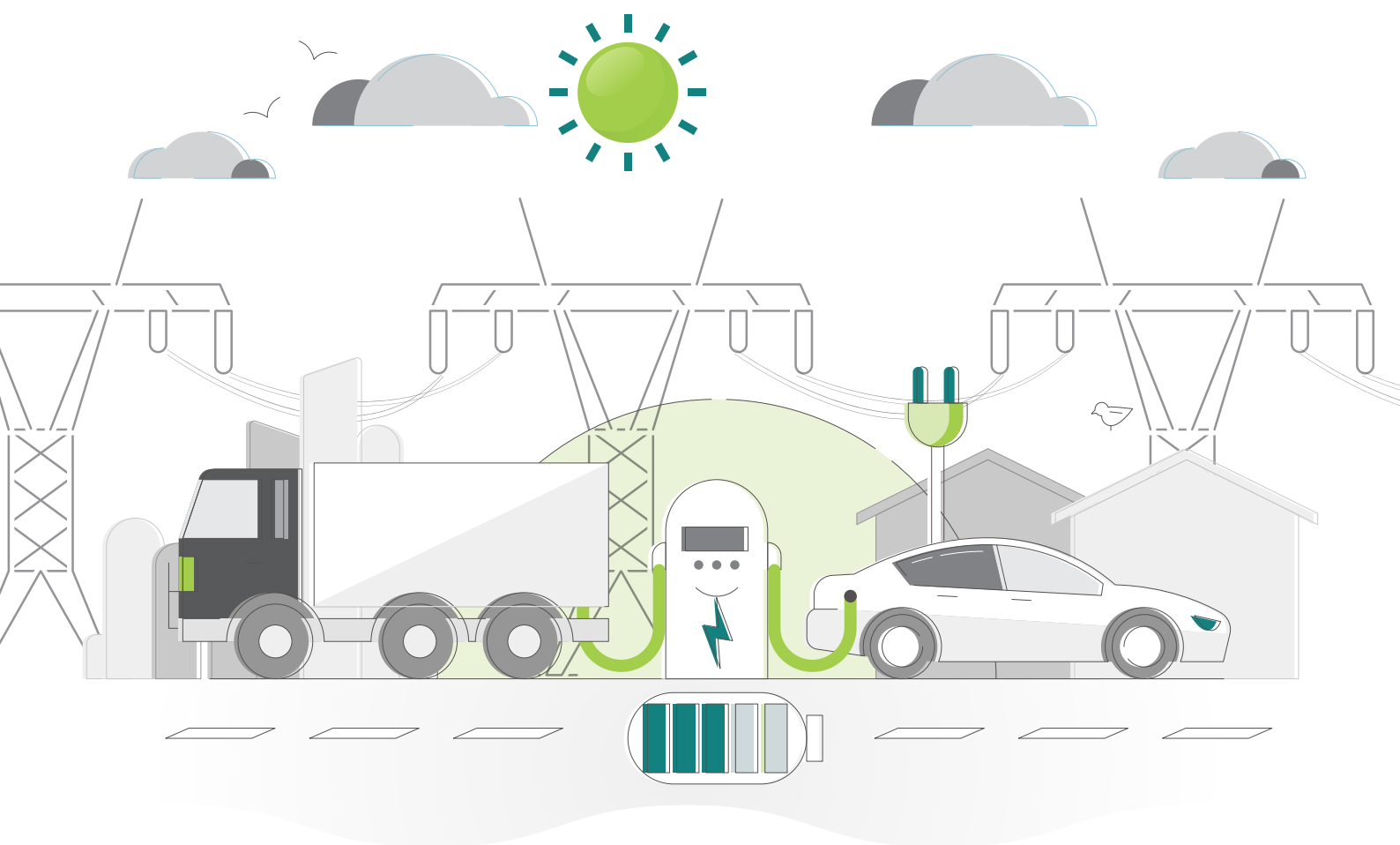


VEHICLE-GRID INTEGRATION A NEW FRONTIER FOR ELECTRIC MOBILITY IN INDIA



Shyamasis Das, Sanchari Deb

October 2020

VEHICLE-GRID INTEGRATION – A NEW FRONTIER FOR ELECTRIC MOBILITY IN INDIA

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Shyamasis Das, Sanchari Deb

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1. Electric Vehicles – A Potential Grid Resource For India

The ever-escalating energy demand, coupled with concerns regarding increasing greenhouse gas (GHG) emissions from the use of Internal Combustion Engine (ICE) driven vehicles, has forced mankind to look for alternative energy options for mobility. This, in turn, has paved the path for electrification of road transport. Electric Vehicles (EVs) are considered a clean mode of transport, as well as an environmentally friendly option to tackle the problem of poor air quality. Moreover, low maintenance and operating costs, as compared to ICE vehicles, are an additional benefit associated with EVs (Teixeira ACR, 2016). Motivated by the aforementioned advantages, the Government of India (GoI) is keen to promote the use of EVs for both public and private transport.

Unlike conventional road transport, electric mobility (e-mobility) offers a unique bouquet of opportunities and challenges due to its interface with the power utility sector. On one hand, EV adoption can potentially result in a substantial increase in revenue for power distribution companies (DISCOMs) from additional electricity sales due to EV charging. On the other hand, the gains may be accompanied by various risks. The risks are at multiple levels – from the DISCOM's service area to the feeder level.

The EV charging demand may increase the peak load in the DISCOM's service area (refer to Figure 1), which could have a significant impact on the cost of electricity supply. To meet the higher power demand during peak hours, a DISCOM may have to resort to unplanned power purchase in the spot market, which is usually expensive. This leads to higher power procurement costs for the DISCOM, which has a cascading effect on its cost of supply. Increased load due to EV charging could also exacerbate distribution and transmission losses.

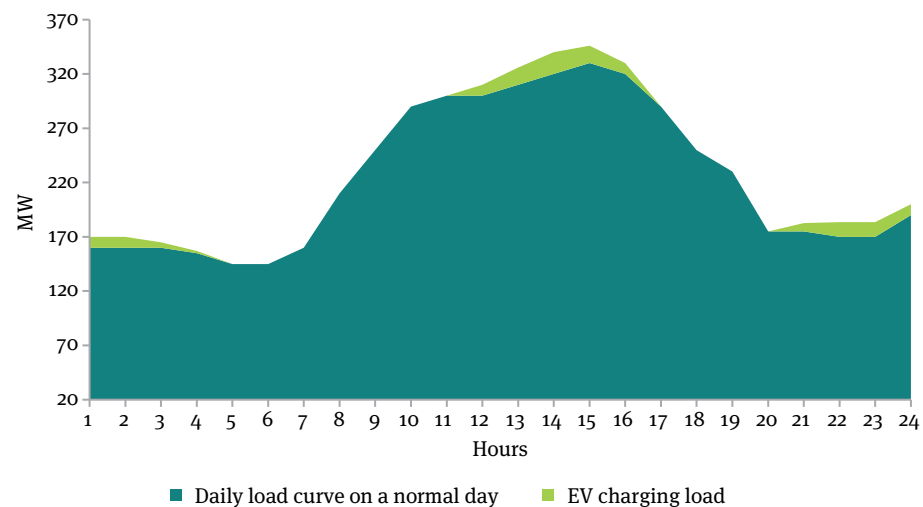


FIGURE 1: POTENTIAL IMPACT OF EV CHARGING ON AN INDIAN DISCOM'S DAILY LOAD CURVE

Source: AEEE analysis

However, EV charging is expected to have a more significant impact at the local level of the distribution network. EV charging loads at charging points are anticipated to be very dynamic, with spikes in the demand curve. This can potentially have a serious impact on the distribution network, especially in distribution areas with low available hosting capacity. Unmanaged EV charging at the charging stations can hamper smooth power system operations, by causing the following (Dubey A, 2015):



UNMANAGED EV CHARGING AT THE CHARGING STATIONS CAN HAMPER SMOOTH POWER SYSTEM OPERATIONS

- **Voltage instability:** Sudden load changes due to EV charging can hinder the power system from maintaining steady voltage at all points, causing degradation in the voltage profile.
- **Harmonic distortion:** EV chargers are non-linear loads with high harmonic content. The non-linear nature of the charging load may result in harmonic distortion, which lowers power system efficiency.
- **Power losses:** The increased load due to EV charging may result in increased power losses in the distribution network.
- **Degradation of reliability indices:** The augmented load due to charging activities may hamper the quality and continuity of the power supply. Reliability indices such as System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), and Customer Average Interruption Duration Index (CAIDI) will be degraded because of the increased load.

How can these impacts on the power system, both at the grid level and feeder level, be managed or avoided? There are both passive and active solutions, as mentioned below.

- **Passive management**, influencing EV users' charging behaviour using specially designed electricity tariffs (e.g. Time-of-Use (ToU) charges, demand charges, or customer fees) or incentives to encourage charging at a certain level and/ or a certain time (e.g. rebates for lower level charging or charging during off-peak hours)
- **Unidirectional active management** of charging, such as ramping charging levels up or down (referred to as V1G)
- **Bidirectional active management** of electricity, entailing vehicle-to-grid power flow (referred to as V2G)

Source: California Public Utilities Commission (California Public Utilities Commission 2017)

Vehicle-Grid Integration (VGI) refers to this entire gamut of EV charging management solutions to mitigate the negative impacts of uncontrolled EV charging on the power system. The benefits of VGI extend beyond EV charging load, as it can provide useful services to the grid. Hence, VGI is often defined as “*the many ways in which a vehicle can provide benefits or services to the grid, society, the EV driver, or charge point operator by optimising plug-in electric vehicle interaction with the electrical grid*” (California Public Utilities Commission, 2017).

V1G (also called smart charging or managed/ controlled charging), a key constituent of the suite of grid services available under VGI, involves ramping up and down charging (alternating current (AC) or direct current (DC)) for individual EVs or multiple EVs, where the control can be done at the level of the charging station, EV, EV management system, or building management system.

On the other hand, in V2G, energy from the EV battery is converted into an AC current, which flows from the EVSE (Electric Vehicle Service Equipment) to a facility circuit connected to the electric grid, even if there is no net export of power from the facility. V2G has a bidirectional energy transfer capability and does not just entail battery discharging. The combined EVSE and EV form a distributed energy resource (DER). The DC-AC conversion can be performed on board the EV (Society of Automotive Engineers International (SAE) term V2G-AC) or within the EVSE (SAE term V2G-DC). These different DER

systems have different requirements regarding communication between the EVSE and EV (California Public Utilities Commission, 2017).

A simple demonstration of the differences in impact of unmanaged EV charging, V1G, and V2G is shown in Figure 2.

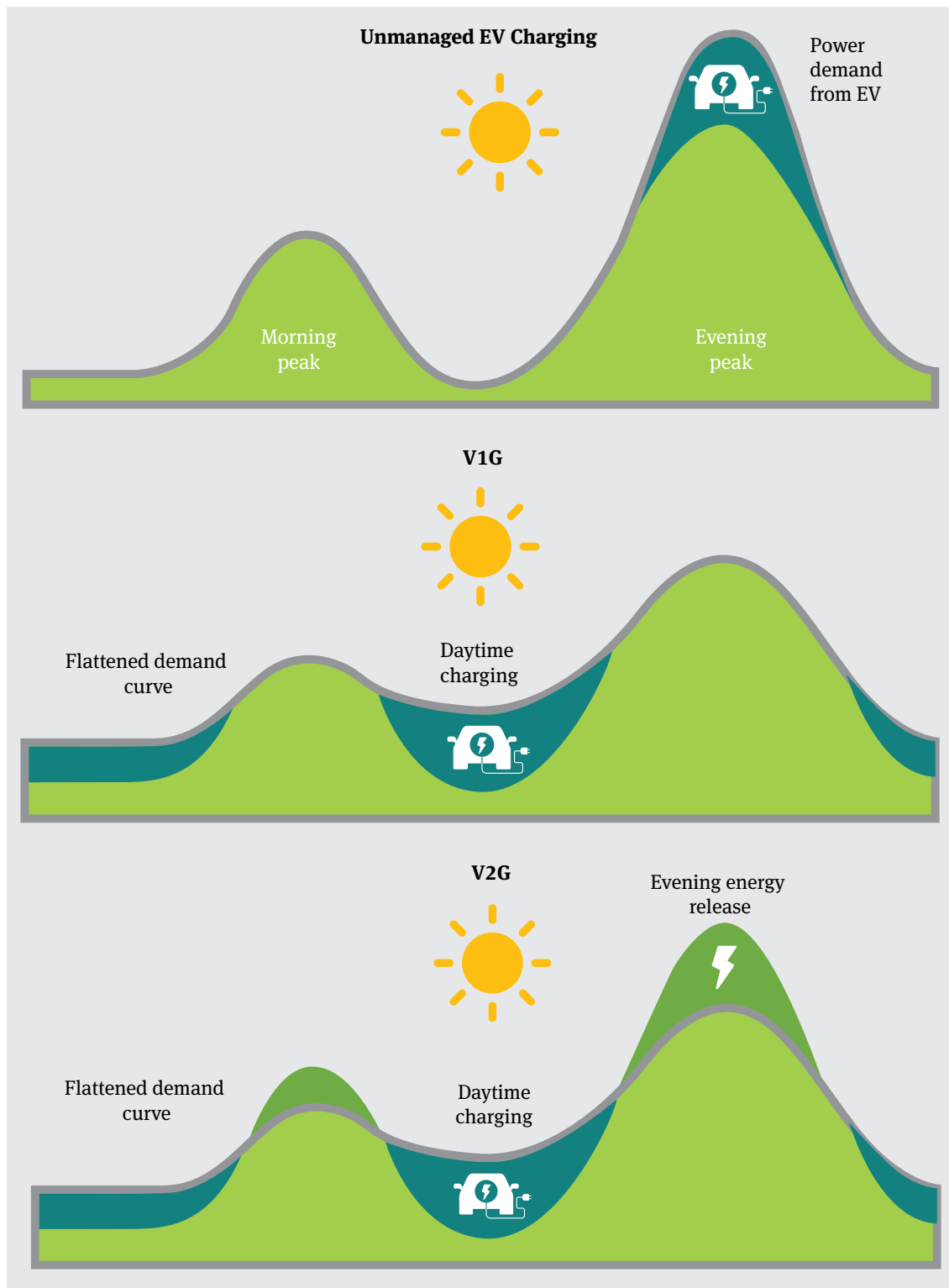


FIGURE 2: IMPACTS OF UNMANAGED CHARGING, V1G, & V2G ON LOAD CURVE

1.1 VGI benefits

There is a range of VGI benefits at different levels and for different stakeholders. Figure 3 summarises these potential benefits, grouped by topic/beneficiary.

It should be noted that, in order to realise these benefits, major technological interventions are required, which may have economic implications, along with a conducive regulatory ecosystem enabling the introduction of different market mechanisms to harness the full potential of VGI.

	Customer Benefits (EV Owners/ Charging Station Operators)	<ul style="list-style-type: none"> • Reduction in electricity bills through use of ToU rates and/ or avoiding high demand charges • Provision of back-up power in case there is a supply disruption or issue with power quality • Increased solar self-consumption to address localised overgeneration from solar energy
	Distribution System Benefits	<ul style="list-style-type: none"> • Deferral of distribution capacity upgrades • Better integration of renewables and reduction in backflow on distribution system in high solar penetration areas • Voltage support and resiliency services (reliability services)
	Transmission System Benefits	<ul style="list-style-type: none"> • Deferral of transmission capacity expansion • Better integration of renewables • Voltage support and primary frequency response • Operational efficiency and black-start services
	Wholesale Market Benefits	<ul style="list-style-type: none"> • Primary and secondary frequency regulation (response) • Reactive power support and management of energy imbalances
	Compliance Benefits	<ul style="list-style-type: none"> • Utilities/ consumers: achievement of regulatory requirements and/ or renewable energy targets • Cities/ states: achievement of renewable energy targets
	Societal & Environmental Benefits	<ul style="list-style-type: none"> • Reduction of power system/ transport sector's carbon footprint • Reduction of criteria air pollutants and air toxics • Creation of economic opportunities • Generation of employment and upskilling opportunities

FIGURE 3: VGI BENEFITS

Source: California Public Utilities Commission (California Public Utilities Commission, 2017)

1.2 Need for investigation

India is making great strides toward large-scale EV-based transport, and the central and state governments view the sector as a key pillar for economic development and a means to achieving its climate goals. GoI has expressed its ambition to achieve 100% EV sales by 2030. To facilitate this, it has launched the Faster Adoption and Manufacturing of (Hybrid and) Electric Vehicles (FAME) scheme. FAME is an incentive scheme that aims to reduce the upfront purchase price of hybrid vehicles and EVs to stimulate their

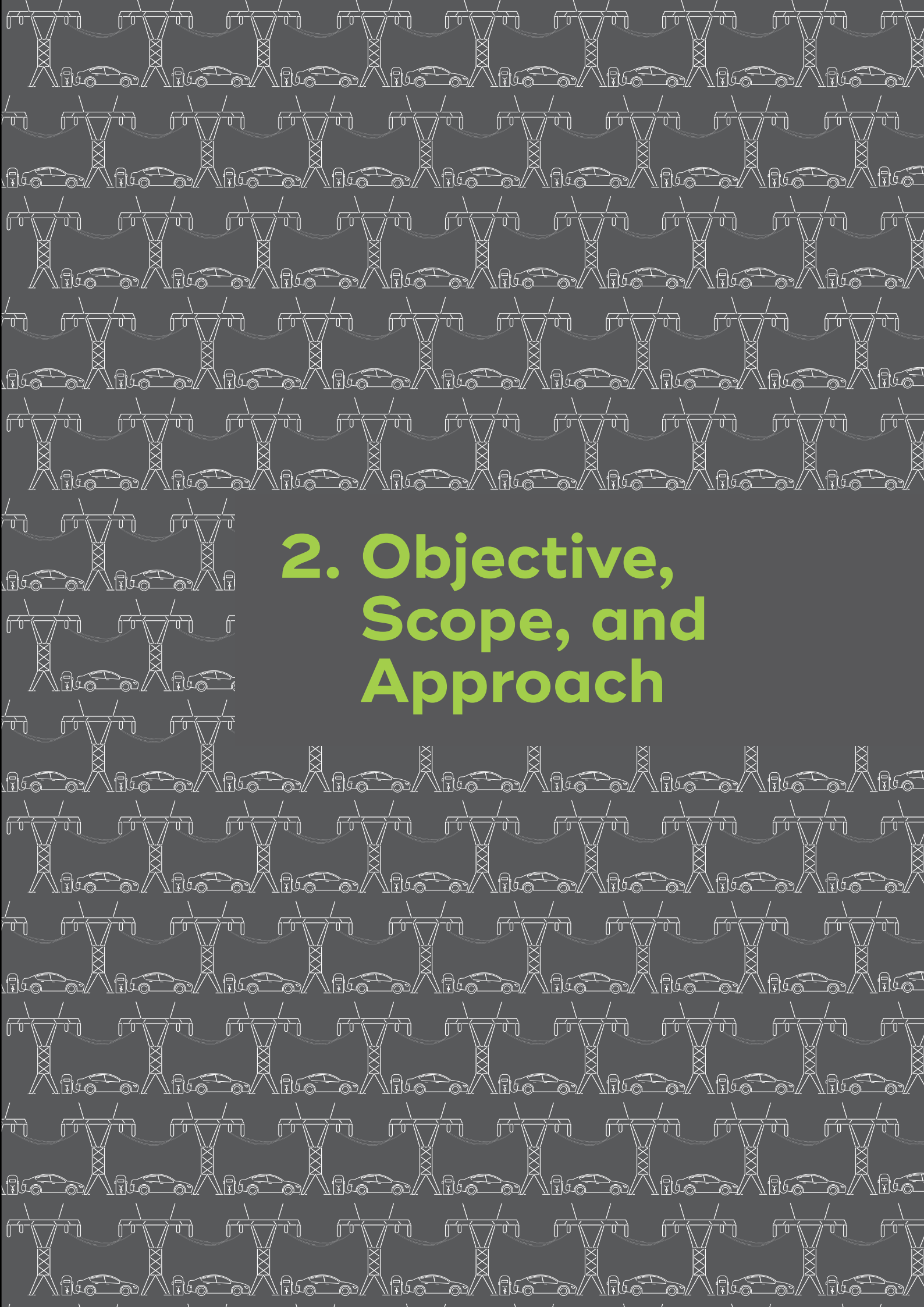
early adoption and market creation (Government of India, March 2015). At the sub-national level, several states and one union territory (UT) have announced EV policies.



VGI IS A NEW FRONTIER THAT THE COUNTRY SHOULD EXPLORE, BUT SO FAR, THERE HAS BEEN LITTLE INITIATIVE ON THE GROUND TO RESEARCH AND IMPLEMENT THIS CONCEPT.

With EV adoption gaining traction and momentum in the country, EVs, as a new addition to the list of electricity consumer categories, becomes an important subject to study from the perspective of load management. Studies across the world have indicated that EVs are not only an energy-efficient and cleaner mode of transport; they have considerable capacity to provide an inexpensive, flexible, and rapid response storage option. VGI enables EVs to participate in grid balancing schemes as generation or demand assets for grid operators. Furthermore, VGI facilitates grid frequency regulation, voltage profile improvement, and reliability improvement.

The EV revolution in India has started. It is time for power utilities, regulators, EV market players, and policymakers to examine the interactions of EVs with the power system. VGI is a new frontier that the country should explore, but so far, there has been little initiative on the ground to research and implement this concept. There is therefore a need to investigate the suite of potential grid services from EVs, including their technical and economic aspects and the regulatory reforms required to implement these services and tap their benefits in the Indian context.



2. Objective, Scope, and Approach

This study aims to present the evolving concept of Vehicle-Grid Integration and its different elements and analyse the feasibility of its implementation in the Indian context. Moreover, this report provides specific guidance on VGI implementation in India.

To this end, the study includes the following:



Review of the flagship pilot projects on VGI carried out in different parts of the world, drawing key learnings from these pilots' outcomes



Techno-economic assessment of VGI



Consultation with key stakeholders whose decisions and actions would influence the implementation of VGI in India



Examination of the regulatory framework necessary for realising VGI and the adequacy of existing Indian power sector regulations to support VGI



Development of recommendations for a VGI implementation roadmap in India



3. Global Status of Vehicle- Grid Integration Projects

VGI implementation in real-world situations is at an early stage; the application of VGI technologies in grid services is just beginning. Pilot projects driven by academia, as well as industry, across the world are exploring various aspects of VGI. The EV market is currently mature in several locations worldwide, including North America, Western Europe, China, and the Organisation for Economic Co-operation and Development (OECD) Asia Pacific nations. It is estimated that the global market for VGI enabling technologies, such as bidirectional DC EVSE and EVSE networking software for VGI services, reached nearly United States Dollar (USD) 28.4 million in 2017 (Navigant Research, 2017). According to Navigant Research's projections, by 2026, the market is forecast to grow steadily at a compound annual growth rate (CAGR) of 35.8% to reach USD 447.5 million (Navigant Research, 2017). In total, it is estimated that the market for VGI enabling technologies and actual VGI services will reach nearly USD 517.5 million by 2026, as shown in Figure 4 (Navigant Research, 2017). It should be noted that this forecast was based on the market health and sentiment before the world economy experienced an unprecedented shock due to the Coronavirus disease 2019 (COVID-19) pandemic. The current economic crisis will inevitably have an impact on the adoption of advanced VGI applications in the near future.

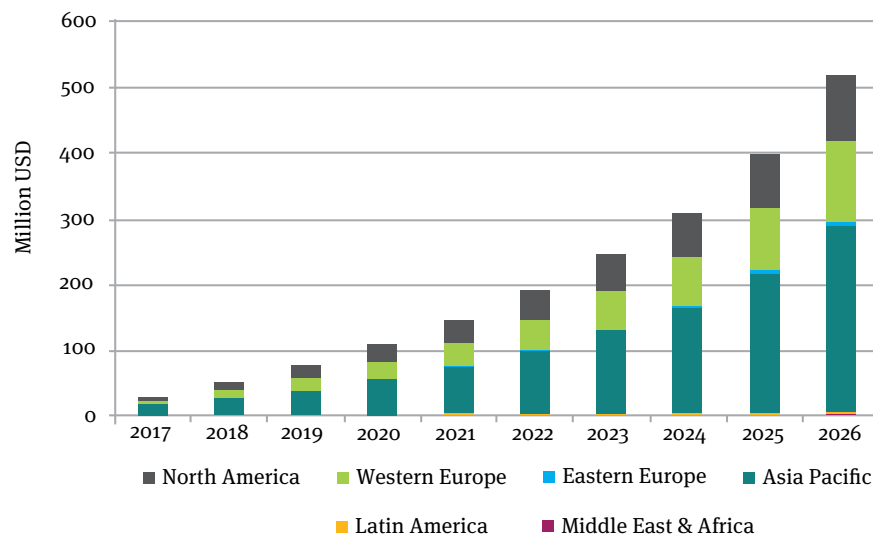


FIGURE 4: VGI TECHNOLOGY AND SERVICE REVENUE BY REGION: 2017-2026

Source: Navigant Research (Navigant Research, 2017)

Globally, pioneering VGI projects have provided interesting insights into different aspects of VGI technology. A list of major VGI projects is given in Appendix A – List of International VGI Pilot Projects. Some of the selected V1G and V2G pilot projects are presented in the following sub-sections.

3.1 V1G Pilot Projects

In a V1G pilot, a fraction of the EVSE capacity of the charging unit is enrolled in grid services. V1G is achieved by throttling the EV charging rate. Several V1G pilot projects are summarised below.

- 1. BMW i Charge Forward Pilot Project:** The i Charge Forward programme was launched in July 2015 in the US by Bayerische Motoren Werke (BMW) and Pacific Gas and Electric (PG&E) to test the value proposition of residential V1G business models for the utility, aggregator, and EV owner

(Navigant Research, 2017). The first phase of the project, completed in December 2016, showed a high level of consumer satisfaction: 92% of participants were very satisfied with the pilot, and 86% indicated they were likely to recommend it to others. There was a total of 192 demand response (DR) events, with the programme successfully reaching a full grid load reduction of 100 kilowatts (kW) in 94% of the events—in total, over 19,000 kilowatt-hours (kWh) shifted.

The pilot was subsequently extended and expanded after receiving a grant from the California Energy Commission (CEC). The programme planned to incorporate at least 250 eligible BMW i3, i8, iPerformance (Series 2, 3, 5, & 7), and X5 plug-in hybrid EV (PHEV) owners, who could receive up to USD 900 for participation through December 2018. The pilot is the first attempt by an automotive original equipment manufacturer (OEM) to act as an aggregator for its own vehicles. The hope is that it will prove a profitable business model for aggregators to organise EVs in grid services and reduce the cost of EV ownership (Navigant Research, 2017).

2. **Avista Utilities Pilot Project:** Avista Utilities caters to Eastern Washington's electricity needs in the US. A large amount of electricity comes from hydropower (which diminishes the grid services opportunity), and the local EV population is likely to grow faster than most other US markets, given its proximity to one of the largest EV markets in the US (Seattle, Washington). In 2016, Avista began developing a 2-year VGI pilot, with plans to install over 200 EVSE units in residential, workplace, and public charging sites within its service territory. The purpose of the pilot is to determine how much EV load can be shifted from peak load times to off-peak times without using ToU rates. Under a Real-Time Pricing (RTP) model, electricity prices change hourly and allow consumers to adjust electricity usage accordingly (Navigant Research, 2017). While RTP may offer cost savings to both the utility and the consumer over other DR pricing schemes like ToU rates, rates are more volatile, and individual charging events may be costly. Nevertheless, advances in technologies like smart meters have steadily improved the viability of RTP as a VGI solution for EVs (Navigant Research, 2017).



EVS ARE NOT ONLY A VIABLE ENERGY-EFFICIENT AND CLEANER MODE OF TRANSPORTATION, THEY HAVE GREAT POTENTIAL TO PROVIDE FLEXIBLE, AND RAPID RESPONSE STORAGE OPTIONS BASED ON V2G FUNCTIONALITY.

3.2 V2G Pilot Projects

EVs are not only a viable energy-efficient and cleaner mode of transportation, they have great potential to provide flexible, and rapid response storage options based on V2G functionality. V2G technology facilitates bidirectional flow of energy to and from the vehicle through a power converter. EVs can serve as revenue generating agents by acting as energy storage units and providing peak shaving or demand shifting to buildings, as well as the power grid, when the load is high. However, there is scepticism regarding V2G's economic viability (Navigant Research, 2017). Furthermore, there is apprehension among researchers that more frequent use of the battery will decrease its lifetime, thereby increasing the battery replacement cost. Despite the aforementioned challenges, V2G technology is being explored and tested in mature markets. A number of V2G pilot projects across the world have investigated different aspects of V2G integration, such as technological readiness, economic feasibility, societal benefits, and challenges. The V2G

technology was invented by a University of Delaware research group led by Prof. Willett Kempton in 1990. The University of Delaware developed a set of communication technologies, policies, and market strategies to facilitate V2G implementation. In 2012, researchers started focusing on the technical viability of V2G. In this context, pilot projects, such as Grid to Wheel project and Intelligent integration of electric vehicles into the power grid for the provision of system services (INEES) project, analysed the technical aspects of V2G. In 2016, researchers started investigating the economic and commercial viability of V2G. The global distribution of pilot V2G research initiatives is shown in Figure 5. From the figure, it can be seen that the European market is taking the lead in the execution of V2G pilot projects.

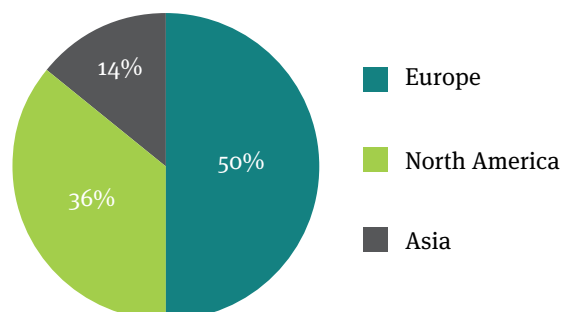


FIGURE 5: GLOBAL DISTRIBUTION OF V2G PILOT PROJECTS

Source: Navigant Research (Navigant Research, 2017)

Several V2G pilot projects are summarised below:

1. **EDISON Pilot Project:** The EDISON project was a Virtual Power Plant (VPP) pilot project implemented by seven companies and organisations in Denmark, Germany, and other countries in 2009. The project aimed to explore how to implement EV management and grid connection through VPPs. EVs, as active energy storage units, were an integral part of VPPs in the EDISON project. Therefore, it was necessary to develop an EV charging plan, taking into account all the system boundaries and uncertainty of the power demand. The EDISON project investigated how to schedule EV charging while respecting grid and production constraints and minimising power consumption and costs.
2. **University of Delaware V2G Pilot Project:** Since developing V2G technology and enabling mechanisms for its implementation, researchers at the University of Delaware have continued to advance the state of the art through various projects funded by Pepco Holdings, Inc., the California Air Resource Board, Los Angeles Department of Water and Power, Delaware Green Energy Fund, and Google. This culminated in the public demonstration of a retrofitted EV connected to the PJM grid acting as a regulation resource in 2007. In 2011, a group of University of Delaware researchers teamed up with NRG Energy, a large power company headquartered in New Jersey, for a joint venture exploring the commercial potential of V2G technology (Stephanie M, 2014). Around this time, BMW and EV Grid provided 30 Mini EVs to the university for research. While typical EVs have chargers that run in one direction, converting grid-based AC power to DC power to be stored in the battery at a level of approximately 3 kW, these vehicles were retrofitted with 18-kW AC propulsion bidirectional chargers. Participating in the hour-ahead power market with a 100-kW resource of 15 vehicles aggregated together, the vehicles began providing regulation services, and each car received approximately USD 5 per day. The research revealed that the aggregator and pay-as-you go models are better strategies, as drivers did not prefer V2G contracts.

3. **ACES Pilot Project:** The Across Continents Electric Vehicles Services (ACES) project aimed to analyse the technical and economic benefits of EV integration in the island of Bornholm in Denmark. The research undertaken as part of this project was based on real EV usage patterns, grid data, and field testing. The project focused on research questions regarding the feasibility of a large set of EVs balancing an islanded power system without causing local grid issues and battery degradation due to V2G functionality, among others (Zecchino, 2019).

The research simulated a 100% EV penetration scenario in Bornholm in order to assess the impact of EV integration on the power system. A small pilot involving 50 publicly- and privately-owned Nissan vehicles and V2G chargers to effectively balance the power system was also part of the project. The key findings of the project are summarised below:

- Based on the simulation in the Danish island, 16% EVs could reduce 7 terawatt-hours (TWh) of renewable curtailment in Japan.
- 100% EVs in Bornholm (equal to 17,500 vehicles) could lead to an equivalent storage of 700 megawatt-hours (MWh) of electricity, although most of this would only be available at night.
- Bidding into the frequency market can be very remunerative, with annual revenue of up to Danish krone (DKK) 10,000. However, the need for an additional V2G charger and the grid losses incurred could negatively impact the profitability. Unidirectional modulation for frequency requires less hardware, but in this case, annual revenue is limited to DKK 450.
- A generic power system would be able to accept a primary power reserve of up to 50% from EVs without particular problems.

A photo of a V2G charger in the ACES pilot project is shown in Figure 6.



FIGURE 6: ACES PROJECT V2G CHARGER

Source: ACES website (Zecchino, 2019)

4. **Parker Project:** The Parker Project was a Danish V2G technology demonstration project. The project built on the findings of the EDISON project and other projects regarding the capability of EVs to support power systems. The project analysed the grid applications, grid readiness, and scalability and replicability of V2G technology. Project partners included Nissan, Mitsubishi Corporation, Mitsubishi Motors Corporation, Nuvve, Frederiksberg Forsyning A/S, Insero A/S, Enel X, and the Electrical Engineering Department of Denmark Technical University. A V2G unit from

the Parker Project is shown in Figure 7. The main findings of the project were the following:

- Automakers such as PSA Group, Mitsubishi, and Nissan, together with DC V2G charger providers (e.g. Enel X), can support V2G implementation and are ready to provide advanced frequency regulation services to the grid.
- A field test in Copenhagen concluded that it is possible to commercialise this technology through the provision of a Frequency Containment Reserve¹ (FCR).
- Further steps must be taken for universal support of V2G services across all EV brands, standards, and markets.



FIGURE 7: PARKER PROJECT V2G UNIT

Source: Parker Project Report (Navigant Research, 2017)

3.3 Findings of other pilot projects

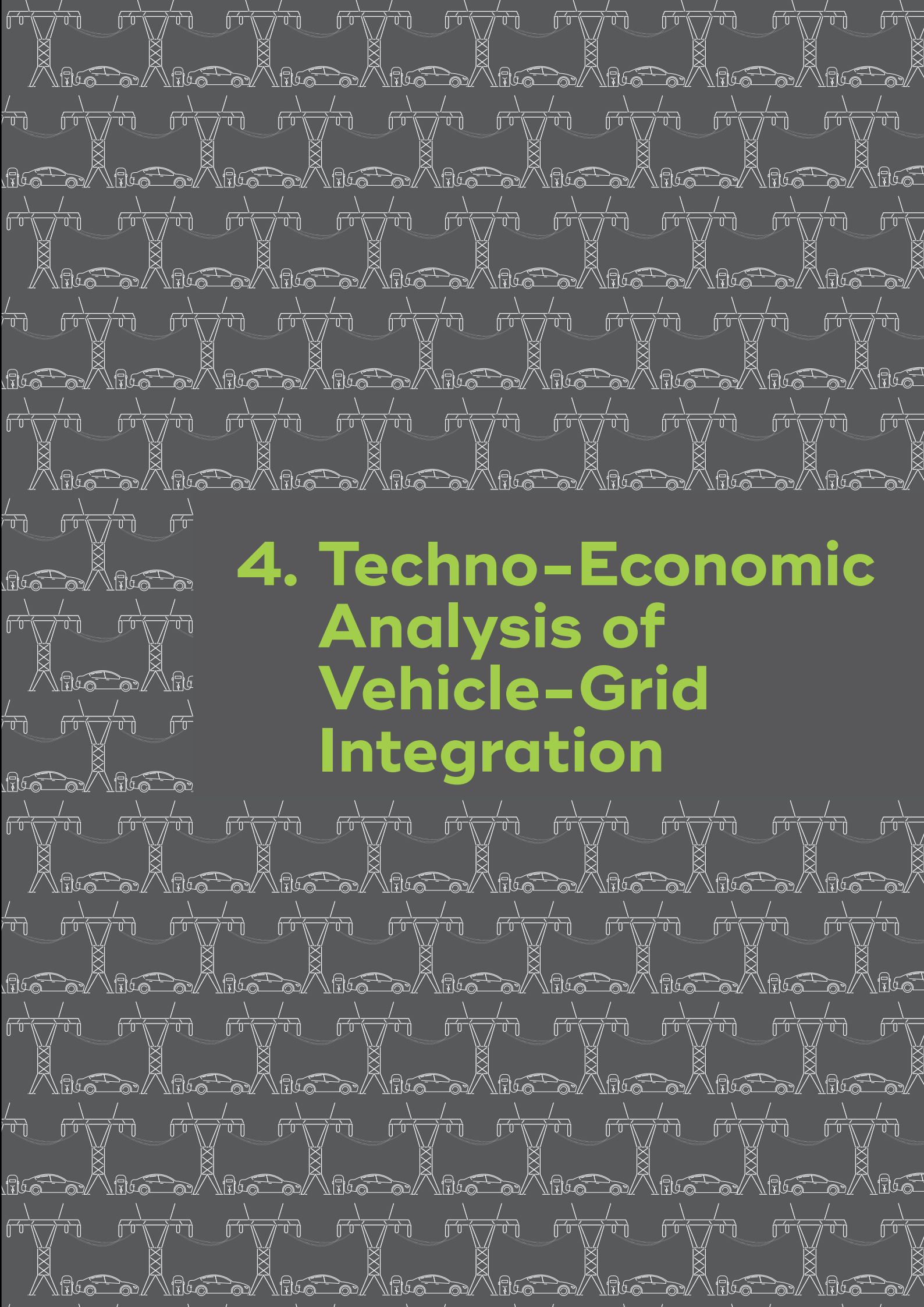
There is an ongoing debate among experts regarding the feasibility of VGI. Some researchers question the economic attractiveness of VGI and its scope for implementation. Table 1 presents the key findings of the other international pilot projects on VGI. The details of those pilot projects are captured in Appendix A – List of International VGI Pilot Projects.

TABLE 1: FINDINGS OF OTHER PILOT PROJECTS

Project name	Type of VGI	Findings
INVENT	V2G	DC CHARge de MOve (CHAdemo) solutions dominate the market at present, but there is significant interest in AC solutions.
City-zen	V2G	Slow starters in the V2G chargers limit the inrush current, making the power quality more consistent.
Grid Motion	V1G, V2G	Onerous interconnection requirements were flagged in this project.
Redispatch V2G	V2G	An intelligent load control system was developed and tested, facilitating grid stabilisation and providing cost savings for end users.

From the review of V1G and V2G pilot projects around the world, it is evident that V1G is ready for commercial deployment, whereas V2G is still at the testing and pilot stage.

¹ A frequency containment reserve is a production capacity (or any other machine) that can reduce or increase its output to contain any possible frequency deviations.



4. Techno-Economic Analysis of Vehicle-Grid Integration

In this chapter, the differences between V1G and V2G in terms of their possible value streams and the associated techno-economic factors are examined. In view of the lack of data, particularly data relevant to the Indian context, the scope of this study does not include the quantitative estimation of the market value of VGI and the direct or indirect implementation costs.

4.1 Value streams

EVs can be used for a multitude of applications, including congestion management, frequency regulation, and increasing the uptake of renewable energy (RE)-based electricity – and all of these can be realised through V1G. Meeting peak demand, particularly when the demand rises above the anticipated level, is an ongoing challenge for DISCOMs. V1G plays an important role, especially in situations where the power demand becomes too high. To curtail the rising peak demand, many utilities in advanced markets have utilised demand response programmes that apply time-based rates or other financial incentives to encourage consumers to reduce or shift their electricity usage during peak periods of demand. EVs can contribute to these programmes, acting as controllable loads and effectively participating in DR events. One can remotely control the power level at which EVs charge, so that the grid does not get overburdened. Even on its own, smart charging (V1G) can have a major impact on the grid.



A PLETHORA OF NEW OPPORTUNITIES OPEN UP FOR THE POWER MARKET

Nevertheless, with both V1G and V2G, a plethora of new opportunities open up for the power market. According to experts, there are four key benefits one should consider in the techno-economic analysis of V1G and V2G:

1. **Peak shaving:** V1G and V2G are well suited for peak shaving. The EV batteries can charge during off-peak hours, thus filling the valleys in the load curve through V1G. If there is bidirectional capability with V2G, then EV batteries can be discharged when there are peaks in demand and excess power is required. Thus, V1G and V2G can potentially help utilities manage their daily load and meet the peak demand efficiently and cost-effectively.

The main challenge here is to create a real-time market for energy, wherein supply and demand can meet at relatively low power levels. Aggregation of demand and supply are crucial to successfully participating in the market.

2. **Arbitrage opportunities:** V2G makes it possible for the EV market players to trade on the power markets. When electricity prices are low, energy can be bought and stored by charging the vehicles. When the prices become high, the stored energy can be sold on the power market.
3. **Frequency regulation:** The power grid is set up at a frequency of 50 hertz (Hz). When there is a supply – demand mismatch, there will be variations in frequency, and this has an impact on the grid stability. Since EV batteries can respond to the changes within a few seconds, this is a much more efficient solution compared to slow responding mechanical, spinning reserves. V2G enabled EVs can therefore be competitive in the ancillary service market for frequency regulation.
4. **As an RE storage unit :** EVs can be charged either when there is a high volume of renewable energy in the grid but not sufficient demand or directly by RE sources (e.g. solar photovoltaic (PV)), and the EVs can then store the energy. When there is an increase in power demand in

the grid, the charged EVs can feed the stored renewable energy back into the grid, thus maximising RE utilisation and minimising the power system's carbon footprint.

Undoubtedly, V1G and V2G offer a large range of grid services.

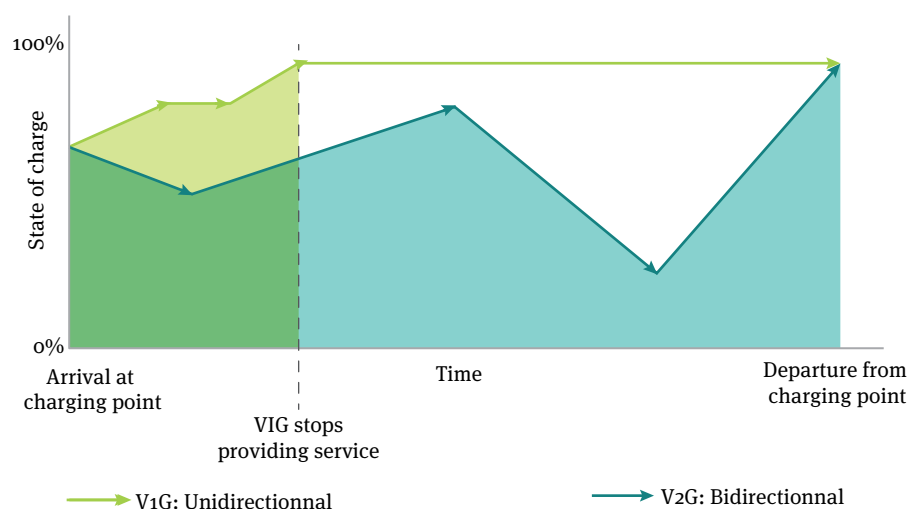


FIGURE 8: PROPORTION OF GRID SERVICES THROUGH V1G AND V2G

Source: IEA (IEA Clean Energy Ministerial, 2020) and AEEE analysis

Figure 8 above shows how V2G, due to bidirectional energy flow, has an edge over V1G in providing grid services. The lines in the graph indicate how V1G and V2G can impact the EV state of charge. In V1G's case, charging can be done at different times, but eventually reaches 100%, after which no further changes can happen; in contrast, V2G enables the EV battery to be discharged and charged according to the needs of the grid, thus offering more flexibility. According to the International Energy Agency (IEA), V2G can potentially unlock 9 times more value from EV-grid integration than V1G (IEA Clean Energy Ministerial, 2020).

It should be noted that the actual economic value of VGI depends not just on the adopted use case, but also on the scale of implementation. For better economic return from V1G or V2G, achieving the required scale is essential. Hence, VGI is considered to have three levels -- Smart Charging (V1G), Aggregated Smart Charging, and Large-Scale Bidirectional Charging (V2G). Figure 9 summarises how the value of flexibility services to the grid varies among the different VGI applications.

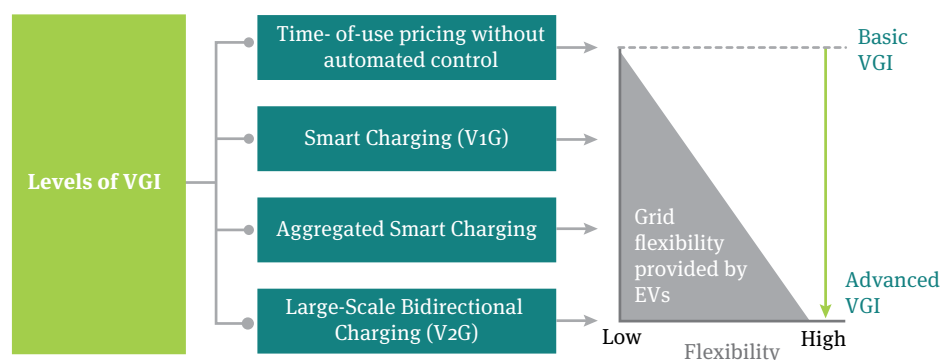


FIGURE 9: VGI APPLICATION VALUE IN GRID FLEXIBILITY SERVICES

Source: AEEE analysis

Although the value of V2G-based grid services is potentially greater than that of V1G, realising those benefits may not be a straightforward task. There are a set of major technological requirements that could potentially impact the on-ground implementation and the possibility of scale-up in the near future.

4.2 Key techno-economic factors for VGI implementation

The study has identified the following three important technological aspects of VGI that impact its commercial attractiveness, as detailed below:

1. **Advanced charging technologies:** Charging infrastructure plays a critical role in VGI. Not only is it the backbone of e-mobility, but it also closely binds mobility to the electricity sector and has the potential to bring about major transformations in the power system. VGI requires sophisticated charging technology to enable EV participation in grid services. The charging technology used for V1G, or smart charging, is very different from that required for V2G, because of the fundamental difference in energy flow in the two systems. V1G entails the usual unidirectional energy flow, from the EVSE to the battery inside an EV, as seen in any EV charging system. Furthermore, similar to a simple charger, the smart charger can be either AC or DC. However, considering that DC fast charging has greater impact on the load on the grid, it makes sense to make DC fast chargers “smart”. The basic difference between a simple EVSE and an EVSE used in V1G is that the latter shares a data connection with an EV, as well as with the charging point operator. As opposed to a simple charging device that is not connected to the cloud, smart charging allows the charging service provider to monitor, manage, and restrict the use of chargers remotely to optimise energy consumption. Moreover, smart chargers can be enabled to respond to price signals on their own (based on the applied algorithms). Smart charging is powered by an intelligent back-end solution that enables real-time data sharing between the EV, EVSE, and charging point operator, called the Central Management System (CMS). A major operational advantage of smart chargers is that their functions can be modified at any point in time; it is easy to add and remove features and design a system to meet one’s needs. Hence, the costs of smart chargers vary depending on the features. Smart chargers are widely available in advanced EV markets and are becoming a mainstream solution. Such EVSEs are also available on the Indian market, and many of the existing installed chargers already have smart features of varying degree, but currently, these features are often disabled due to lack of use.



THE CHARGING TECHNOLOGY USED FOR V1G, OR SMART CHARGING, IS VERY DIFFERENT FROM THAT REQUIRED FOR V2G, BECAUSE OF THE FUNDAMENTAL DIFFERENCE IN ENERGY FLOW IN THE TWO SYSTEMS.

On the other hand, V2G goes one step further and enables the feeding back of energy stored in the EV battery into the grid, apart from the usual energy flow during EV charging to the EV battery. V2G requires additional electrical equipment compared to standard or smart charging, such as a bidirectional inverter to convert the DC output power from the on-board EV battery to AC. This conversion equipment is normally integrated into the EVSE, although some manufacturers are considering integrating the bidirectional equipment within the vehicle. Currently, the J1772 connector and IEC 62196 connector are capable of AC discharging (provided the EV is equipped with a bidirectional inverter), whereas a CHAdeMo connector is suitable for DC discharging (again, if the EVSE has a bidirectional inverter). Control units are also required for efficient, reliable, and safe battery

charging and discharging, along with upstream communication protocols to manage these interactions between EVs and the grid (International Energy Agency, 2019).

A number of additional technical requirements need to be met to enable V2G implementation. For example, the EVSE should have appropriate Loss of Mains (LOM) protection equipment to ensure the vehicle does not feed power into the grid during a fault or when maintenance work is under way. Furthermore, two-way metering capability is required to measure electricity exchanges with the grid for bill settlement. All such requirements must comply with grid codes defined by local or national network operators. Globally, there are few V2G-ready EVSEs. Moreover, because of the need for expensive hardware, V2G EVSEs are much more costly than smart chargers.



CURRENTLY, ONLY A FEW COMMERCIALY AVAILABLE EV MODELS HAVE THE POTENTIAL TO PARTICIPATE IN V2G

2. EV suitability: The EV, along with its battery, is at the core of VGI. As in the case of charging technology, the vehicle features required for V2G application differ considerably from those needed for V1G. As data sharing between an EV and EVSE provides the basis for smart charging, the vehicle design should allow for that. Fortunately, most EV models with advanced batteries² and a Battery Management System (BMS) currently available on the market, including in India, have the necessary capability. Hence, smart charging does not require a different set of specially equipped EVs. However, this does not hold true for V2G; in this case, the EV should have the discharge functionality. Currently, only a few commercially available EV models have the potential to participate in V2G, including the 2013 Nissan LEAF Model (and newer models), Nissan e-VN200, Mitsubishi iMiev, and Mitsubishi Outlander PHEV³. These models are charged and discharged by CHAdeMo using DC power, and the EVSE hosts the bidirectional inverter to convert DC power to AC. None of these EV models are currently commercially available in India. There are also a few prototype EVs that can potentially discharge AC power, i.e. the power conversion happens on board the vehicle. Automakers such as Honda, Renault, Fiat Chrysler, and Blue Bird are reportedly developing such prototypes. However, these are not yet commercially available anywhere in the world.

3. Battery health: The on-board battery is the heart of an EV and also contributes about half of the EV cost. Hence, maintaining battery health is important for EV users. Battery performance deteriorates gradually with the number of charging-discharging cycles⁴. For this reason, an OEM's battery performance warranty is highly valued and one of the key considerations at the time of vehicle purchase. Usually, such warranties are given based on the years of vehicle usage or distance travelled and are often bound by certain clauses on vehicle usage. More often than not, OEMs de-recognise their warranties for EVs if they are used for purposes other than mobility. The extent to which this affects VGI implementation should therefore be examined.

As V1G entails unidirectional energy flow and battery charging, the same as any other charger, an EV battery does not have to undergo additional cycles of charging or discharging to participate in V1G. Hence, smart charging is not expected to degrade battery health. On the other hand, V2G involves bidirectional energy flow between the EV battery and the EVSE,

² E.g. lithium-ion batteries

³ PSA Groupe also reportedly has an electric car model suitable for V2G.





⁴ There are several other factors, such as ambient temperature, humidity, driving behaviour, etc., that can also potentially impact the battery health.

so the battery has to undergo additional charging-discharging cycles to participate in V2G and feed power back into the grid. A contentious issue in this regard is to what extent the additional use of the EV battery will affect battery health. There have been several studies on this subject, but with no unanimous conclusions regarding this issue. Some literature claims that the additional effect is expected to be minimal (Shinzaki, Sadano, Maruyama, & Kempton, 2015), while others have highlighted it as a challenge to V2G implementation (Bishop, et al., 2013). In any case, the typical OEM clause on the withdrawal of EV battery warranty on the grounds of non-mobility use of the battery remains a major barrier to V2G implementation. Under such circumstances, EV owners are less likely to participate in a V2G programme.

The study considers these three technological factors critical to the feasibility of VGI implementation in India. However, there are other technological aspects that are also important, such as the BMS. Battery charging and discharging generates heat in the battery, particularly at a high C-rate⁵. To participate in V1G or V2G, the battery may have to charge or discharge at a fast rate, potentially generating excess heat. The impact of heating could be serious when the ambient temperature is high, as in many places in India. BMS therefore plays a crucial role in maintaining battery health and preventing the possibility of a battery catching fire in VGI.

4.3 Techno-economic comparison of V1G and V2G

From the assessment, it becomes clear that V2G can potentially offer substantial value but is complex and expensive too, whereas V1G has limited complexity and offers value less than V2G (Figure 10).

Values from VGI	Technical complexities			
	 Smart charger	 Battery health	 Smart charger with bidirectional functionality	 Suitability of EV
Peak shaving	✓	✓✓	✓✓	✓✓
Congestion management	✓	✓✓	✓✓	✓✓
Frequency regulation	✓	✓✓	✓✓	✓✓
Increase in RE uptake	✓	✓✓	✓✓	✓✓
RE storage		✓✓	✓✓	✓✓
Arbitrage opportunities		✓✓	✓✓	✓✓

V1G ✓ V2G ✓✓

FIGURE 10: SNAPSHOT OF BENEFITS AND COMPLEXITIES OF V1G AND V2G

⁵ The C-rate is defined as the rate of battery discharging relative to its maximum capacity.

To make a techno-economic comparison of V1G and V2G vis-à-vis unmanaged charging, this study has created a three-dimensional matrix, where the horizontal axis shows the value proposition of the possible flexibility services, the vertical axis indicates the complexity of the required technology, and the size of a bubble depicts the relative estimated cost of implementation (Figure 11).

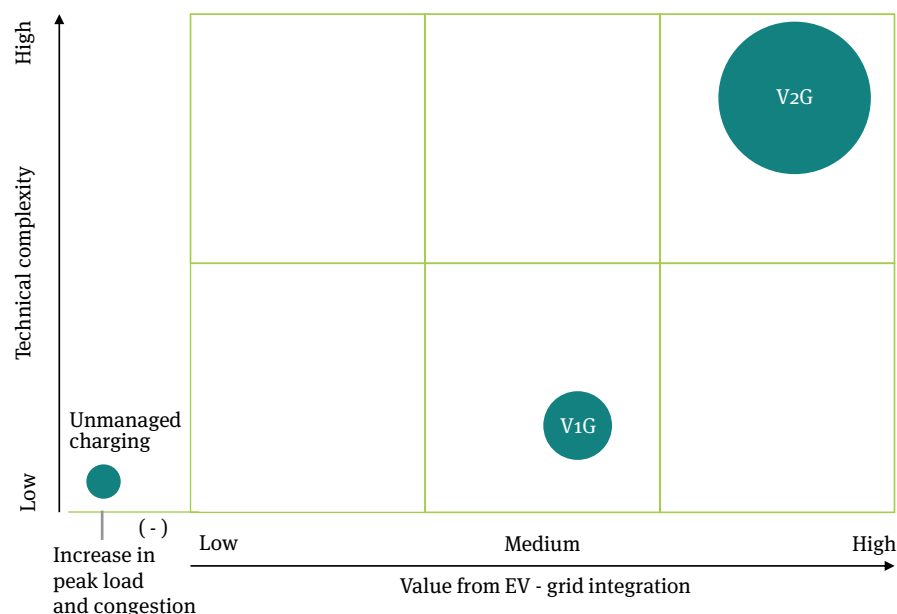
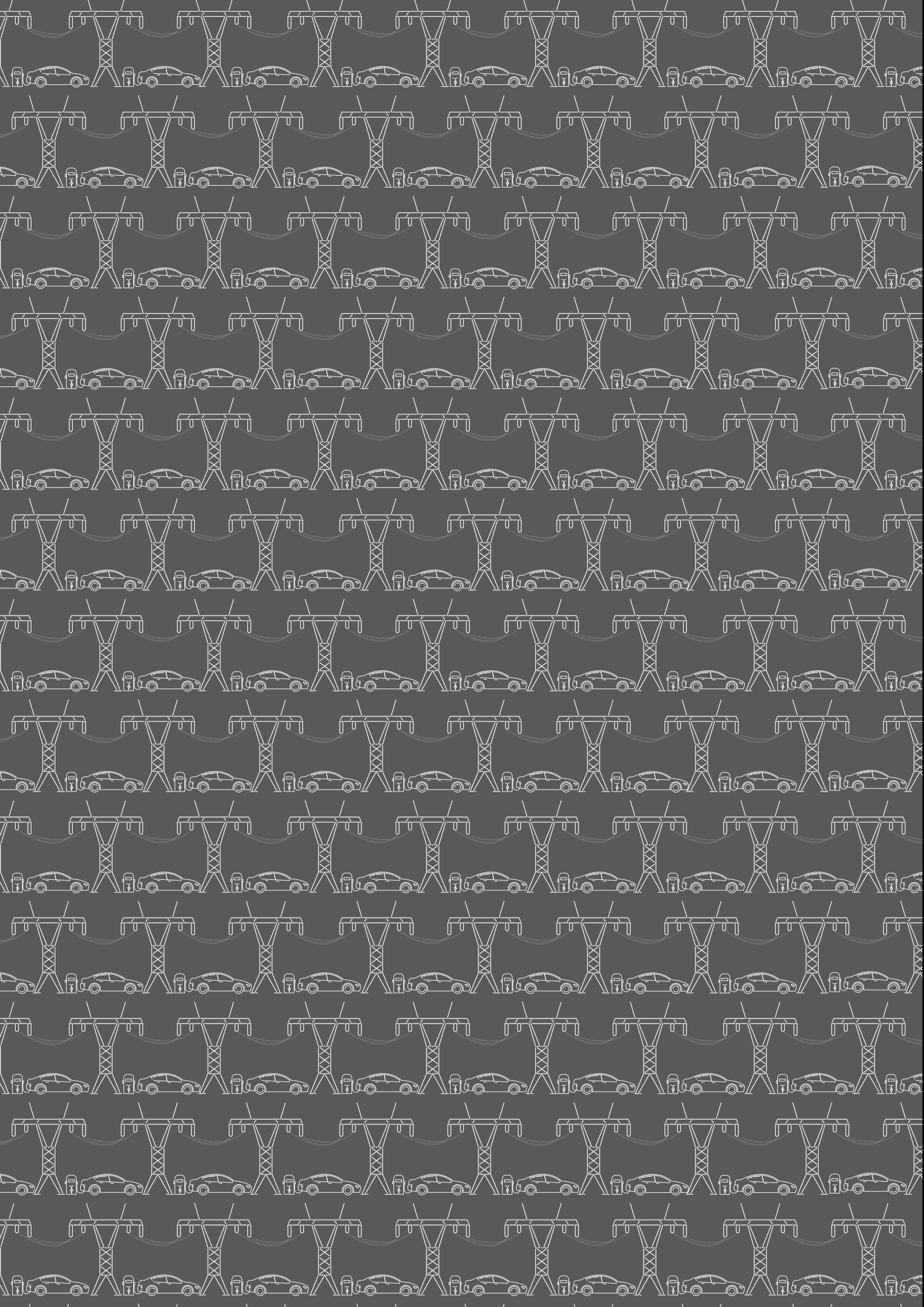


FIGURE 11: TECHNO-ECONOMIC COMPARISON OF UNMANAGED CHARGING, V1G, & V2G

Source: AEEE analysis

From the matrix, one can infer that although V2G enables a greater range and value of grid flexibility services compared to V1G, it also involves a highly complex set of technological factors, which, in turn, increases its cost of implementation. In contrast to VGI, unmanaged charging does not require a sophisticated charger, but it has a considerable negative impact on the power system in terms of possible increase in peak demand and congestion in the distribution network. It is important that DISCOMs, regulators, charging point operators, and policymakers in India take cognisance of the techno-economic advantages and challenges of the different VGI solutions in contrast to unmanaged charging and decide on the best way forward accordingly, while simultaneously taking into account the local context, which varies from state to state and city to city.

Beyond the techno-economic attributes of VGI, it is important to understand how the different stakeholders in the Indian EV ecosystem perceive VGI and its potential application, and, hence, the next chapter presents their views on the different aspects of VGI.



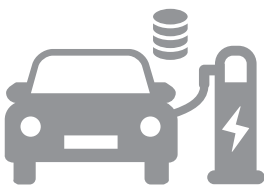


5. Stakeholder Consultation on Vehicle-Grid Integration

EV adoption and integration with the power grid through VGI depend on the decisions and actions taken by different stakeholders. VGI is a multilateral concept involving a variety of different stakeholders. The various stakeholders have different benefits to pursue, different barriers to overcome, and different perspectives on the uptake of EVs and their integration with the grid. This study has reached out to different stakeholders in the Indian EV sector and attempted to capture their views on VGI in the Indian context. The research entailed a questionnaire-based consultation with these stakeholders on the key aspects of VGI.

5.1 Stakeholders and their roles

The different Indian stakeholders whose involvement is necessary for VGI deployment include battery experts, DISCOMs, Research and Development (R&D) institutions, fleet operators, and charging service providers (Figure 12). The roles of these stakeholders are detailed below.



EV OWNERS COULD BE INTERESTED IN CONTROLLED CHARGING OR VGI PROGRAMMES IF THE FINANCIAL INCENTIVES TO PARTICIPATE WERE HIGH ENOUGH AND THE VEHICLE RANGE WAS NOT NEGATIVELY IMPACTED.

1. **DISCOMs:** The primary concern of DISCOMs is ensuring the reliability and stability of the power grid. These parameters can be disturbed if many EVs are being charged at the same time, causing the grid to be overloaded. DISCOMs could be interested in controlled EV charging or V2G if peak loading of the grid could be avoided or delayed. With controlled charging, the charging rate could be lowered, or charging could be shifted to off-peak hours. Additionally, with V2G, EVs could feed power into the grid during peak hours.
2. **Fleet Operators:** The main interest of the fleet operator is to fulfil transportation needs. In terms of e-mobility requirements, fleet operators want to minimise EV charging costs. EV owners could be interested in controlled charging or VGI programmes if the financial incentives to participate were high enough and the vehicle range was not negatively impacted. Regarding V2G, EV owners are concerned about possible battery degradation.
3. **Battery Experts:** There is apprehension among battery experts that EV battery health may be degraded in VGI. The cost of battery degradation as a result of V2G charging/ discharging has to be offset by the financial incentives to participate in a V2G programme. Battery experts see the need to model EV battery operations in order to analyse the impact of VGI on different battery chemistries and develop strategies to reduce this impact, as well as explore the potential use of degraded batteries as second life batteries.
4. **R&D Institutions:** VGI is still at its nascent stage, and a lot of research is needed to enable successful VGI implementation; in this context, R&D institutions play a vital role. The role of these institutions is to execute pilot projects on different aspects of VGI, such as the feasibility of EV-based VPPs, bidding strategies for VPPs, considering uncertain outputs from EVs and RE sources, frequency regulation and improvement in grid reliability through V2G, consideration of V2G enabled charging stations in distribution network planning, etc.
5. **Charging Service Providers:** A huge demand for EV charging infrastructure exists on most urban roads, as well as highways. A good charging facility and demand aggregation strategy is essential for the success of charging infrastructure businesses. All chargers and charging stations will be new additions in terms of load on the grid, and it is

important that the grid gets some signal regarding the charging demand in order to optimise peak load management. This EV charging data management and analytics for improved grid management through VGI shall emerge as a new business opportunity.

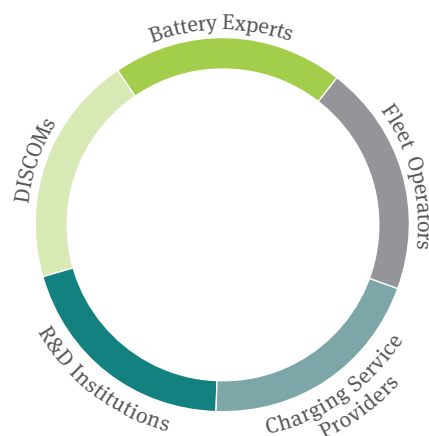


FIGURE 12: POTENTIAL STAKEHOLDERS IN VGI IMPLEMENTATION IN INDIA

5.2 Stakeholder consultation

The purpose of the stakeholder consultation was to get the different stakeholder perspectives on various aspects of VGI and recommendations regarding the promotion of VGI in India. To this end, a set of questions were posed to the interviewees, as listed in Appendix B – Questionnaire. During the stakeholder consultation, the research team reached out to a number of stakeholders actively involved in India's EV ecosystem. The stakeholders consulted are listed in Appendix C – Stakeholders Consulted. The views expressed by different stakeholder categories on specific VGI aspects are detailed below:

1. **General view of VGI:** All the stakeholders believe that VGI is important and has the potential to harness the usage characteristics of EVs to enable them to serve as a grid asset. The views of different stakeholder groups on VGI are presented in Table 2. An important takeaway from the consultation is that the majority of the players are currently interested in V1G, as no infrastructural upgradation is required for its implementation, and V2G implementation may have to wait for several years.

TABLE 2: STAKEHOLDER VIEWS ON VGI

Stakeholder	View
DISCOMs	<ul style="list-style-type: none"> • Futuristic concept • Not enough EVs on road for aggregation
Charging service providers	<ul style="list-style-type: none"> • Can be effectively utilised to deal with the variability associated with RE sources, since EV batteries can be used for energy storage
R&D institutions	<ul style="list-style-type: none"> • Requires high-quality electronics and communication • Requires a stable grid and framework for EV integration with the grid
Fleet operators	<ul style="list-style-type: none"> • Sceptical regarding VGI • Not very interested in feeding power back into the grid • Priority is battery swapping and battery-to-grid, before considering V2G

2. **Challenges associated with VGI:** When asked about the challenges associated with VGI implementation in the Indian context, the stakeholders highlighted the following:
 - Insufficient number of EVs on the road
 - For V2G implementation, hardware and software infrastructure should be improved.
 - Lack of regulatory framework – regulators need to be educated on this concept.
 - Requirement of infrastructure to discharge EV batteries with different States of Charge (SoCs) at the same charging point
 - Selection of appropriate voltage level for VGI implementation
 - Chargers not equipped for V2G
 - Potential battery degradation with V2G
 - The bidirectional battery charger has a complex controller and high-tension cable. In the case of the high-tension cable, safety precautions are needed.
 - In the charging-discharging cycles, energy conversion takes place, which results in energy losses in the power system.
 - Lack of initiatives to implement pilot projects
3. **VGI applicability to different EV segments:** Is VGI suitable for all EV segments, including electric two-wheelers (e-2Ws), three-wheelers (e-3Ws), four-wheelers (e-4Ws), and e-buses? This is an important aspect to examine. Most of the stakeholders remarked that the suitability of an EV segment to participate in VGI depends on the battery conditions. e-2Ws and e-3Ws can only provide grid support to a minimal extent and may not be a good option for VGI, as the economics may not be favourable. VGI using e-buses could work, as they could provide more power to the grid during downtime. However, stakeholders suggested that the economics of VGI with e-buses needs to be further investigated in the Indian context.
4. **Cost of battery degradation due to VGI:** Research conducted across the world has flagged the issue of battery degradation due to VGI. As a consequence of more charging-discharging cycles occurring during provision of V2G services, battery degradation can potentially be more severe. No research has investigated the impact of V2G on battery degradation in the Indian context. Hence, during the consultation, the stakeholders were asked for their views on battery degradation due to VGI. R&D institutions mentioned that developing new simulation models is highly essential to determining the impact of VGI on battery degradation in the Indian context. Some of the interesting remarks made by the respondents include the following:
 - The impact of VGI on different battery chemistries, such as nickel manganese cobalt (NMC), lithium ferrophosphate (LFP), etc., should not be very different.
 - Battery degradation due to VGI is not a major concern and can be handled with a Battery Thermal Management System (BTMS).
5. **VGI profitability for fleet operators:** The profitability of fleet operators participating in VGI is an important issue, as engagement of fleet operators is a prerequisite for successful VGI implementation. Hence, the views of the interviewed stakeholders on VGI profitability for fleet



THE PROFITABILITY OF FLEET OPERATORS PARTICIPATING IN VGI IS AN IMPORTANT ISSUE, AS ENGAGEMENT OF FLEET OPERATORS IS A PREREQUISITE FOR SUCCESSFUL VGI IMPLEMENTATION.

operators were captured and are summarised in Table 3. There was a lack of consensus among stakeholders regarding this issue.

TABLE 3: STAKEHOLDER VIEWS ON VGI PROFITABILITY FOR FLEET OPERATORS

Stakeholder	View
R&D institutions	<ul style="list-style-type: none"> There is a necessity to analyse the profitability of EV drivers/ fleet operators in participating in VGI in Indian context. Critical factors mentioned in Figure 13 should be considered when analysing the profitability of EV fleet operators participating in VGI.
Fleet operators	<ul style="list-style-type: none"> Currently, EV charging is a challenge in many parts of India due to a lack of chargers. Under such circumstances, fleet operators will not be interested in feeding power back into the grid.
Charging service providers	<ul style="list-style-type: none"> No separate incentive is required for V1G. Current incentives for EV adoption will be sufficient for V1G. Separate incentives may be required for V2G.

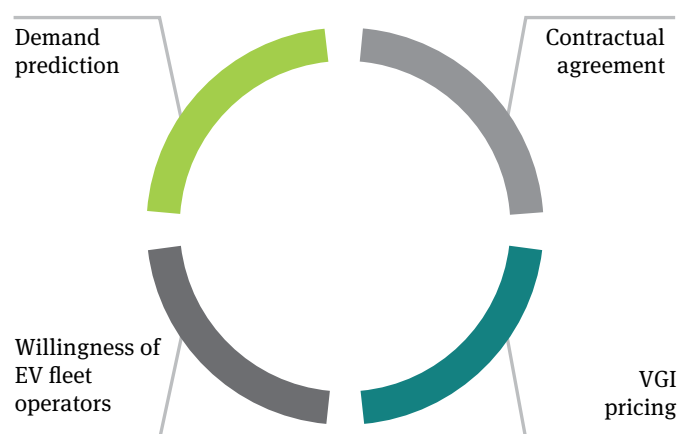


FIGURE 13: CRITICAL FACTORS IN PROFITABILITY ANALYSIS OF VGI FOR FLEET OPERATORS

6. **Necessity of slow starters in V2G chargers:** Slow starters restrict or limit inrush current, making the power quality more stable. However, the additional cost of these slow starters needs to be considered. The stakeholders were questioned on the necessity of these slow starters. R&D experts stated that it should be mandatory to incorporate such slow starters into all V2G chargers. They also added that the cost of these slow starters would be negligible compared to the benefits they would help achieve in terms of tackling the power quality issue. They also referred to a key finding of the City-zen project in Amsterdam, that is it is important to ensure that grid stability is not negatively impacted due to the introduction of V2G chargers. Facing this problem early on in their project, the City-zen team recommended that grid acceptance standards be amended to make it mandatory to equip V2G chargers with 'slow starters'.
7. **Charger suitability:** Availability of V2G enabled chargers on the market is an essential criterion for successful VGI implementation. In this context, charging service providers mentioned that CHAdeMO chargers are equipped for VGI, but Combined Charging System (CCS) chargers are not. One of the interviewees also mentioned that the Parker project investigated the efficiency characteristics, activation time, response granularity, ramping up/down time, accuracy, and precision of CHAdeMO

chargers. The findings of the aforementioned research showed that charger performance is dependent on operating conditions, highlighting the importance of good calibration and knowledge of the employed hardware when providing standard-compliant grid regulation services via V2G technology.

8. **Value proposition of VGI for DISCOMs:** Stakeholders are generally positive about the benefits of VGI for DISCOMs. According to them, V1G can potentially play an important role in demand response, and V2G can assist in frequency regulation, voltage regulation, black start support, and reliability improvement. However, there is uncertainty about the financial attractiveness of V2G for DISCOMs, due to limited use cases. There is currently no regulatory framework for V1G or V2G in India. There is a need to sensitise regulators about the different aspects of VGI and encourage them to develop a suitable regulatory framework.
9. **VPP opportunities in India:** The research also tried to capture the opinions of the stakeholders on the market opportunities for VPP in India. It was discovered that researchers in the Department of Electrical Engineering at the Indian Institute of Technology (IIT), Madras are working on different aspects of VGI, including VPP and its interaction with the electricity market, optimal bidding strategies for VPP, business models for VPP in India, etc. Although different players are talking about VPP, not enough pilot projects have been carried out in this domain globally. Stakeholders stressed the need to execute industry-sponsored VPP pilot projects in the technical research institutes. Stakeholders further emphasised that approaches need to be developed for VPP implementation in India. Internet of Things (IoT) based management, energy resource aggregation, smart control strategies, sustainable business models, availability of EV owners, and telematics are essential topics to investigate. According to DISCOMs, VPP pilot projects need to be implemented to draw useful learnings to help further develop the technology and concept and enable its scale-up. In addition, regulations need to be framed in order to enable commercialisation of the technology.

5.3 Key observations and recommendations

Based on the inputs received during the stakeholder consultation, the key issues have been mapped by stakeholder category. Table 4 summarises the views of different stakeholders on key issues related to VGI. The following key recommendations regarding VGI implementation came out of the stakeholder consultation:

- VGI pilot projects need to be carried out.
- It is important to conduct research on EV battery degradation in V2G.
- Regulators need to be educated on different aspects of VGI.
- Slow starters should be mandatory in V2G chargers.
- Electric four-wheelers and e-buses are potential candidates for testing V2G feasibility.
- It is important to frame regulations to facilitate commercialisation of VGI.
- It is critical to analyse the profitability of participation in VGI for EV fleet operators in Indian cities.



ELECTRIC FOUR-WHEELERS AND E-BUSES ARE POTENTIAL CANDIDATES FOR TESTING V2G FEASIBILITY.

TABLE 4: STAKEHOLDER VIEWS ON KEY ASPECTS OF VGI

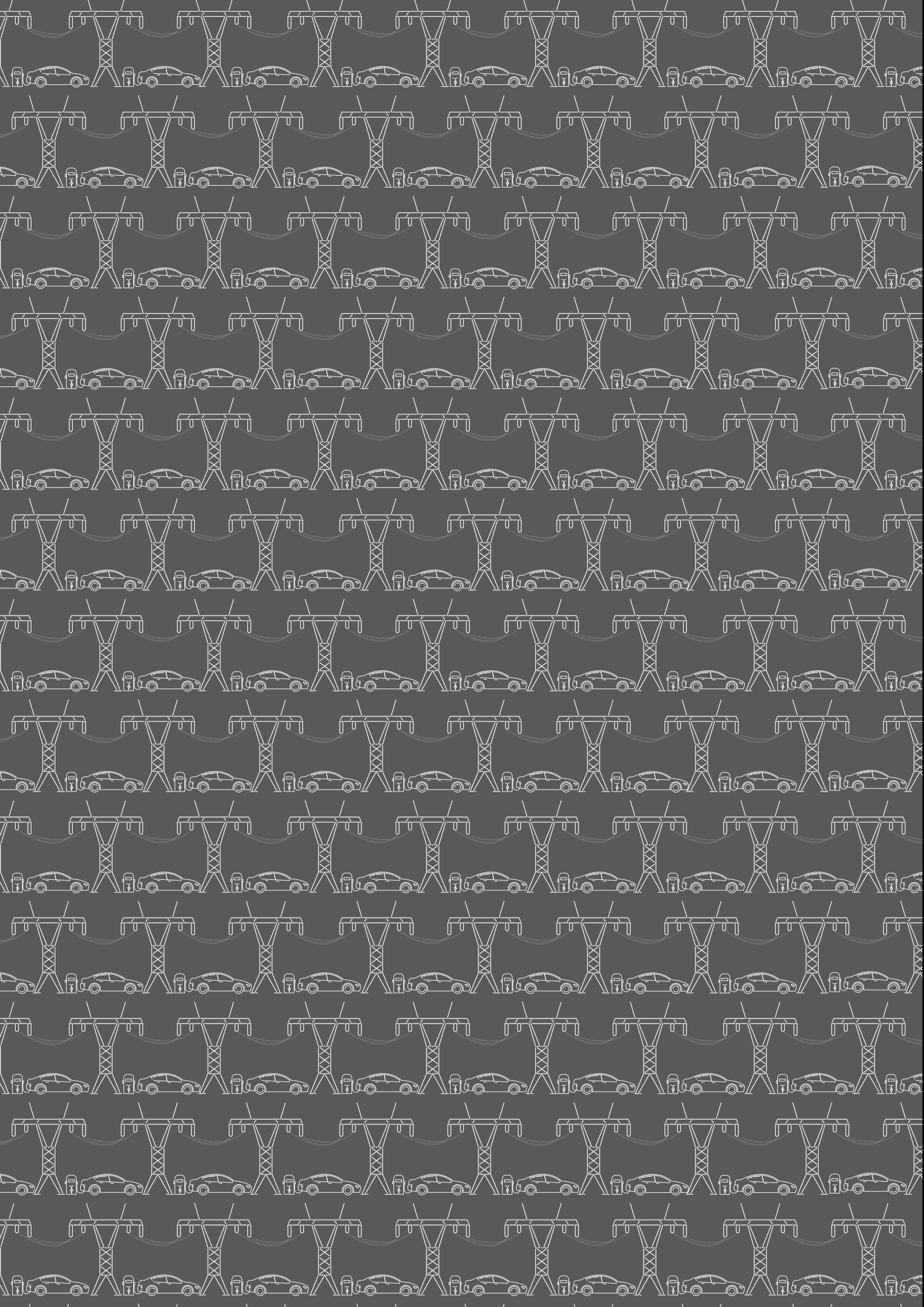
Key issue	Battery experts	R&D institutions	Charging service providers	Fleet operators	DISCOMs
Readiness for V1G	✓	✓ ✓	✓ ✓	✗	✓
Readiness for V2G		✗	✗	✗	✗
Technical feasibility of VGI	✓	✓ ✓	✓	✗	✓
Economic feasibility of VGI				✗	
Suitability of e-2Ws & e-3Ws for VGI		✗	✗	✗	✗
Suitability of e-4Ws & e-buses for VGI		✓ ✓	✓ ✓	✓ ✓	✓ ✓
Necessity of battery degradation research	✓ ✓	✓ ✓			✓ ✓
Profitability of VGI for fleet operators		✓	✓	✗	✓
Feasibility of VPP in India	✓	✓			

✓ ✓ Completely Agree

✓ Partially Agree

✗ Do Not Agree

Apart from the active involvement of key stakeholders in the implementation of VGI, another critical enabling factor in the Indian context is a conducive policy and regulatory environment, and this topic is explored in the following chapter.



The background of the slide is a dark gray color, overlaid with a repeating pattern of white line art. The pattern consists of stylized electrical transmission towers connected by horizontal lines, with small car icons positioned below each tower. This pattern is repeated across the entire slide, creating a grid-like effect.

6. Regulations for Vehicle-Grid Integration

Regulations are essential to ensuring the proper functioning of an economy. They underpin markets, protect the rights and safety of citizens, and ensure the delivery of public goods and services. Regulatory mechanisms exist in different forms depending on the purpose. It is paramount that appropriate regulations are brought in or reformed to enable the use and disallow misuse of new technologies or solutions like VGI. However, care should be taken to ensure that regulatory compliance does not become too burdensome or practically difficult in the applicable context. This chapter delves into the importance of regulations to VGI implementation and reviews the relevant existing power sector regulations in India.

6.1 Key regulatory instruments



A PREREQUISITE FOR VGI IMPLEMENTATION IS APPROPRIATE PRICE SIGNALS FOR ELECTRICITY.

A prerequisite for VGI implementation is appropriate price signals for electricity. Price signals to EV users are needed to shift EV charging to off-peak hours and coincide it with the availability of RE sources, thus enabling V1G and maximising its potential benefits. Furthermore, price signals can encourage EV users to participate in V2G programmes. The first and most simple step in providing appropriate price signals is implementing ToU electricity rates, in which the tariffs vary in a predetermined way throughout the day. In India, some form of ToU tariff is implemented by many states, with varying rates between peak and off-peak hours. This is referred to as a Time-of-Day (ToD) tariff. The rate differentiation may also vary by season or day. Typically, in such a pricing regime, tariffs are higher during peak demand periods and lower during off-peak periods. However, the tariff structure is typically designed to be revenue-neutral and generally reflects the marginal cost of electricity generation. Implementing a ToU tariff regime for EV charging is found to be cost-effective and does not require sophisticated metering technology. Smart meters installed at charging points are sufficient. Many markets around the world have benefitted from effective ToU tariff design for EV charging. Notable examples include ToU EV charging rates in California and Nevada in the US, tariffs offered by RWE and E.ON in Germany, and the off-peak discount for EV charging provided by Électricité de France (EDF) in France (Nelder, Newcomb, & Fitzgerald, 2016). Utilities in Japan, the United Kingdom (UK), and other countries have also successfully implemented such ToU rates for EV charging (Hall & Lutsey, 2017). In all the cases, ToU rates changed the charging patterns of EV users. Apart from utilities benefiting from the load management, EV users also realise savings from ToU rates. Estimates suggest that annual savings in the US due to time-varying electricity prices can range from USD 200 to 450 per EV user (Hall & Lutsey, 2017).

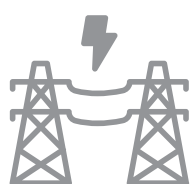
While ToU tariffs are useful in EV load management, they may become less effective as EV penetration in a given region increases. A key concern regarding ToU rates is that they may lead to creation of new peaks when the EVs start charging. More intelligent management of charging loads would be required in this case to avoid new peaks and reduce impacts on the local distribution network. Introducing real-time electricity pricing as an extension of ToU rates, in which the tariff can vary in smaller time-bands to more accurately reflect the real-time wholesale market prices and grid conditions, is considered an important regulatory mechanism for the future. Such dynamic pricing would help prevent secondary peaks due to ToU rates and synchronise EV charging with the availability of intermittent power from RE sources that otherwise might have been curtailed. Dynamic rates are yet to be sufficiently tested, and there is a lack of data to confirm their impact on EV charging. A key concern

with respect to real-time pricing is the complexity in its implementation. Customers may find it too complex to realise the benefits. Load aggregators can potentially play a crucial role in such situations, as they can offer more predictable price signals to customers while simultaneously unlocking the benefits of real-time electricity tariffs.

6.2 New approach required for regulatory framework

The importance of the regulatory framework is not limited to tariff-setting for EV charging. There are other key aspects surrounding VGI that need to be dealt with through appropriate regulations. Several of these aspects are highlighted below.

Defining EV as a resource



THE FUNDAMENTAL REGULATORY STEP TO ENABLING VGI IS RECOGNISING EV AS A GRID “RESOURCE”.

The fundamental regulatory step to enabling VGI is recognising EV as a grid “resource”. Existing regulations lack clarity regarding the application of EVs as a grid resource. Appropriate provisions are necessary in regulations to clearly define how EVs should be treated as a “resource,” since EV charging involves multiple elements: the vehicle with the battery, charging station, host facility (in case the charging station is part of a facility with a different purpose), and aggregator. This is particularly tricky, because each of these elements may be controlled by multiple entities. How an EV is defined as a resource would determine who would need to comply with the regulatory requirements and utility interconnection requirements, and this, in turn, would influence the business model for VGI implementation. The implications of the definition of “resource” would be varied and at different levels. For instance, if the vehicle, along with its battery, is recognised as the resource, metering has to be close to the charger (or inverter, if providing bidirectional energy). In such a case, the vehicle may need to have a meter to measure energy transactions. Furthermore, necessary regulatory provisions would be required to allow the “resource” to move around, and the vehicle has to be registered to the DISCOM. If the charging station is recognised as the “resource”, there would be fewer transactional complexities, since it would have a fixed location with specific metering. Another potential solution is to define the aggregator as the “resource”. Here, the resource would be “virtual” and could be geographically spread out. Necessary regulatory changes would be required to enable this, and a different metering approach would be needed to aggregate the transactions.

Resource aggregation

EV aggregation is essential in order to adequately respond to wholesale market signals. A small number of EVs⁶ at a given location is not sufficient to act as a grid resource. Depending on the applicable regulations, a grid resource has to be above a minimum threshold in terms of size (i.e. MW) to be eligible to participate in a wholesale market. Hence, it would be important to find out the minimum number and mix of EVs required to participate in the wholesale market. Since aggregation of EVs spread out over an area is the most plausible option, one has to check whether the applicable regulations permit aggregation of geographically-dispersed resources and, if so, what the permitted geographic spread is.

⁶ Only heavy duty EVs in small numbers can viably participate as a resource, due to their large battery sizes.



AGGREGATING EVs IS ESSENTIAL TO VGI, AND THE DISCOMS ARE AN IMPORTANT ACTOR IN THIS RESOURCE AGGREGATION.

Role of DISCOMs in resource aggregation

It is evident that aggregating EVs is essential to VGI, and the DISCOMs are an important actor in this resource aggregation. However, DISCOMs' role in this respect is fuzzy, and, hence, the applicable regulations have to provide clarity on this. As an aggregator, the DISCOM could help align distribution requirements with wholesale market participation, but this could create a monopoly in the market and limit business innovation in this space.

There are four potential aggregators models with different levels of DISCOM involvement: (i) DISCOM as the sole aggregator; (ii) DISCOM as meta-aggregator; (iii) competitive aggregation market without DISCOM participation; and (iv) a hybrid approach where both DISCOMs and non-regulated firms can serve as aggregators. In the first model, the DISCOM would be the sole entity responsible for EV aggregation (Figure 14). They would be responsible for enrolling customers and would also have control of EV charging or discharging. This would allow the DISCOM to have full knowledge of and control over how these resources are used, in order to most effectively manage the power system. However, for effective management, the DISCOM has to have detailed knowledge about EVs, customers' travel behaviours and preferences, etc., which is beyond its traditional scope. Moreover, this approach will create a market monopoly and may limit opportunities to innovate with new business models. Furthermore, the DISCOM may not have enough incentive to offer customers sufficient benefits in such a programme.

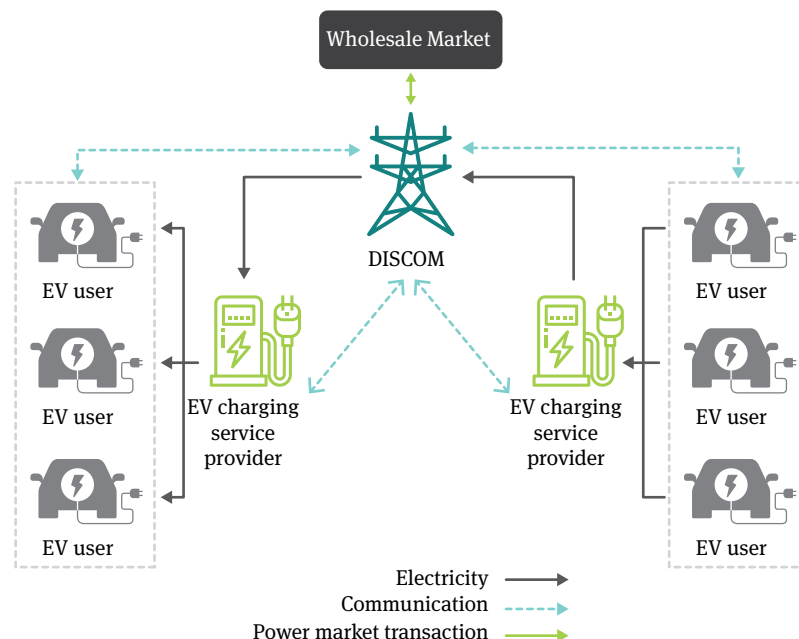


FIGURE 14: DISCOM AS THE SOLE AGGREGATOR

When the DISCOM acts as the meta-aggregator, a non-DISCOM third party aggregator serves as the intermediary between the customer and the DISCOM (Figure 15). In this case, the DISCOM has no direct interaction with the customer, and the aggregator(s) has no direct involvement in the wholesale market. A key limitation in this model is that by only allowing DISCOMs to represent the EV load on the wholesale market, this may reduce competition in the wholesale market. In addition, the aggregator(s) would be at the mercy of the DISCOM in terms of compensation. Regulatory oversight would also be required to make sure that aggregators are properly compensated and that their resources are efficiently used.

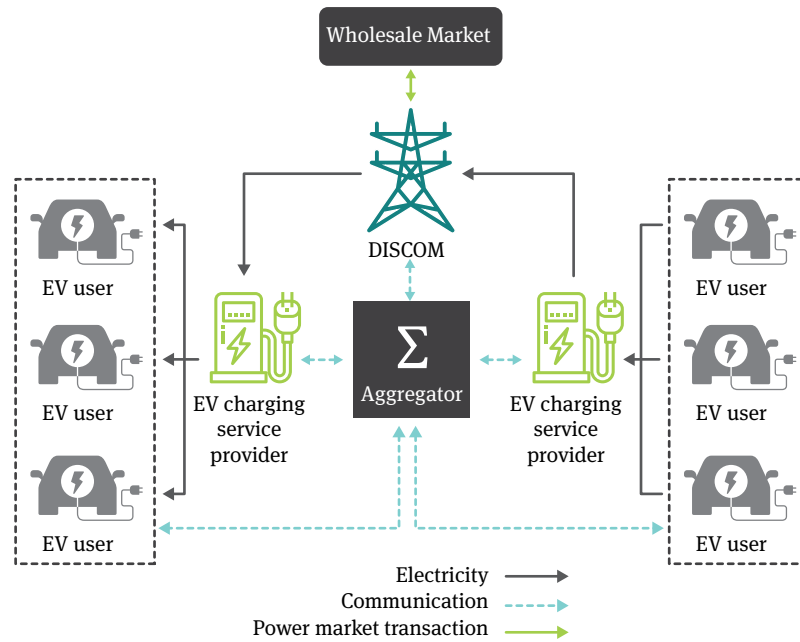


FIGURE 15: DISCOM AS META-AGGREGATOR

In the case of a competitive aggregation market without DISCOM participation, non-DISCOM aggregators are solely responsible for aggregating EVs to provide services to both the wholesale and ancillary service markets and to the DISCOM for distribution system benefits (Figure 16). In order for aggregators to provide services to the DISCOM, the DISCOM needs to develop price signals that reflect the costs and benefits of EV charging and grid services. A means to communicate these price signals to aggregators and customers is also required. Furthermore, realising DISCOM benefits and allowing third-party wholesale access to the EV resource would require regulations that allow these two functions to co-exist.

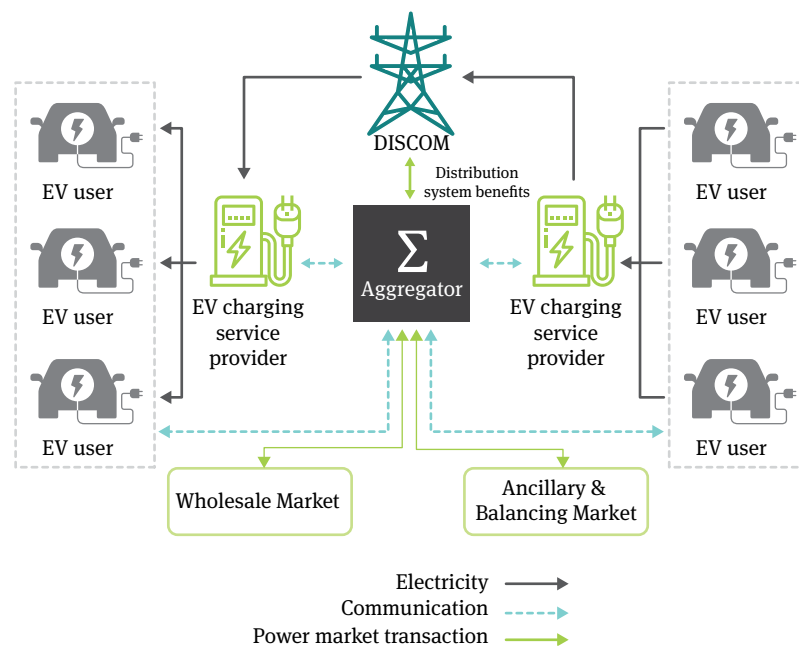


FIGURE 16: COMPETITIVE AGGREGATION MARKET WITHOUT DISCOM PARTICIPATION

The fourth model, i.e. a hybrid market approach, allows DISCOMs and third-party aggregators to compete for customers, rather than limiting the

involvement of DISCOMs and other actors (Figure 17). In such a scenario, a regulatory framework would be necessary to enable all these entities to compete on a level playing field and maximise opportunities to reap both wholesale and distribution benefits.

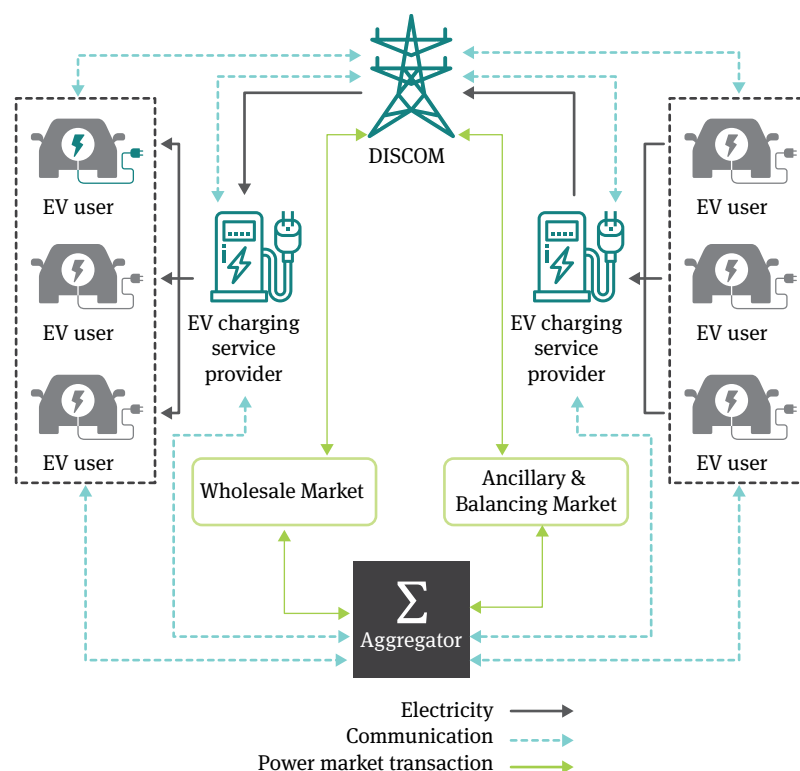


FIGURE 17: HYBRID APPROACH

Unlocking distribution benefits from VGI

Apart from the wholesale market, the distribution system can potentially benefit from VGI. This also benefits electricity consumers, due to a reduction of infrastructure costs. In order to realise the benefits, the regulator may need to create an incentive system that, on one hand, would encourage DISCOMs to consider the value of VGI in their planning and operations, and, on the other hand, would motivate customers to provide services to the distribution system while accessing the wholesale market. When developing the incentive mechanism, one should consider the existing interconnection rules and keep in mind the fact that mobility services are the primary use of EVs. In addition, the regulations should protect the rights of customers – they should be given the ability to override DISCOM signals when participating in such programmes, in which case they would have to forgo any monetary benefit they would have otherwise received from the DISCOM. In any case, an incentive system for VGI would have to be harmonised with the chosen aggregator model.

Competition among different grid services markets

EVs can offer grid services to three main systems – the facility (e.g. through Vehicle-to-Home (V2H)), distribution system, or bulk power system (wholesale market). The preferences or requirements of these three systems may conflict at any given time. For example, a situation may occur where the wholesale market experiences an imbalance and requires additional load, and, thus, sends a signal to the ancillary service market participants to draw more

electricity. However, certain distribution feeders may be facing overloading at the same time and could send a signal to the same EV owners participating in the V2G programme to stop consuming electricity. In absence of coordination, participants in a VGI programme could receive conflicting signals from the DISCOM and the wholesale market, with the wholesale market encouraging additional load and the DISCOM discouraging it. It is unclear how the resource would respond to these competing requests. Necessary rules need to be established to reconcile such competing needs.

Safety

The regulator should ensure that EVs operate in accordance with all applicable safety and electrical standards when operating in the V2G mode. To this end, the regulator has to work with other departments to ensure that codes and standards for equipment and facilities maintain the safety of customers and DISCOM operations.

Interconnection requirements

This is especially important for the application of EVs in grid storage. Based on the implementation model, the regulator and utility have to determine what interconnection requirements would be necessary for EV storage resources. Due to bidirectional energy flow in the case of V2G, the interconnection requirements are different from those of resources with unidirectional energy flow. Net metering rules may be used to simplify these requirements.

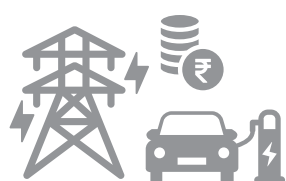
Communication standards

VGI involves two types of communication functions: receiving wholesale market signals for the resource and sending meter performance data to the wholesale market. A communication standard is essential to sending messages between the aggregator (either the DISCOM or non-DISCOM third party) and the wholesale market. Standards will also likely be required for downstream communication to ensure that each element of the VGI programme is equipped to respond to the message. Such downstream communication can use existing smart grid communication standards, such as OpenADR or SEP 2.0, or new standards, including ISO 15118.

Understanding these regulatory aspects is crucial to developing the necessary regulations or reforms in a market to enable VGI implementation. However, contextualising these regulatory requirements in the local regulatory ecosystem is also critical; otherwise, identifying and addressing the regulatory gaps would be a serious challenge. The following section covers the regulatory landscape in the e-mobility sector in India.

6.3 Indian regulatory landscape

The e-mobility market in India is still in its infancy. Guidelines are being introduced, and technical, safety, and performance standards and protocols being developed, for charging infrastructure. However, VGI is yet to prominently feature in the Indian policy and regulatory discourse around EVs. Consequently, there is a lack of specific VGI regulations. To initiate the discussion on VGI and the required regulations, it is important to identify the existing policy, legislative, and regulatory provisions that can be effectively leveraged to create the building blocks for VGI implementation. These key provisions are described below.



VGI INVOLVES TWO TYPES OF COMMUNICATION FUNCTIONS: RECEIVING WHOLESALE MARKET SIGNALS FOR THE RESOURCE AND SENDING METER PERFORMANCE DATA TO THE WHOLESALE MARKET.

Tariff design in India

As consumer tariffs are a key regulatory tool for VGI implementation, it is important to understand the current tariff system in the context of VGI. Typically, the consumer tariff comprises two parts – fixed/ demand charge and variable/ energy charge. As tariff-setting in India is a state subject, i.e. the State Electricity Regulatory Commission (SERC) in each state is responsible for determining tariffs for different consumer categories, the charges vary from state to state. However, the National Tariff Policy remains the overarching guidance for the SERCs on tariff-setting.

As far as tariffs for EV charging are concerned, the electricity regulators of 18 states and 5 UTs have stipulated specific rates in their respective tariff orders through November 11, 2019. However, treatment of EVs as a consumer category and the corresponding rate design vary across states. Some states have introduced a separate category called Public EV Charging Stations (such as UTs, Goa, etc.), which is distinct from existing consumer categories, whereas other states (e.g. Andhra Pradesh, Chhattisgarh, and Punjab) have specified EV tariffs under the existing categories, such as non-domestic or non-commercial. Jharkhand is the only state that has introduced an EV tariff under the commercial category. A few states, including Andhra Pradesh, Delhi, Gujarat, Maharashtra, and Uttar Pradesh, have also specified tariffs for EV charging stations by type of connection (High-Tension (HT)/ Low-Tension (LT)). Such EV categorisation could have an impact on the conceptualisation of VGI programmes; in the absence of EV-specific tariffs, designing a VGI programme would be challenging.

What about ToU tariffs for EV charging? The study has found that there are only three states (Uttar Pradesh, Kerala, and Maharashtra) that have introduced ToD rates specifically for EV charging. In the case of Delhi, ToD rates are applicable to consumers with a load above 10 kilowatts (kW)/ kilo-volt-ampere (kVA), including EV users. Similarly, ToD rates are applicable by default for EV consumers with HT connections in the case of Chhattisgarh and Telangana. The existing ToU/ ToD rates can be leveraged to implement VGI programmes in these states. However, as highlighted above, static ToU rates have inherent limitations in achieving load flattening. Hence, the introduction of real-time tariffs is required. In India, there is currently no precedent for application of real-time electricity tariffs.

Electricity tariffs are an important regulatory instrument that can facilitate VGI implementation. ToU tariffs for EV charging, which is the first regulatory step needed to implement VGI, exist in a few states. Other states should adopt ToU tariffs tailor-made for EV charging. Going forward, the regulators in states with high EV penetration should engage with DISCOMs, charging service providers, EV users, and other stakeholders to initiate discussions on dynamic tariffs for EV charging and test such rates at a pilot level. Based on the experience from the pilots, these states can plan large-scale rollout of dynamic tariffs for EV charging, in order to realise the benefits of VGI.

Does national tariff policy have the potential to show the direction for rolling out dynamic rates in the near future? The National Tariff Policy 2016 only mentions that tariffs need to progressively reflect the Cost of Supply of electricity and should be within $\pm 20\%$ of the Actual Cost of Supply (Ministry of Power, 2016). Nevertheless, the existing tariff policy recognises the importance of deploying smart meters and implementation of peak and off-peak tariffs and demand side management through DR for load-generation



TREATMENT OF EVS AS A CONSUMER CATEGORY AND THE CORRESPONDING RATE DESIGN VARY ACROSS STATES.

balancing. Therefore, as a baby step, the concept of dynamic rates needs to be introduced in the applicable tariff policy.

In addition to tariffs, it is critical to examine the current regulations, standards, and guidelines that govern or support the goals/ mechanisms of V1G and V2G. As a point of departure, the current Indian regulatory framework supporting Demand Side Management (DSM) interventions should be examined, since the same framework can be used to facilitate VGI implementation. These DSM regulations are described below.

DSM Regulations

DISCOM-driven DSM is increasingly recognised as an effective way to exploit demand side energy efficiency potential in India. In this regard, the Forum of Regulators (FoR), tasked with harmonising state regulations, came out with the 'Model DSM Regulations' in May 2010, which state regulators generally follow when designing state-level DSM regulations (Sarkar, et al., 2016). Broadly, the DSM Regulations cover aspects such as the implementation framework and cost recovery mechanism, while also outlining the roles envisaged for the DISCOMs and state regulators in implementing DSM programmes. These regulations ideally should include provisions that support different DSM interventions, e.g. VGI. Table 5 summarises the key aspects covered in the Model DSM Regulations (Forum of Regulators, 2010) that are important for VGI implementation.

TABLE 5: KEY PROVISIONS IN MODEL DSM REGULATIONS FOR VGI

Provision in Model DSM Regulations	Significance for VGI
DISCOMs to carry out assessment of potential for DSM in the state	In this exercise, the DISCOM should consider the load management potential from application of EVs as a grid resource when assessing this potential.
Regulatory Commission to set DSM targets for each DISCOM in the state. The targets could be in the form of: <ul style="list-style-type: none"> Percentage reductions in load growth Savings in kW/ kWh Savings as a percentage of total resources to meet load 	This could motivate DISCOMs to explore all kinds of opportunities to meet the targets, including new, promising ones like VGI.
DISCOM to undertake load research to identify the target consumer segment/s and end uses for DSM programmes	This could enable the DISCOM to understand the DSM potential from VGI implementation.
DISCOM to provide a detailed description for each DSM programme, including details on technology, schedule for deployment, budget, cost effectiveness assessment, detailed implementation plan, estimation of savings, etc.	Such a study would help the DISCOM and regulator make an informed decision regarding the opportunity to unlock benefits from VGI.
Commission can direct DISCOM to undertake DSM programmes that may not be cost-effective but are highly beneficial to society.	V2G, in particular, may not be cost-effective during the early stages of implementation, until it reaches a certain scale. The existing provision allows the regulator to still promote such innovative programmes, which have multiple benefits to society and significant future potential.

Some SERCs have taken further steps to realise the full potential of DSM in their states. For example, Delhi Electricity Regulatory Commission and Maharashtra Electricity Regulatory Commission have clearly mentioned in their “DSM Guiding Principles” that DISCOMs should implement programmes that help reduce peak demand, including DR initiatives, which entail consumers agreeing to modulate their load profiles through a contract with the licensee. This provision can be leveraged to execute VGI. However, the Model DSM Regulations, as well as the state-level regulations, are still silent on the subject of possible involvement of “aggregators” in implementing VGI programmes.

The fact that DSM Regulations exist in many states in India is a positive thing. Other states should also notify DSM regulations. The provisions in these regulations can be used to design and implement VGI in the country. Some state regulations have advocated demand response initiatives, which provide the foundation for executing V1G, in particular. However, the regulations have neither introduced the concept of “resource aggregation” nor defined the role of an “aggregator”. This is a major gap that could make it difficult to scale up VGI implementation and also limit adoption of innovative business models.

In the case of V2G, the provisions in the DSM regulations are not sufficient, because DSM is only concerned with energy consumption or power demand, whereas V2G is also related to provision of electricity supply. Because of the bidirectionality in energy flow in V2G, the study investigated the Indian regulatory framework dealing with prosumers⁷.

Key regulations for prosumers

Electricity generation from rooftop solar systems is a major focus area of India’s climate action. To promote rooftop solar systems, most state policies have traditionally advocated “net metering” for these prosumers. Consequently, the SERCs have introduced necessary regulations for net metering. In net metering, electricity produced is deducted from the total electricity consumed over a fixed period of time, which lowers the prosumer’s electricity bill. The prosumer either pays for the difference in units or gets paid by the DISCOM for extra units at the end of the billing cycle (based on the individual state policy). In this way, a bidirectional net meter typically accounts for both the import and export of electricity. It does not record the total amount of energy generated by the solar system on the premises. Figure 18 presents a schematic of the net metering arrangement commonly seen in India.

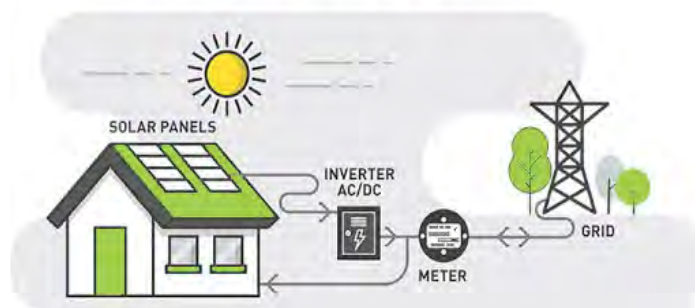


FIGURE 18: NET METERING ARRANGEMENT FOR ROOFTOP SOLAR SYSTEM

Picture courtesy: proteus

⁷ According to Central Electricity Authority regulations, “prosumer” means an agent, including energy storage systems, that consumes electricity from the grid and can also inject electricity into the grid, using the same point of connection.

As a greater number of consumers are turning into prosumers, DISCOMs often discourage net metering because of potential revenue loss, as the prosumers are compensated at the same tariffs they are charged for consumption. As an alternative, DISCOMs prefer “gross metering”, where a prosumer is compensated at a fixed feed-in tariff (FiT) for the total electricity generated and exported to the grid, which is recorded by a unidirectional “gross meter”. For the amount of electricity consumed and drawn from the grid, the prosumer has to pay the DISCOM at the retail supply tariff. In the gross metering arrangement, the FiT and retail supply tariff can be fixed at different levels, which enables DISCOMs to set FiTs lower than retail supply tariffs, to reduce their revenue loss. Figure 19 shows a typical gross metering arrangement for a solar rooftop system.

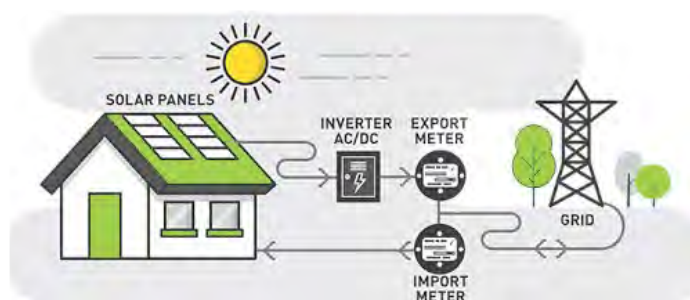


FIGURE 19: GROSS METERING ARRANGEMENT FOR ROOFTOP SOLAR SYSTEM

Picture courtesy: proteus



BOTH NET AND GROSS METERING REGULATIONS ARE IMPORTANT FOR THE IMPLEMENTATION OF V2G PROGRAMMES.

Following the issuance of the Model Net Metering Regulation 2013, various states notified their Net Metering Regulations, with modifications/additions to the national regulation. A few states are inching towards gross metering. States like Andhra Pradesh and Telangana have adopted both gross metering and net metering schemes.

Both net and gross metering regulations are important for the implementation of V2G programmes. The provisions of these regulations cover a range of issues, such as applicability (allowing all consumers to participate), metering principles, system capacity, applicable charges (wheeling charges, cross-subsidy surcharge, and banking charges are exempted), communication capability (Meter Reading Instrument (MRI) compatible; a few states have chosen Advanced Metering Infrastructure (AMI) compatible net meters), applicable FiTs, Power Purchase Agreement (PPA) rate or Average Power Purchase Cost (APPC)), settlement period (commonly 1 year), and safety (consumer responsibility and provisions for auto-shutdown of solar power plants when grid supply fails) (Forum of Regulators, 2019).

Most of these regulations can support VPPs. However, the scope has to be expanded to recognise VPPs, as, currently, the regulations are made primarily to allow small grid-connected RE set-ups like rooftop solar PV. For example, the Model Net Metering Regulation puts a cap of 1 MW on the system capacity, whereas state regulations allow capacity up to 40–100% of the sanctioned load. Furthermore, the regulations put a limit on Distribution Transformer (DT) loading to avoid any reverse electricity flow, as the distribution system (below 33 (kilovolts (kV)) is designed for unidirectional power flow. According to the Model Regulation, the cumulative capacity of grid-connected rooftop solar PV systems on a particular DT should be restricted to 15% of peak capacity. Some states have relaxed this rule and

increased it up to 75% of the peak capacity or rated capacity of the DT. In a scenario where the state regulations recognise VPPs, these rules may remain, and VPP developers would have to take these into account when evaluating the business viability and planning the implementation.

The current Net Metering Regulations (or Gross Metering Regulations) can set the basic framework for V2G implementation in the country. However, these regulations are designed for implementing grid-connected rooftop solar PV systems, and, hence, necessary amendments have to be incorporated to expand the scope to recognise the VPP concept. Regulations on applicable rates for electricity export, settlement period, limit on system capacity, communication capability, etc. would affect the design of VPP projects and thus be important for VPP developers.

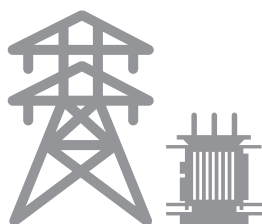
While regulations on prosumers pave the path to implement VPPs, the ability of the grid to interact with consumers, including prosumers, is crucial to realising the benefits of V1G and V2G. In this context, smart grids are considered an important infrastructural requirement for VGI implementation. Hence, understanding the smart grid regulations in India is required, to get a sense of how the regulations can support VGI application in the country.

Smart grid regulations

FoR developed the Model Smart Grid Regulations in 2015 for adoption at the state level. The objectives of these regulations are “*to enable integration of various smart grid technologies and measures to bring about economy, efficiency improvement in generation, transmission and distribution licensee operations, manage the transmission and distribution networks effectively, enhance network security, integrate renewable and clean energy into the grid and microgrids*” (Forum of Regulators, 2015). More specifically, the goal is to enhance network visibility and access, promote optimal asset utilisation, and improve consumer service levels, thereby improving the operations of transmission and distribution licensees through better technology adoption across the value chain in the electricity sector, particularly in the transmission and distribution segments.

The Model Regulations also list indicative components of smart grid projects: AMI, DR, Microgrids, Supervisory Control and Data Acquisition (SCADA) for Distribution/Distribution Management, Distributed Generation, Peak Load Management, Outage Management, Asset Management, Wide Area Measurement Systems, Energy Storage Projects, Grid Integration of Renewables, EVs, including Grid to Vehicle (G2V) and V2G Interactions, Smart Grid Data Collection and Analysis, and Tariff Mechanisms—interruptible and dynamic tariffs, ToU, critical peak pricing, RTP, etc. It is evident that smart grid regulations take into consideration multiple aspects of V1G and V2G and could play an important role in facilitating VGI in India.

States should adopt smart grid regulations with the provisions delineated in the Model Smart Grid Regulations developed by FoR. The Model Regulations recognise V1G and V2G as important elements of a smart grid project and also cover the supporting elements of VGI, such as AMI, DR, dynamic tariffs, ToU tariffs, critical peak pricing, real-time pricing, etc. From the regulatory point of view, the Smart Grid Regulations can effectively enable VGI implementation in India.



**SMART GRIDS ARE
CONSIDERED
AN IMPORTANT
INFRASTRUCTURAL
REQUIREMENT FOR
VGI IMPLEMENTATION.**

Other regulatory initiatives indirectly supporting VGI

In addition to the regulations highlighted in the previous section, there are other important initiatives in India that can indirectly support VGI implementation. Table 6 captures these key regulatory actions.

TABLE 6: OTHER REGULATORY INITIATIVES TO SUPPORT VGI

Regulatory action	Type	Developer	Issue date	Description	Relevance
Introduction of Five-Minute Scheduling, Metering, Accounting and Settlement in Indian Electricity Market	Report	Forum of Regulators	2018	Sets a target date of April 1, 2020 for migration to 5-minute scheduling, metering, accounting, and settlement	The report asserts that with the “ <i>advent of new technologies and fast responding resources i.e. Storage, Demand Response, Electric Vehicles, there is need for faster despatch to incentivise the participation of distributed resources, aggregators and neighbouring markets best able to contribute to system needs</i> ”.
Re-designing Real Time Electricity Markets in India	Discussion Paper	Central Electricity Regulatory Commission (CERC)	2018	Focuses on real-time pricing to introduce a demarcation between ‘energy trade’ and ‘system imbalance’ management	The discussion paper states that although “ <i>novel uses of electricity (e.g. for electric vehicles, battery charging) can also increase demand uncertainty, on the brighter side, distributed energy resources and novel uses of electricity may also lead to greater demand-side flexibility in some power systems, which can mitigate some of the challenges associated with renewable integration</i> ”.
Re-designing Ancillary Services Mechanism in India	Discussion Paper	CERC	2018	Focuses on designing a reserve market that can bid at the regional and national levels	<p>The discussion paper makes an important observation that “<i>while thermal generators, which are currently utilised for providing ancillary support, are typically classified as Ramp-Limited Resources (RLRs), Batteries, Plug-in Hybrid Electric Vehicles and hydro generators may be classified as Energy-Limited Resources (ELRs)</i>”.</p> <p><i>Ramp-Limited Resources can provide energy and sustain output, but take time to ramp up and ramp down. Energy-Limited Resources can match control signals at sub-second time levels, but cannot sustain energy output, which depends on the state of the charge and storage capacity</i>”.</p>

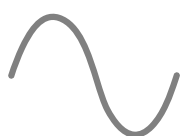
Regulatory action	Type	Developer	Issue date	Description	Relevance
Deviation Settlement Mechanism and related matters 2013	Draft Regulation	CERC	2019 (amended)	Aims to enforce accurate renewable energy generation, forecasting, and scheduling by levying penalties on RE generators for deviating from the scheduled generation	The Deviation Settlement Mechanism is expected to bring discipline into electricity despatch from intermittent energy sources and, in turn, encourage DISCOMs to benefit from EVs as a resource.
Central Electricity Authority (Technical Standards for Connectivity of the Distributed Generation Resources) Amendment Regulations, 2019	Regulation (amendment)	Central Electricity Authority	February 6, 2019	Expands the scope to include EV charging station and energy storage system	This is an important regulatory step, paving the way for application of EVs as one of the Distributed Generation Resources connected to the grid.
Central Electricity Authority (Measures relating to Safety and Electric Supply) (Amendment) Regulations, 2019	Regulation (amendment)	Central Electricity Authority	June 28, 2019	Includes safety provisions for EV charging stations	Safety is a major concern in VGI. Hence, this amendment is an important regulatory action. Although it only covers AC and DC charging stations, the provisions can be used to implement V1G. Further amendments would be required to cover safety provisions for V2G.

6.4 Gaps in regulatory framework and power market

While there are several regulatory provisions in India that are supportive of VGI or its different elements, directly or indirectly, and, if needed, they can be amended to effectively address gaps or ambiguity, there are certain major gaps in the existing regulatory framework that warrant attention and necessary action. A key gap is the lack of a provision for third party aggregators to participate in “resource aggregation”. As mentioned above, recognition of EVs as a grid resource is not sufficient to realise the full benefits of VGI. Aggregation of a suitable mix of EVs is required to enable them to participate in the wholesale or ancillary service market. Hence, applicable regulations should enable aggregation of geographically-dispersed resources and clarify what the permitted geographic spread is.

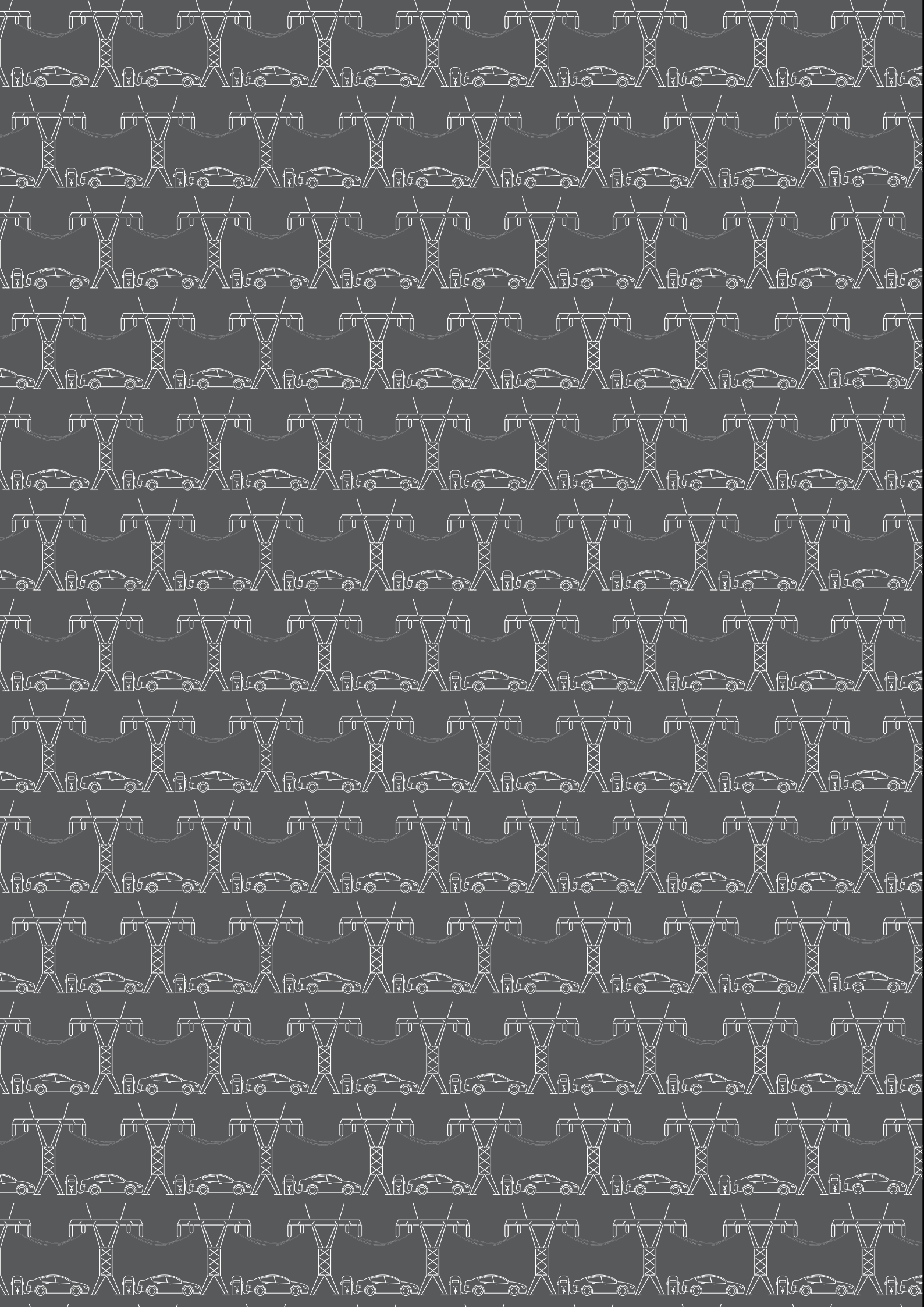
Existing Indian regulations lack provisions that permit “aggregation” of distributed energy resources in general, including EVs, to provide grid services. Consequently, the different principles or implementation models for resource aggregation are currently not covered in the regulations, which is a major barrier to VGI implementation in India. A potential solution would be for

FoR to develop a model regulation on resource aggregation, which states can subsequently adopt (with possible amendments, if required). FoR has already prepared the “Draft Model Regulation for Grid Interactive Distributed Renewable Energy Sources,” which can be potentially adapted to include provisions on resource aggregation and its different implementation models. The model regulation on distributed RE, in defining the role of DISCOMs, mentions that DISCOMs “*may undertake demand aggregation and other related activities to effectively deploy [distributed renewable energy] in its area of supply*”. The main concern is that it does not recognise the role of a non-DISCOM entity in carrying out demand aggregation. As a first step, it is recommended that the regulators incorporate necessary amendments into current regulations (e.g. State DSM Regulations) to allow non-DISCOM third party aggregators to participate in grid service provision.



**SIGNIFICANT
CHALLENGE TO
IMPLEMENTING VGI IN
INDIA IS THE LACK OF
AN ANCILLARY SERVICE
MARKET IN THE
COUNTRY.**

Another significant challenge to implementing VGI in India is the lack of an ancillary service market in the country. Ancillary services are an indispensable part of the power system operations, required for improving and enhancing the reliability of the power system. These services may include a number of different operations, such as frequency support, voltage support, and system restoration. EVs can effectively provide such ancillary services if there are appropriate regulations to enable market mechanisms allowing EVs to participate. Pilot projects have already shown that with aggregation and fast demand response, EVs can be an effective resource for frequency response services. Unfortunately, India’s electricity sector does not yet have a market for ancillary services such as Fast Tertiary Control, Secondary Frequency Control, Voltage Control, and Black-Start. Only slow tertiary reserves (with response times between 15 to 60 minutes) are currently used. In the absence of an ancillary service market, the full benefits of VGI cannot be tapped.





7. Conclusions and the Way Forward

EVs have the potential to become either a friend or foe of the power system in India. On one hand, they can cause serious problems in terms of electricity supply and grid management, by increasing the peak load in a distribution area and negatively impacting the stability of the distribution network (in the form of voltage instability, degradation of reliability indices, harmonic distortion, etc.). On the other hand, DISCOMs can greatly benefit from EVs, as they can potentially be an effective source of flexibility and a useful asset for energy storage in the power system. Can the potential negative impacts of EV charging be mitigated and EVs used as a grid resource in VGI? This chapter answers these questions and highlights the key takeaways from the study.



DEPENDING ON THE SCALE OF AGGREGATION, EVs CAN DELIVER SERVICES AT DIFFERENT LEVELS OF THE ELECTRICITY SYSTEM, FROM BULK POWER MARKETS TO LOCAL DISTRIBUTION SYSTEMS.

Different VGI use cases

Integration of EVs with the power system can be done at different levels; at each level, there are different value propositions and complexities. The greater the potential value of grid services from EVs, the more complexity there is, which needs to be dealt with in order to tap the benefit. There are three main levels of VGI – Smart Charging (V1G), Aggregated Smart Charging, and Large-Scale Bidirectional Charging (V2G). Depending on the scale of aggregation, EVs can deliver services at different levels of the electricity system, from bulk power markets to local distribution systems. Aggregated smart charging can offer system services such as demand response, voltage regulation, and other ancillary services and help avoid the need for investment in capacity addition. Services from less aggregated smart charging are usually at the distribution network level, and the benefits could be operational savings and avoiding or delaying the need for investment in local network capacity expansion. In contrast, large-scale V2G can provide flexibility services to DISCOMs to a much greater extent than any form of V1G. Both DISCOMs and EV owners can realise substantial financial benefits from V2G.

V2G – revolutionary, but feasible in India?

By dynamically controlling EV charging and enabling the EV batteries to feed electricity back into the grid, V2G technology allows EVs to provide flexibility and additional capacity at the power system and distribution levels. It is anticipated that the need for such flexibility in the power system will rise in the future, due to an increase in the penetration of intermittent RE sources such as wind and solar. Hence, enabled by V2G technology, EVs can help shape the future load curve to match RE supply and provide frequency regulation services to improve grid security and stability. In spite of such benefits, V2G is yet to see commercial adoption beyond a few small pilot projects, even in advanced EV markets. The reason for this is that there are several significant technical and practical challenges to implementing V2G at scale, especially in India, which are highlighted below.

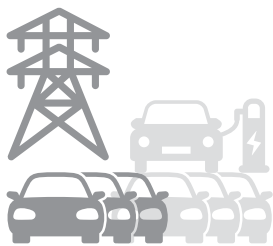


THERE ARE SEVERAL SIGNIFICANT TECHNICAL AND PRACTICAL CHALLENGES TO IMPLEMENTING V2G AT SCALE, ESPECIALLY IN INDIA.

- **Lack of hardware for V2G:** Currently, there is a limited number of EVs on the global market that are capable of providing bidirectional energy flow between EVs and charging points. None of these models is currently available on the Indian market. Moreover, globally, there are few V2G-ready EVSEs. Lack of availability of the necessary hardware can be attributed to the absence of a market for these solutions – a classic chicken-and-egg issue. Furthermore, OEMs have concerns about the impact of V2G on battery health, and, hence, they de-recognise the warranty on the EV battery if it is used for purposes other than mobility. In summary, the key components for V2G implementation are not

commercially available and are largely in different stages of development. Hence, it may take several years to indigenously develop V2G-capable EVs and EVSEs in India and create sufficient market demand for such products. In addition, these EVs and EVSEs would be more expensive than the standard models, and it is unclear whether India's price-sensitive market would be open to adopting these technologies in near future.

- **Aggregation challenge:** Achieving scale is crucial to commercially implementing a V2G programme, and EV aggregation is key to achieving that. There are major barriers to achieving this required aggregation. Vehicles are highly distributed and mobile assets by default, and to use them as a grid resource, one would require advanced communication and control infrastructure, which is still at an early stage of development. Furthermore, the concept of “resource aggregation” and the role of “aggregators” are largely non-existent in India's electricity market and regulatory framework. Moreover, lack of a proven business case for V2G, even in advanced markets, does not make a strong argument for it.
- **Unfavourable regulatory ecosystem:** Regulatory frameworks in the mobility and power sectors are not currently adequate for V2G implementation. While the EV regulations need to allow commercial use of EVs for grid services, the electricity regulatory framework has to recognise mobile distributed energy resources. Moreover, the ancillary service market is largely absent in India. In addition to the limited market size for such services, another challenge is that the DISCOMs primarily opt for these services to bridge supply gaps during peak hours, which defeats the very purpose of ancillary services. Until an efficient ancillary service market emerges in India, leveraging V2G benefits will remain a distant possibility, which, in turn, hurts the business viability of V2G.
- **Low-capacity EV batteries:** Although the EV market in India is still nascent, the path it is taking is quite different from that of advanced EV markets around the world. Unlike in the developed markets, light EVs (e-2Ws and e-3Ws) are gaining more traction than e-4Ws in India⁸. In the future as well, light EVs are expected to dominate the market. Furthermore, the average battery size of e-4W models in India is much lower than those available in developed markets⁹. This could have a major impact on V2G implementation. Since the scale of the aggregated EV batteries is critical to making V2G a viable business case, EVs with large battery sizes are desired. This means that, due to the lower battery sizes in India, a greater number of EVs will need to be aggregated to participate in V2G, which makes implementation more challenging, both logistically and financially.



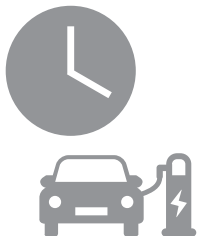
DUE TO THE LOWER BATTERY SIZES IN INDIA, A GREATER NUMBER OF EVS WILL NEED TO BE AGGREGATED TO PARTICIPATE IN V2G, WHICH MAKES IMPLEMENTATION MORE CHALLENGING, BOTH LOGISTICALLY AND FINANCIALLY.

Heavy-duty vehicles with large battery sizes should be targeted for V2G. Electric buses used in public transport particularly could be a suitable candidate for implementation of V2G. Apart from having large batteries, these vehicles are used following a specific time-schedule and are often parked at the depots for a duration sufficient to take part in VGI.

For example, a bus garage in London is set to become a “virtual power station” where 100 newly inducted electric buses will be employed for V2G application in a project called Bus2Grid. It is believed to be the world's largest V2G trial site.

⁸ Out of the total sales of 1.56 lakh EVs (excluding e-rickshaws) in FY 2019–20, 1.52 lakh units were reportedly e-2Ws, 3400 e-4Ws, and 600 e-buses.

⁹ Popular electric car models in India have battery sizes of about 21 kWh, whereas best-selling electric cars in advanced EV markets have battery sizes above 40 kWh (base models of Tesla Model 3 and Nissan Leaf have battery sizes of 50 kWh and 40 kWh, respectively).



PILOT PROJECTS HAVE DEMONSTRATED THAT V1G IS EFFECTIVE IN SHIFTING A SUBSTANTIAL SHARE OF THE EV CHARGING LOAD TO OFF-PEAK TIMES, WHILE STILL SATISFYING EV CUSTOMERS' CHARGING NEEDS.

In addition to the abovementioned constraints, there are other factors that can impact commercial deployment of V2G in any country—potential energy loss due to the DC–AC conversion during discharging¹⁰, EV users' willingness to discharge their batteries as and when required, financially struggling utilities, etc. Based on the findings, one can infer that, with V2G yet to evolve from a concept into a commercial project in advanced markets, it may only remain a topic of academic interest in India for the foreseeable future. To make V2G a reality in the country in the future, not only does India's EV market have to evolve, but its power sector also needs to undergo a major transformation.

Is V1G the low hanging fruit?

Pilot projects have demonstrated that V1G is effective in shifting a substantial share of the EV charging load to off-peak times, while still satisfying EV customers' charging needs. Furthermore, V1G can be leveraged to achieve higher RE uptake, by synchronising vehicle charging with grid-connected RE power generation. Hence, V1G can offer system-wide benefits, from DR and voltage regulation at the bulk system level, to avoiding or delaying the need for system upgrades and capacity expansion at the distribution level. The hallmark of smart charging is that its implementation is neither contingent on complex and expensive new EV or charging technologies nor requires significant regulatory and market reforms. Appropriate price signals are the most important tool needed to implement V1G. To apply the time varying rates, both static and dynamic, only simple metering technology is required; smart meters installed at charging points are sufficient for this purpose. Furthermore, unlike V2G-enabled bidirectional chargers, smart chargers have been commercialised in advanced markets and are becoming a mainstream solution. Such smart chargers are also available on the Indian market, albeit to a lesser extent, and many of the existing installed chargers already have smart features, of varying degree. Hence, V1G can be achieved in India without waiting for new charging technology to emerge.

However, there are some major challenges in the country to realising the full spectrum of benefits from V1G. These include the following:

- **Missing backend communication system:** V1G is a challenge due to a lack of the necessary backend communication system—with a uniform messaging protocol that enables communication between charging point operators and Central Management System—in India. The most common standard protocol used in such systems is the Open Charge Point Protocol (OCPP), which allows for the mix-and-match of different software and hardware. It can accommodate all types of charging technologies and, hence, enables interoperability and “e-roaming”¹¹ between charging station networks. Without a uniform backend communication system and Central Management System, V1G implementation is difficult.

¹⁰ 10% to 20% of the energy drawn from the battery can be lost (International Energy Agency 2020).

¹¹ e-roaming refers to an EV driver's ability to use various charging stations even if it is a customer of only one charging network operator. In practice, it means that an EV driver can have access to thousands of charging stations of different operators with just one customer account.

The Central and State Nodal Agencies, two important oversight authorities in India, should mandate all smart charging service providers to install OCPP-compliant charging equipment and create a central cloud-based backend system (Charging Station Management System) adhering to the OCPP communication protocol, to enable real-time charging data transfer to a Central Management System, remote modification of charger configuration, and remote charging session control. This will also allow the smart charging network to accommodate different charging technologies, EVs, and charging point operators. Furthermore, as already mandated in the guidelines issued by the Ministry of Power on October 1, 2019, the charging service providers should share charging-related data with the concerned DISCOM. This would facilitate seamless communication between the DISCOM and charging service providers and, in turn, ensure effective V1G implementation.

- **Aggregation challenge:** Similar to V2G, realising scale is needed in V1G to maximise its benefits and, hence, EV aggregation is required for this. As discussed above, EV aggregation faces multiple challenges in India, including the requirement of advanced communication and control infrastructure and lack of the concept of “resource aggregation” and the role of “aggregators” in the power market and regulatory framework. Existing Indian regulations lack provisions that permit “aggregation” of distributed energy resources, including EVs, to provide grid services. Consequently, the different principles and implementation models for resource aggregation are currently not covered in the regulations, which is a major barrier to effective V1G implementation (with maximum benefits).

To get the ball rolling on necessary regulatory and market reforms, the FoR should develop a model regulation on resource aggregation for states to adopt. The “Draft Model Regulation for Grid Interactive Distributed Renewable Energy Sources” prepared by FoR can be adapted to include provisions on resource aggregation and the different potential implementation models. The model regulation should recognise the role of non-DISCOM entities in carrying out demand aggregation. Furthermore, the SERCs should incorporate amendments into current regulations (e.g. State DSM Regulations) to allow non-DISCOM third party aggregators to participate in grid service provision.

- **Lack of dynamic tariffs:** Dynamic electricity pricing in India is currently limited to ToD tariffs. As highlighted in the previous chapter, ToD tariffs may become less effective as EV penetration increases. Real-time electricity pricing, which can more accurately reflect the bulk power market prices and grid conditions, is therefore essential for effective V1G deployment. Although DISCOMs are encouraged to install smart meters to measure consumers’ energy consumption, the main purpose of this has been to improve DISCOMs’ billing efficiency, and there is little to no effort to allow two-way communication between consumers and DISCOMs and bring in dynamic tariffs.

As a first step, the SERCs should introduce ToD tariffs specially designed for EV charging. Going forward, the concept of dynamic rates should be introduced into the National Tariff Policy, and the regulators in states that are likely to have high EV penetration should engage with stakeholders to initiate discussions on dynamic EV charging tariffs and pilot test such rates. Based on the learnings from the pilots, these states should plan large scale roll-out of dynamic tariffs for EV charging.

Despite these challenges, V1G merits immediate action, especially since it can be implemented in a phased manner, starting with simple smart charging

using ToD tariffs and gradually expanding the scope to include aggregated smart charging and dynamic tariffs, along with innovative business models on specialised aggregators and under the larger Distributed Energy Resources banner. This, however, requires long-term planning, starting now.

7.1 Recommended pathway for VGI implementation

Considering the level of maturity of India's e-mobility and power markets and the status of VGI internationally, this study has created a possible phase-wise VGI implementation roadmap for India, as depicted in Figure 20. As previously highlighted, VGI has different use cases, and each of them has a unique set of challenges and value propositions. And the greater the potential value, the more complex the solution is to implement. The three major levels of VGI – V1G, Aggregated Smart Charging, and V2G – can be considered sequentially for VGI implementation, i.e. achievement of one can be regarded as the stepping stone to the next level.

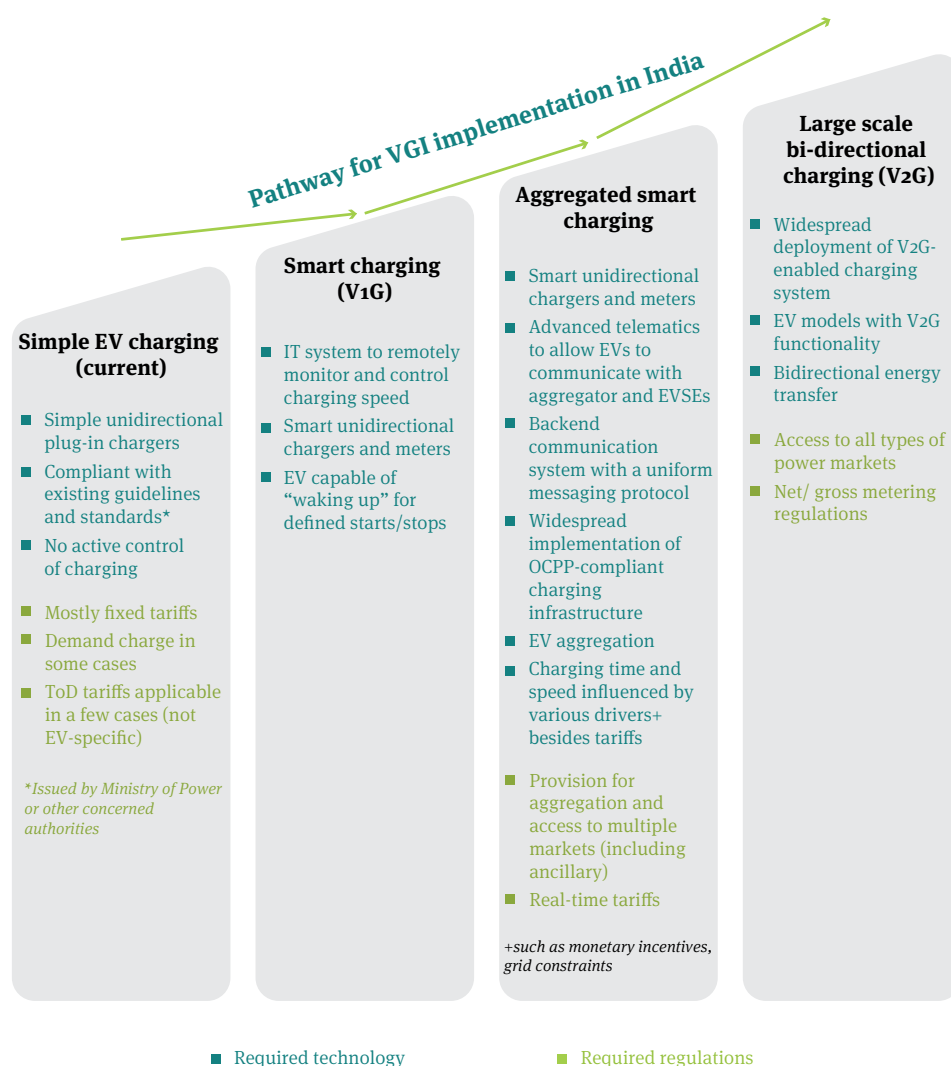


FIGURE 20: PROPOSED VGI IMPLEMENTATION PATHWAY FOR INDIA

Source: AEEE analysis



**EFFORTS SHOULD BE
MADE TO ENCOURAGE
INTERNATIONAL
COLLABORATION AND
KNOWLEDGE
EXCHANGE ON VGI.**

The steepness of an arrow in the pathway signifies the level of additional effort required to achieve the next level of VGI. Therefore, the pathway shows that implementing simple smart charging would not require much additional technological and/ or regulatory intervention, whereas to implement aggregated smart charging, requirement of more complex technology and/ or regulatory/ market reforms is expected. Similarly, to go up to the next VGI level, i.e. V2G, even greater changes, both in terms of technology and regulations, would be necessary.

The large-scale uptake of VGI would depend on the particular solution's value proposition and ease of adoption by end-users and other actors. It is likely that a number of winning use cases will begin to emerge, based on a pilot offering to different EV user groups and sets of standard commercial arrangements between new and existing actors in the power and mobility sectors. Efforts should be made to encourage international collaboration and knowledge exchange on VGI. A large amount of knowledge is accumulating from research and demonstration projects around the world, and it is crucial that this is consolidated in order to move forward with the commercialisation of VGI solutions, taking into account the local context.

8. Appendix

Appendix A – List of International VGI Pilot Projects

Project Name	Location	Start Date	Type	Project Summary
Avista Utilities	Washington state, USA	2016	V1G	Project focused on determination of how much plug-in EV (PEV) load can be shifted from peak load times to off-peak times without using ToU rates.
BMW i Charge Forward	San Francisco Bay Area, USA	2015	V1G	Project tested the value proposition of residential V1G business models for the utility, aggregator, and PEV owner.
V2G Pilot Project	Hong Kong	2011	V2G	Small-scale proof of concept trial in Hong Kong
Jeju Smart Grid Project	South Korea	2009	V1G	First project to test commercialisation of smart grid technology incorporating V1G scheme
Toyota Tsuho Pilot Project	Japan	2018	V2G	First government funded V2G trial in Japan
Yokohama City Pilot Project	Japan	2010	V1G	Provided 2000 EVs and their charging infrastructure and also focused on smart charging
Elia V2G	Belgium	2018	V1G/ V2G	Belgium project to evaluate the potential of V2G and V1G to provide frequency response services to Transmission System Operator (TSO) Elia
Parker Project	Denmark	2016	V2G	Danish demonstration project to test whether series-produced EVs, as part of an operational vehicle fleet, can support the power grid by becoming a vertically integrated resource, providing seamless support to the power grid.
ACES Project	Denmark	2017	V2G	Danish project to evaluate the techno-economic benefits of V2G
Suvilahti Project	Finland	2017	V2G	Finland's first two-way public EV charger connected to a solar plant and electrical storage facility
Grid Motion	France	2017	V1G/ V2G	Privately-funded demonstration in France to test the frequency response of V1G and V2G
Redispatch V2G	Germany	2018	V2G	German trial with 10 EVs having both uni- and bidirectional capability. Project investigated the dispatchability of EVs to manage network constraints, reduce curtailment, and reduce upgrades.
INEES	Germany	2012	V2G	German lighthouse project that demonstrated the real-world technical feasibility of V2G through the use of 20 SMA bidirectional inverters and modified Volkswagen UP vehicles.
Genoa Project	Italy	2017	V1G/ V2G	Two car trial testing of V1G and defining V2G in the regulatory framework in Italy

Project Name	Location	Start Date	Type	Project Summary
SEEV4City	Netherlands, Norway, UK, Belgium	2016	V2G	North European trial including 5 projects in 4 countries, namely, Netherlands, Norway, UK, and Belgium. The 5 pilots include: <ul style="list-style-type: none"> • Loughborough Living Lab • Amsterdam Arena, with up to 200 unidirectional and bidirectional connected EVs as part of the smart energy system • City depot of Kortrijk, with single Nissan LEAF van providing Vehicle-to-Business (V2B) service with onsite solar power • Leicester City Hall V2B trial with four vehicles • Vulkan Real Estate Building Oslo pilot with innovative EV parking garage, aiming to deploy V2G in next phase
Smart Solar Charging	Netherlands	2015	V2G	V2G project with 22 chargers installed as part of city car share and solar power scheme in Lombok. Now seeking to scale up to 1000 chargers across region of Utrecht.
New Motion V2G	Netherlands	2016	V2G	First V2G project in Netherlands to provide frequency response services to TSO TenneT with chargers installed in homes, offices, and public locations.
Hitachi, Mitsubishi, and Engie Project	Netherlands	2018	V2G	One V2G charger installed at Engie office in order to increase self-consumption of power from on-site solar PV generation
Amsterdam V2G Project	Netherlands	2017	V2G	Combination of solar and V2G to store and supply electricity. Exploration of energy buffer solutions and societal issues
Grow Smarter	Spain	2015	V2G	6 V2G chargers installed at Endesa facility and used for time shift, power balancing, and power quality support
Zem2All	Spain	2012	V2G	Largest real-world V2G trial in the world, forming part of wider e-mobility trial in Malaga
Nissan Enel UK Project	UK	2016	V2G	Large-scale trial proposed in UK by Enel and Nissan, aiming to connect 100 V2G units
The Network Impact of Grid-Integrated Vehicles Project	UK	2018	V2G	Distribution Network Operator-run project to understand the negative and positive impacts of V2G-enabled EVs on the distribution network
ITHECA	UK	2015	V2G	Microgrid demonstration project at Aston University, which installed UK's first ever V2G charger
EFES	UK	2013	V2G	Cenex-led project developing V2G technology and software for residential and commercial applications
Integrated Transport and Smart Energy Solutions (ITSES)	UK	2015	V2G	Project aiming to find new technical solutions and business models for integrating V2G with two urban systems: energy and transport

Project Name	Location	Start Date	Type	Project Summary
IREO	Canada	2012	V2G	Technology demonstration of bidirectional power flow for an assembled electric test vehicle and charging station
Powerstream Pilot	Canada	2013	V2G	Small scale, microgrid proof-of-concept trial incorporating V2G in Phase 2
NYSERDA	USA	2016	V2G	6 Nissan LEAF vehicles used to provide V2G services on the CUNY Queens College campus
BlueBird School Bus V2G Project	USA	2017	V2G	8 Bluebird electric school buses deployed in the Rialto Unified School District, providing ancillary services and energy management services
US Air Force Project	USA	2012	V2G	Small-scale V2G pilot completed by the US Department of Defense
KIA Motors, Hyundai Technical Center Project	USA	2016	V2G	UC Irvine partnered with KIA/Hyundai to demonstrate V2G control software, understand charging behaviour, and assess impact on the grid
US DoD – Fort Carson V2G	USA	2013	V2G	V2G grid service demonstration was performed at Fort Carson. This was part of the 3-phase SPIDERS programme, which sought to demonstrate the viability and benefits of creating secure microgrid architecture.
Grid on Wheels	USA	2012	V2G	First real-world field test of V2G technology, with 15 vehicles with varied driving patterns providing frequency response services over 2-year period
Fiat-Chrysler V2G	USA	2009	V2G	Large-scale V2G demonstration with 140 PHEVs, a portion of which were fitted with bidirectional charging capability, to test V2H and V2G capability
Clinton Global Initiative School Bus Demo	USA	2014	V2G	Project seeking to improve economic viability of electric school buses through V2G and V2B trials in two school districts
Distribution System V2G for Grid Stability as well as Reliability Project	USA	2015	V2G	Project initiated by Electric Power Research Institute (EPRI) seeking to assess the value of and barriers to V2G implementation at the distribution level, including whether these benefits can be monetised and quantified
UCLA Win Smart EV Project	USA		V2G	Research project on maximum power flow from EVs, simultaneously addressing response time and control, for applications such as reactive power, voltage regulation, and distributed storage
Massachusetts Electric School Bus Pilot	USA	2015	V2G	Pilot project to test deployment of three electric school buses for V2G in cold weather environments
INVENT Pilot Project	USA	2017	V2G	V2G technology provider Nuvve seeking to deploy V2G technology in 50 EVs at University of California San Diego in collaboration with California Energy Commission
Torrance V2G School Bus Project	USA	2014	V2G	Department of Energy-funded project that retrofitted 2 school buses with V2G technology

Appendix B – Questionnaire

- What are your views on VGI (V1G and V2G), and how important is it for India?
- Will it be applicable to all EV segments: e-2Ws, e-3Ws, e-4Ws, and e-buses?
- What are the challenges for VGI in India?
- What are some of the possible solutions/strategies that should be adopted for VGI?
- What are the knowledge/technological gaps that need to be addressed to integrate EVs with the grid?
- Are the existing policies and regulatory and institutional frameworks sufficient for VGI implementation in India? If not, what policies and regulatory and institutional reforms are required?
- Are the available battery technologies in India suitable for VGI? Which battery technology is most appropriate?
- What will be the impact of VGI on EV battery degradation in the Indian environment?
- What will be the value proposition of VGI for DISCOMs?
- What role will smart charging play in congestion management of distribution networks?
- What role will VGI play in demand response, frequency regulation, voltage regulation, black-start support, and reliability improvement?
- To what extent is a VPP using EV batteries economically viable in India? What are the available market opportunities?
- To what extent can VPPs contribute to the current Indian ancillary service/ balancing market?
- What are the gaps in the current regulatory framework for V1G and V2G in India?
- Will participating in the VGI scheme be profitable for fleet operators?
- Do you think fleet operators will be willing to participate in VGI?
- What types of incentives would encourage fleet operators to participate in VGI?
- What are the technical barriers that may hinder large-scale VGI in India?
- How can the losses during the charging-discharging cycle be reduced through V1G/V2G?
- How can the problem of harmonics caused during the charging-discharging process be mitigated with VGI?
- Are the current chargers available on the Indian market equipped for VGI (V1G/V2G)?
- Is there a necessity to use slow starters in V2G chargers?
- Are the EVs on the Indian market V2G-ready?

Appendix C – Stakeholders Consulted

Category	Organisation	Mode of Interaction
Battery Expert	Vision Mechatronics	Telephonic
Battery Expert	Department of Energy Science and Engineering, IIT Bombay	Telephonic
Battery Expert	Centre for Electric Vehicle and Battery Engineering, IIT Madras	Telephonic
Fleet Operator	Ola Electric	Telephonic
R&D Institution	Department of Electrical Engineering, IIT Delhi	In Person
Charging Service Provider	Fortum	Telephonic
R&D/ Individual Expert	GIZ – India	In Person
DISCOM	BSES Rajdhani	In Person
R&D Institution	Centre of Advanced Research in Electrified Transportation (CARET), Aligarh Muslim University	Telephonic
R&D Institution	Department of Electrical Engineering, IIT Madras	Telephonic
Charging Technology Provider	Volttic Electric Vehicle Charging	Telephonic
Fleet Operator	eee-Taxi	Telephonic

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