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V2G BUSINESS MODELS: GLOBAL INSIGHTS AND THEIR OUTLOOK IN INDIAN EV ECOSYSTEM

REPORT

**GRID INTEGRATION LAB
INDIAN INSTITUTE OF TECHNOLOGY BOMBAY
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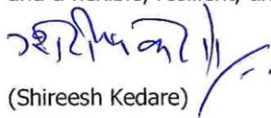


Foreword

The rapid growth of electric mobility is bringing the transportation and electricity sectors closer together than ever before. Global electric-car sales have increased multifold, creating a growing requirement for flexibility, energy storage, demand-side management, and other balancing resources within electricity systems. Through coordinated smart charging, the energy stored in vehicle batteries can potentially support homes, commercial facilities, charging depots, distribution networks, and the wider power system in handling high share of renewable. Technologies such as Vehicle-to-Grid (V2G), Vehicle-to-Home (V2H), and intelligent charging therefore offer an important opportunity to make electric mobility an active participant in the transition towards a more flexible, resilient, and sustainable energy system. The opportunity is particularly significant for India. As of August 2026, more than 10 million electric vehicles (EVs) were registered in the country, alongside the continuing expansion of renewable generation and charging infrastructure. However, practical issues about charging time, charging period, willingness & convenience of stakeholders need to be taken into account while developing & implementing the related technology.

Indian Institute of Technology Bombay is committed to contributing to this transition through technically rigorous, implementation-oriented research and close engagement with utilities, government agencies, industry, technology providers, and other stakeholders. The reports developed under **Vehicle to Grid (V2G) Study** undertaken by **Grid Integration Lab** at the Department of Energy Science and Engineering, IIT Bombay and funded by Federal Ministry for Economic Cooperation and Development (Germany) through Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), address different complementary dimensions of this emerging ecosystem and associated energy transition. Together, they aim to provide a comprehensive technical and strategic knowledge base for the safe, interoperable, reliable, economically sustainable, and scalable integration of electric vehicles with India's power system.

I would like to congratulate the **Grid Integration Lab**, authors, researchers, reviewers, participating stakeholders, and supporting organisations whose contributions have made this work possible. I hope that the outcomes of the project will contribute meaningfully to the development of an enabling ecosystem for bidirectional electric mobility in India and support the country's broader transition towards clean transportation and a flexible, resilient, and low-carbon energy future.


(Shireesh Kedare)

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Abbreviations

- **AC:** Alternating Current
- **AI:** Artificial Intelligence
- **B2B:** Business-to-Business
- **B2C:** Business-to-Consumer
- **BESS:** Battery Energy Storage System
- **BMC:** Business Model Canvas
- **BMS:** Battery Management System
- **CAN:** Controller Area Network
- **CAPEX:** Capital Expenditure
- **CCS:** Combined Charging System
- **CMS:** Central Management System
- **DC:** Direct Current
- **DISCOM:** Distribution Company
- **EMS:** Energy Management System
- **EV:** Electric Vehicle
- **EVSE:** Electric Vehicle Supply Equipment
- **FAME II:** Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles – Phase II
- **HIL:** Hardware-in-the-Loop
- **IoT:** Internet of Things
- **ISO:** International Organization for Standardization
- **NEMMP:** National Electric Mobility Mission Plan
- **NEP:** National Electricity Plan
- **O&M:** Operations and Maintenance
- **OCPP:** Open Charge Point Protocol
- **OEM:** Original Equipment Manufacturer
- **OPEX:** Operating Expenditure
- **P2P:** Peer-to-Peer
- **PKI:** Public Key Infrastructure
- **PLC:** Power Line Communication
- **PV:** Photovoltaic
- **R&D:** Research and Development

- **RE:** Renewable Energy
- **ROI:** Return on Investment
- **SCADA:** Supervisory Control and Data Acquisition
- **SiC:** Silicon Carbide
- **V2B:** Vehicle-to-Building
- **V2G:** Vehicle-to-Grid
- **V2H:** Vehicle-to-Home
- **V2X:** Vehicle-to-Everything
- **VPP:** Virtual Power Plant



Executive Summary

Vehicle-to-Grid (V2G) technology extends the role of electric vehicles beyond conventional transportation and unidirectional charging by enabling controlled bidirectional exchange of electrical energy between vehicle batteries and the power system network. This capability allows parked electric vehicles to function as distributed and dispatchable energy resources capable of supporting peak-demand management, energy arbitrage, ancillary services, demand response, renewable-energy integration, and grid flexibility. However, the transition from technical feasibility to commercially scalable deployment requires considerably more than bidirectional power transfer. It depends on the coordinated development of charging hardware, vehicle technologies, metering, communication systems, control platforms, electricity-market mechanisms, regulatory frameworks, consumer participation models, and commercially viable revenue structures. This report therefore examines V2G as an integrated technological and business ecosystem and evaluates how existing global business approaches can inform future implementation in India.

The study maps the V2G ecosystem across its principal hardware, software, market, and service segments. These include bidirectional chargers and connectors, power and control modules, V2G-capable vehicle powertrains, battery management systems, bidirectional energy meters, testing and validation equipment, Central Management Systems and Energy Management Systems, communication-specific hardware and software, energy-trading platforms, aggregators, training and technical services, and battery recycling and end-of-life management. These segments are interdependent. Hardware manufacturers provide the physical power-conversion and interface infrastructure; vehicle and battery-system manufacturers ensure safe bidirectional operation; metering and testing providers enable measurement, compliance, and interoperability; and communication, software, CMS, and EMS providers support monitoring, scheduling, optimization, control, and settlement.

Aggregators and trading platforms subsequently combine these distributed assets and connect their technical flexibility with utility requirements and electricity-market opportunities.

To analyse the commercial structure of these activities, the report applies the Business Model Canvas framework to link key partners, activities, resources, customer segments, value propositions, channels, customer relationships, cost structures, and revenue streams. The analysis shows that V2G cannot be represented by a single universal business model because commercial arrangements vary according to the technological segment, ownership structure, regulatory environment, electricity-market design, and maturity of V2G deployment. Product-based models are dominant in hardware-oriented segments such as chargers, connectors, power modules, meters, vehicle components, battery-management systems, and testing equipment. In contrast, service-based, subscription-based, shared-asset, aggregator-based, and platform-based models become increasingly important for fleet coordination, energy management, software services, electricity trading, and participation in grid-support services.

The global survey demonstrates that commercial value in V2G is generated through multiple and complementary mechanisms. These include peak shaving, load shifting, frequency and ancillary services, demand response, energy arbitrage, renewable-energy balancing, improved utilization of charging and battery assets, and, where applicable, resilience and backup applications. Aggregation is particularly important because individual electric vehicles provide relatively small and uncertain capacity when considered independently. Coordinating a large number of vehicles allows their combined charging and discharging flexibility to be scheduled and represented as a more predictable resource for utilities, grid operators, or energy markets. Commercial viability therefore depends on the ability to accurately forecast vehicle availability, manage battery and mobility constraints, execute reliable control, quantify delivered services, and distribute resulting revenues among vehicle owners and other participating entities.

For India, the report identifies potential business opportunities across every layer of the V2G value chain. These include domestic manufacturing of bidirectional chargers and power-electronic modules, communication controllers, advanced battery-management systems, bidirectional metering, testing and certification services, EMS/CMS platforms, fleet-management software, aggregation services, energy-trading platforms, training and consultancy, battery recycling, and second-life battery applications. Development of these capabilities can reduce dependence on imported V2G technologies while strengthening domestic expertise in electric mobility, smart grids, power electronics, communication, and energy-management systems. V2G also has strategic relevance in the Indian context because increasing renewable-energy penetration creates a growing requirement for flexibility, storage, and controllable demand within the electricity system. The report further evaluates an aggregator-based business case for India. Under this model, an aggregator coordinates a portfolio of V2G-enabled vehicles and acts as an interface between electric-vehicle owners and the electricity system. Its responsibilities may include customer enrolment, vehicle-availability forecasting, charging and discharging scheduling, real-time control, data management, communication with participating chargers, settlement with grid or market entities, and revenue distribution to vehicle owners. The associated capital expenditure includes bidirectional charging infrastructure, grid interfaces, metering, communication equipment, and digital platform development, while operating expenditure includes maintenance, communications, software operation, customer acquisition, technical support, settlement, and compensation to EV owners. Potential revenues may arise from peak-demand support, demand response, energy arbitrage, ancillary services, and other grid-flexibility services where market regulations permit participation.

Despite the technical and commercial opportunities, the report identifies several regulatory, technical, and market barriers that currently constrain large-scale V2G implementation in India. These include the absence of dedicated V2G grid codes, limited recognition of aggregators, unclear market-participation and settlement mechanisms, inadequate revenue mechanisms for distributed flexibility, lack of dynamic or sufficiently differentiated tariff structures, limited availability of certified bidirectional chargers, interoperability challenges, and uncertainty regarding consumer protection and battery-degradation treatment. These gaps increase investment risk for manufacturers, utilities, aggregators, and service providers while simultaneously weakening the economic signal available to participating vehicle owners. Technical standardization is particularly important because large-scale bidirectional operation requires defined requirements for grid synchronization, electrical protection, anti-islanding, power quality, metering, communication, authentication, and operational control. Interoperability between vehicles, chargers, communication protocols, software platforms, and utility systems is essential for scalability. Testing, certification, and conformance assessment therefore form an integral component of the V2G business ecosystem. Similarly, cybersecurity and data privacy become critical because V2G relies on digitally coordinated and remotely controlled energy transactions. Secure communication, authentication, access control, data governance, software-update mechanisms, and cybersecurity compliance are necessary to protect both power-system operation and consumer information.

Overall, the findings establish that V2G should be treated as an ecosystem-development and market-design challenge rather than solely as a bidirectional charging technology. Its commercial success requires coordinated progress in vehicle capability, charging infrastructure, communication standards, metering, software platforms, testing, grid regulation, market participation, tariff design, cybersecurity, and consumer engagement. The report provides a structured understanding of the principal V2G business models currently observed globally, identifies the mechanisms through which value is created and captured across the ecosystem, and evaluates how these models may be adapted to Indian technical, regulatory, and market conditions. The analysis indicates that V2G can develop into a commercially relevant component of India's future electric-mobility and power-system ecosystem, provided that technological readiness is accompanied by interoperable infrastructure, explicit regulatory recognition, transparent market mechanisms, viable revenue-sharing arrangements, and coordinated participation among government agencies, utilities, automotive manufacturers, technology providers, aggregators, and consumers.

1. Introduction

Vehicle-to-Grid system enables electric vehicles to exchange energy bidirectionally with the grid, transforming them from passive consumers to active participants in energy management¹. By connecting through Electric Vehicle Supply Equipment (EVSE), EVs can supply power during peak demand and absorb excess energy during low-demand periods, enhancing grid stability and efficiency. This capability supports the seamless integration of renewable energy sources, such as solar and wind, by mitigating their intermittency and balancing fluctuations in power generation². Figure 1.1 illustrates a typical V2G system architecture, highlighting the energy flow and communication among

various entities. This smart communication protocols enable real-time coordination between EVs and the grid, optimizing power distribution and minimizing losses. Additionally, V2G technology supports demand response programs by enabling EV owners to earn incentives while enhancing the reliability and stability of the power grid. Beyond economic advantages, it also facilitates critical functions such as frequency regulation, voltage stabilization, and ancillary grid services, thereby reducing reliance on conventional power generation sources³. As EV adoption rises, V2G is set to become a key component of a flexible, sustainable, and resilient energy infrastructure⁴.

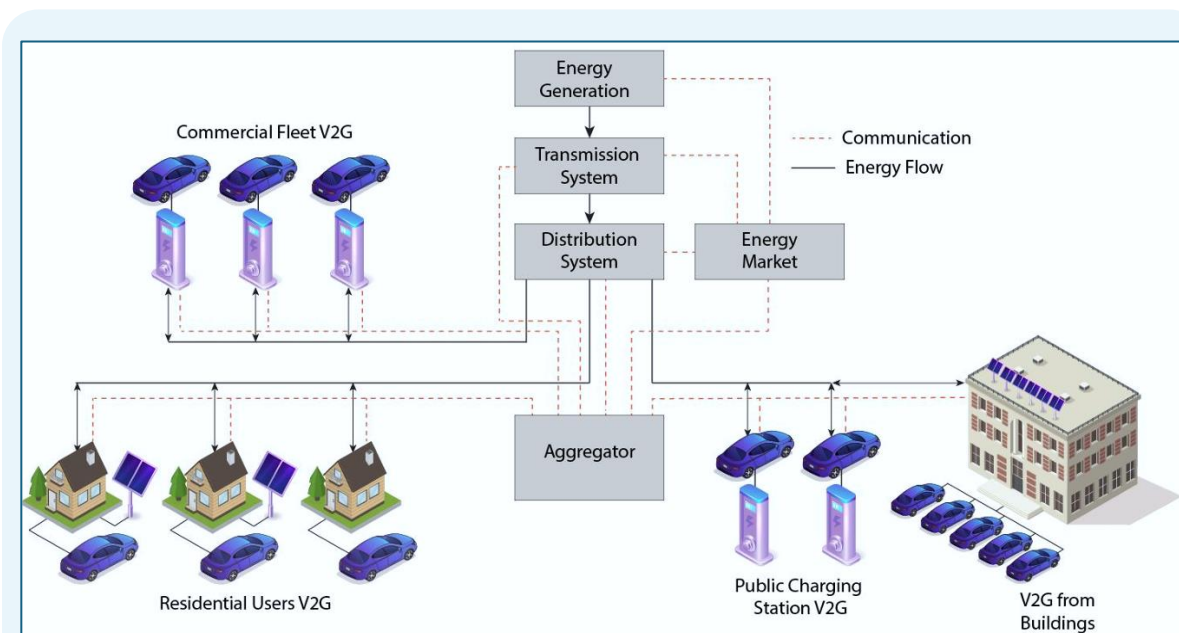


Figure 1.1: V2G system architecture⁴

¹ Heydaryan, B., M. A. Khatib, M. Hess, and N. Bajcinca. "Optimal Energy Transactions for Bidirectional Charging Stations Enabling Grid Ancillary Services." In Proceedings of the 2024 European Control Conference (ECC), 2003-2009. Stockholm, Sweden: IEEE, 2024.

² Wei, Y., et al. "A Hierarchical Framework for Vehicle-to-Grid (V2G) Distributed Control Combining Peer-to-Peer Blockchain with Systemic Scheduling." In Proceedings of the 2023 13th International Conference on Power and Energy Systems (ICPES), 436-441. Chengdu, China: IEEE, 2023.

³ Lee, J.-W., S.-W. Park, and S.-Y. Son. "Gamification-Based Vehicle-to-Grid Service for Demand Response: A Pilot Project in Jeju Island." IEEE Access 12 (2024): 30209-30219.

⁴ Indian Institute of Technology (IIT) Bombay. Implementation of Vehicle-to-Everything (V2X) in India: Executive Summary. Prepared in cooperation with the Central Electricity Authority (CEA), Ministry of Power. December 2023.

The V2G market growth projection, illustrated in **Error! Reference source not found.**, highlights promising business

opportunities in this sector by different V2G services listed in Figure 1.3⁵.

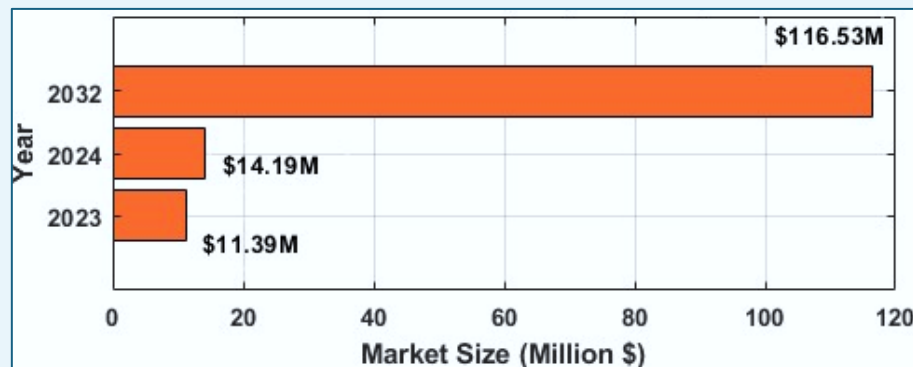


Figure 1.2: V2G Market Growth Projection Over the Year^{Error! Bookmark not defined.}

1.1 V2G Services

V2G services refer to the set of grid-support functions provided by electric vehicles through controlled bidirectional power exchange with the electricity grid. There are various types of V2G services, some of which are already commercially deployed, while others are still in development but hold significant potential for future commercialization.

1.1.1 Types of V2G Services

Broadly, V2G Services can be categorized into four key areas: Ancillary Services, Energy Market Services, Fleet & Commercial Applications, and Resilience & Backup Services, each contributing uniquely to the evolving energy landscape. Figure 1.3 presents a broader classification of grid support services, highlighting those that are readily available worldwide and those that are not.



Figure 1.3: Types of V2G Services

⁵ Fortune Business Insights. Vehicle-to-Grid (V2G) Market Size, Share & Industry Analysis, 2024–2032.

1. Ancillary Services

Ancillary services refer to grid-support functions provided by EV's such as frequency regulation, voltage support, spinning reserves, and reactive power compensation. These services are enabled by the EV's ability to rapidly modulate their charge and discharge rates, thereby helping to maintain grid stability and reliability⁶.

2. Energy Market Services

Energy market services involve the participation of V2G systems in electricity markets through mechanisms like peak shaving, load shifting, and energy arbitrage. V2G-enabled EVs can charge when prices are low and discharge back to the grid during high-price periods, thus creating economic value while aiding in demand-side management⁷.

3. Fleet & Commercial Applications

In fleet and commercial operations, V2G facilitates energy cost optimization and revenue generation by allowing coordinated bidirectional charging across multiple EVs. Commercial fleets can participate in grid services while ensuring mobility needs are met, thereby turning idle battery capacity into an economic asset⁸.

4. Resilience & Backup Services

Resilience and backup services in V2G refer to the use of EVs as mobile energy storage units that can supply electricity during grid outages or emergencies. Through vehicle-to-home (V2H), vehicle-to-grid (V2G) or vehicle-to-building (V2B) configurations,

EVs can power critical loads, enhancing local energy resilience and disaster recovery capability⁹.

Each commercially available V2G service operates with a distinct business model that drives market growth, enhances financial viability, and accelerates large-scale adoption by aligning incentives for EV owners, utilities, and service providers.

1.2 Business Model

A business model describes how an organization creates and delivers value to customers and sustains itself financially in the process. David J. Teece (2010) defines a business model as "the design or architecture of the value creation, delivery, and capture mechanisms" employed by a firm. This perspective emphasizes the importance of aligning internal processes and resources to effectively deliver value and achieve competitive advantage¹⁰. In essence, a well-constructed business model serves as a blueprint for how a company operates, competes in the marketplace, and adapts to changing environments.

1.2.1 Importance of Business Model

A well-structured V2G business model is essential for driving the commercialization and large-scale adoption of V2G technology. It lays the foundation for sustainable revenue generation, financial viability, and market growth by attracting investment and encouraging innovation. A robust model defines clear revenue streams while

⁶ Sortomme, Eric, and Mohamed A. El-Sharkawi. 2012. "Optimal Scheduling of Vehicle-to-Grid Energy and Ancillary Services." *IEEE Transactions on Smart Grid* 3(1): 351–359.

⁷ Kempton, Willett, and Jasna Tomic. 2005. "Vehicle-to-Grid Power Implementation: From Stabilizing the Grid to Supporting Large-Scale Renewable Energy." *Journal of Power Sources* 144(1): 280–294.

⁸ Blatiak, Adrian, Francesco Bellizio, Leandro Badesa, and Goran Strbac. 2022. "Value of Optimal Trip and Charging Scheduling of Commercial Electric Vehicle Fleets with Vehicle-to-Grid in Future Low Inertia Systems."

⁹ Uddin, Kotub, Tim Jackson, W. D. Widanage, Gokhan Chouchelamane, and Paul A. Jennings. 2017. "On the Possibility of Extending the Lifetime of Lithium-Ion Batteries through Optimal V2G Facilitated by an Integrated Vehicle and Smart-Grid System." *Energy* 133: 710–722.

¹⁰ Teece, David J. 2010. "Business Models, Business Strategy and Innovation." *Long Range Planning* 43(2–3): 172–194

enabling companies to scale operations effectively and respond to market demands. Beyond financial aspects, a sound business framework ensures regulatory compliance, promotes user engagement, and supports

efficient grid integration, making V2G a reliable and scalable solution. As illustrated in Figure 1.4, these interconnected components are critical to the overall success of V2G systems^{11,12}.



1.2.2 Types of Business Models

Businesses adopt various models depending on their industry, target audience, and revenue strategy.

As illustrated in Figure 1.5, some models center on direct product or service sales, while others generate income through

subscriptions, rentals, shared asset utilization, or financial services such as insurance. Additionally, models like reselling and agency-based promotion create value by acting as intermediaries. Each model has its own strengths, risks, and profitability factors, making it essential for businesses to choose one that aligns with their goals and market dynamics¹³.

¹¹ Grand View Research. Vehicle-to-Grid Technology Market Size, Share & Trends Analysis Report by Vehicle Type (BEVs, PHEVs, FCVs), By Component (Smart Meters, EVSE, Software Solutions), By Application, By Region, And Segment Forecasts, 2024 - 2030.

¹² Jones, Laura, Kathryn Lucas-Healey, and Björn Sturmborg. Creating Value from V2G: A Report on Business Models. Realising Electric Vehicle-to-Grid Services (REVS) Project. Funded by the Australian Renewable Energy Agency (ARENA), September 2022.

¹³ Healy, Patrick. 8 Types of Business Models & the Value They Deliver. Harvard Business School Online, 2021.

Table 1.1 summarizes common business model types and their characteristics. A V2G

business can potentially draw on one or a combination of these models.

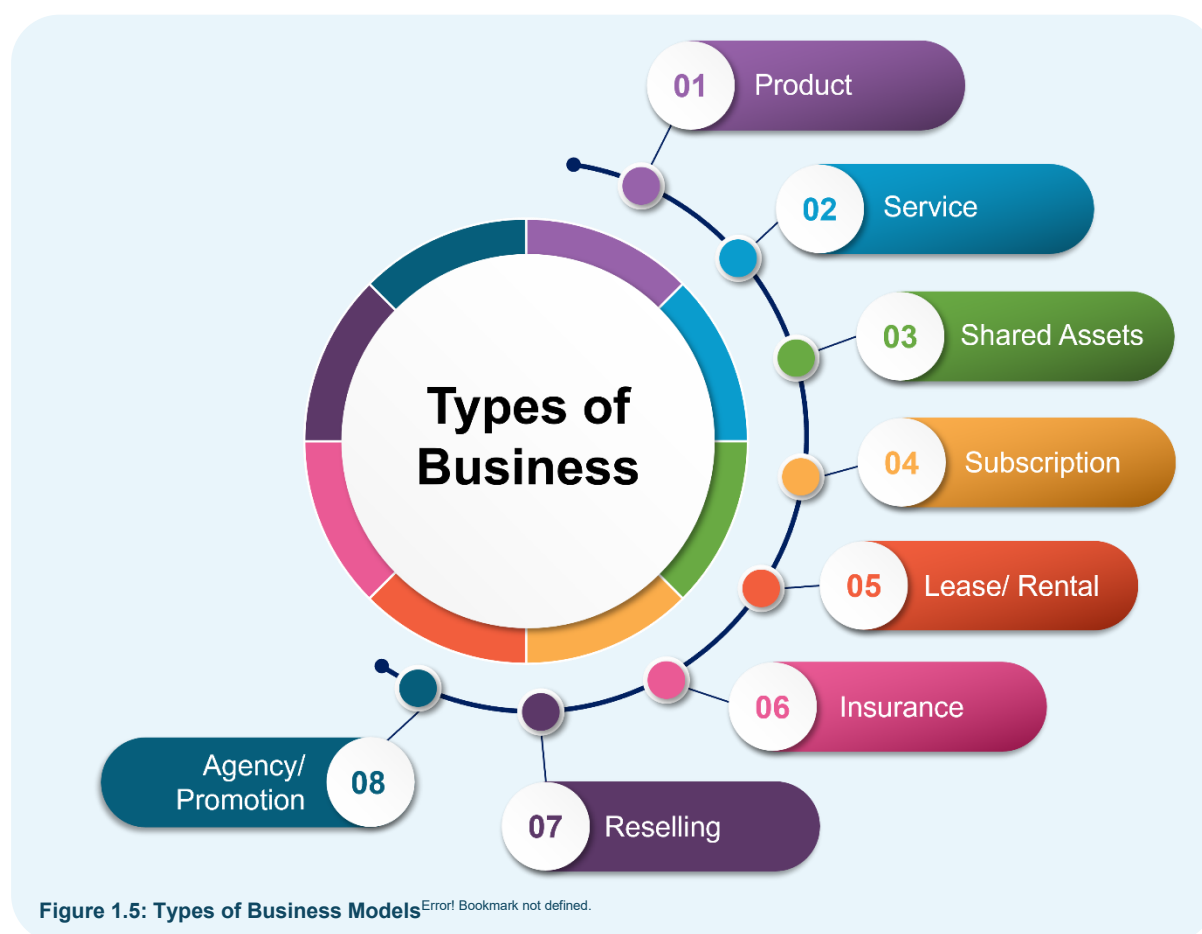


Table 1.1: Types of Business Model and its Description⁸

Business Models	Description
Product	Selling tangible or intangible items for profit. Upsides include economies of scale; downsides include inventory costs and potential damage.
Service	Charging for specialized skills. High demand skills earn more; saturation or under-pricing can limit profitability.
Shared Assets	Leasing shared resources. Balances cost and usage but risks customer misuse.
Subscription	Recurring fees for ongoing access to products/services. Provides stable income but demands consistent quality
Lease/ Rental	Renting durable goods for a fee. Profitable with high-value items but requires safeguards against damage.
Insurance	Selling risk management policies. Profitable with accurate risk assessment but vulnerable to widespread losses.
Reselling	Buying at bulk discounts and selling at a markup. Profitable with good suppliers but requires storage space.

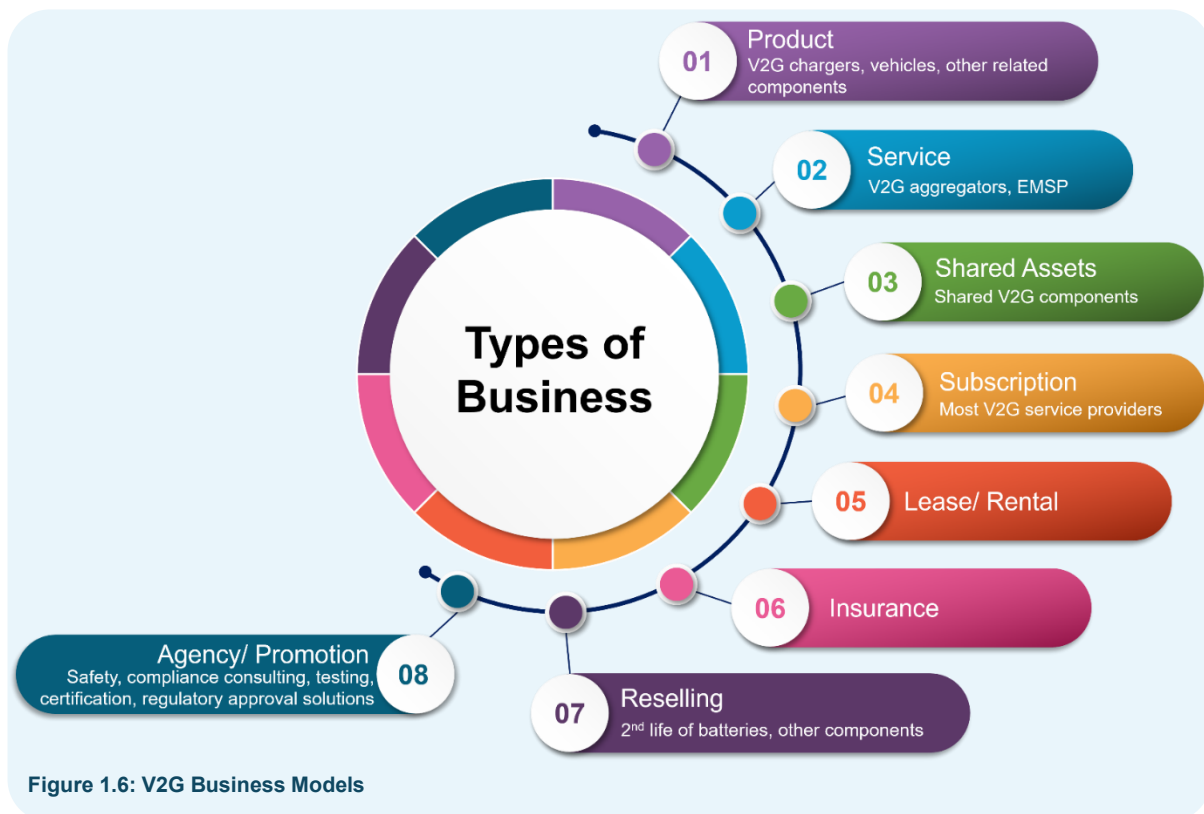
Agency/ Promotion

Earning fees for connecting buyers and sellers. Leverages expertise but income depends on closing deals.

1.2.3 V2G Business Models

In the context of V2G, various business models are emerging worldwide, shaped by regional policies and market conditions (Figure 1.6). Different countries have adopted distinct approaches to commercializing V2G, with key players leveraging fleet aggregation, utility partnerships, and retail energy trading to generate value. For instance, Denmark has pioneered fleet aggregator models,

exemplified by the Parker Project, where Nuvve and Frederiksberg Forsyning managed electric vehicle fleets to provide grid services. Meanwhile, U.S. utilities like PG&E and SDG&E are exploring utility-led models that integrate bidirectional charging into their operations to enhance grid reliability and resilience. Given the critical role of a well-defined business model, one useful framework for designing and analysing V2G business models is the Business Model Canvas.



1.2.4 Business Model Canvas (BMC)

The Business Model Canvas provides a powerful strategic framework to visualize and build such business models by focusing on nine interconnected components i.e. Key Partners, Key Activities, Value Propositions, Key Resources, Customer Relationships,

Customer Segments, Channels, Cost Structure and Revenue Streams as shown in Figure 1.7. It offers a structured framework to analyse and develop business opportunities within the V2G ecosystem.

By outlining key components such as value propositions, revenue streams, and customer segments, it aids stakeholders

including OEMs, aggregators, utilities, and service providers in identifying and

optimizing their roles to effectively deliver and monetize V2G services.

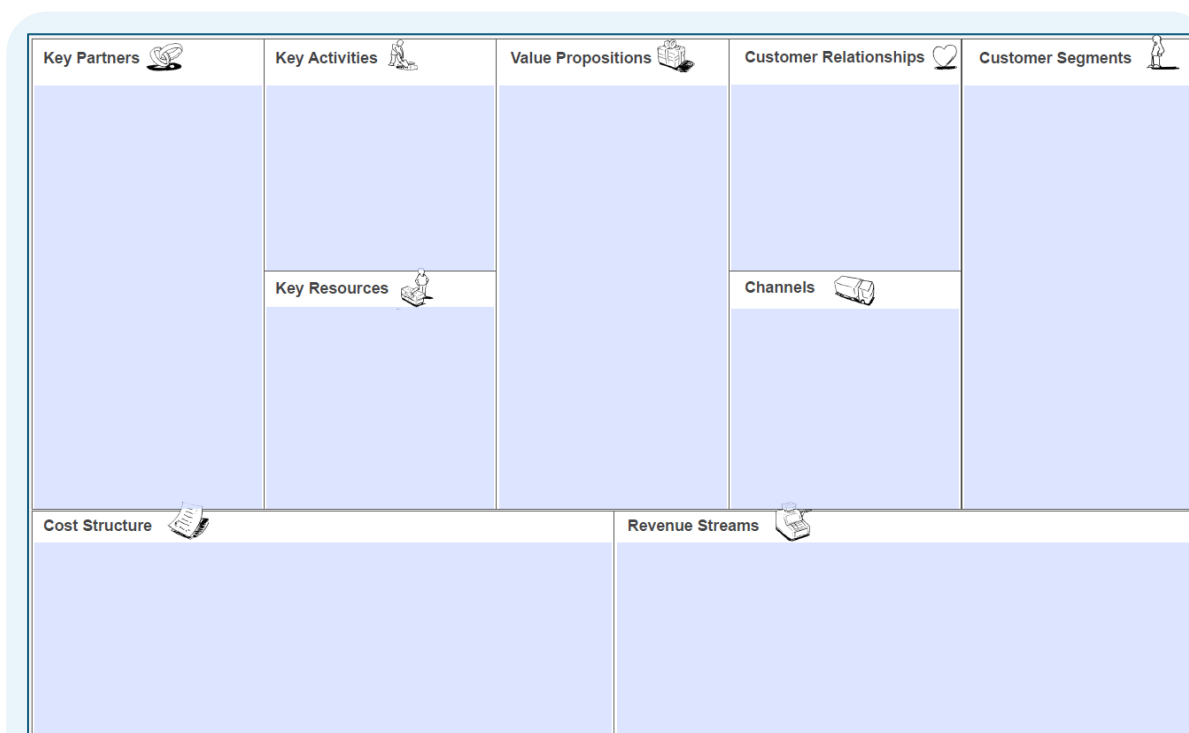


Figure 1.7: Architecture of Business Model Canvas (BMC)

Table 1.2: Components of Business Model Canvas

Component of Business Model Canvas	Description	Importance
Customer Segments	Defines the different groups of people or organizations a business aims to serve.	Understanding your customers is crucial. Different segments have different needs and behaviours. Businesses often tailor products/services to match each segment's demands.
Value Propositions	Describes the unique value the business offers to solve customer problems or fulfill their needs.	This is the core reason why customers choose one company over another. It defines what makes your product/service compelling and distinct.
Channels	Describes how a company delivers its value proposition to its customer segments (e.g., online, physical stores, partners).	Efficient and effective channels are vital to ensure customers receive value. The right channel enhances customer experience and brand perception.

Customer Relationships	Describes the type of relationship a company establishes with each customer segment.	Strong relationships lead to customer retention, satisfaction, and higher lifetime value. It defines how the company interacts and builds loyalty.
Revenue Streams	Revenue Streams represent the various ways a company earns income from its customer segments.	It shows how the business makes money through direct sales, subscriptions, leasing, licensing, advertising, etc.
Key Resources	Describes the most important assets required to make the business model work (physical, human, intellectual, financial).	These are the backbone of business operations. Without them, value can't be delivered or captured.
Key Activities	Describes the most important actions a company must take to operate successfully.	These are mission-critical tasks like manufacturing, problem-solving, platform management, that ensure value creation and delivery.
Key Partnerships	Describes the network of suppliers and partners that help the business operate.	Not everything can or should be done alone. Strategic alliances can reduce risk, optimize resources, and add complementary strengths.
Cost Structure	Describes all major costs involved in operating the business.	Helps determine which activities are cost-heavy, where to cut costs, and how to remain profitable. It reveals the business's economic logic.

1.2.5 Potential Businesses in V2G Ecosystem

The V2G Business Ecosystem presents diverse opportunities for developing sustainable and profitable business models. As depicted in Figure 1.8, this ecosystem spans key domains, including hardware, software, grid-integrated participants, and service-based models. Hardware businesses focus on bidirectional chargers, energy meters, and vehicle powertrain components, while software-driven models can capitalize on EMS/CMS platforms, trading algorithms, and fleet management solutions. Grid-integrated participants, such as aggregators and energy traders, enable innovative market-based models like P2P energy trading, dynamic pricing platforms, and demand-response management. Additionally, service-oriented models including V2G-as-a-service, microgrid management, and corporate energy

solutions offer scalable business opportunities. With increasing EV adoption and grid modernization, these segments create a foundation for monetization, investment, and large-scale deployment of V2G solutions.

1.2.6 Business Model Canvas for the V2G Ecosystem

The Business Model Canvas for the V2G ecosystem provides a strategic framework for understanding the key elements that drive value creation, delivery, and capture within the V2G domain. It systematically outlines the ecosystem's primary stakeholders, technological enablers, revenue mechanisms, and customer engagement strategies.

By detailing components such as key partners, activities, resources, customer segments, and revenue streams, this model highlights how V2G solutions facilitate

bidirectional energy flow between electric vehicles and the power grid. Applying the BMC to the V2G ecosystem highlights how value is created for all parties (from EV owners to grid operators) and how V2G

technology can be monetized in synergy with renewable energy and smart grids. The next chapter will survey how these business model concepts are taking shape globally.



Business Model Canvas for V2G Ecosystem

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- Utilities and Independent System Operators - EV manufacturers - Charging infrastructure providers (Hardware & Software) - Battery Recyclers and BMS Manufacturers - Government policy makers Regulatory Agencies - Energy Aggregators and Trading Platforms - Renewable energy suppliers - Training and Compliance Bodies - Cloud and data service providers	- Real-time energy optimization and forecasting - Development of V2G-capable infrastructure (hardware/software) - Platform development & maintenance - Regulatory compliance, certification, and cybersecurity assurance - Testing and interoperability validation for V2G equipment - Training and capacity-building for stakeholders	- Revenue from demand response, energy arbitrage, and grid services - Grid reliability and renewable integration support - Increased ROI for EVs and improved fleet utilization - Carbon reduction and access to green certificates - Smart energy use through predictive analytics - End-of-life battery solutions and circular economy - Interoperable, compliant, and scalable charging solutions	- Automated smart contracts with revenue sharing - Subscription-based smart energy platforms - Real-time energy usage tracking - Technical support and incentives - Co-branding with EV manufacturers - Technical support, diagnostics, and firmware updates - Community-based/shared asset models for localized grids	- Individual EV Owners - Commercial Fleet Operators - Utility Companies - Grid Operators - Residential communities (solar+V2G homes) - Energy Aggregators - Municipalities and Transit Authorities
	Key Resources - Bidirectional Chargers (CHAdeMO, CCS) - Smart Meters, PLC/IoT Hardware, and Telematics APIs - EMS/CMS Platforms and AI-based Energy Management Software - Testing & Certification Tools (ISO 15118, OCPP) - Cybersecurity Infrastructure (HSMs, Firewalls) - V2G-Compatible EV Powertrains & BMS - Battery Recycling & Second-Life Management Equipment		Channels - OEM-integrated V2G solutions - Energy marketplaces and aggregator platforms - Mobile apps and user dashboards - Partnership with utilities and energy retailers - Smart home and microgrid systems - Training and certification portals	
Cost Structure - Hardware procurement (chargers, bidirectional meters, etc.) - Software development and cloud hosting - Grid interconnection and testing - Customer onboarding and support - Regulatory compliance and certifications - Marketing and outreach		Revenue Streams - Energy trading and arbitrage (buy low/sell high) - Grid ancillary services (frequency regulation, voltage support) - Capacity payments and ancillary grid services - Subscription fees for V2G-as-a-Service - Certification, training, and consulting services - Carbon credits and green certificates - Platform access fees - Recycled battery resale, carbon credits		

Figure 1.9: Business Model Canvas of V2G Ecosystem

2. Global V2G Market and Business Model Survey

V2G business models vary globally based on regulatory frameworks, market readiness, and energy policies¹⁴. Key models include aggregator-based, utility-led, and peer-to-peer trading approaches¹⁵. Countries like the USA, UK, Japan, and Denmark have pioneered V2G pilots, demonstrating feasibility through incentive-based programs⁹. Automakers, utilities, and third-party service providers are collaborating to develop scalable V2G services, ensuring economic viability¹⁰. Revenue mechanisms include demand response, frequency regulation, and energy arbitrage, benefiting both EV owners and grid operators⁹. The scalability of V2G depends on policy support, standardization, and battery impact considerations¹⁰.

2.1 Charging Infrastructure

The V2G infrastructure market is still emerging, driven by pilot projects, regulatory initiatives, and advancements in bidirectional charging¹⁶. However, high costs, interoperability challenges, and uncertain revenue models hinder large-scale deployment¹⁷. Three key business segments comprise this infrastructure (Control Module, Power Module, and V2G Charger & Connector), as listed in Table 2.1. Across these segments, various global players operate, primarily following a product-based business model as shown in Figure 2.1.

Table 2.1: Business Segments in V2G Charging Infrastructure

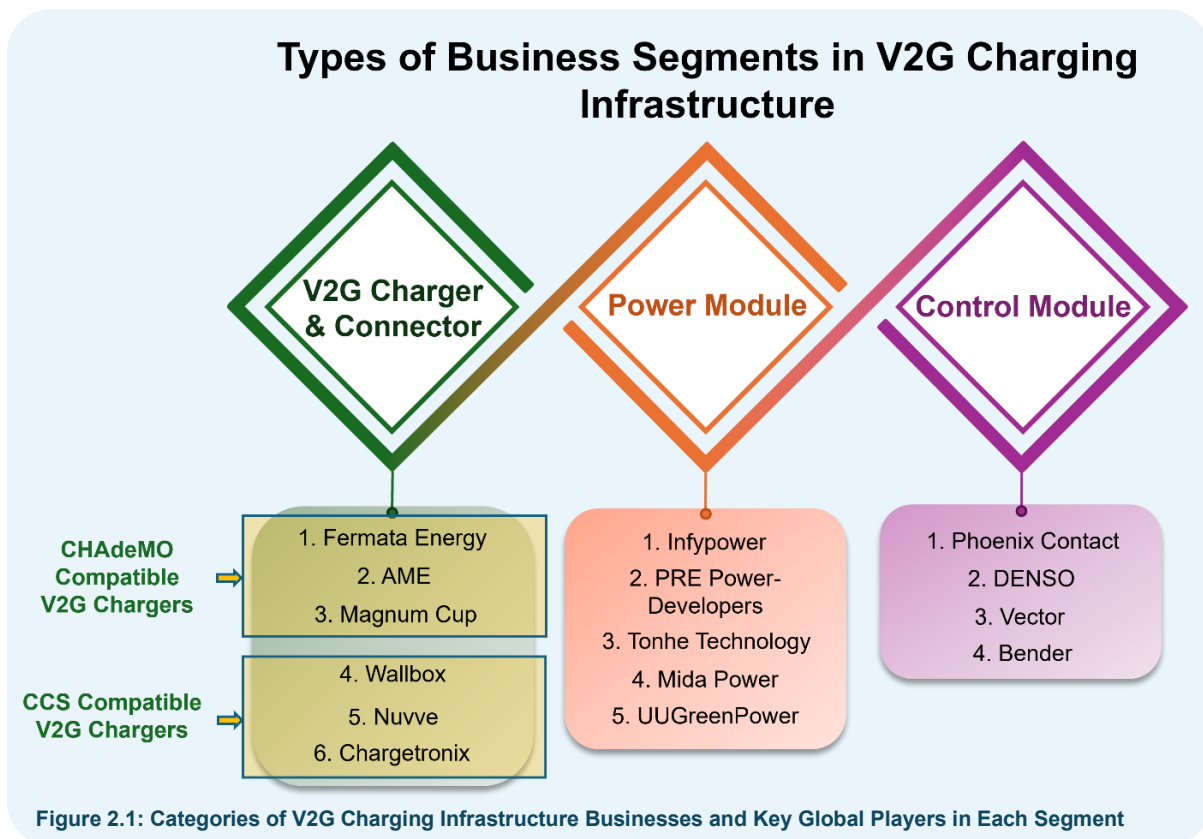
Business Segment	Description
Control Module	Develop electronic units for managing charging sessions and communication
Power Module	Provide bidirectional inverters and power conversion systems
V2G Charger and Connector	Integrate control and power modules into complete V2G chargers

¹⁴ Wang, D., Besselink, B., Johansson, K. H., and Han, Z. "Business Models for Vehicle-to-Grid Services: A Comprehensive Review." *Renewable and Sustainable Energy Reviews* 157 (2022): 112067.

¹⁵ International Energy Agency (IEA). *Global EV Outlook 2022*. Paris: IEA, 2022.

¹⁶ Noel, L., Zarazua de Rubens, G., Kester, J., and Sovacool, B. K. "Vehicle-to-Grid: A Sociotechnical Transition Beyond Electrical Mobility." *Energy Research & Social Science* 51 (2019): 110-123.

¹⁷ Liu, C., Chau, K. T., Wu, D., and Gao, S. "Opportunities and Challenges of Vehicle-to-Home, Vehicle-to-Vehicle, and Vehicle-to-Grid Technologies." *Proceedings of the IEEE* 101, no. 11 (2013): 2409-2427.



2.1.1 V2G Charger and Connector

1. Market Growth of V2G Chargers

The V2G Charger Market is projected to experience significant growth from 2022 to 2032¹⁸, driven by increasing adoption of electric vehicles and advancements in charging infrastructure. The market is segmented based on power output into Level 1 (up to 2 kW), Level 2 (3-22 kW), and Level 3 (above 22 kW), with Level 3 chargers expected to dominate due to their

high efficiency and faster charging capabilities. The market is forecasted to grow at a CAGR of 19.5% from 2024 to 2032, reaching approximately USD 1,700 million by 2032¹⁸. Figure 2.3 illustrates this projected growth, while Figure 2.2 shows the V2G charger market share in Europe. The European V2G charger market has grown from 125.2 million in 2022 to 125.2 million in 2023¹⁸ and is expected to reach 300 million by 2032. This growth reflects the increasing adoption of V2G technology and investment in smart charging infrastructure across the region¹⁸.

¹⁸ Global Market Insights. Vehicle-to-Grid (V2G) Chargers Market - By Power Output, By Charging Mode (AC Charging, DC Charging), By Vehicle (Battery EVs, Plug-in Hybrid EVs, Fuel Cell Vehicles), By Communication Technology, By Application & Forecast, 2024 - 2032. Global Market Insights, 2024.

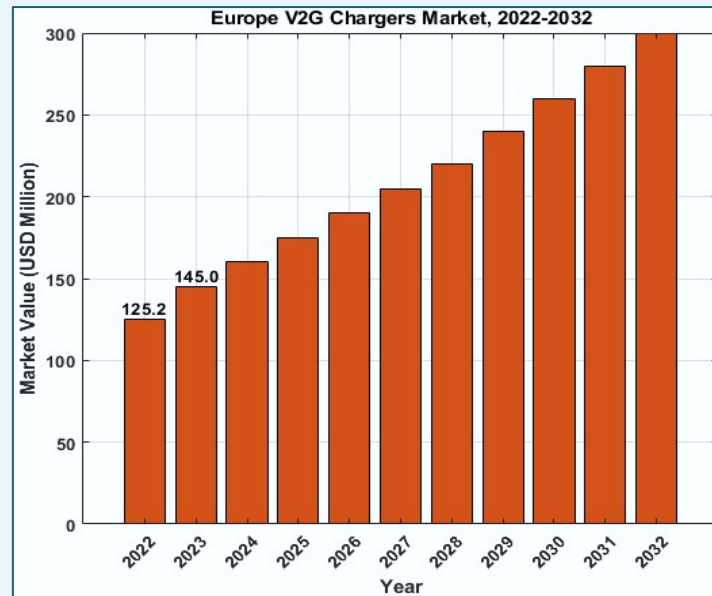


Figure 2.3: Europe V2G Chargers Market

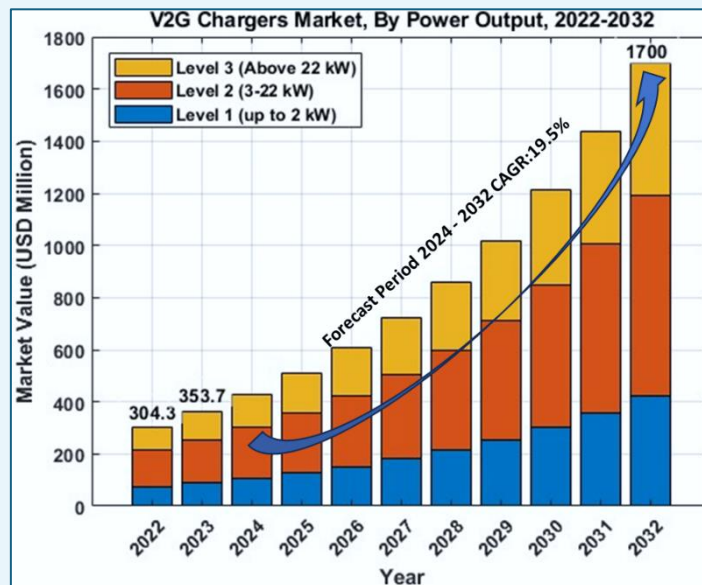


Figure 2.2: V2G Charger Market Growth Projection

2. Global Business Model for V2G Charger

The V2G Charger Market consists of multiple manufacturers producing chargers compatible with CHAdeMO and CCS standards, serving various global markets¹⁹. For CHAdeMO-Compatible V2G Chargers, key manufacturers include ABB, AME, Fermata Energy, Magnum Cap, and

Tsubakimoto. For CCS-Compatible V2G Chargers, manufacturers include Wallbox, Nuvve, Infypower, Chargetronix, and Tellus Power Green. These chargers are designed for EV manufacturers, fleet operators, charging network providers, utilities, and grid operators. They enable bidirectional power flow, ensuring compliance with global standards like ISO 15118, CHAdeMO, OCPP (Open Charge Point Protocol), and

¹⁹ Mouli, G. R. C., J. Kaptein, P. Bauer, and M. Zeman. "Implementation of Dynamic Charging and V2G Using CHAdeMO and CCS/Combo DC Charging Standard." In Proceedings of the 2016 IEEE Transportation Electrification Conference and Expo (ITEC), 1-6. Dearborn, MI, USA: IEEE, 2016.

integrating with energy management platforms. These chargers facilitate bidirectional charging solutions across their respective markets, supporting grid optimization, energy cost reduction, and renewable energy management. Both categories operate within a product-based

V2G business model as shown in Table 2.2, focusing on developing hardware and software solutions. As V2G adoption grows, these technologies will play a crucial role in creating a more resilient and sustainable energy infrastructure.

Table 2.2: Global Business Model for V2G Charger

Type of V2G Charger	Manufacturer	Markets covered	Who	What	How	The Value	Business model
CHAdeMO-Compatible V2G Chargers	ABB	Worldwide	EV manufacturers, fleet operators, charging network providers, utilities, grid operators, and businesses adopting bidirectional energy solutions	Design, development, and deployment of V2G-compatible chargers that support bidirectional power flow	Manufacturing hardware and software-integrated charging solutions, ensuring compliance with global standards like ISO 15118 (for CCS), CHAdeMO, OCPP, and energy management platforms for seamless grid communication and operation	Facilitates grid stability, reduces charging costs for EV users, supports renewable energy integration, and enables EVs as distributed energy resources, contributing to a sustainable energy ecosystem	Product Based
	AME	Europe					
	FERMATA ENERGY	United States					
	Magnum Cap	EU					
	TSUBAKIMOTO	Japan					
CCS-Compatible V2G Chargers	Wallbox (Quasar 2)	United States					
	Nuvve Holding Corp	North America and Europe					
	Infypower	China					
	Chargetronix	North America and Europe					
	Tellus Power Green	United States					

2.1 Business Model Canvas of Key Players

Business Model Canvas of TSUBAKIMOTO (a CHAdeMO-Compatible V2G Charger Manufacturer)				
Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- CHAdeMO Association (for standardization) - EV OEMs (e.g., Nissan compatibility) - Power companies in Japan for grid integration pilots - IoT & EMS solution providers	- V2X product development & certification (CHAdeMO) - Quality manufacturing and system testing - Grid integration pilots (e.g., through regional utilities) - Partner onboarding & training	- V2G, V2H, V2B through a 5kW CHAdeMO-certified bidirectional charger - Grid support, energy savings, backup supply - Uses SiC semiconductors for high efficiency - Smart integration with IoT, meters, EMS	- Dedicated technical support - Custom integration and training services - Co-development projects with utilities and fleets - System performance feedback loops	- Commercial and industrial energy consumers - EV fleet operators - Utilities & energy service companies - Homeowners V2G compatible EV's
	Key Resources		Channels	
	- R&D team in V2X technology - Patents related to energy control & SiC power semis - Manufacturing plants in Japan - Strong distribution and partner network		- Direct B2B sales via corporate outreach - Integration with energy companies & resellers - Showcased at exhibitions (e.g., Smart Grid Expo) - Joint marketing with OEMs and energy firms	
Cost Structure			Revenue Streams	
- R&D (semiconductors, bidirectional tech) - Production and quality assurance - Marketing and partner support - After-sales services and field maintenance			- Product Sales: eLINK charger units ((priced around ₹3.3–₹4.5 lakh) - Service Contracts: Installation, O&M	

Business Model Canvas of Nuvve Holding Corp. (a CCS-Compatible V2G Charger Manufacturer)

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- EV Manufacturers - Utility Companies - Charging Infrastructure Providers - Energy Management System Developers - Government and Regulatory Agencies	- V2G Technology Development - Deployment of V2G Charging Stations - Fleet Electrification Services - Energy Market Participation	- Grid Stabilization - Cost Savings - Environmental Impact Reduction - Revenue Generation for EV Owners through Grid Services	- 24/7 Technical Support - Customer Training Programs - Consulting Services - Consulting Services for Energy Management	- Commercial Fleet Operators - Utility Companies - Government Agencies - Individual EV Owners
	Key Resources - Proprietary V2G Platform (GIVe™) - Strategic Partnerships - Expert Engineering and Development Team - Intellectual Property Portfolio (16 active patents)		Channels - Direct Sales Team - Online Platform - Industry Events and Trade Shows - Collaborative Projects and Joint Ventures	
Cost Structure		Revenue Streams		
- Research and Development (R&D): \$0.8 million in Q4 2024, a 61.3% decrease from \$2.0 million in Q4 2023 - Selling, General, and Administrative Expenses: \$5.1 million in Q4 2024, down from \$5.9 million in Q4 2023 - Cost of Product and Service Revenues: \$1.5 million in Q4 2024, an increase of \$0.3 million compared to Q4 2023		- Hardware Sales (DC and AC Chargers): \$1.18 million in Q4 2024 - Engineering Services: \$0.51 million in Q4 2024 (Income from providing turnkey electrification solutions, including infrastructure design, installation, and integration services) - Grid Services: \$0.01 million in Q4 2024 (Revenue from enabling EVs to supply energy back to the grid, offering services like frequency regulation and demand response)		

3. Global Business Model for CHAdeMO Connector

The Global Business Model for CHAdeMO Connectors operates on a product-based approach as shown in Table 2.3, where key manufacturers E-valucion, Electway Electric, Fujikura, JAE, Sam Woo Electronics, Yazaki

Corporation, and Sumitomo Electric. They supply their products across various regions, including North and South America, Europe, Asia, Africa, and Oceania.

These companies primarily cater to EV charger manufacturers and charging infrastructure providers (B2B model).

Table 2.3: Global Business Model for CHAdeMO Connector

Manufacturer	Markets covered	Who	What	How	The Value	Business model
E-valucion	North and South America, Europe, Africa	EV CHAdeMO charger manufactures (B2B Model)	Production and supply of CHAdeMO-compatible	Manufacturing and distributing standard-compliant	Enables fast DC charging, supports V2G	Product Based
Electway Electric	Global					

Fujikura	Europe, North & South America, Asia, Africa, Australia & Oceania		charging connectors for DC fast-charging stations	CHAdeMO connectors through direct sales and partnerships with charging infrastructure providers	applications, and ensures compatibility with CHAdeMO-based EVs	
JAE	Europe, North America, Asia, Oceania					
Sam Woo Electronics	Asia					
Yazaki Corporation	Japan, Europe, and North America					
Sumitomo Electric	Europe, North & South America, Asia, Africa, Oceania					

3.1 Business Model Canvas of Key Players

Business Model Canvas of Sumitomo Electric (a CHAdeMO Connector Manufacturer)				
Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- Automotive Manufacturers - Research Institutions - Government Agencies - Suppliers (Sumitomo Electric adheres to CSR Procurement Guidelines, ensuring that its suppliers engage in environmentally responsible practices)	- Research & Development (Innovations in EV Connectors and Power Cables) - Production of CHAdeMO Connectors (SEVD™-V3) - Quality Control - Supply Chain Management	- Reliable EV Charging Solutions (SEVD™ series of CHAdeMO-compliant connectors, such as the SEVD™-02 and SEVD™-11U, are designed for durability and user-friendliness) - Integrated Infrastructure - Sustainable Practices - Technological Innovation	- Technical Support - Collaborative Development - Feedback Mechanisms	- Automotive OEMs - Utility Companies - Infrastructure Developers - Government Bodies
	Key Resources		Channels	
	- Manufacturing Facilities - Skilled Workforce - Intellectual Property - Global Network		- Direct Sales - Online Platforms - Trade Shows - Partnerships	
Cost Structure		Revenue Streams		
- Research & Development Expenses (₹7,810 crore in FY-2023) - Manufacturing Costs (₹10,659 crore in FY-2023) - Logistics (Logistics costs rose by ₹1,375 crore in FY2023)		- Product Sales: CHAdeMO Connectors and EV Components (Sumitomo Electric has delivered over 27,000 units of its SEVD series CHAdeMO-compliant high-power charger connector assemblies, primarily in Europe, the U.S., and Japan) - Project Contracts - Licensing: Patented Technologies and Designs (The company signed a licensing agreement with Soitec to utilize Smart Cut™ technology for manufacturing engineered gallium nitride (GaN) substrates, which are crucial for high-performance electronic applications) - Maintenance Services: Ongoing Support and Product Servicing		

Business Model Canvas of Yazaki Corporation (a CHAdeMO Connector Manufacturer)

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- Automotive OEMs - CHAdeMO Association - Charging Infrastructure Providers (Joint development agreement to develop and market Plugless Power™ technology, a hands-free charging system for EVs) - Suppliers (Yazaki Europe's Supplier Quality Manual outlines the company's expectations for suppliers, including adherence to chemical regulations and CSR policies)	- Product Development - Manufacturing - Quality Assurance - Research and Development	- Reliable Charging Solutions - Compliance with International Standards - Innovation in Connector Design (Innovations include ergonomic grip shapes for ease of use, high-flexibility cabtire cables for better manoeuvrability, and features like solenoid locking mechanisms to ensure secure connections) - Global Reach	- Technical Support - Collaborative Development (Custom Connector Design) - Feedback Mechanisms (Customer Satisfaction Initiatives and Digital Collaboration Platforms)	- Automotive OEMs - Charging Station Operators - Government Bodies
	Key Resources - Manufacturing Facilities - Skilled Workforce - Intellectual Property (Innovations in connector fitting structures, conductor members with cooling structures, and electrical connection boxes) - Global Network (Operating in 46 countries and regions with 141 companies and employing over 241,000 individuals)		Channels - Direct Sales - Online Platforms - Trade Shows (CHAdeMO- EVS27 Exhibition) - Partnership	
Cost Structure		Revenue Streams		
- Research & Development Expenses - Manufacturing Costs - Logistics - Compliance		- Product Sales (Yazaki contribution to EV industry projected to reach USD 10.4 billion by 2032) - Project Contracts (Company has invested in the construction of a €30 million factory in Egypt, aimed at producing automotive components) - Licensing - Maintenance Services		

2.1.2 Control and Power Modules

Power and control modules primarily follow a product-based business model as shown in **Error! Reference source not found.**, though control modules can also be integrated into service-based solutions.

Leading manufacturers for Power Modules are Infypower (China), PRE Power-Developers (Netherlands), Tonhe Technology (China), MIDA Power (China), and UUGreenPower (China). They develop

bidirectional AC-DC and DC-DC power modules with various power and voltage levels. These modules support efficient energy transfer between EVs and the grid. Manufacturers like Bender (Germany), Vector (Germany), Phoenix Contact (Germany & U.S.), and Denso (Japan) specialize in V2G control modules that enable safe and seamless EV-grid integration. Their offerings include insulation monitoring systems, smart charging communication controllers, and power control units.

Table 2.4: Global Business Model for Power and Control Modules

Module	Manufacturer	Markets covered	Who	What	How	The Value	Business model
Power Modules	Infypower	China	EV charger manufacturers, grid operators	Bidirectional AC-DC Power Modules in various power and voltage levels, including 62.5 kW and 22 kW at 1000V, and 15 kW at 750V. Additionally, Bidirectional DC-DC Power Modules are offered at 15 kW at 750V	Provides high-reliability and efficient power modules	Enhances reliability and efficiency in V2G energy exchange	Product Based
	PRE Power-Developers	Netherlands	Energy companies, grid operators	V2G Charger Module: 10kW and 6kW, compatible with a DC voltage range of 50-500V	Develops advanced power electronics for energy exchange	Supports grid integration and smart energy management	Product-Based
	Tonhe Technology	China	EV charger manufacturers, power utilities	15kW Bidirectional DC/DC EV Power Module for Charger	Enables bidirectional energy flow between EVs and grid	Improves grid interaction and EV charging efficiency	Product-Based
	MIDA Power	China	EV charging infrastructure providers	20kW and 30kW Bidirectional DC/DC Power Modules, along with a 62.5kW Bidirectional AC/DC Converter (BEG1K0110G)	Supports energy transfer between vehicles and grid	Facilitates rapid deployment of V2G technology	Product-Based
	UUGreenPower	China	EV charger manufacturers, energy companies	UBR100030: 30kW Bidirectional AC/DC Power Module with a wide output voltage range of 150V to 1000V	Facilitates efficient energy exchange in V2G infrastructure	Enhances grid stability and energy efficiency	Product-Based

Control Modules	Bender	Germany	Grid operators, electrical safety regulators	Bender offers ISOMETER® isoCHA425HV for insulation monitoring, RCMBs for residual current detection, and the CC613 Charge Controller for AC charging management.	Ensures safe and reliable energy transfer	Ensures electrical safety in V2G systems	Product and Service Based
	Vector	Germany	Automotive manufacturers, EV technology providers	vSECC (Supply Equipment Communication Controller) for managing EV-grid communication, VC36PLC-24, a smart charging ECU for Power Line Communication, and VC-EVCC (Electric Vehicle Communication Controller) for secure and efficient V2G interactions.	Develops communication tools for seamless V2G integration	Optimizes EV-to-grid communication and operation	Product and Service Based
	Phoenix Contact	Germany, U.S.	EV charger manufacturers, grid operators	Vehicle charging controllers and AC charging controllers for charging stations and home chargers	Provides hardware solutions for bidirectional energy transfer	Enables seamless bidirectional energy flow	Product-Based
	Denso	Japan	Automotive manufacturers, energy companies	Power Control Unit (PCU) for use in motor-driven hybrid and electric vehicles	Advances EV-grid interaction with innovative components	Enhances EV-grid compatibility and smart charging	Product-Based

1. Business Model Canvas of Key Players

Business Model Canvas of UUGreenPower (V2G Power Module Manufacturer, China)				
Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- EV charger manufacturer (Primarily customers who integrate UBR100030 modules into their chargers) - Energy storage system integrators (Use bidirectional modules in stationary V2G-enabled systems) - V2G technology firms (Partners for software/ protocol compliance) - Component suppliers (Provide key semiconductors, casings, and PCB components)	- R&D in bidirectional power electronics (Core for innovation and maintaining voltage/ power needs (Common in B2B power electronics (e.g., different EV/ ESS specs)) - Compliance with grid standards	- 30 kW bidirectional AC/ DC module - Wide voltage range (150V-1000V) - Enables compatibility with various EV battery systems - Efficient and stable V2G operations - Compact, modular, scalable design (Enables charger manufacturers to easily integrate and scale solutions)	- Technical support & integration assistance - Long-term OEM partnerships - Lifecycle service & warranty support	- EV charger manufacturers (Primary B2B customer) - Energy companies (Use in energy storage + grid V2G integration) - Charging infrastructure providers (Deploy UUGreenPower modules in field-ready stations) - Grid service integrators (Use modules for DER integrations and demand response systems)
	Key Resources		Channels	
	- Power electronics engineers - Advanced manufacturing facilities - Patents and modular design IP - Testing & QA labs		- Direct OEM sales (Standard for B2B high-value hardware sales) - Industry exhibitions (e.g., EV expos, energy forums) - Website and product brochures - Distributor/ reseller network	
Cost Structure		Revenue Streams		
- R&D and product testing - Manufacturing and quality control - Supply chain and logistics - After-sales service and support		- Sale of power modules (Primary revenue source, offering various power modules suitable for different applications) - Custom engineering services - OEM bulk orders (Collaborates with manufacturers and suppliers to deliver products in bulk, catering to large-scale operations) - Licensing of modular design IP		

2.2 V2G Capable Electric Vehicle Powertrain

There are two kinds of businesses possible in terms of powertrain, one which is specifically made by OEMs for their V2G capable electric vehicles, and other is powertrain which is being made by other OEMs in B2B type business models. Both business types follow product-based

business model as shown in **Error! Reference source not found..**

2.2.1 Types of business model

1. OEM-Specific Powertrains

These are powertrains developed by OEMs specifically for their own V2G-capable electric vehicles.

These are proprietary designs optimized for the automaker's V2G ecosystem.

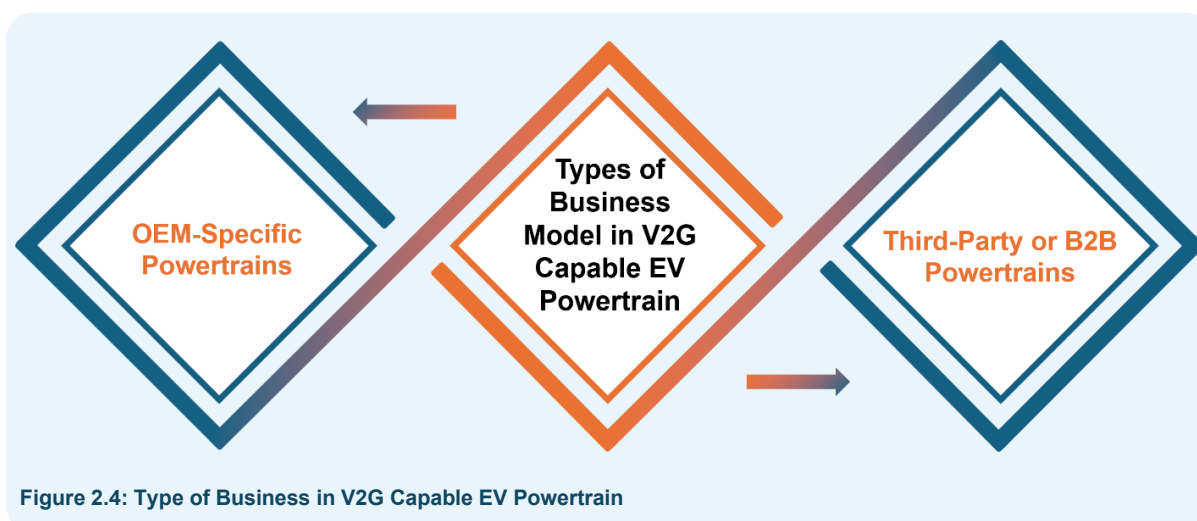


Table 2.5: OEM-Specific Powertrains

Manufacturer	Markets covered	Who	What	How	The Value	Business model
Nissan	Europe, North America, Japan, and parts of Asia	Automakers manufacturing V2G-compatible EVs for consumers, fleet operators, and commercial entities requiring bidirectional charging for smart grid integration (B2B & B2C).	Design and produce V2G-capable EVs that allow bidirectional power flow between the vehicle and the grid	Developing V2G-compatible EVs with built-in technology and ensuring compatibility with CCS or CHAdeMO standards, sold directly to consumers and fleet operators.	Empowers sustainable energy by turning EVs into mobile energy storage, supporting grid stabilization, renewable energy integration, and cost reduction through active participation in the energy ecosystem.	Product Based
Mitsubishi	Europe, North America, Asia, and Australia					
Honda	Europe, Japan					
BMW	Europe, North America, and Asia					
Volkswagen	Europe, North America, and parts of Asia					
Tesla	North America, Europe, China, and parts of Asia					
BYD	China, Europe, and parts of Asia					

2. Third-Party or B2B Powertrains

These are powertrains developed by other OEMs or independent suppliers, intended for business-to-business (B2B) applications.

This could include powertrains supplied to fleet operators, commercial EV manufacturers, or other vehicle makers that do not develop their own V2G capable powertrain.

Table 2.6: Third-Party or B2B Powertrains

Manufacturer	Markets covered	Who	What	How	The Value	Business model
ElectronEV	United States, India	Software driven powertrain for EV manufacturers	800V SiC Platform for Bi-Directional Power Transfer of upto 300 kW	V2V and V2G compatible with Power density of 10 kW/kg. Digitally controlled & calibrated to user's requirements	Smart, robust, reliable, scalable & cost effective, advanced technology ensuring high performance and reliability for bi-directional power transfer	Product Based

1. Business Models Canvas of Key Players

Business Model Canvas of Nissan (a V2G EV Manufacturer)				
Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- Utility Companies (Nissan has collaborated with E.ON in the UK on the e4Future project, deploying 20 V2G chargers for field demonstration) - Technology Firms (A joint venture between EDF and Nuvve, Dreev working with Nissan to develop V2G solutions, including data collection and charging/discharging plans) - Research Institutions - Government Agencies - Automotive Manufacturers (Nissan joined ChargeScape, a joint venture with BMW, Ford, and Honda to develop software platforms facilitating V2G services.	- Product Development - Infrastructure Deployment - Software Integration - Customer Education - Disaster Response and Energy Resilience - Global Pilot Projects	- Energy Cost Savings - Grid Stability - Sustainability - Emergency Power Supply - Support for Renewable Energy Integration - Economic Opportunities for EV Owners	- Technical Support - Collaborative Development - Feedback Mechanisms	- Individual EV Owners - Fleet Operators - Utility Companies - Government and Public Sector Entities - Aggregators and Energy Service Providers
	Key Resources - Production Facilities - Human Capital - Intellectual Property - Global Presence		Channels - Direct Sales - Online Platforms - Trade Shows and Industry Events - Partnerships - Utility Collaborations - Mobile Applications	
Cost Structure			Revenue Streams	
- R&D Expenses (In the nine months ending December 31, 2023, Nissan invested ₹281.75 billion in R&D, focusing on advancements in battery technologies and modular powertrains) - Manufacturing Costs - Infrastructure Deployment (Nissan plans to offer its AC bi-directional V2G chargers at prices comparable to conventional home chargers, significantly lowering the cost barrier for consumers) - Compliance and Certification (Nissan has achieved ENA Engineering Recommendation G99 certification in the UK for its AC-based V2G solution, allowing compliant export of electricity from EVs to the national grid)			- Vehicle Sales: Nissan has sold over 650,000 LEAF models globally, many equipped with V2G capabilities. - Energy Transactions (a Nissan LEAF owner in Australia reported making around ₹2,13,450 annually by exporting excess power to the grid) - Software Services (Nissan holds a 25% stake in ChargeScape focusing on software that manages EV charging and V2G operations) - Maintenance Services	

2.3 Battery Management System

Battery Management Systems are essential in the automotive sector, particularly for EVs and hybrid vehicles²⁰. With the rise of V2G technology, the role of BMS has expanded beyond just battery monitoring and protection during energy exchange between vehicles and the grid. Table 2.5 highlights the differences between standard

automotive BMS and V2G-compatible BMS. This shift opens new business opportunities in the BMS ecosystem. The market size for BMS is expected to reach 11.7 billion USD by 2028, growing at a rate of 19.8% annually²¹. Additionally, long-term projections indicate that the BMS market will surpass 16 billion USD by 2032, showing sustained growth in demand¹⁶. This section explores the potential business opportunities related to BMS and how its landscape will evolve with V2G.

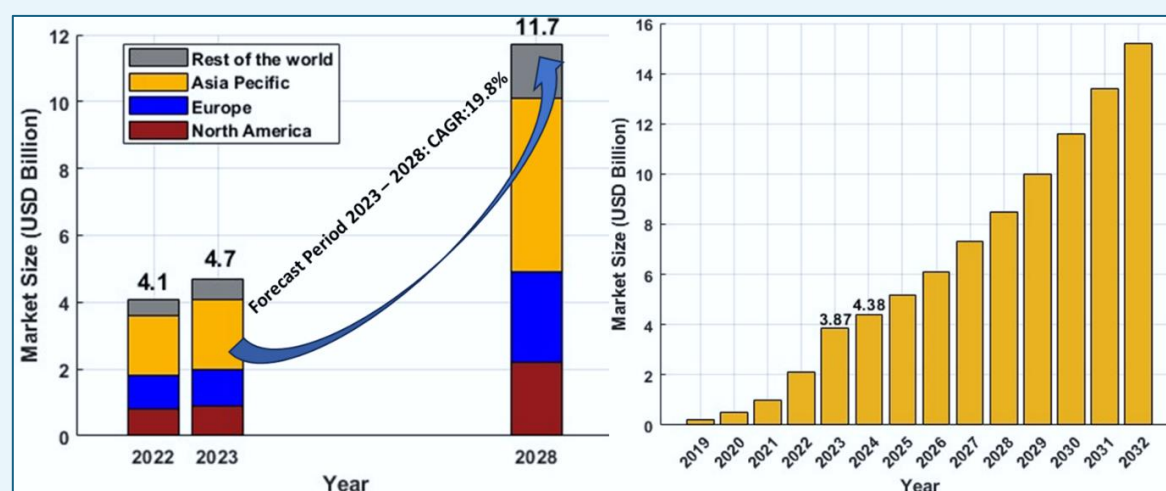


Figure 2.5: Market Size¹⁶

2.3.1 Difference Between V2G-Specific BMS and Standard Automotive BMS

While traditional automotive BMS focuses solely on managing battery charging and discharging for driving applications, V2G-specific BMS extends its functionality to

enable bi-directional energy flow, allowing vehicles to interact with the power grid.

This key distinction enables V2G-enabled vehicles to support grid stability through demand response, frequency regulation, and energy storage services. The following Table 2.7, outlines the major differences between these two types of BMS:

²⁰ Cheng, K. W. E., B. P. Divakar, H. Wu, K. Ding, and H. F. Ho. "Battery-Management System (BMS) and SOC Development for Electrical Vehicles." IEEE Transactions on Vehicular Technology 60, no. 1 (January 2011): 76-88.

²¹ MarketsandMarkets. Automotive Battery Management System Market Size, Share & Industry Analysis by Battery Type (Lithium-ion, Lead-acid, Nickel-based, Solid-state), Topology (Modular, Centralized, Distributed), Application (Passenger Vehicles, Commercial Vehicles), and Region—Global Forecast to 2028.

Table 2.7: Difference between V2G BMS and Non-V2G BMS

Feature	V2G BMS	Non-V2G BMS
Functionality	Manages both charging and discharging ²²	Manages only charging ²³
Grid Interaction	Actively communicates directly/indirectly with the grid to provide services like demand response and frequency regulation ²⁴ .	No interaction with the grid; focuses solely on vehicle energy management ²³ .
Communication Protocols	Utilizes advanced protocols such as ISO 15118 for secure communication between the vehicle and the grid ²⁴ .	Primarily uses internal communication protocols like CAN bus for monitoring and control within the vehicle ²³ .
Compliance & Regulations	Must adhere to grid codes and power quality standards to ensure safe and efficient energy exchange ²⁵ .	Designed to meet internal vehicle safety and performance standards without external grid considerations ²³ .
Hardware Requirements	Requires bidirectional inverters and additional safety features to manage energy flow to and from the grid ²⁵ .	Equipped with standard BMS components focused on battery monitoring and protection ²³ .
Energy Services	Provides services such as frequency regulation, peak shaving, and demand response to support grid stability ²⁴ .	Does not offer grid services; solely manages the vehicle's battery for driving purposes ²³ .
Power Conversion	Works with bidirectional chargers capable of both AC-DC and DC-AC conversion ²⁶ .	Utilizes unidirectional chargers that convert AC to DC for battery charging ²³ .
Battery Utilization	Optimizes battery usage for both driving and grid services, potentially increasing battery cycling ²⁷ .	Focuses on battery health and efficiency primarily for driving, with controlled charging cycles ²³ .
Use cases	Ideal for applications like fleet management and grid-support services where vehicles can act as energy storage assets ²⁶ .	Suited for personal transportation without the need for grid interaction ²³ .

2.3.2 Automotive BMS Market Segments and Key Players

The BMS industry is evolving rapidly, driven by advancements in hardware, software, and regulatory frameworks.

Companies are focusing on battery optimization, predictive maintenance, energy management, and second-life applications, creating new opportunities for innovation and business growth in the electric vehicle and energy storage sectors.

²² "Vehicle-to-Grid (V2G): Everything You Need to Know," Virta, [Link](#)

²³ "Battery Management System (BMS): What Is It?" Synopsys, [Link](#)

²⁴ "The Ultimate Guide to Vehicle-to-Grid (V2G)," Enode, [Link](#)

²⁵ "Technical Requirements of Vehicle-to-Grid (V2G) Technology," CleanTech Controls, [Link](#)

²⁶ "Bidirectional Charging and Electric Vehicles as Mobile Storage," U.S. Department of Energy, [Link](#)

²⁷ "Technical Requirements of Vehicle-to-Grid (V2G) Technology," CleanTech Controls, accessed March 2, 2025, [Link](#)

1. Automotive BMS Market Segments

The chart shown in Figure 2.6 categorizes these developments into key areas, highlighting major companies that contribute to different aspects of BMS, from battery analytics and charging optimization to regulatory compliance and second-life applications²⁸. This segmentation provides insight into the diverse business opportunities within the BMS ecosystem.

2. Key Players

The BMS industry is evolving with diverse business models, including hardware

development, software solutions, aftermarket services, and regulatory compliance.

Companies are integrating AI-driven analytics, predictive maintenance, and cloud-based monitoring to optimize battery performance and sustainability²⁹. Some focus on direct BMS hardware sales, while others offer data-driven software platforms and energy management solutions.

As the industry grows, collaborations among automakers, battery manufacturers, and energy providers are shaping the future of EV and V2G technology. Table 2.8 highlights key market segments and industry leaders.

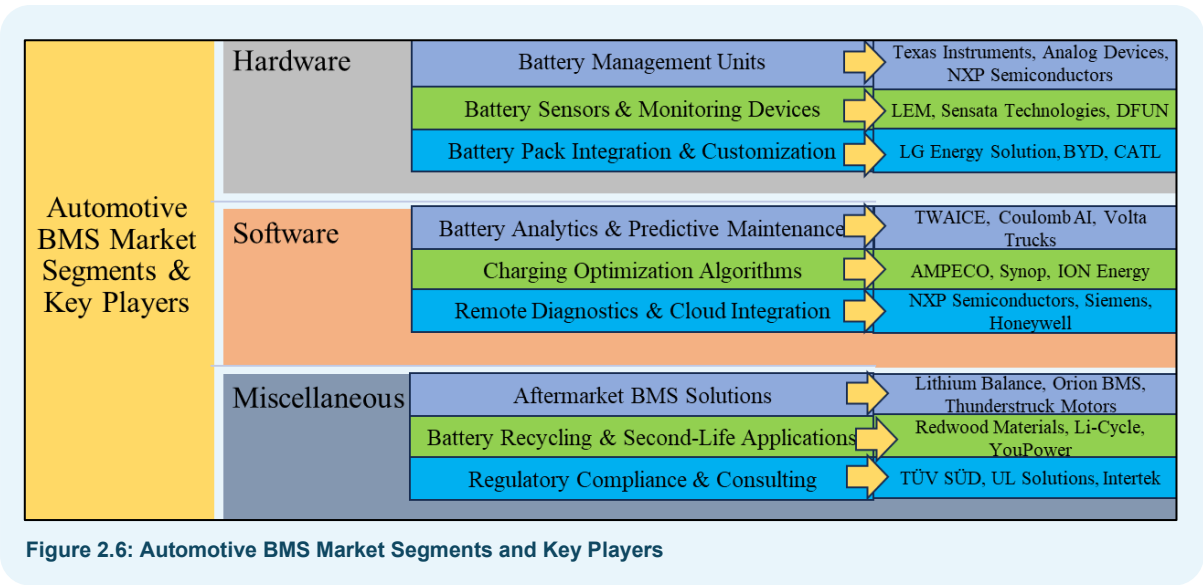


Figure 2.6: Automotive BMS Market Segments and Key Players

Table 2.8: Global Players and Business Model in BMS Business

OEM	Country of Operation	Who	What	How	The Value	Business Model
Texas Instruments	USA	EV manufacturers, battery producers	Battery Management Units (BMUs)	B2B sales to EV manufacturers and integrators	Reliable BMS hardware for EVs	Product

²⁸ MarketsandMarkets. Automotive Battery Management System Market Size, Share & Industry Analysis by Battery Type (Lithium-ion, Lead-acid, Nickel-based, Solid-state), Topology (Modular, Centralized, Distributed), Application (Passenger Vehicles, Commercial Vehicles), and Region—Global Forecast to 2028.

²⁹ Ismail, M., and R. Ahmed. "A Comprehensive Review of Cloud-Based Lithium-Ion Battery Management Systems for Electric Vehicle Applications." IEEE Access 12 (2024): 116259-116273.

Analog Devices	USA	Automakers, battery companies	BMUs and ICs for EV battery systems	Direct supply to OEMs and component makers	Advanced BMUs for high-performance batteries	Product
NXP Semiconductors	Netherlands	EV OEMs, component suppliers	Smart BMS solutions	Licensing BMS technology & hardware sales	Smart battery management & energy efficiency	Product
LEM	Switzerland	Automotive OEMs, EV battery producers	Battery sensors, current monitoring devices	Selling sensors and monitoring devices	Accurate battery monitoring & fault detection	Product
Sensata Technologies	USA	OEMs, fleet operators	Battery monitoring solutions	Providing real-time data solutions	Real-time battery diagnostics	Product
DFUN	China	Battery manufacturers, EV makers	BMS hardware & sensors	OEM partnerships and direct sales	Affordable BMS components	Product
LG Energy Solution	South Korea	EV manufacturers, energy storage providers	Battery pack solutions with integrated BMS	OEM collaborations & direct sales	Integrated BMS solutions for enhanced battery life	Product
BYD	China	OEMs, energy firms	Integrated BMS for EV battery packs	In-house EV battery integration	Efficient and safe EV battery solutions	Product
CATL	China	Automakers, fleet operators	Custom BMS for automakers	Partnerships with global automakers	Customized BMS for automakers	Product
TWAICE	Germany	EV fleet operators, OEMs	Battery analytics and predictive maintenance	Subscription-based analytics platform	Increased battery lifespan & reliability	Subscription
Coulomb AI	India	Battery analytics users, OEMs	Battery observability and optimization	Cloud-based predictive BMS solutions	Real-time analytics for battery health	Subscription
Volta Trucks	Sweden	Fleet owners, logistics firms	Fleet battery monitoring via AI	AI-based fleet monitoring software	Optimized fleet operations	Subscription

AMPECO	Bulgaria	Charging infrastructure operators, fleet owners	Charging optimization software	Cloud-based charging optimization	Energy-efficient charging for EVs	Service
Synop	USA	Fleet operators, utility providers	AI-driven charging solutions	Fleet integration services	Reduced fleet energy costs	Service
ION Energy	India	EV charging network operators	Smart charging software	Software licensing & cloud platform	Improved EV charging efficiency	Service
NXP Semiconductors	Netherlands	OEMs, EV developers	Remote diagnostics & cloud-based BMS	Software-as-a-Service (SaaS) for diagnostics	Enhanced battery performance via cloud analytics	Shared Assets
Siemens	Germany	Automakers, battery manufacturers	Digital twin solutions for BMS	Digital twin simulations & integration	Simulation-driven battery management	Shared Assets
Honeywell	USA	Industrial energy firms, fleet owners	Remote battery monitoring and maintenance	Subscription-based maintenance & diagnostics	Preventive maintenance & battery safety	Subscription
LiTHIUM BALANCE	Denmark	Battery pack manufacturers, retrofitters	Aftermarket BMS for various applications	BMS hardware sales & retrofitting	Affordable aftermarket BMS for old EVs	Product
Orion BMS	USA	EV modders, retrofitters	Universal BMS for multiple chemistries	Direct sales and distributor partnerships	Flexible BMS solutions for any chemistry	Product
Thunderstruck Motors	USA	DIY EV builders, conversion shops	BMS for DIY and retrofitting	Selling DIY kits & retrofit solutions	DIY & conversion-friendly BMS	Product
Redwood Materials	USA	Recyclers, energy storage firms	Battery recycling and second-life applications	Battery material recovery & reuse	Sustainable battery disposal & reuse	Reselling
Li-Cycle	Canada	Battery producers, recyclers	Recycling of lithium-ion batteries	Recycling contracts with EV makers	Closed-loop recycling for EV batteries	Reselling

YouPower	China	Battery manufacturers, circular economy providers	Battery repurposing for energy storage	B2B partnerships for repurposed batteries	Extending battery lifecycle through repurposing	Reselling
TÜV SÜD	Germany	EV manufacturers, regulatory bodies	Regulatory compliance & safety certification	Testing, certification & compliance consulting	Ensuring EV battery safety & compliance	Agency/Promotion
UL Solutions	USA	Automakers, battery manufacturers	Battery safety testing & certification	Safety & compliance consulting services	Reducing risk via safety certifications	Agency/Promotion
Intertek	UK	OEMs, safety compliance teams	Global EV battery compliance solutions	Regulatory approvals & testing solutions	Facilitating global EV battery standards	Agency/Promotion

3. Business Model Canvas of Key Players

Business Model Canvas of Sensata Technologies (a BMS Manufacturer)				
Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- EV OEMs (e.g., Hyundai) - Battery Pack Manufacturers - Power Electronics Firms - V2G Technology Integrators - Tier-1 Automotive Suppliers	- Design and development of advanced and highly reliable BMS - Safety, diagnostics, and cell balancing features - Firmware updates and OEM-specific customization - Compliance with ISO 26262 and other global safety standards - Collaboration on V2G ready BMS	- Precision battery monitoring and advanced safety features - Enhanced battery life and performance optimization - V2G-ready BMS with fast communication protocols - Modular scalability across EV platforms - Proven global integration and OEM partnerships	- Technical collaboration with OEMs - Long-term B2B partnerships - After-sales engineering support - Co-development agreements for tailored BMS solutions	- EV OEMs - Battery pack manufacturers - Fleet vehicle integrators - Energy storage system providers - V2G platform providers
	Key Resources - Global manufacturing facilities - Dedicated R&D centers for EV systems - Proprietary sensor technologies - BMS software IP and communication stacks		Channels - Direct collaboration with OEMs and Tier-1 suppliers - Global sales and distribution network - Industry exhibitions and technical seminars - Online platforms for product information and engineering support	
Cost Structure		Revenue Streams		
- R&D Expenses (In 2023, Sensata Technologies invested \$179 million in R&D, focusing on innovations in hardware and software for BMS) - Manufacturing and Testing (Sensata operates manufacturing facilities in 12 countries, including the U.S., Mexico, China, Malaysia, and the U.K.) - Certification and Regulatory Compliance (The company ensures its products meet global safety and quality standards, such as ISO 26262 for functional safety and UL standards for product safety) - Partner Support and Customization Services		- Electrification Revenue (In 2023, Sensata's electrification segment, which includes BMS products, generated approximately \$700 million, marking a significant growth in this area) - Software and Firmware Licensing (Licensing revenue from proprietary software and firmware platforms) - Engineering Services for Custom Integration - Long-term Supply Agreements with OEMs		

Business Model Canvas of TÜV SÜD (a V2G Testing, Certification & Compliance Services Provider)

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- EV OEMs and Tier-1 Suppliers (for V2G-capable component testing) - Charging Infrastructure Manufacturers (e.g., AC/DC V2G charger vendors) - Battery and Energy Storage System Providers - Industry Alliances (e.g., CharIN) - Regulatory Bodies (e.g., national grid authorities and standards organizations)	- V2G Charger and EV Component Testing (Electrical Safety, EMC, Environmental Stress) - Certification Services for Compliance (e.g., IEC, ISO Standards) - Participation in Standardization Working Groups (e.g., ISO 15118, DIN, IEC) - Training and Knowledge Dissemination on Grid Compliance and Charging Standards	- Assurance of Safety, Reliability (comprehensive testing and certification services) - Accelerated Market Access via Globally Recognized Certification Marks - Independent Validation that Supports Regulatory Compliance and Brand Trust - End-to-End Testing Capabilities from Lab to Field Simulation	- Collaborative Engineering Engagements During Testing Phases - Technical Helpdesk & Post-Certification Support - Long-Term Certification & Recertification Partnerships with OEMs and Charger Makers	- EV Manufacturers and Tier-1 Suppliers - EVSE Manufacturers (AC/DC Chargers with V2G Capability) - Battery Manufacturers for Grid-Connected Systems - Utilities & Distribution System Operators (DSOs) Seeking Certified Grid-Interactive Systems
	Key Resources - Global Laboratory Infrastructure with EVSE and High-Voltage Testing Capabilities - Certified V2G Testing Personnel & Auditors - Accreditations (ISO/IEC 17025, etc.) Ensuring Global Recognition - Proprietary Testing Protocols (e.g., for Interoperability or Grid Compliance)		Channels - Direct B2B Client Services & Key Account Managers - Technical Web Portals for Bookings and Certifications - Industry Events & Alliances (e.g., Electric Vehicle Symposium, CharIN Conferences) - TÜV SÜD Academy for Training Programs	
Cost Structure		Revenue Streams		
- High Operational Costs for Running Accredited Labs and High-Voltage Test Benches (In 2022, TÜV SÜD invested €142.6 million in intangible assets and property, plant, and equipment) - Expert Staff & Continuous Technical Training (TÜV SÜD employs a global team of over 26,000 professionals, including highly skilled engineers and technical experts) - Standards Alignment and Protocol Development Costs - Global Compliance & Quality Assurance Systems		- Testing and Certification Fees (Main Revenue from V2G and EVSE Certification) (In 2023, the company achieved a total revenue of ₹3,048.5 crore, marking a 9.6% increase from the previous year. The Mobility segment, which encompasses services related to EVs and charging infrastructure, contributed approximately ₹1,042.9 crore to this total) - Custom Advisory Projects on Regulation, Safety, and Technical Design - Professional Training & Workshops for V2G Standards, Compliance, and Implementation		

Business Model Canvas of Redwood Materials (Battery Recycling & Circular Supply Chain Innovator)

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- Automotive OEMs (Toyota, Ford, Volkswagen, Audi, etc) - Battery Manufacturers (Panasonic (notably for Tesla), Envision AESC) - Consumer Electronics Companies (Amazon, Lyft) - E-Waste Recyclers (ERI) - Government Agencies: U.S. Department of Energy (DOE) - Strategic Investors (Breakthrough Energy Ventures, T. Rowe Price, Microsoft Climate Innovation Fund)	- Collection of end-of-life batteries and electronic waste - Recycling and refining of critical battery materials (e.g., lithium, cobalt, nickel) - Manufacturing of battery components, including cathode active materials - Research and development to enhance recycling efficiency and material recovery - Establishment and operation of battery materials campuses (e.g., Nevada and South Carolina facilities)	- Provision of a sustainable, domestic supply of critical battery materials - Reduction of environmental impact through high recovery rates (up to 95% for key materials) - Support for a circular economy by reintegrating recycled materials into new batteries - Enhancement of supply chain security and reduction of reliance on foreign sources - Contribution to cost reduction in battery manufacturing through material reuse	- Long-term partnerships with automotive and electronics manufacturers - Collaborative development agreements for sustainable material sourcing - Provision of customized recycling solutions and services - Engagement through environmental responsibility initiatives	- Automotive Manufacturers (Seeking sustainable battery material sourcing) - Battery Producers (Requiring refined materials for cell production) - Consumer Electronics Companies (Needing recycling solutions for electronic waste) - Government Agencies: Interested in domestic recycling capabilities - E-Waste Recyclers: Partnering for processing and material recovery
	Key Resources - Proprietary recycling and refining technologies - Experienced leadership team (e.g., founder JB Straubel) - Battery materials campuses with integrated operations - Strong network of industry partnerships and collaborations - Intellectual property related to recycling processes		Channels - Direct sales and partnerships with manufacturers - Collaborations with government programs and initiatives - Participation in industry events and conferences - Digital platforms for information dissemination and engagement	

Cost Structure	Revenue Streams
- Capital Expenditures for Facility Development and Equipment (Redwood Materials is investing ₹298.83 billion in constructing a battery materials campus in McCarran, Nevada, supported by a ₹170.76 billion loan from the U.S. Department of Energy) - Operational Costs Associated with Collection, Recycling, and Manufacturing (Redwood's extensive operations including processing approximately 75% of North America's lithium-ion batteries) - Research and Development Investments for Process Improvement (In April 2025, Redwood opened a 15,000-square-foot R&D center in San Francisco to advance battery recycling technologies) - Logistics and Transportation Expenses for Material Collection and Distribution - Labor Costs for Skilled Workforce and Technical Staff (As of late 2024, Redwood employs approximately 1,600 people, encompassing roles in engineering, operations, and technical fields)	- Sale of Recycled and Refined Battery Materials to Manufacturers (It generates revenue by selling recovered materials like lithium, nickel, and cobalt to battery manufacturers. In 2024, the company was on track to achieve ₹17.08 billion in revenue) - Service Fees for Recycling and Material Recovery Processes - Government Grants and Loans Supporting Sustainable Initiatives - Long-Term Contracts and Agreements with Industry Partners (The company has secured long-term supply agreements with major automakers, such as Toyota, to provide recycled materials for electric vehicle battery production) - Potential Licensing of Proprietary Recycling Technologies

Business Model Canvas of LiTHIUM BALANCE (Battery Management Systems Provider)

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- Battery Pack Manufacturers (IMECAR) - Retrofitters and OEMs (BD Auto) - Parent Company (Sensata Technologies)	- Design and Development (Creation of advanced BMS hardware and software solutions) - Manufacturing (Production of BMS units tailored for various applications) - Research and Development (Continuous innovation to enhance BMS performance and integration) - Customer Support (Providing extensive support from prototype to production stages)	- Advanced Monitoring (Ensuring safety, performance, and longevity of lithium batteries through sophisticated BMS solutions) - Customization (Providing tailored BMS solutions to meet specific customer requirements across various applications) - Reliability (Demonstrated expertise with over 700 customer projects worldwide, establishing a strong track record in the industry)	- Long-Term Partnerships (Building enduring relationships with manufacturers and retrofitters) - Collaborative Development (Working closely with clients to develop customized BMS solutions) - After-Sales Support (Providing ongoing assistance to ensure optimal product performance) - Training Programs (Educating customers on BMS integration and maintenance through tailored training sessions)	- Battery Pack Manufacturers - Retrofitters - Industrial Equipment Manufacturers - Energy Sectors
	Key Resources - Proprietary Technologies (Advanced BMS designs with proprietary algorithms for various applications) - Experienced Team (Over 15 years of expertise in battery management systems) - Manufacturing Facilities (HQ in Denmark and manufacturing partnership in India) - Global Network (Established distributors and partners across multiple regions) - Parent Company Support (Enhanced capabilities through Sensata Technologies' resources)		Channels - Direct Sales - Distributors (Utilizing third-party distributors to reach broader markets) - Online Platforms (Providing product information and support through the company website) - Industry Events - Training Sessions (Conducting workshops and seminars for customer education)	
Cost Structure - Research and Development - Manufacturing Costs (Expenses related to producing BMS units, including materials, assembly, and quality assurance) - Personnel Expenses (Salaries and benefits) - Marketing and Sales (Costs associated with promoting products and acquiring customers) - Operational Overheads (General administrative and facility-related expenses)			Revenue Streams - Product Sales - Software Licensing - Customization Services - Training Programs - Maintenance and Support	

Business Model Canvas of TWAICE (Battery Analytics & Predictive Maintenance Provider)

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- Automotive OEMs (Audi, BMW, Mercedes-Benz) - Fleet Operators (ViriCiti) - Insurance Providers: (Munich Re) - Cloud Service Providers (AWS)	- Battery Analytics Development - Digital Twin Modelling - Data Integration - Customer Support & Training	- Enhanced Battery Lifespan - Cost Reduction - Real-Time Monitoring - Warranty Management	- Subscription-Based Engagement (Software-as-a-Service (SaaS) model) - Collaborative Development (The platform's microservices architecture enables customers and partners to build solutions without managing underlying infrastructure) - After-Sales Support	- Automotive OEMs - EV Fleet Operators - Energy Storage Operators
	Key Resources - Proprietary Software (Advanced Analytics Platform Combining AI and Battery Expertise) - Expert Team (Skilled Professionals in Battery Technology and Data Analytics) - Cloud Infrastructure (Robust Cloud-Based Systems for Data Processing and Storage) - Research Facilities (In-House Laboratories for Battery Testing and Model Validation)		Channels - Direct Sales - Online Platforms - Partnerships - Conferences and Summits - Email Newsletters	
Cost Structure		Revenue Streams		
- Research and Development (In April 2022, the company raised ₹249 crore in Series B funding, totalling ₹622 crore, to enhance its cloud platform and expand in Europe and North America, including its Chicago office) - Personnel Expenses (As of December 31, 2023, TWAICE employed 58 individuals. Assuming an average annual salary of ₹66.4 lakh, the estimated annual personnel expenses would be approximately ₹38.5 crore) - Cloud Services (AWS cloud-native platform has improved the speed and accuracy of its data analytics by 300%, helping customers optimize battery usage) - Marketing and Sales - Operational Overheads		- Subscription Fees (TWAICE operates on a Software-as-a-Service (SaaS) model) - Customized Solutions - Consulting Services - Partnership Programs (Collaborations with other firms, such as the partnership with Modo Energy, allow TWAICE to integrate additional data and analytics capabilities)		

2.4 Bidirectional Energy Meter

A bidirectional energy meter is essential in V2G systems, as it accurately measures the flow of energy both to and from the grid. It

enables precise tracking of energy usage, billing, and grid interaction, ensuring fair compensation for EV owners participating in V2G services. By supporting smart energy management and grid stability, bidirectional energy meters play a key role in optimizing renewable energy integration and demand

response³⁰. Both Indian and global companies are actively involved in the development and production of bidirectional energy meters. These companies provide solutions for utilities, energy providers, EV charging station operators, and residential

and commercial consumers. Their focus is on ensuring accurate measurement of energy flow, smart billing, real-time energy management, and seamless integration with V2G infrastructure.

Table 2.9: Global Players and Business Model in Bidirectional Energy Meter

Type of V2G Charger	Manufacturer	Who	What	How	The Value	Business model
Indian Companies in bidirectional energy meter businesses	HPL Electric & Power Ltd.	Utilities, energy providers, EV charging station operators, residential and commercial consumers	Bidirectional energy meters that measure energy flow in both directions	Direct sale of meters to energy providers and EV charging operators. Integration with smart energy management systems for real-time monitoring and billing. Bundling with analytics software for dynamic pricing and demand-side energy management	Bidirectional energy meters facilitate V2G adoption by enabling precise measurement of energy flow between EVs and the grid, ensuring accurate billing, supporting net metering policies, and providing real-time data for efficient energy management	Product Based
	Genus Power Infrastructures Ltd.					
	Larsen & Toubro (L&T)					
	DN Tech Enterprises					
	Techno Meters Electronics					
	Avon Meters					
	Secure Meters Ltd.					
Global Companies in bidirectional energy meter businesses	Balaji Engineers					
	Eastron Electronic Co., Ltd.					
	Gomelong Meter Co., Ltd.					
	IVY METERING Co., Ltd.					
	Landis+Gyr					
	SATEC					
	Finder					
	Itron					

³⁰ Fahmy, A. M., Hamad, M. S., Sayed, Mahmond M. A., and Madbouly, Tarek A. Smart Bidirectional Energy Meter for a Grid-Interfaced Electric Vehicle Charger. European Journal of Engineering and Technology 5, no. 1 (2017): 44-50. Progressive Academic Publishing, UK.

1. Business Model Canvas of Key Players

Business Model Canvas of Secure Meters Ltd. (Bidirectional Energy Meters Manufacturers)

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- Public Utility Partnerships - Component Suppliers (Component Suppliers (semiconductors, comm. modules) - Manufacturing Partners (Joint ventures in Malaysia and Ghana to cater to African and Southeast Asian markets) - International Energy Retailers (Partnerships, especially in the UK, for the rollout of SMETS-2 meters)	- Innovative Product Development - Service Provision (Installation, maintenance, and after-sales services for metering solutions) - Project Execution (Implementing Advanced Metering Infrastructure Service Provider (AMISP) projects under RDSS) - Research & Development	- Enhanced Revenue Management (Accurate billing and reduced Aggregate Technical & Commercial (AT&C) losses for utilities) - Energy Efficiency - Regulatory Compliance (Products that meet international standards, aiding utilities in compliance) - Sustainability	- Long-term Contracts (Multi-year agreements, especially under schemes like RDSS) - After-Sales Support (Dedicated teams for maintenance and troubleshooting) - Customer Training (Workshops and training sessions for utility staff on product usage)	- Indian SEBs & DISCOMs (core B2B clients) - International Energy Retailers (e.g., UK market) - Industrial & Commercial Users (via utilities or direct contracts) - Residential Consumers (indirect end-users via utility installations)
	Key Resources - Manufacturing Facilities (State-of-the-art plants in India, Malaysia, and Ghana) - Skilled Workforce (Engineers, technicians, and R&D personnel driving innovation) - Intellectual Property (Patents and proprietary technologies in metering solutions) - Financial Assets		Channels - Local Collaborations - E-commerce Platforms - Direct Sales Force - Authorized Distributors	
Cost Structure		Revenue Streams		
- Manufacturing Costs (In FY23, the company's total operating income was ₹1,609 crore, with a Profit Before Interest, Lease, Depreciation, and Tax (PBILDT) of ₹119 crore, indicating substantial manufacturing expenditures) - Research & Development Expenditure - Operational Expenses - Marketing & Sales		- Product Sales (Income from selling smart meters and related hardware forms a significant portion of the company's revenue. In FY24, Secure Meters reported a total operating income of ₹2,442 crore) - Service Contracts (Revenue from installation, maintenance, and Advanced Metering Infrastructure Service Provider (AMISP) services is a growing segment. The company has secured long-term contracts under schemes like RDSS, enhancing this revenue stream) - Export Sales (Earnings from international markets, notably the UK, contribute to the company's income. Secure Meters has been involved in the rollout of SMETS-2 meters in the UK, reflecting its international presence) - Consulting Services (Fees from advisory services on energy efficiency and power quality are part of the company's offerings)		

Business Model Canvas of IVY METERING Co., Ltd (Bidirectional Energy Meters Manufacturers)

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- OEM/ODM Clients - Technology Providers (The company integrates RS485, LoRaWAN, 4G, GPRS, and Wi-Fi to enable communication in its smart metering solutions) - Component Suppliers (It manufactures and utilizes components like shunt resistors and CTs in their products) - Distributors & System Integrators - Certification Bodies	- Product Development (They specializes in designing and manufacturing a range of products, including energy meters, latching relays, and EV charging modules) - Quality Assurance - Global Marketing & Sales - After-Sales Support (It provides comprehensive technical assistance and maintenance services) - Research & Development	- Advanced Metering Solutions (A range of bi-directional AC/DC energy meters equipped with various communication protocols. For instance, their EM619002 model supports RS485 communication with Modbus RTU and DLT645 protocols) - Customized OEM/ODM Services - Compliance & Certification\ - Energy efficiency - Sustainability (Smart meters are combined with communication technologies like Wi-Fi and RS485, promoting a smarter and cleaner energy ecosystem)	- Long-Term Partnerships (The company has provided products and services to more than 91 countries across Europe, Asia Pacific, America, the Middle East, and Africa) - Technical Support - Training & Education - Feedback Mechanisms	- Utility Companies - Industrial & Commercial Enterprises - EV Charging Infrastructure Providers - Renewable Energy Installers - Smart Building Developers
	Key Resources		Channels	
	- Manufacturing Facilities (They operates a state-of-the-art manufacturing facility located in Zhejiang Province, China, encompassing an area of 80,000 square meters. The facility boasts an annual production capacity of 8 million meters and 12 million relays) - Skilled Workforce - Global Sales Network - Certifications - Intellectual Property		- Factory-Direct Sales without intermediaries - Online Platforms - Trade Shows & Expos (Enlit Europe 2024, Enlit Asia 2024, Indian Utility Week) - Distributors & Agents - Digital Marketing	
Cost Structure		Revenue Streams		
- Manufacturing Expenses (IVY METERING operates a factory in Zhejiang province with an annual production capacity of 8 million meters and 10 million relays) - Research & Development - Marketing & Sales - Operational Costs (The company maintains a sales center in Shanghai, which contributes to its operational expenditures) - Quality Assurance (It ensures product compliance with international standards, obtaining certifications from bodies such as MID, KEMA, SGS, UL, and ANSI)		- Product Sales (The company offers a wide range of products, including energy meters, relays, and related components. Single-phase smart meters are priced between ₹1,000 and ₹1,500 per unit, while three-phase meters range from ₹2,500 to ₹4,200 per unit) - OEM/ODM Contracts (IVY METERING provides customized manufacturing services to clients, tailoring products to specific requirements) - Service Agreements (The company offers maintenance, support, and training services to its clients) - Export Sales (IVY METERING exports its products to over 91 countries across Europe, Asia Pacific, America, the Middle East, and Africa) - Consulting Services		

2.5 Testing Equipment

The V2G testing market comprises various equipment segments essential for ensuring the efficiency, safety, and reliability of V2G systems. These segments are categorized based on device type, service type, and connectivity. In terms of device type, V2G testing utilizes tools such as signal & spectrum analyzers, simulators & emulators, hardware-in-the-loop (HIL) test systems, RF conformance tools, communication test equipment, and system integration tools³¹.

These devices play a crucial role in simulating real-world grid interactions and validating V2G communication protocols. The service type segment includes consulting, system integration, and support services, which aid in deploying and optimizing V2G infrastructure for smooth integration with power grids. Additionally, connectivity testing focuses on Dedicated Short-Range Communication (DSRC) and cellular connectivity, which are critical for enabling real-time energy exchange between EVs and the grid³².

The Global V2X Test Equipment Market Share (2022) indicates that Asia-Pacific dominates the market with a 32.2% share, followed by North America and Europe²⁸. This distribution reflects the increasing demand for advanced testing solutions to support the seamless integration of EVs into the energy grid³³. As the V2G ecosystem continues to expand, the need for robust testing equipment will play a vital role in

ensuring grid stability, optimizing renewable energy usage, and enhancing overall energy efficiency.

2.5.1 Key Global Players

The V2G testing equipment market is driven by global manufacturers providing hardware and software solutions to EV manufacturers, charging station providers, grid operators, and research institutions. These companies develop simulation, emulation, and validation tools to ensure seamless communication, safety, and compliance with global standards such as ISO 15118, CHAdeMO, CCS, and DIN 70121.

Their offerings include automated test systems, charging analyzers, conformance test tools, and smart charging emulators, all of which facilitate high-power charging tests, interoperability assessments, and grid-integration simulations. These solutions help accelerate product development, improve regulatory compliance, and enhance the reliability of EV charging infrastructure. Most manufacturers follow a product-based business model as shown in Table 2.10, focusing on delivering cutting-edge testing equipment, while some also offer a product and service-based approach, providing consulting, software integration, and support services.

As V2G adoption expands globally, robust testing solutions will be essential for ensuring grid stability, optimizing smart charging capabilities, and supporting the large-scale deployment of electric vehicle infrastructure.

³¹ Keysight Technologies. Test for EV & V2G Compliance. [Link](#)

³² Cavli Wireless. C-V2X: Cellular Vehicle-to-Everything. [Link](#)

³³ Grand View Research. Vehicle-to-Grid Technology Market Size, Share & Trends Analysis Report by Vehicle Type (BEVs, PHEVs, FCVs), By Component (Smart Meters, EVSE, Software Solutions), By Application, By Region, And Segment Forecasts, 2024 - 2030. Grand View Research, 2024.

Segment of Equipment used for V2X Testing

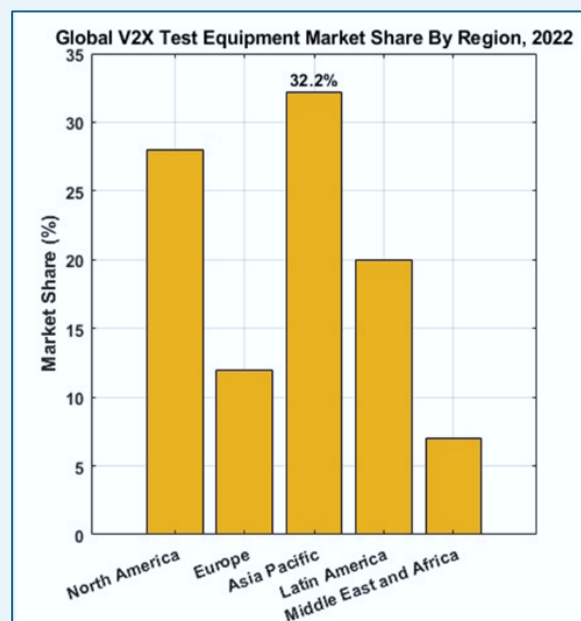
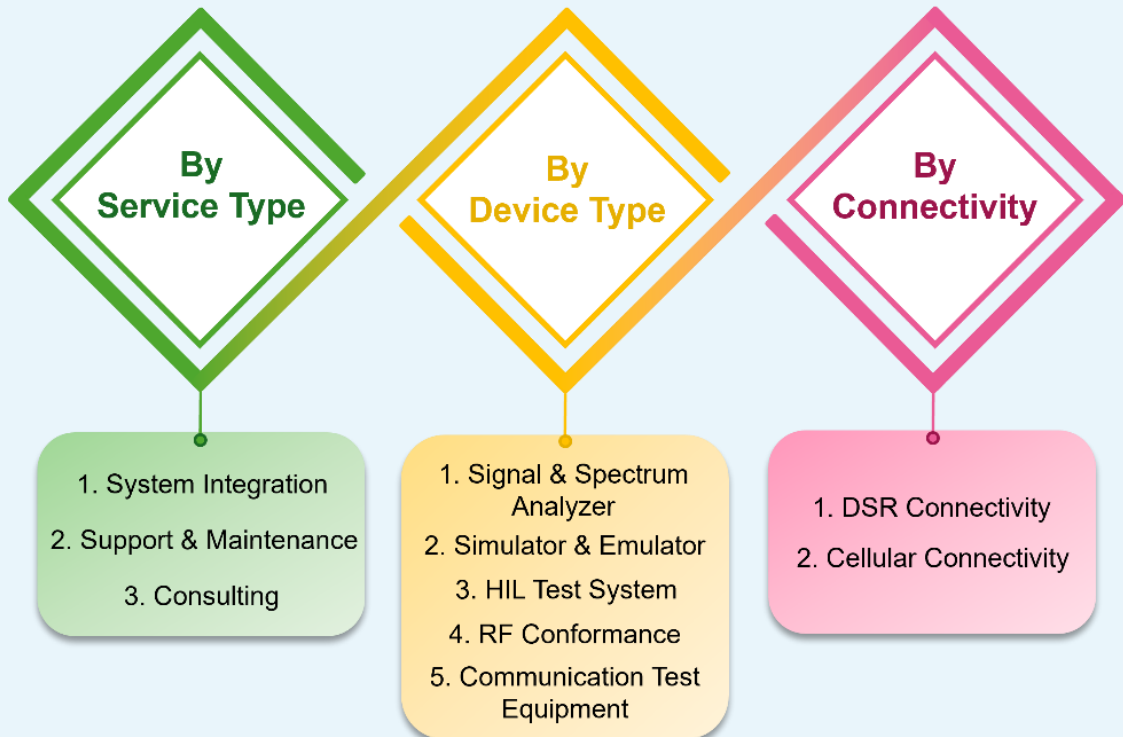


Figure 2.7: (top) Segments of Equipment used for V2X Testing, (bottom) Global V2X Test Equipment Market Share

Table 2.10: Global Players and Business Model in Testing Equipment

Manufacturer	Country of Operation	Who	What	How	The Value	Business model
Keysight Technologies	Global	EV manufacturers, charging station developers, grid operators, and research institutions	Comprehensive design, emulation, and testing solutions for EV charging and V2G systems	Providing hardware and software tools for high-power charging tests, interoperability testing, and smart charging emulation	Ensures compliance with global standards, accelerates product development, and improves the reliability of EV charging infrastructure	Product and Service model
Trialog	France	Charging station manufacturers, grid operators, EVSE providers	Simulation and testing tools for ISO 15118 and DIN 70121 compliance in smart charging and V2G applications	Developing software solutions that validate interoperability and performance of charging stations	Speeds up market entry, ensures seamless communication between EVs and charging infrastructure, and enhances reliability	Product Based
SEVENSTAX	Germany	EVSE manufacturers, automotive OEMs, embedded system developers	V2G communication software stack compliant with ISO/IEC 15118 and DIN 70121	Providing lightweight, high-performance embedded software for V2G integration	Facilitates reliable and secure V2G communication, reduces development time, ensures interoperability, and supports compliance with international charging standards	Product Based
VERISCO	Germany	EV and charging station manufacturers, regulatory bodies, research organizations	Conformance and interoperability testing services for V2G communication	Providing modular, automated test systems and validation platforms for the Combined Charging System (CCS) to verify secure and	Ensures secure and reliable EV-grid communication, improving user trust and accelerating the adoption of V2G technology	Product Based

				reliable EV-grid communication		
Chroma	Global	EV manufacturers, charging station providers, and research institutions requiring testing solutions for DC fast chargers and EVs	Chroma offers automated test systems (Model 8000) that test CHAdeMO-compatible EVs, DC fast chargers, and support V2G applications	Chroma provides automated test systems for CHAdeMO, CCS, and V2G, featuring bidirectional power supplies and protocol testing capabilities for EVs and charging infrastructure, ensuring scalable, efficient testing for R&D and quality assurance	It tests global compliance, enhance interoperability, and support V2G integration, enabling efficient testing, grid stability, and the deployment of smart charging infrastructure	Product Based
comemso	Global	EV manufacturers, charging station providers, battery management system developers, and operators requiring automated test solutions for charging standards like CHAdeMO, CCS, and GB/T	Comemso offers the EV Charging Analyzer, a system that verifies communication and load circuits between electric vehicles (EVs) and chargers, ensuring compliance with CHAdeMO and other industry standards	The system supports manual and automated testing, including charge state simulations, timeouts, and CAN drop-out monitoring, and supports CHAdeMO (0.9.1 to 2.0), DC-CCS Combo, and GB/T standards, with no need for connector changes	Ensures compliance with global standards, improving charging reliability, safety, and interoperability, while automated testing reduces errors and ensures high-quality, consistent results for the e-mobility industry	Product Based
dSPACE	Global	EV manufacturers, charging station providers, and testing facilities requiring	dSPACE offers the Smart Charging Solution, which includes hardware and software to simulate AC	The solution supports EVSE, EV, and man-in-the-middle testing with customizable voltage and	Helps manufacturers of EVs and charging stations develop and test smart charging	Product Based

		simulation and validation of electric vehicle charging processes, including V2G communication and power transfer	and DC charging stations, electric vehicle behaviour, and ensure compliance with charging standards for EVs and charging infrastructure	current ratings. It allows simulation of charging protocols, including CHAdeMO and CCS, and integrates easily into various test setups for testing and development purposes	technologies, ensuring reliable charging processes, compliance with international standards, and supporting the advancement of V2G communication for grid integration.	
Vector	Global	Automotive manufacturers, EV manufacturers, charging infrastructure providers, and test labs that require automated conformance and interoperability testing for EVs and charging stations in accordance with ISO 15118, DIN 70121, CHAdeMO, and other international standards	The CANoe Test Package EV is a comprehensive library of test cases designed for automated conformance and interoperability testing of EVs and EVSE across multiple charging standards such as CCS, CHAdeMO, NACS, and GB/T. It is updated to the latest version (currently includes ISO 15118-20) and covers all relevant test scenarios	The CANoe Test Package EV integrates with the CANoe software platform, which allows users to perform automated testing of EVs and charging stations for communication and operational standards compliance. It supports testing for conformance with ISO 15118, DIN 70121, and CHAdeMO protocols, ensuring full interoperability across different EVs and charging systems.	By offering a powerful, automated test library, the CANoe Test Package EV ensures that electric vehicles and charging infrastructure comply with international standards, enabling reliable interoperability and enhanced functionality for the e-mobility ecosystem	Product Based
GRIDWIZ	South Korea and Global	EV manufacturers, EV charging station operators, energy	The Gridwiz V2G Analyzer is a device designed for sniffing and analyzing charging	The system includes a V2G Analyzer Hub Box with Control Pilot Measurement, HomePlug	The Gridwiz V2G Analyzer enables precise testing and validation of V2G	Product Based

providers, testing laboratories, and R&D teams involved in V2G technology testing	messages between electric vehicles (EVs) and EV chargers according to the CCS standard for V2G applications	Green PHY modem, and PLC packet sniffer. It integrates with Gridwiz V2G Analyzer software for monitoring and analyzing V2G messages, charging sequences, and PWM signals	communication, ensuring interoperability, compliance with charging standards, and efficient energy management for both EVs and charging stations
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1. Business Model Canvas of Key Players

Business Model Canvas of Keysight Technologies (a V2G testing equipment manufacturer)

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- Semiconductor Manufacturers (Collaborations with companies like Intel and TSMC to optimize electronic design automation tools) - Technology Partners (Partnerships with technology vendors to enhance network visibility and performance testing solutions) - Academic and Research Institutions	- Research & Development (Continuous investment in R&D to develop cutting-edge testing and measurement technologies) - Product Development (Designing and manufacturing a wide range of electronic measurement instruments, including oscilloscopes, signal generators, and network analysers) - Software Development (Creating software solutions like PathWave for design and test automation)	- Comprehensive Testing Solutions - Innovation Leadership (Recognized for continuous innovation in the test and measurement industry) - Global Reach (Serving over 32,000 customers in more than 100 countries) - Quality and Reliability (Providing high-precision instruments known for their accuracy and durability)	- Dedicated Account Management - Technical Support Services - Training and Education - Customer Feedback Integration	- Communications Industry - Aerospace and Defence - Automotive Industry - Energy Sector - Semiconductor Industry - Education and Research Institutions
	Key Resources - Skilled Workforce (A team of over 15,000 employees, including engineers and technical experts) - Intellectual Property - Manufacturing Facilities - Global Sales and Support Network		Channels - Direct Sales Force - Online Platforms - Distributors and Resellers (Partnering with third-party vendors to reach broader markets)	
Cost Structure		Revenue Streams		
- Research and Development (In fiscal year 2023, Keysight invested approximately ₹7,320 crore in R&D, marking a 4.88% increase from the previous year) - Manufacturing Costs (The company's manufacturing expenses totalled around ₹6,972 crore in 2023) - Sales and Marketing (SG&A) (SG&A expenses amounted to roughly ₹10,848 crore in 2023, showing a 1.87% increase from 2022) - Operational Expenses (Total operating expenses for 2023 were about ₹34,081 crore, reflecting a 1% increase compared to the previous fiscal year)		- Product Sales (Keysight's total revenue for fiscal year 2023 was approximately ₹45,318 crore) - Software Solutions (The company offers software products like PathWave, which significantly contribute to its revenue) - Services (Keysight provides a range of services including calibration, repair, and consulting) - Recurring Revenue (In 2023, recurring revenue from software and services reached about ₹10,790 crore, accounting for 23% of total revenue. This reflects a 9% year-over-year growth, indicating a successful shift toward a stable and predictable revenue model)		

Business Model Canvas of Trialog (a V2G testing equipment manufacturer)

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- Charging Station Manufacturers & EVSE Providers - Grid Operators - Automotive OEMs - Certification Laboratories (e.g., TÜV, Dekra) - Open Standard Alliances (e.g., CharIN, E-mobility) - Interoperability Interest Group) - Standardization Bodies (ISO, IEC, CENELEC)	- Software Development (e.g., ComboCS, YaCCS, QOCPP-CS) - Communication Protocol Implementation (ISO 15118, DIN 70121, OCPP) - Interoperability Testing & Simulation - Research & Development - Client Training & Technical Support - Participation in Standardization Forums	- Accelerated Time-to-Market for EVSE and OEMs - Seamless Interoperability between EVs and Charging Infrastructure - Regulatory Readiness for EU and Global Compliance - End-to-End Support for ISO 15118 and Smart Charging Integration - Customizable, Reliable, and Industry-Validated Testing Tools	- Technical Support Services - Annual Maintenance & Upgrade Contracts - Client-Specific Integration & Onboarding - Developer Training & Documentation - Feedback-Driven Product Improvement	- Charging Station Manufacturers - Grid Operators and DSOs - EVSE Software and Hardware Providers - Automotive OEMs - Certification and Compliance Labs - Smart Grid and Energy Aggregator Platforms - Academic and Research Institutions
	Key Resources - In-house protocol and systems engineers - Proprietary Simulation Tools and Testing Framework (ComboCS, YaCCS stack, QOCPP-CS) - Protocol Libraries (ISO 15118, OCPP, DIN 70121) - Intellectual Property in EV Communication Systems - Industry Relationships and Regulatory Access - Developer Portals and Test Environments		Channels - Direct B2B Sales - Online Product Portals (via company website) - Developer & API Access (where applicable) - Industry Events, PlugFests, and Trade Shows - Strategic Integrations with OEMs and EVSE partners	
Cost Structure		Revenue Streams		
- Research & Development Expenditures - Protocol Maintenance and Standard Updates - Salaries and Operational Overheads - Sales and Technical Support Expenses - Marketing and Participation in Industry Consortia		- Product Sales (e.g., ComboCS simulation toolkits) - Annual Software Licensing and Update Contracts (Income from clients subscribing to annual licenses for software stacks, including updates and maintenance services as per annual or per-seat model) - Annual Support & Maintenance Contracts - Consulting for Pre-Certification and Protocol Debugging - Protocol Stack Integrations and Project Services (Earnings from integrating communication protocols like ISO 15118 and DIN 70121 into client systems, as well as providing project-based services) - Customized Test Environment Consulting (Fees from consulting services that offer tailored testing environments to meet specific client requirements) - Technical Training for Developers and Compliance Teams (Revenue from conducting training sessions and workshops aimed at educating clients on protocol standards and compliance procedures)		

Business Model Canvas of Vector (a V2G testing equipment manufacturer)

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- Automotive OEMs (Vector Informatik partners with OEMs like Mercedes-Benz, Stellantis, and Mahindra to develop software-defined vehicle solutions and testing tools.) - Test Laboratories & Certification Bodies (It collaborates with Hubject to support Plug & Charge technology, helping OEMs and charger makers achieve interoperability and conformance certifications) - Charging Infrastructure Providers - Standardization Bodies (Vector sponsored the 2023 VOLTS event by CharIN, showcasing its commitment to interoperability in the e-mobility sector)	- Development of Testing Tools: (Creation and maintenance of the CANoe Test Package for EV and EVSE for automated conformance and interoperability testing) - Protocol Implementation: (Supporting multiple charging standards, including ISO 15118, DIN 70121, CHAdeMO, GB/T, and NACS, to ensure comprehensive testing coverage) - Continuous Updates (Regularly updating tools to align with the latest versions of charging standards, such as incorporating ISO 15118-20 functionalities) - Participation in Standardization Forums	- Comprehensive Testing Solutions - Multi-Standard Support (The tool supports development and testing of various charging standards, including CCS, NACS, GB/T, and CHAdeMO, ensuring compatibility across different protocols) - Integration with CANoe Platform (The CANoe Test Package EV integrates seamlessly into the CANoe software platform, facilitating automated testing within a familiar environment for users) - Enhanced Interoperability	- Technical Support & Training - Maintenance & Update Contracts - Customized Integration Services - Feedback-Driven Improvements	- Automotive Manufacturers - Charging Infrastructure Providers - Test Laboratories
	Key Resources		Channels	
	- Skilled Workforce - Proprietary Tools - Intellectual Property - Industry Relationships		- Direct Sales - Online Platforms - Industry Events - Training Workshops	
Cost Structure		Revenue Streams		
- R&D (Vector invests significantly in R&D to develop and update testing tools like the CANoe Test Package EV and EVSE) - Personnel Expenses (Over 4,500 employees worldwide) - Maintenance of Testing Platforms - Participation in Standardization Activities (Vector actively participates in industry forums and standardization bodies such as ISO, IEC, and CharIN)		- Product Sales (Revenue is generated through the licensing of the CANoe Test Package EV and EVSE to clients, providing them with tools for automated conformance and interoperability testing) - Software Licensing (Vector offers annual or per-seat licenses for continued access to their testing tools and updates, contributing to recurring revenue) - Support & Maintenance Contracts (Clients subscribe to support services, including technical assistance and regular software updates, forming a steady revenue stream) - Consulting Services (Vector provides consulting services for custom integration, training, and protocol debugging, catering to specific client needs and generating additional income)		

2.6 Central Management System (CMS) / Energy Management System (EMS)

The CMS and EMS play a crucial role in the V2G ecosystem, enabling the efficient management, monitoring, and optimization of energy flow between electric vehicles (EVs) and the power grid. These systems consist of hardware and software components as shown in Figure 2.8, that ensure seamless interaction between EVs, charging infrastructure, and grid operators.

Hardware components include measurement and monitoring devices such as smart meters, power quality sensors, and IoT-enabled sensors, which track energy consumption, battery state of charge, and grid stability³⁴. Additionally, control and automation devices like energy management controllers (PLCs), microgrids, and V2G controllers allow for automated power distribution and demand response.

Communication and networking devices, including IoT gateways, SCADA interfaces, and Modbus protocols, facilitate secure and

high-speed data exchange between EVs, charging stations, and grid operators³⁵.

On the software side, CMS and EMS provide advanced energy monitoring and analytics, featuring load forecasting, fault detection, and real-time dashboards to enhance V2G operations³⁶. Control and optimization tools help manage peak load balancing, automated demand response, and dynamic load adjustments, ensuring grid stability and optimal charging schedules.

Moreover, grid and utility integration solutions support SCADA-based power management, energy trading, and EV charging network optimization, allowing for seamless participation of V2G in smart grids³⁷. To ensure security and compliance, these systems incorporate cybersecurity protocols³⁸, encrypted data storage, and ISO 50001 reporting to safeguard energy transactions and regulatory adherence. By integrating CMS and EMS into V2G infrastructure, utilities, EV owners, and grid operators can achieve enhanced energy efficiency, cost reduction, improved grid stability, and greater integration of renewable energy sources, making V2G a vital component of the evolving smart energy ecosystem.

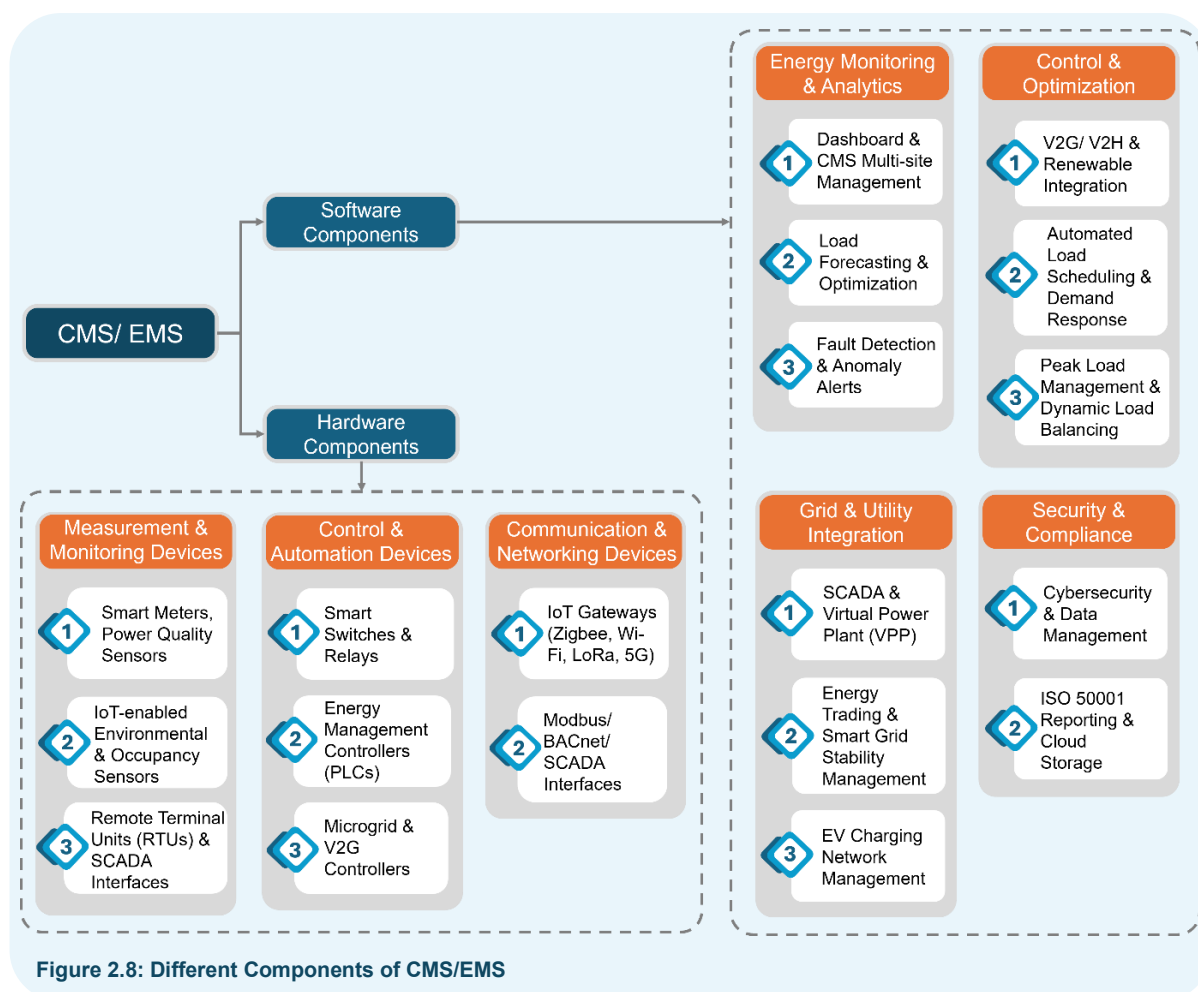
³⁴ Alsharif, Abdulgader, Chee Wei Tan, Razman Ayop, Abdulhakeem Dobi, and Kwan Yiew Lau. "A Comprehensive Review of Energy Management Strategy in Vehicle-to-Grid Technology Integrated with Renewable Energy Sources." *Sustainable Energy Technologies and Assessments* 47 (2021): 101439. ISSN 2213-1388.

³⁵ Gungor, V. C., et al. "Smart Grid Technologies: Communication Technologies and Standards." *IEEE Transactions on Industrial Informatics* 7, no. 4 (November 2011): 529-539.

³⁶ Fei, Liu, Muhammad Shahzad, Fazal Abbas, Hafiz Abdul Muqet, Muhammad Majid Hussain, and Li Bin. "Optimal Energy Management System of IoT-Enabled Large Building Considering Electric Vehicle Scheduling, Distributed Resources, and Demand Response Schemes." *Sensors* 22, no. 19 (2022)

³⁷ Lipman, Timothy, and Jarvis Yuan. *Electric Vehicle Charge Management Strategies to Benefit the California Electricity Grid*. UC Office of the President, Institute of Transportation Studies, February 2025. [Link](#)

³⁸ Southwest Research Institute. "SwRI Evaluates Cybersecurity Risks Associated with EV Fast-Charging Equipment." SwRI Newsroom, July 16, 2024. [Link](#)



2.6.1 Key Global Players

Several manufacturers shown in Table 2.11, provide EMS and CMS solutions for V2G integration, covering control & optimization³⁹, grid & utility integration, energy monitoring & analytics, automation, communication, and security & compliance. In control & optimization and energy monitoring, companies offer smart charging solutions, energy management platforms, and virtual power plant (VPP) capabilities. These solutions allow EV owners, fleet operators, and energy providers to optimize power usage, manage charging schedules, and participate in grid services for cost savings and grid stability.

Grid and utility integration solutions provide bidirectional energy flow, demand response, and energy trading, enabling renewable energy integration and revenue generation through V2G participation. Measurement & monitoring devices, including smart meters and SCADA interfaces, ensure stable power delivery and fault prevention, enhancing EV charging reliability. Control & automation solutions, such as microgrid controllers and energy management controllers (PLCs), facilitate smart energy distribution and EV fleet optimization. Communication and networking devices, including IoT modules and gateways, enable secure, high-speed data exchange between EV chargers, grid operators, and management systems.

³⁹ Chen, Zhiyi, Ali Moradi Amani, Xinghuo Yu, and Mahdi Jalili. "Control and optimisation of power grids using smart meter data: A review." *Sensors* 23, no. 4 (2023): 2118.

Finally, security & compliance solutions ensure real-time monitoring⁴⁰, cybersecurity protection, and regulatory compliance, safeguarding EV charging networks from cyber threats. These companies operate under service-based, product-based, or hybrid business models, offering EMS and

CMS solutions tailored to V2G infrastructure. By integrating energy management, grid connectivity, automation, and security, EMS and CMS providers enhance grid stability, renewable energy utilization, and the overall efficiency of V2G systems.

Table 2.11: Global Players and Business Model in CMS/EMS

Category	Manufacturer	Markets covered	Who	What	How	The Value	Business model
Control & Optimization, Energy Monitoring & Analytics	VOOL	Estonia	Residential EV owners	VOOL, with Enode's integration, enables users to connect their electric vehicles (EVs) and OCPP-compliant chargers to the VOOL app. This platform supports V2G functionality	Users to connect EVs and chargers, set preferences for outages, energy price spikes, or demand response events, and optimize charging schedules	Managing efficient energy consumption, achieve cost savings, and contribute to grid stability by feeding energy back into the grid during peak demand periods	Service Based
Grid & Utility Integration, Control & Optimization	Synop	United States	Commercial fleet operators and energy providers	Energy management software for EV fleets, including virtual power plant (VPP) capabilities	Synop offers an Energy Management System platform, which allows user to optimize power use and energy across multiple load/generation sources and access V1G/V2G opportunities	Reduces energy costs for fleet operators, enhances grid flexibility, and supports the integration of renewable energy sources	Service Based

⁴⁰ Ayaz, Ferheen and Maziar M. Nekovee. "Smart Energy Management with Optimized Prosumerism for Achieving Dynamic Net-Zero Balance in Electrified Road Transport Networks." *ArXiv* abs/2312.08162 (2023).

					for revenue generation		
Energy Monitoring & Analytics, Control & Optimization	Jedlix	Netherlands, Belgium, Germany	EV owners, energy providers, and automakers	Smart charging solutions for V2G optimization	Offers an app-based platform and APIs that connect EV owners with energy providers, enabling efficient charging/discharging and participation in energy markets	Reducing Total Cost of Ownership, Monetizing Charging Flexibility, Optimizing Renewable Energy Use	Service/Subscription-based model
Control & Optimization, Grid & Utility Integration	The Mobility House	Germany, United States, Switzerland and	Private EV owners, businesses with EV fleets, and energy providers	Smart charging and energy management solutions	Provides technology that allows EVs to store renewable energy and discharge it back to the grid or use it within buildings, optimizing energy costs and supporting grid stability	Reduces energy costs for users, provides backup power, and contributes to grid stability by balancing supply and demand	Service Model
Grid & Utility Integration, Control & Optimization	Nuvve Corporation	United States, Denmark, United Kingdom, France	Fleet operators including school bus fleet, utility companies, and individual EV owners	Aggregation of electric vehicles to provide grid services	Nuvve operates a GIVe™ Platform which comprises of High-Powered, Bidirectional Charging Stations, Nuvve Energy Regulation Aggregator (NERA), and Vehicle Smart Link (VSL) that enables EVs to discharge electricity back to the grid	Offers revenue generation for EV owners through grid services, enhances grid stability, and supports renewable energy integration	Shared Asset

Measurement & Monitoring Devices	Schneider Electric	Global	Energy utilities, grid operators, EV charging infrastructure providers	Provides smart meters, power quality sensors, and SCADA interfaces	Offers products like the PowerLogic ION8650 meter, which delivers high-accuracy monitoring for utility networks, ensuring stable power delivery and enhanced reliability of EV charging infrastructure	Ensures stable power delivery, prevents faults, and enhances the reliability	Product
Control & Automation Devices	Siemens	Global	Charging network operators, energy providers, smart grid developers	Energy Management Controllers (PLCs) and Microgrid controllers	Siemens offers SICAM Microgrid Controller for energy management, VersiCharge AC/DC chargers for EV infrastructure, and eMobility software solutions for load balancing and grid integration	Enables smart energy distribution, and optimized EV fleet charging while enhancing grid stability.	Product based
Communication & Networking Devices	Telit Cinterion	US, Brazil, Italy, Israel, and South Korea	EV charging operators, grid operators, smart city developers	Supplies IoT modules and gateways for reliable EV charging connectivity.	Provides EXS82-W Module (LTE Cat M/NB/2G) and IoT Gateways & Terminals to enable secure and stable communication between EV chargers, grid operators, and	Ensures secure, high-speed, and reliable data transmission for smart EV charging networks, optimizing network uptime and remote monitoring.	Product & Service-based

Security & Compliance	VicOne	Japan, Taiwan, South Korea, India, Germany, US	EV charging network operators, OEMs, and fleet managers	Provides EV Charging System Protection, offering real-time security monitoring, threat detection, and compliance management.	management systems.		
					Uses the xNexus XDR platform for early detection and response to cybersecurity threats. Implements firmware and software vulnerability scanning with virtual patching for extended protection.	Ensures compliance with global security standards (NIST IR 8473, ETSI EN 303 645), protects EV charging infrastructure from cyber threats, and enhances operational reliability.	Service-based (Cybersecurity Solutions)

1. Business Model Canvas of Key Players

Business Model Canvas of Jedlix (A Smart Charging and Energy Management Solutions Provider)

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- Automotive OEMs (It partners with major automakers, Renault, Kia, Hyundai, BMW, Tesla, Polestar, to deliver integrated smart charging services) - Energy Providers & Utilities (It partners with energy firms, Engie, Vattenfall, Eneco, EDF Luminus, Wien Energie, CKW, to enable smart charging aligned with energy market dynamics) - CPOs & EVSE Manufacturers (It integrates with hardware providers, Easee, Zaptec, Wallbox, Go-E, to enable optimized charging through compatible home chargers) - Grid Operators & Balancing Service Providers (It partners with grid operators, CKW in Switzerland, Next Kraftwerke in the Netherlands to deliver aFRR grid balancing services using electric vehicle fleets) - Technology Partners (Jedlix was acquired by Kraken Technologies in October 2024 to integrate its smart charging solutions into Kraken's) broader energy management platform	- Smart Charging Platform Development (Jedlix continuously enhances its app, APIs, white-label solutions to provide seamless smart charging experiences) - Energy Market Integration - Partnership Management - Customer Support & Engagement (Providing user support, education, and engagement to promote platform adoption, enhance user experience) - Research & Development (Innovating new features like solar smart charging and bidirectional charging capabilities to stay at the forefront of smart charging technology)	- Cost Savings (Jedlix enables EV owners to save up to 30% on charging costs by optimizing charging schedules to utilize off-peak and renewable energy) - Monetization of Flexibility (Users can earn rewards by participating in grid balancing and energy market services through Jedlix's Virtual Power Plant (VPP) functionalities) - Environmental Impact - User Convenience - Scalability for Partners	- Digital Engagement - Incentive Programs - Partner Support (Jedlix provides dedicated support for partners integrating its services, offering APIs and white-label solutions to seamlessly add smart charging functionalities to their offerings) - Community Building (The company engages users through newsletters, updates, and feedback mechanisms, fostering a loyal user base and continuously improving its services based on user input)	- Individual EV Owners - Automotive Manufacturers - Energy Retailers & Utilities - Charge Point Operators - Fleet Operators
	Key Resources - Proprietary Technology (Jedlix's smart charging platform encompasses its mobile app, Smart Charging APIs, Virtual Power Plant (VPP) capabilities) - Human Capital - Strategic Partnerships - Data Analytics (The company utilizes advanced algorithms, data processing capabilities to optimize charging schedules and energy usage)		Channels - Mobile Application - APIs & White-Label Solutions - Web Platform - Partnership Networks	
	Cost Structure - Research & Development (Jedlix has invested around ₹480 crore in advancing smart charging technologies, supported by ₹480 crore in funding from investors like Osaka Gas, Skagerak Energi, and Groupe Renault) - Operational Expenses (Jedlix's operational costs cover platform maintenance, customer support, and administration, with an estimated 25 employees and annual revenue of around ₹307 crore, translating to approximately ₹1.22 crore per employee) - Partnership Management - Marketing & Sales - Regulatory Compliance		Revenue Streams - Subscription Fees (Jedlix generates recurring revenue from users subscribing to premium smart charging services. While the app is free to download, premium features may be offered through subscription models) - Energy Market Participation (Jedlix earns by aggregating EV charging flexibility into VPPs for energy and balancing market participation) - White-Label Solutions - API Access Fees - Incentive Programs (Jedlix also earns revenue through incentive programs from grid operators and energy providers, with users receiving around ₹0.90–₹1.80 per kWh of smart charging based on provider and location)	

Business Model Canvas of The Mobility House (Smart Charging & Energy Flexibility Solutions Provider)

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- Automotive OEMs (Collaborates with over 15 vehicle manufacturers to ensure seamless integration of smart charging solutions) - Energy Providers & Utilities (Partners with over 150 energy companies to enable grid integration and provide energy market services) - Infrastructure & Technology Providers (Works with companies like Schneider Electric and AlphaStruxure to offer turnkey Energy-as-a-Service (EaaS) solutions) - Installation & Service Providers (Engages a network of 2,000+ certified installers for deploying and maintaining charging infrastructure) - Government & Municipalities (Collaborates with public authorities on fleet electrification initiatives and regulatory support)	- Smart Charging Platform Development (Continuously enhancing the ChargePilot® platform to optimize and automate EV charging processes) - Energy Management Services (Implementing V2G and dynamic load management for grid-friendly charging) - Project Implementation (Planning, designing, and deploying customized EV charging infrastructure for fleets and facilities) - Customer Support & Training - Research & Innovation	- Cost Savings (Jedlix enables EV owners to save up to 30% on charging costs by optimizing charging schedules to utilize off-peak and renewable energy) - Monetization of Flexibility (Users can earn rewards by participating in grid balancing and energy market services through Jedlix's Virtual Power Plant (VPP) functionalities) - Environmental Impact - User Convenience - Scalability for Partners	- Dedicated Account Management (personalized guidance and support throughout the entire project lifecycle to ensure client satisfaction and success) - Training & Education (Hands-on workshops, documentation, and tools to empower clients in managing and optimizing their charging infrastructure) - Continuous Engagement (Ongoing communication through updates, feedback collection, and collaborative solution development to improve user experience and product alignment)	- Fleet Operators - Charge Point Operators (CPOs) - Utilities & Energy Providers - Municipalities & Public Transport Authorities: (Government bodies electrifying public transport and municipal vehicle fleets)
	Key Resources - ChargePilot® Platform (TMH's proprietary smart charging and energy management software that enables dynamic load control and grid integration) - Expert Team - Strategic Partnerships - Intellectual Property		Channels - Direct Sales - Partner Networks (Strategic collaborations with over 15 OEMs, more than 150 energy providers, and key infrastructure players (e.g., Schneider Electric, AlphaStruxure)) - Digital Platforms	
Cost Structure - Research & Development (The Mobility House received a ₹135 crore loan from the European Investment Bank to enhance R&D for its ChargePilot® platform and V2G technology) - Operational Expenses (Cover system deployment, platform maintenance, support, and admin tasks. For example, ChargePilot®'s deployment for NYC Transit aimed to cut over ₹3.5 crore in annual operating costs) - Marketing & Sales - Partnership Management (Resources are allocated to establishing, nurturing, and expanding strategic partnerships across sectors)		Revenue Streams - Charging as a Service (CaaS) (TMH provides bundled subscription services including hardware, software, and maintenance) - Software Licensing (Revenue comes from clients using the ChargePilot® platform for smart charging, it significantly supports TMH's ₹380 crore revenue, with operations at 2,200+ global sites) - Energy Market Participation (TMH earns by integrating EVs into energy markets via V2G) - Consulting & Project Services (TMH earns from site assessments, design, installation, and project management)		

2.7 Communication

Specific Hardware related business

The communication-specific hardware business in the V2G ecosystem plays a crucial role in enabling secure, high-speed, and efficient data transmission between electric vehicles, charging stations, grid operators, and energy management systems. This sector includes Powerline Communication (PLC) devices, IoT modules, gateways, and hardware security modules (HSMs) that facilitate real-time monitoring, bidirectional communication, and seamless integration with smart grids. Companies such as Qualcomm provide PLC devices like the QCA7006AQ⁴¹, which enable bidirectional energy management and smart-grid integration through secure

and efficient data exchange. Utimaco⁴² and Infineon Technologies⁴³ offer HSMs for V2G security, ensuring encrypted communication, authentication, and protection against cyber threats in EV-grid interactions. These hardware solutions support industry standards such as ISO 15118, IEEE 1609.2, and IEC 61850, ensuring interoperability and cybersecurity across global EV charging networks.

By leveraging technologies like LTE, 5G, Wi-Fi, Zigbee, and DSRC, communication-specific hardware optimizes smart charging, predictive maintenance, and secure transactions, contributing to grid stability, enhanced cybersecurity, and the overall efficiency of V2G systems⁴⁴. Most companies in this segment operate on a product-based business model, offering specialized hardware solutions for secure and scalable V2G communication.

Table 2.12: Global Players and Business Model in Communication Specific Hardware

Manufacturer	Markets covered	Who	What	How	The Value	Business model
Qualcomm	Brazil, China, Germany, Singapore, India, Japan, the UK, South Korea, and the US	Electric Vehicle (EV) manufacturers, EV charging station manufacturers, and smart grid infrastructure developers	Provides Powerline Communication (PLC) devices for V2G integration in EV charging systems.	Offers the QCA7006AQ, a next-generation PLC device that enables bidirectional communication between EVs and the power grid, facilitating smart-grid integration and efficient energy management.	Enables secure and efficient bidirectional communication for V2G integration, optimizing EV-grid interactions.	Product-based
Utimaco	Germany and USA	EV manufacturers, charging	Provides Hardware Security Modules	Offers Automotive HSMs that secure V2G	Ensures secure authentication, encrypted	Product (Security Solutions)

⁴¹ Qualcomm. "Qualcomm Unveils Next-Generation Powerline Communication Device." Qualcomm Newsroom, May 2022. [Link](#)

⁴² Utimaco. "Hardware Security Modules (HSM)." Utimaco, [Link](#)

⁴³ Infineon Technologies. "Infineon Enables Next-Generation Electric Vehicle Charging with Advanced Power Electronics." Infineon Press Release, October 2021. [Link](#)

⁴⁴ ElGhanam, Eiman, Mohamed Hassan, Ahmed Osman, and Ibtihal Ahmed. 2021. "Review of Communication Technologies for Electric Vehicle Charging Management and Coordination" World Electric Vehicle Journal 12, no. 3: 92.

		station operators, grid infrastructure providers	(HSMs) for securing V2G communication and protecting EV charging infrastructure.	communication, Plug & Charge transactions (ISO 15118), and firmware updates, ensuring data integrity and cybersecurity in EV charging systems.	communication, and protection against cyber threats in V2G transactions.	
Infineon Technologies	Global	Automotive OEMs, Tier-1 suppliers, EV manufacturers, and smart grid infrastructure providers	Provides Hardware Security Modules (HSMs) for V2X and V2G communication in connected and electric vehicles.	Offers SLS37 V2X HSM, a tamper-resistant security controller that enables secure communication, encryption, and authentication in V2X and V2G applications, ensuring compliance with IEEE 1609.2, ETSI TS 103 097, and CAR 2 CAR Communication Consortium standards.	Enhances secure bidirectional communication, protects private keys and sensitive data, prevents cyber threats, and ensures compliance with global automotive security standards.	Product Based (Security & Communication Solutions)

1. Business Model Canvas of Key Players

Business Model Canvas of Infineon Technologies (V2X/V2G Security Solutions)

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- Automotive OEMs (e.g., BMW, Volkswagen, Hyundai) - Tier-1 Suppliers (e.g., Bosch, Continental, Denso) - V2X Stack and TCU Developers (e.g., Cohda Wireless, Commsignia) - EVSE/V2G Gateway Manufacturers & Energy Aggregators - Industry Collaboration & Standards Bodies (e.g., C2C-CC, ETSI, AUTOSAR, IEEE)	- Design and manufacturing of tamper-resistant HSMs for V2X and automotive applications - Ensuring compliance with IEEE 1609.2, ETSI TS 103 097, and global automotive security standards - Continuous R&D in cryptographic algorithms, post-quantum security, and secure IC design - Technical support, SDKs, and integration services for OEMs, Tier-1s, and infrastructure vendors	- Tamper-resistant HSMs (e.g., SLS37 V2X HSM) enabling secure communication, encryption, and authentication for V2X/V2G systems - Full compliance with IEEE 1609.2, ETSI TS 103 097, and CAR 2 CAR standards for automotive-grade V2X security - Protection of private keys, credentials, and sensitive data within vehicles and charging infrastructure - Prevention of cyber threats such as spoofing, man-in-the-middle attacks, and unauthorized access - Support for global OEMs in achieving regulatory cybersecurity compliance (e.g., UNECE WP.29, ISO/SAE 21434) - Enhances trust and safety in EV-grid and vehicle-to-vehicle communications	- Joint development and integration support - Long-term supply and lifecycle support agreements - Certification assistance and secure firmware update services - SDKs, documentation, and integration toolchains for developers	- Tier-1 Automotive Suppliers (Primary integrators of Infineon HSMs into TCUs and ECUs) - Automotive OEMs (Direct or indirect beneficiaries using secure communication systems) - EV Manufacturers (Including startups developing in-house platforms needing HSMs for secure V2G) - Charging Infrastructure Developers (Who build V2G-capable chargers and energy gateways with built-in security modules) - Smart Grid & Energy Aggregators (Who rely on secure EV-grid integration for demand response, frequency regulation, etc.) - Telematics Platform Providers (Using Infineon's HSMs to ensure secure OTA and V2X messaging)
	Key Resources - Proprietary IP (cryptographic cores, secure microcontroller designs) - Manufacturing capacity (own fabrication plants+ foundry partners like TSMC, UMC) - R&D Labs in Germany, Austria, India (focused on V2X, automotive security, and post-quantum research) - Global Field Engineering & Technical Support network - Strong brand trust in functional safety and automotive cybersecurity		Channels - Direct Sales - Authorized Distributors & Partners (e.g., Avnet, Arrow) - Developer & Partner Portals (Technical documentation, SDKs, integration guides) - Automotive Trade Shows & Conferences (e.g., CES, EVS) - Industry Collaborations & Working Groups (e.g., AUTOSAR, C2C-CC) - Collaborative Projects & Proof of Concepts (Joint V2G/V2X demos)	
Cost Structure		Revenue Streams		
- R&D Expenditure ₹178.65 billion in FY 2023 (~12.2% of revenue); supports cryptography, PQC, ISO/SAE 21434) - Manufacturing & Testing (Partnered with TSMC; high-cost secure chip fabrication and automotive-grade testing) - Compliance & Certification (ISO 26262, IEEE 1609.2, ETSI TS 103 097; costs for audits, tools, and regulatory updates) - Customer Enablement (SDKs, developer support, integration tools) - Sales & Marketing (Budget allocated for CES, IAA, Embedded World; B2B promotion and joint PoCs) - Ecosystem Engagement (Member of AUTOSAR, C2C-CC)		- Product Sales (Core income from HSM chips (e.g., SLS37 V2X HSM); contributes to the ₹757.8 billion Automotive segment revenue in FY2024) - Long-Term Supply Agreements (Multi-year contracts with automotive clients) - Licensing Fees (IP monetization from cryptographic cores and firmware used in ECUs) - Custom Design & Integration (Revenue from tailored HSM solutions, secure boot, and compliance support; contributes to the ₹135.54 billion Connected Secure Systems segment revenue in FY2024) - Developer Toolkits & SDKs		

2.8 Software Related Business

2.8.1 Communication Specific Software

The communication-specific software segment in V2G (Vehicle-to-Grid) systems focuses on enabling secure and efficient communication between electric vehicles, charging stations, and grid infrastructure. This software ensures seamless data exchange, compliance with international charging protocols, and interoperability between different V2G components.

Elektrobit⁴⁵ provides EB tresos V2G ChargeIn, an AUTOSAR-compliant V2G software solution that enables seamless EV-to-grid communication, supporting ISO 15118, AC/DC charging, and Plug & Charge

functionality. Integrated within the EB tresos AutoCore AUTOSAR environment, this software reduces integration complexity, enhances security, and allows flexibility for OEM-specific applications. Similarly, Arrow Electronics⁴⁶ offers a V2G communication software stack that integrates ISO 15118, IEC 61851, DIN 70121, and OCPP standards, ensuring optimized charging schedules, secure transactions, and regulatory compliance. The company also provides a V2G reference board, accelerating the deployment of smart charging solutions. Both manufacturers operate under a product-based business model, focusing on software solutions that facilitate interoperability, secure data transmission, and seamless EV-grid communication. These software solutions play a vital role in ensuring smart charging, efficient grid interaction, and the scalability of V2G technology.

Table 2.13: Global Players and Business Model in Communication Specific Software

Manufacturer	Markets covered	Who	What	How	The Value	Business model
Elektrobit	Germany and other branches in Asia, Europe and North America	Automotive OEMs, Tier-1 suppliers, and EV charging infrastructure developers.	Provides EB tresos V2G ChargeIn, an AUTOSAR-compliant V2G software solution that enables seamless communication between electric vehicles and charging stations.	Offers a pre-integrated V2G communication software stack within the EB tresos AutoCore AUTOSAR environment, supporting ISO 15118, AC/DC charging, External Identification Means, and Plug & Charge functionality.	Reduces integration complexity, ensures compliance with ISO 15118, supports secure V2G communication, and provides flexible architecture for OEM-specific applications.	Product Based (Software-based solutions)
Arrow Electronics	Global	EV charging infrastructure developers, automotive	Provides a V2G communication software stack,	Offers a V2G software stack that enables secure and	Ensures seamless EV-grid communication,	Product Based (Software-

⁴⁵ Elektrobit. "EB tresos V2G ChargeIn – Secure Communication for EV Charging." [Link](#)

⁴⁶ Arrow Electronics. "Arrow Electronics Released Their Own Vehicle-to-Grid Communication Software Stack." [Link](#)

OEMs, and energy service providers	integrating ISO 15118, IEC 61851, DIN 70121, and OCPP standards.	efficient communication between EVs and charging stations, supporting both MPU and MCU platforms. Also provides a V2G reference board to accelerate deployment of smart charging solutions.	optimized charging schedules, and compliance with global V2G standards.	based solutions)
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1. Business Model Canvas of Key Players

Business Model Canvas of Elektrobit (V2G Communication Software Solution provider)

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- Automotive OEMs - Tier-1 Suppliers & ECU Developers - Continental AG (Parent Company and system integrator) - AUTOSAR Alliance Members - SEVENSTAX (ISO 15118 software stack provider) - V2G Charging Ecosystem Collaborators (for interoperability validation)	- Development of V2G communication software within AUTOSAR framework (EB tresos) - Implementation of ISO 15118 standards including AC/DC, PnC, and EIM - Partner collaboration for communication stack integration (e.g., SEVENSTAX) - Technical support, configuration, and customization for OEM/Tier-1 deployment	- Pre-integrated V2G communication stack within EB tresos AUTOSAR environment - Full ISO 15118 support including AC/DC charging, Plug & Charge, and External Identification Means - Reduces integration time and engineering effort for OEMs and Tier-1s - Enables secure, compliant, and interoperable EV-grid communication - Modular and flexible architecture tailored for OEM-specific applications	- Co-development and Engineering Collaboration - Long-term Licensing and Maintenance Contracts (supporting lifecycle updates, patches, and compliance upgrades) - Customization and Configuration Services - Dedicated Technical Support and SDK Access - Training, Workshops, and Documentation Access	- Automotive OEMs (developing in-vehicle ECUs with V2G capabilities) - Tier-1 Suppliers (integrating V2G stacks into production ECUs) - Automotive Software Engineering Teams (developing AUTOSAR-based modules) - ECU Software Service Providers (supporting OEM/Tier-1 integration of EB tresos)
	Key Resources - EB tresos Platform & Software IP (core AUTOSAR software framework including EB tresos AutoCore and V2G ChargeIn module) - Skilled Engineering Teams (experts in AUTOSAR, ISO 15118, embedded systems, and automotive cyber-security) - Partnerships with Standards Bodies & Stack Providers - Global Delivery Centers (located in Germany, Romania, India, USA, Japan) - Toolchain and SDK Infrastructure - Brand Trust in Automotive Software (20+ years of experience)		Channels - Direct Sales - Technical Pre-sales & Consulting Engagements (through long-term automotive software programs) - Developer Portals & Product Documentation Access - Industry Events & Conferences - Strategic Collaborations (e.g., with SEVENSTAX) - Online Webinars, Demos, and Training Programs	
Cost Structure		Revenue Streams		
- R&D Investment - Software Engineering & Customization - Compliance & Certification - Technical Support & Integration Services		- Software Licensing (Revenue from licensing the EB tresos V2G ChargeIn module to OEMs and Tier-1 suppliers) - Customization & Integration Services (Income from tailoring the V2G software stack to specific client requirements and integrating it into existing systems) - Maintenance & Support Contracts (Ongoing revenue from providing technical support, updates, and maintenance services to clients) - Training & Consulting Service (Earnings from offering training sessions and consulting services to clients for effective implementation and usage of the V2G solution)		

2.8.2 Energy Trading Platform

With the increasing integration of V2G technology, energy trading platforms are transforming the way electric vehicles interact with the power grid⁴⁷. These platforms enable bidirectional energy exchange, allowing EVs to store, consume, and sell excess energy back to the grid⁴⁸. By leveraging smart charging, AI-driven optimization, and automated demand response, these platforms enhance grid stability, reduce electricity costs, and generate new revenue streams for EV owners, fleet operators, and energy providers⁴⁹. Companies like Nuvve Corporation facilitate energy aggregation and grid participation through their GIVe™ Platform⁵⁰, which integrates bidirectional charging stations and smart link technology to regulate energy flow between EVs and the grid.

GridBeyond takes an AI-powered approach, optimizing EV fleet management and real-time energy trading, ensuring cost savings

and increased flexibility for industrial users⁵¹. ChargeScape, a joint venture by BMW, Ford, Honda, and Nissan, provides a seamless V2G integration platform that connects EVs, utilities, and automakers, offering financial incentives for grid participation and reducing carbon footprints⁵². Driivz, a leading provider of smart EV charging and energy management solutions, offers a modular platform that enhances network efficiency, monetization, and fleet electrification while supporting AC/DC charging, billing, and predictive maintenance⁵³.

Operating on service-based or shared asset models as shown in Table 2.14, these platforms play a pivotal role in optimizing energy consumption, reducing peak demand pressure on grids, and ensuring the sustainable adoption of V2G technology. Their integration with AI, predictive analytics, and smart automation is shaping the future of grid-interactive electric mobility, making EVs a key component of the modern energy ecosystem.

Table 2.14: Global Players and Business Model in Energy Trading Platform

Manufacturer	Markets covered	Who	What	How	The Value	Business model
Nuvve Corporation	United States, Denmark, United Kingdom, France	Fleet operators including school bus fleet, utility companies, and individual EV owners	Aggregation of electric vehicles to provide grid services	Nuvve operates a GIVe™ Platform which comprises of High-Powered, Bidirectional Charging Stations, Nuvve Energy Regulation Aggregator (NERA), and	Offers revenue generation for EV owners through grid services, enhances grid stability, and supports	Shared Asset

⁴⁷ Virta Global. "Vehicle-to-Grid (V2G): The Future of Energy Flexibility." <https://www.virta.global/vehicle-to-grid-v2g>

⁴⁸ Mojumder, Md. Rayid Hasan, Fahmida Ahmed Antara, Md. Hasanuzzaman, Basem Alamri, and Mohammad Alsharif. 2022. "Electric Vehicle-to-Grid (V2G) Technologies: Impact on the Power Grid and Battery" Sustainability 14, no. 21: 13856.

⁴⁹ Escoto, Marc, Antoni Guerrero, Elnaz Ghorbani, and Angel A. Juan. 2024. "Optimization Challenges in Vehicle-to-Grid (V2G) Systems and Artificial Intelligence Solving Methods" Applied Sciences 14, no. 12: 5211.

⁵⁰ Nuvve. "Nuvve Introduces Artificial Intelligence into Its GIVe™ Software Platform via Integration into the FleetBox Charge Management App." PR Newswire, July 12, 2023. [Link](#)

⁵¹ GridBeyond. "Transforming Energy Demand into Opportunity." [Link](#)

⁵² Ford Media. "BMW, Ford, and Honda Agree to Create ChargeScape, a New Company for Optimized EV Grid Services." Ford Media Center, September 12, 2023. [Link](#)

⁵³ Driivz. "SmartChain™ Smart Charging Platform." [Link](#)

				Vehicle Smart Link (VSL) that enables EVs to discharge electricity back to the grid	renewable energy integration.	
GridBeyond	Ireland, UK, Japan, US, Australia	Fleet operators, utility companies, commercial and industrial energy consumers	AI-powered energy trading, fleet management, and grid automation platform	Point Platform: AI-driven EV fleet integration, Smart Forecasting for real-time market participation, demand & storage optimization	Increases revenue from idle EV fleets, reduces fleet electrification costs, avoids peak charging prices, and maximizes energy flexibility for industrial users	Service Based Energy-as-a-Service (EaaS)
ChargeScap e (Joint venture by BMW, Ford, Honda, and Nissan)	US, Canada	EV owners, utility companies, automakers	V2G and smart charging integration platform	Open Vehicle-Grid Integration Platform (OVGIP) enabling seamless communication between utilities, automakers, and EVs; managed charge scheduling through vehicle telematics, eliminating the need for Wi-Fi-enabled chargers	Provides EV customers financial incentives for grid participation, enhances grid resilience, supports renewable energy utilization, and reduces personal carbon footprints	Service Based (Energy Services & Grid Optimization)
Driivz (Vontier-owned)	Global (Europe, US, Canada, Nordics, UK, Ireland)	Charge point operators, fleet managers, energy companies, convenience store chains	Smart EV charging & energy management platform	Modular platform for real-time operations management, billing, fleet electrification, smart energy management, and V2G services; Supports AC & DC charging, online booking, and maintenance planning	Optimizes network efficiency, enhances grid integration, enables monetization, improves driver experience, and supports large-scale fleet electrification	Service Based (Software as a Service (SaaS))

1. Business Model Canvas of Key Players

Business Model Canvas of GridBeyond (AI-Driven Energy Optimization and Management Solutions Developer)

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- Energy Network Operators & Grid Authorities - Commercial & Industrial Clients - Technological Collaborators (Partner with companies like ABB and Yokogawa Electric to integrate advanced hardware and software solutions) - Strategic Investors (Supported by investment from firms such as Energy Impact Partners, Mirova, and Constellation Energy, providing financial backing and industry expertise to drive innovation and expansion)	- Advanced Energy Market Participation (Leverage AI/ML to forecast energy market trends, enabling automated, real-time trading strategies that maximize financial returns while mitigating risks associated with market volatility) - EV Fleet Integration - Real-Time Grid Balancing Solutions (Develop and implement technologies that facilitate real-time grid balancing and demand response) - Continuous Enhancement of the Point Platform (Regularly update and refine the Point Platform)	- Unlocking New Revenue Streams (GridBeyond's AI-driven platform enables businesses to monetize underutilized energy assets) - Optimized Energy Expenditure (Through intelligent forecasting and automated trading, clients can minimize energy costs by avoiding peak pricing and capitalizing on favourable market conditions) - Advancing Sustainability Goals - Enhanced Operational Efficiency	- Collaborative Solution Development (Engage with clients through a consultative approach, co-creating tailored energy solutions that align with their specific operational needs and sustainability goals) - Strategic Long-Term Alliances - Comprehensive Support Services	- Electric Vehicle Fleet Operators - Utility Companies and Grid Operators - Commercial and Industrial Energy Consumers
	Key Resources - Point Platform (An AI-driven energy management system integrating hardware (TouchPoint), analytics (CentrePoint), user interface (ViewPoint) to optimize energy assets) - Expert Team (A multidisciplinary group of professionals specializing in AI, energy markets, and software development) - Global Presence (Operations across Ireland, UK, USA, Japan, and Australia) - Data Infrastructure		Channels - Personalized Client Engagement - Digital Interfaces - Industry Participation - Collaborative Alliances	
Cost Structure		Revenue Streams		
- Innovation and Product Development (Significant investment in research and development, highlighted by a ₹5.06 billion Series C funding round in April 2024, aimed at enhancing the AI-driven Point Platform and expanding into new market) - Infrastructure and Operational Expenses - Client Support and Training - Marketing and Business Development		- Energy-as-a-Service (EaaS) (GridBeyond offers subscription-based energy solutions) - Software Licensing (The company licenses its AI-driven Point Platform to clients) - Managed Services (GridBeyond provides comprehensive energy management services, including real-time trading and optimization) - Consulting Services (The company offers expert advice and customized solutions, assisting clients in developing and implementing effective energy strategies)		

2.8.3 Grid-Integrated V2G Participants

1. Aggregator and Individual Owner

The transition toward grid-integrated V2G systems is driven by aggregators and individual EV owners who facilitate bidirectional energy exchange between EVs and the grid. Aggregators act as intermediaries, managing fleets of V2G-enabled vehicles and optimizing energy distribution, while individual EV owners contribute to grid stability by storing and supplying electricity based on real-time energy demands^{54,55}. These participants play a crucial role in reducing energy costs, integrating renewable energy, and enhancing grid resilience.

Companies like We Drive Solar in the Netherlands integrate solar energy with V2G-enabled EVs, allowing residential communities to store excess solar power and return it to the grid, promoting sustainability and financial savings⁵⁶. E.ON Drive, in partnership with Nissan, offers smart bidirectional charging solutions in the

UK, helping residential customers, businesses, and fleet operators optimize energy costs and load balancing⁵⁷. In the public transit sector, Proterra develops V2G-compatible electric buses, providing high-power bidirectional charging and energy management software to reduce operational costs and support grid stability. Nuvve Corporation, a global leader in V2G aggregation, operates its GIVe™ Platform, which enables fleet operators, school bus fleets, and utilities to generate revenue by supplying electricity back to the grid, enhancing grid flexibility and renewable energy integration⁵⁸.

These players operate under various business models, including shared asset models for community-based charging, service-based models for energy management, and product-based approaches for V2G-compatible electric buses and bidirectional charging systems. Their collective efforts contribute to a more resilient, cost-efficient, and sustainable energy ecosystem, demonstrating the potential of V2G technology in both residential and commercial applications.

Table 2.15: Global Players and Business Model in Aggregator and Individual Owner

Type of Participant	Manufacturer	Markets covered	Who	What	How	The Value	Business model
Aggregator	We Drive Solar	Netherlands	Residential communities and utility companies	Solar energy integration with V2G-enabled EVs	Develops community-based charging solutions powered by solar energy, allowing EVs to store and	Promotes sustainable energy use, reduces carbon footprints, and provides	Shared Assets

⁵⁴ U.S. Department of Energy. "Bidirectional Charging and Electric Vehicles as Mobile Storage." Federal Energy Management Program (FEMP). [Link](#)

⁵⁵ Hammon, Beth. "The Truth About Electric Vehicles and the Grid: Strengthening, Not Straining, Our Energy System." Natural Resources Defense Council (NRDC). [Link](#)

⁵⁶ Hyundai News. "Hyundai and We Drive Solar Launch Energy System of the Future in Utrecht." [Link](#)

⁵⁷ Nissan News. "Nissan, E.ON Drive, and Imperial College Highlight the Carbon-Saving and Economic Benefits of Vehicle-to-Grid Technology." [Link](#)

⁵⁸ Nuvve Holding Corp. "Nuvve Highlights Details of Recent State of New Mexico Contract." Business Wire, February 28, 2025. [Link](#)

				return energy to the grid	financial benefits for communi- ties	
E.ON Drive (Partnered with Nissan)	United Kingdom	Residential customers, businesses, and EV fleet operators	Smart V2G charging solutions, including bidirectional chargers and energy management systems, designed to integrate EVs with the grid	Provides integrated solutions with bidirectional EV chargers and energy management systems	Helps customers save on energy costs, supports load balancing, enhances grid stability, and integrates renewable energy into the energy ecosystem	Service and Shared Assets
Proterra	United States	Electric bus fleets and transit operators	V2G- enabled electric buses, bidirectional charging systems, and energy management solutions	Provides electric buses equipped with Proterra battery systems capable of V2G integration. Offers high- power, bidirectional charging systems for efficient energy transfer. Deploys energy management software to optimize charging and energy flow	Reduces fleet operating costs by enabling energy arbitrage, enhances grid stability through bidirectional energy transfer, Provides a sustainable solution for decarbon- izing transit systems	Product (electric buses and charging systems) and Service (energy management and consultation)
Nuvve Corporation	United States, Denmark , United	Fleet operators including	Aggregation of electric vehicles	Nuvve operates a GIVE™ Platform	Offers revenue generation for EV	Shared Asset

	Kingdom, France	g school bus fleet, utility companies, and individual EV owners	to provide grid services	which comprises of High-Powered, Bidirectional Charging Stations, Nuvve Energy Regulation Aggregator (NERA), and Vehicle Smart Link (VSL) that enables EVs to discharge electricity back to the grid	owners through grid services, enhance s grid stability, and supports renewable energy integration.
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1. Business Model Canvas of Key Players

Business Model Canvas of We Drive Solar (Solar-powered EV sharing service integrated with bidirectional charging infrastructure)

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments			
- Municipality of Utrecht (Collaborates with We Drive Solar to implement V2G infrastructure, aiming to make Utrecht the world's first bidirectional city) - Renault Group (Provides 500 Renault 5 E-Tech electric vehicles equipped with Mobilize's V2G technology for the car-sharing fleet) - MyWheels (Operates the shared EV fleet, integrating mobility and energy solutions) - Hyundai (Supplies IONIQ 5 vehicles equipped with V2G technology for pilot projects in Utrecht)	- Development of Bidirectional Charging Infrastructure - Integration of Solar Energy with EV Charging (Utilizing solar energy to charge EVs, which can then supply energy back to the grid during peak demand) - Operation of Shared EV Fleet (Managing a fleet of V2G-enabled shared electric vehicles in partnership with MyWheels) - Community Engagement and Education (Promoting sustainable energy use and educating residents about the benefits of V2G technology)	- Sustainable Energy Utilization (Enables communities to use locally generated solar energy efficiently, reducing reliance on fossil fuels) - Grid Stabilization (Provides grid services such as frequency response and peak shaving through V2G technology) - Financial Incentives for Communities - Reduced Carbon Footprint	- Collaborative Partnerships - Community Engagement - Customer Support Services	- Residential Communities (Targeted for the deployment of shared EVs and bidirectional charging stations to create neighbourhood energy systems) - Utility Companies (Collaborate with We Drive Solar to integrate V2G technology into the broader energy grid) - Municipalities (Partner with We Drive Solar to implement sustainable mobility and energy solutions at the city level)			
	Key Resources		Channels				
	- Bidirectional Charging Infrastructure (Includes the development and deployment of AC bidirectional chargers and the "Solar City" charging stations) - Shared EV Fleet (Comprises V2G-enabled EVs from manufacturers like Renault and Hyundai) - Technical Expertise - Partnership Network (Collaborates with various stakeholders, including municipalities, utility companies, and technology partners)		- Direct Partnerships (Engages with municipalities and utility companies to implement V2G projects) - Online Platforms (Utilizes digital platforms for customer engagement and information dissemination) - Community Events (Participates in local events to promote awareness and adoption of sustainable energy solutions)				
	Cost Structure				Revenue Streams		
	- Infrastructure Development (Invested in installing 60 bidirectional AC charging stations in Utrecht, each costing approximately ₹1.23 lakh, excluding installation expenses) - Fleet Acquisition and Maintenance (Procured 500 Renault 5 E-Tech electric vehicles equipped with Mobilize's V2G technology for their car-sharing fleet) - Research and Development (Committed resources to developing and refining V2G technologies and solutions, including smart charging software and energy market integration)				- Car-Sharing Subscriptions (Offers EV car-sharing services with monthly fees) - Pay-Per-Use Model (MyWheels charges users per hour and per km Rates vary depending on the vehicle type and specific usage. For example, hourly rates can range from ₹291-₹380, with daily maximums between ₹2,911 and ₹3,804) - Energy Market Participation (Utilizes V2G technology to supply stored energy from EVs back to the grid during peak demand, providing up to 10% of the required grid flexibility in the Utrecht region and earning revenue through energy trading and grid services) - Infrastructure Partnerships (Collaborates with partners like Koolen Industries to develop and deploy bidirectional charging stations, with 60 units installed in Utrecht as of March 2025, generating income from equipment sales or leasing)		

2.9 Service Based V2G Business

2.9.1 Training

As V2G technology continues to evolve, industry professionals require specialized training programs to ensure compliance with global standards, effective energy management, and seamless integration of smart charging solutions.

Several organizations provide service-based V2G training programs, equipping EV manufacturers, charging station operators, grid operators, and industry professionals with technical knowledge and hands-on experience in V2G communication, grid integration, and interoperability testing⁵⁹. Trialog in France offers modular training programs, including EM-100 on ISO/IEC 15118 standards and EM-200 on OCPP technology, delivered in English and French at its Paris premises or globally on request⁶⁰. It also provides customized training on PKI, OCPI, EEBus, OpenADR,

IEC 63110, and fleet operation to enhance industry expertise. The British Academy for Training and Development provides global training programs covering V2G technology, smart charging, and energy grid integration, offering in-person and online courses with practical case studies to foster innovation and compliance with industry standards⁶¹. CharIN Academy, a leading organization in e-mobility education, delivers workshops, seminars, and deep technical training on topics like ISO 15118, Plug & Charge implementation, cybersecurity in charging infrastructure, and global charging standardization⁶².

These programs ensure that electrical engineers, managers, and industry stakeholders gain a comprehensive understanding of V2G technology, interoperability, and smart charging solutions. These service-based training programs play a crucial role in promoting industry collaboration, accelerating V2G adoption, and fostering the development of intelligent and sustainable e-mobility solutions worldwide.

Table 2.16: Global Players and Business Model in Training

Manufacturer	Markets covered	Who	What	How	The Value	Business model
Trialog	France	Charging station manufacturers, grid operators, EVSE providers, and industry professionals	Trialog offers specialized training programs dedicated to Smart Charging and related technologies, designed to be modular and adaptable to different	Providing expert-led training in: 1. EM-100: ISO/IEC 15118 standards and its services 2. EM-200: OCPP technology They are available in	Enhances industry expertise, ensures compliance with smart charging standards, and supports technology integration. Trialog also provides	Service Based

⁵⁹ Tonex. "Vehicle-to-Grid (V2G) and Smart Charging Infrastructure Development Essentials." [Link](#)

⁶⁰ Trialog. "Trainings." [Link](#)

⁶¹ BATD Academy. "Vehicle-to-Grid (V2G) Technologies." [Link](#)

⁶² CharIN. "CharIN Academy Training: Charging Communications with ISO 15118." [Link](#)

			learning objectives	English and French and can be delivered at Trialog's premises in Paris, France, or anywhere worldwide upon request	tailored training on PKI, OCPI, EEBus, OpenADR, IEC 63110, energy management, and fleet operation.	
British Academy for Training and Development	Global	Professionals, corporate employees, researchers, and organizations seeking specialized training in V2G technology and energy systems	Comprehensive training programs on Vehicle-to-Grid (V2G) technology, smart charging, energy management, and related industry standards	Delivering expert-led in-person and online training sessions covering topics like ISO 15118, OCPP, energy grid integration, and charging station operations, with practical case studies and hands-on learning	Enhances professional skills, ensures compliance with industry standards, fosters innovation in V2G technology, and supports organizations in integrating smart charging solutions effectively	Service Based
CharIN Academy	Global	Electrical engineers, Managers, Product designers, Entrepreneurs, Technology consultants, anyone interested in the field of e-mobility and the energy market	Training programs through the CharIN Academy, covering ISO 15118 communication standards, V2G technology, smart charging, and interoperability testing for e-mobility solutions	Providing expert-led workshops, seminars, and technical deep dives on plug & charge implementation, cybersecurity in charging infrastructure, and global charging standardization, ensuring hands-on learning and real-world application	Facilitates industry collaboration, promotes standardization, ensures seamless interoperability, and accelerates the adoption of intelligent and sustainable e-mobility solutions worldwide	Service Based

1. Business Model Canvas of Key Players

Business Model Canvas of CharIN Academy (V2G Training & Certification Institution)					
Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments	
- CharIN e.V. members - Standardization bodies (IEC, ISO) - Technology providers - Universities & research institutions	- Curriculum development - Training delivery (online & on-site) - Certification programs - Pilot testbed partnerships	- High-quality, standardized training in V2G, EV charging, and communication protocols - ISO 15118 & Plug & Charge readiness for both individuals and organizations - Certification programs for professionals, engineers, and corporate teams - Acts as a bridge between industry needs and technical training	- Long-term engagement - Membership-based access to specialized resources, training content, and exclusive programs - Feedback loops for curriculum updates, ensuring content reflects latest standards and industry needs	- Engineers and technical professionals involved in EV charging, V2G, and ISO 15118 implementation - EV OEMs seeking workforce upskilling and compliance with global standards - Charging solution providers focused on interoperability and Plug & Charge - Utilities and grid operators involved in grid integration, flexibility services, and demand response - Academic institutions and training partners for curriculum deployment, research collaboration, and talent development	
	Key Resources - Subject matter experts (V2G, ISO 15118) - Online learning platform and course infrastructure - Standardized training materials and interoperability testing labs - Global brand recognition and trust through CharIN e.V.		Channels - CharIN Academy's online learning portal - Participation in industry events, conferences, and webinars - Collaboration through academic and industry partner networks - Communication via CharIN newsletters and working group meetings		
Cost Structure		Revenue Streams			
- Development of course material (investment in keeping content aligned with evolving standards (e.g., ISO 15118-20)) - Expert salaries and trainer fees - Platform maintenance (Online platform and LMS maintenance) - Event management and certification logistics		- Training fees (individual & corporate) - Certification program fees (includes exam charges and credentials like the ISO 15118 Expert badge) - Sponsored workshops (Co-hosted events by partners or funded by industry) - Institutional licensing or B2B contracts (Agreements with companies or academic partners for scaled delivery or white-label access)			

2.9.2 Battery Recycling and Disposal

With the rapid growth of electric vehicle (EV) adoption, the demand for battery recycling and disposal solutions has become critical for sustainable energy management in the V2G ecosystem.

As lithium-ion batteries reach the end of their lifecycle, recycling companies and manufacturers are investing in advanced technologies to recover valuable materials such as cobalt, lithium, nickel, copper, and graphite, reducing reliance on virgin materials and minimizing environmental

impact^{63,64}. Kerui Machinery⁶⁵ and Henan Renewable Energy Technology Co., Ltd.⁶⁶, both China-based global manufacturers, specialize in lithium-ion battery recycling machines that use negative pressure systems, shredding, crushing, screening, and separation processes to achieve high-purity material recovery with minimal dust pollution. Their fully automated, PLC-controlled recycling equipment ensures efficient and environmentally friendly operations. Metso, a global leader in metal recovery solutions, provides a hydrometallurgical recycling process using proprietary technologies like VSF® X

Solvent Extraction and Larox® PF Filters to extract nickel, cobalt, lithium, and manganese from battery black mass, reducing embedded carbon by over 60% compared to virgin material production⁶⁷. These manufacturers operate under a product-based business model, offering customized equipment sales and proprietary recycling technology solutions to battery recyclers, EV manufacturers, and industrial plants. Their contributions play a vital role in creating a circular economy for EV batteries, reducing environmental impact, and supporting the long-term sustainability of V2G technology.

Table 2.17: Global Players and Business Model in Battery Recycling and Disposal

OEM	Markets covered	Who	What	How	The Value	Business model
Kerui Machinery	Global (China-based)	Battery recyclers, manufacturing plants, energy companies	Lithium-ion Battery Recycling Machine	Negative pressure recycling system with shredding, drying, crushing, screening, and separation processes for recovering black mass, aluminium, copper, and graphite	High recovery rates, no dust pollution, fully automated process with PLC control	Product Based (Equipment Sales & Customization)
Henan Renewable Energy Technology Co., Ltd	Global (China-based)	Battery recyclers, EV manufacturers, electronics manufacturers, industrial plants	Lithium Battery Recycling Machines & Plants	Closed negative pressure system with shredding, crushing, grinding, air separation, gravity separation, and pulse dust collection for high-purity metal recovery	High recovery efficiency (≥99% cobalt & lithium, ≥98% copper & aluminium, ≥99% iron), low energy consumption, dust-free operation, environmentally friendly	Product Based (Equipment Sales & Customization)

⁶³ Anuradha, S., R. Manimegalai, and M. Devasena. "Challenges in Recycling Lead Acid Battery and Lithium-Ion Battery: A Comprehensive Review." 2024 International Conference on Smart Systems for Electrical, Electronics, Communication and Computer Engineering (ICSSECC), Coimbatore, India, 2024, pp. 101-106.

⁶⁴ Gu, Xiaoyu, Li Zhou, Hongfu Huang, Xiutian Shi, and Petros Ieromonachou. "Electric vehicle battery secondary use under government subsidy: A closed-loop supply chain perspective." International Journal of Production Economics 234 (2021): 108035.

⁶⁵ Kerui Machinery. "Lithium-Ion Battery Recycling Machine." [Link](#)

⁶⁶ HN Renewable. "Production Line." [Link](#)

⁶⁷ Mining.com. "Metso Introduces Sustainable Battery Black Mass Recycling." [Link](#)

Metso	Global	Battery manufacturers, recycling facilities, and metal recovery industries	Battery Black Mass Recycling Process	Hydrometallurgical process utilizing proprietary technologies: VSF® X Solvent Extraction, OKTOP® Reactors, Larox® PF Filters, Dual Media (DM) Filters, LSF Filters, Thickeners, and Scrubbers	Enables sustainable recovery of valuable metals (nickel, cobalt, lithium, manganese, copper) from battery black mass, reducing embedded carbon by over 60% compared to virgin material production	Product Based (Technology and Equipment Sales)
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1. Business Model Canvas of Key Players

Business Model Canvas of Henan Renewable Energy Technology Co., Ltd (Lithium Battery Recycling Equipment Manufacturer)				
Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
- Battery recycling firms - EV manufacturers and electronics producers - Industrial plant operators - Environmental authorities	- R&D and design of battery recycling systems - Customization of equipment - Manufacturing and installation - After-sales technical support	- Closed-loop, dust-free lithium battery recycling systems - High-purity metal recovery (≥99% cobalt/lithium, ≥98% copper/aluminium, ≥99% iron) - Low energy consumption and environmentally friendly - Custom-engineered systems for diverse industrial needs	- Dedicated technical support - After-sales service agreements - Long-term service and maintenance contracts - On-site training and remote diagnostics	- Battery recyclers - EV manufacturers - Electronics manufacturers - Industrial facilities handling end-of-life lithium batteries
	Key Resources		Channels	
	- In-house R&D and engineering teams - Manufacturing facility in China - Proprietary technologies such as air & gravity separation and pulse dust collection systems - Established client network and reference case studies		- Direct B2B sales with global outreach - Official website with product demos and technical resources - Participation in industry expos and recycling trade fairs - Strategic partnerships with government and recycling programs	
Cost Structure		Revenue Streams		
- Manufacturing costs (machinery, precision components) - R&D expenditure for system upgrades and innovation - Installation and commissioning expenses - Personnel costs (engineers and technical staff) - Packaging, logistics, and international shipping		- Installation and commissioning service fees (bundled or charged separately) - Annual maintenance and service contracts (recurring income source) - Spare parts sales and system upgrades - Technical consulting and training services - Equipment sales (standard and customized systems)		

3. Current EV and Grid Scenario

The rapid expansion of electric vehicles and renewable energy capacity in India presents both opportunities and challenges for the energy ecosystem⁶⁸. With the government's push towards e-mobility, increasing investments in charging infrastructure, and ambitious targets for renewable energy generation, the need for smart grid solutions has become more critical. However, the intermittency of solar and wind power, coupled with the growing demand for EV charging, poses challenges in grid stability and energy distribution.

V2G technology offers a transformative solution by enabling bidirectional energy flow, where EVs not only consume electricity but also feed surplus energy back into the grid during peak demand periods.

This can help in load balancing, reducing stress on the grid, and optimizing renewable energy utilization.

As India continues its transition towards a sustainable and resilient energy system, integrating V2G with smart grids will be crucial in enhancing grid flexibility, reducing energy costs, and improving overall energy security.

3.1 EV Market Growth and Projections

India's electric vehicle (EV) market is experiencing significant growth, with projections indicating a substantial increase in sales and market share by 2030⁶⁹ as shown in Figure 3.1 and Figure 3.2.

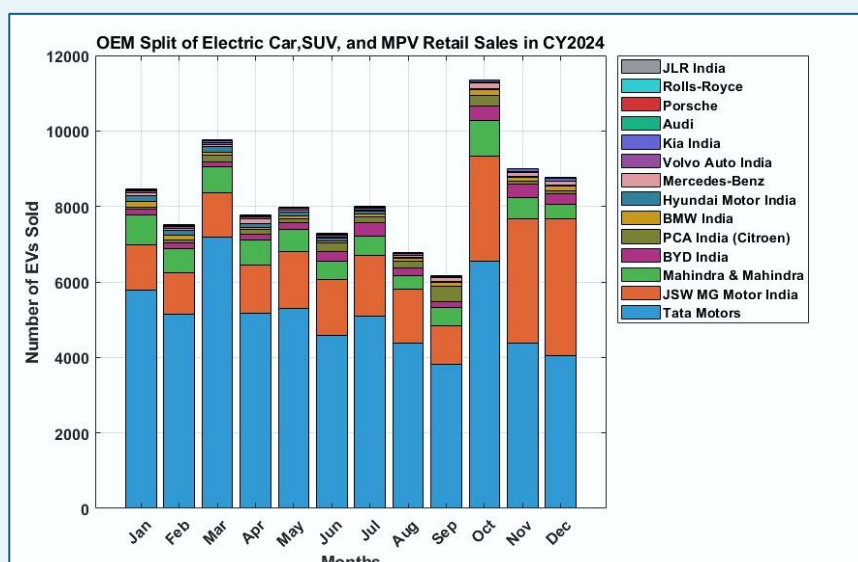


Figure 0.1: OEM Split of Electric Car, SUV, and MPV Retail Sales in CY2024⁶⁹

⁶⁸ Tank, I., S. Vignesh, Y. K. Bhatashvar, and K. C. Vora. "Vehicle to Grid (V2G): Booster for EV Adaptation in India." 2021 IEEE 2nd International Conference on Smart Technologies for Power, Energy and Control (STPEC), Bilaspur, Chhattisgarh, India, 2021, pp. 1-6.

⁶⁹ Autocar Professional. "Electric Car and SUV Sales Hit Highest Level in CY2024: 99,000 Units." [Link](#)

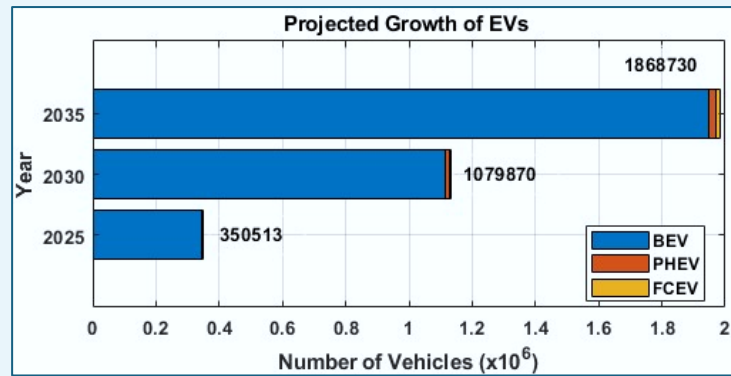


Figure 0.3: Projected Growth of EVs

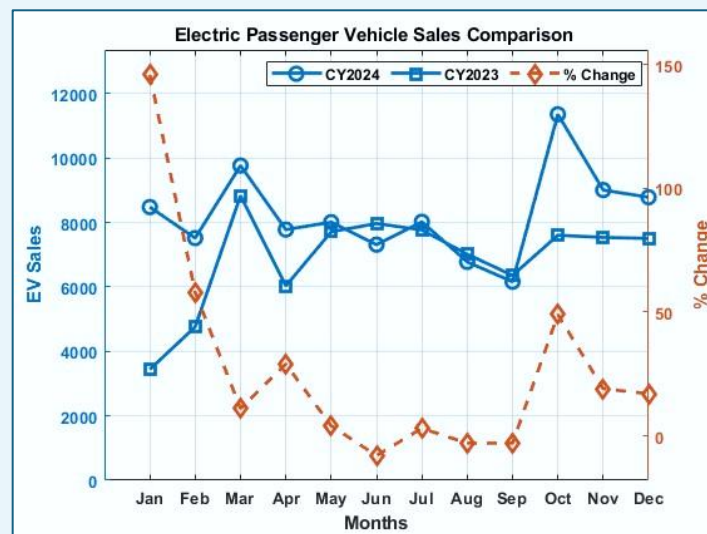


Figure 0.2: Electric Passenger Vehicle Sales Comparison

In 2024, the market was valued at approximately USD 8.49 billion and is expected to reach USD 152.21 billion by 2030, growing at a compound annual growth rate (CAGR) of 40.7% from 2025 to 2030⁷⁰ as shown in Figure 3.3. This growth is driven by several factors, including government initiatives such as the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme, which provides incentives for EV adoption. Additionally, increasing environmental awareness and advancements in battery technology are contributing to the rising demand for electric passenger cars and commercial vehicle⁷¹.

3.2 Effect of Large-Scale EV penetration in power grid

The widespread adoption of electric vehicles (EVs) has profound implications for power grid stability, infrastructure investments, and energy management strategies.

As EV penetration increases, challenges such as transformer overloading, voltage instability, and increased peak load demand become more pronounced.

⁷⁰ Grand View Research. India Electric Vehicle Market Size, Share & Trends Analysis Report By Product (Battery Electric Vehicle, Plug-In Hybrid Electric Vehicle), By Vehicle (Passenger Cars, Commercial Vehicles), And Segment Forecasts, 2025 - 2030. [Link](#)

⁷¹ International Energy Agency (IEA). Global EV Data Explorer. [Link](#)

However, managed charging, bidirectional power flow (V2G), and smart grid technologies can mitigate these effects and improve grid efficiency.

A study on California's 2045 EV projections highlights a 25 GW peak load increase, requiring substantial grid infrastructure upgrades (\$6–\$20 billion by 2045)^{72,73}. However, V2G integration and managed charging can significantly reduce peak impacts. Similarly, Norway's low-voltage grid study found that voltage deviations and power cable overloads occurred at 20% EV penetration, but time-of-use (ToU) tariffs and reactive power control effectively mitigated these issues⁷⁴. In Texas, the electrification of heavy-duty EVs resulted in voltage violations, emphasizing the need for coordinated charging strategies and infrastructure assessments⁷⁵. A Danish grid study revealed that uncoordinated EV

charging led to voltage deviations, but integrating distributed energy resources (DERs) like solar power with EVs reduced grid strain and enhanced flexibility⁷⁶. Additionally, Norway's BATTPOWER simulation demonstrated that grid overload occurs beyond 20% EV penetration, reinforcing the importance of coordinated charging to minimize stress on transformers and lines⁷⁷. Lastly, an ERCOT study in Texas found that high EV charging demand led to frequency deviations, requiring EVs to provide frequency regulation services to maintain grid stability while addressing cybersecurity vulnerabilities in charging infrastructure⁷⁸.

These case studies underscore the critical need for strategic grid investments, smart charging solutions, and V2G integration to ensure grid resilience and efficient energy distribution as EV adoption accelerates.

Table 0.1: Global case studies of Effect of Large-Scale EV penetration in power grid

Case Study	Region	Observed Grid Effect	Key Findings
California's 2045 EV Projections Error! Bookmark not defined.	California, USA	- Overloaded transformers and feeders due to increased EV charging demand. - Peak load increase of 25 GW by 2045. 50% of feeders require upgrades by 2035; 67% by 2045. - High infrastructure investment needed.	- Estimated upgrade cost: \$6–\$20 billion by 2045. - Managed charging & V2G can reduce peak impacts. - Strategic grid investments essential for reliability.
Norwegian Low-Voltage	Norway	Voltage instability and localized congestion in weak distribution networks.	Time-of-use (ToU) tariffs and smart charging can mitigate grid stress.

⁷² UC Davis Energy Institute. "New Study Forecasts EV Impact on California's Grid." [Link](#)

⁷³ Li, Yanning, and Alan Jenn. "Impact of electric vehicle charging demand on power distribution grid congestion." *Proceedings of the National Academy of Sciences* 121, no. 18 (2024): e2317599121.

⁷⁴ Lillebo, Martin, Salman Zaferanlouei, Antonio Zecchino, and Hossein Farahmand. "Impact of large-scale EV integration and fast chargers in a Norwegian LV grid." *The Journal of Engineering* 2019, no. 18 (2019): 5104-5108.

⁷⁵ El Helou, Rayan, S. Sivaranjani, Dileep Kalathil, Andrew Schaper, and Le Xie. "The impact of heavy-duty vehicle electrification on large power grids: A synthetic Texas case study." *Advances in Applied Energy* 6 (2022): 100093.

⁷⁶ Pillai, Jayakrishnan R., Paul Thøgersen, Jan Møller, and Birgitte Bak-Jensen. "Integration of electric vehicles in low voltage danish distribution grids." In 2012 IEEE power and energy society general meeting, pp. 1-8. IEEE, 2012.

⁷⁷ Zaferanlouei, Salman, Venkatachalam Lakshmanan, Sigurd Bjarghov, Hossein Farahmand, and Magnus Korpås.

"BATTPOWER application: Large-scale integration of EVs in an active distribution grid—A Norwegian case study." *Electric Power Systems Research* 209 (2022): 107967.

⁷⁸ Sneha, Fariha Hakim, Yilu Liu, Le Xie, and Tao Xia. "Grid Stability and Cybersecurity Challenges in Electric Vehicle Integration: A Case Study of the ERCOT System." (2025).

Grid Study ^{Error!} Bookmark not defined.		- Power cable overload at 20% EV penetration. - Voltage deviations mitigated by reactive power control near fast chargers. - Network tolerated 50% EV penetration with respect to voltage limits.	- Reactive power injection significantly reduces voltage deviations. - Weakest distribution cables need upgrades for sustained EV growth.
Texas Heavy-Duty EV Electrification ^E Error! Bookmark not defined.	Texas, USA	- Voltage violations observed in transmission networks when 11% of heavy-duty EVs charge simultaneously. - Localized voltage issues at distribution levels when a few dozen EVs charge simultaneously. - Increased reactive power demand, affecting grid stability.	- Coordinated charging & smart inverters are suggested as mitigation strategies, but their quantitative impact on voltage violations is uncertain. - Infrastructure assessments required for both transmission & distribution networks. - Further studies needed to assess mitigation effectiveness.
Danish Low-Voltage Grid Analysis ^{Error!} Bookmark not defined.	Denmark	- Feeder capacity varies from 0-40% for EV loads. - Transformers can handle 6-40% EV loads based on grid strength. - Voltage deviations due to uncoordinated charging.	- Voltage-dependent reactive power control can stabilize voltage profiles and enhance EV hosting capacity. - Integration of Distributed Energy Resources (DERs) like solar + EVs can reduce grid strain and support flexibility. - Further analysis needed on long-term impact on grid infrastructure.
BATTPOWER Simulation – Norway ^{Error!} Bookmark not defined.	Norway	- Overloading of lines & transformers above 20% EV share. - Operational limits violated above 36% EV share under certain conditions. - Higher operational costs with uncoordinated charging.	- Coordinated charging strategies reduce stress on transformers and lines. - Proper grid control can extend EV penetration without major upgrades.
ERCOT System Frequency Stability ^{Error!} Bookmark not defined.	Texas, USA	- Frequency deviations due to high EV charging demand. - Potential for grid instability during peak EV charging periods.	- Coordinated EV charging can provide frequency regulation services. - Integration of EVs into grid operations enhances stability. - Cybersecurity vulnerabilities introduced by EV charging infrastructure need to be addressed.

3.3 Increasing Renewable Energy Penetration & Storage Needs

India is witnessing a significant increase in renewable energy (RE) capacity, with solar and wind power playing a dominant role in the energy transition. As seen in the RE capacity distribution, solar power (ground-mounted and rooftop) accounts for over

56% of total RE capacity, followed by wind power contributing nearly 30%⁷⁹. Other sources, including small hydro, bio power, and waste-to-energy, hold a smaller share, highlighting the country's focus on solar and wind expansion. The progressive capacity addition over the months indicates a consistent rise in RE deployment, with February 2024 to January 2025 adding over 7,000 MW of new capacity, reflecting India's commitment to scaling up renewable energy adoption^{80,81}.

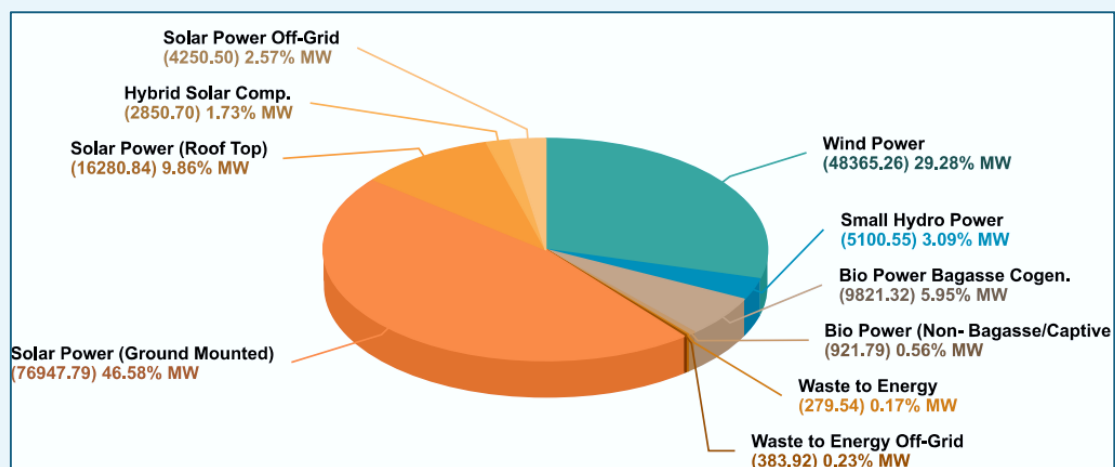


Figure 0.4: Increasing RE Penetration in India⁷⁹

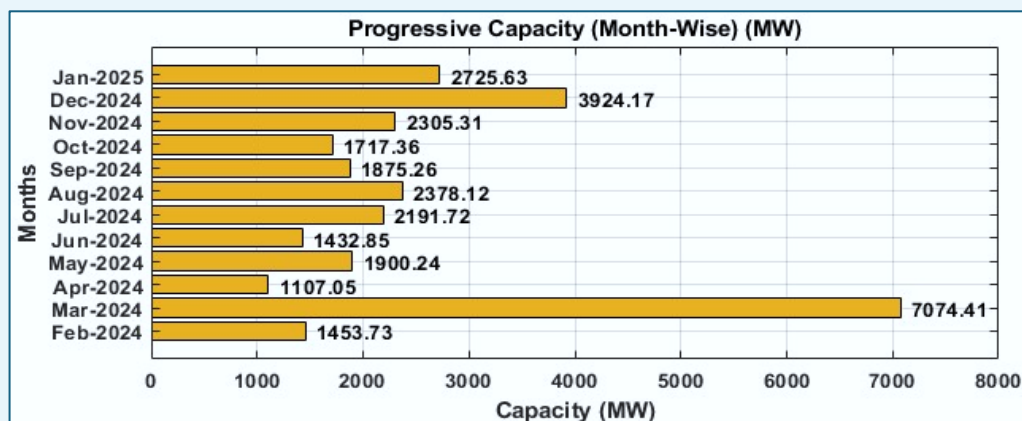


Figure 0.5: Progressive Capacity (Month-Wise) (in MW)⁷⁶

⁷⁹ Press Information Bureau (PIB). "Energy Security in India." Press Information Bureau, February 1, 2025. [Link](#)

⁸⁰ Ministry of New and Renewable Energy (MNRE). "Physical Progress." [Link](#)

⁸¹ Ministry of New and Renewable Energy, Government of India. Renewable Energy: All India Capacity Ministry of New and Renewable Energy, 2025. [Link](#)

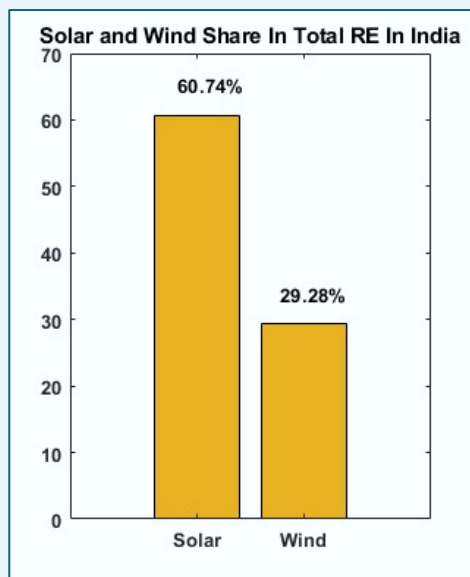


Figure 0.7: Solar and Wind Share in Total RE in India⁷⁷

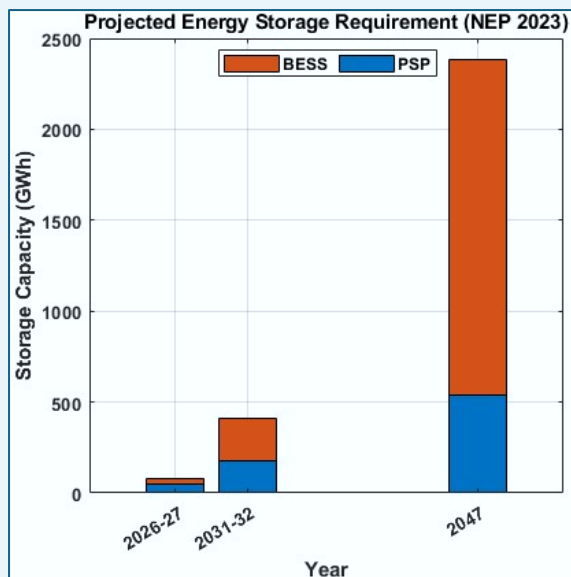


Figure 0.6: Projected Energy Storage Requirement (NEP 2023)⁷⁷

However, with the growing RE penetration, the need for energy storage solutions becomes critical to ensure grid stability, reliability, and efficient power utilization. The projected energy storage requirements (as per NEP 2023) indicate a significant surge in storage capacity, with Battery Energy Storage Systems (BESS) and Pumped Storage Plants (PSP) playing a crucial role in balancing supply and demand⁸².

By 2047, the storage requirement is expected to exceed 2,000 GWh, emphasizing the importance of integrating advanced storage technologies to support India's ambitious RE targets^{Error! Bookmark not defined.}. As solar and wind energy account for over 90% of total RE, robust energy storage systems, grid modernization, and smart energy management strategies will be essential in optimizing renewable power usage, reducing intermittency challenges, and enabling a resilient clean energy ecosystem.

3.4 Grid Infrastructure Requirements

The rising number of EVs will substantially increase electricity demand, posing challenges for the existing grid infrastructure. Uncoordinated charging patterns may lead to localized grid overloads and peak demand issues. To address these challenges, upgrades in grid capacity, implementation of smart charging solutions, and development of bidirectional power flow capabilities are essential^{83,84,85}.

3.4.1 Current DISCOM State

India's power distribution companies (DISCOMs) continue to face significant financial losses, posing a major challenge to the stability of the power sector. The state-wise accumulated DISCOM losses reveal that Tamil Nadu (26%), Rajasthan (15%), and Uttar Pradesh (15%) contribute the

⁸² Ministry of New and Renewable Energy (MNRE). "Energy Storage Systems (ESS) Overview." [Link](#).

⁸³ National Renewable Energy Laboratory (NREL). Report No. 89775. U.S. Department of Energy, 2024. [Link](#)

⁸⁴ National Renewable Energy Laboratory (NREL). Report No. 79080. U.S. Department of Energy, 2021. [Link](#)

⁸⁵ Belfer Center for Science and International Affairs. "Leveraging Charging Strategies to Reduce Grid Impacts of Electric Vehicles." [Link](#)

largest share to the national aggregated losses, followed by Madhya Pradesh and Telangana (10% each). Other states, including Maharashtra, Andhra Pradesh, Karnataka, Bihar, Haryana, Punjab, and Uttarakhand, also account for a portion of the losses, reflecting widespread inefficiencies in power distribution and revenue recovery^{86,87,88}. The financial losses of DISCOMs over the years have remained consistently high, with figures reaching ₹80,179 crore in 2017-18, and though fluctuating, still amounting to ₹68,832 crore

in 2022-23⁸⁹. Despite government reforms, subsidy support, and debt restructuring efforts, the losses highlight persistent issues such as high aggregate technical and commercial (AT&C) losses, power theft, inadequate tariff revisions, and inefficiencies in billing and collection. Addressing these challenges requires enhanced grid management, smart metering solutions, financial restructuring, and policy interventions to improve DISCOM sustainability and ensure a reliable power supply across the country.

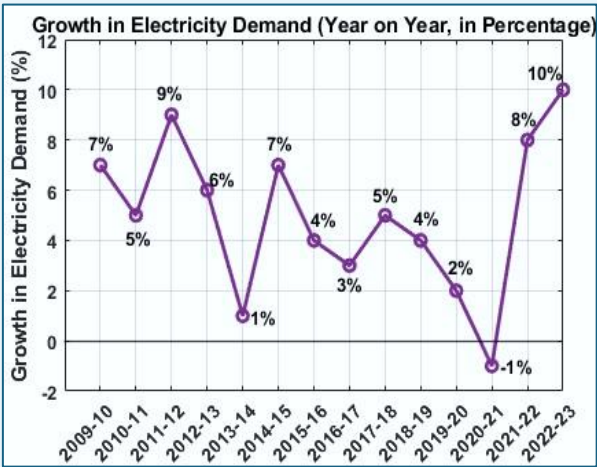


Figure 0.8: Growth in Electricity Demand (Year on Year, in Percentage)

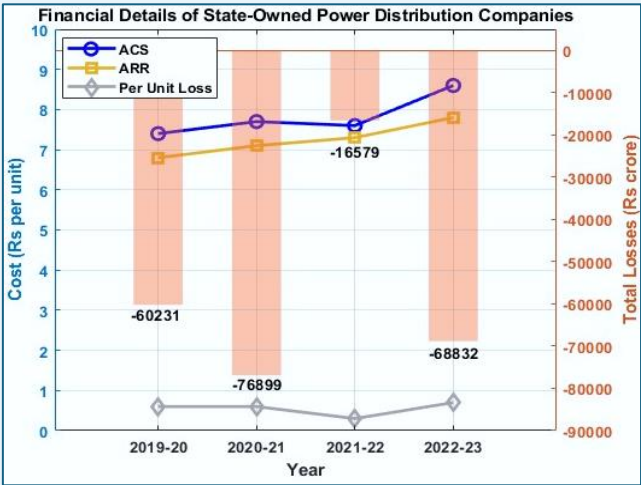


Figure 0.9: Financial Details of State-Owned Power Distribution Companies

⁸⁶ Central Electricity Authority (CEA). (2023). Annual Report on Power Sector. Central Electricity Authority, Ministry of Power, Government of India.
⁸⁷ Ministry of Power, Government of India. Report on Electricity Supply Position in India: November 2024. Ministry of Power, 2024. [Link](#).
⁸⁸ Prayas (Energy Group). DISCOM Finance: An Overview of Financial Challenges and Solutions. National Institute of Public Finance and Policy (NIPFP), July 9, 2024. [Link](#).
⁸⁹ PRS Legislative Research. "What Is Fueling Power Sector Losses?" PRS India, January 18, 2023. [Link](#).

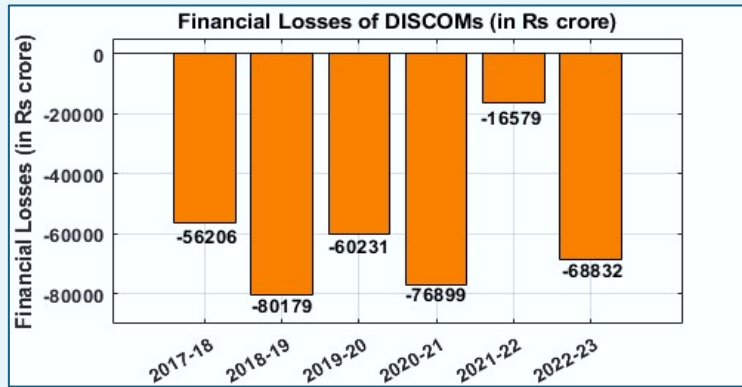


Figure 0.11: Financial Losses of DISCOMs (in Rs. Crore)

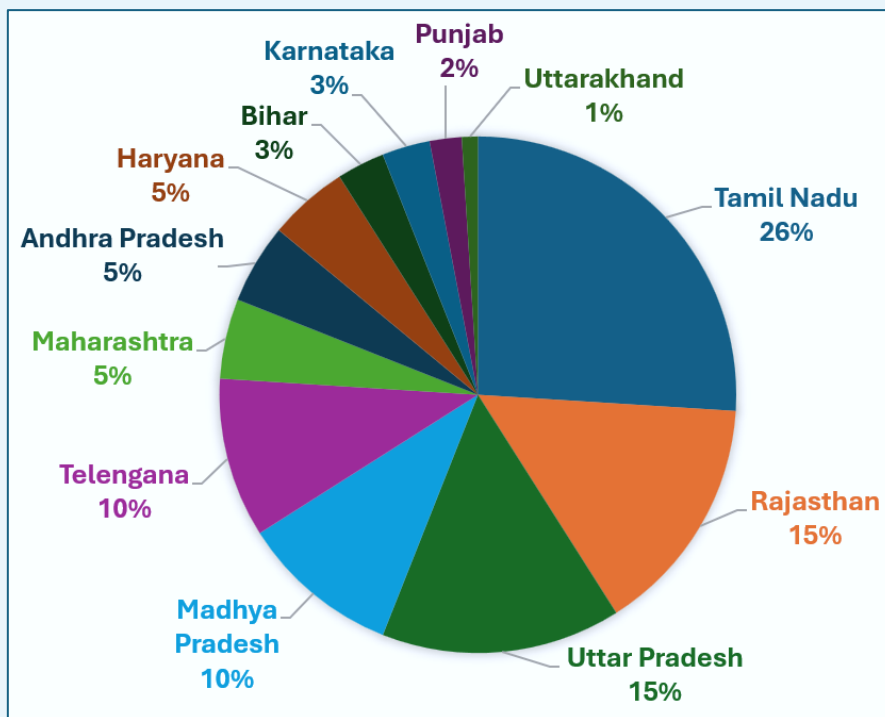


Figure 0.10: State-Wise accumulated DISCOM losses as a percentage of the national aggregated losses

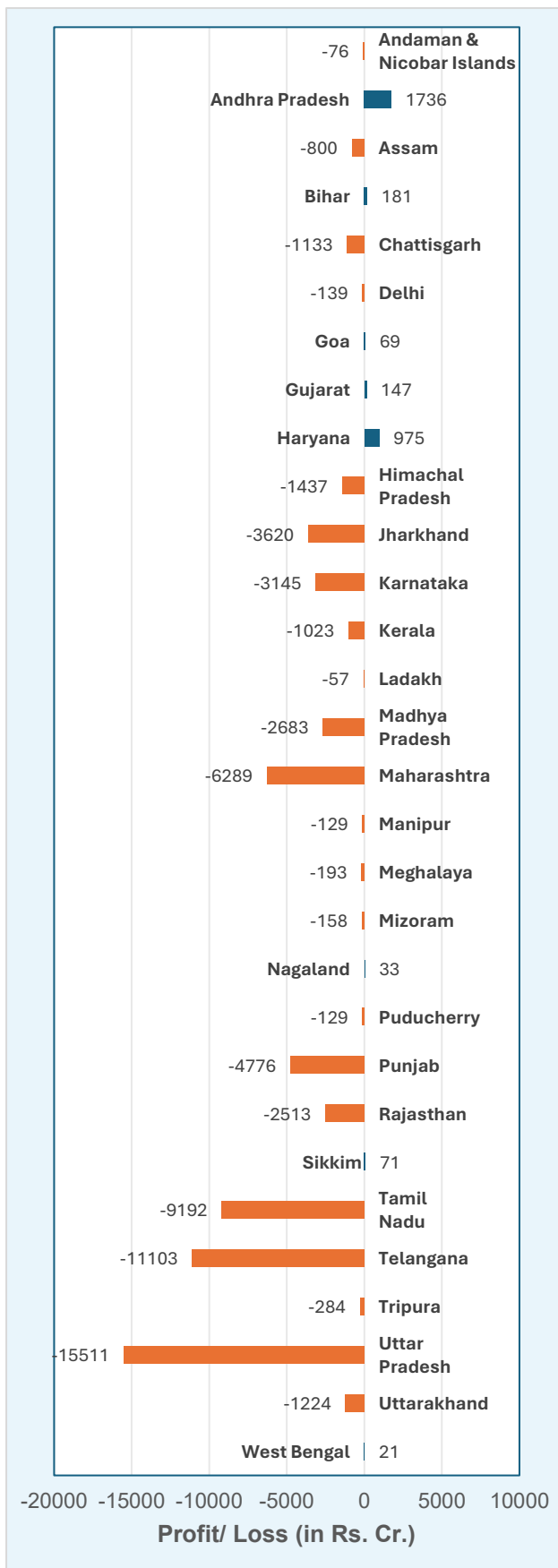


Figure 0.13: Cumulative annual profit/loss of state owned DISCOMs in each state for 2022-23

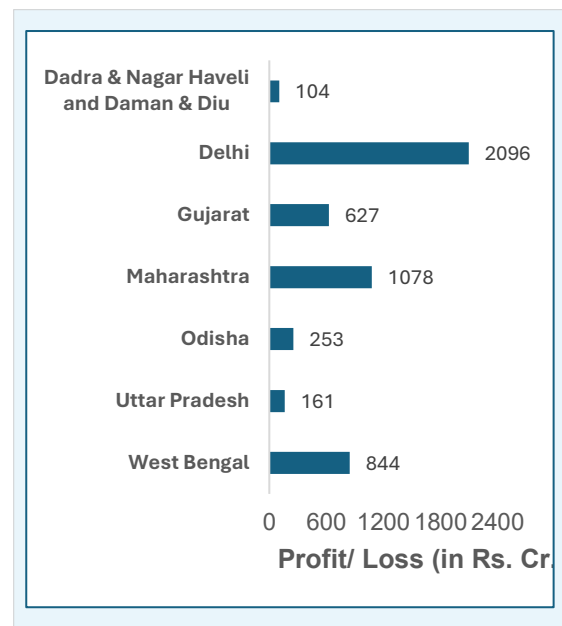


Figure 0.12: Cumulative annual profit/loss of private owned DISCOMs in each state for 2022-23

3.5 Importance of V2G

V2G technology plays a crucial role in optimizing energy management, reducing costs, and enhancing grid stability by enabling bidirectional energy flow between electric vehicles (EVs) and the power grid. One of the primary benefits of V2G is reducing investment in Battery Energy Storage Systems (BESS) by utilizing existing EV batteries as distributed storage resources. This allows for peak shaving and load balancing, minimizing strain on the grid during high-demand periods.

Additionally, V2G supports energy arbitrage and renewables integration, enabling EVs to store excess renewable energy and

discharge it when needed, ensuring efficient energy utilization^{90,91,92}. Beyond storage, V2G contributes to reducing grid upgrade costs by deferring infrastructure investments, as EVs can act as decentralized energy assets that supply power when demand is high. Moreover, it enhances grid stability by providing voltage and frequency support, helping to maintain power quality. Another key advantage is its role in mitigating renewable intermittency, ensuring a smoother transition to a clean energy future by balancing fluctuations in solar and wind power generation⁹³. As the EV ecosystem expands, integrating V2G technology will be essential for creating a resilient, cost-effective, and sustainable energy infrastructure.

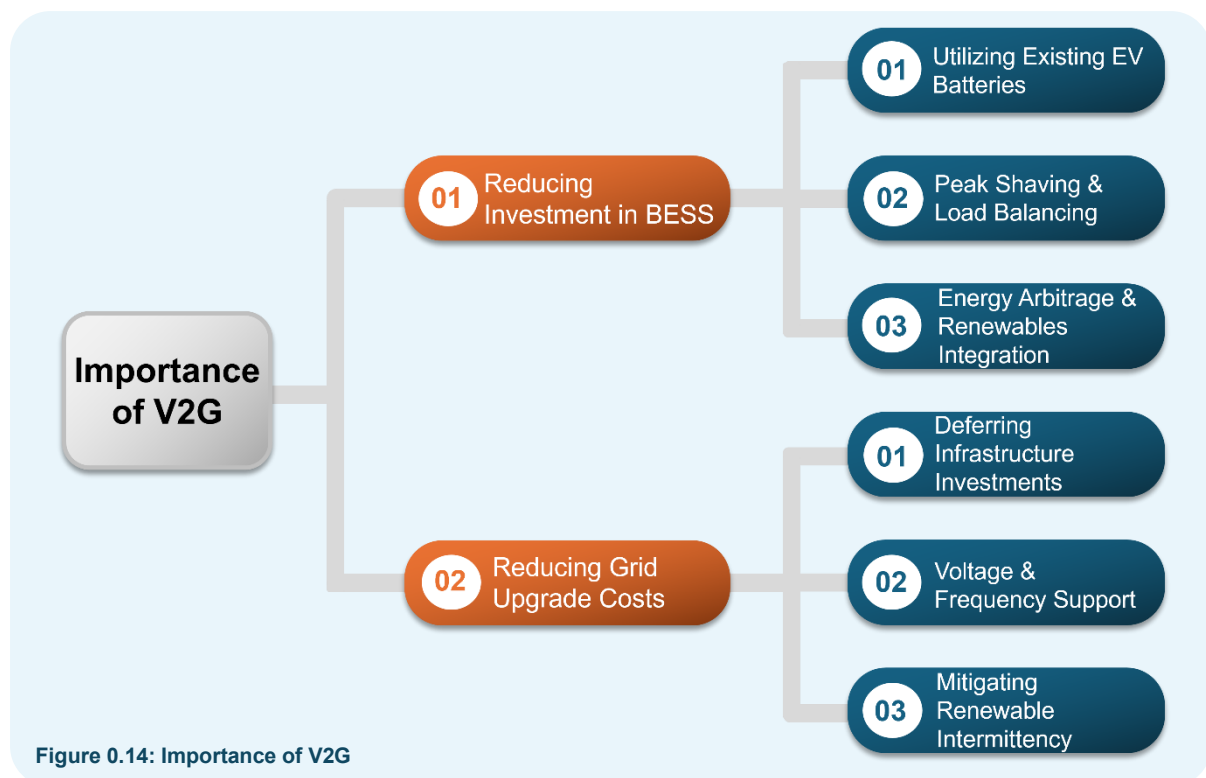


Figure 0.14: Importance of V2G

⁹⁰ Rao, Sriram Prabhakara, Tomomewo Stanley Olusegun, Prakash Ranganathan, Utku Kose, and Neena Goveas. "Vehicle-to-Grid technology: Opportunities, challenges, and future prospects for sustainable transportation." *Journal of Energy Storage* 110 (2025): 114927.

⁹¹ Naik, Nivedita, and C. Vyjayanthi. "Optimization of vehicle-to-grid (V2G) services for development of smart electric grid: A review." In *2021 International Conference on Smart Generation Computing, Communication and Networking (SMART GENCON)*, pp. 1-6. IEEE, 2021.

⁹² Yusuf, Jubair, and Sadrul Ula. "A comprehensive optimization solution for buildings with distributed energy resources and V2G operation in smart grid applications." In *2020 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT)*, pp. 1-5. IEEE, 2020.

⁹³ Kumar, Pulkit, Harpreet Kaur Channi, Raman Kumar, Asha Rajiv, Bharti Kumari, Gurpartap Singh, Sehijpal Singh, Issa Farhan Dyab, and Jasmina Lozanović. "A comprehensive review of vehicle-to-grid integration in electric vehicles: Powering the future." *Energy Conversion and Management: X* (2024): 100864.

3.5.1 Case studies related to V2G

The V2G technology has been tested across various regions to assess its feasibility, impact on grid stability, and economic benefits. Several pilot projects and trials have demonstrated the potential of V2G to reduce grid upgrade costs, integrate renewable energy, and support demand-side energy management. However, these studies also highlight key challenges such as high initial costs, regulatory hurdles, and the need for standardized communication protocols⁹⁴.

In the UK, the OVO Energy and Kaluza V2G trial (2018-2021) deployed 330 V2G devices to allow EVs to discharge energy to the grid during peak hours, potentially saving up to £3.5 billion annually in grid infrastructure costs^{Error! Bookmark not defined.}. Similarly, the enX and ARENA V2G Study in Australia simulated a 10% V2G uptake, reducing peak demand by over 6%, which helped in minimizing network expansion needs^{Error! Bookmark not defined.}. The Rabobank Dynamic Charging Project in the Netherlands (2021-2022) tackled grid congestion using movable chargers, converting parking spaces into temporary energy storage units, thereby reducing infrastructure upgrade costs^{Error! Bookmark not defined.}. Apart from grid integration, V2G and V2H (Vehicle-to-Home) applications have also been explored. The V2H Integration with Residential PV and Battery Storage Project

in Australia (2017-2020) demonstrated how integrating V2H with solar and battery storage could reduce energy costs by up to 25%^{Error! Bookmark not defined.}. In Germany, BMW and TenneT's V2G project (2019-2022) tested Bidirectional Charging Management (BCM), where 50 BMW i3 vehicles stored and supplied renewable energy, successfully enhancing grid stability and reducing fossil fuel reliance^{Error! Bookmark not defined.}.

The USA's Nuvve & UC San Diego V2G Campus Pilot (2017-2021) integrated 50 V2G chargers into the UCSD microgrid, participating in demand charge management, solar energy optimization, and frequency regulation, proving V2G's potential in large-scale grid services^{Error! Bookmark not defined.}. Meanwhile, Denmark's Parker Project (2016-2018) validated EVs as reliable grid assets by proving their effectiveness in frequency regulation services, with fleet owners earning up to €1,860 per car/year^{Error! Bookmark not defined.}. While these studies highlight V2G's promising impact on grid flexibility, cost savings, and renewable energy integration, challenges such as limited V2G-ready vehicles, charger compatibility issues, regulatory barriers, and fluctuating electricity market conditions remain. Addressing these obstacles through policy support, standardization, and technological advancements will be key to scaling V2G adoption globally.

Table 0.2: V2G Case Studies

Case Study	Objective	Project Summary	Conclusion	Limitations
V2G (UK) "OVO Energy and Kaluza Vehicle-to-Grid (V2G) trial⁹⁵."	1. Reduce grid upgrade costs 2. Enhance grid stability	1. Involved 330 V2G devices 2. Allowing EVs to discharge to grid during peak times	V2G could potentially save up to £3.5 billion annually in grid	1. Higher initial costs for bidirectional chargers

⁹⁴ Yilmaz, Murat, and Philip T. Krein. "Review of benefits and challenges of vehicle-to-grid technology." In 2012 IEEE Energy Conversion Congress and Exposition (ECCE), pp. 3082-3089. IEEE, 2012.

⁹⁵ Kaluza. "Case Study: Kaluza Enabled Vehicle-to-Grid (V2G) Charging." Kaluza, 2024. [Link](#).

(2018-2021)			infrastructure costs.	2. Need for standardized protocols
V2G(Australia) “enX and ARENA V2G Study with Ausgrid ⁹⁶ .” (18 months)	1. Manage peak loads 2. Integrate renewable energy	Simulating a 10% V2G uptake, which reduced peak demand by over 6%	1. Demonstrated significant cost savings 2. Minimizing the need for network expansions by effective peak load management	1. Regulatory challenges 2. Need for consumer incentives for broader adoption
V2G(Netherlands) “Rabobank Dynamic Charging and Congestion Management Project ⁹⁷ .” (2021-2022)	Alleviate grid congestion	1. It uses dynamic congestion compensation. 2. Movable chargers to manage peak loads by transforming parking spaces into temporary batteries	1. This reduces grid congestion. 2. Avoided significant upgrade costs by providing flexible battery capacity during peak hours	1. Higher costs for implementing movable chargers 2. Need for strong economic incentives
V2H (Australia) “V2H Integration with Residential PV and Battery Storage Project ⁹⁸ .” (2017-2020)	1. Optimize home energy use 2. Reduce grid dependency	Researchers from the University of South Australia developed a model integrating V2H with residential PV and battery storage.	V2H reduced energy costs by up to 25% for public charging scenarios decreasing reliance on the grid and mitigating upgrade needs.	1. Variability in tariff structures 2. Need for robust home energy management systems
V2G (Germany) “BMW and TenneT V2G Project ⁹⁹ ” (2019-2022)	1. Stabilize the grid 2. Enhance renewable energy use	The Bidirectional Charging Management (BCM) project deployed 50 BMW i3 vehicles with V2G capabilities to support grid stability by storing and feeding back renewable energy. The project tested integration with TenneT's grid and demand response programs.	Successfully demonstrated grid balancing and renewable energy optimization, reducing reliance on fossil fuels	Successfully demonstrated grid balancing and renewable energy optimization, reducing reliance on fossil fuels
V2G (USA) –	Test V2G feasibility for a	Installed 50 V2G-capable chargers,	Reduced demand charges,	Limited V2G-ready vehicles, charger

⁹⁶ Australian Renewable Energy Agency (ARENA). V2X AU Summary Report: Opportunities and Challenges for Bidirectional Charging in Australia. Australian Renewable Energy Agency, June 2023. [Link](#)

⁹⁷ Rabobank. "V2G: Transforming Electric Vehicles into Rolling Energy Storage." Rabobank, 2024. [Link](#)

⁹⁸ Wu, Yan, Syed Mahfuzul Aziz, and Mohammed H. Haque. "Vehicle-to-home operation and multi-location charging of electric vehicles for energy cost optimisation of households with photovoltaic system and battery energy storage." Renewable Energy 221 (2024): 119729.

⁹⁹ TenneT. "The Right Way to Green Electricity: TenneT Investigates Bidirectional Charging Management for E-Cars." TenneT, 2024. [Link](#)

“Nuvve & UC San Diego V2G Campus Pilot¹⁰⁰” (2017-2021)	university campus, Support grid stability	integrating EVs into the UCSD microgrid EVs participated in demand charge management, solar energy optimization, frequency regulation, and demand response with CAISO.	supported 8 MW curtailment during the 2020 heat wave, and proved V2G’s potential for grid services	compatibility issues, and policy barriers restricting market participation
V2G (Denmark) “Parker Project: Grid-Balancing with V2G¹⁰¹” (2016-2018)	Assess V2G for frequency regulation services, Prove technical feasibility of EVs as grid assets	The project demonstrated that EVs could reliably provide Frequency Containment Reserve (FCR) services, validating their technical capability. Cross-brand tests (Nissan, Mitsubishi, PSA) were conducted.	EVs successfully participated in grid frequency regulation, with some fleet owners earning up to €1,860 per car/year. However, profitability was inconsistent due to market fluctuations.	Limited V2G-ready vehicles, high dependency on electricity market conditions, and regulatory barriers affecting large-scale implementation

¹⁰⁰ Nuvve Corporation. "Nuvve Announces Momentum for Vehicle-to-Grid (V2G) Technology." Nuvve, December 2018. [Link](#)

¹⁰¹ Parker, Mark. Final Report: V2G – Vehicle to Grid Integration. Technical University of Denmark, 2019. [Link](#)

4. Potential V2G Business Models for India

India's transition towards V2G technology will present diverse business opportunities across charging infrastructure, grid integration, energy management, and battery solutions.

The expansion of V2G-compatible charging infrastructure will be driven by public-private partnerships, government incentives, and advancements in semiconductor technology.

Table 4.1: Potential Business Models

Business Ecosystem	Potential Business Models	Key Elements	Market Drivers
Charging Infrastructure	Product, Service	- V2G Charger, - Power Module, - Control Module, - Charger Connector	- Public-Private Partnerships: (Tata Power-DDL) for V2G Demonstration ¹⁰² and Private players investment in EVCI ¹⁰³ - Government Initiatives for EVCI ¹⁰⁴ - India Semiconductor Mission and international collaborations ^{105,106,107,108} - Local EV Ecosystem
Electric Vehicle Powertrain	Product	Powertrain	- Government Incentive for EV manufacturing value chain ¹⁰⁹ - Private Players ^{110,111,112} - International collaborations ^{113,114}

¹⁰² The Economic Times Energy World. "Tata Power-DDL Signs MoU with ISGF for New V2G Technology Demonstration in North Delhi." The Economic Times Energy World, May 15, 2024. [Link](#)

¹⁰³ Mandayam, Nandan. "India's Tata Motors Plans to More Than Double EV Charging Stations." Reuters, February 13, 2025. [Link](#)

¹⁰⁴ Kohli, Sumati. Charging Infrastructure in India: Incentives under FAME II and Considerations for PM E-DRIVE. Washington, D.C.: International Council on Clean Transportation, October 10, 2024. [Link](#)

¹⁰⁵ IMPRI Impact and Policy Research Institute. "India Semiconductor Mission (2021): Fostering a Self-Reliant Semiconductor Industry." IMPRI Insights, October 2021. [Link](#)

¹⁰⁶ SEMI. "India and Taiwan Deepen Collaboration to Drive Semiconductor Development." EE Times Asia, May 31, 2024. [Link](#)

¹⁰⁷ Swain, Gyana. "US and India Partner to Strengthen Semiconductor Supply Chain." Computerworld, September 10, 2024. [Link](#)

¹⁰⁸ Reuters. "Israel's Tower Semiconductor Ties Up with Adani Group for \$10 Billion Chip Project in India." Reuters, September 6, 2024. [Link](#)

¹⁰⁹ Ministry of Heavy Industries. "Steps Taken by the Government to Boost Domestic Manufacturing of Electric Vehicles and to Reduce the Country's Dependence on Imports." Press Information Bureau, December 5, 2023. [Link](#)

¹¹⁰ ElectronEV. "ElectronEV: Smart and Sustainable Electric Vehicle Solutions." [Link](#)

¹¹¹ The Economic Times Auto. "Tsuyo Launches India's First Indigenous EV Powertrain Production Line for Commercial Vehicles." The Economic Times Auto, March 4, 2025.

¹¹² Electra EV. "EV Powertrain Manufacturing & Series Production." Electra EV. [Link](#)

¹¹³ Musashi Seimitsu Industry Co., Ltd. "Musashi Seimitsu Announces Strategic Partnership with Log9 Materials to Revolutionize EV Powertrain and Battery Solutions." Musashi Seimitsu Industry Co., Ltd., September 26, 2024. [Link](#)

¹¹⁴ Wood, Izzy. "VinFast to Build EV Facilities in India." Automotive Powertrain Technology International, January 12, 2024. [Link](#)

				4. Inter-Country Partnerships ^{115,116}
Grid Integrated V2G Participants	Service, Shared Asset	1.	Energy Trading Platform,	1. AI-Driven EV Fleet Integration ^{117,118,119}
		2.	Vehicle-Grid Integration Platform enabling seamless communication between utilities, automakers, and EVs,	2. Startup in Fleet Integration Services ¹²⁰
		3.	Aggregation of electric vehicles to provide grid services,	3. Well-Established Energy Trading Platforms such as IEX, PXIL, PTC India, and GMR Group ^{121, 122}
		4.	Solar energy integration with V2G-enabled EVs, AI-driven EV fleet integration, Smart Forecasting for real-time market participation,	4. Growing Renewable Energy Integration
		5.	Smart EV charging & energy management platform,	5. Favourable Government Regulations & Policies: Time-of-Day Tariffs and Smart grid initiative
		6.	Fleet integration services	6. Advancing Smart Charging Infrastructure ¹²³
BMS	Product, Service, Subscription, Shared Asset, Agency/Promotion, Reselling	1.	BMUs,ICs, Sensors and other Electronic Components,	1. India Semiconductor Mission and international collaborations ^{124, 125, 126, 127}
		2.	Battery pack solutions, Universal BMS for multiple chemistries,	2. Government Incentive ¹²⁸
		3.	Aftermath BMS Retrofitting, Software licensing & cloud	3. Indigenous Microprocessor Development ¹²⁹
				4. Government Incentive for Indigenous battery manufacturing ¹³⁰

¹¹⁵ Wood, Izzy. "Volkswagen and Mahindra & Mahindra Collaborate to Increase E-Mobility in India." Automotive Powertrain Technology International, February 19, 2024. [Link](#)

¹¹⁶ Reuters. "REE Automotive Raises \$45 Million, Announces Partnership with Mitherson Group." Reuters, September 16, 2024. [Link](#)

¹¹⁷ Intangles. "How AI is Revolutionizing Fleet Management Systems in India: A Deep Dive." Intangles, December 24, 2024. [Link](#)

¹¹⁸ Kalia, Abhinav. "Leveraging AI and Machine Learning for Efficient EV Operations." Energetica India, February 26, 2025. [Link](#)

¹¹⁹ Autocar Pro News Desk. "ZF Introduces AI-Powered Fleet Management Platform in India." Autocar Professional, January 21, 2025. [Link](#)

¹²⁰ Bhardwaj, Mani. "Rilox EV's Journey to Transform Logistics with Sustainable Innovation." TICE News, February 27, 2025. [Link](#)

¹²¹ GMR Group. "Power Trading." GMR Group. [Link](#)

¹²² Wikipedia contributors. "PTC India." Wikipedia, The Free Encyclopedia. Last modified October 15, 2024. [Link](#)

¹²³ Fortum India. "GLIDA and Statiq Forge Partnership to Transform India's Electric Vehicle Charging Services." Fortum India, March 22, 2024. [Link](#)

¹²⁴ IMPRI Impact and Policy Research Institute. "India Semiconductor Mission (2021): Fostering a Self-Reliant Semiconductor Industry." IMPRI Insights, October 2021. [Link](#)

¹²⁵ SEMI. "India and Taiwan Deepen Collaboration to Drive Semiconductor Development." EE Times Asia, May 31, 2024. [Link](#)

¹²⁶ Swain, Gyana. "US and India Partner to Strengthen Semiconductor Supply Chain." Computerworld, September 10, 2024. [Link](#)

¹²⁷ Mehta, Tanvi. "Israel's Tower Semiconductor, Adani Plan \$10 Billion Chip Project in India." Reuters, September 6, 2024. [Link](#)

¹²⁸ Acharya, Shivangi, and Aftab Ahmed. "India to Offer \$4-\$5 Billion in Incentives for Electronics Production, Weaning off China." Reuters, November 22, 2024. [Link](#)

¹²⁹ Wikipedia contributors. "SHAKTI (microprocessor)." Wikipedia, The Free Encyclopedia. [Link](#)

¹³⁰ Ministry of Heavy Industries. "Steps Taken by the Government to Boost Domestic Manufacturing of Electric Vehicles and to Reduce the Country's Dependence on Imports." Press Information Bureau, December 5, 2023. [Link](#)

		platform, Software-as-a-Service (SaaS) for diagnostics,	5. Private Players ^{131,132,133}
		4. Digital twin simulations & integration,	6. Strategic Partnerships ¹³⁴
		5. Remote diagnostics & cloud-based BMS,	7. Battery Waste Management Rule ^{135,136}
		6. Remote battery monitoring and maintenance, Subscription-based analytics platform,	8. Digital Transformation and Cloud Adoption ¹³⁷
		7. Cloud-based predictive BMS solutions,	9. Economic Impact of Cloud Computing ¹³⁸
		8. Subscription-based maintenance & diagnostics, Testing, certification & compliance consulting, Safety & compliance consulting services, Regulatory approvals & testing solutions, Battery Recycling	10. Investments by Technology Giants ^{139,140}
			11. Local Players ¹⁴¹
			12. Energy Storage Systems (ESS) Policies ¹⁴²
			13. Battery R&D ecosystem ¹⁴³
			14. Battery Waste Management Rule ^{144,145}
			15. Central Pollution Control Board (CPCB) EPR Portal ¹⁴⁶
			16. Local Market ¹⁴⁷
			17. Startups ^{148,149}
CMS/EMS	Product, Service, Shared Asset	1. Energy management software for EV fleets,	1. India smart meter mission ^{150,151}
		2. App Based platform to support V2G functionality,	

¹³¹ Wikipedia contributors. "Log 9 Materials." Wikipedia, The Free Encyclopedia. [Link](#)

¹³² Greenfuel Energy Solutions Pvt. Ltd. "Made in India Li-ion Batteries for Clean Mobility & Energy Storage Solutions." Greenfuel Energy Solutions Pvt. Ltd. [Link](#)

¹³³ Evolute Group. "Custom Lithium-Ion Battery Pack Solutions." Evolute Group. [Link](#)

¹³⁴ Wikipedia contributors. "SHAKTI (microprocessor)." Wikipedia, The Free Encyclopedia. [Link](#)

¹³⁵ Handa, Vikram. "Building a Green Future: Strategic Policies to Strengthen the EV Ecosystem." The Times of India, January 9, 2025. [Link](#)

¹³⁶ Ministry of Environment, Forest and Climate Change. "Government Notifies Battery Waste Management Rules, 2022." Press Information Bureau, August 25, 2022. [Link](#)

¹³⁷ TechSci Research. "India License Management Market Report & Forecast 2030." TechSci Research, 2025. [Link](#)

¹³⁸ NASSCOM. "Future of Cloud and Its Economic Impact: Opportunity for India." NASSCOM, July 20, 2022. [Link](#)

¹³⁹ Microsoft. "Microsoft Announces US \$3 Billion Investment Over Two Years in India Cloud and AI Infrastructure to Accelerate Adoption of AI, Skilling, and Innovation." Microsoft Stories India, January 7, 2025.

¹⁴⁰ Manikandan, Ashwin, and Haripriya Suresh. "India Cenbank Plans 2025 Launch of Cloud Services, Countering Dominance of Global Firms." Reuters, November 18, 2024.

¹⁴¹ F6S. "12 Top Battery Management Systems Companies in India." F6S. [Link](#)

¹⁴² Ministry of New and Renewable Energy. "Energy Storage Systems (ESS) Policies and Guidelines." Ministry of New and Renewable Energy. [Link](#)

¹⁴³ Meshram, Abhishek, and Parveen Kumar. "Decoding India's Battery R&D Ecosystem: The Commercialization Challenge." WRI India, May 9, 2024. [Link](#)

¹⁴⁴ Handa, Vikram. "Building a Green Future: Strategic Policies to Strengthen the EV Ecosystem." The Times of India, January 9, 2025. [Link](#)

¹⁴⁵ Ministry of Environment, Forest and Climate Change. "Government Notifies Battery Waste Management Rules, 2022." Press Information Bureau, August 25, 2022. [Link](#)

¹⁴⁶ Central Pollution Control Board. "Extended Producer Responsibility Portal under Battery Waste Management Rules, 2022." Central Pollution Control Board. [Link](#)

¹⁴⁷ E-Vehicle Info. "Top Lithium-Ion Battery Recycling Companies in India." E-Vehicle Info, March 5, 2025. [Link](#)

¹⁴⁸ Khan, Saniya Ahmad. "Battery Recycling Startups Are Shaping the Future of EVs." YourStory, May 30, 2024. [Link](#)

¹⁴⁹ Recycling Startups. "LICO Materials." Recycling Startups, January 3, 2025. [Link](#)

¹⁵⁰ Sharma, Dinesh Chand. "Smart Metering in EU and India: Market Dynamics, Regulation & Standards." 4th Edition Smart Meter Summit 2024, July 25, 2024. [Link](#)

¹⁵¹ India Smart Grid Forum. "Smart Metering Program in India: A Critical Assessment – Revision 1." India Smart Grid Forum, October 2023. [Link](#)

		3. Smart charging solutions for V2G optimization, 4. Cybersecurity Solutions, 5. IoT modules and gateways for reliable EV charging connectivity, Smart meters, power quality sensors, and SCADA interfaces, 6. Energy Management Controllers (PLCs) and Microgrid controllers, 7. IoT modules and gateways for reliable EV charging connectivity, 8. Cybersecurity Solutions	2. Local Players¹⁵² 3. Union Budget 2024¹⁵³ 4. Market Growth^{154,155} 5. Technological Advancements and Industry Collaboration¹⁵⁶ 6. Revamped Distribution Sector Scheme^{157,158} 7. ISO 50001 Adoption¹⁵⁹
Testing Equipment	Product, Service	1. High Power Charging and Interoperability test, Signal and Spectrum Analyzer, 2. Simulator and Emulator, 3. HIL Test System, 4. RF Conformance, 5. Communication Test Equipment, 6. Conformance and interoperability testing services	1. Government Incentive¹⁶⁰ 2. Schemes for Electronics Manufacturing in India¹⁶¹ 3. State Govt. Incentives¹⁶² 4. High Power Charging and Interoperability test^{163,164} 5. Government Initiatives and Investments¹⁶⁵ 6. Govt. Body for Interoperability Standards Development¹⁶⁶ 7. Private Sector Participation¹⁶⁷

¹⁵² Press Trust of India. "Indian Cybersecurity Startups Poised for Strong Growth amid Rising Global Spend: Accel's Prayank Swaroop." The Economic Times, July 25, 2024. [Link](#)

¹⁵³ The Indian Express. "Union Budget 2024: Boosting Cybersecurity Budget to Defend India's Thriving Digital Economy." The Indian Express, August 17, 2024. [Link](#)

¹⁵⁴ Fournage, Ludo. "India Cybersecurity Job Market: Trends and Growth Areas for 2025." Nucamp, February 24, 2025. [Link](#)

¹⁵⁵ Grand View Research. "India IoT Node and Gateway Market Size & Outlook, 2030." Grand View Research, 2023. [Link](#)

¹⁵⁶ Messe Frankfurt. "India's EV Charging Network Is Booming." Messe Frankfurt, February 10, 2025. [Link](#)

¹⁵⁷ Ministry of Power. "Status of Upgradation to Prepaid Meters: Incentives and Agencies for the Installation of Smart Meters." Press Information Bureau, December 16, 2021. [Link](#)

¹⁵⁸ KPMG in India. "Smart Metering Market Transformation in India: Case Study." South Asia Regional Energy Partnership, January 2025. [Link](#)

¹⁵⁹ Bureau Veritas. "Energy Management System (ISO 50001) Certification." Bureau Veritas Certification. [Link](#)

¹⁶⁰ The Economic Times. "Govt to Offer \$5 Bn Incentives to Local Electronics Firms." The Economic Times, November 22, 2024. [Link](#)

¹⁶¹ Government of India. "Schemes for Electronics Manufacturing in India." Make in India. [Link](#)

¹⁶² Global Trade Alert. "India (Tamil Nadu): Incentives under the Semiconductor and Advanced Electronic Manufacturing Policy." Global Trade Alert, January 7, 2024. [Link](#)

¹⁶³ Mazars. "The Potential of EV Infrastructure Market in India." Mazars, August 2024. [Link](#)

¹⁶⁴ The Economic Times. "India Saw Ninefold Increase in EV Charging Stations in Last Two Years, but Why It Isn't Enough." The Economic Times, February 16, 2024. [Link](#)

¹⁶⁵ World Bank Group. "EV Charging Infrastructure, India." Public-Private Partnership Resource Center, 2024. [Link](#)

¹⁶⁶ NITI Aayog. "Handbook for EV Charging Infrastructure Implementation." NITI Aayog, August 2021. [Link](#)

¹⁶⁷ Reuters. "India's Tata Motors Plans to More Than Double EV Charging Stations." Reuters, February 13, 2025. [Link](#)

Battery Recycling and Disposal	Product	Lithium-ion Battery Recycling	1. Raw material availability¹⁶⁸ 2. Battery Waste Management Rules, 2022¹⁶⁹ 3. Startups¹⁷⁰
Communication Specific Hardware and Software	Product	5. Powerline Communication (PLC) devices, 6. V2G communication software stack, 7. Hardware Security Modules (HSMs) for securing V2G communication	• National Policy on Electronics 2019^{171,172} • Industry Collaborations and Investments for smart meter and automation¹⁷³ • Development of Indigenous Microprocessors^{174,175} • Semiconductor Manufacturing¹⁷⁶
Energy Meter	Product	Bidirectional Energy Meter	1. National Smart Grid Mission¹⁷⁷ 2. Domestic Manufacturing Capabilities^{178,179}

4.1 Business case for India from the perspective of an aggregator

4.1.1 Overview

An energy aggregator coordinates a network of EVs to provide grid services by aggregating their battery capacity. The aggregator earns revenue from utilities or energy markets for services like peak shaving, frequency regulation, and energy arbitrage, while sharing benefits with EV owners. This model reduces the need for dedicated stationary storage by leveraging

idle EV batteries¹⁸⁰.

Use-Case Scenarios (Public, Fleet, Residential)

• Public Charging V2G

The aggregator partners with public charging station operators to use parked EVs for grid support. For example, EVs at a mall or parking lot could discharge power during peak hours, and charge during off-peak hours. ToU tariffs and smart charging are used to optimize this, charging vehicles when rates are low and discharging when prices are high. Public V2G hubs can act as virtual power plants in cities.

¹⁶⁸ Mercom India. "India Has Potential to Attract Global Investments in Battery Recycling." Mercom India, August 2, 2023. [Link](#)

¹⁶⁹ Press Information Bureau. "Government Notifies Battery Waste Management Rules, 2022." Press Information Bureau, August 25, 2022. [Link](#)

¹⁷⁰ European Commission. "Six Companies Selected from Europe and India During the Battery Recycling Technologies Matchmaking Event." Research and Innovation. July 16, 2024. [Link](#)

¹⁷¹ International Trade Administration. "India - Information and Communication Technology." International Trade Administration, 2024. [Link](#)

¹⁷² Deshpande, Prashant Prabhakar. "Government Measures to Develop India as a Global Hub for Electronics System Design & Manufacturing." The Times of India, December 25, 2023.

¹⁷³ The Business Research Company. "Power Line Communication (PLC) Global Market Report 2025." The Business Research Company, January 2025. [Link](#)

¹⁷⁴ Kamakoti, V. "Building the Shakti Microprocessor." 4th Edition Smart Meter Summit 2024, July 25, 2024. [Link](#)

¹⁷⁵ Wikipedia contributors. "VEGA Microprocessors." Wikipedia, The Free Encyclopedia. [Link](#)

¹⁷⁶ Wikipedia contributors. "Electronics and Semiconductor Manufacturing Industry in India." Wikipedia, The Free Encyclopedia. [Link](#)

¹⁷⁷ National Smart Grid Mission. "Smart Grid." National Smart Grid Mission, 2025. [Link](#)

¹⁷⁸ Genus Power. "Net Meter - Shikhar." Genus Power, 2025. [Link](#)

¹⁷⁹ Techno Meters & Electronics. "Electronic Energy Meter Manufacturer in India." Techno Meters & Electronics, 2025. [Link](#)

¹⁸⁰ Gourav Mishra, "Sheru's Vehicle-to-Grid Station to Support Delhi DISCOM's Peak Power Demand," Mercom India, May 24, 2023, [Link](#)

• Fleet/ Depot V2G

The aggregator works with fleet operators (e.g. electric buses, delivery vans, taxi aggregators). Fleet vehicles have large batteries and predictable schedules, making them ideal for V2G. For instance, buses can charge overnight and discharge back to the grid in the evening peak before their next run¹⁸¹. Depot V2G helps the grid handle peaks and gives fleet owners extra revenue. In Delhi, discoms are pushing app-based mobility and delivery fleets to electrify by 2030, creating a future opportunity for fleet V2G programs.

• Residential V2G

The aggregator enrolls private EV owners

who plug in at home. When the grid is under stress (e.g. evening peak), the aggregator can discharge small amounts from each EV. Owners are compensated for energy returned to the grid during peak demand. This helps manage local peak loads and integrate rooftop solar by storing excess solar in EVs and feeding it back at night.

4.1.2 Infrastructure and Cost Breakdown

Implementing V2G for an aggregator requires bi-directional charging infrastructure and IT systems. Table outlines a typical cost breakdown for setting up V2G capability per site or customer (in the Indian context):

Table 4.2: Sample Infrastructure Cost Breakdown for Aggregator V2G (per charging site/EV)¹⁸²

Component	Description	Approx. Cost (₹)
Bi-directional Charger (AC)	7–22 kW V2G-capable charger (home or public)	1,50,000 – 2,50,000
Bi-directional Charger (DC)	50 kW fast V2G charger (fleet/depot)	10,00,000 – 15,00,000
Installation & Grid Interface	Wiring, smart meter upgrade, protection relay	40,000 – 75,000
Permitting & Approvals	DISCOM interconnection permission, paperwork	10,000 (one-time)
Communications & Controls	IoT gateway, SIM or network for aggregator control	5,000 – 10,000 (annual)
Software Integration	Aggregator platform integration (per charger license)	10,000 – 20,000 (annual)
Maintenance	Charger upkeep, warranty, calibration	~5% of hardware cost/year

¹⁸¹ Darlene Steward, Critical Elements of Vehicle-to-Grid (V2G) Economics (Golden, CO: National Renewable Energy Laboratory, September 2017), [Link](#)

¹⁸² Alice Grundy, "World's Largest Domestic V2G Trial Finds Hardware Costs Still Too High Despite 'Significant Financial Rewards,'" Current News, June 3, 2021, [Link](#)

Bi-directional chargers are currently significantly more expensive than one-way chargers. For example, a UK V2G trial found V2G charger hardware + install cost about £3,700 higher than a normal smart charger currently (approximately ₹3.5-4 lakh extra). In India, initial V2G equipment may be imported or manufactured in low volume, keeping costs high. Over time, domestic manufacturing and scale economies could reduce these costs; recent global offerings show prices falling (e.g. a small bidirectional charger now sells for about US \$4,000, ~₹3.3 lakh¹⁸³, much lower than early models).

The aggregator's IT platform requires upfront development to handle real-time energy dispatch, monitoring, and settlement with both the grid operator and EV owners. Communications must be reliable and low-latency for fast-response services (e.g. frequency regulation). In the TEPCO Japan V2G pilot, the system demonstrated control of EV outputs on a second-by-second basis for grid stability¹⁸⁴, so aggregators need robust control infrastructure.

4.2 CAPEX, OPEX, and ROI Analysis

An aggregator's CAPEX includes subsidizing or deploying V2G chargers and building the software platform. OPEX covers customer acquisition, communications, and payments to EV owners for battery use. The revenue comes from grid services payments.

4.2.1 Key Revenue Streams

- **Peak Demand Shaving**

Discoms pay for energy injected during peak hours to avoid expensive power purchases or blackouts. For example, if an EV supplies 5 kWh during a critical peak at ₹10/kWh, that's ₹50 earned in one event.

- **Frequency Regulation/ Ancillary Services**

Regional grid operators may pay for capacity that can respond in seconds. In markets abroad, this is lucrative. UK trials showed that participating in fast frequency response (Dynamic Containment) could yield up to £725 per EV per year in revenue¹⁸⁵.

While India's ancillary markets are nascent, new regulations now allow demand response resources (like aggregated EVs) to qualify for ancillary service payments.

- **Energy Arbitrage**

Charging EVs when electricity prices or solar generation are low and discharging when prices are high. ToD tariffs enable this by making off-peak power cheaper and peak power costly. Many Indian states (Maharashtra, Delhi, etc.) have special EV tariffs with lower off-peak rates that an aggregator can exploit for arbitrage gains.

Table 4.3 provides a simplified Return on Investment (ROI) illustration for an aggregator per EV in a residential V2G program¹⁸⁶:

¹⁸³ Jason Svarc, "Bidirectional EV Chargers Review," Clean Energy Reviews, October 22, 2024, [Link](#)

¹⁸⁴ Tokyo Electric Power Company Holdings, Inc., "Implementation of Demonstration to Prove the Feasibility of V2G Aggregators," February 26, 2019, [Link](#)

¹⁸⁵ Alice Grundy, "World's Largest Domestic V2G Trial Finds Hardware Costs Still Too High Despite 'Significant Financial Rewards,'" Current News, June 3, 2021, [Link](#)

¹⁸⁶ Darlene Steward, Critical Elements of Vehicle-to-Grid (V2G) Economics, NREL/TP-5400-69017 (Golden, CO: National Renewable Energy Laboratory, September 2017), [Link](#)

Table 4.3: ROI illustration for an aggregator per EV in a residential V2G program

Metric	Amount (₹)	Notes
Gross V2G Revenue per EV (annual)	15,000 (e.g. ₹5/kWh×3,000 kWh)	Payments from grid for ~3,000 kWh exported in peak periods (roughly 250 kWh/month) – realistic with daily peak discharge of ~8–10 kWh.
Payment to EV Owner (annual)	9,000	Compensation to ensure owner participation (e.g. 60% of revenue). Owners need strong incentives due to battery use and inconvenience. (Studies show private EV owners demand >\$2,600/year (₹2 lakh) under restrictive V2G contracts for it to be worthwhile– highlighting that generous compensation is needed for high participation.)
Net Revenue to Aggregator (annual)	6,000	~40% of V2G revenues retained by aggregator for operations and profit. At scale, aggregator can improve margins by optimizing dispatch across many vehicles. Research shows smart aggregation can increase revenue per vehicle up to 7x compared to uncoordinated use ¹⁸⁷ , by targeting the highest-value grid services.
Allocated Charger Cost per EV (annual)	30,000 (spread over 5 years)	If the aggregator provides a ₹1,50,000 V2G charger upfront, the cost is spread across 5 years. (In some models, the EV owner may bear this cost, but the aggregator might subsidize it to attract users.)
Other OPEX per EV (annual)	2,000	Aggregator's operational cost per EV: IT infrastructure, communications, support, etc.
Net Profit (Loss) per EV (Year 1)	–26,000	Negative initially if aggregator fully subsidizes hardware. The hardware cost dominates early years. By year 5, hardware is paid off; afterward, each EV could net ~₹4,000 annual profit (₹6k revenue – ₹2k OPEX) to aggregator.
Payback Period	~5+ years	With the above assumptions, payback exceeds 5 years. Lower hardware costs or higher revenues are needed to improve this. For instance, if hardware costs drop 50% or revenue per EV rises to ₹25k/year (e.g. via premium ancillary services), payback could shorten to ~3 years.

¹⁸⁷ Benedikt Tepe et al., "Optimal Pool Composition of Commercial Electric Vehicles in V2G Fleet Operation of Various Electricity Markets," Applied Energy 308 (2022): 118351, [Link](#)

Interpretation

The aggregator model can be marginal in early stages if hardware costs are high and revenue streams are limited. Today's pilot programs rely on grants or partnerships. In our example, the aggregator barely breaks even over 5 years. However, there is upside potential as technology matures:

Falling costs: *If V2G charger prices fall (as global trends indicate) or if EVs come with built-in V2G capability (so only software is needed), the CAPEX burden eases¹⁸⁸.*

Stacked services: *Aggregators can stack multiple revenue streams (peak shaving, ancillary, demand response) to increase per-vehicle earnings. In a high-value scenario (like California or UK frequency markets), an EV can earn significantly more, e.g. up to £513-£725/ year (₹50k-₹70k) in grid services value as shown in UK trials.*

Larger batteries/ fleets: *A single electric school bus (large battery ~150 kWh) participating in V2G in California was estimated to generate \$17,000+ per year in grid services revenue, vastly improving the business case. An aggregator focusing on commercial fleets or bus depots in India (where buses often idle at depots during midday and night) could achieve much better ROI than targeting private cars.*

Another critical factor is battery degradation. Cycling EV batteries for V2G accelerates their wear. The aggregator must either limit depth of discharge or compensate owners for battery depreciation. Research indicates that after accounting for battery wear costs, net profits shrink substantially (in one analysis, gross revenues were three times higher than net profits after battery replacement costs were deducted¹⁸⁹). In practice, Indian aggregators will likely start with shallow discharge cycles and use only spare battery capacity to minimize impact on vehicle range and longevity.

¹⁸⁸ Jason Svarc, "Bidirectional EV Chargers Review," Clean Energy Reviews, October 22, 2024, [Link](#).

¹⁸⁹ C. Hellmann and G. Friedl, "Factors Influencing the Economic Success of Grid-to-Vehicle and Vehicle-to-Grid Applications: A Review and Meta-Analysis," Renewable and Sustainable Energy Reviews 145 (2021): 111030, [Link](#).

5. Implementation Challenges & Opportunities in India

Implementing V2G businesses in India presents both challenges and opportunities. Key challenges include grid infrastructure limitations, regulatory uncertainties, and the high upfront costs of V2G-compatible EVs and chargers¹⁹⁰. However, opportunities arise from India's growing EV adoption, government initiatives promoting smart grids, and the potential for cost savings through demand response programs. Addressing interoperability issues and developing favourable policies can accelerate V2G deployment¹⁹¹. Collaboration between policymakers, utilities, and private players is essential to unlock the full potential of V2G in India.

5.1 Regulatory Challenges and Barriers to V2G

Implementation in India

The implementation of V2G technology in India faces significant regulatory challenges that hinder its large-scale adoption¹⁹². The absence of a unified national policy framework, inconsistencies in state-level regulations, and ambiguity in tariff structures for bidirectional energy flow create uncertainty for stakeholders¹⁹³. Overcoming these regulatory barriers is crucial for enabling a seamless V2G integration, ensuring financial viability, and fostering a resilient and sustainable energy ecosystem.

5.1.1 Key Barriers to V2G Business Models in India

The key barriers to V2G business models in India are explained in Table 5.1.

Table 5.1: Key Barriers to V2G Business Models in India

Major Barrier	Specific Barrier	Impact on V2G Business Models
Grid Code and Technical Barriers	Lack of V2G-Specific Grid Codes	Creates uncertainty, delaying large-scale V2G investments.
	Power Quality and Harmonics Regulations	Increases compliance costs for V2G charger manufacturers.
Market and Revenue Model Barriers	Electricity Market Participation Restrictions	Prevents V2G from accessing revenue streams in energy markets.
	Unclear Compensation Models	Unclear pricing models make V2G business cases less viable.

¹⁹⁰ Rao, Sriram Prabhakara, Tomomewo Stanley Olusegun, Prakash Ranganathan, Utku Kose, and Neena Goveas. "Vehicle-to-Grid technology: Opportunities, challenges, and future prospects for sustainable transportation." *Journal of Energy Storage* 110 (2025): 114927.

¹⁹¹ Kumar, Pulkit, Harpreet Kaur Channi, Raman Kumar, Asha Rajiv, Bharti Kumari, Gurpartap Singh, Sehijpal Singh, Issa Farhan Dyab, and Jasmina Lozanović. "A comprehensive review of vehicle-to-grid integration in electric vehicles: Powering the future." *Energy Conversion and Management: X* (2024): 100864.

¹⁹² Tirunagari, Sridevi, Mingchen Gu, and Lasantha Meegahapola. "Reaping the benefits of smart electric vehicle charging and vehicle-to-grid technologies: regulatory, policy and technical aspects." *IEEE Access* 10 (2022): 114657-114672.

¹⁹³ Chen, Ching-Fu, and Ching-Ming Lai. "Understanding the acceptance of vehicle-to-grid (V2G) services: Evidence from Taiwan." *Transport Policy* 159 (2024): 230-240.

	Double Taxation Issues	Double taxation discourages participation in V2G programs.
	Inflexible Energy Tariffs	Tariff structures may not support bidirectional charging benefits.
	Absence of Dynamic Pricing for V2G	Lack of real-time pricing reduces profitability for V2G providers.
	No Legal Recognition of Aggregators	V2G aggregators face regulatory barriers, limiting scalability.
	Lack of Demand Response Inclusion	V2G is not considered in demand response, reducing incentives.
	High Market Entry Costs	High fees discourage new entrants from offering V2G services.
	Uncertain Role in Balancing Mechanisms	V2G may not be recognized in grid balancing mechanisms, reducing revenue potential.
Charging Infrastructure and Licensing Barriers	Uncertain Licensing for V2G Providers	Unclear licensing slows down new V2G business deployments.
	Prohibitive Grid Connection Costs	High connection costs deter investment in V2G infrastructure.
	Non-Standardized Smart Meters	Smart metering issues make V2G participation more complex.
	Interoperability Gaps Between Grid Operators	Different requirements make multi-region V2G operations difficult.
	Lack of Public Charging Station Integration	Public chargers may not support V2G, limiting deployment options.
	Limited Certification for Bi-Directional Chargers	Lack of certified chargers prevents large-scale V2G adoption.
Consumer Protection and Legal Barriers	Lack of Consumer Protection for V2G Participants	No consumer rights protection reduces user trust in V2G.
	Unclear Insurance and Liability Policies	Legal liability uncertainties discourage business participation.
	Battery Warranty and Degradation Risks	Battery wear concerns make users hesitant to join V2G services.
	Cybersecurity and Data Privacy Concerns	Data security risks limit adoption and regulatory acceptance.
	Legal Risks for Homeowners Participating in V2G	Homeowners may face restrictions from energy providers.
	Unclear Responsibilities in Case of V2G Malfunctions	Unclear accountability for failures discourages investments.
Policy and Incentive Limitations	Lack of National V2G Roadmaps	Lack of clear policies reduces investor confidence in V2G.

	No V2G Subsidies or Incentives	No financial incentives make V2G business models less attractive.
	Inflexible Net Metering Policies	Net metering issues reduce financial viability of V2G services.
	No Recognition in Carbon Credit Markets	No carbon credit recognition limits sustainability incentives.
	Lack of Long-Term Policy Commitments	Unclear policies create risks for long-term V2G investments.
Utility and Distribution Network Barriers	Opposition from Utilities	Utilities resisting V2G slows adoption and innovation.
	Transformer Overloading Concerns	Grid capacity concerns limit V2G scalability.
	Unclear Load Management Rules	Strict discharge limits reduce V2G revenue potential.
	No Compensation for Grid Benefits	No compensation for grid services reduces V2G profitability.
Technical and Operational Barriers	Non-Uniform V2G Protocols Across EV Manufacturers	Different communication protocols create integration issues.
	Limited Bi-Directional Charging Infrastructure Availability	Limited availability of bi-directional chargers slows adoption.
	Lack of Vehicle Identification Mechanisms	Lack of verification systems creates security and operational risks.
Futureproofing and Scalability Barriers	Lack of Regulations for Future EV Penetration Growth	Lack of future-focused policies limits V2G market growth.
	Limited Integration with Decentralized Energy Systems	Poor integration with microgrids reduces business opportunities.
Miscellaneous Barriers	Public Awareness and Education Gaps	Lack of awareness slows down consumer adoption of V2G.
	Limited Government Coordination Between Agencies	Limited government collaboration delays policy standardization.

5.1.2 Ongoing Efforts Toward Regulatory Reform

The ongoing efforts toward regulatory reform for V2G integration involve both government-led initiatives and public-private

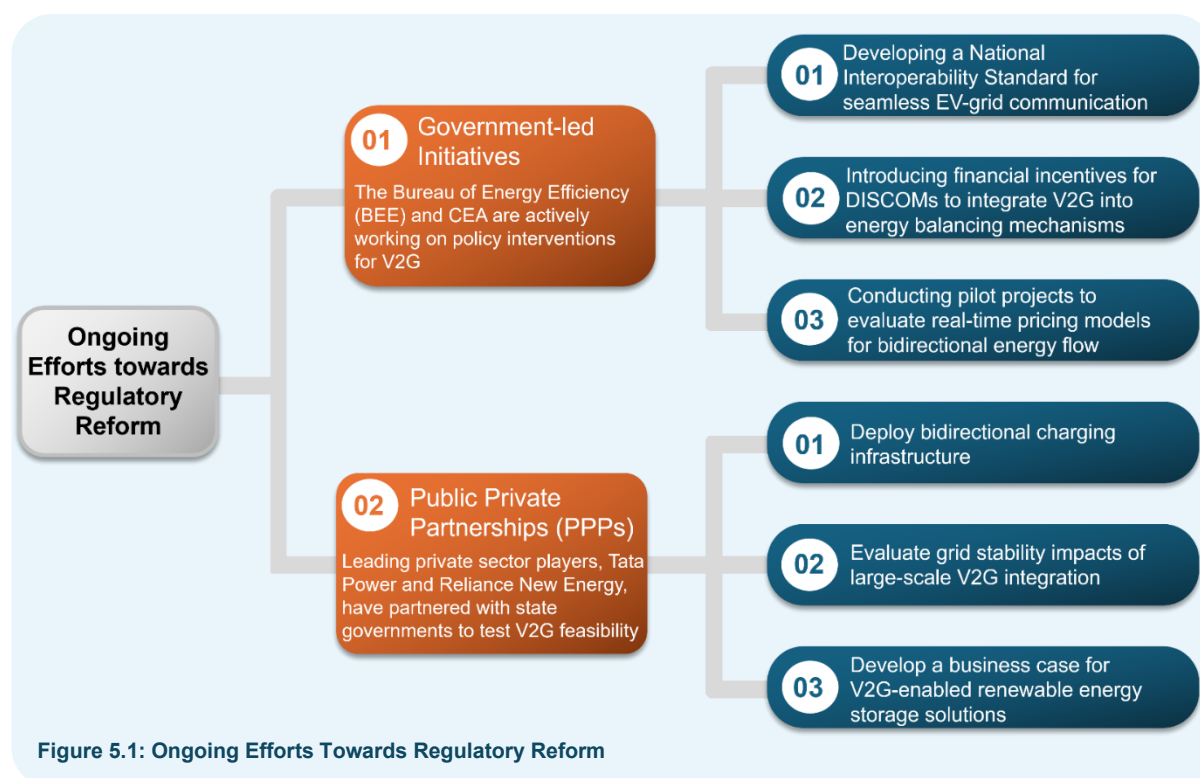
partnerships. The Bureau of Energy Efficiency (BEE)¹⁹⁴ and the Central Electricity Authority (CEA)¹⁹⁵ are actively working on policy interventions, while private sector players like Tata Power and Reliance New Energy are collaborating with

¹⁹⁴ Bureau of Energy Efficiency. "Bureau of Energy Efficiency, Government of India, Ministry of Power." [Link](#)

¹⁹⁵ Central Electricity Authority. "Electric Vehicles Utilization for Vehicle-to-Grid (V2G): Draft Report." New Delhi: Central Electricity Authority, November 2023. [Link](#)

state governments to assess feasibility. Key initiatives include developing national interoperability standards, financial incentives for DISCOMs, pilot projects for real-time pricing models, and deploying bidirectional charging infrastructure.

Additionally, evaluating grid stability impacts and building a business case for V2G-enabled renewable energy storage solutions are essential steps toward large-scale adoption.



5.2 Technical Constraints

V2G technology in India encounters several technical challenges, including infrastructure readiness, grid stability concerns, and cybersecurity risks. The Indian grid, managed by state electricity boards (SEBs) and private utilities, experiences significant fluctuations in frequency and voltage¹⁹⁶. A study by the Central Electricity Authority (CEA) found that integrating bidirectional chargers could

increase voltage instability in some regions¹⁹⁷.

Additionally, interoperability challenges between EV models, charging stations, and power distribution units limit smooth V2G implementation¹⁹⁸. According to the India Smart Grid Forum (ISGF), a significant portion of the current EV chargers are not V2G-ready¹⁹⁹. Strengthening cybersecurity measures, improving grid flexibility, and investing in smart grid solutions can help overcome these technical constraints²⁰⁰.

¹⁹⁶ Central Electricity Authority. Electric Vehicles Utilization for Vehicle-to-Grid (V2G) Services. November 2023. [Link](#)

¹⁹⁷ India Smart Grid Forum. "V2G Tech Can Rewrite Energy Playbook in India." *ET Auto*, January 2024. [Link](#)

¹⁹⁸ Buedi, Emmanuel Dana, Ali A. Ghorbani, Sajjad Dadkhah, and Raphael Ferreira. "Enhancing EV Charging Station Security Using a Multi-Dimensional Dataset." In Proceedings of the 2024 IEEE Transportation Electrification Conference and Expo (ITEC), March 2024.

¹⁹⁹ Virta Global. "Vehicle-to-Grid (V2G): Everything You Need to Know." May 2024. [Link](#)

²⁰⁰ Servotech Power Systems. "Is India Ready to Accelerate into the Future with V2G?" Servotech Blog, February 2024. [Link](#)

Table 5.2: Technical constraints to V2G implementation in India

Technical Constraint	Challenges	Potential Solutions	Opportunity for V2G Business
Battery Degradation	1. Accelerated wear from bidirectional cycles 2. Increased replacement costs	1. Advanced battery management systems (BMS) 2. Incentivize partial discharge cycles	1. Monetize battery health monitoring services 2. Dynamic pricing models to reward EV owners for controlled discharge
Bidirectional Charging Infrastructure	1. Limited bidirectional chargers 2. Grid incompatibility with reverse flow	1. Invest in DC/AC-coupled systems 2. Standardize hardware required for bidirectional charging	1. Revenue from grid upgrade partnerships with utilities. 2. Retrofitting services for fleet operators
Grid Stability	1. Peak demand deficits 2. Intermittent renewable integration	1. Deploy smart grids and real-time demand response systems 2. Enhance forecasting	1. Sell grid-balancing services (peak shaving, frequency regulation) 2. Renewable energy arbitrage models
Standardization & Interoperability	1. Fragmented protocols (e.g., communication, billing) 2. State-level policy gaps	1. Adopt ISO/IEC 15118 standards 2. Harmonize state and central regulations	1. Lead standardization efforts to dominate the market 2. Cross-state V2G platforms for seamless interoperability
Cybersecurity Risks	Vulnerable data exchange between EVs, chargers, and grids	1. Implement blockchain/IoT-based security layers 2. Regular vulnerability audits	1. Cybersecurity-as-a-service for EV networks 2. Insurance products against cyberattacks
Economic & Consumer Barriers	1. High infrastructure costs 2. User distrust in battery control	1. Dynamic pricing models 2. User-friendly apps for scheduling/control	1. Revenue-sharing agreements with DISCOMs 2. Consumer education campaigns to drive adoption

5.3 Consumer Perspective and Incentives

Consumer adoption of V2G services in India depends on financial incentives, awareness, and convenience. A 2023 survey by NITI

Aayog found that 70% of Indian EV owners were unaware of V2G capabilities, and 55% were concerned about battery degradation²⁰¹. Research from IIT Bombay suggests that frequent cycling of batteries in V2G mode could reduce battery lifespan by 8-12% over five years²⁰². However,

²⁰¹ NITI Aayog. Electric Vehicles Charging Infrastructure and its Grid Integration in India. 2023. [Link](#)

²⁰² IIT Bombay. Fundamentals of Vehicle-to-Everything (V2X). [Link](#)

innovative tariff structures and incentives can drive participation. The Delhi government's EV policy includes time-of-use (ToU) tariffs, rewarding EV owners for

feeding power back to the grid during peak hours²⁰³. Similar incentives in Karnataka and Maharashtra could enhance consumer confidence in V2G adoption²⁰⁴.

Table 5.3: Consumer Concerns in V2G Adoption

Consumer Concern	Challenges	Potential Solutions	Role of V2G Business Model
Lack of Awareness ²⁰⁵	A significant portion of Indian EV owners are unaware of V2G capabilities.	Implement nationwide educational campaigns by collaborating with automakers and utilities to provide accurate information.	Develop consumer outreach programs to educate on V2G advantages.
Battery Degradation Concerns ^{206,207}	Some studies suggest increased degradation due to frequent V2G cycles, with reports indicating up to 33% higher degradation compared to normal use if V2G is performed daily. Consumers fear unexpected costs for battery replacement due to energy cycling	1. Development of Advance BMS to optimize degradation. A simulation study estimates around 2.68% capacity loss over ten years with optimized use. 2. Provide financial incentives or discounted tariffs for V2G users, compensating for potential battery wear	1. V2G providers can offer battery health analytics & insurance. 2. Offer warranties or assurances to alleviate consumer concerns about battery degradation.
Unclear Tariff Structures ²⁰⁸	Lack of transparency regarding earnings from V2G participation. Insufficient incentives to encourage consumer involvement.	Establish clear and dynamic pricing models for energy exchange. - Implement government-backed Time-of-Use (ToU) tariffs to benefit participants.	1. Develop real-time tariff tracking applications for consumers. 2. Create reward-based programs to incentivize V2G participation.
Charging Infrastructure Availability ²⁰⁹	Limited availability of bidirectional chargers, charging stations, and supporting infrastructure.	Expansion of V2G-compatible charging hubs.	Private players can invest in exclusive V2G charging stations.

²⁰³ Central Electricity Authority. Electric Vehicles Utilization for Vehicle-to-Grid (V2G) Services. [Link](#)

²⁰⁴ KPMG. Enabling Infrastructure Changes through Policies for Growth of EVs. [Link](#)

²⁰⁵ NITI Aayog. "Electric Vehicle Charging Infrastructure and Its Grid Integration in India." New Delhi: NITI Aayog, May 2023.

[Link](#)

²⁰⁶ Wang, D., S. Saxena, J. Coignard, E. Apostolaki Iosifidou, and X. Guan. "Quantifying electric vehicle battery degradation from driving vs. V2G services." In 2016 IEEE Power and Energy Society General Meeting.

²⁰⁷ Central Electricity Authority. Electric Vehicles Utilization for Vehicle-to-Grid (V2G): Draft Report. New Delhi: Central Electricity Authority, November 2023. [Link](#)

²⁰⁸ India Smart Grid Forum. Electric Vehicle Policies and Electricity Tariff for EV Charging in India. New Delhi: India Smart Grid Forum, July 2019. [Link](#)

²⁰⁹ Das, Shyamasis, and Sanchari Deb. Vehicle-Grid Integration: A New Frontier for Electric Mobility in India. New Delhi: Alliance for an Energy Efficient Economy, October 2020. [Link](#)

Regulatory Uncertainty²¹⁰

Consumers hesitant
due to policy ambiguity.

Clearly defined consumer
rights and incentives for
V2G users.

V2G businesses
can push for
consumer-friendly
policy frameworks.

5.4 Government Policies & Market Reforms

Government initiatives are crucial for V2G deployment in India. The FAME II scheme and the National Electric Mobility Mission Plan (NEMMP) have played key roles in expanding EV adoption.

However, V2G-specific policies are still evolving. The Indian government's Energy Storage Mission targets 50 GWh of advanced battery storage by 2030, which

could aid V2G integration. Recent amendments to the Electricity Act propose allowing EV owners to participate in the energy market, potentially opening new revenue streams.

Additionally, reforms in the Green Open Access Rules 2022 allow renewable energy-based EV charging infrastructure to source cheaper power directly from renewable sources, fostering cleaner V2G participation. Collaborations between central and state governments can create a conducive market environment for V2G.

Table 5.4: Government Initiatives for V2G Adoption in India

Government Initiative	Objective	Details
FAME II Scheme²¹¹	Promote EV adoption and charging infrastructure.	₹10,000 crore budget (2019-2024); Supports 7,000 e-buses, 5 lakh e-3 wheelers, 55,000 e-4 wheelers, and 10 lakh e-2 wheelers; 2,877 charging stations sanctioned.
National Electric Mobility Mission Plan (NEMMP)²¹²	Drive EV market growth and reduce fuel dependence.	Target: 6-7 million annual EV sales; Estimated fuel savings of 2.2-2.5 million tons.
PLI Scheme for National Programme on Advanced Chemistry Cell (ACC) Battery Storage^{213,214}	Strengthen the ecosystem for Electric Mobility and Battery Storage in the country and boost domestic battery manufacturing.	₹18,100 crore allocated for Advanced Chemistry Cell (ACC) Battery Storage; Target: 50 GWh capacity. ₹15.58 billion allocated to enhance local battery production in Union Budget 2025-26.

²¹⁰ Ashok, B., C. Kannan, Kaisan Muhammad Usman, R. Vignesh, Chirag Deepak, Rathana Ramesh, Tharun MV Narendhra, and C. Kavitha. "Transition to electric mobility in India: barriers exploration and pathways to powertrain shift through MCDM approach." Journal of the institution of engineers (india): series c 103, no. 5 (2022): 1251-1277.

²¹¹ Ministry of Heavy Industries. Scheme for Faster Adoption and Manufacturing of Electric Vehicles in India Phase II (FAME India Phase II). New Delhi: Ministry of Heavy Industries, March 8, 2019. [Link](#)

²¹² Ministry of Heavy Industries. National Electric Mobility Mission Plan 2020. New Delhi: Ministry of Heavy Industries, 2013. [Link](#)

²¹³ Ministry of Heavy Industries. Production Linked Incentive Scheme for National Programme on Advanced Chemistry Cell (ACC) Battery Storage. New Delhi: Ministry of Heavy Industries, May 12, 2021. [Link](#)

²¹⁴ Ministry of Heavy Industries. "Programme Agreement Signed with Reliance New Energy Battery Limited for 10 GWh Capacity under the PLI for Advanced Chemistry Cell (ACC) Scheme." Press release, February 18, 2025. Press Information Bureau. [Link](#)

Electricity Act Amendments²¹⁵	Reform power distribution and promote renewable energy integration.	Allows open access for renewable energy, enabling direct procurement for EV charging stations; Open access must be granted within 15 days of application.
Green Open Access Rules 2022²¹⁶	Enable direct purchase of renewable energy.	Reduces the open access transaction limit from 1 MW to 100 kW, allowing smaller consumers, including EV charging stations, to procure 100% renewable energy; no load limitations for captive consumers.
Central-State Government Collaborations²¹⁷	Align state-level policies with national EV goals.	As of June 2023, 29 states and Union Territories have notified EV policies, and 3 states have draft policies. These policies provide incentives for EV purchases, development of charging infrastructure, and support for manufacturing.
Union Budget 2025-26²¹⁸	Financial support for battery storage and EV manufacturing.	Full exemption of Basic Customs Duty (BCD) on critical materials such as cobalt powder, lithium-ion battery waste, lead, zinc, and 12 other minerals to support domestic manufacturing. Inclusion of 35 additional capital goods for EV battery manufacturing and 28 for mobile phone battery manufacturing in the list of exempted items to promote local production.
PM E-DRIVE Program²¹⁹	Support mass EV adoption across various segments.	The PM E-DRIVE Program has a ₹10,900 crore outlay (Oct 1, 2024 - Mar 31, 2026), including ₹3,679 crore in subsidies for 28 lakh EVs and ₹7,171 crore for 14,028 e-buses, charging infra, and testing upgrades. Additionally, ₹500 crore each is allocated for e-ambulances and e-trucks, with truck incentives linked to vehicle scrapping.

²¹⁵ Ministry of Power. Amendments in Charging Infrastructure for Electric Vehicles: The Revised Consolidated Guidelines & Standards. New Delhi: Ministry of Power, November 8, 2022. [Link](#)

²¹⁶ Ministry of Power. Compilation of Reforms. New Delhi: Ministry of Power, Government of India, 2022. [Link](#)

²¹⁷ Bureau of Energy Efficiency. "Electric Mobility." Bureau of Energy Efficiency, Government of India, Ministry of Power. Accessed March 4, 2025. [Link](#)

²¹⁸ Sitharaman, Nirmala. Budget 2025-2026: Speech of Nirmala Sitharaman, Minister of Finance, February 1, 2025. New Delhi: Government of India, 2025. [Link](#)

²¹⁹ Ministry of Heavy Industries. "PM E-DRIVE Scheme: Electric Vehicle Sales Soar." Press Information Bureau, November 5, 2024. [Link](#)

5.5 Government and Industry Collaboration Efforts

Table 5.5 highlights key recent initiatives in India's EV ecosystem, showcasing major investments, collaborations, and programs aimed at increasing V2G adoption in India.

Table 5.5: Government and Industry Collaboration Efforts for V2G Adoption in India

Initiative	Objective	Details
JSW Group's Investment in Maharashtra²²⁰	Expand EV and battery manufacturing	JSW Group announced an investment of ₹3 trillion (approximately \$34.67 billion) in Maharashtra to establish facilities for electric vehicle and lithium-ion battery production, among other projects.
Tata Power and IOCL Partnership²²¹	Expand EV charging infrastructure	Tata Power and Indian Oil Corporation have partnered to establish over 500 EV charging points across India, aiming to enhance the country's EV infrastructure and facilitate intercity travel for EV users.
Reliance Industries' EV Battery Production²²²	Boost domestic EV battery manufacturing	Reliance Industries secured a bid under India's Production-Linked Incentive (PLI) scheme to produce up to 10 GWh of advanced chemistry cells (ACCs) for EV batteries, supporting India's goal of increasing EV adoption.
EU-India Startup Collaboration on EV Battery Recycling²²³	Promote innovation in EV battery recycling.	The European Union and India launched a joint initiative inviting startups to collaborate on electric vehicle battery recycling projects, aiming to enhance sustainable practices in the EV sector.
Wardwizard Innovations & Mobility and iCreate Partnership²²⁴	Support EV startups in India	Wardwizard Innovations & Mobility Ltd partnered with iCreate to provide funding and support for electric vehicle startups, fostering innovation and growth in the EV industry.
Revfin's Participation in PM Solar2EV Initiative²²⁵	Promote EV adoption through financing	Revfin joined the PM Solar2EV Initiative to offer digital lending services, aiming to finance 2 million electric vehicles nationwide by 2029, thereby enhancing financial inclusion and EV adoption.

²²⁰ Mukherjee, Hritam. "JSW Group to Invest \$35 Billion in India's Maharashtra State." Reuters, January 21, 2025. [Link](#)

²²¹ Business Standard. "Tata Power Ties Up with Indian Oil to Set Up Over 500 EV Charging Stations." Business Standard, December 11, 2023. [Link](#)

²²² Mukherjee, Hritam. "India's Reliance Wins Bid for Govt Incentives to Make EV Batteries." Reuters, September 4, 2024. [Link](#)

²²³ European Commission. "EU-India Join Forces to Promote Start-up Collaboration on E-Vehicles Batteries under Trade and Technology Council." European Commission, April 9, 2024. [Link](#)

²²⁴ The Hindu Business Line. "WardWizard Innovations Partners with iCreate to Fund EV Start-ups in India." The Hindu Business Line, November 22, 2022. [Link](#)

²²⁵ Autocar Professional. "Revfin Partners with Maharashtra Govt for PM Solar2EV Initiative, Targets Financing 2 Million EVs." Autocar Professional, March 18, 2024. [Link](#)

6. Indian vs Global V2G Readiness

A comparative analysis of India's V2G readiness against global benchmarks is crucial to assess technological maturity, regulatory frameworks, and market feasibility for large-scale deployment.

Evaluating global best practices enables the identification of key infrastructural, policy, and operational gaps that need to be addressed for seamless V2G integration.

6.1 Parameters

Considered for Analysis

The analysis of Indian Vs Global V2G readiness utilizes 29 parameters grouped into four key categories: Expanded Policy and Regulatory Readiness, Expanded Market & Business Readiness, Technological Readiness, and Consumer & Security Readiness.

Table 6.1 details each parameter and its corresponding relevance.

Table 6.1: Key Parameters for Analysing India vs. Global V2G Readiness and Their Relevance

Category	Parameters	Relevance
Expanded Policy and Regulatory Readiness	Any Specific V2G Policy (National or State Level)	Essential for establishing a structured approach towards V2G deployment
	Any V2G-Related Legislation (National or State Level)	Legal backing ensures compliance and security for stakeholders
	Any Government Incentives for V2G	Encourages adoption by reducing financial barriers for users and investors
	Grid Code for V2G (National or State Level)	Defines how V2G interacts with the grid, ensuring stability and reliability
	Feed-In tariff or Net Metering for Renewable (National or State Level)	Supports energy balancing and financial viability for V2G users
	ToD/ToU Tariff for any type of consumer (National or State Level)	Encourages flexible charging/discharging based on grid demand
	Any National-Level V2G Roadmap	Provides a long-term vision and policy direction for stakeholders
	Any Legal Framework for Aggregators or single unit Participating in energy trading market (National or State Level)	Clarifies the role of aggregators and individual units in V2G participation
	Any Energy Trading Market (National or State Level)	Facilitates trading of stored energy, enhancing economic feasibility
	Any V2G Market Participation Rules	Regulates participation, ensuring fair and efficient market operations

Expanded Market & Business Readiness	Any Carbon Credit, Emission Reduction Incentives, or Carbon Tax (National or State Level)	Encourages V2G participation through financial and environmental benefits
	Any Second-Life EV Battery Management Legislative	Addresses sustainability concerns by ensuring proper battery lifecycle management
	Utility Participation in V2G Pilots	Involvement of utilities indicates feasibility and potential scalability
	Any Market-Driven Business Models for EV	Encourages private sector involvement in making V2G commercially viable
	Any Active V2G Pilots	Indicates real-world implementation and technological readiness
Technological Readiness	Revenue Mechanisms for V2G Users	Determines economic attractiveness for end-users
	Any V2G Investment from Private & Public Sectors	Reflects confidence from financial and governmental bodies in V2G
	Availability of Indigenous Bidirectional Chargers	Essential for local manufacturing and reducing reliance on imports
	Any Indigenous EV Models with any V2X Support	Shows the capability of domestic EV manufacturers in V2X applications
	Any Indigenous manufactured EV Model with V2G Support	Indicates domestic readiness for supporting V2G functionalities
	Smart Grid Infrastructure	Enables the integration of V2G into existing and future power infrastructure
	Any V2B Implementations or Pilot Projects	Explores potential in commercial buildings, improving business models
	Any Indigenous Battery Manufacturing Support	Supports domestic battery production, reducing supply chain dependencies
Consumer & Security Readiness	Any Indigenous Battery Recycling Facility	Ensures proper disposal and reuse of EV batteries for sustainability
	Provision for RE based EV charging	Links V2G with renewable energy, ensuring green energy utilization
	Any Consumer Awareness Programs for V2G	Educates consumers, leading to higher adoption and participation
	Availability of Vehicle OEM Participation	Indicates manufacturer willingness to integrate V2G functionalities
	Any Battery Degradation Incentives for V2G	Compensates users for battery wear, making V2G participation more attractive
	Cybersecurity regulations related to EV	Ensures data security and resilience against cyber threats in V2G systems

6.2 Countries Included in the Analysis

For this analysis, we examined 27 countries spanning six continents as shown in **Error! Reference source not found.**

Each parameter listed in **Error! Reference source not found.** was evaluated for these countries by assigning a value of "1" if the parameter is present, and "0" if it is absent.

The cumulative score is then compared against the ideal total.

Table 6.2: Countries considered for analysis

Continent	Countries
Asia	India, China, Japan, Singapore, Thailand, South Korea
Africa	South Africa
North America	USA, Canada
South America	Chile, Brazil
Europe	UK, Denmark, Netherland, Finland, Norway, France, Germany, Spain, Italy, Poland, Switzerland, Belgium, Portugal, Austria, Sweden
Australia	-

6.2.1 Mathematical Formulation of country and parameter score:

Let $C = \{1, 2, \dots, 27\}$ be the set of countries and $P = \{1, 2, \dots, 29\}$ be the set of parameters. For each country $i \in C$ and parameter $j \in P$, define: $p_{ij} = 1$: if parameter j is present in country i , otherwise 0.

1. Country Score:

The cumulative score for country i is given by:

$$S_i = \sum_{j=1}^{j=29} p_{ij}$$

The ideal total score is **29**. A normalized score for country i can be expressed as:

$$N_i = \frac{S_i}{29}$$

The normalized score for country i is being considered as "V2G readiness index" for that country for this analysis as shown in **Error! Reference source not found.** and **Error! Reference source not found.**

2. Parameter Score:

The cumulative score for parameter j across all countries is:

$$S_j = \sum_{i=1}^{i=27} p_{ij}$$

The ideal total score is **27**. A normalized score for parameter j can be expressed as:

$$N_j = \frac{S_j}{27}$$

The normalized score for parameter j is being considered as "V2G parameter adoption index" for that parameter for this analysis as shown in Figure 6.5.

6.3 V2G Readiness Index

The "V2G readiness index" spans from as low as 0.34 (South Africa) to as high as 0.86 (United States) as shown in Figure 6.2 and Figure 6.3, indicating a diverse landscape of policy, technological, and market support. Notably, several Asian countries like Japan and South Korea score around 0.69, with

China leading at 0.76, while India registers at 0.59. European nations also show varied performance with the UK at 0.72, Denmark and Spain at 0.62, and Italy, France, and Belgium around 0.59, suggesting moderate to strong readiness. North American performance is highlighted by the United States at 0.86, while Canada lags at 0.48. In South America, Chile and Brazil score 0.52

and 0.38 respectively, and in Oceania, Australia stands at 0.66. Continental averages further illustrate these trends: Asia at 0.63, North America at 0.67, Australia at 0.66, and Europe at 0.6, contrasted with lower averages in South America (0.45) and Africa (0.34). These variations underscore the need for tailored regional strategies to enhance V2G readiness globally.

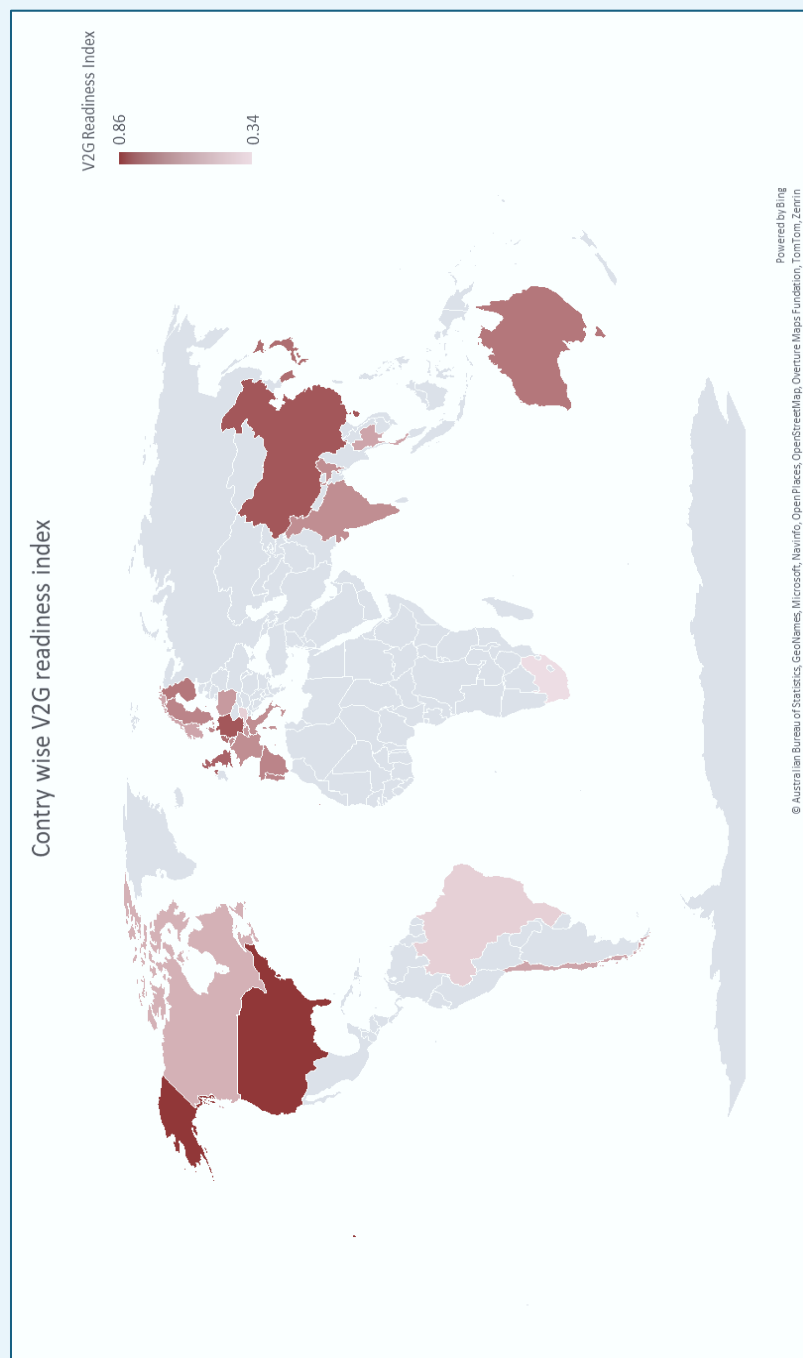


Figure 6.1: Country wise V2G readiness index

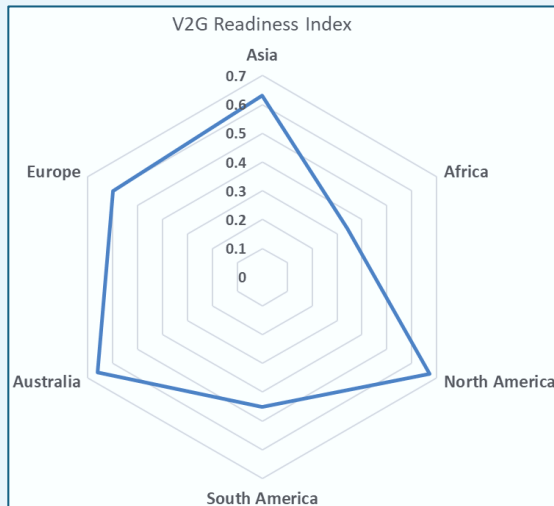


Figure 6.4: Radar Chart for V2G Readiness Index for different continents

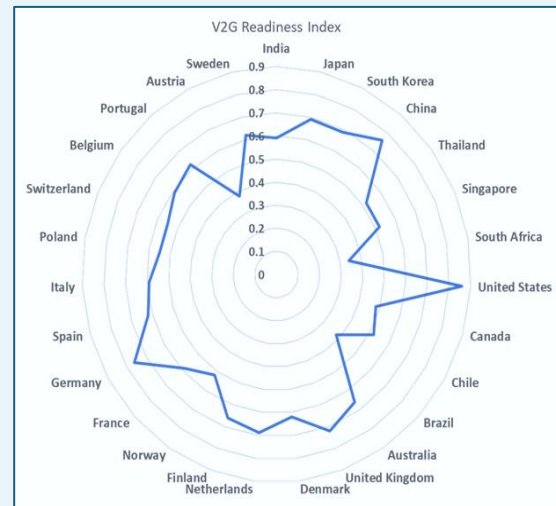


Figure 6.3: Radar Chart for V2G Readiness Index for different countries

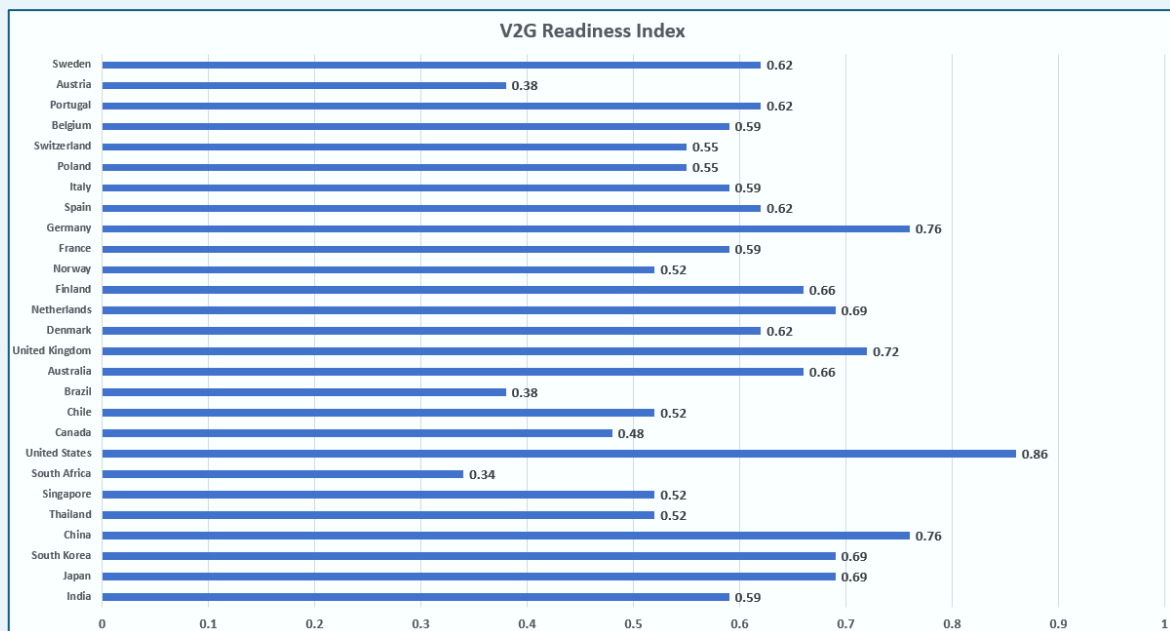


Figure 6.2: Bar plot of V2G Readiness Index for different countries

6.4 V2G Parameter Adoption Index

The “V2G Parameters Adoption Index” spans from minimum value “0” to maximum value “1” as shown in Figure 6.5. The parameters such as Feed-In Tariff/Net Metering, Time-of-Use Tariffs, Carbon Credit/Emission Reduction Incentives, Smart Grid Infrastructure, Indigenous Battery Manufacturing Support, RE-based

EV Charging, and Cybersecurity Regulations all score “1”, reflecting near-universal adoption or strong policy support. There is also substantial progress in establishing frameworks for Aggregators, Energy Trading Markets, Active V2G Pilots, and Consumer Awareness Programs (scores above 0.80). However, several parameters score “0”, notably Government Incentives for V2G, V2G Market Participation Rules, Revenue Mechanisms for V2G Users, and Battery Degradation

Incentives. Their absence underscores the lack of direct financial or regulatory mechanisms specifically targeting V2G adoption and user benefits.

Additionally, specific V2G Policies and V2G-related legislation remain quite low (0.07 and 0.04, respectively), indicating a need for more explicit and robust legal frameworks. Mid-range parameters, such as Utility Participation in V2G Pilots (0.67), Indigenous Bidirectional Chargers (0.44), and Second-Life EV Battery Management

Legislative (0.52), show partial progress but also reveal room for further development. Foundational policies and technologies for renewable integration, grid modernization, and battery manufacturing are well-established, direct incentives and regulations focused on V2G deployment remain underdeveloped. Strengthening these missing elements, particularly revenue mechanisms, market participation rules, and targeted government incentives will be crucial to advancing V2G adoption and unlocking its full potential.

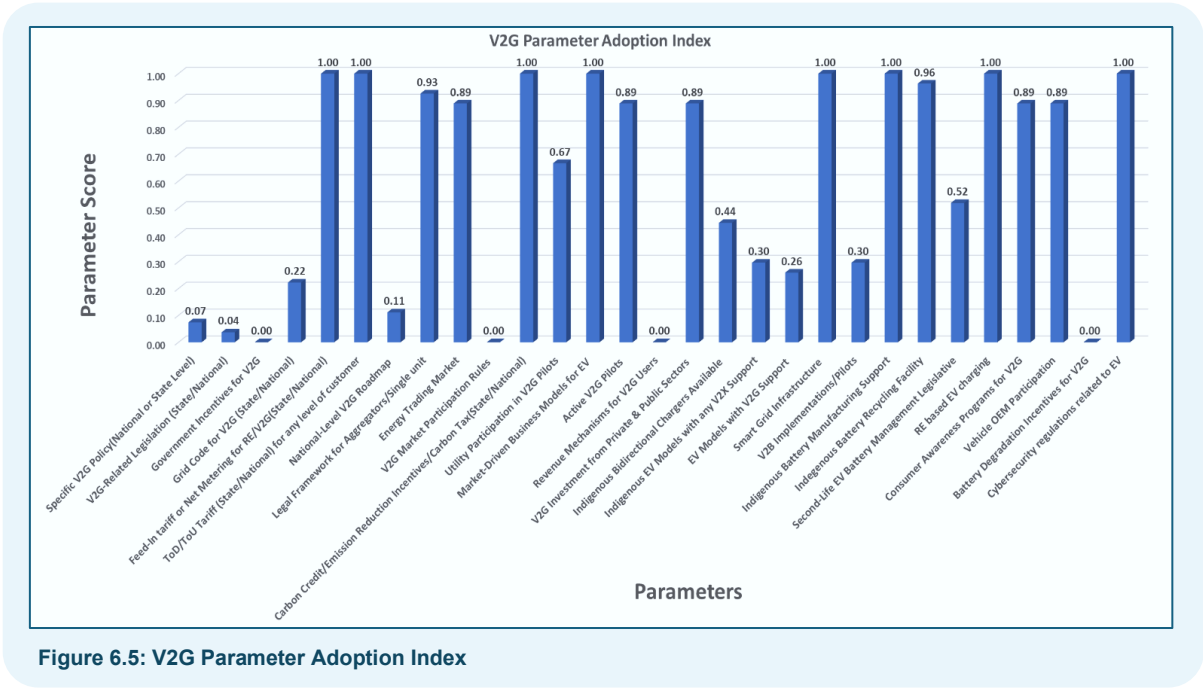


Figure 6.5: V2G Parameter Adoption Index

7. Conclusion

The adoption of V2G technology has emerged as a transformative solution for energy management, offering bidirectional energy flow between electric vehicles and the grid. This report has provided a comprehensive analysis of global V2G business models, the current EV and grid scenario, and potential business opportunities for India. V2G holds immense potential to enhance grid stability, integrate renewable energy, optimize energy costs, and create new revenue streams for EV owners and businesses. However, its successful implementation in India requires overcoming several regulatory, technical, and market-related challenges.

Key Takeaways from the Study

1. Global V2G Business Models:

- Various countries have implemented different business models for V2G, including aggregator-based services, energy trading platforms, shared asset models, product-based infrastructure development, and service-oriented approaches.
- Europe, North America and Asia have seen extensive pilots and commercial V2G deployment.
- India is still in the early stages of developing its regulatory framework and infrastructure.

2. Potential V2G Business Models for India:

- **Charging Infrastructure:** Expansion through public-private partnerships,

along with product-based and service-based business models to support the deployment and operation of V2G-enabled charging solutions.

- **Grid-Integrated V2G Platforms:** AI-driven fleet management, energy trading, and smart energy solutions.
- **Battery Management Systems and Battery Recycling:** Emphasis on indigenous large-scale battery production facilities, development of robust battery management systems, and promotion of second-life applications to enhance battery sustainability and reuse.
- **Central Management Systems (CMS), Energy Management Systems (EMS), and Communication Systems:** Smart meters, power management solutions, and cybersecurity for secure energy exchange.

3. Impact of Large-Scale EV Penetration on the Grid:

- Case studies from California, Norway, Texas, Denmark, and Germany show that uncontrolled EV charging can increase peak loads by up to 25 GW, leading to voltage instability and grid congestion.
- Managed charging strategies, V2G-enabled services, and smart grid technologies have proven to reduce infrastructure upgrade costs by 30-40% and improve grid efficiency.

4. Opportunities and Challenges for V2G in India

Opportunities:

- **Growing EV Market:** India's EV market was valued at \$8.5 billion in 2024 and is projected to reach \$152 billion by 2030, with a 40% CAGR.
- **Renewable Energy Integration:** V2G can help address intermittency issues in solar and wind power generation, supporting India's 500 GW non-fossil fuel target by 2030.
- **Government Policies and Incentives:** Programs like FAME II, Battery Waste Management Rules, and energy storage incentives encourage V2G infrastructure development.
- **Technological Advancements:** AI-driven fleet management, bidirectional charging, and smart grid integration offer new business prospects.

Challenges:

- **Regulatory and Policy Barriers:** India currently lacks a dedicated V2G policy framework and financial incentives, which slows adoption.
- **Infrastructure Limitations:** No V2G chargers currently available in the Indian market, coupled with grid readiness challenges and high initial costs hindering large-scale deployment.
- **Consumer Awareness and Market Adoption:** Low awareness about V2G benefits, economic viability, and business models among Indian EV owners and fleet operators.
- **Cybersecurity Risks:** Need for robust

security protocols to prevent cyber threats in bidirectional energy transactions.

5. Future Outlook

- Scaling V2G in India will require a coordinated approach involving policymakers, utilities, automotive OEMs, technology providers, and consumers.
- Investment in smart charging infrastructure, AI-based energy management, and grid modernization is estimated to require \$10-15 billion over the next decade.
- V2G can play a pivotal role in India's clean energy transition, reducing reliance on fossil fuels and optimizing the use of renewable energy sources.
- Developing localized business models tailored to India's energy landscape will be essential for accelerating V2G adoption.

V2G technology offers tremendous potential to transform India's energy and mobility sectors, making them more sustainable, resilient, and cost-effective. While challenges remain significant, the opportunities outweigh them, provided there is policy support, infrastructure development, and industry collaboration. With the right strategies, India can leverage V2G technology to drive the future of e-mobility, enhance grid reliability, and unlock new economic opportunities for EV owners, businesses, and utilities.



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