load curve and optimizing the generation schedule. It also benefits the CPO and the EV user by providing periods where the charging can be done cost effectively. To implement time-based EV tariffs, related regulations have to be prepared by the state electricity regulators and the EV users need to have a smart meter installed to log in the energy use with time.

4.3.1.2 Fast charging infrastructure

Fast charging infrastructure would enable the EV users to charge their EVs with minimal time required. As the vehicles would be charged faster, the CPOs are is likely to be benefited with higher numbers of vehicles served per day. However, the fast chargers would put a higher stress on the distribution system and are also likely to increase the peak load of the system. Fast charging infrastructure would also likely warrant an investment on upgradation of the grid infrastructure in addition to the higher cost of fast chargers itself.

4.3.1.3 Slow charging infrastructure

Slow chargers draw much lesser power compared to fast chargers and so are more attractive for distribution system operators. However, slow chargers require much longer charging times thereby negatively impacting the EV users. Also, the slow charging reduces the number of vehicles that can be serviced by CPOs per day. On the economics side, slow chargers are much cheaper compared to fast chargers because they generally do not require anyrequire minimal grid upgradation as compared to fast chargers.

4.3.1.4 Battery Swapping Infrastructure

Battery swapping infrastructure benefits the EV user as it minimizes the time required for charging. At the same time, while it also can benefit the DSO by controlling the battery charging to control the maximum power demand by the charging station. Regarding costs, the swapping infrastructure needs to bear the costs of the battery chargers and the swapping mechanism. Also, depending on the ownership model of batteries adopted by the swapping station, the costs may increase, as the swapping station may also need to purchase EV batteries. The implementation of battery swapping infrastructure would be difficult as it would require the standardization for battery types among different vehicle classes, requiring coordination among different stakeholders such as EV OEM, EV battery OEM as well as the battery swapping facilities.

4.3.1.5 Smart Charging – Unidirectional

Smart charging would enable EV charging while minimizing its impact on the local distribution network. In unidirectional smart charging, the charging power is controlled based on control signals from the central management system. This management system can be designed to benefit both the DSO and the TSO.

4.3.1.6 Smart Charging – Bidirectional

Bidirectional smart charging is the pinnacle of EV charging from the utility perspective. By utilizing bidirectional charging both the DSO and TSO can extract a variety of grid support services. By providing such grid support services, the CPO and EV user would also be benefited in terms of monetary gains. But the impact of bidirectional charging on the health of the EV battery may be a cause of concern. The cost of implementation of bidirectional charging would also be significant, as the chargers capable of bidirectional chargers are themselves costly, with added costs of communication infrastructure and advanced metering unit. Also, a larger number of stakeholders needs to be involved for implementation of bidirectional charging including CPO, Charge management system operator, EV OEM, DSO and EV user.

4.3.1.7 Interoperability

Enabling interoperability would increase the utilization factor of CPOs and increase the availability of public charge point to an EV user, making it a win-win situation for both the parties. To ensure interoperability however, different CPOs need to have agreements with each other or with an electric mobility service provider, besides having hardware interoperability, i.e., standardized charging protocols. It has been extensively used in the European markets, thus clearly indicating its market viability.

4.3.1.8 Energy Market Participation for EV

Participation in the Energy Market would enable EVs to perform Demand Response Services, and provide grid support/management including ancillary services. This would potentially increase income of the EV user as well as benefit the DSO and TSO in maintaining grid stability. However, there needs to be adequate infrastructure in place, such as communication infrastructure, aggregation of EVs, adequate metering infrastructure etc. to enable such participation.

4.3.1.9 RE Integration for EV Charging

Coordination between RE generation and EV charging is beneficial for the involved stakeholders including DSO, TSO, CPO and the EV user. For the DSO and TSO, it helps in load managements and increased penetration of EV, while for CPO and EV user it helps in reduction of charging cost. Although the technology is mature, it would require smart energy management system with smart meter installation. Regulation and policies incentivizing utilization of REs by CPOs for EV charging would go a long way in making EV charging profitable for CPOs, as highlighted in Section 8.3 (Page 239) of Report-3 Report 3 - Electric Vehicle Charging Infrastructure and its Grid Integration in India: Status Quo, Critical Analysis and Way Forward. The implementation of such policies would be relatively quick with lower hindrance from the different stakeholders

The impact/influence of the different interventions on different criteria chosen for evaluation have been given in Table 4.3, Table 4.4, Table 4.5, Table 4.6 and Table 4.7. These evaluations have been used for ranking the alternatives using the decision-making tools given in 'Annexure 2 and Annexure 3'.

Table 4.3: Benefits of each alternative provided to different entities

Framework attributes	DSO	TSO	CPO	EV user
Time based EV tariffs	✓	✓	✓	✓
Fast Charging Infrastructure	-	-	✓	✓
Slow Charging Infrastructure	✓	-	-	-
Battery Swapping Infrastructure	✓	-	-	✓
Smart Charging – Unidirectional	✓	✓	✓	✓
Smart Charging – Bidirectional	✓	✓	✓	✓
Interoperability	-	-	✓	✓
Energy market participation for EV	✓	✓	✓	✓
Renewable Energy integration for EV charging	✓	✓	✓	✓

Table 4.4: Negative impacts of each alternative on different entities

Alternatives	DSO	TSO	CPO	EV user
Time based EV tariffs	-	-	-	-
Fast Charging Infrastructure	✓	✓	-	-
Slow Charging Infrastructure	-	-	✓	✓
Battery Swapping Infrastructure	-	-	-	-
Smart Charging – Unidirectional	-	-	-	-

Alternatives	DSO	TSO	CPO	EV user
Smart Charging – Bidirectional	-	-	-	✓
Interoperability	-	-	-	-
Energy market participation for EV	-	-	-	-
Renewable Energy integration for EV charging	-	-	-	-

Table 4.5: Associated costs for each intervention

Alternatives	Costs
Time based EV tariffs	Smart meters
Fast Charging Infrastructure	Grid upgradation costs, Expensive chargers
Slow Charging Infrastructure	Inexpensive chargers
Battery Swapping Infrastructure	Battery charger, Battery (based on ownership model) Battery (based on ownership model)
Smart Charging – Unidirectional	Smart meters, Communication infrastructure
Smart Charging – Bidirectional	Smart meters, Chargers with bidirectional charging capability, Communication infrastructure
Interoperability	Financial contracts among different CPO and eMSP, May lead to increase in cost for CPO
Energy market participation for EV	Smarty meters, Aggregator fee, Communication infrastructure
Renewable Energy Integration for EV charging	Smart meters, Renewable generator (Rooftop PV/ micro hydro/ wind turbine etc.) Open access

Table 4.6: Stakeholder responsible for implementation of intervention

Alternatives	Shareholders
Time based EV tariffs	Electricity regulator, DSO
Fast Charging Infrastructure	CPO, DSO, Electricity regulator
Slow Charging Infrastructure	CPO, DSO, Electricity regulator
Battery Swapping Infrastructure	Battery swapping facility, EV OEM, Battery OEM DSO , Electricity regulator
Smart Charging – Unidirectional	CPO, Charge management system operator, DSO EV user, Fleet Aggregator/ EV user, Electricity regulator
Smart Charging – Bidirectional	CPO, Charge management system operator, EV OEM, DSO, Fleet Aggregator/EV user, Electricity regulator
Interoperability	CPO, eMSP, Charge management system operator,
Energy market participation for EV	CPO, Energy market through VPP/aggregator Electricity regulator
Renewable Energy Integration for EV charging	CPO, DSO/TSO, EV user Energy market through VPP/aggregator Electricity regulator

Table 4.7: Technical maturity of intervention

Alternatives	Technical Maturity levelCosts
Time based EV tariffs	Mature
Fast Charging Infrastructure	Mature
Slow Charging Infrastructure	Mature
Battery Swapping Infrastructure	Early stage of market introduction
Smart Charging – Unidirectional	Early stage of market introduction
Smart Charging – Bidirectional	Commercial demonstrations/ implementation
Interoperability	Early stage of market introduction
Energy market participation for EV	Commercial demonstrations/ implementation
Renewable Energy Integration for EV charging	Early stage of market introduction

4.3.2 Policy Interventions

The detailed analysis of different policy/ regulatory interventions as per the different criteria/objectives have been discussed in this section.

4.3.2.1 Support for distribution system upgradation for charging infrastructure

One of the major bottlenecks in the installation of EV charging infrastructure is the availability of margin on the local distribution feeders. If grid upgradation is required, the CPOs are generally asked to bear the cost, which is a major barrier. So, it would be fruitful if the government could provide financial stimulus to the DISCOMs for the upgradation of the grid infrastructure. However, grid upgradation is a substantial investment, so cost implication of such schemes would be high. Also, upgradation of necessary grid infrastructure throughout the nation would be a time-consuming venture.

4.3.2.2 Adequate EV charging infrastructure deployment regulations.

Regulations for deployment of EV charging infrastructure in specific zones of the city, would enable a widespread EV charging infrastructure network, making EV users eager to purchase an EV and removing their range anxiety. However, just regulations alone are not enough to grow the charging network, as the private/public CPOs would also have their own requirements for EV charger installation. The design and implementation of such regulation would take some time as different analysis and forecasts, such as predicted EV growth forecast, EV charging demand forecast, current EV charger deployment etc. would be necessary. Moreover, there may be reluctance froorm different stakeholders involved like municipal bodies, state governments, public utilities, CPOs etc.

4.3.2.3 Mandating EV charging infrastructure in publicly accessible parking locations

In order to increase the widespread deployment of EV chargers, publicly accessible charging parking locations should be mandated to reserve a minimum number of parking spaces for EV charging. However, implementation of such regulations/byelaws may also warrant the provision of financial incentives to the parking lots.

4.3.2.4 Mandating EV charging infrastructure in building bye-laws

Bye-laws mandating EV charging regulations for buildings, would provide private charging options for a wide number of EV users, thereby significantly meeting their charging requirements. These regulations would be easier to implement as the building owner/management just needs to make their parking spaces ready with adequate cabling for accepting EV chargers. There may be some disagreement by the building owner/management as it would increase the costs incurred by them. While inclusion of EV ready parking spots may not be a major issue for new buildings, retrofitting of existing buildings to make them EV ready could be difficult without adequate regulations and mandates in place, specially for multi-unit dwellings. Still, most other stakeholders should not have any major objection to such regulation.

4.3.2.5 Easy access of land for setting up PCS

Another bottleneck in the growth of the EV charging station landscape in India is the dearth of available space. Being one of the most highly populated countries, there is acute scarcity of publicly available land in the urban centres of the nation. Most of the available land is owned by public authorities like municipalities/ government offices/ PSUs etc. So, the government can prepare policies to open this land to the private CPOs in the form of lease/rentals for the growth of EV charging business. However, these schemes are also likely to have high-cost implications but

will also have high influence on the EV charging adoption. The implementation of the policy would also be relatively quicker with high acceptability among stakeholders. While opening up of land owned by government organisations for EV charging may increase the available land, location of such land parcels may be in the outskirts of the city/market with limited footfall from EV users, making them economically unviable options for PCS installation. Therefore, it is important that provision of land availability is restricted to the areas with better flow of EVs to ensure minimum utilisation of the chargers. Hence a strategic planning to utilise the existing land spots with higher traffic flow should be aimed through various attractive business models.

4.3.2.6 Support market creation for private investment in public charging infrastructure

Most matured EV charging hotspots in the world have a thriving competitive CPO market, with multiple leading CPOs. In contrast, in India, the initial thrust for the installation of EV chargers has been seen to be undertaken by the public sector utilities like DISCOMs and PSUs. In this respect, there needs to be policies in place to level the playing field for private players to enter the EV charging infrastructure business.

4.3.2.7 Subsidized battery swapping

Policies and schemes have been in place providing subsidies for EVs and EV chargers. However, no policy has been yet announced to provide subsidies for battery swapping facilities. Providing subsidies to battery swapping facilities would carry a slight economic burden but would have a high impact on the charging infrastructure network.

4.3.2.8 Grid integration of EV charger regulations (technical)

It has been seen that adequate grid code regulations introduced at right time have played an instrumental role in successful integration of RE in majority of RE rich countries. Similarly, grid integration regulations are also mandatory for the seamless integration of EV chargers into the grid. Electricity utilities like the regulatory commissions should come with robust technical regulations mentioning the different operating conditions for EVs under different grid conditions.

4.3.2.9 Harmonization of EV charging standards

Harmonization of EV charging standards is necessary to improve the interoperability of vehicles with chargers. Further, currently there is no harmonized standards for 2W and 3W charging. Harmonizing charging standards would have a significant impact on fuelling the growth of the EV charging landscape in the nation.

4.3.2.10 Grid support services from EV

EVs have a significant potential in providing grid support services. Utilization of these services is very attractive for the electrical utilities and operators, as it would provide them with an extra resource providing grid services. Provision of these services is also attractive for the CPOs and the EV users due to monetary benefits. However, implementation of these services would require a lot of regulatory changes[12].

4.3.2.11 Regulations to make smart charging compulsory

Smart charging enables coordinated and controlled charging of EVs thereby helping the DSO and TSO in maintaining the grid within secure and stable operating limits, potentially without the need for grid augmentation. Although it would not directly benefit the growth of the EV charging infrastructure, it would help grid operators as it would enable more installations without the need of grid augmentation. It may lead to reluctance from charger OEMs and CPOs, as smart charging functionality typically increases the cost of the EV chargers.

4.3.2.12 Aggressive awareness

Availability of roadside assistance and general knowledge on the benefits of EVs are two of the major factors that influence the decision making of customers on whether to purchase an EV. Further, the assurance of fire safety for EVs are important so as to encourage people to purchase EVs. The impact of promotional campaigns and increased manpower pool would lead to increased EVs on the road, thereby increasing the utilization of the charging network. These high utilizations would incentivize the PCS owner-operators to ramp up the deployment of charging infrastructure. Further, the publicization of the nationwide network of chargers to the public in a web/app-based platform would also help reduce the range anxiety of EV users.

4.4 Framework for Assessment of Interventions

Assessment of the identified key interventions/recommendations involves a multi-criteria decision making (MCDM) process, as different interventions needs to be cross compared while taking into consideration different criteria for the analysis. Different MCDM processes have been developed with each process having its own sets of advantages and disadvantages. Usually, the different criteria are contradicting in nature, and by using the MCDM process an optimal recommendation can be curated based on the needs of the decision maker.

The authors in[13], did an extensive survey to determine the most used MCDM techniques. The study analysed 393 different literatures and their findings have been presented in Table 4.8. Analytic Hierarchy Process (AHP) has been found to be the most common MCDM tool used in the literature, almost twice that of Hybrid MCDM which comes in the second place. Even in the energy sector, AHP has been found to be one of the most prevalent MCDM methods, due to its ease of computation[14].

Table 4.8: Summary of literature survey[13]

MCDM technique	Frequency of application
AHP	128
ELECTRE	34
DEMATEL	7
PROMETHEE	26
TOPSIS	45
ANP	29
Aggregation DM methods	46
Hybrid MCDM	64
VIKOR	14
Total	**393**

Analytic Hierarchy Process (AHP) proposed by Saaty in 1980 is one of the standard tools of decision making, where a pair-wise comparison of all the proposed options is needed. For every n options a (n × n) pair-wise comparison matrix

12 The Danish grid code encourages the use of EVs for different grid support services. It has been provided in Annexure A4.

13 Abbas Mardani et al., "Multiple Criteria Decision-Making Techniques and Their Applications – a Review of the Literature from 2000 to 2014," Economic Research-Ekonomska Istraživanja 28, no. 1 (January 2015): 516–71, https://doi.org/10.1080/1331677X.2015.1075139.

14 Indre Siksnelyte-Butkiene, Edmundas Kazimieras Zavadskas, and Dalia Streimikiene, "Multi-Criteria Decision-Making (MCDM) for the Assessment of Renewable Energy Technologies in a Household: A Review," Energies 13, no. 5 (March 4, 2020): 1164, https://doi.org/10.3390/en13051164.

needs to be created. So, if the number of options increases, the matrix of pair-wise comparisons significantly increases, which may lead to inconsistencies in part of the experts' opinions due to the increase in the number of questions.

The TOPSIS method is used to find the optimal solution based on its proximity to the ideal solution. Here the ideal solution is determined by best option for each criterion. By calculating the average distance of each alternative for each criterion from the ideal solution, the optimal alternative is selected. So, this method penalizes an attribute if it significantly deviates from the optimal solution for any criteria.

Another simple tool for multi-criteria analysis that has seen use in different fields is expert opinion based recommendations, as used in . Although this method is simple, it is heavily biased towards the opinion of the pool of experts, which may result in instability of the result, each time the method is carried out.

Based on the analysis above, Consistent Fuzzy Preference Relations (CFPR) which is a modified version of AHP is one of the chosen MCDM processes to rank the interventions in this study, to reduce the complexity of AHP with increased criteria, while maintaining its computational simplicity. Along with CFPR, MULTIMOORA and Fuzzy TOPSIS have been considered for ranking of the interventions to increase the robustness of the proposed solutions. The details of the MCDM processes have been provided in Annexure A2.

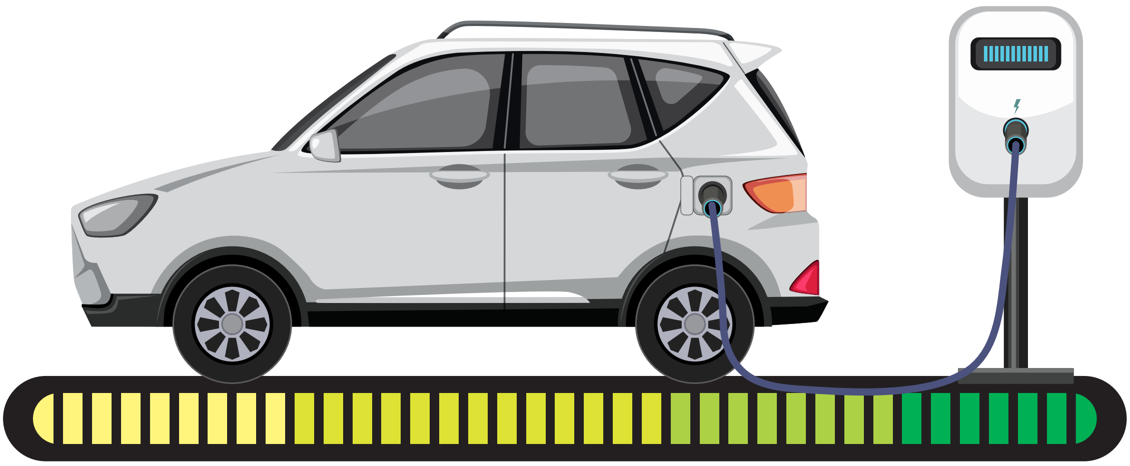
4.5 Ranking of Interventions

4.5.1 Ranking of Technical interventions

The ranking of the technical interventions using the three different decision-making tools have been provided in Table 4.9. Overall, 'Time based EV tariffs' has been identified as the most preferred alternative, due to its ease of implementation, along with high benefits. 'RE integration' has been ranked second, while deployment of slow charging infrastructure, battery swapping infrastructure and the bidirectional charging has been deemed as the least preferred alternatives. The detailed calculations are provided in Annexure A3.

Table 4.9: Overall ranking of technical interventions

	MULTIMOORA	Fuzzy TOPSIS	CFPR	Final Rank
Time based EV tariffs	1	1	1	1
RE integration	2	2	2	2
Smart Charging – Unidirectional	3	5	3	3
Interoperability	4	3	4	3
Fast Charging Infrastructure	6	4	6	4
Energy market participation for EV	5	7	5	5
Battery Swapping Infrastructure	7	8	7	6
Slow Charging Infrastructure	9	6	9	7
Smart Charging with V2G	8	9	8	8



4.5.2 Ranking of Policy and Regulatory Interventions

The ranks achieved by the policy and regulatory interventions are given in Table 4.10. As can be seen, among the policy and regulatory interventions, 'Mandating EV charging infrastructure in building bye-laws' achieved the highest rank followed by 'Support market creation for private investment in public charging infrastructure'. 'Aggressive awareness', 'Easy access of land for setting up PCS' and 'Support for distribution system upgradation for charging infrastructure' achieved the 3rd, 4th and 5th rank respectively.

Table 4.10: Overall ranking of policy/regulatory interventions

	MULTIMOORA	Fuzzy TOPSIS	CFPR	Final Rank
Mandating EV charging infrastructure in building bye-laws	1	1	2	1
Support market creation for private investment in public charging infrastructure	2	4	1	2
Aggressive awareness	4	2	6	3
Easy access of land for setting up PCS	4	5	5	4
Support for distribution system upgradation for charging infrastructure	7	6	3	5
Mandating EV charging infrastructure in publicly accessible parking locations	4	7	6	6
Harmonization of EV charging standards	7	3	8	7
Battery swapping should be subsidized at par with EV chargers	3	9	8	8
Adequate EV charging infrastructure deployment regulations.	9	10	4	9
Regulations to make smart charging compulsory	10	8	10	10
Grid integration of EV charger regulations (technical)	11	11	12	11
Grid support services from EV	12	12	11	12

Although the three different frameworks do not provide the same ranks to the alternatives, most alternatives are ranked within a close range. 'Mandating EV charging infrastructure in building bye-laws' and 'Support market creation for private charging investment' are among the top two alternatives, given in Table 4.10. 'Grid integration of EV charger regulations (technical)', 'Grid support services from EV' and 'Regulations to make smart charging compulsory' have all been ranked relatively on lower side . Although these regulations would highly benefit the electrical grid operator, their influence is not directly reflected in the growth of the charging infrastructure.

It can be interpreted from Table 4.10, the interventions are mostly ranked similarly by MULTIMOORA and Fuzzy TOPSIS. However, looking at the ranks assigned by CFPR for a few of the interventions, a wider mismatch of ranks is seen. As an example, 'Harmonization of EV standards' is ranked quite high by CFPR, while MULTIMOORA and Fuzzy TOPSIS assign it a poor rank. This discrepancy is due to the way the frameworks calculate the ranks. MULTIMOORA and Fuzzy TOPSIS both use a 'distance from ideal solution' metric as one of its metrics to assign the rank. The 'distance from ideal solution' metric is the distance of the performance of the intervention for one objective/criteria from the best solution for the objective/criteria. If the intervention has higher distance for any objective, its rank immediately drops in MULTIMOORA and Fuzzy TOPSIS. In the case of 'harmonization of EV standards', the intervention performed relatively poorly in the 'Acceptability' criteria.

So even though it performed well in the other criteria, the 'distance from the ideal solution' for the 'acceptability' criteria pulled its rank down in MULTIMOORA and Fuzzy TOPSIS. The same is true for 'Easy access of land for setting up PCS' which is bright down due to 'Cost implications'.

4.6 In-depth Analysis of Top Five Technical Interventions

For the benefit of, and better understanding by the policy and regulatory agencies and other stakeholders, a detailed in depth analysis of top five technical interventions has been provided in this section, which shall enable the relevant authorities to take an informed decision on technical interventions.

4.6.1 Time Based EV tariffs

Time based EV tariffs is a smart charging methodology, using which the EV load can be passively controlled. It provides benefits to both the electrical utilities as well as the CPO and EV user by potentially lowering the cost of charging for both private and public charging stations. Implementation of time based tariffs can be enabled by the necessary regulations from the state electricity regulatory commissions and the provision of smart meters for logging the energy use with time.

The following case study will analyze the impact of time based EV tariff[16].

Two different ToD tariffs have been used for analysis, a standard ToD tariff based on current available ToD rates[17], and an aggressive ToD tariff with higher peak charges and lower off-peak charges. The impact of the ToD tariffs has been compared with a flat energy tariff[18]. The two tariffs along with the fixed tariff have been shown in Figure 4.2[19].

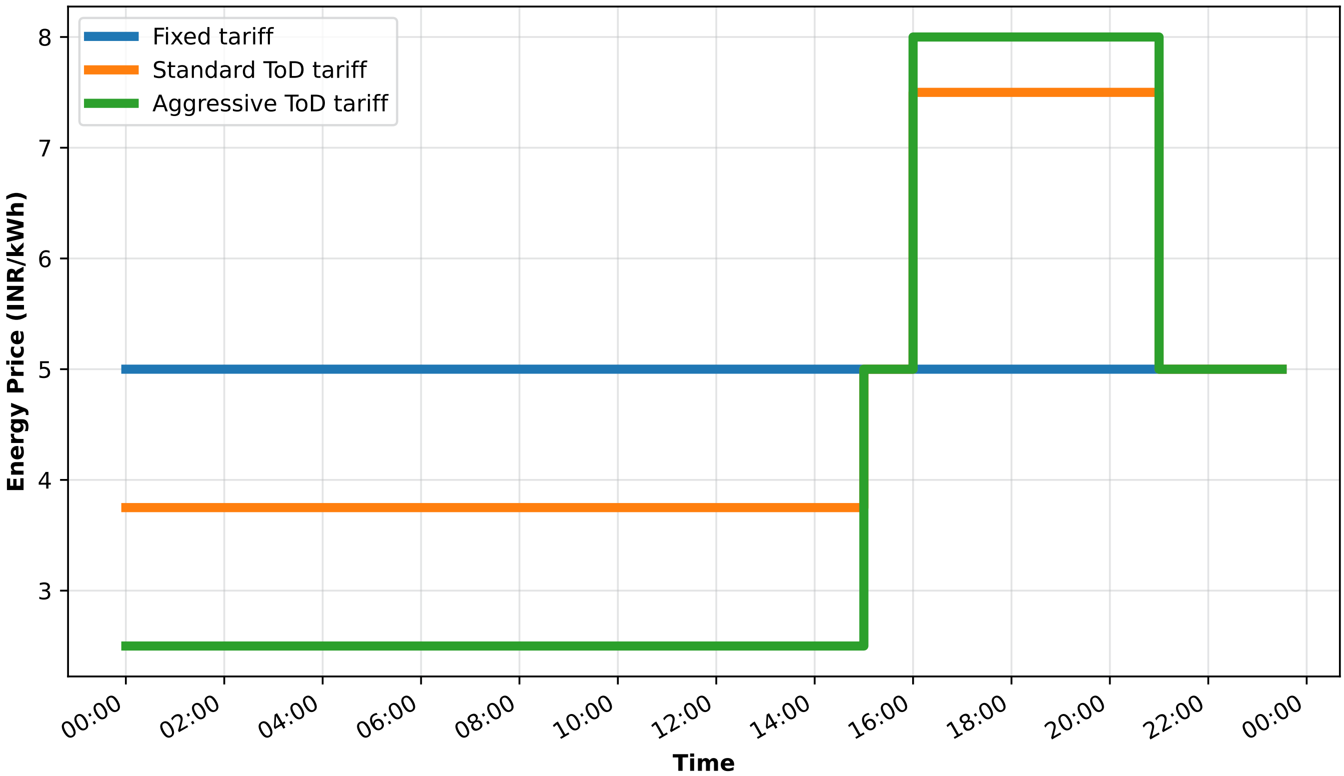


Figure 4.2: Comparison of ToD tariff with flat energy tariff

16 Analysis done by IIT Bombay

17 The rates of ToD tariff given in Kerala tariff order released on 8th July 2019 have been used for the 'Standard ToD tariff' with changes made to the time of peak and off-peak periods.

18 Here, only the energy charges have been considered. Other charges such as demand charges (if two-part tariff), wheeling charges, surcharges etc have not been considered.

19 In the Kerala tariff order released on 8th July 2019, ToD rates were only applicable to loads above 22 kW. However, to show the impact of ToD tariff in EV charging, this report considers that all EV users can utilize the ToD tariff.

A distribution feeder with peak non-EV load of around 600 kW has been considered for the analysis as shown in Figure 4.3. The feeder has 40 residences with private EV chargers. The chargers are rated at either 3 kW or 7 kW or 11 kW. Additionally, the feeder also has a public charging station with details given in Table 4.11.

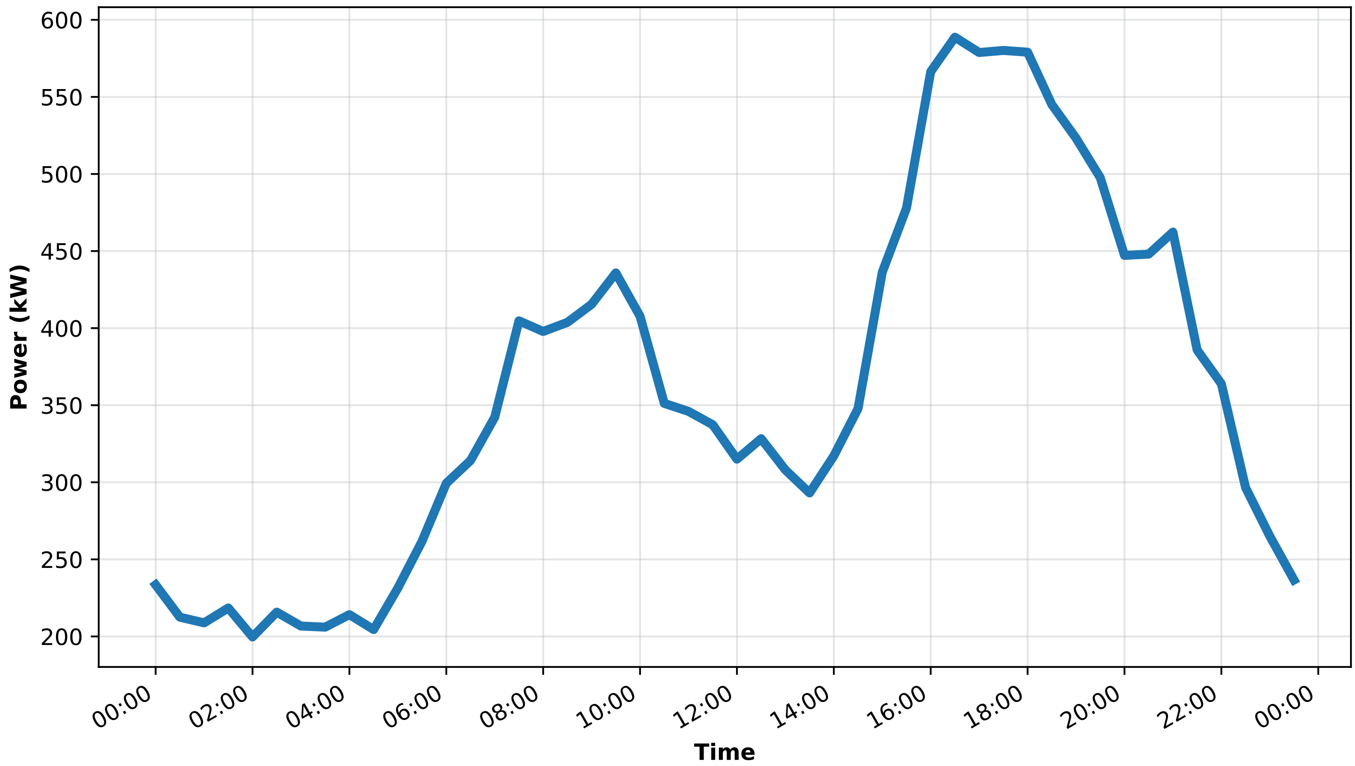


Figure 4.3: Load curve of distribution feeder

Table 4.11: Details of Private EV chargers and Public EV charging station

Details of Private EV chargers		
Number of private EV chargers		40 nos.
Power rating of private EV chargers		3/7/11 kW
EV battery capacity	For EV with 3 kW charger	20 kWh
	For EV with 7/11 kW charger	40 kWh
Daily distance travelled	For EV with 3 kW charger	Randomized between 50 and 150 km
	For EV with 7/11 kW charger	Randomized between 50 and 250 km
If EV travelled in the day, arrival time at residence		Given in Figure 4.4
Cost of Smart Meter	INR 8,000	
Details of Public Charging Station		
Number of Chargers	10	
AC Chargers	7 nos. of 22 kW chargers	
DC Chargers	3 nos. of 50 kW chargers	

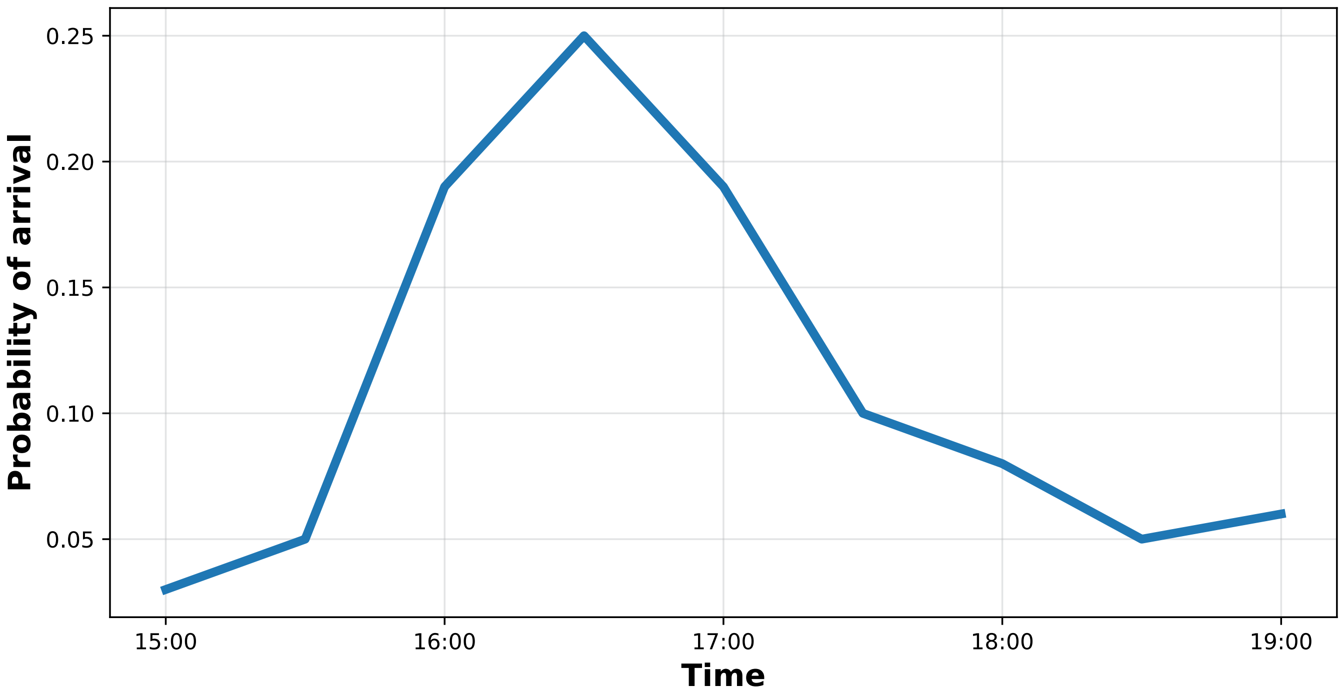


Figure 4.4: Probability of EV arriving at home[20]

4.6.1.1 Impact on residential EV users

By shifting the tariff structure to ToD tariff from a fixed tariff the residential EV users can reduce their energy bill. The annual savings for the two considered ToD tariffs have been given in Figure 4.5. It can be seen that, annually, an EV user can potentially make a saving of around INR 6,769 (EUR 74.4) (mean) using the 'Standard ToD' and INR 12,801 (EUR 140.75) (mean) using the 'Aggressive ToD'. The statistical measures of the annual savings have been given in Table 4.12.

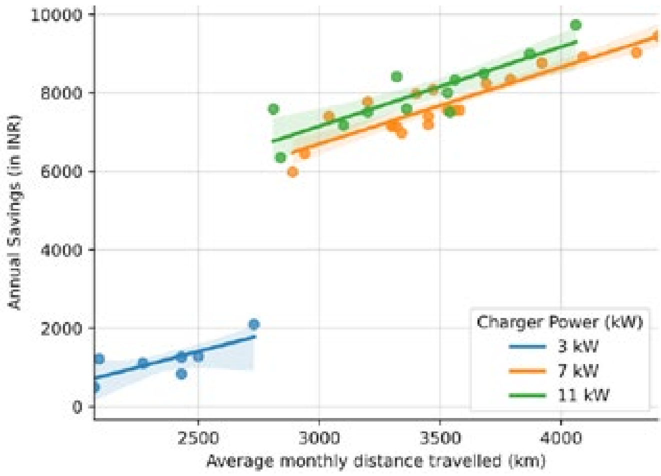
Table 4.12: Statistical measures of annual savings

	Mean (INR/EUR)	Median (INR/EUR)	Standard deviation (INR/EUR)
Standard ToD	6769.12/ 74.4	7586.2/ 83.41	2538.07/ 27.91
Aggressive ToD	12801/ 140.75	14280/ 157.01	4586.62/ 50.43

Figure 4.5: Potential annual revenue by switching to a) Standard ToD tariff and b) Aggressive ToD tariff from flat energy tariff

20 Xinyu Chen et al., "Impacts of Fleet Types and Charging Modes for Electric Vehicles on Emissions under Different Penetrations of Wind Power Xinyu," Nature Energy 3, no. May 2018 (2018), https://doi.org/10.1038/s41560-018-0133-0.

The amount of savings that can be potentially made is dependent on the charger rating and the average distance travelled, which is shown in Figure 4.6.The amount of savings is positively correlated to the charger power rating, with higher power chargers having higher annual savings. There is also a positive correlation between the average monthly distance travelled with the annual savings.



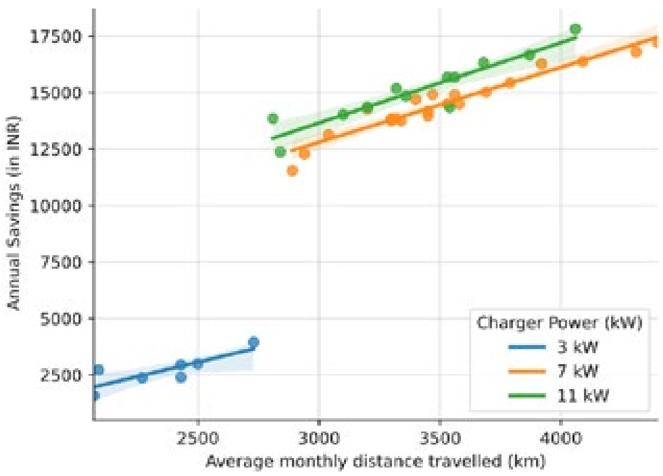
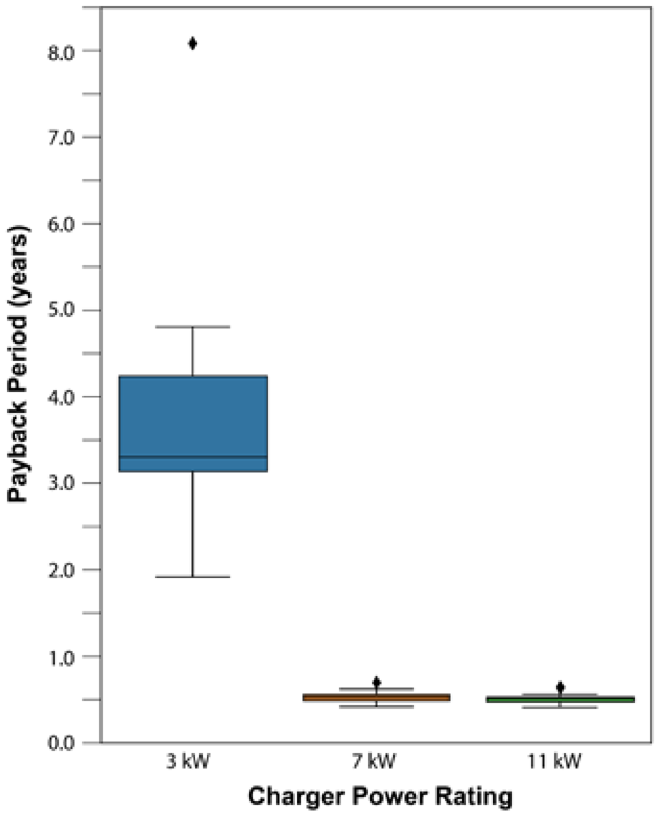


Figure 4.6: Variation of annual savings as per monthly distance travelled and the EV charger rating a) Standard ToD b) Aggressive ToD

However, implementation of ToD tariff requires a smart meter to be installed in the user residence. The capital for these smart chargers is typically paid for by the utility and then adjusted in the user's electricity bill. So, considering that the EV owner needs to pay the cost of the smart meter, the payback period for the smart meter have been given in Figure 4.7, which shows that, for charger ratings of 7 kW or higher, the smart meter is paid back for within a year, however, for slow chargers of 3 kW, the payback period is higher.



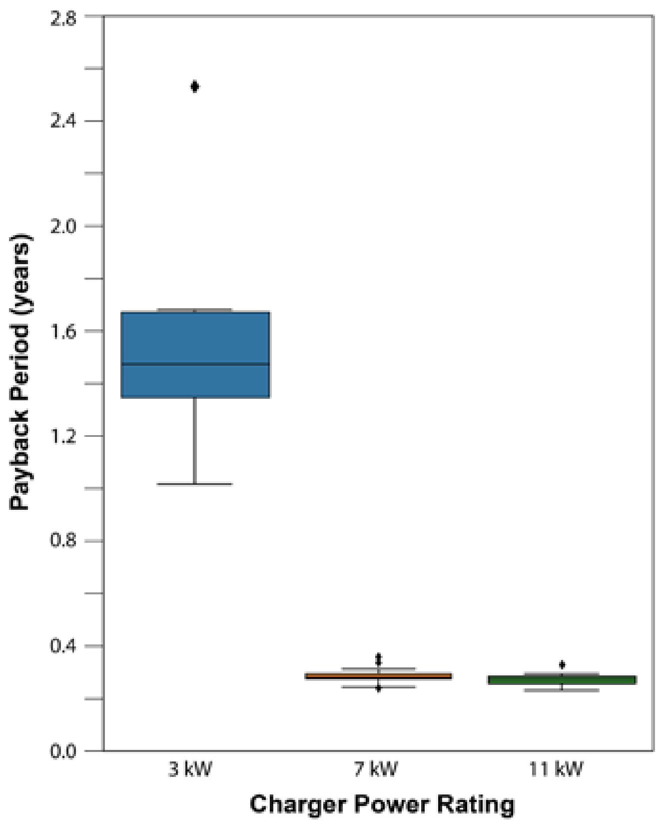


Figure 4.7: Payback period of smart meters with EV charger power rating for a) Standard ToD tariff and b) Aggressive ToD tariff

4.6.1.2 Impact on Public Charging Station

In the analysis it has been assumed that ToD tariff has no impact on the charging behaviour of EV users while utilizing PCS. The charging behaviour is determined solely by their charging needs. However, depending on the business model adopted, the PCS can have different profit margins.

The behaviour of EVs arriving at the PCS to charge their EVs has been given in Figure 4.8Figure 5.8 and Figure 4.9 Figure 5.9. Figure 4.8 gives the probability of an EV arriving at the PCS for charging, which shows that the mid-day periods are the busiest for the PCS, with the EV arrival significantly reduced for the late evening and early morning periods. Each EV has its own energy requirement as well as charging configurations. The EVs arriving at the PCs are either configured with a 3 kW/ 7 kW/11 kW/ 22 kW onboard charger and a 50 kW DC charging (not all EVs are equipped with DC charging). The amount of time the EVs need to be plugged-in to a charger in the PCS based on the energy required and the charging configuration is given in Figure 4.9.

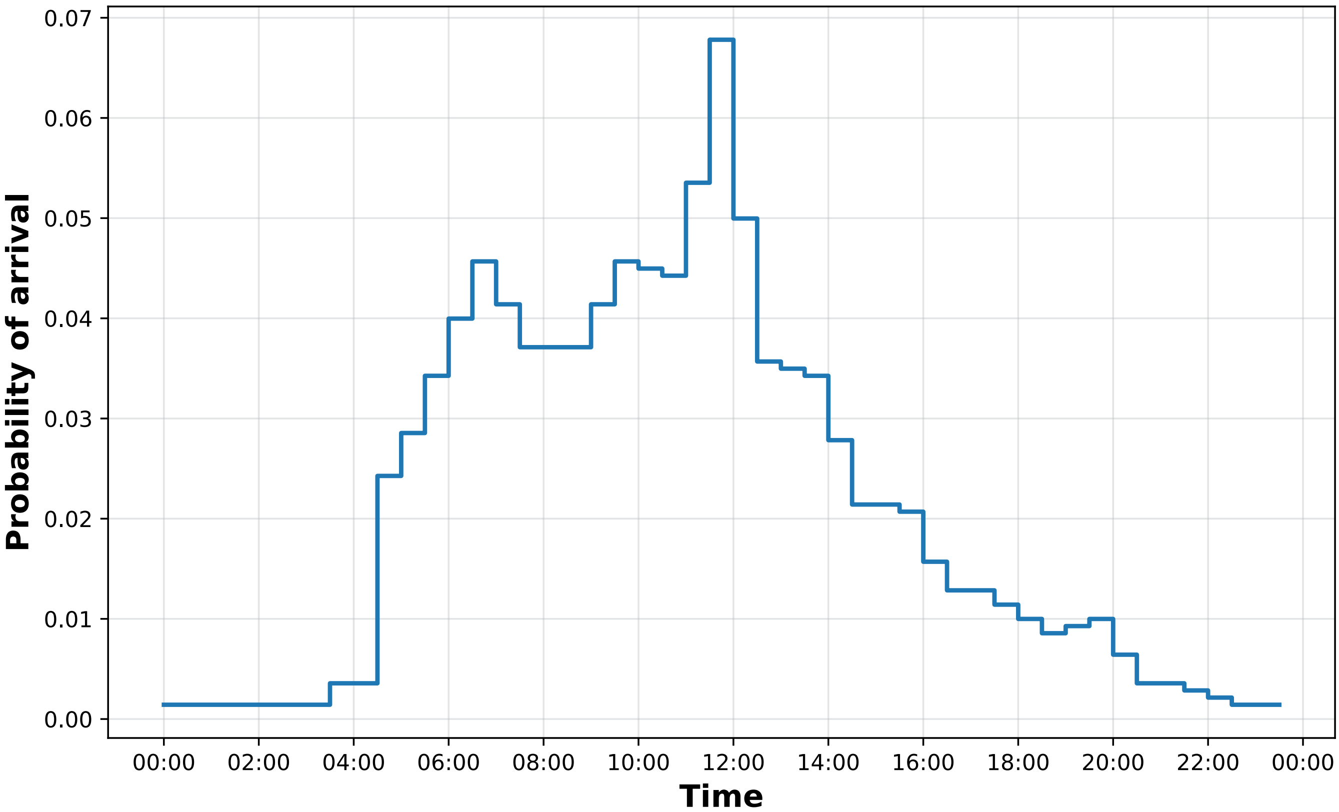
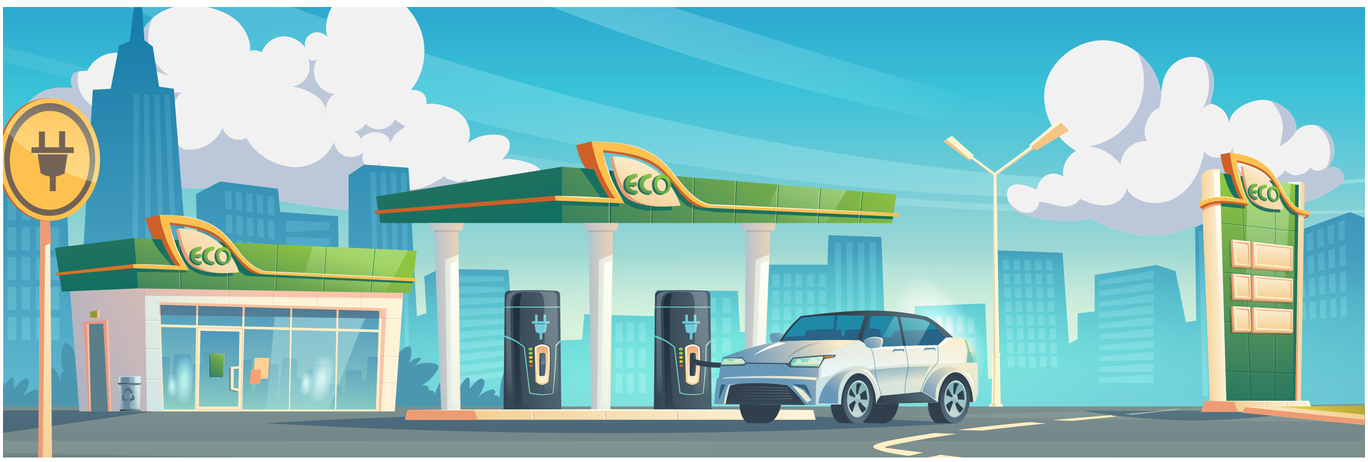


Figure 4.8: Probability of EV arriving at PCS[21]



21 Ahmad Almaghrebi et al., "Data-Driven Charging Demand Prediction at Public Charging Stations Using Supervised Machine Learning Regression Methods," Energies 13, no. 16 (January 2020): 4231, https://doi.org/10.3390/en13164231.

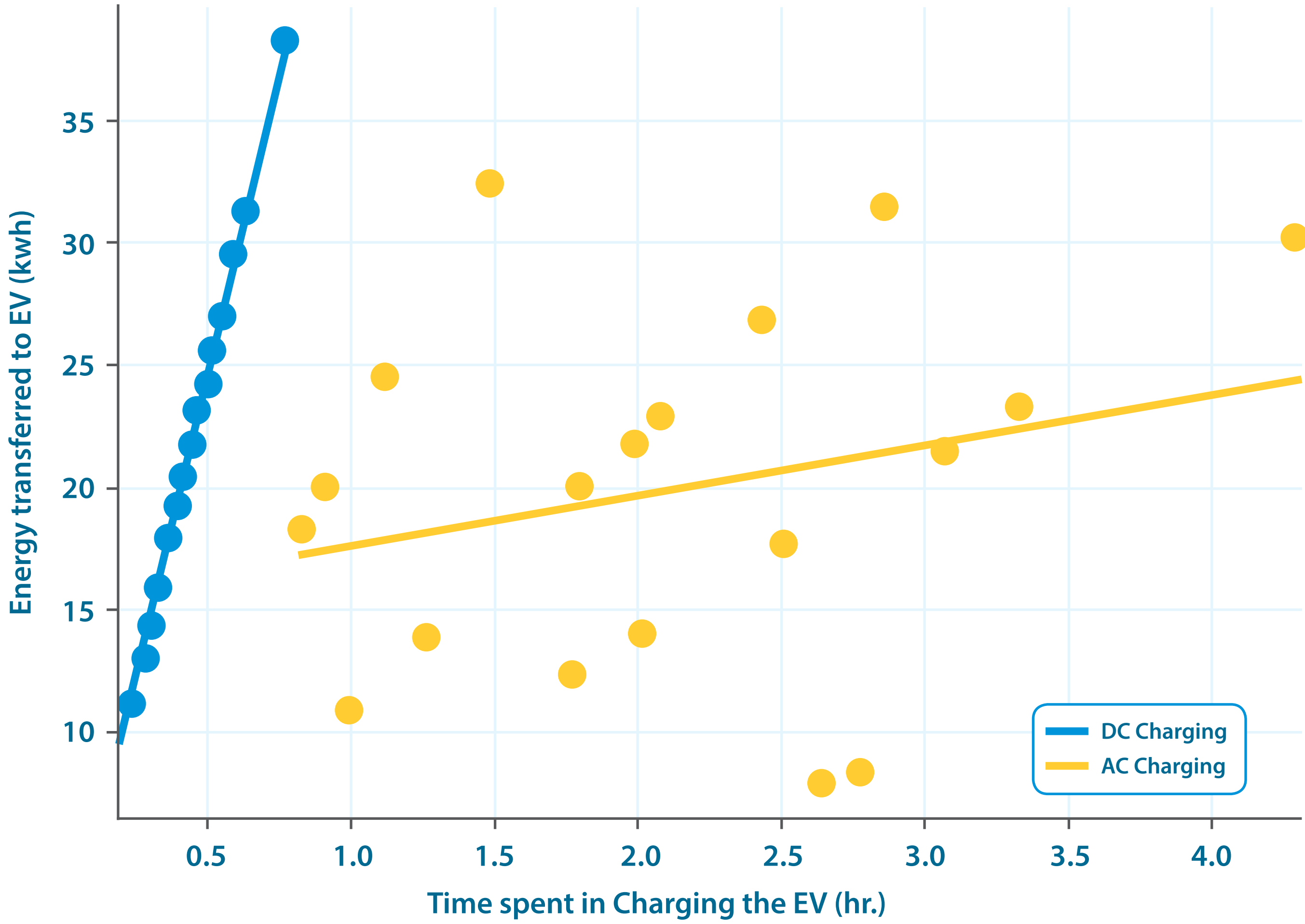


Figure 4.9: Dependence of energy transferred to EV on the time required for charging

Three different PCS business models have been considered for analysis, as given Table 4.13. For the three business cases the two different ToD tariffs were applied and analyzed.

Table 4.13: Scenarios used for analysis

		Buy energy from utility	Sell energy to EV user
Case 1: Standard ToD	Scenario 1	At fixed tariff (INR 5/ kWh)	Sell at fixed price (INR 7.5/kWh)
	Scenario 2	At Standard ToD tariff	Sell at fixed price (INR 7.5/kWh)
	Scenario 3	At Standard ToD tariff	At Standard ToD tariff with 15% profit margin
Case 2: Aggressive ToD	Scenario 1	At fixed tariff (INR 5/ kWh)	Sell at fixed price (INR 7.5/kWh)
	Scenario 2	At Aggressive ToD tariff	Sell at fixed price (INR 7.5/kWh)
	Scenario 3	At Aggressive ToD tariff	At Aggressive ToD tariff with 15% profit margin

The monthly profits for the PCS in the different scenarios and different utilization factors have been given in Table 4.14, which shows that the PCS is greatly benefited by purchasing the power from the utility at the ToD grid while selling the energy at a fixed price. However, by selling the energy at ToD price with an added profit margin, although the profit of the PCS has significantly reduced, it can be argued that the benefits have been enjoyed by the EV user, thereby making them more inclined to use the PCS, which may, in turn, increase the utilization factor of the PCS.

Table 4.14: Monthly profit (in INR/EUR)of PCS under different scenarios and different utilization factors

		Utilization factor = 10%	Utilization factor = 27%
Case 1: Standard ToD	Scenario 1	INR 51,313 (EUR 564.18)	INR 1,17,865 (EUR 1295.91)
	Scenario 2	INR 70,288 (EUR 772.81)	INR 1,45,055 (EUR 1594.87)
	Scenario 3	INR 12,547 (EUR 137.95)	INR 31,280 (EUR 343.92)
Case 2: Aggressive ToD	Scenario 1	INR 51,313 (EUR 564.18)	INR 1,17,865 (EUR 1295.91)
	Scenario 2	INR 91,707 (EUR 1008.31)	INR 1,87,709 (EUR 2063.84)
	Scenario 3	INR 9,335 (EUR 102.64)	INR 24,882 (EUR 273.58)

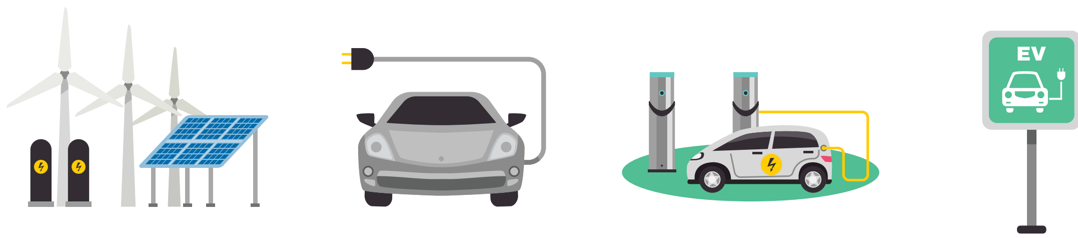
4.6.2 RE Integration for EV charging

The use of renewable energy in addition to providing benefits to emissions, can also potentially impact the economics of the PCS.

A 210 kVA EV charging station with two 50 kW CCS chargers and five 22 kW Type 2 AC chargers have been considered for the analysis. The average CAPEX and OPEX cost for installation of the charging station has been detailed in Table 4.15.

Table 4.15: Charging station specification[22]

Type of Charger	Number of Chargers	Power Output (kW)	Approx. Cost in INR Including GST @18% (INR/EUR)	Number of EVs that can be charged	Simultaneously Maximum Energy sold to EVs per day (8 hrs/day) (kWh)
CCS	2	50	14,50,000/ 16,462	2	800
Type 2 AC	5	22	6,25,000/ 7,095	5	880
New Electricity connection (250 kVA) Transformer, Cables, breaker, Energy Meter			7,50,000/ 8,515		
Civil Works			2,50,000/ 2,838		
EVSE Management Software			40,000/ 454		
CCTV Camera Setup			30,000/ 340		
Total (excluding RE CAPEX cost)			**31,45,000/ 35,706**		**1,680**



22 Framework adopted from Nimesh Shah, "Cost Estimates and Revenue Model for a Public Charging Station (PCS)," PluginIndia, 2019, https://www.pluginindia.com/blogs/cost-estimates-and-revenue-model-for-a-public-charging-station-pcs.

OPEX	
Technicians (1 @ INR 25,000/ month for 6 months)	1,50,000/ 1,703
Site Maintenance (1 @ INR 15,000/month for a year)	1,80,000/ 2,043
Network service provider fee	6000/68.12
Land Lease Rental @ INR 50,000/ month	6,00,000/ 6,811
EVSE Management Software Fee (10% of net margin on electricity charges	10% of revenue margin
Advertising @ INR 3,000/month	36,000/ 408.72

Assumptions made for this analysis

- The PCS purchases electricity at INR 6.09/kWh (EUR-¢ 6.91/kWh)
- Four different prices for provision EV charging service have been considered INR 7/kWh (EUR-¢ 7.95/kWh), INR 9/kWh (EUR-¢ 10.22/kWh), INR 15/kWh (EUR-¢ 17.03/kWh) and INR 20/kWh (EUR-¢ 22.71/kWh).
- The utilization of the chargers is expected to increase by 10% annually.
- It has been assumed that the chargers have an operational life of 10 years, while the PV has a lifetime of 20 years.

For analysis of the impact of RE integration, different PV penetration levels have been considered. The penetration level is defined based on the annual energy consumption of the PCS. The NPV of the PCS considering 10 years of operation has been given in Table 4.16. From the table it can be observed that, with higher penetration of RE, although there is a larger initial investment, the NPV of the business over a period of 10 years is higher compared to without RE. The same trend is seen irrespective of the charge levied by the PCS for EV charging.

Table 4.16: NPV of the PCS business for the different scenarios considering 10 years of operation

	Scenario A (85% RE)	Scenario B (60% RE)	Scenario C (50% RE)	Scenario D (45% RE)	Scenario E (40% RE)	Scenario F (15% RE)	Scenario G (0% RE)
Size of PV installation (kW)	293	207	173	155	138	52	0
Total CAPEX (including PV) (INR/EUR)	1,92,60,000/ 218,664	1,45,30,000/ 164,963	1,26,60,000/ 143,733	1,16,70,000/ 132,493	1,07,35,000/ 121,877	60,05,000/ 68,176	31,45,000/ 35,706
NPV (EV charging @ INR 7/kWh)	1,63,292.87/ 1,853	-9,28,324.92/ -10,540	- 13,83,579.26/ -15,708	-15,64,688.38/ -17,764	-17,92,315.55/ -20,349	-28,83,933.35/ -32,742	-35,20,296.81/ -39,967
NPV (EV charging @ INR 9/kWh)	1,00,60,020.15/ 114,215	89,68,402.35/ 101,821	85,13,148.01/ 96,652	83,32,038.89/ 94,596	81,04,411.72/ 92,012	70,12,793.93/ 79,618	63,76,430.47/ 72,394
NPV (EV charging @ INR 15/kWh)	3,97,50,201.96/ 451,297	3,86,58,584.17/ 438,903	3,82,03,329.83/ 433,734	3,80,22,220.71/ 431,678	3,77,94,593.54/ 429,094	3,67,02,975.74/ 416,700	3,60,66,612.29/ 409,476
NPV (EV charging @ INR 20/kWh)	6,44,92,020.15/ 732,198	6,34,00,402.35/ 719,805	6,29,45,148.01/ 714,636	6,27,64,038.89/ 712,580	6,25,36,411.72/ 709,996	6,14,44,793.93/ 697,602	6,08,08,430.47/ 690,377

The impact of RE penetration is also dependent on the EV tariff placed on the PCS by the respective DISCOMs. So, the analysis has been extended to get the NPV of the PCS businesses considering 10 years of operation for different EV tariffs placed on the PCS and the charges levied by the PCS from the EV users.

Besides the potential economic savings of the PCS, usage of renewable energy for charging of EVs also has huge implications on the greenhouse gas emissions. However, financial quantification of the externalities of electric power generation is needed to analyse the impact of RE integration. These external costs include the impact of greenhouse gas emissions from electricity generating facilities, the associated climate change and other related effects. Extensive work has already been carried out in determining the financial implication of greenhouse gas emissions from different generating units. A study by the European Commission have determined that the external costs for electricity production in the European Union (EU) as given in Table 4.17. These costs were determined for most EU member states and is within the EU range as mentioned in Table 4.17. In this analysis, the median value of the external costs has been utilized.

Table 4.17: External costs for electricity production in the EU (INR/kWh (EUR-¢/kWh)) [23]

	Coal & Lignite	Peat	Oil	Gas	Nuclear	Biomass	Hydro	PV	Wind
EU range	1.76-13.21 (2-15)	1.76-4.04 (2-5)	2.64-9.69 (3-11)	0.89-3.52 (1-4)	0.17-0.62 (0.2-0.7)	0-4.4 (0-5)	0-0.88 (0-1)	0.53 (0.6)	0-0.22 (0-0.25)
Median	3.52 (4)	2.20 (2.5)	2.64 (3)	0.88 (1)	0.26 (0.3)	0.88 (1)	0.18 (0.2)	0.53 (0.6)	0.11 (0.125)

Figure 4.10 shows the sensitivity of the NPV of the PCS business to the energy buying price for the PCS and the selling price considering different PV penetration levels. In this analysis, the total capital expenditure, all the operational and maintenance cost, the annual revenue and the additional cost of emissions (shown in Figure 4.11) have all been taken into consideration. Figure 4.10 indicates that under the assumptions considered for this analysis, increasing RE penetration leads to increased profitability for the PCS, for example, at a buying price of INR 8/kWh (EUR-¢ 9.08/kWh) and selling price of INR 19/kWh (EUR-¢ 21.57/kWh), the net benefits can be increased from INR 25 million (EUR 0.28 million) to INR 43.5 million (EUR 0.49 million) over a 10-year period by increasing the RE penetration to 85% from 0%. The return on investment is further increased if the PCS sells its charging services at lower price points (but the overall profit margin of the business is reduced). For example, for a selling price of INR 13/kWh, the net benefits can be increased from INR 0.25 million (EUR 2,800) to INR 18.82 million (EUR 0.21 million) by increasing the RE penetration from 0% to 85%.

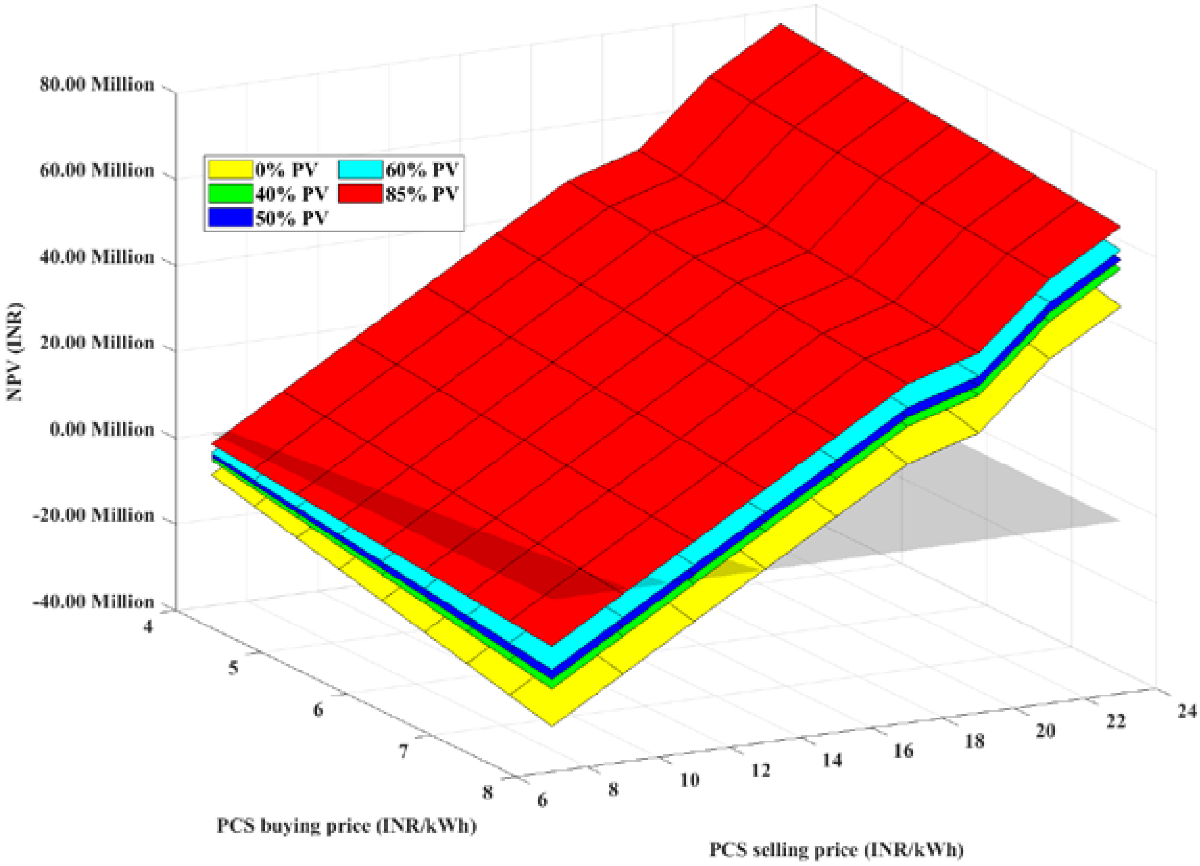


Figure 4.10: Sensitivity of NPV for the PCS with its buying and selling price

23 Owen, Anthony D. "Renewable energy: Externality costs as market barriers." Energy policy 34, no. 5 (2006): 632-642.

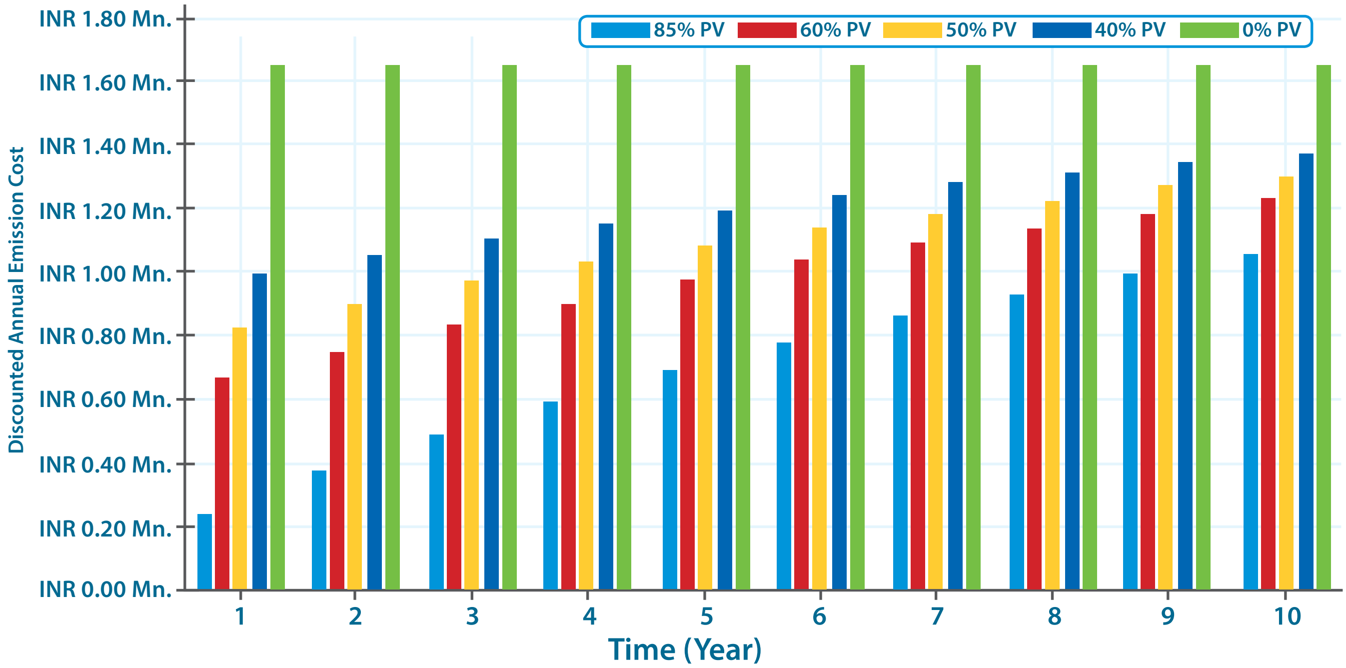


Figure 4.11: Discounted annual emission costs for the different RE penetration levels

The discounted annual emission costs have been shown in Figure 4.11, which have been calculated based on the amount of energy purchased from the utility for the year and considering that all utility power is produced in coal based thermal power plants. It can be observed that the annual emission costs are highest for the scenario with 0% RE penetration, and the lowest with 85% RE penetration, which is to be expected as higher amount of energy is being produced by coal based thermal generating stations. Another trend seen is that the cost of emission increases with time. This is because the usage of the PCS has been considered to have an annual increment of 10%, while the installed PV capacity remains constant. So, in the later years, a share of the total energy would be purchased from the utility. This cost can be potentially reduced if PV capacity addition accounts for future increase in energy usage.

4.6.3 Smart Charging- Unidirectional

Smart charging – unidirectional are of different types as already discussed in Chapter 8 (Page 131) of Report 1: Fundamentals of Electric Vehicle Charging Technology and Its Grid Integration. The implementation time period, complexity, and benefits are dependent on the type of smart charging utilized.

4.6.3.1 Dynamic price based smart charging

Here, the electricity price is changing in real-time based on the load on the system, with the price being higher during peak periods and vice-versa. The time resolution of the price signal is dependent on the system but maybe as frequent as in 15 min intervals. Implementation of smart charging using dynamic pricing is however subject to the development of the energy market.

For analysis purposes, dynamic price signal with 30 min time resolution have been considered16. The dynamic price compared to the ToD price have been given in Figure 4.12. Utilizing the dynamic pricing, the EV user can make further savings by charging in periods with lower prices, as given in Figure 4.13.

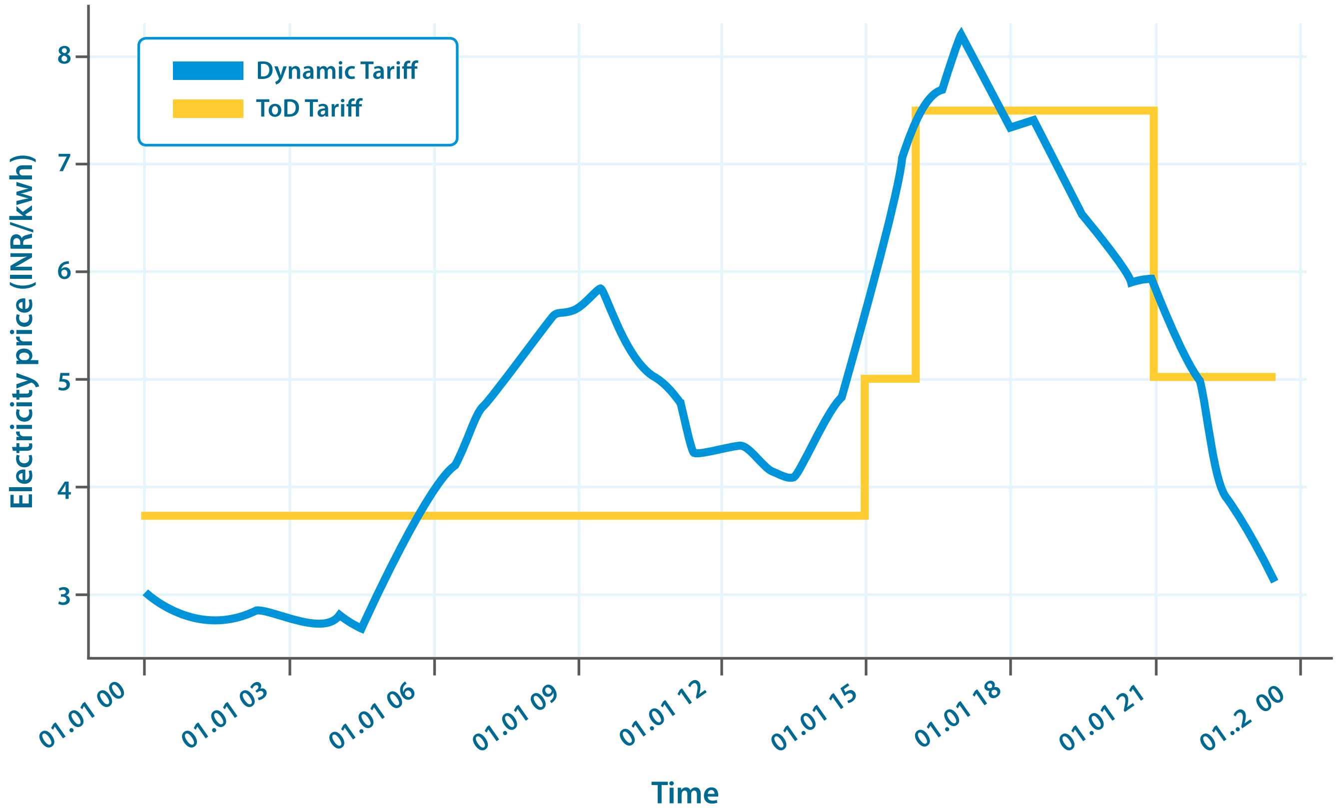


Figure 4.12: Comparison of dynamic pricing with ToD pricing

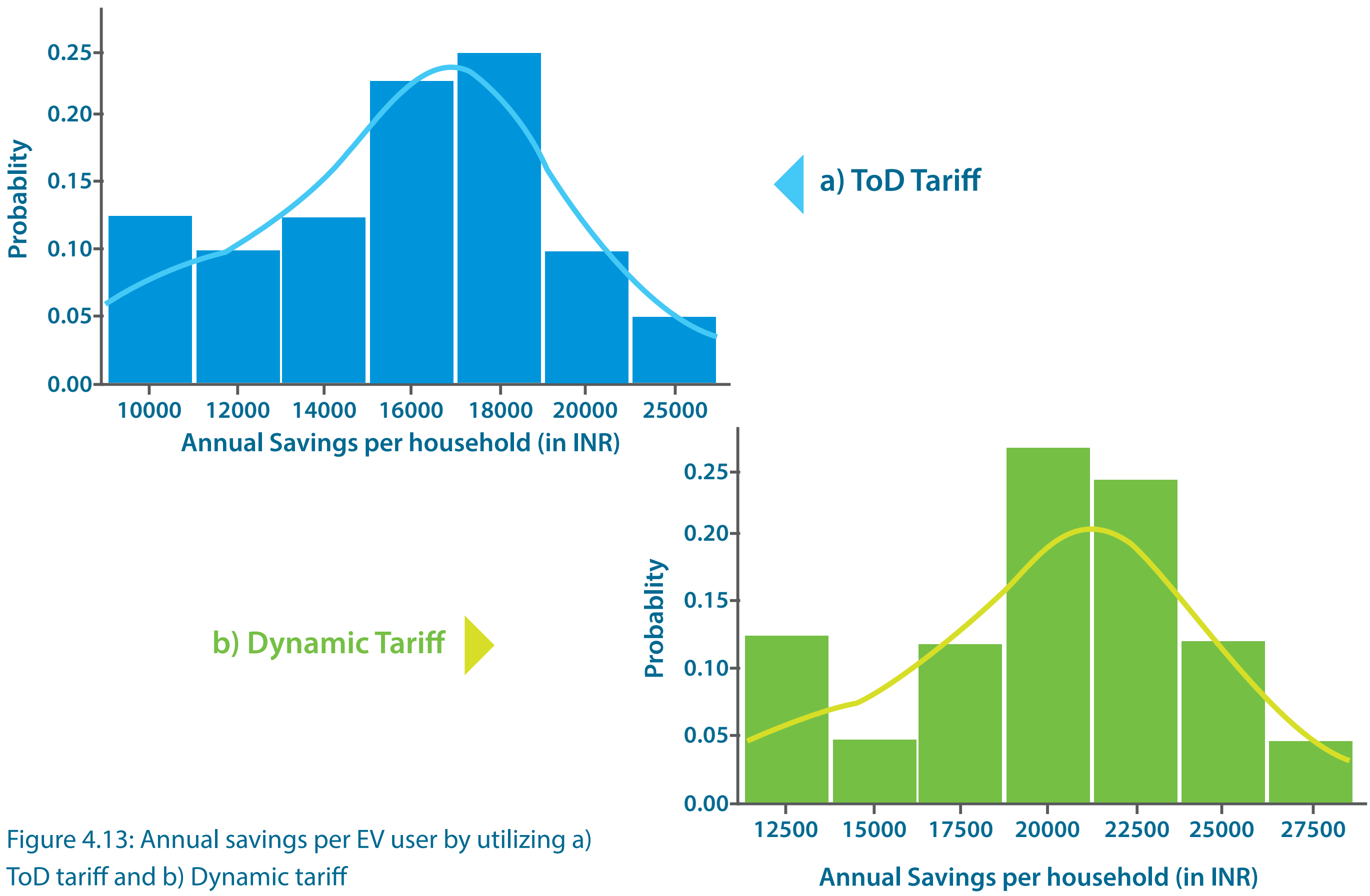


Figure 4.13: Annual savings per EV user by utilizing a) ToD tariff and b) Dynamic tariff

Similar to ToD tariff, dynamic pricing also assists the distribution system operator in reducing the load during peak period and filling up the valley periods as shown in Figure 4.14.

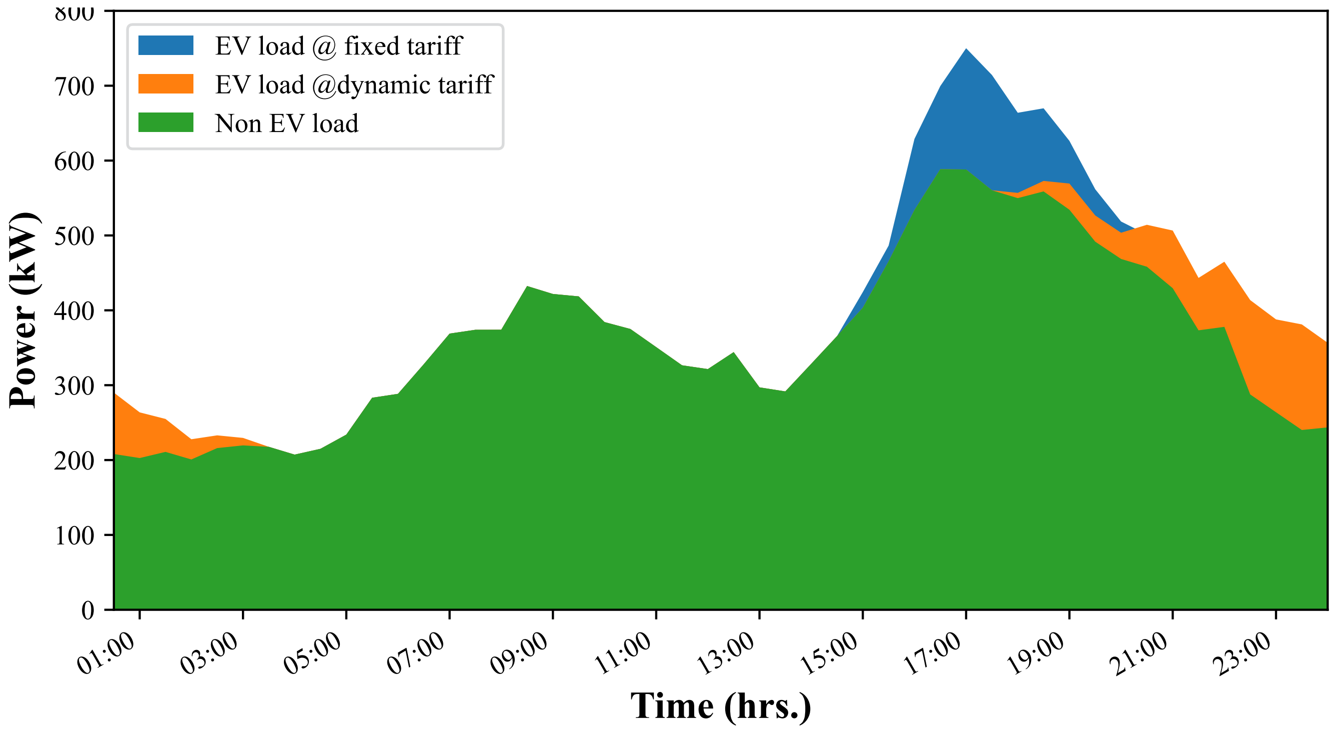


Figure 4.14: Load curve with and without dynamic pricing

4.6.3.2 ToD tariff implemented in system

A simulation study for analyzing the effectiveness of ToD pricing and combination of ToD and PV is performed. A modified 13 bus feeder network shown in Figure 4.15 is considered for the case study. The EV loads are added on specific buses to mimic EV integration into the grid. EV as a constant power load is considered for the simulation.

Case I: ToD tariff implemented in system

The time of use tariff structure is considered as the controlled charging mechanism in the case study. The locations of EV load integration are given in Table 4.18.

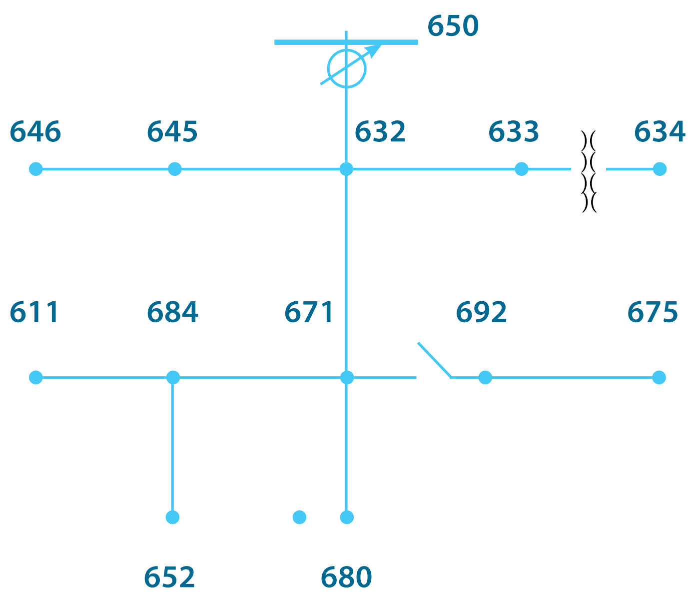


Figure 4.15: Modified 13 bus feeder system

Table 4.18: Number and location of EV load in the system

Bus number	Number of two wheeler or Light load EV	Number of four wheeler or medium load EV
645	20	10
633	10	5
459	30	15
611	15	6
680	30	15
675	20	10

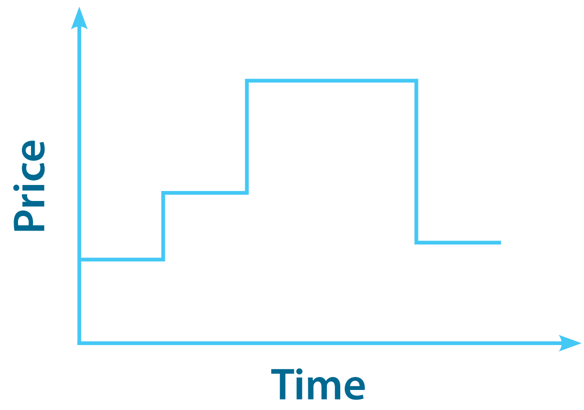


Figure 4.16: ToD tariff structure

The power rating of 2W is considered as 3.3kW whereas 4W vehicle's rating is considered as 24kW. A total of 1176 kW EV load is added in the system. The nature of ToD tariff is shown in Figure 4.16. It tries to mimic the practice ToD tariff prices in the grid.

The corresponding loading of EVs is shown by varying the penetration level of EV loads during different pricing intervals. The simulation results are given below, which focuses on the analysis of bus voltage and the loading profile at varying EV penetration due to ToD prices.

The simulation result of the 632 node voltage and 633-632 line is represented in Figure 4.17 and Figure 4.18. The results shows that the EVs charging behaviour follows the ToD tariff prices i.e., at low price block, more EVs are connected in the network so the pu voltage value is comparatively lower as compared to high-cost blocks. The price and loading relation are shown in Figure 4.18. It shows that at low price block, line loading is high as compared to high price block's line loading because at low price block, higher number of EVs simultaneously charge together. The significant loading variation following the ToD price is shown in loading of line A and B because EVs are not connected in phase C.

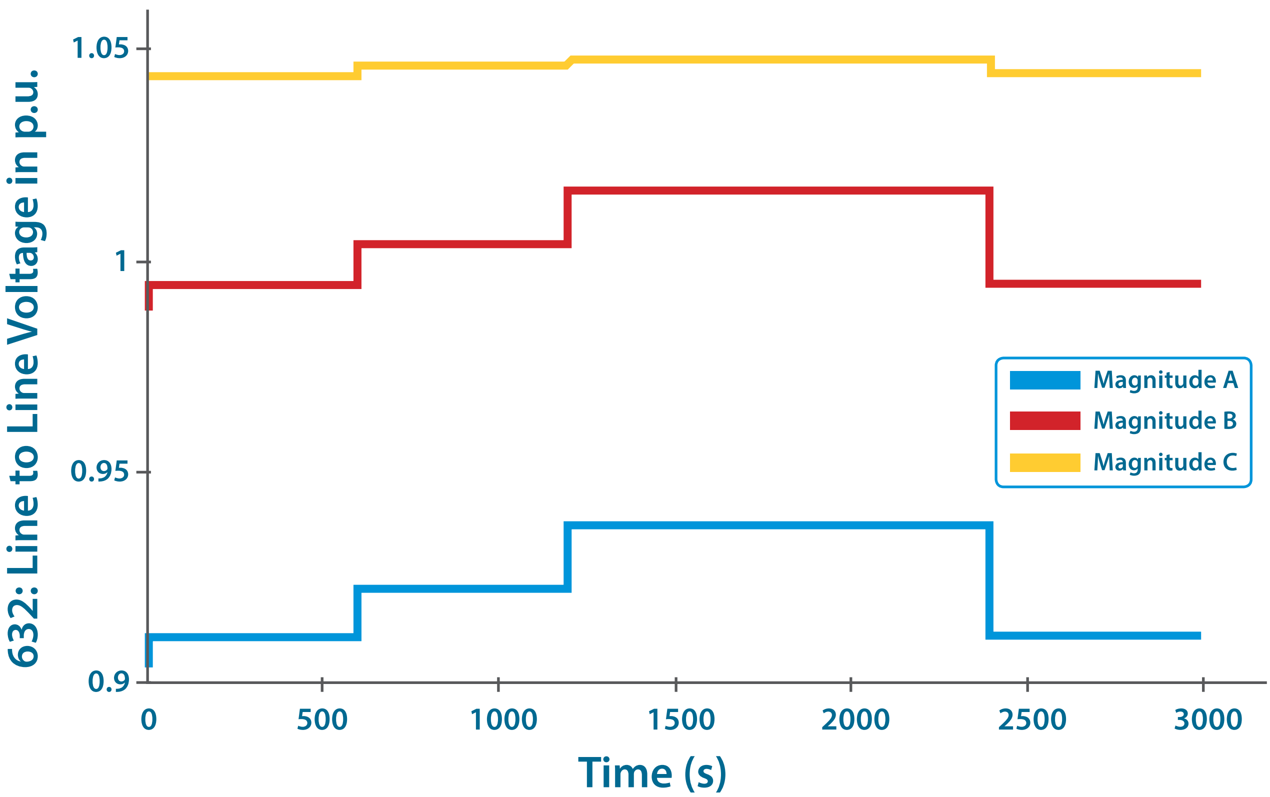


Figure 4.17: Voltage profile of bus 632

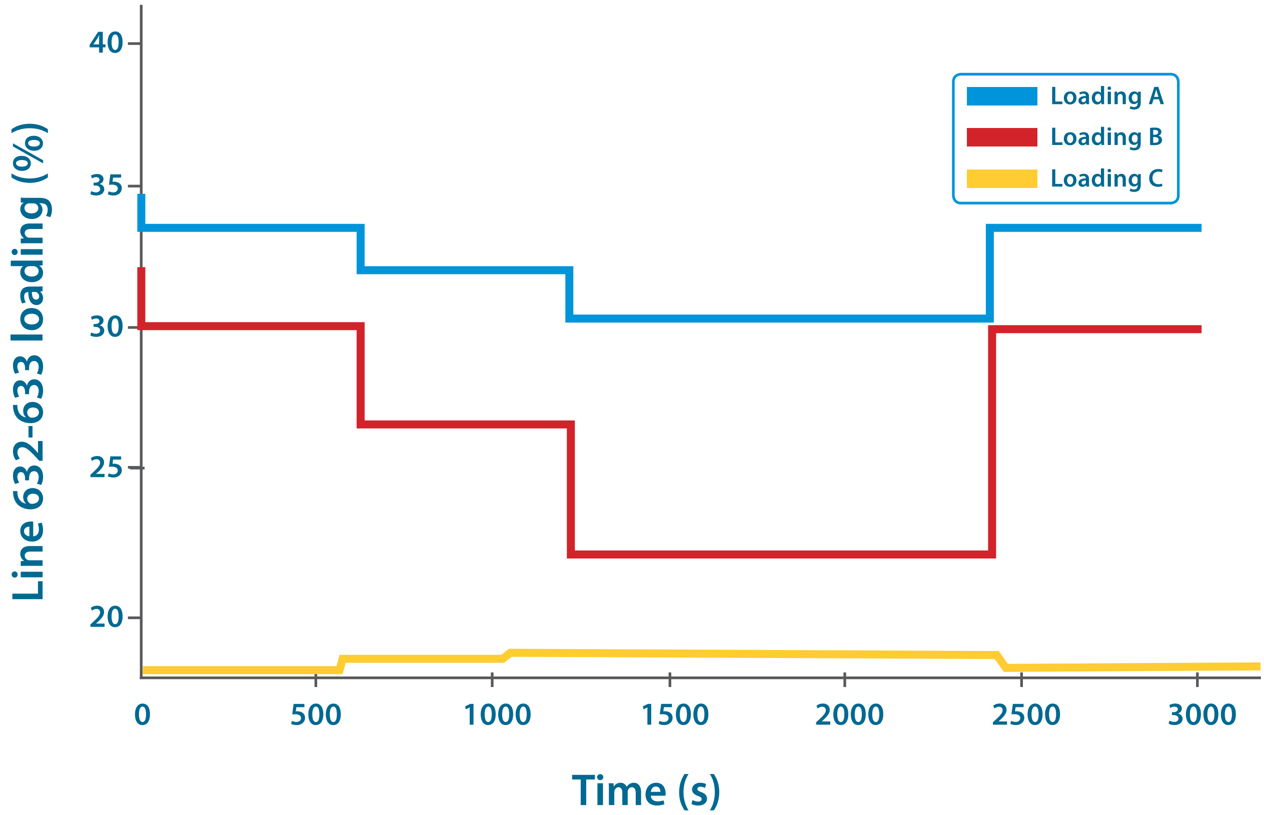


Figure 4.18: Loading profile of 632-633 line

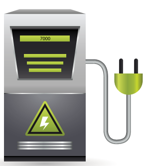
Case II: ToD tariff and PV is present in system

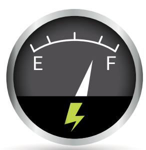
In reference to the previous case study, renewable generation from solar PV is integrated into the system. It further supports the grid by providing clean energy near to the loads. Locations of PV interjection in modified 13 bus feeder system is shown in Table 4.19:

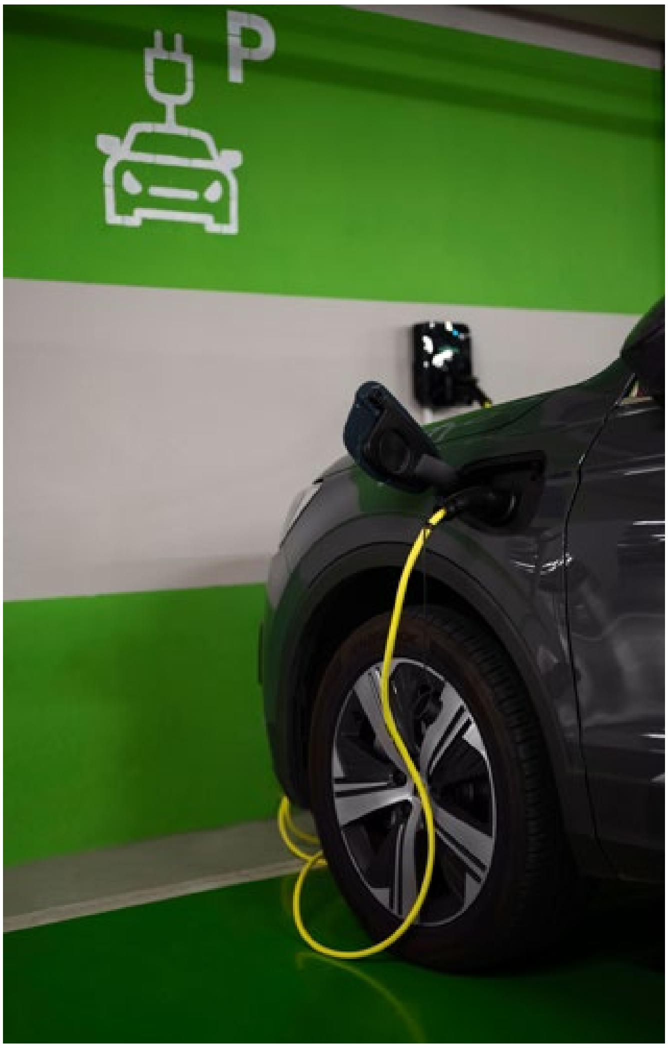
Table 4.19: Location and amount of PV added in the network

Bus Number	PV capacity (kW)
640	200 kW
634	700
684	200
RG 60	700

The presence of the PVs in the system has reduced the ToD tariff further at high RE generation periods.







The results show voltage and loading profile of the same bus and line shown in previous case.

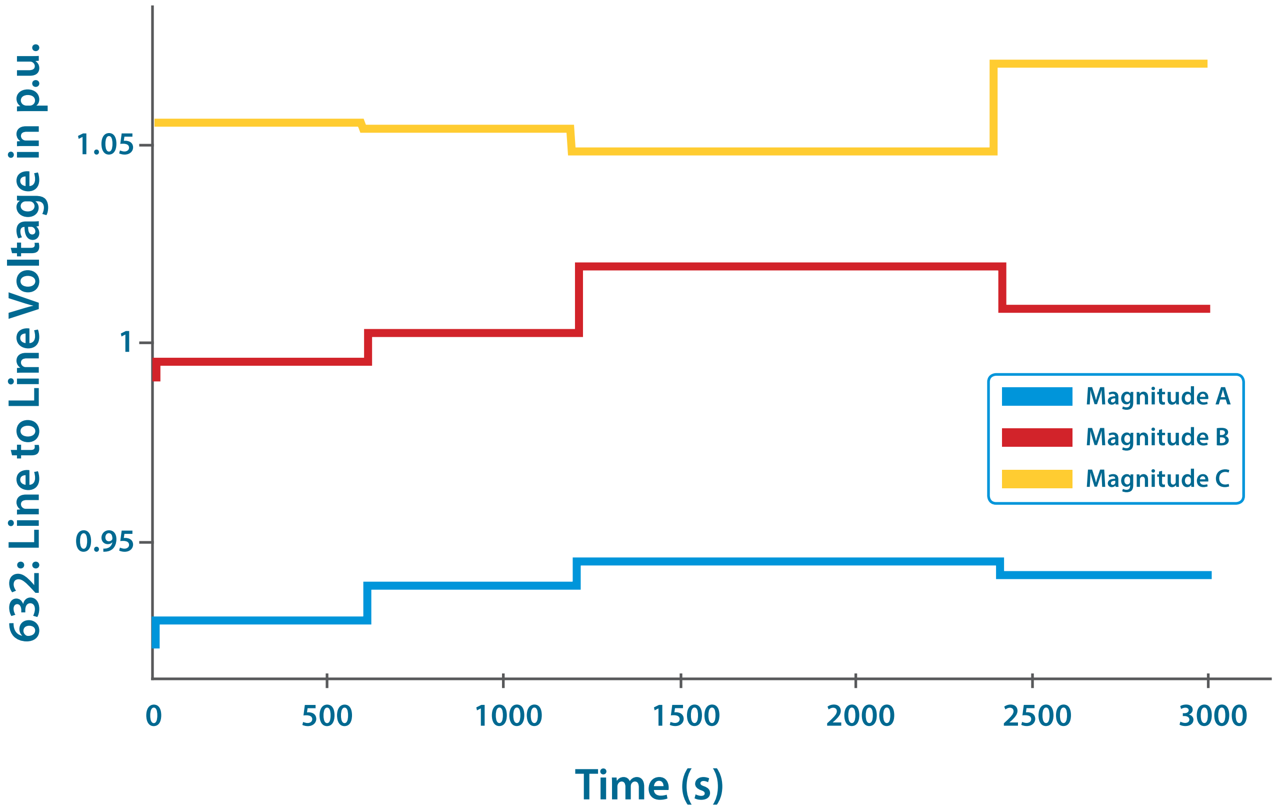


Figure 4.19: Voltage profile of bus 632

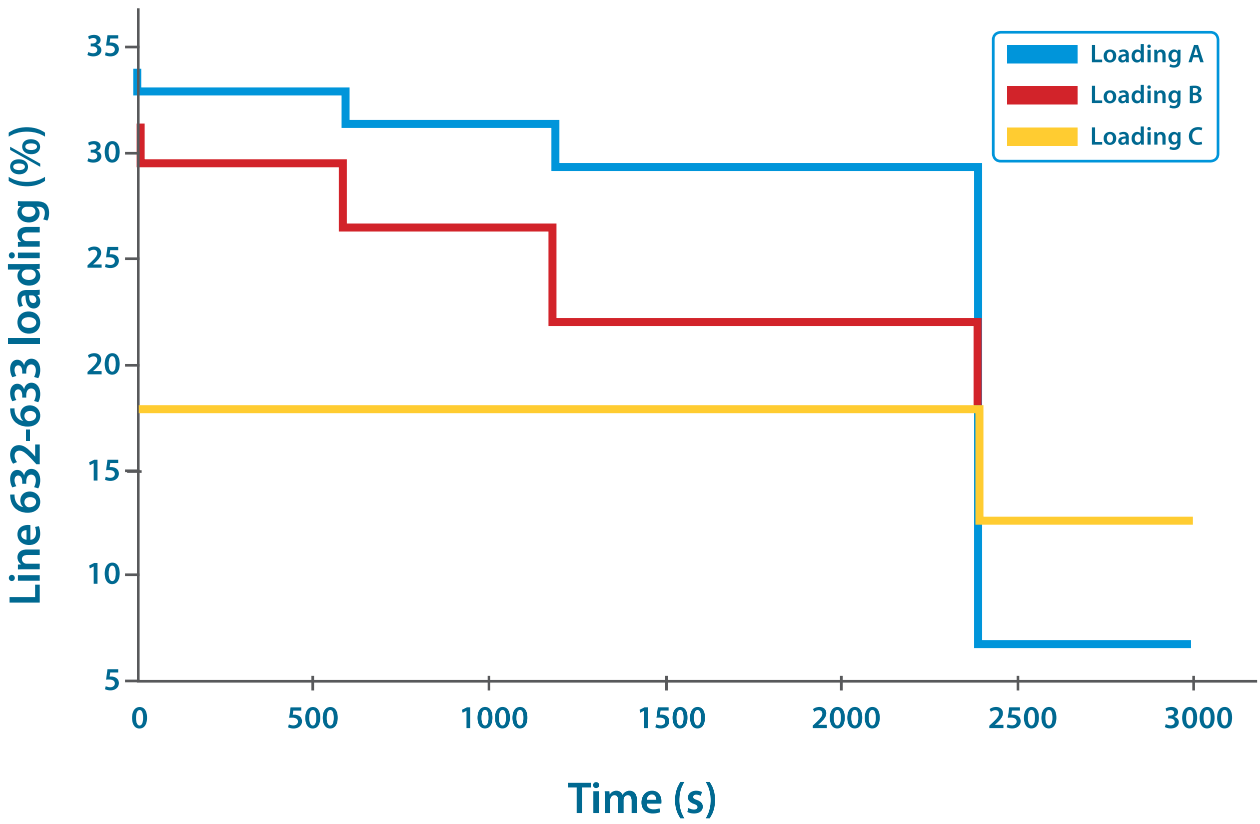


Figure 4.20: Loading profile of 632-633 line

Comparative analysis of the results of voltage and loading in both the cases, shown in Figure 4.19 and Figure 4.20, depicts that the voltage profile and loading profile are improved in case II when PV and ToD combination is implemented in the network.

The phase A voltage value in case I is around 0.91 pu and it improves to 0.93 pu in case II. In the loading profile of case I and II the improvement is shown in the figures. Loading at the last block of time shows that in presence of PV the loading is reduced as compared to case I.

4.6.3.3 Demand response from EV

Another application of smart charging is utilization of EVs as demand response resources. To achieve this, the EVs need to be aggregated by some aggregator to have a sufficient minimum capacity to participate in demand response. By participating in demand response programs, the EV user gains monetary benefits, while system operator can optimize the system operation.

An example architecture for the implementation of demand response has been given Figure 4.21, where the main participants are the independent system operator (ISO), the aggregators and the EVs[24]. The roles of the aggregator are,

- It aggregates distributed EV resources into sufficient capacities
- It forecasts the EV charging load
- Streamlines the provision of demand response, so that the EV owners do not have to manually control the EV charging based on the demand response requirement

However, not all EV users are able to participate in demand response services throughout the year, with their participation being dependent on their travel needs. The EV users who are willing to participate can be termed as flexible EV loads and the remaining as inflexible loads.

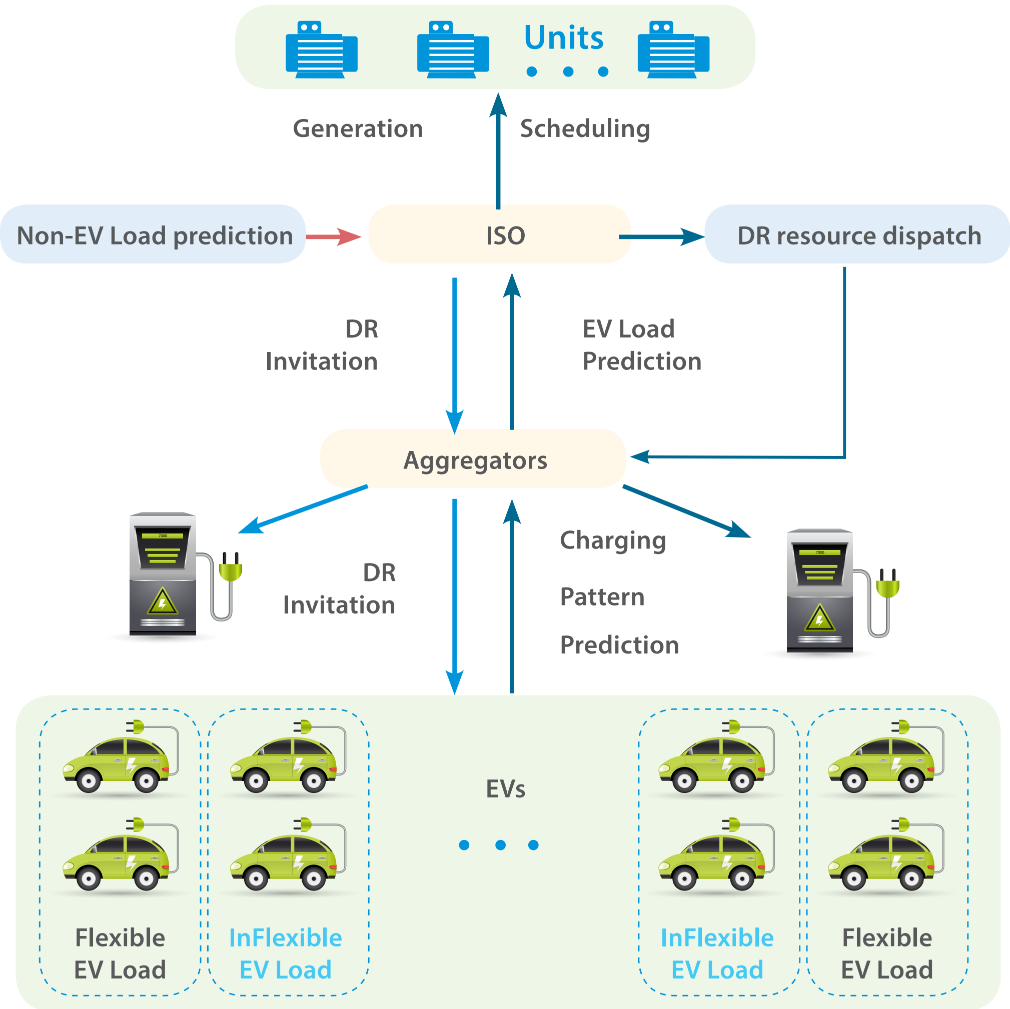


Figure 4.21: Demand response architecture[25]

25 Fang et al.

A sample case study has been referred to analyse the impact of demand response. The daily load curve of the test system has been given in Figure 4.22. The test system also imports power, as given in Figure 4.22. The difference between the peak and valley is more than 10,000 MW. It has been considered that there are 250,000 EVs in the test system with a charger rating of 7 kW each. Each EV has been modelled with its own charging patterns and requirements, and of the total EV fleet 30% have considered participating in a demand response program.

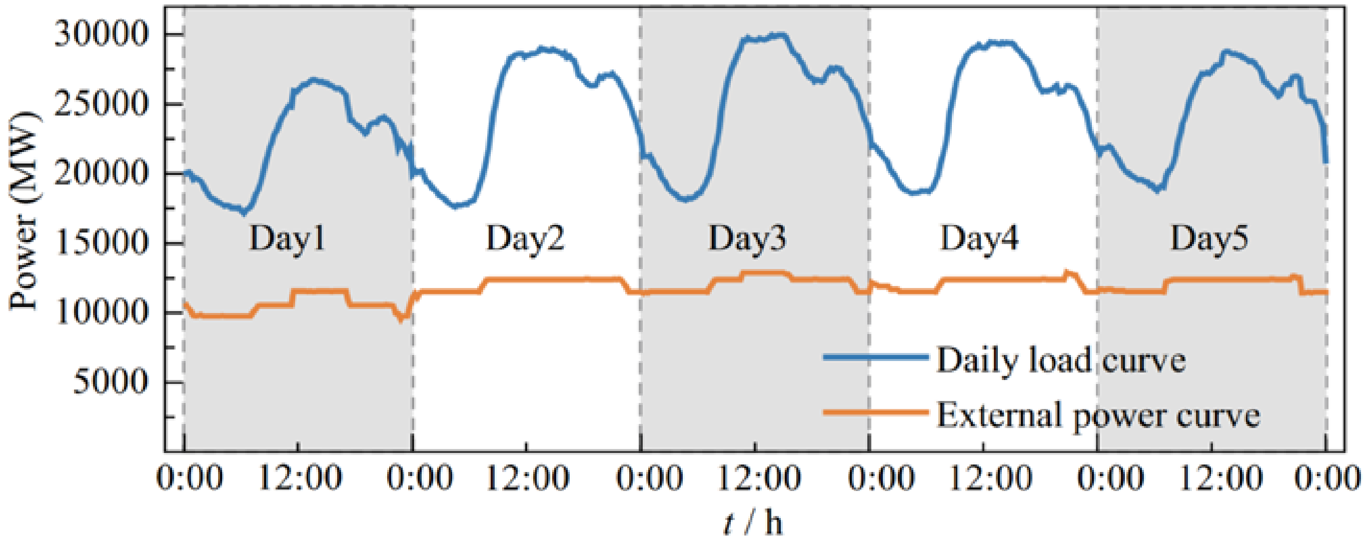


Figure 4.22: Daily load curve and the external power import for the test system[26]

The impact of DR on the load curve of the system has been given in Figure 4.23, which shows that the peak-valley difference has been reduced. The start-up and shutdown costs have also reduced as the load curve have been slightly levelled, as given in Table 4.20. With time, as the EV market grows, the impact of a larger number of EVs participating in DR has been shown in Figure 4.24.

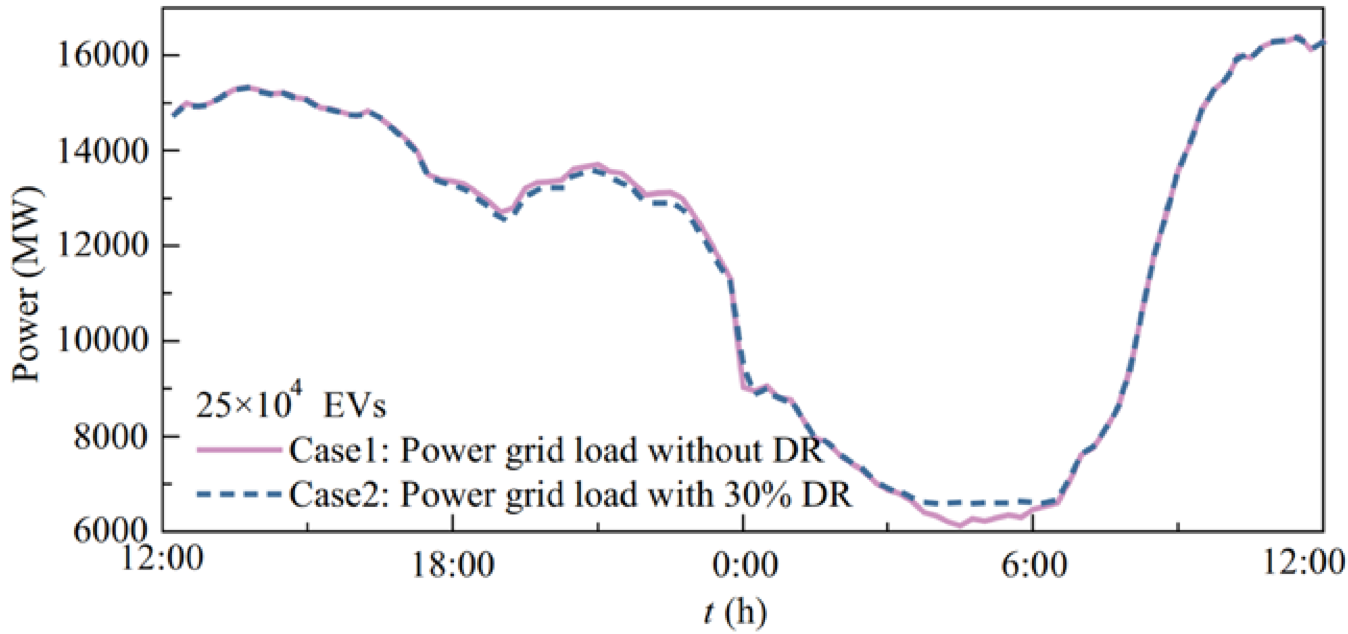


Figure 4.23: Load curves with and without DR from EVs[27]

26 Fang et al.
27 Fang et al.

Table 4.20: Results of the test system [28]

Case	Start-up/shutdown costs (104 INR)	Peak-valley ratio (%)
No DR from EV	5848	61.5%
30% EV participate in DR	3369	58.59%

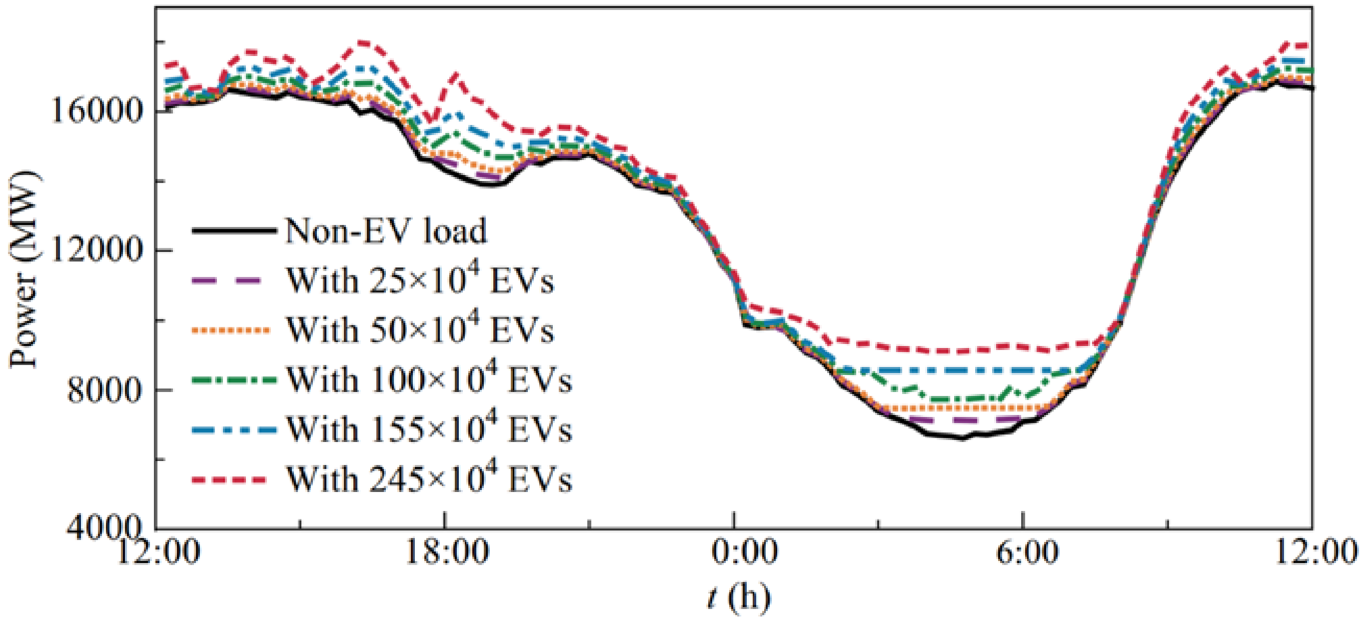


Figure 4.24: Impact of DR from EV on load curve with increased number of EVs [29]

4.6.4 Interoperability

Interoperability, is one of the cornerstones for seamless adoption of EV charging infrastructure, as this will enable the CPOs to facilitate charging services to a higher number of EV users, while at the same time increasing the number of available charging stations for the EV user. It incorporates two different necessities, as mentioned below.

- To have an interoperable ecosystem, the charging standards need to be harmonized, so that any EV can be plugged into the chargers provided by the charging stations.
- There is also need for software interoperability, i.e., an EV should have the necessary authentication and permission to seamlessly charge at any charging station. This is called eRoaming.

The following design principles are needed for EV roaming,

1. **Demand and supply of roaming services** - The demand for roaming services is increasing as the number of EVs increase. Private charging stations can meet the significant demand for EV charging. Still, public charging stations are also crucial for EV owners who travel long on holidays, or long trips, the ones owning EVs with small battery capacities and those who cannot charge their vehicles at home or work. Under such circumstances, EVs can take a subscription of one charge point operator and execute their charging from that operator. If there are many charge point operators, multiple subscriptions would be required, which is not practical.

   Hence, roaming allows the EV owners to use any charging point as a guest user without a subscription. This extends the network of charge points where the EVs can charge. This service is similar to the concept of roaming in mobile phones, where consumers can use their mobile phones abroad by having a subscription to the home operator.

2. **Inclusion of core functionalities** - The functionalities that are required for seamless experience are identification of EV users, authentication of the charging session, recording the charging session information, capturing billing details and ensuring data security and privacy.

28 Fang et al.
29 Fang et al.

3. **Fiscal Regulations** - Charging an EV is termed as either an act of 'providing a service' or 'selling energy'. A clear framework complying with the international trade rules and regulations is required if it is treated as 'providing a service' and not a case of energy selling, making selling energy to private customers difficult. This issue can be resolved by making the charge point the end-customer, not the EV user. In this case, the CPO has to take care of the energy tax, and this provision is considered an exception to regulation for e-mobility. For example, in Germany, EV charging is classified as selling energy, whereas it is classified as a service in France.

4. **Architectural openness** - Architectural openness should be the design principle for roaming protocols. This indicates the degree of flexibility of integration of new modules, elements into the system. A standard having a list of authentication options and allowing an authentication option to be added on the list without updating the standard is an example of a standard with a high degree of architectural openness.

5. **Scalability** - The protocol should be scalable in terms of performance, processing capacity should enable data exchange linearly with the data exchange requests.

6. **Quality control** - Three dimensions are highlighted for the support of quality control

    1. Conformance with other standards,
    2. Support to assess the quality of implementation, and
    3. Support to assess the quality of data input

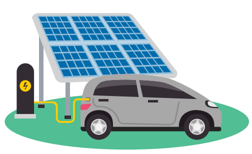
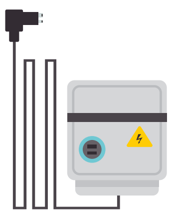
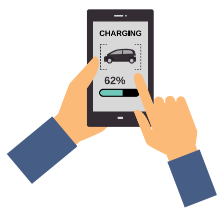
7. **Open Standards** - The regulatory environment for EV roaming depends on the degree of use of specific standards. Most countries consider standardization a critical task in using and participating in the development and setting of standards.

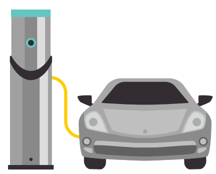
    Many stakeholders should be allowed in the standardization process, and it is recommended to make the protocol an open standard. There are a few principles developed by the World Trade Organization's Committee, such as transparency, openness and impartiality for open standards.

8. **Business model agnostic** - The Our final recommendation is to make the standards for a standardeRoaming business model agnostic. It indicates that the protocols are flexible in selecting any desired business model for eRoaming .

9. **Data protection** - A huge amount of personal data is being populated for eRoaming, which must be maintained securely and made to comply with General Data Protection Regulation (GDPR). The GDPR processes the populated data through pseudonymization and anonymization. It processes the data only if it is done under one of the below lawful bases, which are (1) consent, (2) contract, (3) public task, (4) vital interest, (5) legitimate interest or (6) legal requirement. The GDPR also needs transparency in collecting data for which reason the data is collected, how long the data has to be retained, on what legal basis to share with third parties. Data subjects can request a copy of the data and for the data to be erased under certain conditions.

    The main reason to secure data storage is e-mobility. The data of the charging session gives you the personal information which an individual can trace. If the subscription data of EV users is stolen, then the thief would use the subscription to charge the EV, and billing goes to the victim. The government is still not involved in the security of roaming protocols which is a drawback for the regulation. The existing e-roaming protocols do not have end-to-end encryption and electronic signatures, which results in an insecure process. This is because different stakeholders are proposing other ideas about security in the protocols and ID cards. Security will remain an issue for e-mobility and roaming in future years.



4.6.5 Fast Charging Infrastructure

The viability of public charging is highly dependent on the type of chargers installed. Fast chargers enable more EVs to be served thereby increasing the profitability of the charging station. However, there is need for higher capital expenditure as well as the added stress on the distribution network.

Four different PCS configurations have been considered for comparison, show in Table 4.21. All the configurations have a total of 10 chargers 16.

Table 4.21: Charger configuration in different cases

Charger Sl. No.	1	2	3	4	5	6	7	8	9	10
Case 0 (Slow Charging)	3 kW	3 kW	3 kW	3 kW	3 kW	3 kW	3 kW	3 kW	22 kW	22 kW
Case 1	7 kW	7 kW	7 kW	7 kW	7 kW	7 kW	7 kW	7 kW	7 kW	50 kW
Case 2	22 kW	22 kW	22 kW	22 kW	22 kW	22 kW	22 kW	50 kW	50 kW	50 kW
Case 3	50 kW	50 kW	50 kW	50 kW	50 kW	50 kW	50 kW	150 kW	150 kW	200 kW

The cost associated with installation of the charging station include both the chargers costs as well as the costs for the electrical infrastructure[30] . The capital cost of chargers and the distribution transformers have been given in Table 4.22.

Table 4.22: Cost of infrastructure considered for analysis [31]

Equipment	Capital Cost (INR/ EUR)
3 kW AC charger	INR 11,000 (EUR 120)
7 kW AC charger	42,000INR 42,000 (EUR 462)
22 kW AC charger	INR 60,000 (EUR 660)
50 kW DC charger	INR 11,00,000 (EUR 12094)
150 kW DC charger	INR 15,00,000 (EUR 16492)
200 kW DC charger	INR 20,00,000 (EUR 21990)
100 kVA Distribution Transformer	INR 1,43,000 (EUR 1572)
120 kVA Distribution Transformer	INR 1,75,000 (EUR 1924)
250 kVA Distribution Transformer	INR 3,82,000 (EUR 4200)
850 kVA Distribution Transformer	INR 9,00,000 (EUR 9895)
11 kV XLPE 3 core 95sqmm cable (per metre)	INR 990[32] (EUR 10.88)

Regarding the utilization of chargers, the faster the charging, the more vehicles that can be served. So, considering that 25 vehicles arrive at the PCS per day, the utilization factor of the PCS is given in Figure 4.25 (a), which shows that Case 0 (PCS with slow chargers) has the highest utilization at around 50%, but for PCS with faster chargers the utilization is significantly lower at 15%, 10% and 9.3% respectively. However, it also signifies that the PCS is preoccupied for a significant amount of time, which leads to denial of service to new EV arrivals as highlighted in Figure 4.25 (b). With increase in the EVs on road this bottleneck is sure to add up resulting in potential loss of revenue for the PCS.

30 It has been considered that the PCS would set up the distribution transformer and the necessary cabling and pay for it themselves. Also, other electrical costs such as protection have not been considered. These costs would also scale up with the increase in rated power of the charging station.

31 IESA, "Indian Energy Storage Alliance," n.d., https://indiaesa.info/products.

32 Cable length of 500m have been considered to be needed between the DT and the feeder.

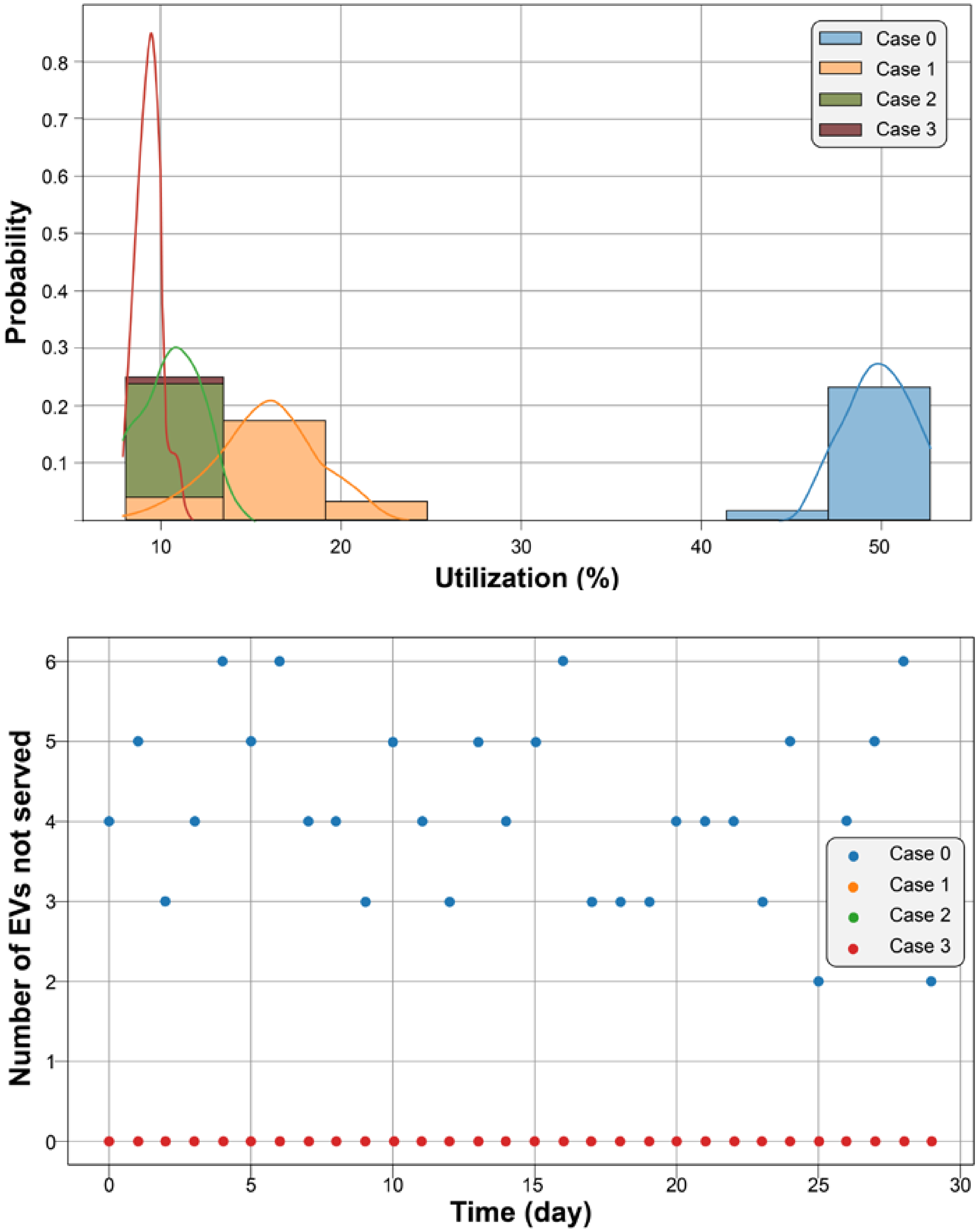


Figure 4.25: a) Utilization of PCS, considering 25 vehicles arrive per day and b) numbers of EVs that were denied service due to preoccupancy of chargers

The annual revenue, the NPV considering the CAPEX and OPEX costs for 10 years operational lifetime are given in Figure 4.26. Here the cost of equipment as given in Table 4.22 has been considered, with retail price of electricity at ToD rates given in Section 5.5.1, while the EV users are charged at INR 7.5/kWh. However, year on year, the number of EVs on road are expected to increase which would increase the number of EVs arriving at the PCS.

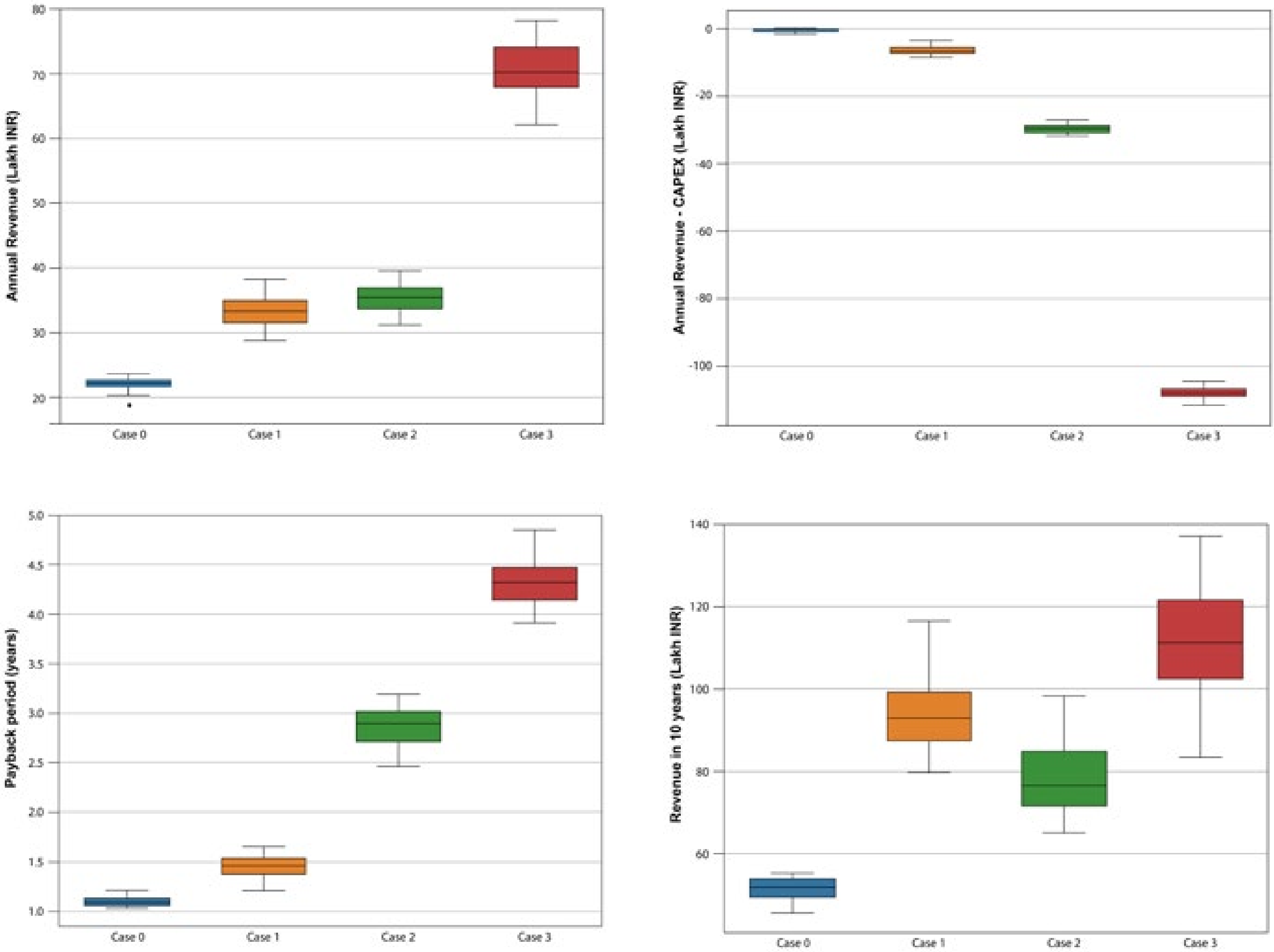


Figure 4.26: For 25 EVs arriving on average per day at the PCS, a) Annual Revenue made by the PCs, b) The net revenue of the PCs in the first year considering capital costs c) The payback period of the capital costs d) NPV of PCs considering 10 years of operation

Considering that on average 50 EVs arrive at the PCS with charging needs, the utilization factor of the PCS is given in Figure 4.27 (a). From Figure 4.27(b) it can be seen that, the PCS is now severely bottlenecked by the power rating of the chargers, with the PCS of Case 0 not able to service almost 50% of the total EVs, while the PCS of Case 2 and Case 3 were able to serve all their arriving EVs. The resulting annual revenue, the NPV considering the CAPEX and OPEX costs for 10 years operational lifetime is given in Figure 4.28.

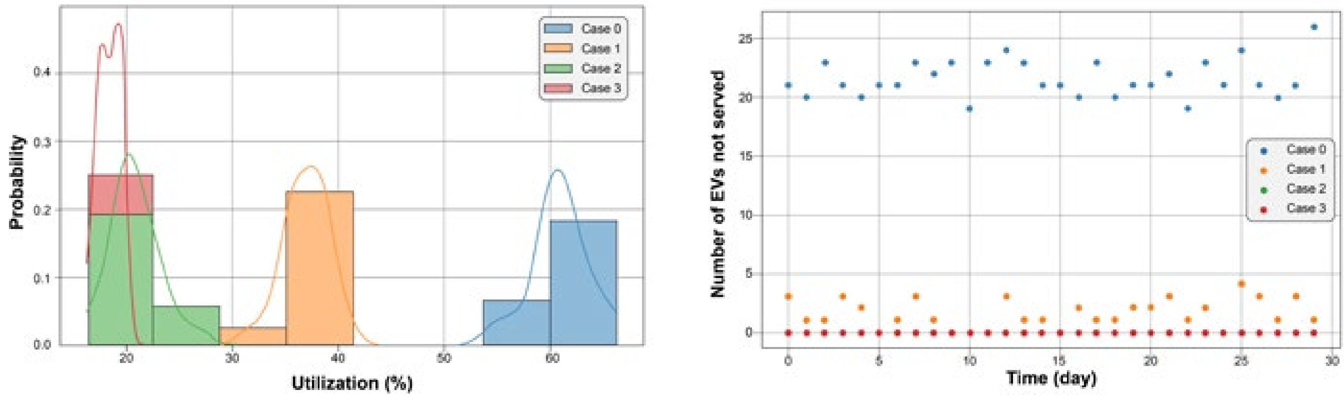


Figure 4.27: a) Utilization of PCS, considering 50 vehicles arrive per day and b) numbers of EVs that were denied service due to preoccupancy of chargers

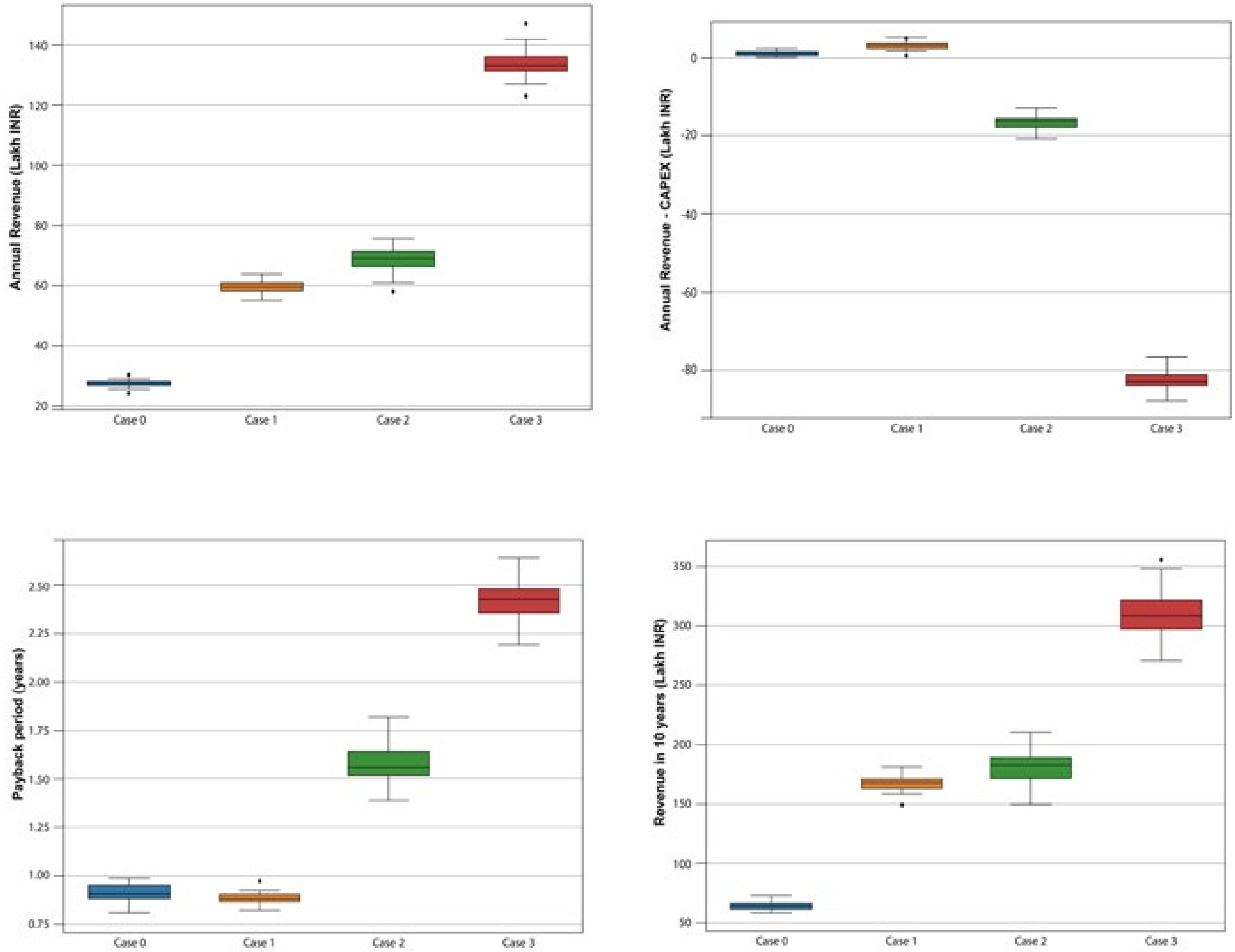


Figure 4.28: For 50 EVs arriving on average per day at the PCS, a) Annual Revenue made by the PCs, b) The net revenue of the PCs in the first year considering capital costs c) The payback period of the capital costs d) NPV of PCS considering 10 years of operation

One of the major investments in a fast-charging station is the initial CAPEX cost as highlighted in Figure 4.26(b) and Figure 4.28(b). However, with economies of scale, i.e., installation of a number of chargers at the same location the per unit price of installation would be lowered considerably. Based on data sourced from different real life CPO in the USA, the cost per charger with addition of more chargers in the PCS have been given in Table 4.23, Figure 4.29 and Figure 4.30. It is seen that, as the number of chargers in the site increases the cost per charger reduces.

Table 4.23: Installation cost per DC charger based on charger power level and number of chargers per-site

	50 kW DC Charger				150 kW DC Charger			
	1 charger per site (INR/EUR)	2 charger per site (INR/EUR)	3-5 charger per site (INR/EUR)	6-50 charger per site (INR/EUR)	1 charger per site (INR/EUR)	2 charger per site (INR/EUR)	3-5 charger per site (INR/EUR)	6-50 charger per site (INR/EUR)
Labour	14,20,224.00/ 16,124	11,24,344.00/ 12,765	8,28,464.00/ 9,406	5,32,584.00/ 6,047	14,91,235.20/ 16,930	11,80,561.20/ 13,403	8,69,887.20/ 9,876	5,59,213.20/ 6,349
Materials	19,23,220.00/ 21,835	15,38,576.00/ 17,468	11,53,932.00/ 13,101	7,69,288.00/ 8,734	20,19,381.00/ 22,927	16,15,504.80/ 18,341	12,11,628.60/ 13,756	8,07,752.40/ 9,171
Permit	14,794.00/ 168	11,095.50/ 126	7,397.00/ 84	3,698.50/ 42	15,533.70/ 176	11,687.26/ 133	7,766.85/ 88	3,920.41/ 45
Taxes	7,840.82/ 89	6,287.45/ 71	4,808.05/ 55	3,106.74/ 35	8,210.67/ 93	6,583.33/ 75	4,955.99/ 56	3,328.65/ 38
Total	**33,66,078.82/ 38,216**	**26,80,302.95/ 30,430**	**19,94,601.05/ 22,645**	**13,08,677.24/ 14,858**	**35,34,360.57/ 40,127**	**28,14,336.59/ 31,952**	**20,94,238.64/ 23,777**	**13,74,214.66/ 15,602**

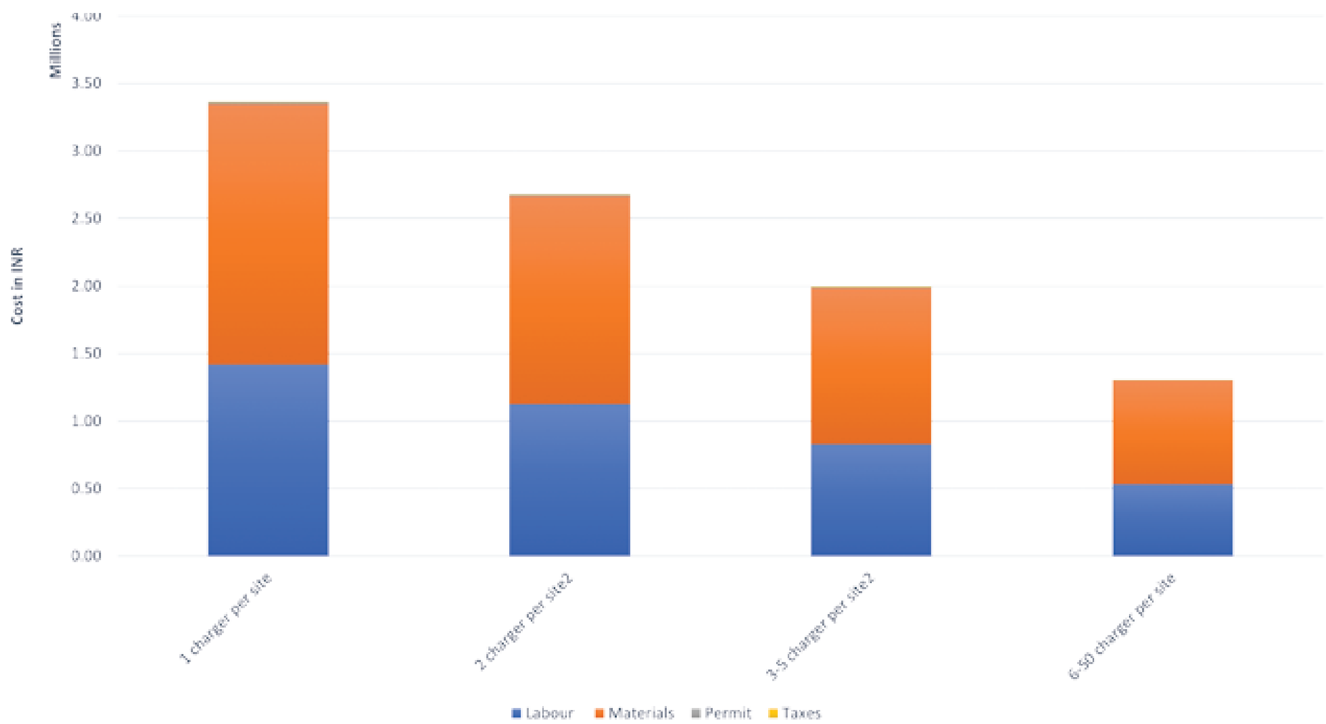


Figure 4.29: Installation cost per 50 kW DC charger based on number of chargers per site

33 Michael Nicholas, "Estimating Electric Vehicle Charging Infrastructure Costs across Major U.S. Metropolitan Areas" (ICCT, August 2019).
34 Nicholas.

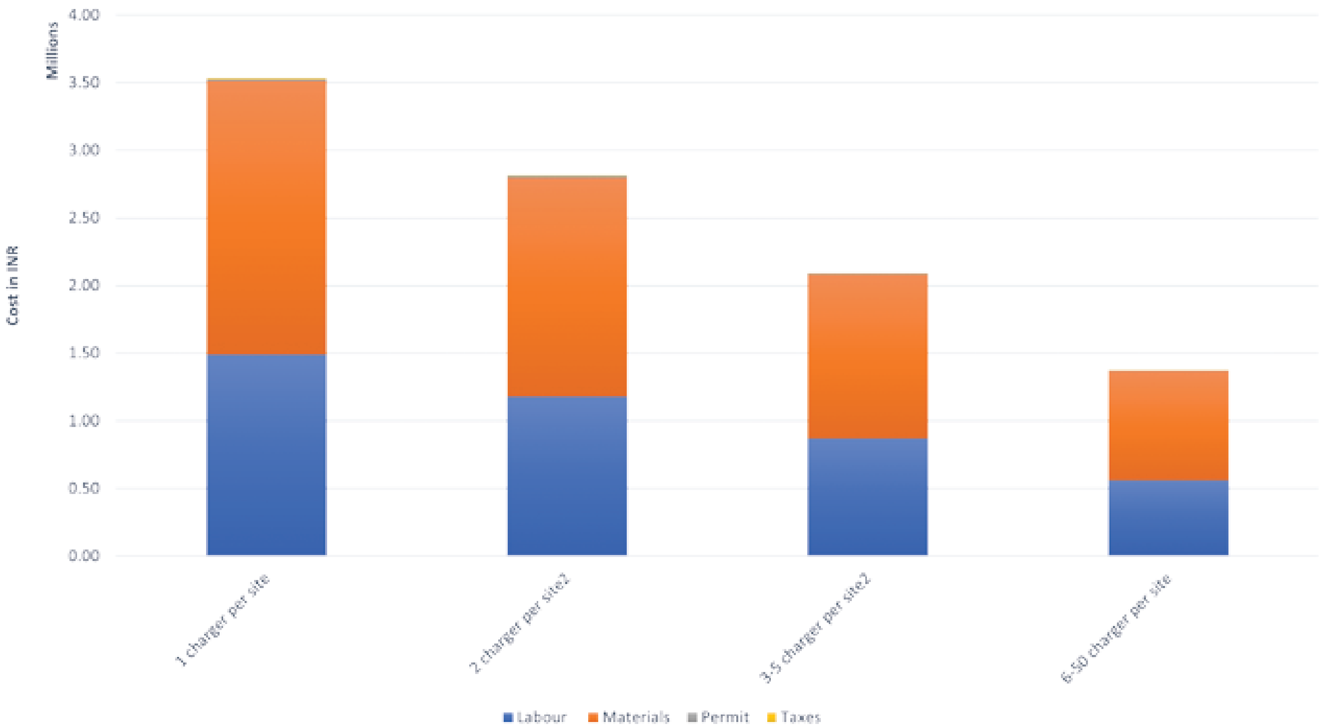
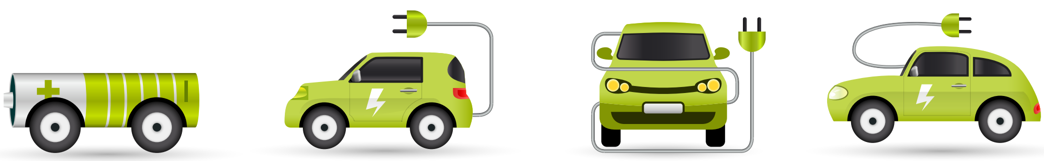


Figure 4.30: Installation cost per 150 kW DC charger based on number of chargers per site

4.6.6 Aggregate impact of above technical interventions

As can be inferred from the analysis above, each technical intervention has its own different impact on the EV charging ecosystem. So, different interventions need to be synergized to have an pronounced effect on the EV charging ecosystem. Fast charging infrastructure, as discussed above, have a very high capital investment. To make up for the high investment, the CPO would prefer a larger share of revenue, to recuperate the capital investment. Thus both RE integration for EV charging as well as time based tariff would help the CPO to increase the profit margin. They would also help the DISCOM to manage the high load that is expected of a fast-charging station. In the same context, smart charging would be essential so that the distribution network is able to handle the added EV charging load. While fast charging stations would put a stress on the distribution system, they would be beneficial both for the CPO (increased revenue in the long run, as higher number of EVs can be served, as shown in Figure 4.28), as well as the EV users (shorter charge durations). The CPOs should also provide eRoaming services, by making tie-up with eRoaming platforms or with contracts with other CPOs. With eRoaming the customer base of the CPO would increase thereby leading to increased utilization of the PCS.

'Smart charging -unidirectional' would enable the addition of more EV chargers to the distribution system, without the need of grid upgradation. Grid upgradation which constitutes very high investment costs, is one of the major bottlenecks for widespread deployment of EV chargers. With smart charging, the EV charging could be shifted to off-peak periods from peak periods, which can provide economic benefits to private/workplace/public charger users.



35 Nicholas.

Table 4.24: Aggregate performance of different baskets of technical recommendation

Fast charging infrastructure	Capital Cost
	Annual revenue
	Distribution grid impact
	User satisfaction
	Deployment of chargers
Fast charging infrastructure Time based tariff	Capital Cost
	Annual revenue
	Distribution grid impact
	User satisfaction
	Deployment of chargers
Fast charging infrastructure Time based tariff RE Integration Smart Charging – Unidirectional	Capital Cost
	Annual revenue
	Distribution grid impact
	User satisfaction
	Deployment of chargers
Fast charging infrastructure Time based tariff RE Integration Smart Charging – Unidirectional Interoperability	Capital Cost
	Annual revenue
	Distribution grid impact
	User satisfaction
	Deployment of chargers
Slow charging infrastructure Time based tariff RE Integration Smart Charging – Unidirectional Interoperability	Capital Cost
	Annual revenue
	Distribution grid impact
	User satisfaction
	Deployment of chargers
Slow charging infrastructure	Capital Cost
	Annual revenue
	Distribution grid impact
	User satisfaction
	Deployment of chargers

4.7 In-depth Analysis of Key Policy and Regulatory Interventions

For the benefit of, and better understanding by the policy and regulatory agencies and other stakeholders, a detailed in-depth analysis of top five policy and regulatory interventions has been provided in this section, which shall enable the relevant authorities to take an informed decision on policy and regulatory interventions.

The impact of the proposed policy and regulatory interventions on a test system described below is used for this analysis.

Test System

A financial model has been built to understand the financial impact of the policy and regulatory interventions on the test system. The test system has three main entities participating,

- The owner-operator: owns and manages the charging station(s)
- Private sector partner: A third party business/ entity that has vested interest on the charging station(s)
- Public sector partner: Public authority along with share owners.

There are three different types of PCS owned by the same owner-operator

- DC fast charging station (Highway)
- AC charging station (within city)
- DC fast charging station (within city)

The owner-operator funds 40% of the total equity, the rest 60% is funded by public debt (50% loans and 50% shareholders). The different assumptions have been given in Table 4.25, Table 4.26 and Table 4.27

Table 4.25: Utilization of PCS

Parameter	Assumption
Annual compounded growth rate in utilization of chargers	15%
Initial DC fast charger utilization	1200 sessions/year
Initial Level 2 charging station utilization	400 sessions/year

Table 4.26: Details of PCS

Parameter	Assumption
DC Fast Charging Station (Highway)	
Total number of chargers	8
Number of sites	4
Charging station equipment cost	INR 12,00,000/ EUR 13,270 (per charger)
Equipment installation and civil costs	INR 1,50,000/ EUR 1,658 (per charger)
Electric utility upgrades and grid connection	INR 26,94,760/ EUR 29,800 (per site[36])
Lease cost of land (one-time fee per site)	INR 2,00,000/ EUR 2,211
Host site identification and screening (one-time per site)	INR 1,00,000/ EUR 1,105
Average energy per charging session	15 kWh[37]
Maximum power drawn	50 kW per charger
Charging fee for user	INR 15/kWh (EUR 0.17/kWh)
Electricity retail price in first year	INR 5/kWh (EUR 0.055/kWh)
Annual compounded growth rate of electricity price	0.25%
Annual maintenance cost (% of equipment cost)	0.1%
Land lease recurring cost (per month)	INR 15,000 (EUR 165)
AC Charging Station (Within city)	
Total number of chargers	50

36 Inclusive of transformer cost and cabling cost.

37 The average battery size of EVs in India is around 30 kWh. Here it has been assumed that the user refills 50% of his battery at fast DC chargers, spending around 20-30 mins at the charging station.

Number of sites	10
Charging station equipment cost	INR 60,000/ EUR 663 (per charger)
Equipment installation and civil costs	INR 35,000/ EUR 387 (per charger)
Electric utility upgrades and grid connection	INR 6,40,000/ EUR 7077 (per site)
Lease cost of land (onetime fee per site)	INR 2,00,000/ EUR 2,211
Host site identification and screening (onetime per site)	INR 1,00,000/ EUR 1,105
Average energy per charging session	10 kWh[38]
Maximum power drawn	7 kW per charger
Charging fee for user	INR 15/kWh (EUR 0.17/kWh)
Electricity retail price in first year	INR 5/kWh (EUR 0.055/kWh)
Annual compounded growth rate of electricity price	0.25%
Annual maintenance cost (% of equipment cost)	0.1%
Land lease recurring cost (per month)	INR 24,000 (EUR 265.40)
DC Fast Charging Station (Within city)	
Total number of chargers	2
Number of sites	1
Charging station equipment cost	INR 12,00,000/ EUR 13,270 (per charger)
Equipment installation and civil costs	INR 1,50,000/ EUR 1,658 (per charger)
Electric utility upgrades and grid connection	INR 12,09,760/ EUR 13,377
Lease cost of land (onetime fee per site)	INR 2,00,000/ EUR 2,211
Host site identification and screening (onetime per site)	INR 1,00,000/ EUR 1,105
Average energy per charging session[39]	15 kWh
Maximum power drawn	50 kW per charger
Charging fee for user	INR 15/kWh (EUR 0.17/kWh)
Electricity retail price in first year	INR 5/kWh (EUR 0.055/kWh)
Annual compounded growth rate of electricity price	0.25%
Annual maintenance cost (% of equipment cost)	0.1%
Land lease recurring cost (per month)	INR 18,000/ EUR 200

Table 4.27: Additional cost assumptions

Parameter	Assumption
Percent equity funded	40%
Owner operator cost of debt	8%
Maximum debt term	10 years
Expected equipment lifespan	10 years
Income tax rate	5%
Owner operator cost of equity	
Risk free rate	1.25%
Beta	0.9
Market risk premium	10%

38 Here the assumption is that the EV user spends around 1.5 hrs at Public AC chargers and so the average energy transacted per session is rounded to 10 kWh.

39 The average battery size of EVs in India is around 30 kWh. Here it has been assumed that the user refills 50% of his battery at fast DC chargers, spending around 20-30 mins at the charging station.

4.7.1 Mandating EV charging infrastructure in building bye-laws

As highlighted by IEA, majority of the charging of EV takes place at residential locations, with more than 90% of all global chargers installed at residential locations. In India, the urban population live mostly in multi-storeyed apartments. The people residing in these multi-storeyed apartments are generally restricted in the availability of personal parking space. In the current scenario, where there is no obligation for the building owner/manager to provide any charging services, the EV users have trouble getting permission from their building owner/manager to install their own charging station at the building parking location due to various reasons[40] .

Building bye-laws mandating the provision of a minimum EV charging infrastructure in each new or renovated building would increase the availability of private charging opportunities for the EV users. There are three distinct ways in which the this can be achieved,

- Make the parking spot of the building EV charger ready, so that the EV user can install their own chargers without requirement of any additional construction or electrical connection cost[41].
- A CPO is contracted to install and operate a charging station in the building premises, and the EV users can utilize these chargers. This makes a positive influence on the EV users as they do not have to personally install any chargers, thereby reducing their capital and operational investment.
- The building owner-operator establishes and operates the charging station as an added amenity for the society, thereby increasing the value of the property.

In the following case study, two scenarios have been compared,

a) CPO operates the charging station and uses a subscription-based model, where users pay a monthly fee and are free to charge as much as they want

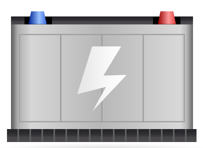
b) CPO operates the charging station and uses a pay-as-you-use model, where the users are charged based on the energy consumption

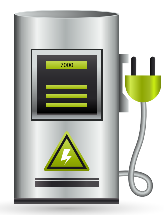
In both the scenarios, there are a total of 5 buildings with 10 chargers in each. The land is provided by the building owner, with electrical infrastructure also in place. So the only major cost for the CPO was the equipment cost and the cost of installation of the chargers.

As can be seen both the scenarios are financially viable for the CPO, with it making its investment back in 4-5 years as given in Table 4.28. With addition of land lease cost, the charges levied from the EV users can be altered accordingly.

Table 4.28: Financial performance statistics for the two scenarios

Scenario		Capital (INR/ EUR)	NPV (INR/EUR)	Payback Period (years)	Internal Rate of Return (IRR)
Owned and operated by	EV charging cost for EV user				
CPO	INR 15/ kWh (EUR 0.17/kWh)	30,77,952/ 34,036	91,86,616/ 1,01z,587	4	30.9%
CPO	INR 1450/month (EUR 16.03/ month)	30,77,952/ 34,036	1,01,87,463/ 1,12,655	5	28.5%

40 Lijee Philip, "EV Customers Face Charging Roadblocks at Residences, Niti Aayog Assures Changes," ET Auto, September 19, 2021, https://auto.economictimes.indiatimes.com/news/industry/ev-customers-face-charging-roadblocks-at-residences-niti-aayog-assures-changes/86336185.

41 Here it is assumed that all the EV users have their own designated parking space.

4.7.2 Support market creation for private investment in public charging infrastructure

The private charging infrastructure today is sparse mainly due to the profitability of the EV charging business. The high upfront cost, and the low utilization of the chargers as well as the low margin of profitability of selling electricity as a good are the primary reasons why private entities are less inclined to invest in the EV charging infrastructure. To make EV charging attractive to private investments, the following policy interventions can be undertaken by the public sector.

4.7.2.1 Grants for installation of EV charging infrastructure

Grants subsidize the upfront cost for purchasing of charging equipment/ electrical connection/ land lease etc. These help in reducing the required capital to set up the charging infrastructure, which helps in making the business more economically viable as well as lowering the risk for the owner. These are also easier to implement and administer.

4.7.2.2 Low Interest Loans

Capital intensive businesses are generally funded in part with loans levied from financial institutions. These institutions generally charge a higher interest rate for the loans. Here, the public authorities (state/central government) could issue loans directly to the owner-operators of the charging station at lower interest rates. Or the governments could also device a fiscally self-sustaining revolving loan fund which offers loans at low interest rates to EV charging businesses. Providing loans at lower interest rates, would improve the business viability for owner-operators while the government would assume the risk that the investors may default on the loan payments. As an example, in the state or Vermont of USA, several state agencies have agreed upon a partnership to facilitate loans to EV charging businesses with interest rates as low as 1%.

Table 4.29 shows how grants and lowering of interest rates can help in making EV charging business models viable. Without grants and favourable interest rates, the EV charging business is money losing enterprise. Although grants and favourable interest rates help make the business net positive, yet the profitability is not lucrative enough.

Table 4.29: Impact of grant and lowered interest rates of loans on EV charging business viability

Scenario		Capital Investment (INR/ EUR)	NPV (INR/EUR)	Payback Period (years)	Internal Rate of Return (IRR)
Subsidy(% on chargers)	Interest Rate on Loan (%)				
0	10%	1,66,83,520/ 1,84,490	-1,09,40,506/ -1,20,982	-	-6.4%
0	5%	1,66,83,520/ 1,84,490	-85,51,783/ - 94,567	-	-5.1%
0	1%	1,66,83,52/ 1,84,490	-68,34,622/ -75,578	-	-4.1%
20%	10%	1,36,80,486/ 1,51,282	-79,37,472/ -87,774	-	-5.1%
20%	5%	1,36,80,486/ 1,51,282	-55,48,749/ -61,359	-	-3.6%
20%	1%	1,36,80,486/ 1,51,282	-38,31,588/ -42,370	-	-2.5%
40%	10%	1,06,77,453/ 1,18,073	-49,34,439/ -54,566	-	-3.5%
40%	1%	1,06,77,453/ 1,18,073	-8,28,555/ -9,162	-	-0.6%
50%	10%	91,75,936/ 1,01,469	-34,32,922/ -37,962	-	-2.6%
50%	1%	91,75,936/ 1,01,469	6,72,962/ 7,441	10	0.5%

In the above analysis, the usage of the charging station would have an annual growth of 15%. However, if the annual growth of usage rate of the charging station deviates, the change in NPV of the project is given in Figure 4.31. The figure shows that if the annual utilization growth rate is less than <10% then the project becomes economically infeasible even with 50% grant and 1% interest rate on loans.

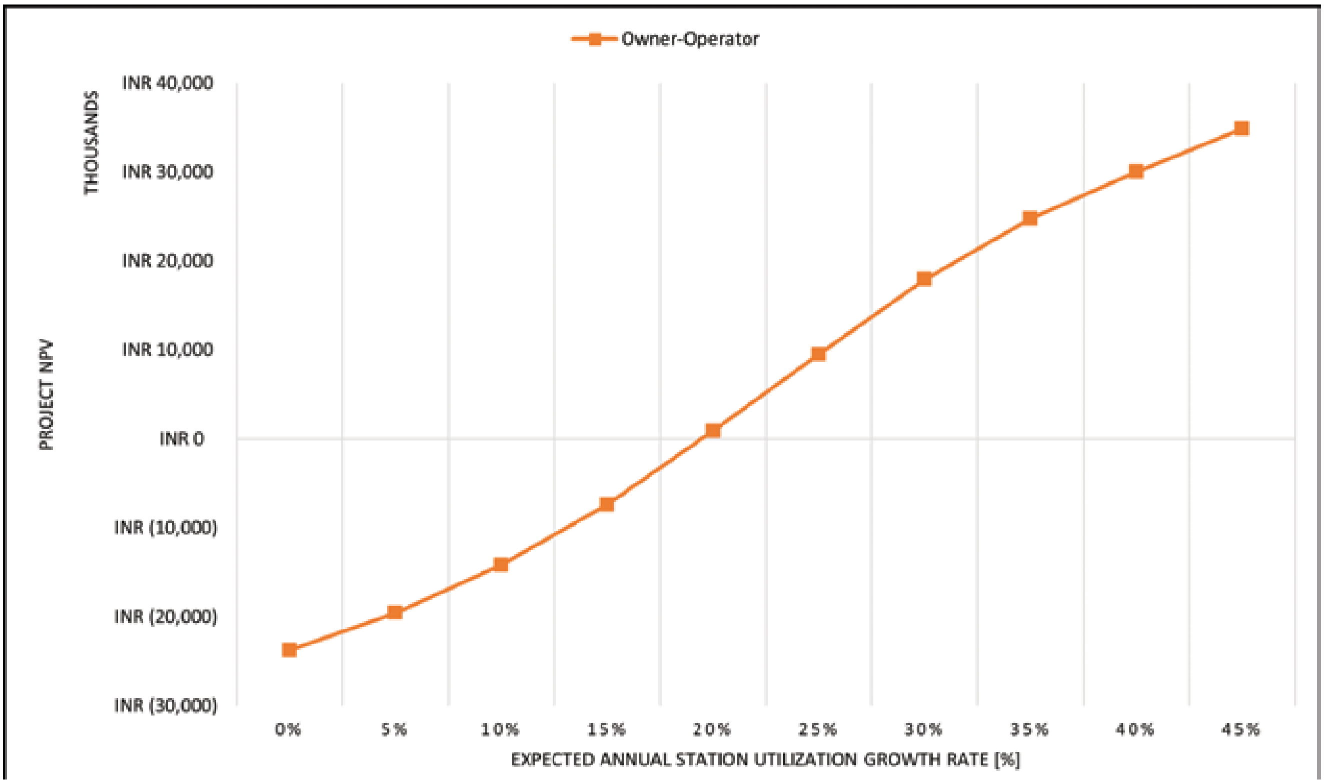


Figure 4.31: Change in project NPV with different expected annual utilization growth rate

The implementation time period of these schemes can be rapid, with minimal need of complex administration procedures. However, the private entities make take some time to develop into the market using these schemes. With lower implementation time period, along with direct impact on the growth of the charging network, polices aimed at increasing the involvement of private entities into the PCS business would go a long way in extending the charger network.

4.7.3 Aggressive awareness

With increased utilization of EV chargers the PCs business becomes cash flow positive. However, different factors would determine the numbers of EVs on the road, which is directly correlated to the utilization factor of PCS. Availability of roadside assistance and general knowledge on the benefits of EVs are two of the major factors that influence the decision making of customers on whether to purchase an EV.

The ICE vehicles have been around for a significant period, as such a large pool of capable technicians and mechanics are available for service and maintenance of ICE vehicles. Such, widely available roadside services encourage the users to purchase an ICE vehicle. Comparatively, EVs are a much newer technology, and the number of technicians and mechanics that are proficient in EV technology is significantly limited currently. In order to increase this manpower pool, aggressive dissemination of EV technology among the technical institutes is required. This manpower pool would be able to service in a variety of EV subsystems such as EV design, EV repair and maintenance, EVSE repair and maintenance and IT troubleshooting related to EV communication, etc.

Publicizing the benefits of EVs over ICE vehicles among the masses is also required to make the general public more favourable to EVs. These may include advertisements in print and visual media, workshops etc.

The impact of these promotional campaigns and increased manpower pool, would lead to increased EVs on the road thereby increasing the utilization of the charging network. These high utilizations would incentivize the PCS owner-operators to ramp up the deployment of charging infrastructure.

The impact of increased awareness on the business viability of the PCs under consideration have been highlighted in Figure 4.32. The initial investment on awareness, helped the PCs in achieving its optimal peak income much earlier than without awareness.

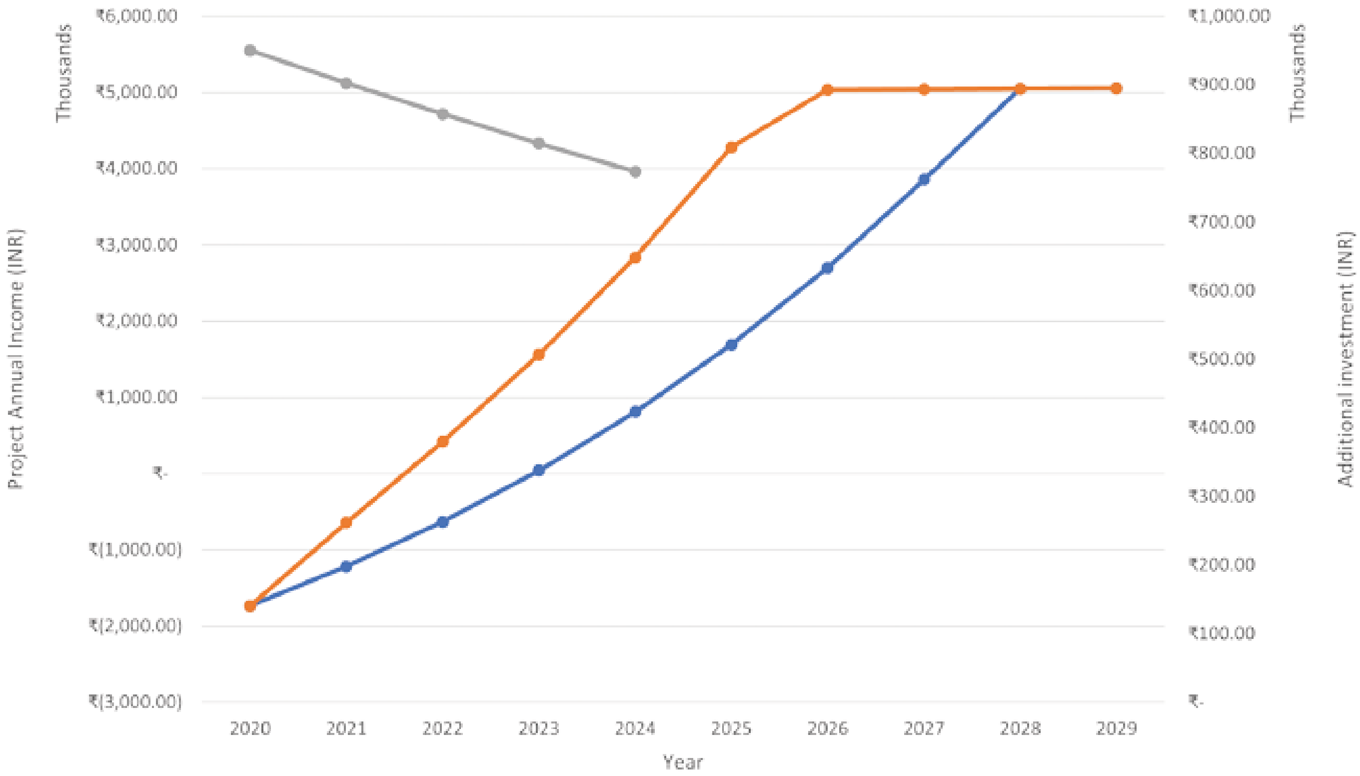


Figure 4.32: Impact of awareness on annual income of PCS

Here, it needs to be mentioned that, although implementation of awareness schemes and policies can be readily implemented, the effects of these interventions would be visible gradually, without any sudden spikes.

4.7.4 Easy access of land for setting up PCS

The charging infrastructure owner-operator mainly faces three issues pertaining to land,

- Land availability
- High cost of land in urban localities
- Optimal siting of charging stations

In a densely populated nation such as India, the availability of suitable land for establishment of charging stations is a significant hindrance. The required plot of land needs to be in a high EV growth locale, with good access points to the road network and sufficient headroom availability in the distribution feeder. Most of the available land are owned by the public utilities and offices, and as currently regulated, private entities cannot lease/buy land occupied by the public authorities. In this regard, formulation of regulations to allow the renting of land owned by public authorities to private entities to help expand the charging network.

Further, there is also a need to locate optimal placements for installation of charging stations. Such optimal siting needs to include different parameters such as

- Locations with high EV growth forecast
- Existing charging landscape
- Capability of distribution network at the location to accommodate the charging station.

So, optimal location of charging stations further complicates the issue of land availability.

One of the options to counter the issue of land availability is the use of a revenue sharing model. As per this model, different financial contracts can be established between the public and private entities so that both parties can be benefitted by the cooperation. In presence of other revenue sources co-located with the EV charging station, the partner businesses would have increased revenue, as the EV users are likely to shop and consume the products of nearby businesses while their vehicle is charging. By strategically partnering with select businesses the PCS may increase the overall revenue earned by all the partners.

In the case study, the partner businesses pay the land lease fees of the PCS, while using the customers of the PCS to increase their own revenues. This helps in reducing the overall cost of the PCS, thus benefiting the PCS too as shown in Figure 4.33. Here, it has been considered that the private partners would pay the land lease of the PCS. The financial performance statistics have been given in Table 4.30.

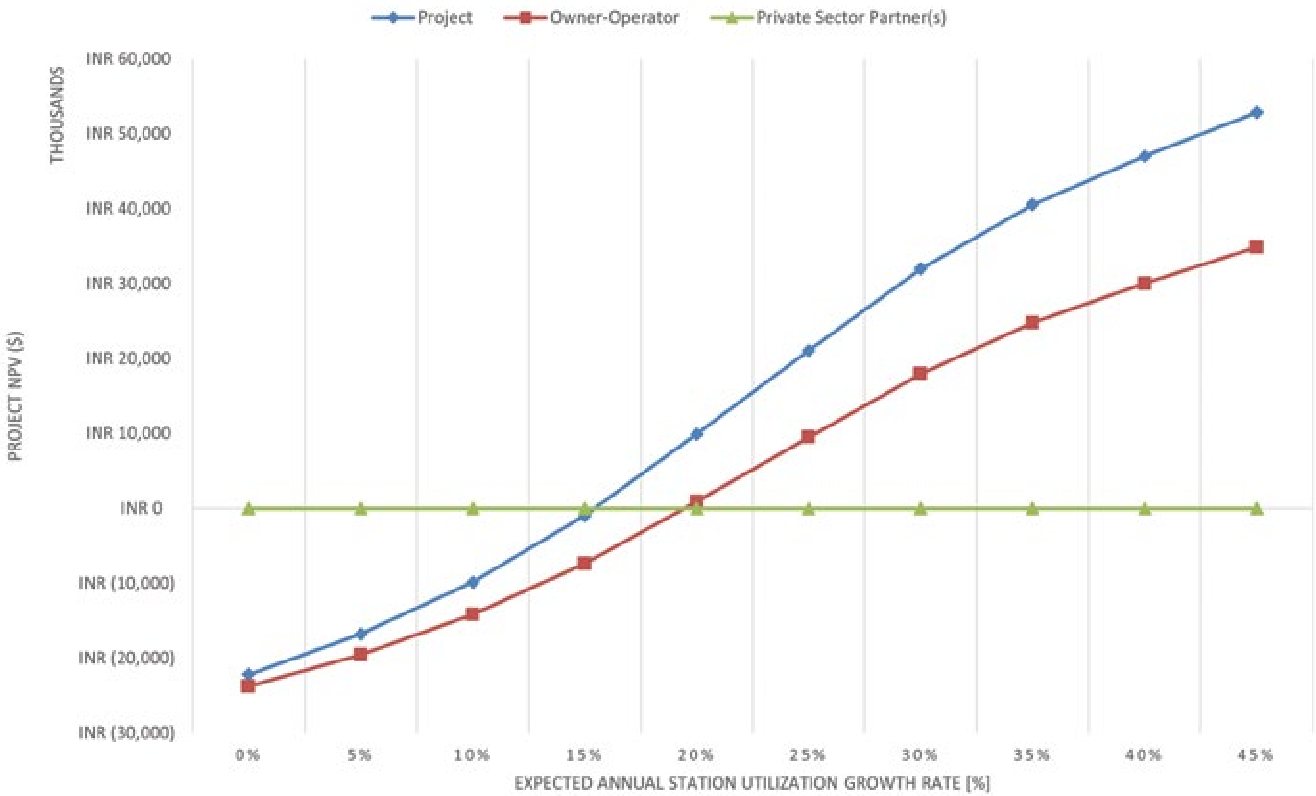


Figure 4.33: Addition of other partners, makes the entire project cash flow positive at even low utilization factor annual growth rates

Table 4.30: Financial performance statistics

Entity	Total Capital Investment (INR/ EUR)	NPV (INR/EUR)	IRR	Payback period (years)
Owner-operator	1,56,83,520/ 1,73,432	1,21,83,520/ 1,34,728	7.9	10
Private Sector Partner	30,00,000/ 33,174	11,53,966/ 12,760	3%	10
Public Sector Partner	79,93,068/ 88,389	-	-	-
Total Project	**3,92,08,800/ 4,33,580**	**2,66,74,802/ 2,94,976**	**9.1%**	**9**

Without the availability of such synergized businesses co-located with the PCS, the public authorities, can work to reduce the land lease cost for the PCS business to operate in the land owned by these public authorities.

4.7.5 Support Distribution System Upgradation

The electrical infrastructure cost is one of the major cost incurred by the CPO for establishment of PCS. Depending on the capacity of the charging equipment capacity this cost can be significantly high. An illustrative cost of electrical infrastructure cost is given in Table 4.31

Table 4.31: Cost of electrical infrastructure

Capacity	Description	Cost (INR/EUR)
Up to 50 kW	Cable (0.5 km length of 11 kV 95 sqmm. Cable including soil excavation)	6,00,000/ 6,634
	Transformer (63 kVA, 11kV/433V 3 phase)	2,00,000/ 2,211
	Cable testing	20,000/ 221
50 kW to 100 kW	Ring Main Unit (RMU) 11 kV class SF6/VCB type	4,50,000/ 4,976
	Cable (0.5 km length of 11 kV 95 sqmm. Cable including soil excavation)	6,00,000/ 6,634
	11 kV HT metering cubicle	1,85,000/ 2,045
	Transformer (100 kVA, 11kV/433V 3 phase)	2,20,000/ 2,432
	Cable testing	20,000/ 221
100 kW to 200 kW	Ring Main Unit (RMU) 11 kV class SF6/VCB type	4,50,000/ 4,976
	Cable (0.5 km length of 11 kV 95 sqmm. Cable including soil excavation)	6,00,000/ 6,634
	11 kV HT metering cubicle	1,85,000/ 2,045
	Transformer (250 kVA, 11kV/433V 3 phase)	5,00,000/ 5,529
	Cable testing	20,000/ 221

In the financial analysis, different amount of subsidies were provided to the electrical infrastructure cost, which have been provided in Table 4.32. As can be seen with 60% subsidy on the electrical infrastructure, the PCS becomes a viable business, with positive NPV.

Table 4.32: Subsidy on electrical infrastructure cost

Subsidy(% on infrstructure)	Capital Investment (INR/EUR)	NPV (INR)	Payback Period (years)	Internal Rate of Return (IRR)
0	1,66,83,520/ 1,84,490	-1,09,40,506/ -1,20,982	-	-6.4%
20%	1,31,01,612/ 1,44,880	-74,16,288/ -82,011	-	-4.8%
40%	93,53,470/ 1,03,432	-36,68,146/ -40,563	-	-2.7%
60%	55,54,678/ 61,424	1,30,646/ 1,444	10	0.1%

4.7.6 Aggregate impact of above policy and regulatory interventions

The section above, analyses the impact of each policy and regulatory intervention in isolation. Here, the impact on EV charging network adoption would be analysed if all 5 of the interventions, mentioned below are implementedimplemented.

- Mandating EV charging infrastructure in building bye-laws
- Support market creation for private investment on public charging infrastructure
- Aggressive awareness
- Support mechanism/ incentives for use of RE in EV charging
- Easy access of land for setting up PCS

As discussed, earlier charging of electric vehicles is either done at home, at the workplace or in public charging stations. For residential charging, a private charger needs to be installed at the residence of the user with a designated parking location. However, in the context of India, a large section of the urban population (the initial growth of EV is expected to be in the urban localities) resides in multi-unitfamily dwellings owned and operated by RWAs. Bye-laws mandating minimum requirement of EV charging infrastructure in the buildings, would enable the EV users to utilize this charging infrastructure. This would facilitate private charging as well as workplace charging.

For the growth of public charging infrastructure, multiple interventions are necessary, as the PCS is capital heavy, poor revenue earning business. Theo three main drawbacks of the PCS business are,

- High capital expenditure
- Low margin of profitability
- Low utilization of product due to limited EVs on the road

Subsidies and loans with low interest rates can help in reduction of the cost of establishment of charging infrastructure. These subsidies can be on the charging equipment, grid connection and upgradation charges, land leases etc. However, subsidies are not sustainable, and as such to negate the high cost of PCS, ways to increase the revenue of the PCS can be thought of.

Although by increasing the cost of charging, the revenue of the PCS can be improved, however, this may result in reduced number of customers. On the other hand, by co-locating the PCS with existing businesses, the land lease may be reduced, as the PCS would increase the footfall of customers in the co-located businesses. The reduction of land lease would increase the net profit of the PCS as well. Further, installation of RE in the PCS, would allow the PCS to generate an extra source of revenue by selling the excess energy generated back to the grid.

To increase the utilization of the PCS, the number of EVs on road needs to increase. For this to happen extensive awareness needs to be done, to motivate the people to purchase an EV instead of an ICE vehicle.

The cumulative impact of different interventions has been applied to the case study, the results of which are given in Table 4.33. Table 4.34 and Figure 4.34 shows the detailed financial performance of the involved parties and their annual discounted cash flows.

Table 4.33: Cumulative impact of different interventions on the financial performance with 5% interest loans

Scenario	Total Capital Investment (INR)	NPV (INR)	Payback Period (years)	Internal Rate of Return (IRR)
More awareness + RE + free electrical connection	1,28,56,192/ 1,42,166	3,22,20,989/ 3,56,307	5	26%
More awareness + RE + free electrical connection + 25% subsidy on chargers	91,05,196/ 1,00,687	3,59,71,985/ 3,97,786	4	36.9%
More awareness + RE + free electrical connection + 25% subsidy on chargers + land lease paid by private partner business	79,22,906/ 87,613	5,91,11,282/ 6,53,666	2	76.1%

It shows that the cumulative implementation of these interventions has a drastic impact on the business viability of the PCS. The NPV of the owner operator has increased along with the private sector partner, in spite paying the land lease, if the land is owned by a third party (if the land is owned by the partnered private business, their NPV would grow even higher).

Table 4.34: Financial performance statistics with no subsidies, 5% interest rate on loans, aggressive awareness, use of RE without any subsidies and co-location of PCS with private sector partner

Entity	Total Capital Investment (INR/ EUR)	NPV (INR/EUR)	IRR (%)	Payback period (years)
Owner-operator	1,90,11,712/ 2,10,236	4,69,53,919/ 5,19,227	26.3%	4
Private Sector Partner	30,00,000/ 33,174	85,93,070/ 95,024	17.3%	7
Public Sector Partner	79,93,068/ 88,389	-12,90,826/ -14,274	-	-
Total Project	**4,24,89,280/ 4,69,856**	**7,67,28,852/ 8,48,486**	**22.2%**	**5**

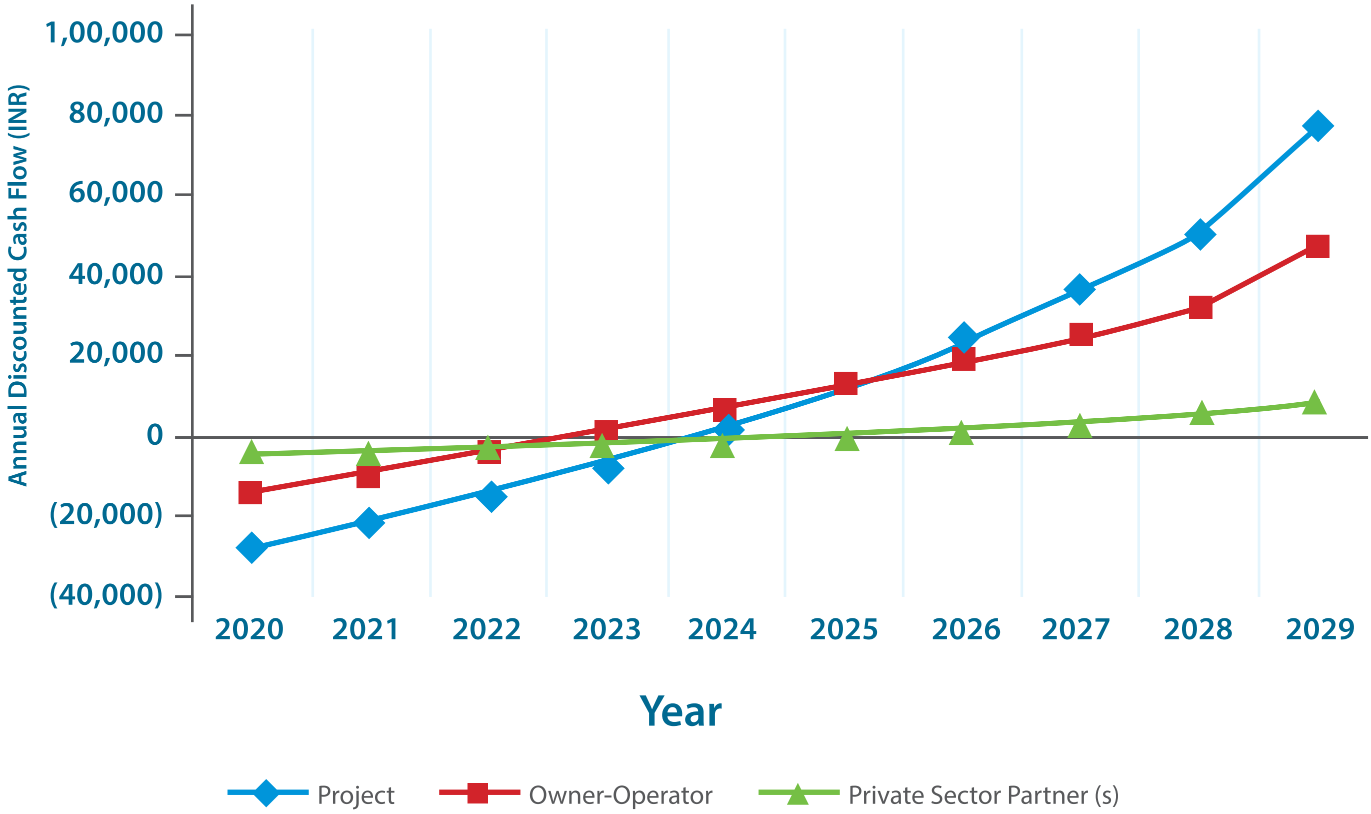


Figure 4.34 Annual cumulative discounted cash flow with no subsidies, 5% interest rate on loans, aggressive awareness, use of RE without any subsidies and co-location of PCS with private sector partner

The different proposed policy and regulatory interventions mentioned in Section 4.3.2, have impacts on different aspects of the EV charging infrastructure. There is no single best policy/intervention that can satisfy all the different requirements. The detailed impact of the interventions on the EV charging infrastructure have been tabulated in Table 4.37 and Table 4.38.

EESL is one of the major agencies that have put up substantial EV charging infrastructure in the country. The revenue earned by EESL from one of its such charging stations in Delhi ishave been given in Table 4.35.

Table 4.35: Revenue of a single EESL charging station in Delhi[42]

Charger Type	Energy consumption per month (kWh)	Rate charged from EV users (INR/kWh (EUR/kWh))	Electricity tariff (INR/ kWh(EUR/ kWh)))	Monthly revenue (INR/ EUR)	Monthly cost (INR/EUR)	GrossNet monthly revenue (INR/ EUR)
Bharat AC001 3.3 kW	396	7.5/ 0.083	5.5/ 0.061	2970/ 32.84	2178/ 24.08	792/ 8.76
Bharat DC001 15 kW	1800	10/ 0.11	5.5/ 0.061	18000/ 200	9900/ 109.48	8100/ 89.57
DC fast charger 140 kW	6000	26/ 0.29	5.5/ 0.061	156000/ 1,725	33000/ 364.92	123000/ 1,360
Total				176,970/ 1957		131,892/ 1458

For installation of the charging station the CAPEX investment is around INR 30 lakh with additional INR 4-5 lakh for electricity connection charges. The performance of this charging station for different interventions proposed in this chapter have been described in Table 4.37. Two different sets of utilization have been considered as given in Table 4.36.

Table 4.36: Description of the two utilizations

Monthly energy consumption per charger (kWh/month)	
U1	AC001 – 396 kWh/month
	DC001 – 1800 kWh/month
	DC fast charger – 6000 kWh/month
U2	AC charger - 328 kWh/month
	DC001 – 1479 kWh/month
	DC fast charger – 1479 kWh/month

As can be seen in Table 4.37, with higher utilization the EV charging station has already paid back its initial investment in 3 years, with a net NPV of INR 1,26,44,654 after 10 years. However, with lower utilization, additional measures were needed to make the charging station business viable.

Table 4.37: Financial performance statistics

Scenario	Utilization	Investment (INR)	NPV (INR)	Payback period (years)	IRR (%)
No additional incentives	U1	28,50,713/ 31,523	1,26,44,654/ 1,39,827	3	47.2%
No additional incentives	U2	28,50,713/ 31,523	9,09,934/ 10,062	9	4.9%
20% subsidy on chargers	U2	22,52,064/ 24,903	15,08,584/ 16,682	7	9.5%
20% subsidy on chargers+ free electrical connection	U2	19,36,064/ 21,409	17,32,944/ 19,163	6	12.8%
20% subsidy on chargers+ free electrical connection+ 180 kW rooftop PV [43]	U2	20,45,683/ 22,621	94,37,136/ 1,04,358	2	81.5%

42 The details of the station have been sourced from ISGF, "Study of Electric Vehicle Charging Infrastructure Planning and Rollout for Bengaluru City, Karnataka," September 2021., however the details could not be validated with official EESL data.

43 Cost of PV capital has been considered

Table 4.38: Impact of policy and regulatory interventions on different aspects of the EV charging infrastructure

Policy and Regulatory Interventions	Private Charging Infrastructure		Workplace Charging Infrastructure		Public Charging Infrastructure				Support utility to accommodate more chargers
	Cost/ Revenue	Number	Cost/ Revenue	Number	Cost	Revenue	Utilization	Number of available locations	
Mandating EV charging infrastructure in building bye-laws	-	Min. number of EV chargers mandated at buildings	-	Min. number of EV chargers mandated at buildings	-	-	-	-	-
Aggressive awareness	-	Increase in number of EV users leading to higher number of EV chargers	-	Increase in number of EV users, resulting in more requirement of workplace EV chargers	-	-	Increased awareness leading to more EV users facilitating more usage of PCS	-	-
Support market creation for private investment on public charging infrastructure	-	-	-	-	Subsidies and low interest rates reducing the cost of installation of PCS	-	-	-	-
Support mechanism/ incentives for use of RE in EV charging	With RE, the amount of energy purchased from grid is reduced, which reduces the cost of charging	-	With RE, the amount of energy purchased from grid is reduced, which reduces the cost of charging	-	-	With RE, the amount of energy purchased from grid is reduced, which reduces the cost of charging	-	-	During high RE generation periods, the power drawn from grid is reduced, reducing the burden on the electrical utility. So, more EV chargers can be accommodated.
Easy access of land for setting up PCS	-	-	-	-	Lower cost of land would reduce the cost of setting up of PCS	-	-	With access to land owned by public authorities, more land is available for setting up of PCS	

Policy and Regulatory Interventions	Private Charging Infrastructure		Workplace Charging Infrastructure		Public Charging Infrastructure				Support utility to accommodate more chargers
	Cost/ Revenue	Number	Cost/ Revenue	Number	Cost	Revenue	Utilization	Number of available locations	
Support for distribution system upgradation for charging infrastructure	-	-	Depending on the number of chargers installed, upgradation of grid may be required. With support for grid upgradation, the required charges may be reduced	-	Depending on the number of chargers installed, upgradation of grid may be required. With support for grid upgradation, the required charges may be reduced	-	-	-	Help utility to strengthen the distribution system to accommodate more EV chargers.
Adequate EV charging infrastructure deployment regulations.	-	-	-	-	-	-	-	Regulations on EV charging infrastructure deployment would increase more potential charging locations like kerb-side chargers, public parking lots etc.	-
Battery swapping should be subsidized at par with EV chargers	-	-	-	-	Reduction in capital cost for establishment of battery swapping stations	-	-	-	-
Grid integration of EV charger regulations (technical)	-	-	-	-	-	-	-	-	Mandating minimum technical requirements for EV chargers would lessen the impact on power quality

Policy and Regulatory Interventions	Private Charging Infrastructure		Workplace Charging Infrastructure		Public Charging Infrastructure				Support utility to accommodate more chargers
	Cost/ Revenue	Number	Cost/ Revenue	Number	Cost	Revenue	Utilization	Number of available locations	
Harmonization of EV charging standards		-	-	Harmonized standards, would reduce the requirement of variability in charger types.	-		Harmonized standards, would reduce the requirement of variability in charger types. More EV model variants would be able to utilize the PCS.	-	
Grid support services from EV	Additional revenue can be earned by participating in grid support services	-	Additional revenue can be earned by participating in grid support services	-	-	Additional revenue can be earned by participating in grid support services	-	-	With grid support from EVs, effective load management can be achieved which can help incorporate more simultaneous EV charging. With ancillary service provision from EV the stability of the grid would be improved
Regulations to make smart charging compulsory	Smart charging methodologies like dynamic pricing, demand response etc. can help reduce the cost of charging or increase the revenue earned	-	Smart charging methodologies like dynamic pricing, demand response etc. can help reduce the cost of charging or increase the revenue earned	-	-	Smart charging methodologies like dynamic pricing, demand response etc. can help reduce the cost of charging or increase the revenue earned	-	-	Smart charging methodologies like dynamic pricing, demand response etc. would enable the grid to incorporate more charging load into the network as the grid is properly managed.

4.8 Summary of recommendations

Section 5.6 provided an in-depth analysis of different technical, policy and regulatory interventions. Now, considering the 'EV charging deployment' issue the following challenges are of paramount impotanceimportance,

a) Lower number of EVs on road leading to unattractiveness of PCS business for the private sector
b) Uncertainty over capability of theWhether the distribution system is able to accommodate the EV charging load?
c) Lack of private charging options for EV users without a designated residential parking spot.
d) Longer time required for charging which is not suitable for public charging
e) Lack of financial options for a private entity to install a PCS.
f) Lower margin of profitability of the PCS business, resulting in poor returns for the PCS business
g) Lack of standards for 2W and 3W charging
h) Dearth of available land for installation of PCS.

Based on the learnings from the in-depth analysis of the top 5 alternatives for both technical and policy and regulatory interventions, a combined ranking for all the 10 alternatives have been undertaken. These rankings would enable the relevant stakeholders and decision makers in prioritizing the implementation of different key interventions identified in this study.

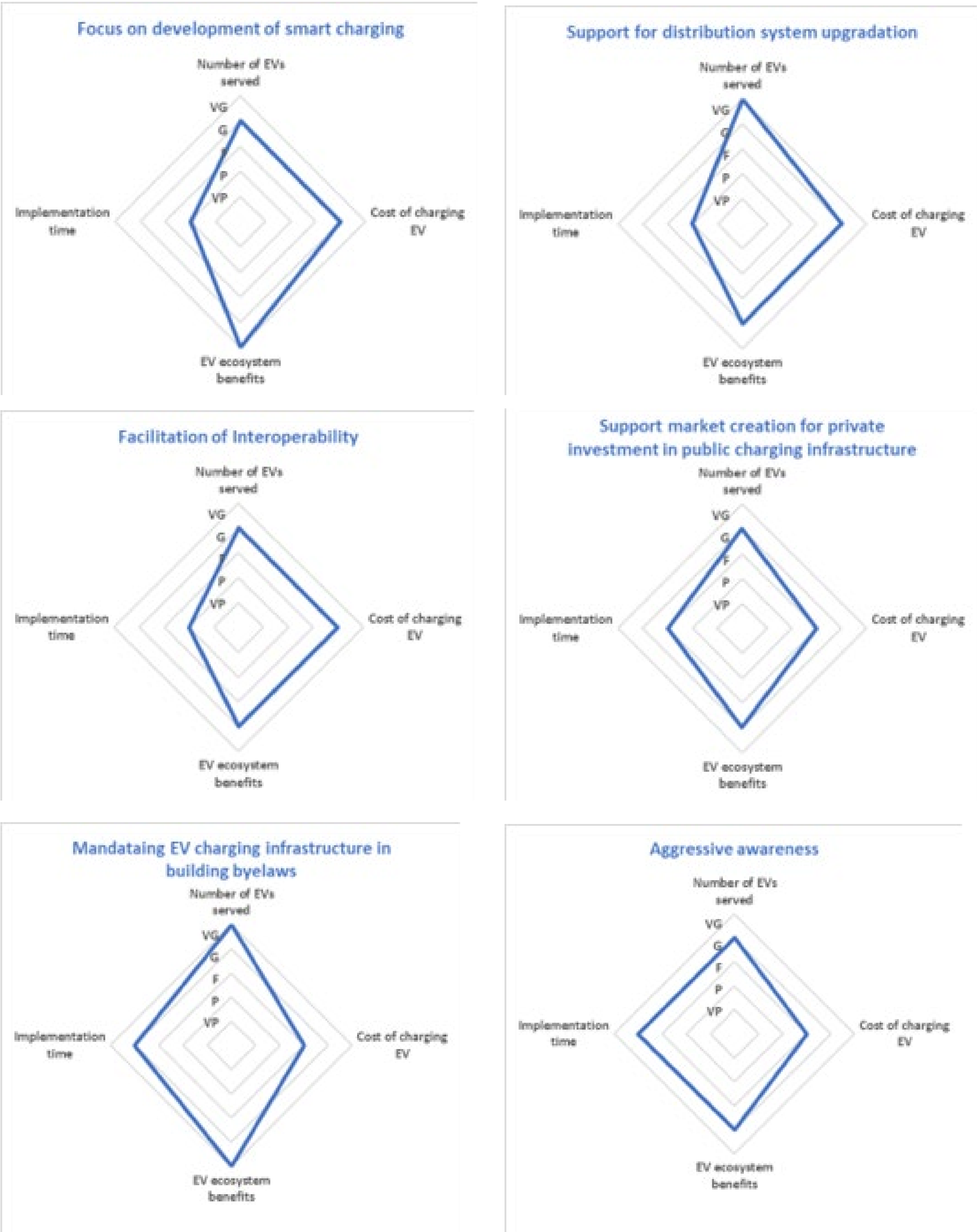
Four different criteria are identified for assessing the impact of the alternatives. These criteria are,

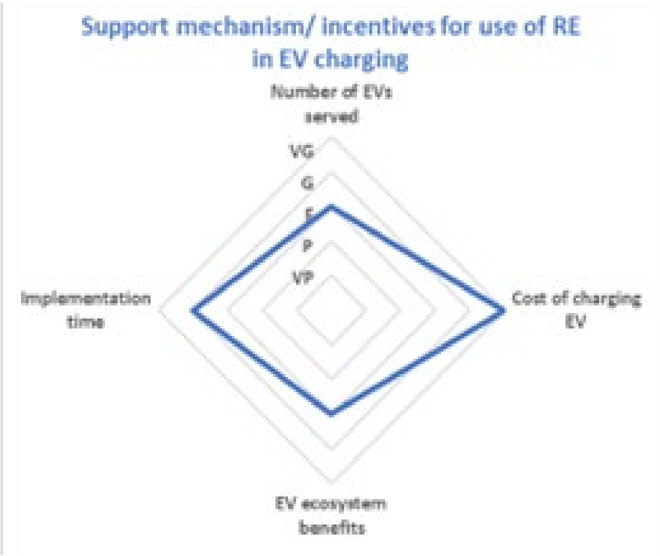
- **Number of EVs served:** This criterion assesses if the proposed alternative has an effect on increasing the number of charging events that can be achieved per day. This can be achieved by either increasing the number of charging points or by reducing the charging time.
- **Cost of EV charging:** The next criterion that have been chosen is the cost of charging EV. Here, the alternatives are scored dependent on whether their implementation has an impact on reducing the cost of EV charging.
- **EV ecosystem benefits:** In this criterion, the alternatives are analysed based on the impact on the overall EV ecosystem. This includes benefits provided by the alternative to CPO, eMSP, fleet operators, electrical system operator etc.
- **Implementation time:** The final criterion chosen for ranking the alternatives is the time required for implementation of the said intervention.

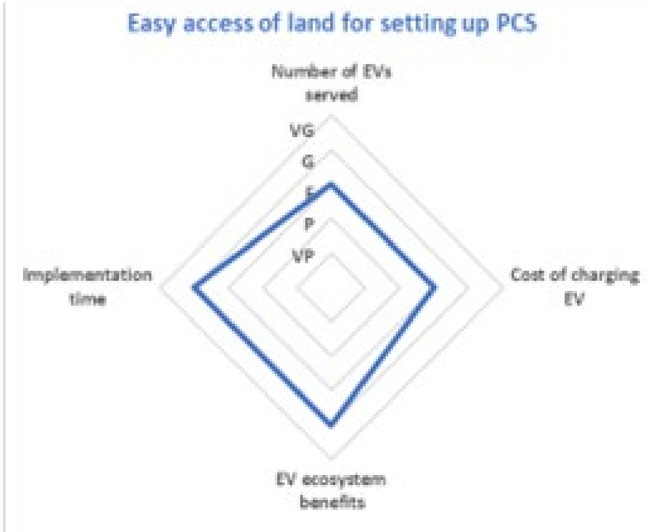
For ranking of these alternatives, the Fuzzy TOPSIS method as described in Section 5.3.3 is utilized. Based on the learnings from the in-depth analysis of the alternatives as provided in Section 5.5 and Section 5.6, the scores achieved by the alternatives are provided in Figure 4.35.

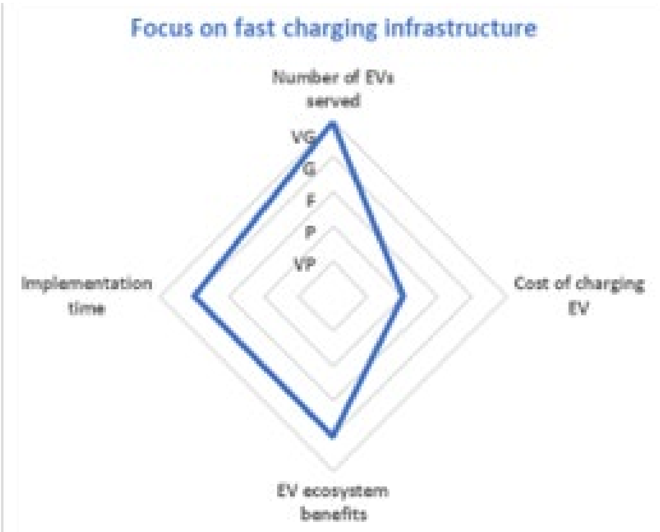
Figure 4.35: Performance of the interventions against the selected criteria. The higher the score for each criterion the more favourable the performance of the intervention for that criterion. (VG: Very good, G: Good, F: Fair, P: Poor, VP: Very poor)

Based on the above scores, the final ranking of the top 10 interventions is provided in Table 4.39.









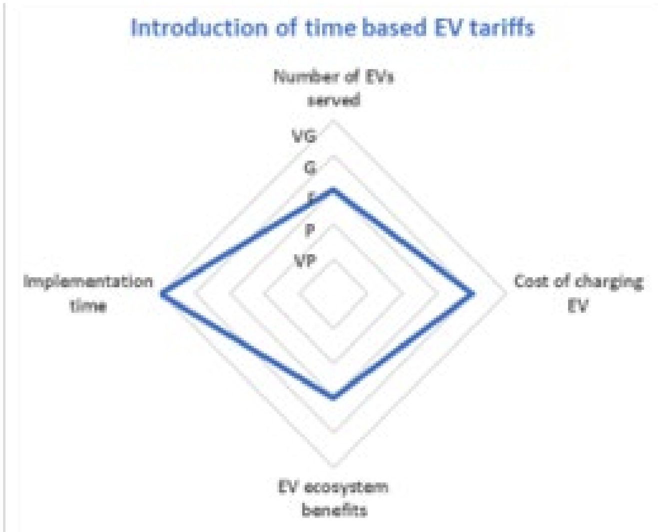


Table 4.39: Priority of recommendations

Intervention	Rank
Mandating EV charging infrastructure in building bye-laws	1
RE Integration for EV charging	2
Introduction of time based EV tariffs	2
Focus on fast charging infrastructure	3
Focus on development of smart charging	3
Support for distribution system upgradation	3
Easy access of land for setting up PCS	4
Aggressive awareness	5
SuppootSupport market creation for private investment in public charging infrastructure	5
Facilitation of Interoperability	6

Further details about these recommendations have been furnished in Chapter 5,

The analysis provided in Section 4.8, provided the list of interventions necessary for increasing the EV charging infrastructure in the country. However, implementation of the same needs further directions/way forward for effective implementation. In this section, the steps needed for implementation of the recommendations have been provided.

1. **Mandating EV charging infrastructure in building bye-laws**

   a. **Responsible agencies** - The necessary building bye-laws needs to be implemented by the respective municipalities/UDAs. After the bye-laws are created their implementation also needs regular monitoring, to ensure that the building owners/managers are adhering to the bye-laws. Here, the CPOs also need to create business models for installation of charging infrastructure in building premises.

   b. **Prerequisites** – The municipalities/UDAs can prepare the building bye-laws, after model bye-laws are created at the central level. This prerequisite has been met in Indian context, as MoHUA has already released model building bye-laws with EV charging infrastructure.

   c. **Timeframe** – Once the bye-laws have been released by the respective authorities, the newer buildings would be constructed as per the latest bye-laws. However, as such building bye-laws are generally restricted to renovated or newer buildings only, the inclusion of charging infrastructure in older buildings would take a few years. But, if the bye-laws made it compulsory for all buildings to provide EV charging infrastructure it would significantly quicken the implementation time-period.

Action items	Stakeholders
Amendments to existing building bye-laws to include EV charging infrastructure regulations as per the amendments made to Model Building Bye-Laws 2016 is necessary.	Municipalities, Urban development authorities
Enforcement of building bye laws can be done by mandating the presence of EV charging infrastructure while providing approval for building construction. Also adding the requirement of a separate certificate on the fulfilment of minimum charging infrastructure criteria prior to building construction approval..	Municipalities, Urban development authorities
While obtaining electrical connection for the building, charging infrastructure for EVs needs to be accounted for.	Electricity distribution company, Building manager
Provision of separate submeter and EV tariff for EV charging.	SERC, Electricity distribution company

2. Aggressive awareness

a. **Responsible agencies** – The central and state government are the primary responsible authorities to provide mass awareness about EVs. The inclusion of courses on EV should also be prescribed by the Ministry of Education and Training. The different stakeholders in the EV ecosystem such as CPOs, fleet aggregators, eMobility service providers, OEMs can also actively participate in promotion of EVs over ICE vehicles. There is also a need of a portal showing the details of location and status of EV chargers around the nation.

b. **Prerequisites** – There are no specific prerequisites for this intervention which makes it very suitable for implementation.

c. **Timeframe** – Although the growth of EV users is likely to grow up organically, aggressive awareness is likely to increase the growth rate. However, the quantification of this growth rate would also be dependent on other factors such as, cost of ownership of EV models over ICE vehicles, risk aversion of the general public, customer service etc.

Action items	Stakeholders
Develop EV awareness program for mass awareness of benefits of EV over ICE vehicles	Ministry of Information and Broadcasting, Ministry of Heavy Industries (Department of Heavy Industries), Ministry of Road Transport and Highways, Ministry of Power (BEE)
Promote EV awareness through advertisements in media	Ministry of Information and Broadcasting, Ministry of Heavy Industries (Department of Heavy Industries), Ministry of Road Transport and Highways, Ministry of Power (BEE), Media houses
Focus on ad campaigns in high footfall areas such as malls, movie halls etc.	Industry players, Ministry of Information and Broadcasting,
Country-wide awareness on benefits of EVs over ICE vehicles through mass communication channels such as TV broadcast, radio, newspapers, dedicated awareness campaigns etc.	Ministry of Information and Broadcasting, Ministry of Heavy Industries (Department of Heavy Industries), Ministry of Road Transport and Highways, Ministry of Power, Media houses

Action items	Stakeholders
Mass deployment of charging infrastructure would also serve as awareness of EV.	Industry players, Ministry of Heavy Industries(Department of Heavy Industries),
Utilization of charging infrastructure itself as medium for placement of ads on EV benefits.	Industry players
Develop curriculum in technical institutes including polytechnic colleges, ITIs for developing manpower pool	Ministry of Education and Training (Dept. of Higher Education), Ministry of Labour and Employment
Develop online portal showing the availability of charging points in a region	Ministry of Information and Broadcasting, Ministry of Heavy Industries(Department of Heavy Industries), Ministry of Road Transport and Highways, , Ministry of Power (BEE), Industry players

3. Support mechanism/ incentives for use of RE Integration forin EV charging

a. **Responsible agencies** – Different ministries can facilitate/ support incentives and schemes for integration of RE with EV charging, such as Ministry of Heavy Industries, Ministry of Power, Ministry of New and Renewable Energy etc. The electricity regulatory bodies such as CERC/SERCs may also need to create regulations allowing EV charging stations to purchase power from RE plants across India, and allow Open Access. Along with the creation of regulations, the CPOs and the EV users with private charging, must also be willing to install captive RE plants/ procure RE from other plants.

b. **Prerequisites** – In order to maximize the revenue, net metering should be used, so that the excess generated power can be sold back to the grid. Also, smart energy management systems could help further increase the usage of the captive RE generation, helping the CPO/ EV user reduce the energy bought from the grid.

c. **Timeframe** – With the creation of regulations, the transition to use of RE for EV charging should be relatively quick, as relatively less number of authorities are involved for this transition to occur.

Action items	Stakeholders
Create awareness programs showcasing the benefits of RE integration with EV charging	Ministry of Information and Broadcasting, Ministry of Heavy Industries, Ministry of Power, Ministry of New and Renewable Energy, Media houses
Develop renewable energy purchase obligations for EV charging load	CEA
Provide financial support for RE installation in EV charging stations at remote areas such as highways and rural areas	Ministry of Power (BEE), Ministry of New and Renewable Energy (Indian Renewable Energy Development Agency Limited (IREDA)),
Ease of lending from financial institutions for projects with RE integrated EV charging	Ministry of New and Renewable Energy (Indian Renewable Energy Development Agency Limited (IREDA)), Banks,
Remove/reduce the minimum load requirement/ connection voltage level for participating in Open access regulations for EV charging stations	CERC, SERC
Create tariffs to incentivize EV charging during periods of high RE generation.	CERC, SERC
Develop residential smart energy management products using EV as storage unit to maximize the local RE generation usage.	Industry players, Electricity distribution company, Ministry of Power

4. Introduction of time based EV tariffs

a. **Responsible agencies** – For implementation of time based EV tariff, the necessary tariff regulations are to be designed and implemented by the respective SERC. Once the regulations are in place, the DISCOMs needs to oversee the proper implementation of the tariff. Further, the end users i.e., the CPOs and the EV users should also have smart meters installed for them to utilize the benefits of time based tariffs.

b. **Prerequisites** – Apart from the necessary regulations, the EV user/CPO should also be equipped with smart meters to accurately log the energy use.

c. **Timeframe** – Once the regulations are launched, the implementation of this intervention would be fairly quick (~1 year).

Action items	Stakeholders
Introduction of Time of Day EV tariffs for EVs, for all types of customers such as ❖ Peak and off peak pricing ❖ RE generation based pricing etc.	CERC, SERC
Introduction of dynamic and real time tariffs	CERC, SERC
Smart meter proliferation in the country	Electricity distribution company, Ministry of Power
Awareness of presence of time-based tariffs and their benefits among the user base.	Electricity distribution company

5. Focus on fast charging infrastructure

a. **Responsible agencies** – The tenders released by the different government agencies should focus more on fast charging infrastructure, rather than slow charging. The Ministry of Power in the latest amendment (1st October, 2019) to the charging station guidelines has already removed the requirements for a public charging station. This step was necessary, for public charging stations to install chargers as per their design goals. Besides, subsidies for upgradation of grid infrastructure should be provided to the DISCOMs in order to incorporate more fast chargers. The CERC/SERCs should also bring about adequate changes in the tariff structure helping the CPOs reduce the cost of electricity purchase.

b. **Prerequisites** – For the growth of fast charging the distribution grid is the bottleneck. ThereforeSo, support for distribution grid augmentation from the government is preferred.

c. **Timeframe** – For implementation of fast charging infrastructure, the initial hurdle is to shift the mindset of the policy makers and key stakeholders to a favourable attitude towards fast charging infrastructure. Thereafter, the actual implementation of fast charging infrastructure growth depends on the EV ecosystem growth and can range between 2-5 years.

Action items	Stakeholders
Installing fast chargers at high traffic, high impact zones such as transport hubs, refuelling stations, highways	Department of Transport, Municipalities, Urban development authorities, Industry players
Install fast chargers in high footfall areas such as community parks, malls, movie halls, etc.	Department of Transport, Municipalities, Urban development authorities, Industry players
Ensure proper planning for accommodation of present and future EV load.	Electricity distribution company
Ease of lending from financial institutions for fast charging infrastructure	Banks, Venture Capitals, Investment Banks
Create public-private partnerships and increase private participation in installing fast charging infrastructure	Electricity distribution company, Municipality, Government and semi-government offices with available land, Industry players
Identify optimal sites for establishment of fast charging stations	Department of Transport, Municipalities, Urban development authorities, BEE

6. Focus on development of smart charging [44]

a. **Responsible agencies** – Implementation of smart charging requires the cooperation of different stakeholders. The electricity regulators, i.e., CEA/CERC/SERCs should create regulations detailing the requirements in smart charging functionality. These functionalities then needs to be incorporated in the smart chargers by the respective OEMs. The DISCOM should also have the necessary smart grid infrastructure in place, to have observability over the distribution feeder. This information would be then used by the Charge Management System (CMS) to control the charging of the different smart chargers. Then EV user/CPO should have smart charging enabled chargers installed with access to communication pathways.

b. **Prerequisites** – Smart grid infrastructure should be in place for enabling of smart charging, along with smart chargers. A central charging management system should also be created to control the charging based on the different grid parameters

c. **Timeframe** – The timeframe for implementation of smart charging depends on the smart charging strategy used. Tariff based smart charging can be implemented relatively quickly (within 1-2 years, depending on the smart meter installation), however, communication based smart charging would be a long term goal due to necessary growth of EV ecosystem and the IT infrastructure.

44 Here, smart charging implies coordinated, communication signal based smart charging.

Action items	Stakeholders
Increase the smart meter proliferation in the country	Electricity distribution company, Ministry of Power
Include smart charging pilot projects to identify the challenges of smart charging in India	Ministry of Power, Ministry of Heavy Industries, Ministry of Road Transport and Highways
Develop robust communication infrastructure for communication between the different involved entities	Ministry of Power, Ministry of Heavy Industries,
Develop robust metering and billing infrastructure	Electricity distribution company
Develop stringent cyber security measures	Ministry of Electronics and Information Technology
Study and identify EV user behaviour to maximize user benefits.	Industry players
Develop products in the energy market for EV participation such as ❖ Demand response ❖ Ancillary services	CEA, CERC, Energy Exchanges (IEX, PXIL)
Develop conducive market for smart energy management products. This includes transparent and adequate electrical regulations, fiscal regulations,	Ministry of Power, CEA, CERC, SERC
Formation of smart charging cell for collaborative efforts in development of smart charging	

7. **Support for distribution system upgradation**

a. **Responsible agencies** – The Ministry of Power, CEA, CERC and SERC should come up with different avenues by which the distribution utility could be reimbursed for the investment on grid upgradation infrastructure.

b. **Prerequisites** – None

c. **Timeframe** – Implementation of distribution system upgrades would be in phases. The first phase involves assessment of bottlenecks in the distribution network which can take anywhere between 6 months to a year. These bottlenecks needs to be assessed with forecast of EV growth in the respective feeders. So, the entire assessment period would take somewhere between one to two years. The actual upgradation of the critical components would be achieved in two to three years.

Action items	Stakeholders
Identification of locations with significant potential increase in electrical mobility and energy demand.	Electricity distribution company, Transport authority, Municipality, Industry players
Assessment of bottlenecks in current electrical system such as ❖ Congested lines ❖ Low margin in transformers ❖ Protection equipment etc.	Electricity distribution company
Land allocation for setting up of substations, and right of way clearance for high tension lines setup	Transmission System Operator, Electricity distribution company, MoRTH, MoP, Transport authority, Municipality
Fund allocation and disbursement	Electricity distribution company, MoP
Upgradation of critical components in the network ❖ Lines and cables ❖ Transformers ❖ Other electrical distribution equipmentsequipment	Electricity distribution company
Setting up a smart grid infrastructure for continuous monitoring of system health.	Electricity distribution company
Periodic assessment of network upgradation requirements	Electricity distribution company

8. **Easy access of land for setting up PCS**

a. **Responsible agencies** – State government and ministries need to offer the available land in their offices for lease by PCS. Here, regulations increasing the availability of land in urban centres needs to be created by respective authorities like MoHUA. This would open up higher amount of available space. Further, the municipalities and the urban developments authorities, need to allow installation of EV chargers in existing infrastructure such as street lights/ other street side electrical equipment along with kerb side chargers.

b. **Prerequisites** – None

c. **Timeframe** – Once the regulations are in place, the CPOs would be able to immediately use the land of these public spaces for installation of PCS.

Action items	Stakeholders
Instrument for leasing of land owned by government to private companies for EV charging infrastructure	Municipalities, Urban development authorities, BEE,
Retrofitting of existing street infrastructure with EV chargers	Municipalities, Urban development authorities, Electricity distribution company
Ease of lending from financial institutions	Banks, Venture Capitals, Investment Banks
Strategic partnership between CPOs and other business ventures.	Industry players

9. Facilitation of Interoperability

a. **Responsible agencies** – The regulations for requirement of interoperability needs to be published by the respective ministries such as Ministry of Transport/ MoHIPE. Along with the regulations there also needs to be cooperation among the different CPOs and the availability of a roaming platform like Hubject/ Gireve. Besides, there also needs to be standardization of EV charging for interoperability of hardware/ software used by the different CPOs.

b. **Prerequisites** – Interoperability is bottlenecked by the communication infrastructure and harmonization of EV charging standards. Without communication in place eRoaming cannot be implemented.

c. **Timeframe** – As interoperability is dependent on multitude of stakeholders, its implementation would require some time, around 2-3 yrs.

Action items	Stakeholders
Development of harmonized standards for EV charging for all EV sectors	BIS, Ministry of Heavy Industries, Ministry of Power,
Enforcement on OEMs to develop products strictly based on standards approved.	OEM, Testing & Compliance Agencies, Ministry of Power, Ministry of Heavy Industries,
Development of communication protocols for enabling eRoaming	BIS, Ministry of Communications
Strategic partnership between CPOs for enabling eRoaming	Industry players

10. Support market creation for private investment in public charging infrastructure

a. **Responsible agencies** – For private players to invest in the public charging development business, the economics of the venture is of the paramount importance. For the initial growth periods when the number of EVs in the country is limited, the financial institutions would need to provide subsidies and rebates and cheaper credit for charging infrastructure installation to make it attractive for the private players. Here ministries, such as Ministry of Heavy Industries, Ministry of Power, Ministry of New and Renewable Energy, Ministry of Micro, Small and Medium Enterprises can help in providing different grants and schemes to lower the cost of charging infrastructure installation and operation. Further, the financial institutions can introduce cheaper credits for investment in 'green' technologies.

b. **Prerequisites** – None

Action items	Stakeholders
Provision of grants and subsidies during initial growth periods	Ministry of Heavy Industries, Ministry of New and Renewable Energy, Ministry of Micro, Small and Medium Enterprises, State Governments
Introduction of credit for 'green' technologies at lower interest rates	Reserve bank of India, Commercial banks
Reduced cost of electricity for public charging stations	SERCs

06 Conclusion

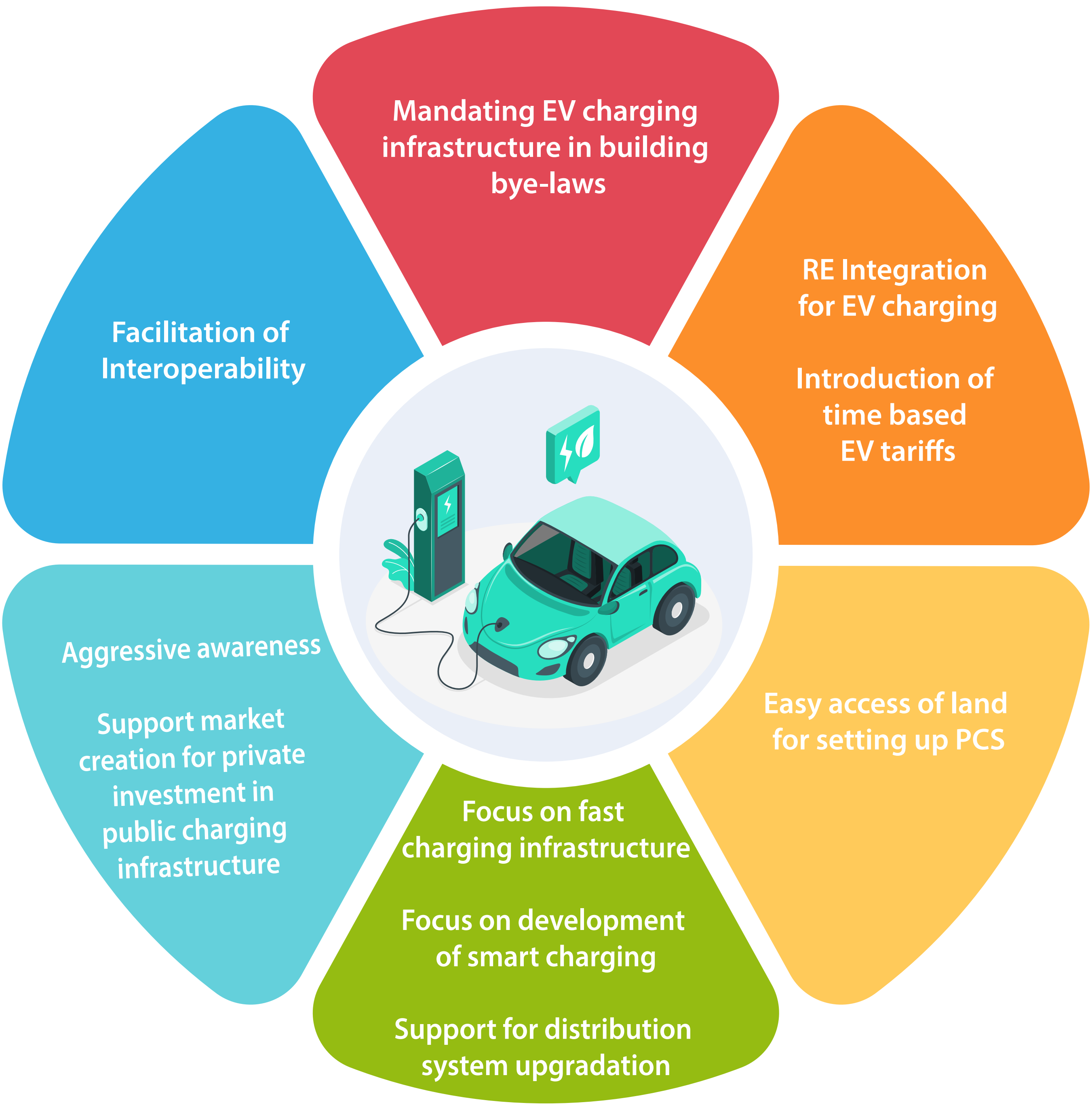
POTENTIAL WAY FORWARD TO IMPLEMENT THE TOP KEY INTERVENTIONS WILL PLAY A CRITICAL ROLE IN SEAMLESS ADOPTION OF EV CHARGING INFRASTRUCTURE, AND THIS REPORT AIMS TO PROVIDE WITH THESE INPUTS TO INDIAN POLICY AND REGULATORY AGENCIES

India has established ambitious goals for electrifying its transportation industry. Both the Central and State governments have also introduced various initiatives and strategies with the intention of encouraging widespread use of electric vehicles. However, there are still multiple challenges that are deterring the widespread development of EV charging infrastructure.

The challenges for EV charging infrastructure adoption ranges are wide and varied. While the government has released different schemes and incentives to accelerate the growth of EV and EV charging infrastructure, they need better planning for effective utilization of the funds earmarked. In addition to supporting the EV charging infrastructure itself, support for upgradation of the electrical infrastructure also needs to be considered. One of the critical challenges in the sector is the lack of available land for installation of charging stations. Even for private charging, the EV users face multiple obstacles in installation of their private chargers specially for residents in multiunit dwelling apartments. In addition, the lack of standards for communication, the absence of the prerequisites for implementation of communication based smart charging also adds to the challenges. The lack of charging infrastructure is also dependent on the fact that the number of EVs in the country is still quite low. This can be attributed to the fact there is a lack of awareness among the general public of the benefits of EV, the cost of EVs is still comparatively higher compared to ICE vehicles and the lack of workforce in the EV sector, particularly for the case for roadside assistance and repair.

Addressing these challenges would need the implementation of a number of potential countermeasures. For a developing nation such as India, it is critical that there is effective utilization of resources, which requires a systematic study to determine the priority of intervention rollout that would maximize the development of charging infrastructure in India. For policy and regulatory agencies, identifying key interventions, priority of each intervention, and potential way forward to implement the top key interventions will play a critical role in seamless adoption of EV charging infrastructure, and this report aims to provide with these inputs to Indian policy and regulatory agencies, and other key stakeholder. Based on the analysis, the following 10 interventions were found to be the most effective in developing the overall charging infrastructure (both public and private) in India.

Implementation of the below list of interventions would need the involvement of multiple stakeholders across different ministries and departments and also private stakeholders. However, with an effective, collaborative and joint effort, supported by a meticulous plan, the Indian EV charging infrastructure can be seamlessly developed across the country.



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A1 Stakeholders consulted

Name of Organization	Nature of Organization
Fortum	CPO
Kerala State Electricity Board	DISCOM
Bangalore Electricity Supply Company Limited	DISCOM
CharIn	Charging Standard Issuing Authority
Central Electrical Regulatory Commission	Electricity Regulatory Authority
Central Electrical Authority	Electricity Regulatory Authority
Tripura Electricity Regulatory Commission	Electricity Regulatory Authority
TATA Power-DDL	DISCOM
BSES Yamuna Power Ltd.	DISCOM
BSES Rajdhani Power Ltd.	DISCOM
Department of Science & Technology	Government Agency
Technology Information Forecasting and Assessment Council	Government Agency
National Smart Grid Mission Project Management Unit	Government Agency
Ashok Leyland	OEM
Ola	OEM
Indian Smart Grid Forum	Public Private Partnership Consultancy
Amara Raja	OEM
World Resources Institute	Think-tank

A2 Details of the Multi Criteria Decision Making Process

A2.1: Consistent Fuzzy Preference Relations

CFPR proposed by Herrera-Viedma in 2004[45], uses the following propositions,

Proposition 1,

Initially the set of reciprocal multiplicative preference relations $S=(s_{ij})$ with $s_{ij}\in[1/9, 9]$ based on Saaty's scale is assigned to a group of alternatives $A=\{a_1,a_2,\ldots,a_n\}$. A correlating reciprocal fuzzy preference relation, $G=(g_{ij})$ with $g_{ij}\in[0,1]$ is created using eq. 1.

$$G=f(S),$$

$$g_{ij}=f(s_{ij})=½(1+\log_9 s_{ij})$$ - Eq. 1

Where, f(*) is a transformation function that transforms the reciprocal multiplicative relation matrix into additive preference relation. The base of the logarithm is dependent on the range of s_{ij}. As $s_{ij}\in[1/9, 9]$ so the base considered here is 9, for $s_{ij}\in[1/x, x]$, the base would be x.

Proposition 2,

For the reciprocal preference relation $G=f(S)$, the following statements given in Eq. 2 and Eq. 3 are equivalent,

$$g_{ij}+g_{jk}+g_{ki}=3/2, \forall i, j, k$$ - Eq. 2

$$g_{ij}+g_{jk}+g_{ki}=3/2, \forall i<j<k$$ - Eq. 3

Proposition 3,

Proposition 2 is extended to hold the following statement given in Eq. 4 true,

$$g_{i(i+1)}+g_{(i+1)(i+2)}+\cdots+g_{(i+k-1)(i+k)}+g_{(i+k)i}=(k+1)/2, \forall i, k$$ - Eq. 4

The decision matrix thus formed has entries in the interval [-k,1+k] and not in the interval [0,1]. So, a normalization function to normalize the values of the decision matrix to lie in the interval [0,1] is used. The normalization function is given in Eq. 5,

$$p(x)=(x+k)/(1+2k)$$ - Eq. 5

The aggregation score of each criterion is then calculated using Eq. 6,

$$u_i=1/nf\ (\textstyle\sum^{nf}_{j=1} g_{ij})$$ - Eq. 6

Where, n_f is the number of criteria. The weight (rank) of each criterion can then be calculated using Eq. 7,

$$w_i=u_i/(\textstyle\sum^{nf}_{j=1} u_i)$$ - Eq. 7

A2,2: The MULTIMOORA Method

The MULTIMOORA method is an extension of the MOORA method and was originally proposed in . In essence, the MULTIMOORA method comprises of two parts, the multi-objective optimization by ration analysis (MOORA) and the full multiplicative form of multiple objectives as illustrated in Figure 1.1.

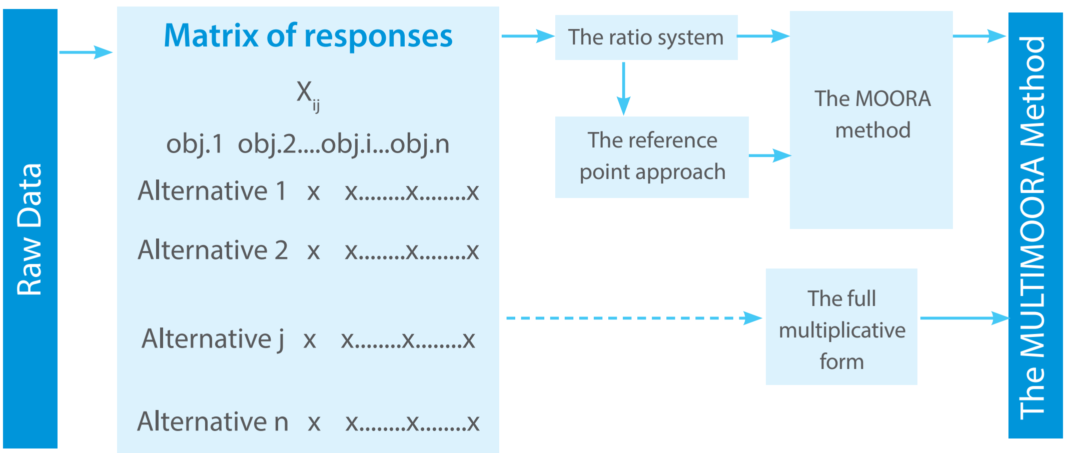


Figure A2.1: The MULTIMOORA methodology

45 E. Herrera-Viedma et al., "Some Issues on Consistency of Fuzzy Preference Relations," European Journal of Operational Research 154, no. 1 (April 1, 2004): 98–109, https://doi.org/10.1016/S0377-2217(02)00725-7.

Multi-objective optimization by ratio analysis (MOORA)

MOORA itself consists of two different parts,

- The ratio system part of MOORA method
- The reference point part of MOORA method

The Ratio System

This method requires a matrix of responses of different alternatives against different set of objectives. The matrix elements denoted by a_ij as the response of the ith alternative on objective j. The performance of each alternative in comparison to other alternatives for a set objective is calculated as per Eq. 8,

$$a^*_{ij}=w_j\ a_{ij}/(\sqrt{(\sum^m_i a^2_{ij})}),\ i=1,2,..m \text{ and } j=1,2,...n$$ - Eq. 8

Where m and n are the number of alternatives and objectives respectively and wj is the weight of each objective. Here $a^*_{ij}\in[0,1]$ and is a dimensionless number.

Next, the normalized values a^*_{ij} are added or subtracted based on whether the objectives are beneficial or non-beneficial. The performance of each alternative for non-beneficial objectives is subtracted from the beneficial objectives as given in Eq. 9

$$b_i=\sum^g_{j=1}a^*_{ij} - \sum^n_{j=g+1}a^*_{ij}$$ - Eq. 9

Where, g denotes the number of beneficial objectives, and the remaining (n-g) objectives are non-beneficial. Based on the value of b_i, every alternative is ranked, with higher values of b_i assigned higher ranks.

The Reference Point System

The reference point system utilizes the normalized scores from Eq. 8. An ideal reference point is selected for each objective based on the performance of each alternative for that objective. For beneficial objectives, the score with the maximum value for that objective is chosen and for a non-beneficial objective, the score with the minimum values is chosen as ideal, i.e.

$$p_j=\begin{cases}\max a^*_{ij}\ \forall\ i=1,2,...m, & \text{if objective j is beneficial}\\ \min a^*_{ij}\ \forall\ i=1,2,...m, & \text{if objective j is non-beneficial}\end{cases}$$

The performance of each alternative is then compared with the reference set point as given and ranked as given in Eq. 10

$$q_i=(\max_j|p_j-a^*_{ij}|)$$ - Eq. 10

The Full Multiplicative Form

The multiplicative form consists of both maximization and minimization of the respective alternatives and their performance against each objective. The performance of the ith alternative can be expressed as given in Eq. 11,

$$U_i=A_i/B_i$$ - Eq. 11

Where, Ai is the product of all beneficial objective for the alternative and B¬i is the product of all non-beneficial objective for the alternative as given in Eq. 12and Eq. 13 respectively.

$$A_i=\prod^g_{j=1}a^{wj}_{ij}$$ - Eq. 12

$$B_i=\prod^n_{j=g+1}a^{\ wj}_{ij}$$ - Eq. 13

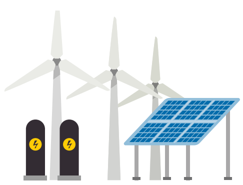
The alternatives are then ranked based on the Ui value, with higher values of Ui given higher rank and vice versa.

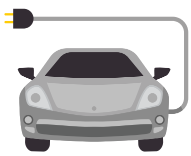
Overall ranking from MULTIMOORA method

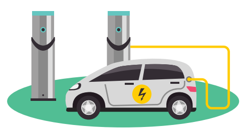
As mentioned above, we have three different ranking methods, the ration system, the reference point system and the full multiplicative form. However, all the three methods can produce different ranks for the alternatives. An overall rank inclusive of the all the three methods is required to rank the alternatives as per the entire MULTIMOORA method, which can be derived using Eq. 14

$$R_i=(R^1_i+R^2_i+R^3_i)/3$$ - Eq. 14

Where, R_i is the overall score of alternative i, $R1_i$ is the rank of alternative i, as per ratio system, $R2_i$ is the rank as per reference point method, and $R3_i$ is the rank as per full multiplicative form method.







A2.3: The Fuzzy TOPSIS Method

The fuzzy TOPSIS method is ideal for ranking of alternatives based on input from experts which can be subjective. The fuzzy TOPSIS method has also been applied to several studies in the field of energy policies.

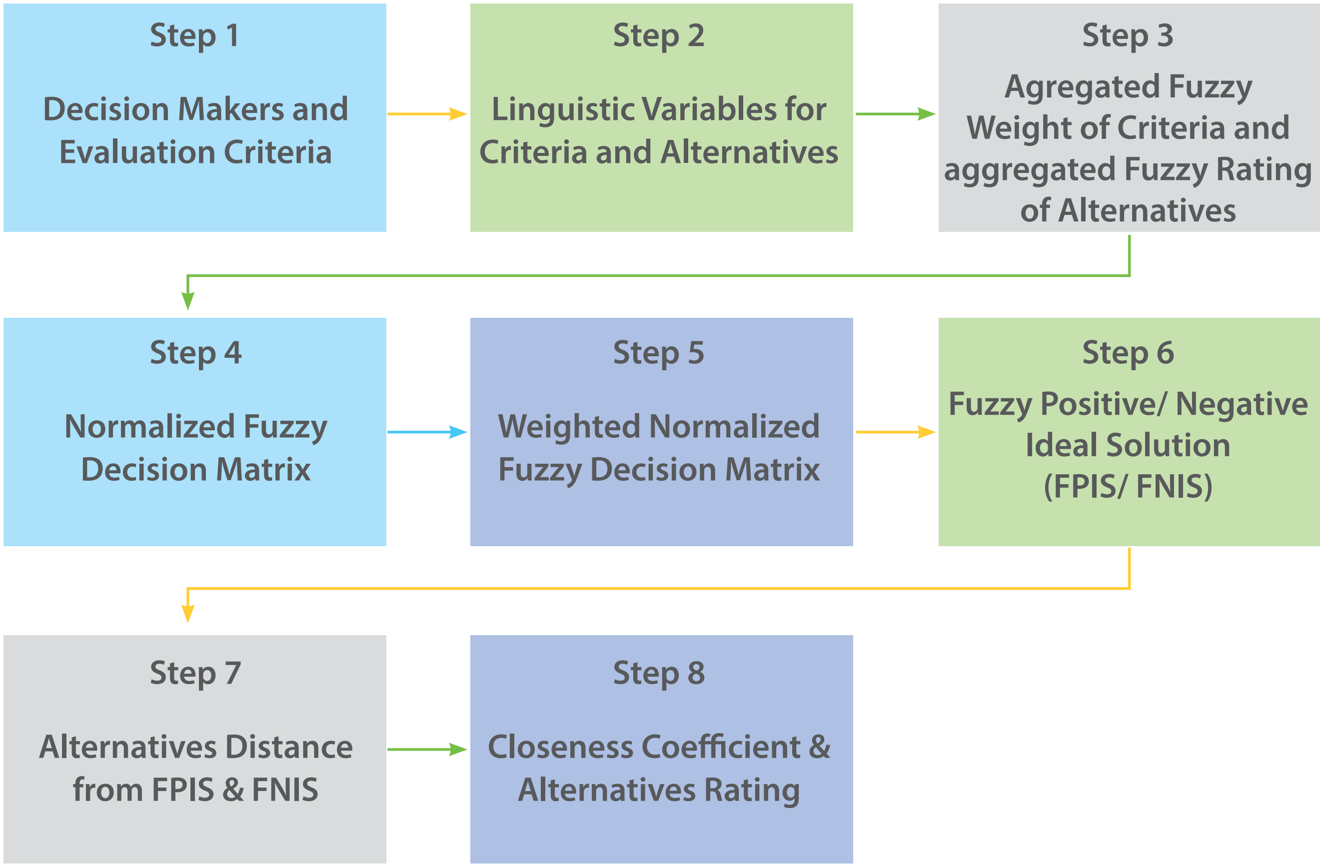


Figure A2.2: Flow chart for implementation of Fuzzy TOPSIS

Implementation of the Fuzzy TOPSIS

The performance of each alternative against a given objective is evaluated in terms of linguistic variable. The importance of each objective over another is also evaluated based on these linguistic variables.

Table A2.1: Definition of linguistic variable for rating of alternatives

Linguistic variable	Fuzzy number
Very low (VL)	(1,1,3)
Low (L)	(1,3,5)
Fair (F)	(3,5,7)
High (H)	(5,7,9)
Very High (VH)	(7,9,9)

A fuzzy decision matrix is formed using the definitions of the linguistic variables given in Table 1.1. Each element of the fuzzy decision matrix is a set of triangular fuzzy number, $\tilde{x}_{ij}=(a_{ij},b_{ij},c_{ij})$

A normalized fuzzy decision matrix $\tilde{R}=[\tilde{r}_{ij}]_{m\times n}$ is formed where,

$\tilde{r}_{ij}= a_{ij}/c^{*}_{j}, b_{ij}/c^{*}_{j},c_{ij}/c^{*}_{j}$ and $c^{*}_{j} = \max_i c_{ij}$ benefit criteria

$\tilde{r}_{ij}=a^{-}_{j}/c_{ij}, a^{-}_{j}/b_{ij} , a^{-}_{j}/a_{ij}$)and $a^{-}_{j} = \min_i a_{ij}$ non-benefit criteria

A weighted normalized fuzzy matrix is then created using Eq. 15

$$\tilde{U}=[u_{ij}]_{(m\times n)}, \text{ where } u\_ij=\tilde{r}_{ij} (.) \tilde{w}_j$$ - Eq. 15

Here, (.) implies that the first element of rij is multiplied with first element of wij, the second element of r_{ij} is multiplied with second element of w_{ij} and so on. The elements, u_{ij} are normalized positive triangular fuzzy numbers lying between [0,1].

Calculate the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS) using Eq. 16and Eq. 17.

$$FPIS=(x+1^{\wedge},x+2,...,x+n), \text{where } x+j = maxi\{xij3\}$$ - Eq. 16

$$FNIS=(x^{-}_{1}, x^{-}_{2}, ..., x^{-}_{n}), \text{ where } x^{-}_{j} = \min_i\{x_{ij1}\}$$ - Eq. 17

After the FPIS and FNIS are calculated for each objective, the distance of each alternative from the FPIS and FNIS are calculated using

$$d^{+}_{i} = \sum^{n}_{j=1} d(u_{ij}, x^{+}_{j}), i=1,2,...m$$ - Eq. 18

$$d^{-}_{i} = \sum^{n}_{j=1} d(u_{ij},x^{-}_{j}), i=1,2,...m$$ - Eq. 19

Where, the distance d is calculated as

$$d(\tilde{p},\tilde{q}) = \sqrt{(1/3 [(p_1-q_1)^2+(p_2-q_2)^2+(p_3-q_3)_2])}$$ - Eq. 20

And $\tilde{p}=(p_1, p_2, p_3)$ and $\tilde{q}=(q_1, q_2, q_3)$ are triangular fuzzy numbers.

The alternatives are then ranked based on the closeness coefficient (CC_i) which is calculated using Eq. 21. The alternative with the largest value of closeness coefficient is assigned a higher rank.

$$CC_i=(d^{-}_{i}/(d^{+}_{i}+d^{-}_{i}), i=1,2,...m$$ - Eq. 21

A3 Ranking of Interventions

A3.1: Technical interventions

A3.1.1: MULTIMOORA method

Each intervention has been scored on the criterions listed in Section 5.2 as per the analysis presented in Section 5.3. The weight of each criterion and the score of each intervention have been given in Table 2.1 and Table 2.2 respectively.

Table A3.1: Weights of objectives/criterions

Criterion	Weight
Benefits	0.277
Negative Impacts	0.277
Economic Impact	0.277
Stakeholder involvement	0.0845
Technology maturity	0.0845

Table A3.2: Score of interventions used for MULTIMOORA analysis

	Benefits	Negative Impacts	Economic Impact	Stakeholder involvement	Technology Maturity
	Maximize	Minimize	Minimize	Minimize	Maximize
Time based EV tariffs	10	0	2	2	10
Fast Charging Infrastructure	6	2	6	2	10
Slow Charging Infrastructure	2	6	2	2	10
Battery Swapping Infrastructure	6	0	7	8	6
Smart Charging – Unidirectional	10	0	5	8	8
Smart Charging with V2G	10	2	8	10	4
Interoperability	6	0	4	8	8
Energy market participation for EV	8	0	5	10	4
RE integration	10	0	2	6	6

The ranks based on the Ratio system has been given in Table 2.3. The Ratio system has identified 'Time-Based EV tariffs' as the most preferred alternative, while 'Slow Charging Infrastructure' has been identified as the least preferred alternative.

Table A3.3: Normalized decision matrix, ratio system and the reference points

	Benefits	Negative Impacts	Economic Impact	Stakeholder involvement	Technology Maturity	bi	Rank
Time based EV tariffs	0.115	0	0.037	0.008	0.037	0.106	1
Fast Charging Infrastructure	0.069	0.083	0.110	0.008	0.037	-0.099	7
Slow Charging Infrastructure	0.023	0.251	0.037	0.008	0.037	-0.237	9
Battery Swapping Infrastructure	0.069	0	0.128	0.032	0.022	-0.074	6
Smart Charging – Unidirectional	0.115	0	0.091	0.032	0.029	0.017	3
Smart Charging with V2G	0.115	0.084	0.147	0.040	0.015	-0.146	8
Interoperability	0.069	0	0.0735	0.032	0.029	-0.006	4
Energy market participation for EV	0.092	0	0.092	0.040	0.014	-0.032	5
RE integration	0.115	0	0.0367	0.024	0.022	0.075	2
Reference point	0.115	0	0.0367	0.008	0.037	-	-

Similar to the Ratio System, the Reference point method has also identified 'Time-based EV tariffs' as the preferred alternative as given in Table 2.4.

Table A3.4: Reference point method

	Benefits	Negative Impacts	Economic Impact	Stakeholder involvement	Technology Maturity	bi	Rank
Time based EV tariffs	0	0	0	0	0	0	1
Fast Charging Infrastructure	0.046	0.083	0.073	0	0	0.085	6
Slow Charging Infrastructure	0.092	0.251	0	0	0	0.251	9
Battery Swapping Infrastructure	0.046	0	0.09	0.024	0.015	0.09	7
Smart Charging – Unidirectional	0	0	0.055	0.024	0.007	0.055	4
Smart Charging with V2G	0	0.084	0.110	0.032	0.022	0.11	8
Interoperability	0.046	0	0.037	0.024	0.007	0.046	3
Energy market participation for EV	0.023	0	0.055	0.032	0.022	0.055	4
RE integration	0	0	0	0.016	0.015	0.016	2

Table 2.5 and Table 2.6, shows the ranking as per the full multiplicative form and the overall ranking respectively. From the final ranking it can be seen that, 'Time-based EV tariff' is the highest ranked alternative across all the methods of MULTIMOORA.

Table A3.5: Full multiplicative form

	A	B	U	Rank
Time based EV tariffs	2.298	1.284	1.789	1
Fast Charging Infrastructure	1.995	2.110	0.945	6
Slow Charging Infrastructure	1.472	2.110	0.697	9
Battery Swapping Infrastructure	1.911	2.043	0.935	7
Smart Charging – Unidirectional	2.256	1.862	1.211	3
Smart Charging with V2G	2.127	2.618	0.813	8
Interoperability	1.958	1.750	1.119	4
Energy market participation for EV	1.886	1.897	0.994	5
RE integration	2.202	1.409	1.561	2

Table A3.6: Final ranking of alternatives

	Ratio System	Reference Point	Multiplicative form	Final Rank
Time based EV tariffs	1	1	1	1
Fast Charging Infrastructure	7	6	6	6
Slow Charging Infrastructure	9	9	9	9
Battery Swapping Infrastructure	6	7	7	7
Smart Charging – Unidirectional	3	4	3	3
Smart Charging with V2G	8	8	8	8
Interoperability	4	3	4	4
Energy market participation for EV	5	4	5	5
RE integration	2	2	2	2

Sensitivity analysis with Monte Carlo simulation

The outcome of the MULTIMOORA analysis is specific to the weights of the objective/criterion assigned. By changing the weights, the results would change. The weights of the objectives are also the interpretation of the decision maker or the expert. So, to have an understanding on the impact of weights on ranking of the alternatives, Monte Carlo approach have been utilized. In the Monte Carlo approach, the ranking of alternatives has been carried out multiple times with randomized weights of objectives for each iteration. A total of 1000 iterations have been undertaken.

The results of the Monte Carlo simulation have been provided in Figure 2.1. Form the figure it can be seen that the top ranked alternative is 'Time based EV tariffs' followed closely by 'RE integration'. 'Smart Charging -Unidirectional' and 'Interoperability' can be third and fourth respectively followed by 'Fast Charging Infrastructure'.

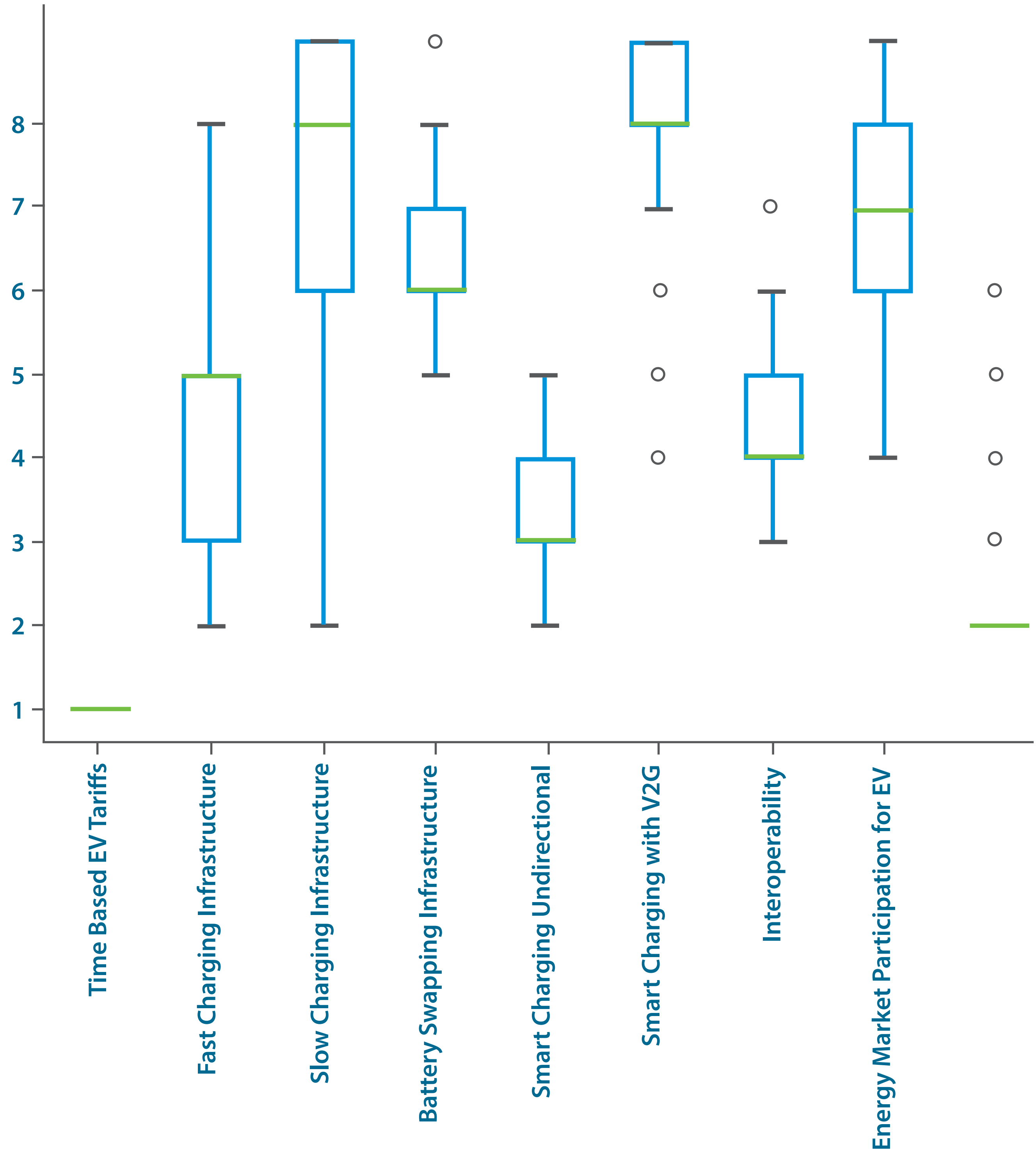


Figure A3.1: Box and whisker plot of Monte Carlo simulation

A3.1.2: Consistent Fuzzy Preference Relations

In CFPR, a preference relation matrix is created with the preference of alternatives over another over different criteria. The preference matrix is given in Table 2.7. In the preference matrix, a pairwise comparison is just made with the immediate next alternative, thereby reducing the number of pairwise comparisons. The weights of each criterion are given in Table 2.1.

Table A3.7: Preference relation matrix

	Benefits	Negative Impacts	Economic Impact	Stakeholder Involvement	Technology Maturity
Time based EV tariffs	3	2	5	1	1
Fast Charging Infrastructure	3	3	⅕	1	1
Slow Charging Infrastructure	⅓	¼	5	4	3
Battery Swapping Infrastructure	⅓	1	⅓	1	½
Smart Charging Unidirectional	1	1	4	2	3
Smart Charging with V2G	3	1	0.125	½	⅓
Interoperability	½	1	5	2	3
Energy market participation for EV	½	1	⅕	⅓	½

From the preference matrix, corresponding reciprocal preference relations are derived. From the reciprocal preference relations, the complete decision matrix is determined for each objective.

The scores achieved by each alternative in the respective criterion and the final ranking of the alternatives are provided in Table 2.8.

Table A3.8: Final ranking of interventions as per CFPR

	Benefits	Negative Impacts	Economic Impact	Stakeholder Involvement	Technology Maturity	Total	Final
Time based EV tariffs	0.0394	0.0377	0.0396	0.0132	0.0113	0.141	1
Fast Charging Infrastructure	0.0253	0.0293	0.0206	0.0132	0.0113	0.099	6
Slow Charging Infrastructure	0.0111	0.0127	0.0396	0.0132	0.0113	0.087	9
Battery Swapping Infrastructure	0.253	0.0342	0.0206	0.0081	0.008	0.096	7
Smart Charging Unidirectional	0.0394	0.0342	0.0336	0.0081	0.010	0.125	3
Smart Charging with V2G	0.0394	0.259	0.0173	0.0055	0.0067	0.094	8
Interoperability	0.0252	0.0342	0.0362	0.0081	0.0100	0.113	4
Energy market participation for EV	0.0323	0.0342	0.0280	0.0055	0.0067	0.107	5
RE integration	0.0394	0.0342	0.0411	0.0095	0.0088	0.133	2

This framework too, assigns 'Time based EV tariffs' as the most favourable technical intervention, followed by 'RE integration for EV charging' and 'Smart Charging Unidirectional' respectively.

Sensitivity Analysis with Monte Carlo Simulation

The ranks mentioned above are, however, dependent on the weights of the criterion. So, in this section, Monte Carlo simulation has been utilized to analyze the sensitivity of the alternatives to change in the weights of the criterion. The results of the Monte Carlo simulation have been presented in Figure 2.2. As seen, the 'Time based EV tariffs' has no variation in the ranking and is the most preferred alternative irrespective of the criteria weights, followed by 'RE integration for EV charging'. Comparatively, 'Smart charging unidirectional' and 'Interoperability', both have the same mean rank, but 'Smart charging unidirectional' has an interquartile range between 5 and 3, while 'Interoperability' has an interquartile range between 5 and 4. On the other hand, 'Battery swapping infrastructure' has the mean rank of 7, while 'Smart charging with V2G' and 'Energy market participation for EV' have the lowest mean rank at 8.

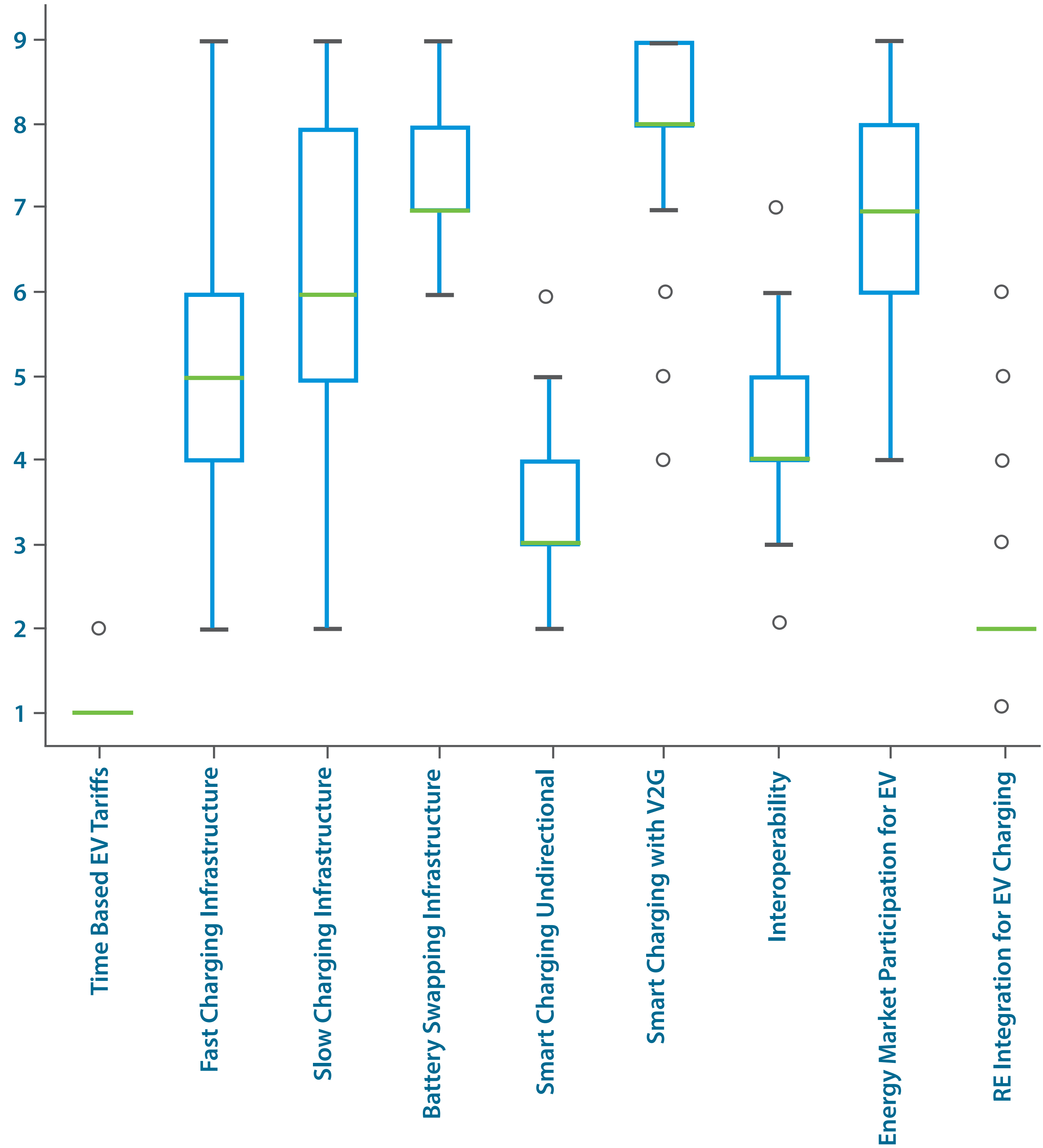


Figure A3.2: Box and whisker plot showing the variability and mean rank of the technical interventions

A3.1.3: Fuzzy TOPSIS Method

Using the framework provided in Section 5, the technical alternatives have been analyzed. The linguistic variables describing the evaluation of each alternative against the objectives have been given in Table 2.9. Each criterion has been assumed to have equal weights for the analysis.

Table A3.9: Ratings of alternatives

	Benefits	Negative Impacts	Economic Impact	Stakeholder involvement	Technology Maturity
	Maximize	Minimize	Minimize	Minimize	Maximize
Time based EV tariffs	VH	VL	L	L	VH
Fast Charging Infrastructure	F	L	H	L	VH
Slow Charging Infrastructure	VL	F	L	L	VH
Battery Swapping Infrastructure	F	VL	H	H	F
Smart Charging – Unidirectional	VH	VL	F	H	H
Smart Charging with V2G	VH	L	VH	VH	L
Interoperability	F	VL	L	F	H
Energy market participation for EV	H	VL	F	VH	L
RE integration	VH	VL	L	H	F

The fuzzy decision matrix has been given in Table 2.10. From the fuzzy decision matrix, a normalized fuzzy decision matrix is formed. The FPIS and FNIS, shown in Table 2.11 and Table 2.12are calculated for each objective using the normalized decision matrix. Next, the distances of each alternative from FPIN and FNIS are calculated. These distances are then used to calculate the Closeness Coefficient (CC), which enables the ranking of the alternatives. The CC and the intervention ranks are given in Table 2.13.

Table A3.10: Fuzzy decision matrix

	Benefits	Negative Impacts	Economic Impact	Stakeholder Involvement	Technology Maturity
Time based EV Tariff	[7,9,9]	[1,1,3]	[1,3,5]	[1,3,5]	[7,9,9]
Fast Charging Infrastructure	[3,5,7]	[1,3,5]	[5,7,9]	[1,3,5]	[7,9,9]
Slow Charging Infrastructure	[1,1,3]	[3,5,7]	[1,3,5]	[1,3,5]	[7,9,9]
Battery swapping Infrastructure	[,3,5,7]	[1,1,3]	[5,7,9]	[5,7,9]	[3,5,7]
Smart Charging(Unidirectional)	[7,9,9]	[1,1,3]	[3,5,7]	[5,7,9]	[5,7,9]
Smart Charging with V2G	[7,9,9]	[1,3,5]	[7,9,9]	[7,9,9]	[1,3,5]
Interoperability	[3,5,7]	[1,1,3]	[1,3,5]	[3,5,7]	[5,7,9]
Energy market participation for EV	[5,7,9]	[1,1,3]	[3,5,7]	[5,7,9]	[1,3,5]
RE Integration for EV charging	[7,9,9]	[1,1,3]	[1,3,5]	[5,7,9]	[3,5,7]

Table A3.11: Distance from FPIS

	Benefits	Negative Impacts	Economic Impact	Stakeholder Involvement	Technology Maturity
Time based EV Tariff	0	0	0	0	0
Fast Charging Infrastructure	0.175	0	0.328	0	0
Slow Charging Infrastructure	0.389	0.193	0	0	0
Battery swapping Infrastructure	0.175	0	0.328	0.409	0.175
Smart Charging(Unidirectional)	0	0	0.272	0.432	0.075
Smart Charging with V2G	0	0	0.352	0.432	0.287
Interoperability	0.175	0	0	0.409	0.075
Energy market participation for EV	0.075	0	0.272	0.432	0.287
RE Integration for EV charging	0	0	0	0.409	0.175

Table A3.12: Distance from FNIS

	Benefits	Negative Impacts	Economic Impact	Stakeholder Involvement	Technology Maturity
Time based EV Tariff	0.390	0.194	0328	0.409	0.287
Fast Charging Infrastructure	0.224	0.193	0	0.409	0.287
Slow Charging Infrastructure	0	0	0.328	0.409	0.287
Battery swapping Infrastructure	0.22	0.193	0	0	0.116
Smart Charging(Unidirectional)	0.390	0.194	0.566	0.0248	0.234
Smart Charging with V2G	0.390	0	0.352	0.432	0
Interoperability	0.224	0.194	0.408	0	00.234
Energy market participation for EV	0.341	0.194	0.056	0.025	0
RE Integration for EV charging	0.390	0.193	0.328	0	0.117

Table A3.13: Final ranking based on closeness coefficient

	CC	Final Rank
Time based EV tariffs	1	1
Fast Charging Infrastructure	0.625	4
Slow Charging Infrastructure	0.571	6
Battery Swapping Infrastructure	0.426	8
Smart Charging – Unidirectional	0.616	5
Smart Charging with V2G	0.358	9
Interoperability	0.673	3
Energy market participation for EV	0.440	7
RE integration	0.711	2

A3.2: Policy Interventions

The evaluation of the policies/regulations against the different objectives/criteria has been given in Table 2.14. In the following section, these scores would be utilized for ranking the different alternatives using the three different frameworks.

Table A3.14: Scores of policies/regulation alternatives across different objectives/criteria

Notation	Intervention	Cost implications	Influence on EV charging adoption	Implementation Time Period	Acceptability
		(High meaning higher cost)	(High meaning more influence)	(High meaning higher time)	(High meaning higher acceptability)
P1	Support for distribution system upgradation for charging infrastructure	9	10	6	9
P2	Adequate EV charging infrastructure deployment regulations.	4	6	7	5
P3	Mandating EV charging infrastructure in publicly accessible parking locations	8	8	5	8
P4	Mandating EV charging infrastructure in building bye-laws	6	8	2	6
P5	Easy access of land for setting up PCS	10	10	4	8
P6	Support market creation for private investment in public charging infrastructure	3	7	6	7
P7	Battery swapping should be subsidized at par with EV chargers	6	7	6	8
P8	Grid integration of EV charger regulations (technical)	5	4	5	4
P9	Harmonization of EV charging standards	4	7	7	7
P10	Grid support services from EV	4	4	8	6
P11	Regulations to make smart charging compulsory	6	5	6	5
P12	Aggressive awareness	7	7	5	7

A3.2.1: MULTIMOORA method

The framework provided in Section 5.3.2 has been used to rank the policy and regulatory interventions given in Section 5.2.2. The rank as per the ratio system, reference point system, the full multiplicative form and the cumulative final rank has been provided in Table 2.15. For this analysis the weight of each criterion has been assumed to be equal.

Table A3.15: Ranking of policy/regulatory interventions by MULTIMOORA method

Intervention	Ratio System	Reference Point	Multiplicative form	Final
Support for distribution system upgradation for charging infrastructure	4	10	5	7
Adequate EV charging infrastructure deployment regulations.	9	8	9	9
Mandating EV charging infrastructure in publicly accessible parking locations	6	6	6	4
Mandating EV charging infrastructure in buiding bye-laws	1	1	1	1
Easy access of land for setting up PCS	3	12	3	4
Support market creation for private charging investments	2	3	2	2
Battery swapping should be subsidized at par with EV chargers	5	3	7	3
Grid integration of EV charger regulations (technical)	10	7	12	11
Harmonization of EV charging standards	7	8	4	7
Grid support services from EV	12	11	10	12
Regulations to make smart charging compulsory	11	5	11	10
Aggressive awareness	8	2	8	4

Sensitivity Analysis with Monte Carlo Simulation

The sensitivity of the intervention rankings to the weights of the criterion has been explored in this section. The Monte Carlo simulation has been carried out by randomizing the weights assigned to each criterion for every iteration.

As per the Monte Carlo analysis, 'Mandating EV charging infrastructure in building bye-laws' achieves the most preferred policy/regulatory intervention, followed by 'Support market creation for private investment in public charging infrastructure '.

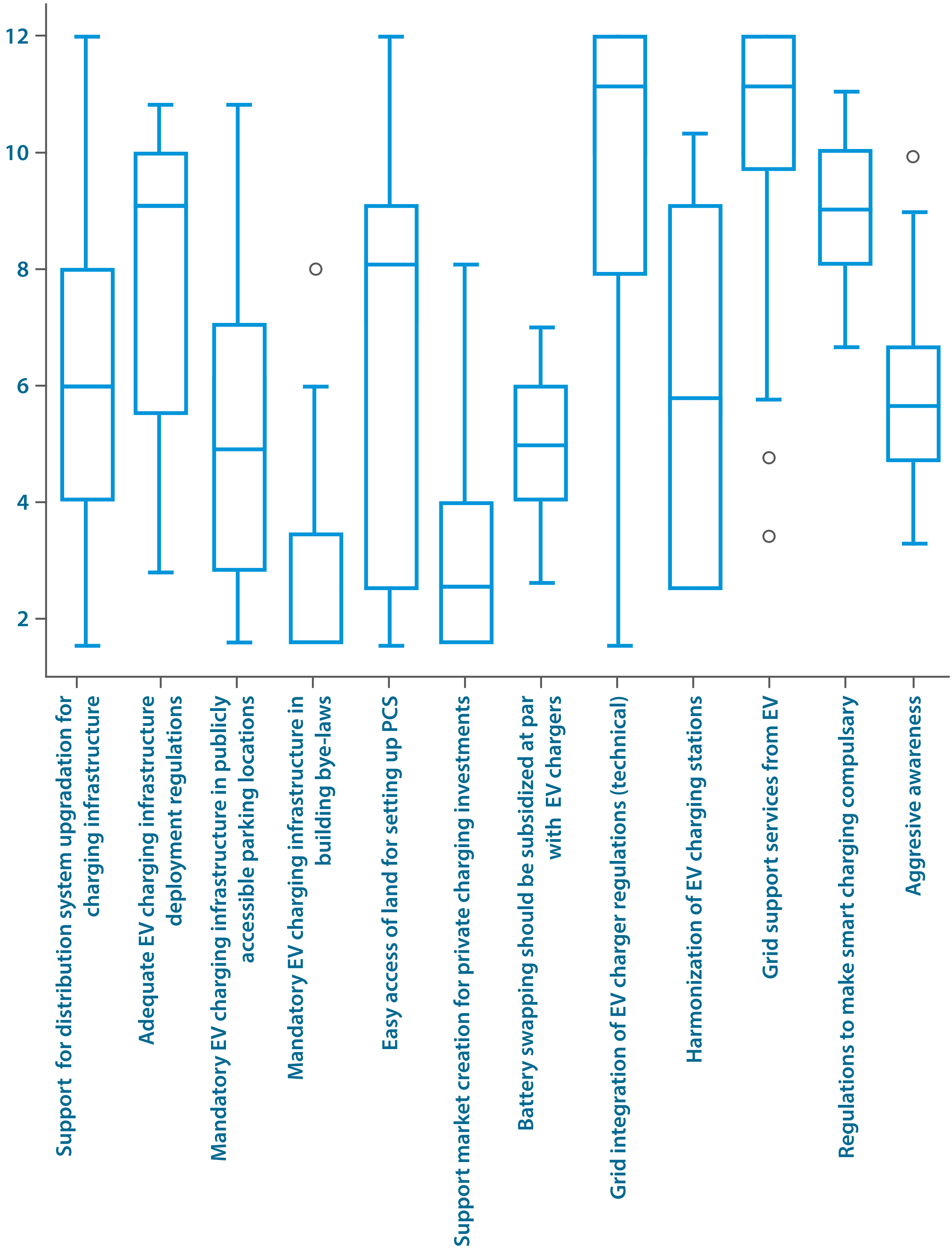


Figure A3.3: Box and whisker plot of Monte Carlo simulation

A3.2.2: Consistent Fuzzy Preference Relations

The initial preference relations have been given in Table 2.16.

Table A3.16: Initial preference relation matrix of policy/regulatory interventions over different criteria

	Cost implications	Influence on EV charging adoption	Implementation Time Period	Acceptability
Support for distribution system upgradation for charging infrastructure	1/5	5	2	5
Adequate EV charging infrastructure deployment regulations.	5	1/3	1/3	1/4
Mandating EV charging infrastructure in publicly accessible parking locations	1/3	1	1/4	3
Mandating EV charging infrastructure in building bye-laws	5	1/3	3	1/3
Easy access of land for setting up PCS	1/9	4	3	2
Support market creation for private investment in public charging infrastructure	4	1	1	1/2
Battery swapping should be subsidized at par with EV chargers	1/2	5	1/2	5
Grid integration of EV charger regulations (technical)	1/2	1/5	3	1/4
Harmonization of EV charging standards	1	5	2	2
Grid support services from EV	2	2	1/7	1/4
Regulations to make smart charging compulsory	1	1/3	1/6	1/3

Here too, the 'mandating EV charging infrastructure in building bye-laws' have been given the highest priority, followed by 'Harmonization of EV charging standards', 'Easy access of land for setting up PCS' and 'Support market creation for private investment in public charging infrastructure' as given in Table 2.17.

Table A3.17: Final ranking of interventions as per CFPR

Intervention	Cost implications	Influence on EV charging adoption	Implementation Time Period	Acceptability	Final
Support for distribution system upgradation for charging infrastructure	0.014	0.027	0.021	0.024	6
Adequate EV charging infrastructure deployment regulations.	0.028	0.019	0.017	0.014	10
Mandating EV charging infrastructure in publicly accessible parking locations	0.014	0.024	0.024	0.023	7
Mandating EV charging infrastructure in building bye-laws	0.023	0.024	0.032	0.016	1
Easy access of land for setting up PCS	0.009	0.030	0.025	0.023	5
Support market creation for private charging investments	0.028	0.023	0.019	0.018	3
Battery swapping should be subsidized at par with EV chargers	0.016	0.023	0.019	0.023	8
Grid integration of EV charger regulations (technical)	0.022	0.014	0.023	0.013	11
Harmonization of EV charging standards	0.028	0.023	0.016	0.021	2
Grid support services from EV	0.028	0.014	0.012	0.017	12
Regulations to make smart charging compulsory	0.022	0.011	0.019	0.026	9
Aggressive awareness	0.016	0.017	0.023	0.032	4

Sensitivity analysis with Monte Carlo Simulation

In the sensitivity analysis, the box and whisker plot, given in Figure 2.4. also assigns the highest priority to 'Mandating EV charging infrastructure in building bye-laws', followed by 'Easy access of land for setting up PCS'. However, much variance is seen for 'Easy access of land for setting up PCS', with an outlier up to 12. 'Regulations to make smart charging compulsory' have received the lowest preference.

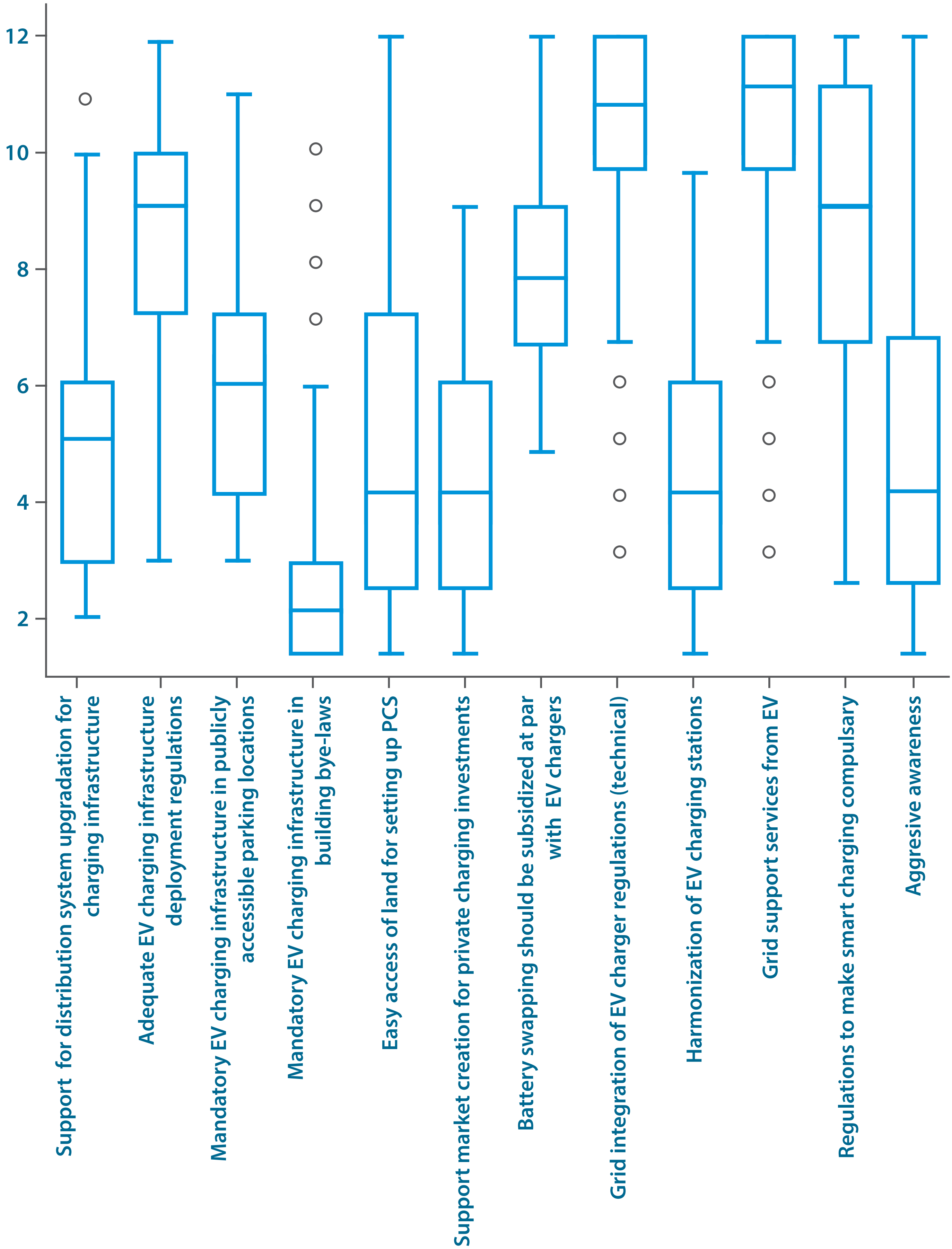


Figure A3.4: Box and whisker plot showing the variability and mean rank of policy/regulatory interventions

A3.2.3: Fuzzy TOPSIS

The evaluation of the policy/regulatory interventions using linguistic variables has been given in Table 2.18.

Table A3.18: Evaluation of policy/regulatory interventions using linguistic variables

	Cost implications	Influence on EV charging adoption	Implementation Time Period	Acceptability
Support for distribution system upgradation for charging infrastructure	VH	VH	F	VH
Adequate EV charging infrastructure deployment regulations.	L	F	H	F
Mandating EV charging infrastructure in publicly accessible parking locations	H	H	F	H
Mandating EV charging infrastructure in building bye-laws	F	H	L	F
Easy access of land for setting up PCS	VH	VH	F	H
Support market creation for private investment in public charging infrastructure	L	H	H	H
Battery swapping should be subsidized at par with EV chargers	F	H	H	H
Grid integration of EV charger regulations (technical)	F	L	F	L
Harmonization of EV charging standards	F	H	H	H
Grid support services from EV	F	L	VH	F
Regulations to make smart charging compulsory	F	F	H	F
Aggressive awareness	H	H	F	H

Based on the linguistic variables, the ranking as per the Fuzzy TOPSIS methodology has been given in Table 2.19.

Table A3.19: Ranking of policy/regulatory interventions by Fuzzy TOPSIS method

Intervention	Closeness Coefficient	Final
Support for distribution system upgradation for charging infrastructure	0.512	3.000
Adequate EV charging infrastructure deployment regulations.	0.474	4.000
Mandating EV charging infrastructure in publicly accessible parking locations	0.433	6.000
Mandating EV charging infrastructure in buiding bye-laws	0.601	2.000
Easy access of land for setting up PCS	0.463	5.000
Support market creation for private charging investments	0.639	1.000
Battery swapping should be subsidized at par with EV chargers	0.433	8.000
Grid integration of EV charger regulations (technical)	0.127	12.000
Harmonization of EV charging standards	0.433	8.000
Grid support services from EV	0.154	11.000
Regulations to make smart charging compulsory	0.264	10.000
Aggressive awareness	0.433	6.000

A4 Denmark Grid Code Regulations

A4.1: Technical Regulations 3.3.1 for battery plants

Denmark, in 2017 released the technical requirements for grid connected battery plants which includes V2G electric vehicle charging stations. As per the technical guidelines, battery stations are categorized into the 5 categories as shown in Table 3.1.

Table A4.1: Categories of battery plants

Category	Rated Power
A1	x≤11 kW
A2	11 kW<x≤50 kW
B	50 kW<x≤1.5 MW
C	1.5 MW<x≤25 MW
D	25 MW<x

A4.1.1: Normal Operating Conditions

The normal operating range has been defined by taking into consideration typical operating voltage and frequency bands. The voltage band has been defined as U_c±10%. And the frequency range has been defined as 47.00 to 52.00 Hz.

Within this normal operating range, a battery plant should be able to start and operate continuously, restricted only by the settings of the protection equipments as shown in Figure 3.1.

Following an abnormal operating condition, the battery plant should automatically reconnect at the earliest by three minutes after the voltage has come within the normal operating range and the grid frequency is within f1 and f2 as indicated in Table 3.2.

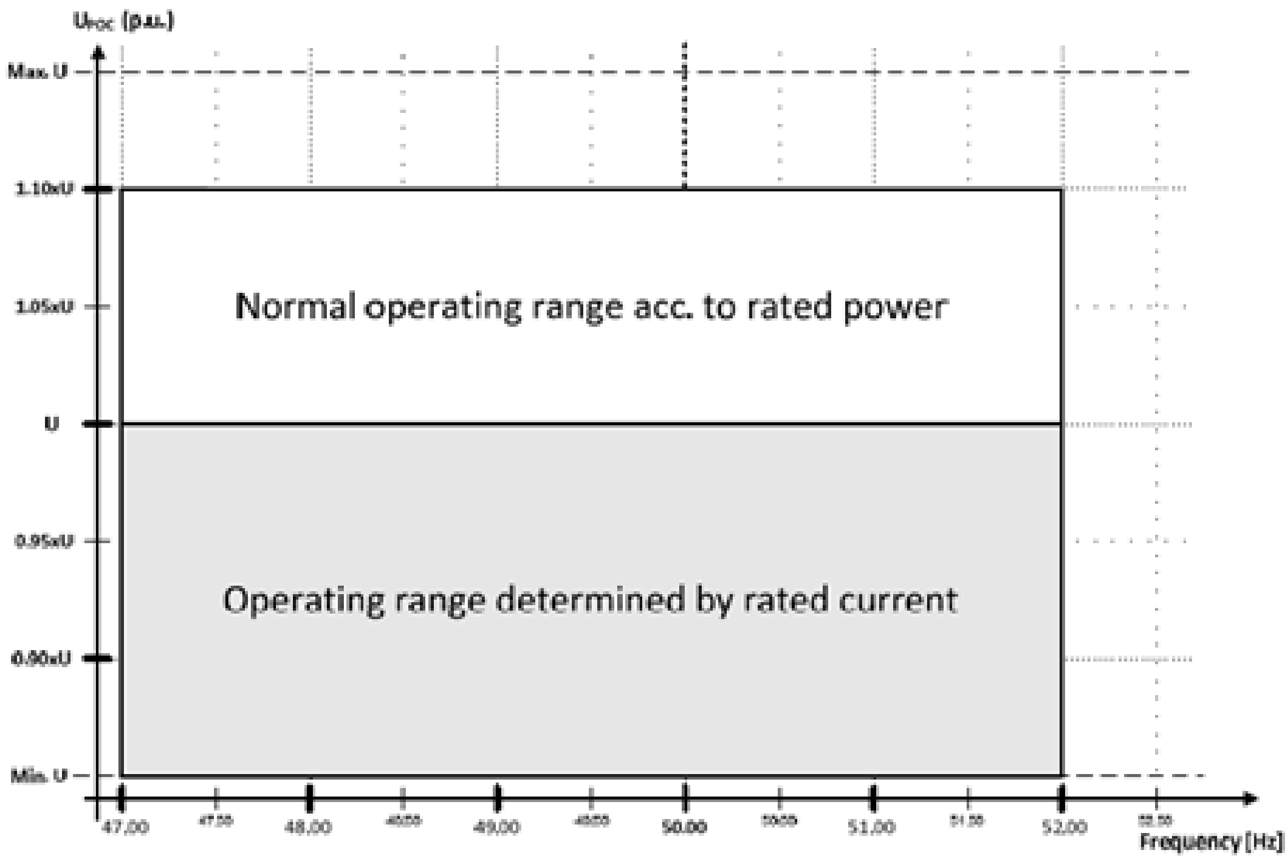


Figure A4.1: Requirement for rated power and rated current in the event of frequency and voltage deviations

Energinet, 'Technical regulation 3.3.1 for battery plants', Denmark, June 2017.

Table A4.2: Frequency band for automatic reconnection

Dk1		Dk2	
f1	f2	f1	f2
49.80 Hz	50.20 Hz	49.90 Hz	50.10

A4.1.2: Abnormal Condition

As per the technical regulations, the battery plants must be designed to withstand transient frequency gradients (df/dt) of up to ±2.5 Hz/s in the Point of Connection without disconnecting.

At the point of connection, the battery plants of categories C and D should also be designed to withstand voltage dips down to 0.1 pu for a period of 250 ms as shown in Figure 3.2. The three areas shown in Figure 3.2 are discussed below,

Area A: The battery plant must stay connected to the grid and maintain normal operation.

Area B: The battery plant must stay connected to the grid and must provide maximum voltage support by delivering a controlled amount of additional reactive current to ensure that the battery plant contributes to stabilizing the voltage as shown in Figure 3.3. Here the delivery of reactive power has been given higher priority over the delivery of active power.

Area C: Disconnecting the battery plant is allowed.

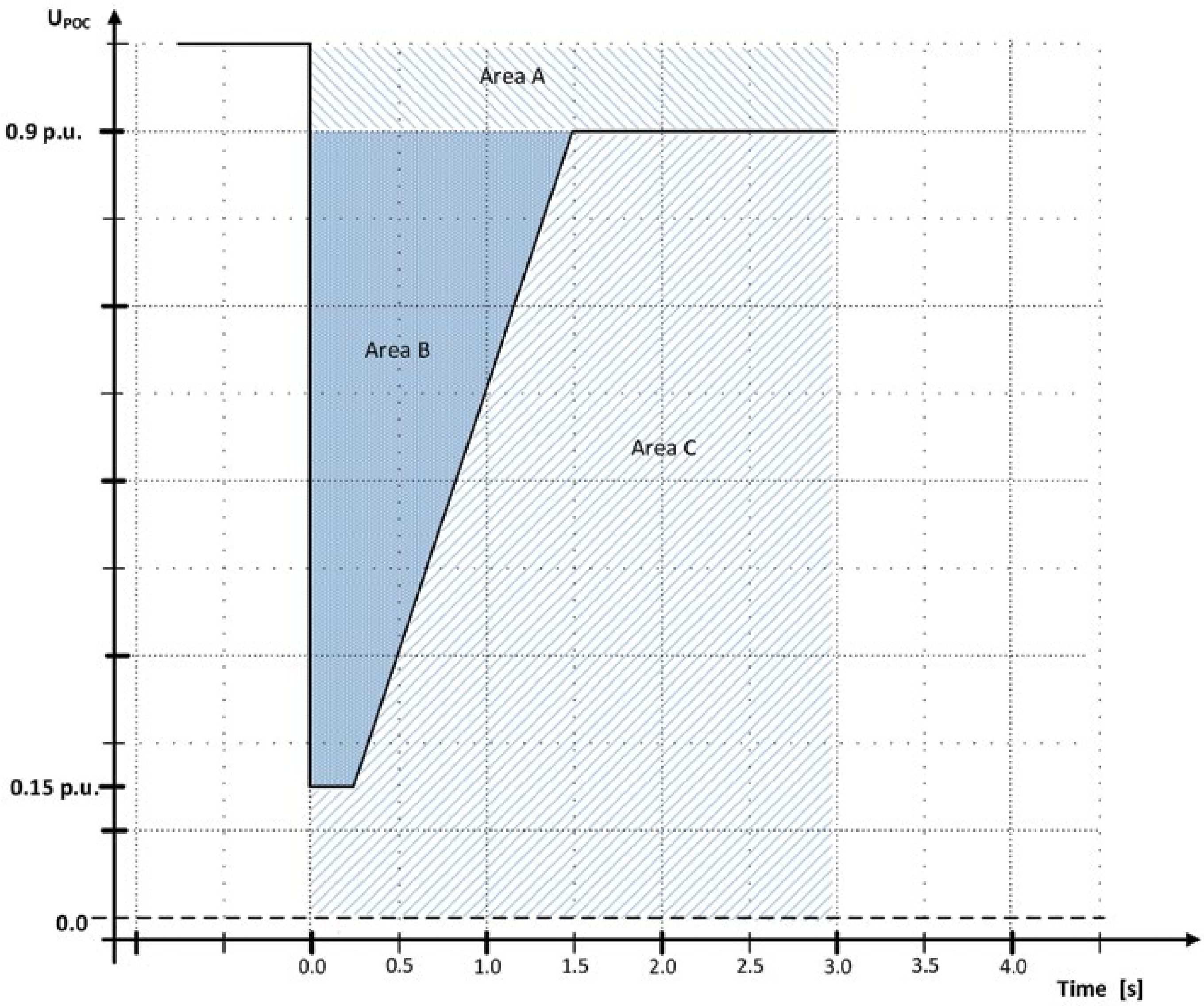


Figure A4.2: Voltage dip tolerance limits for category C and D battery plants

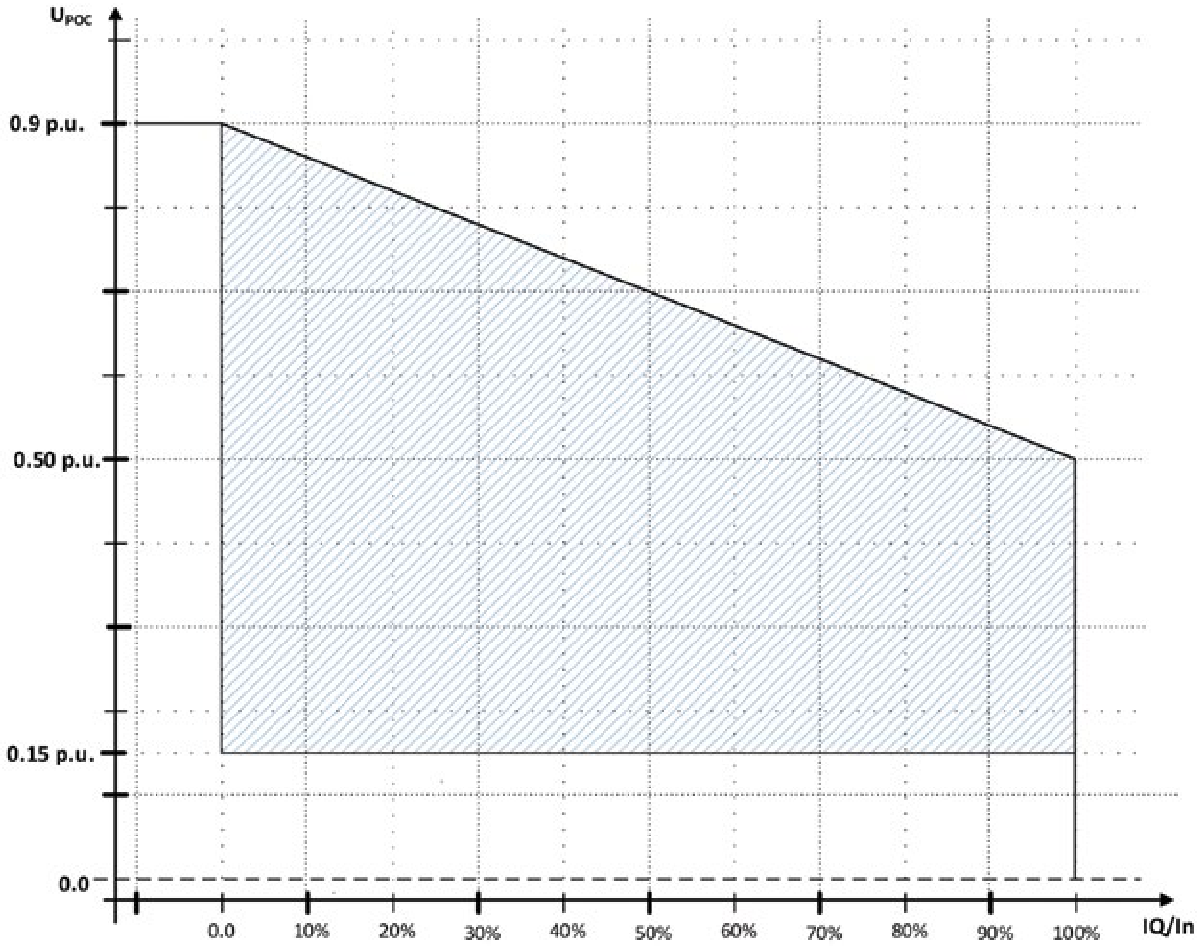


Figure A4.3: Requirements for delivery of reactive power during voltage dips for category C and D battery plants

A4.1.3: Control requirements

The regulation also mandated a basic set of control features that must be available for each category of battery plant as given in Table 3.3.

Table A4.3: Minimum control functionality requirements

	A1	A2	B	C	D
Frequency Response (Over frequency)	Yes	Yes	Yes	Yes	Yes
Frequency response (Under frequency)	-	-	-	Yes	Yes
Frequency control	-	-	-	Yes	Yes
Absolute power limit	Yes	Yes	Yes	Yes	Yes
Ramp rate limit	Yes	Yes	Yes	Yes	Yes
Q Control	Yes	Yes	Yes	Yes	Yes
Power Factor Control	Yes	Yes	Yes	Yes	Yes
Automatic Power Factor Control	Yes	Yes	-	-	-
Voltage Control	-	-	-	Yes	Yes

A4.1.3.1: Active Power and Frequency Control Functions

A battery plant must be equipped with control functions capable of controlling the active power delivered or absorbed in the Point of Connection. It must be possible to specify set points for active power with a resolution of 1% of Pno or Pnl or higher, where Pno is the battery plant's rated power absorbed from the grid and Pnl is the battery plant's rated power delivery to the grid.

A4.1.3.2: Frequency response (LFSM-U and LFSM-O)

All battery plants, irrespective of category must be equipped to aid the power system in the event of frequency deviation by automatically changing their active power injection/ drawl at frequencies below or above reference frequencies f¬1 and f2. This is known as frequency response and is an autonomous function. The frequency measurements has been mandated to be carried out with 10 mHz accuracy or higher. Also, the response should commence no later than 2 seconds after a frequency change is detected It should also be possible to set the frequency points f1 and f2, indicated in Figure 3.4 and Figure 3.5 to any values between 47.00 Hz and 52.00 Hz. The droop for the downward regulation should be allowed to be set at any value in the range 2% to 12% of the rated power.

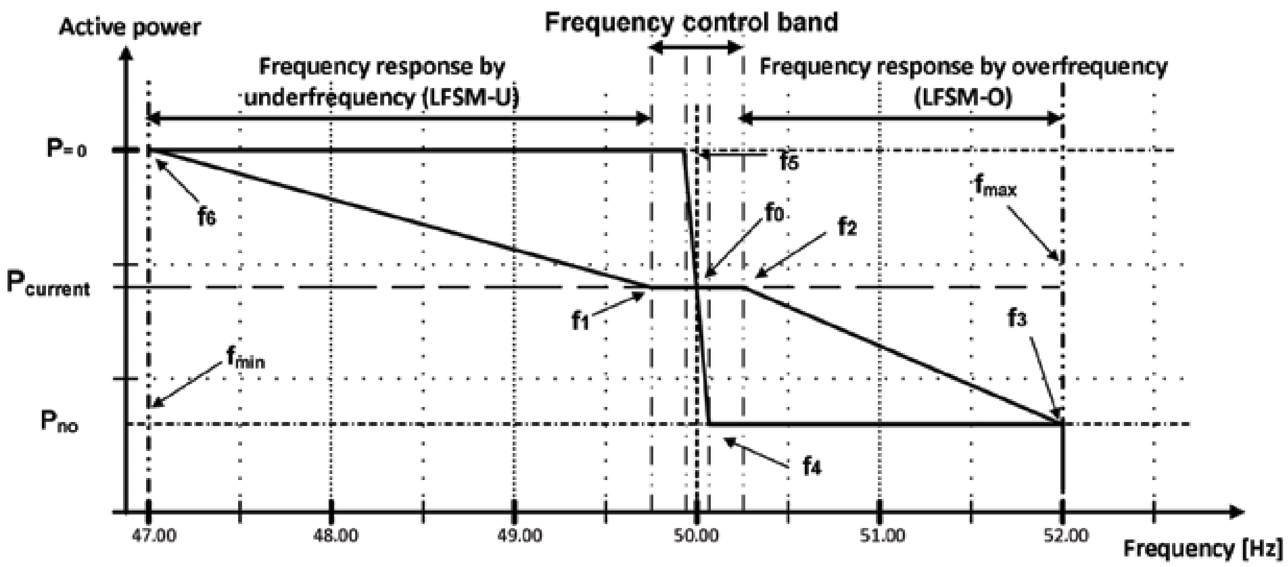


Figure A4.4: Frequency response for a battery plant which can only absorb power

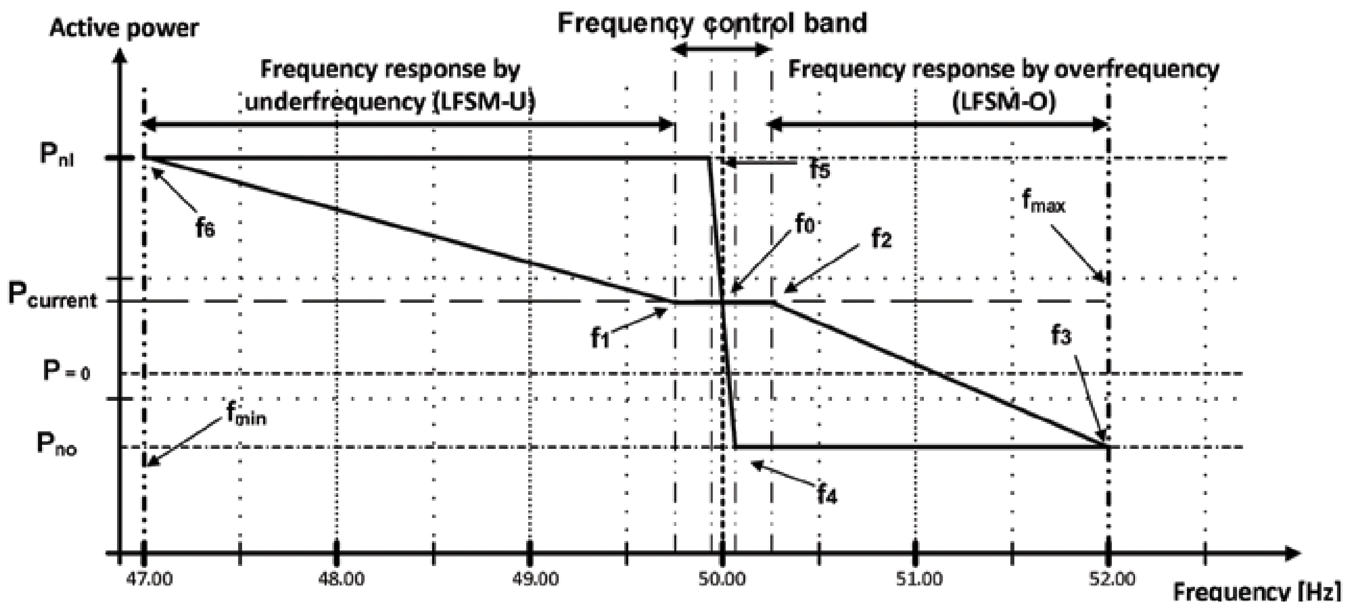


Figure A4.5: Frequency response from a battery plant which can deliver and absorb power

In the event of a frequency increase above f2 (LFSM-O), the droop f2 - f3 must be followed. If the frequency is subsequently stabilized and decreases, the power must be maintained until the frequency has decreased to f4 - f0. Similarly, in the event that frequency decreases to below f1 (LFSM-U), the droop f1 - f6 must be followed and the power set point must be maintained till the frequency has increased to f5 – f0. The standard frequency values have been given in

Table A4.4: Standard frequency values

	fmin	fmax	f0	f1	f2	f3	f4	f5	f6
DK1	47.00	52.00	50.00	49.80	50.20	52.00	50.05	49.95	47.00
DK2	47.00	52.00	50.00	49.50	50.10	52.00	50.05	49.95	47.00

A4.1.3.3: Frequency Control

The regulations mandate provision of frequency control capabilities for category C and D battery plants. The frequency control tries to stabilize the grid frequency between f1 and f2 as shown in Figure 3.4 and Figure 3.5. It must be possible to set the frequency control function in such a way that it is possible to set any frequency point between the frequencies fmin and fmax (47.00-52.00 Hz range) with a 10 mHz accuracy.

A4.1.3.4: Reactive Power and Voltage Control Functions

A battery plant must be equipped with reactive power and voltage control functions capable of controlling the reactive power in the Point of Connection. The minimum functionality requirements for reactive power control are given in Table 3.5

Table A4.5: Reactive Power Control functions

	A1	A2	B	C	D
Q Control	Yes	Yes	Yes	Yes	Yes
Power Factor Control	Yes	Yes	Yes	Yes	Yes
Automatic Power Factor Control	Yes	Yes	-	-	-
Voltage Control	-	-	-	Yes	Yes

Q Control

The Q control function maintains a constant reactive power independently of the grid voltage and the active power in the Point of Connection. This control function is shown as a horizontal line in Figure 3.6.

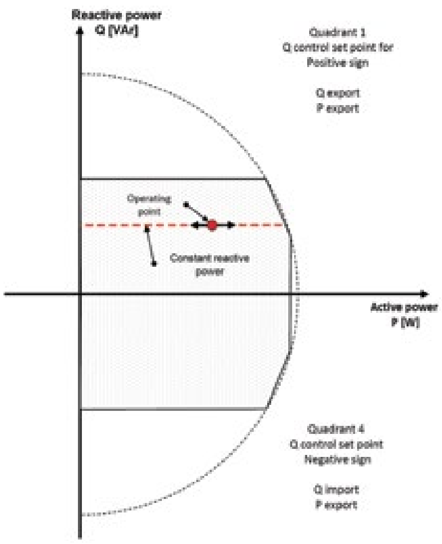


Figure A4.6: Q control

Power factor Control

The Power Factor control function controls the reactive power proportionately (determined by the droop) to the active power in the Point of Connection, which is illustrated by a line with a constant gradient in Figure 3.7. The battery plant must be able to receive a Power Factor set point with an accuracy of 0.01.

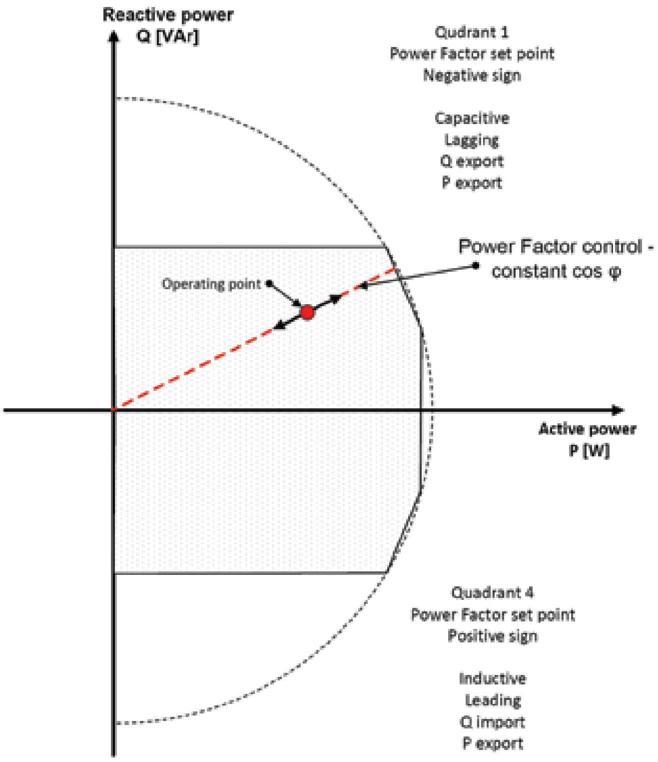


Figure A4.7: Power Factor Control

Voltage Control

Automatic voltage control (AVR) is a control function that automatically controls the voltage within the voltage reference point. Depending on the deviation of the PCC voltage from the set point, the reactive power absorbed/delivered is determined from the droop as shown in Figure 3.8. It must be possible to set the droop for the voltage control to a value in the range 2-12%. The standard value for settings is 4%.

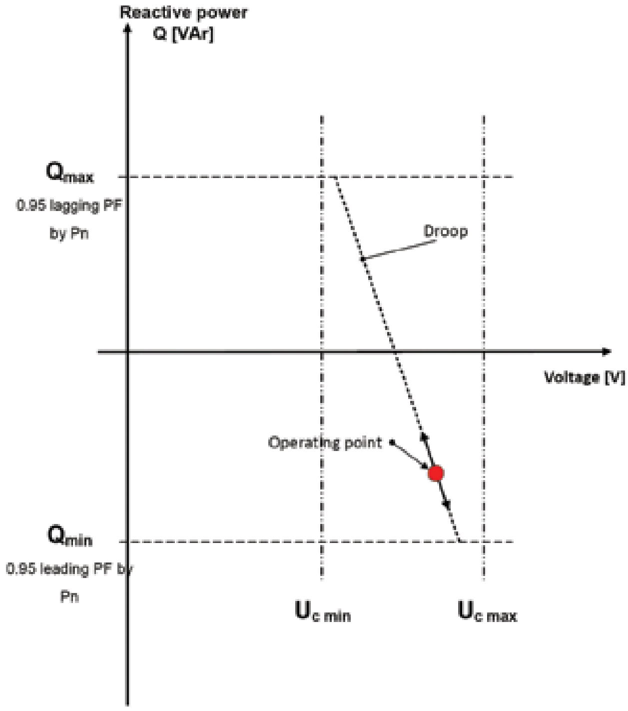
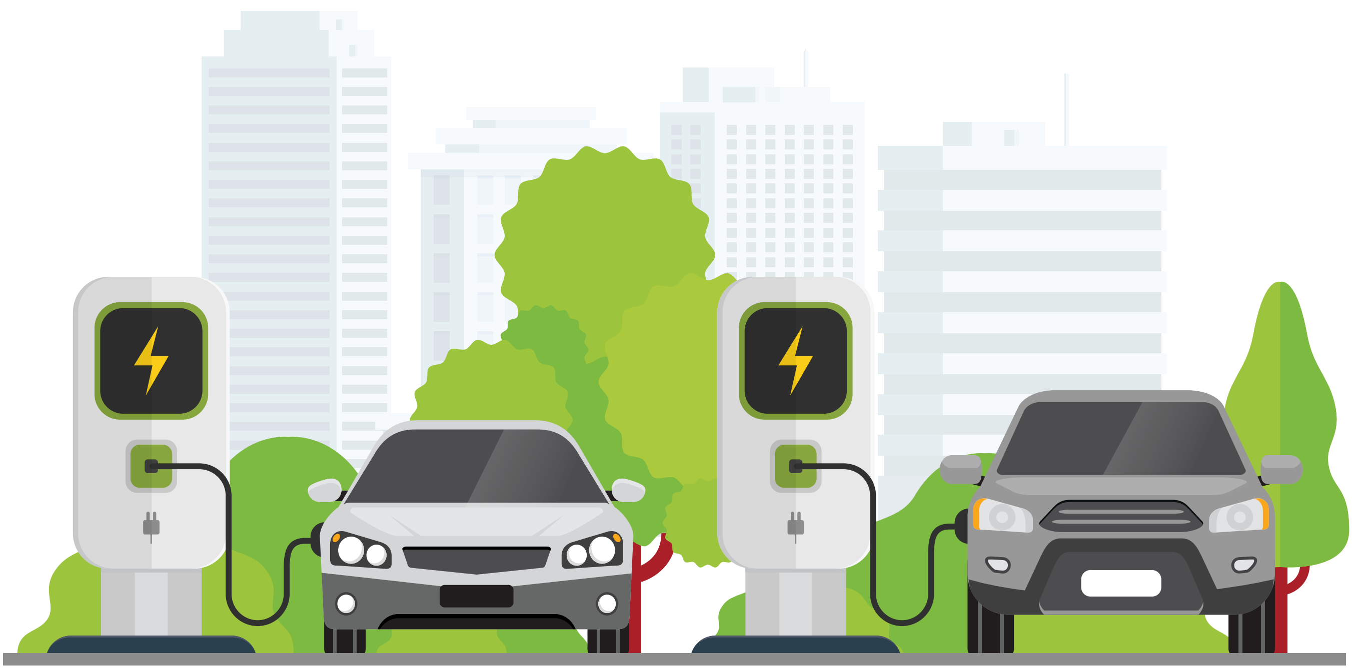


Figure A4.8: Automatic Voltage control



Category C battery Plants

The battery plant must be designed in such a way that its operating point can at any time be ordered to lie within the hatched area shown in Figure 3.9.

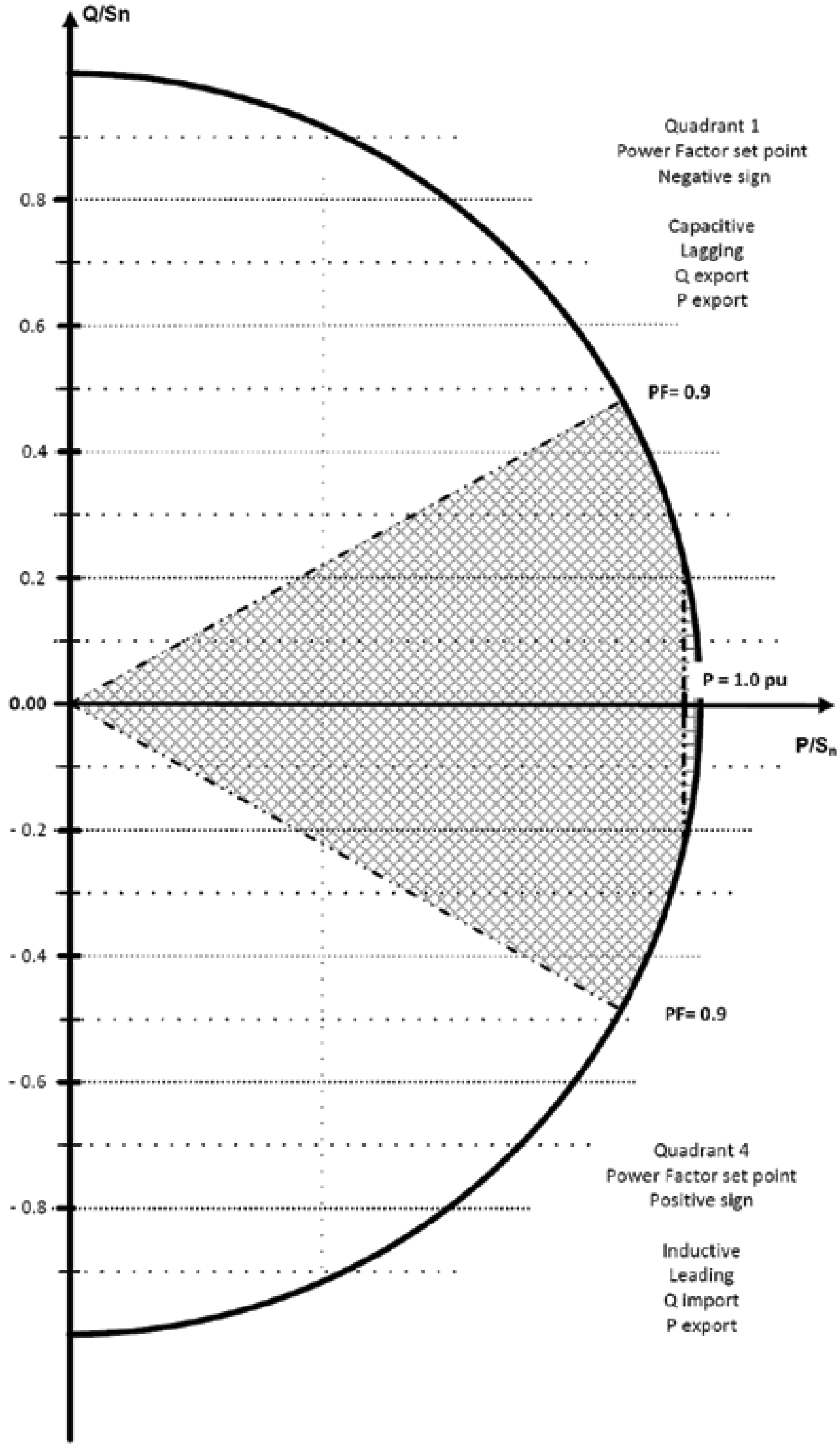


Figure A4.9: Requirement for the delivery of reactive power for battery plants of category C

The battery plant must be capable to deliver reactive power while delivering active power for different voltage levels as shown in

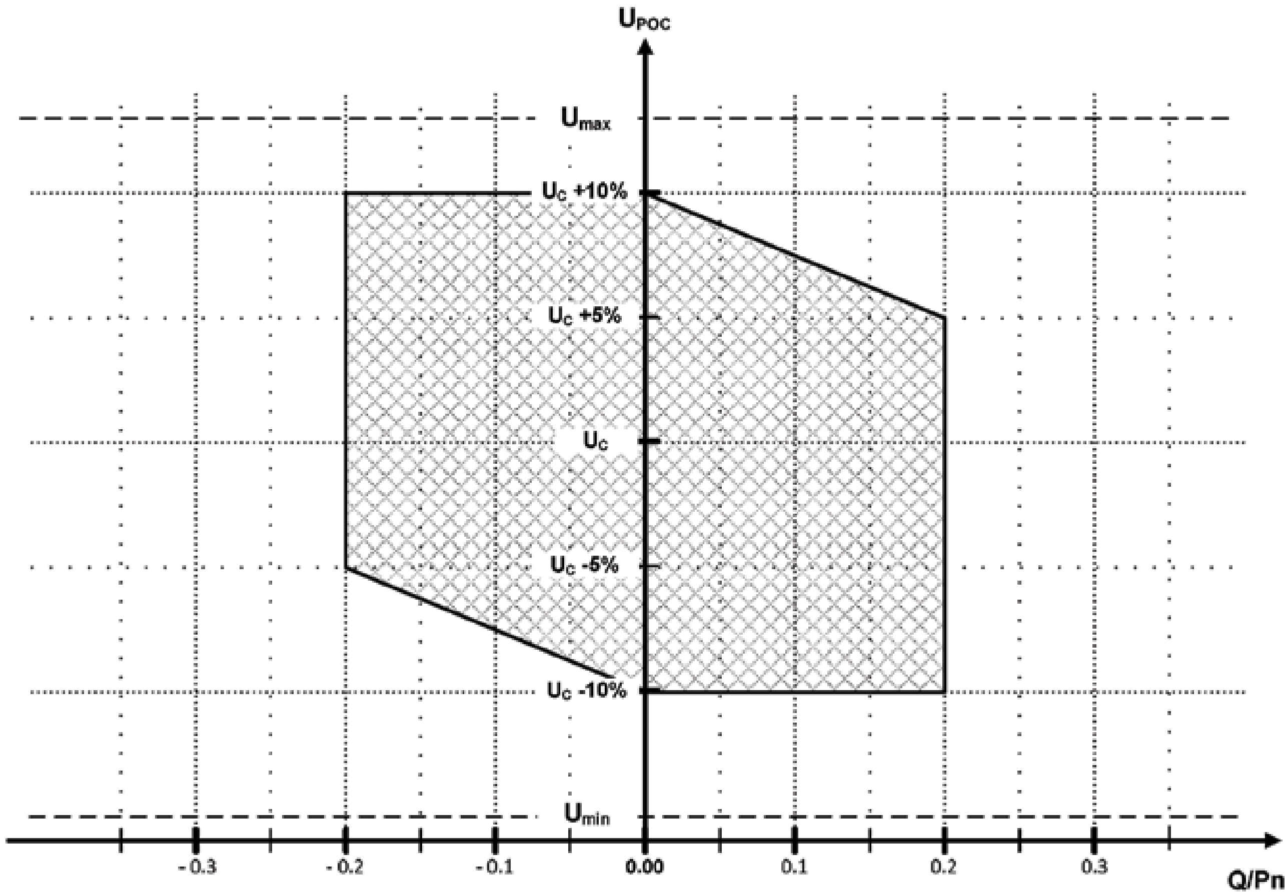


Figure A4.10 Requirements for the delivery of reactive power as a function of the voltage at the Point of Connection for category C battery plants

Category D battery plants

The battery plant must be designed in such a way that its operating point can at any time be ordered to lie within the hatched area shown in Figure 3.11. It must also be possible to deliver the reactive power in the voltage range indicated in Figure 3.12.

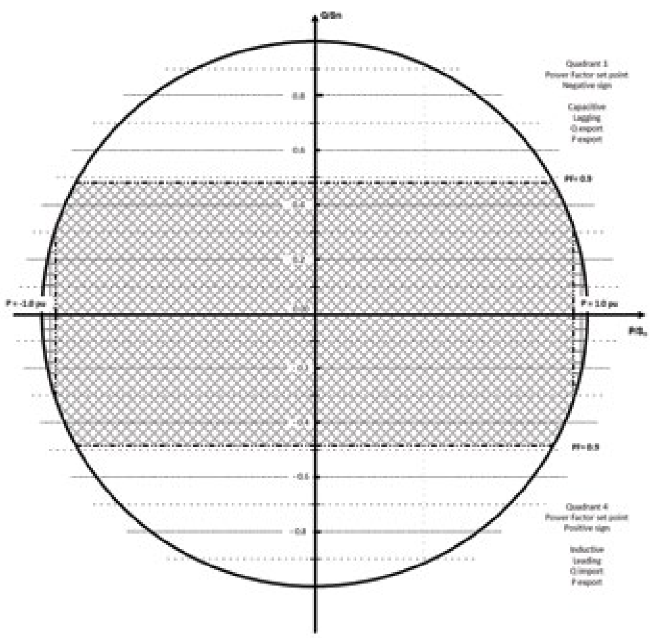


Figure A4.11: Requirements for the delivery of reactive power by battery plants in Category D

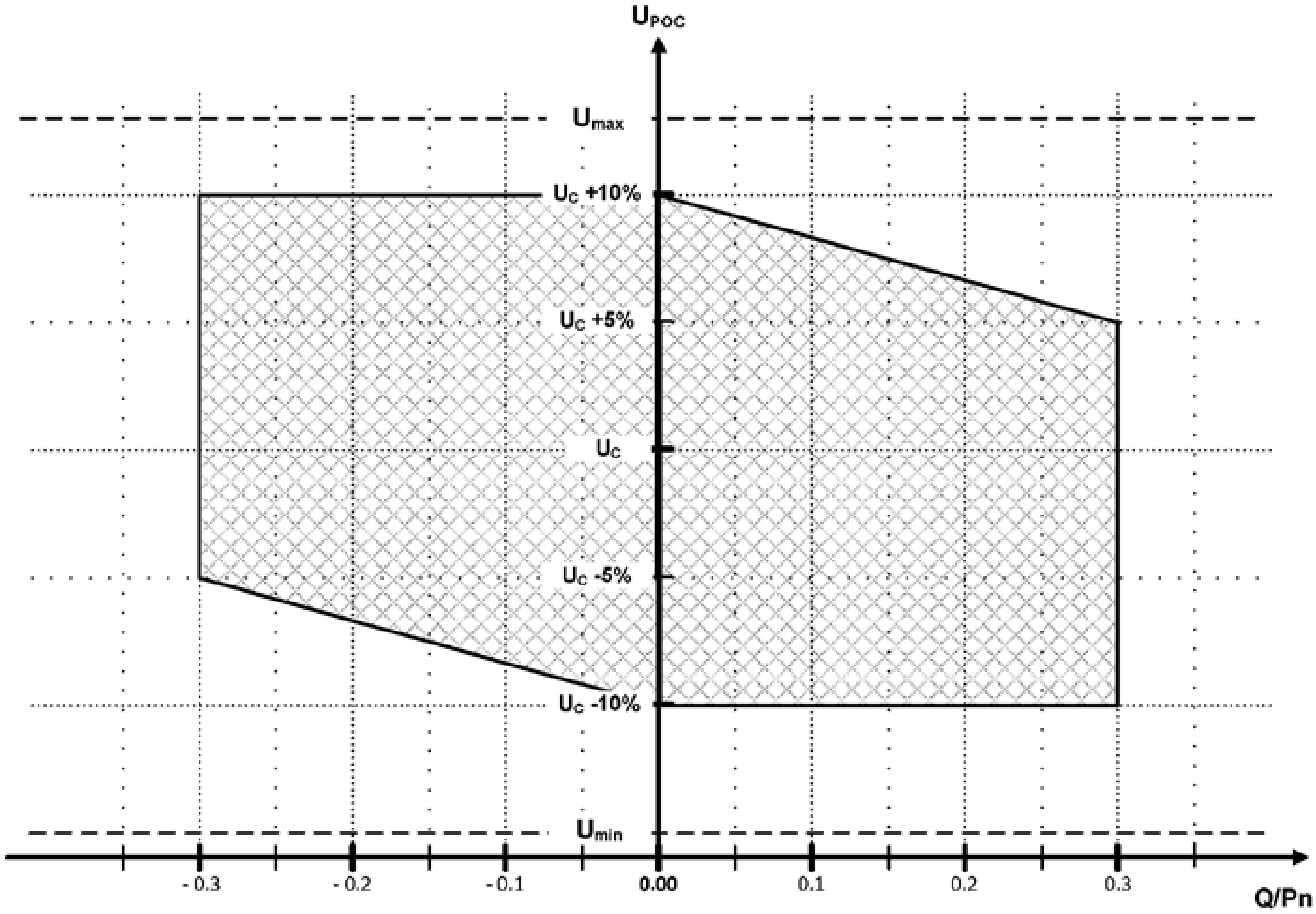


Figure A4.12: Requirements for the delivery of reactive power as a function of the voltage at the Point of Connection for category D battery plants

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