1/V2G, TGC-EMC

Vehicle-to-Grid for Thailand: A Global V2G best practices

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TGC EMC

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Executive Summary

The Thai-German Cooperation on Energy, Mobility and Climate (TGC-EMC)[1] is a joint initiative under Germany's International Climate Initiative (IKI) that supports Thailand's carbon neutrality and net-zero targets through sector coupling, policy advice, and pilot projects in the energy and transport sectors. As part of the TGC-EMC project, the consortium plans to publish a series of reports exploring the implementation of Vehicle-to-Grid (V2G) technology in Thailand. This report series (1/V2G, TGC-EMC) presents a comprehensive analysis of V2G technology, examining its conceptual foundations, current state of readiness, and potential applications—particularly in the context of electric bus depots and the wider electric vehicle (EV) ecosystem. V2G enables bidirectional energy flow between EVs and the power grid, offering numerous benefits such as enhanced grid stability, energy flexibility and new revenue opportunities for EV owners. While the technology is still in its nascent stages globally, with many initiatives focused on feasibility and commercial validation, international developments are advancing rapidly.

Figure 1: source "© GIZ / Florian Kopp"

Europe and North America are at the forefront of V2G pilot projects, targeting residential and commercial applications to provide grid services such as frequency regulation and energy arbitrage. In Asia, countries such as Japan and South Korea are actively exploring V2G integration, leveraging high EV uptake and robust grid infrastructure. Bidirectional charging is

[1] Weblink to TGC-EMC project: https://www.thai-german-cooperation.info/en_US/thai-german-cooperation-on-energy-mobility-and-climate-tgc-emc/

also gaining traction in large-scale transport applications, demonstrating its viability in bus depot electrification. However, the widespread adoption of V2G faces several interrelated challenges. Key technical barriers include the need for interoperable, V2G-capable charging infrastructure, standardized communication protocols (e.g., ISO 15118, OCPP 2.0), and solutions to manage battery degradation associated with frequent battery cycles. Regulatory and market frameworks often lag behind technological progress, with many regions lacking the mechanisms to compensate for distributed resources or to permit aggregator participation in grid service markets.

In Thailand, V2G is recognized as a strategic tool for achieving national decarbonization goals in energy and transport. With pilot projects and policy developments underway, Thailand is aligning V2G activities with its target of 30% domestic EV production by 2030. To capitalize on V2G's potential, Thailand should establish clear regulatory guidelines, expand pilot programs, and adopt international best practices. Overall, V2G represents a transformative opportunity for sustainable energy and transport integration, provided that technical, policy, and market barriers are effectively addressed in Thailand. Therefore, the next report in this series will delve deeply into the current policy landscape, feedback, challenges, barriers, and V2G scenarios in Thailand.

List of Abbreviations

Abbreviations	Definition
aFRR	Automatic Frequency Restoration Reserve
BESS	Battery Energy Storage Systems)
CPO	Charging Station Providers
DER	Distributed Energy Resources
DSO	Distribution System Operator
EGAT	Electricity Generating Authority of Thailand
EU	European Commission
EV	Electric Vehicle
EVCS	Electric Vehicle Charging Station
FCR	Frequency Control Reserve
FFR	Fast Frequency Reserve
IEA	International Energy Agency
OCPP	Open Charge Point Protocol
OEMs	Original Equipment Manufacturers
RfG	Requirements for Generators
TRL	Technology Readiness Level
TSOs	Transmission System Operators
V1G	Unidirectional Controlled Charging
V2G	Vehicle-to-Grid
V2L	Vehicle-to-Load
V2X	Vehicle-to-Everything
VGI	Vehicle-to-Grid Integration

Chapter 1: Vehicle-to-Grid (V2G) Overview

The concept of the bidirectional exchange of electricity between the power grid and an electric vehicle was introduced in (Kempton and Tomić 2005). Vehicle-to-Grid (V2G) integration refers to the technology and processes that allow electric vehicles (EVs) to communicate and interact with the electrical grid. By enabling bi-directional energy flow, V2G systems allow EVs to not only draw power from the grid while charging but also to supply stored energy back to the grid when needed. This can help balance supply and demand, enhance grid stability and flexibility, and provide additional revenue streams for EV owners through various grid services such as peak shaving, frequency regulation, and emergency backup power. V2G integration leverages advanced communication protocols and a smart charging infrastructure to ensure seamless and efficient energy management, thereby supporting the broader adoption of renewable energy sources and contributing to a more sustainable energy ecosystem.

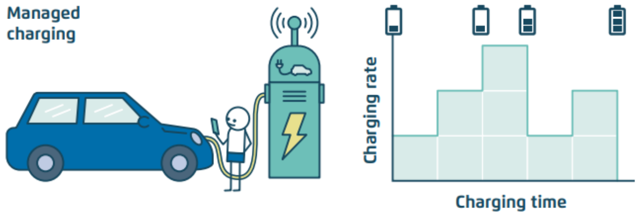
1.1 General Concept and Definitions

Smart Charging

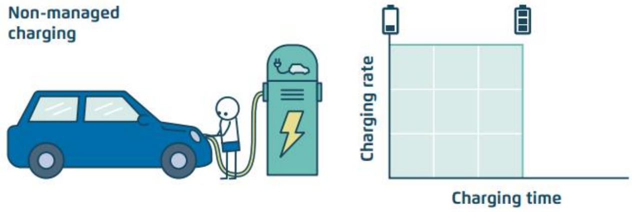
Smart charging is the technical ability to adjust charging patterns according to the needs of the EV user and the power system. By controlling the time and speed of charging, the technology enables the end user to reduce costs or generate additional revenues, the grid operator to minimize the impact of EV integration on the network, and the energy system to integrate intermittent renewable energy. This can generally be achieved by EV users responding to price signals or control signals received by an Electric Vehicle Charging Station (EVCS) from aggregators or Distribution System Operators (DSOs). There are two smart charging technologies that can be used by EVs to provide flexibility, each offering different levels of control and interaction with the grid. They both supports ancillary services, including the provision of frequency regulation, voltage support, energy arbitrage, etc.

Managed Charging

In addition to smart charging, the term managed charging is used to refer to a charging strategy that considers the current status of the power system, initiating the charging process during periods of significant power surpluses and adjusting the charging rate based on the grid's load. Figure 2 visualizes the concept of managed and non-managed charging.



(a): Managed charging



(b): Non-Managed charging

Figure 2: Illustration of managed and non-managed charging (Agora Verkehrswende)

Vehicle-to-Everything (V2X)

Vehicle-to-Everything (V2X) describes how an EV can interact with the grid, a building, a home, or even another vehicle. In this report, we use V2X as a broad term to refer to energy services enabled by smart charging, simple managed (one-way) charging as well as bidirectional options such as V2G, V2B, V2H, V2L, and V2V. For example, Vehicle-to-Load (V2L) lets an EV power devices directly, while V2G allows energy to flow back to the grid through an approved charger (Mobility house 2024). This capability means EVs can be used as a mobile power supply for electric equipment or electronics in various settings, such as camping, construction sites, or emergency situations, thereby maximizing the utility of the vehicle's battery.

Bidirectional Charging: Vehicle-to-Grid (V2G)

In a bi-directional charging process, illustrated in Figure 3, electricity flows from the electricity supply unit to the EV and vice versa, feeding electricity back to the utility in a controlled manner that adheres to all power regulations and standards. The minimum technical requirements are a bidirectional vehicle and bidirectional Electrical Vehicle Supply Equipment (EVSE). Essentially, a bidirectional unit can be created using two units of unidirectional converters. Additionally, V2G also needs a communications layer between the EV, the charger, and the operator/utility so they can exchange live data (e.g., state of charge, connection status, metering), enabling the responsible party to schedule or adjust charging and discharging in real time (Krueger and Cruden 2018).

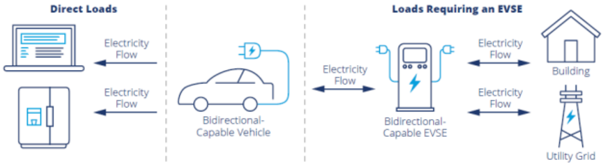


Figure 3: A diagram of a bidirectional charging system (Blair et al. 2023)

Unidirectional Controlled Charging (V1G)

With V1G technology, also often referred to as 'managed (or smart) charging' (Transport and environment report 2022), electricity flows in one direction—from the Electrical Vehicle Supply Equipment (EVSE) to an EV. The charging process is controlled in such a way that the charger can delay charging to avoid peak times in the distribution network or throttle the charging speed to accommodate grid requirements and smooth out demand spikes. For example, by taking advantage of time-of-use tariffs, an EV user can shift charging to off-peak periods when electricity is cheaper.

1.2 Business Models and Services

A V2G-enabled EV can also capitalize on economic opportunities by selling electricity or additional network capacity back to the electricity market. This not only helps to reduce the total cost of ownership of an EV but also contributes to power grid stabilization by providing ancillary services (Wan et al. 2024). As identified by (V2G Hub 2024b), these services include frequency response, reserve power, energy arbitrage, and demand-side management, each of which leverages the bidirectional capability of V2G technology. The business models and value streams are similar to those of stationary Battery Energy Storage Systems (BESS), but with the added benefit of utilizing mobile, distributed storage assets (i.e., EV batteries).

Even in countries with undeveloped electricity markets, where dynamic pricing and open-market participation are limited or absent, V2G technology can still play a vital role by supporting localized, utility-led, or building-level energy-management strategies. Instead of selling electricity back to the grid for profit, V2G can be used to improve grid reliability, reduce peak demand, and enhance emergency-response capabilities—particularly in last-mile areas with unstable grid connections or frequent power cuts (Hackmann et al. 2025). In addition, V2G and V2H capabilities can support urban homes during natural disasters, enabling EVs to power houses and buildings during blackouts. One example can be seen in Japan, where Nissan has used its LEAF model (Nissan RE-LEAF) to provide emergency power and transportation following natural disasters since 2011. The Nissan LEAF has also served as a mobile power station after natural disasters or extreme weather events in several cases (Global Nissan Newsroom 2020; Colin Walker 2025).

In addition, countries with Time-of-Use (TOU) pricing and limited energy market development, such as Thailand, could also leverage V2G technology by offering on-peak and off-peak demand response programs for electric vehicles. Such programs could incentivize EV owners to charge their vehicles during periods of low electricity demand and feed stored energy back into the grid during peak hours, thereby reducing the strain on the power system.

Fleet-based V2G deployments (e.g., buses or government vehicles) offer a controlled environment to demonstrate the benefits of bidirectional charging while helping utilities manage load and improve energy resilience.

1.2.1 Transmission Grid Ancillary Services

Frequency control and reserve services are the key transmission-system ancillary services used to keep electricity supply and demand in balance. If there is an unexpected surge in demand, additional capacity, known as reserve, is activated to stabilize the grid. Such surges often lead to a drop in grid frequency, which is then corrected by deploying reserves to restore frequency to its acceptable tolerance level. Conversely, if supply exceeds demand, causing a spike in grid frequency, services like frequency and voltage regulation are employed to correct the deviation (Energeia 2024).

In practice, technologies such as power plants and battery storage systems provide this service, but EV batteries can now also be used to feed power back into the grid (Ala et al. 2020). Electric vehicles perform this function by either absorbing excess power from the grid or releasing stored power into the grid if there is a shortfall in the power system. This ability to rapidly switch between charging and discharging makes EVs a promising option for V2G applications (Xiao et al. 2013).

Moreover, V2G applications in a distributed network of EVs offer advantages in providing these services, which can be more responsive and cost-effective than centralized solutions. EV owners could generate revenue by bidding into the reserve markets (Energeia 2024). The key stakeholders involved in this process are the grid operators, who procure these services, and aggregators, who manage fleets of EVs to provide the required energy. Communication between these stakeholders is facilitated by smart metering and real-time data exchange to ensure timely responses to grid needs (Iqbal et al. 2018 - 2018). The "PowerLoop" project (Octopus Electric Vehicles 2024a) in the UK and the Frederiksberg Forsyning utility in Denmark (Sophie Rabasch 2022) demonstrate the technical and financial viability of this technology, where the aggregated EVs provide grid services.

1.2.2 Energy Arbitrage

Energy arbitrage is the practice of charging and discharging a battery based on market signals. The price of electricity on the wholesale electricity market varies throughout the day, with typically higher prices in the evenings, so energy arbitrage is a strategy that involves purchasing electricity at low prices during off-peak periods and then selling or using it during peak periods when prices are higher. This saves costs and can even generate revenue, depending on the market structure.

This service can be delivered through various energy storage solutions, including utility-scale batteries. With the advancement of V2G technology, electric vehicle (EV) owners can engage in energy arbitrage as well by charging their vehicles when electricity prices are low and discharging power back to the grid during periods of higher prices, thereby capitalizing on the price differences (Thompson and Perez 2020). The success of arbitrage trading hinges on precise timing and accurate forecasting of electricity prices and demand, allowing EV owners to optimize their charging and discharging schedules to maximize revenue.

On a system-wide level, the widespread adoption of distributed EVs offers distinct advantages for energy arbitrage, which could outperform large-scale storage solutions in electricity markets. Additionally, by participating in energy arbitrage, EV owners can reduce their overall energy costs and potentially earn revenue, providing an economic incentive for broader adoption of V2G technology (Klobasa et al. 2022).

The communication between key stakeholders, such as grid operators, aggregators, and EV users, is facilitated by real-time data exchanges and advanced metering infrastructure (Sovacool et al. 2020). In this context, aggregators play a major role in pooling the distributed EV fleet in the market. In the Netherlands and Denmark, pilot programs are being tested where EV fleets have been used to assess the feasibility of energy arbitrage.

1.2.3 Distribution System Operators (DSO) Services[2]

Distribution System Operators (DSOs) are responsible for managing various network assets, each designed to operate within specific capacity limits. During peak periods, the power demand from residential and commercial consumers can approach or even exceed the capacity of substations to deliver adequate power. If these capacity limits are reached, further investment in network infrastructure may be needed. However, flexible demand solutions, such as V2G technology, can help manage this by exporting power (or reducing imports) to alleviate demand on the network at peak times and charging when capacity is available. These actions constitute what is known as "constraint management," a type of service provided by DSOs (V2G Hub 2024b). Additionally, EVs, as mobile storage units with enabled V2G, can assist DSOs in managing the growing number of EVs on the grid by turning them into active participants in grid management, rather than just passive loads (Habib et al. 2015).

Time Shifting

The cost of electricity in a dynamic market can fluctuate throughout the day, influenced by factors such as time-of-day tariffs, grid charges at specific times, and the presence of onsite solar generation. Time shifting is when an EV shifts its electricity consumption or power discharge to different times of the day to take advantage of varying electricity prices and grid demands. An EV can supply power to a home or business during periods of high electricity prices, thereby reducing overall energy costs and increasing the self-consumption of onsite solar energy. This is comparable to a stationary battery installed within a home or commercial building. Projects with V2G technology providing time-shifting services have been implemented in California (California Energy Commission 2024). In these initiatives, utility companies collaborate with EV owners to charge vehicles during off-peak hours and discharge them during peak periods.

Emergency Power/Off-Grid

The resources that provide emergency power and off-grid services during power outages or in areas not connected to the main power grid are essential. With the right settings, EVs can provide electricity to homes, buildings, or even small communities when grid power is not available. This service is especially valuable during natural disasters, grid failures, or in remote locations where grid access is limited. EVs equipped with advanced V2G systems can disconnect from the grid and function as a power source, providing energy to critical systems such as communication networks and medical facilities, and can switch seamlessly between grid-connected and off-grid modes, ensuring a continuous power supply (Pradana et al. 2023). Thus, the key stakeholders involved here include households, emergency services, and utility companies, which can all contribute to increasing energy security, especially in regions prone to power outages. Some practical examples can be found in Japan, where EVs have been used to provide electricity to evacuation centers and other vital facilities during natural disasters (CHAdeMO 2024).

[2] In countries like Thailand, the term Distribution Network Operator (DNO) is more commonly used, with slightly different regulatory responsibilities compared to DSOs in liberalized markets. However, the fundamental services described above, especially local congestion management, are still conceptually applicable. Specific implementation details will be addressed in Report 2.

1.3 Technology Readiness

The current state of V2G technology is at an early developmental stage, with most projects still in the "proof of concept" phase.

At this stage, the majority of initiatives remain exploratory, focusing primarily on validating the feasibility and potential of the technology. Specifically, application efforts in workplace settings account for approximately 49.0%, with 54.0% in public charging, and 54.0% in home applications, all concentrated on proving the concept. Beyond this, a smaller proportion of these projects has progressed to small-scale commercial trials—27.0% for workplace, 20.0% for public, and 25.0% for home applications illustrated in **Figure 4** (V2G Hub 2024a)[3].

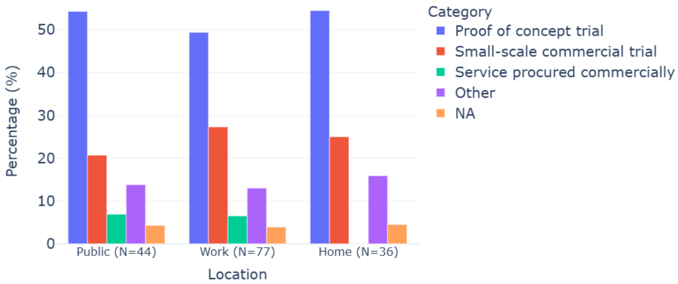


Figure 4: V2G technology readiness level (V2G Hub 2024a)

When it comes to V2G services, only a few have reached full commercial deployment, highlighting the existing gap between technological innovation and widespread market readiness. According to (ENTSO-E 2024), this gap is evident at TRL 6 (Demonstration). For instance, Statnett's pilot project successfully validated the capability of an EV fleet to provide Fast Frequency Reserve (FFR) within 2 seconds. However, challenges remain, particularly regarding the interface. At TRL 5 (Development), the INVADE project conducted preliminary tests of DC V2G technology for congestion management and voltage control services for the DSO. However, this technology is currently available for only a limited number of EVs and faces issues with communication protocols. Table 1 details bi-directional charging (AC and DC) compatibility by manufacturer.

Table 1: AC and DC chargers with bidirectional charging compatibility by manufacturer (Hecht et al. 2023)

Manufacturer	AC Bidirectional Charging	DC Bidirectional Charging
ABB		×
Ambibox		×
AME		×
BorgWarner		×
Dcbel[4]	×	×
Delta	×	
Eaton		×
Enovates		×
Enphase		×
Enteligent		×
Evtex		×
Fermata		×
Ford		×
InCharge		×
Indra		×
Kostal		×
Nichicon		×
Nuvve		×
Silla		×
Wallbox		×
BMW[5] bidirectional (BiDi)		×

Figure **5** shows a detailed outlook of how countries are utilizing their V2G potential, using a V2G score ranking. On the European market, the key obstacle to V2G deployment identified by (Ernst 2024) is not the readiness of homes but the lack of V2G-capable vehicles and adequate smart meter infrastructure. Countries like Norway, Sweden, and the Netherlands are well-positioned in Europe due to their adoption of

[3] In some cases, the status of the services provided by V2G is missing in the V2G-Hub data and is therefore marked as "not available" (NA). Other entries represent pilots that include only limited V2G elements, such as VGI demonstrations or individual charger testing.

[4] This product is not yet available on the market but can be reserved through the DCBLE website.

[5] Launched in September 2025 at the IAA Mobility show in Munich

universal smart meters and their mature EV markets. In these regions, charging infrastructure is widespread. The current focus is on increasing the V2G-enabled fleet.

Figure 5: V2G readiness worldwide (Berylls 2024)

Smart meters and V2G-enabled EVs are expected to increase in Japan and South Korea by 2030. However, countries like India and Brazil, where smart meter adoption rates and V2G penetration are low, need substantial investment in both infrastructure and EV technology to catch up with the V2G market.

1.3.1 Charging Protocols and Grid Codes

To enable Vehicle-to-Grid (V2G) technology, several technical requirements must be met.

1. A compatible charging plug is essential for bidirectional electricity flow, with CHAdeMO and CCS plugs being the most common.
2. A bidirectional charging-enabled EV and a V2G-supporting Electric Vehicle Charging Station (EVCS) are crucial for this setup. A two-way converter is needed for charging and discharging. When charging, it turns AC (alternating current) from the power grid into DC (direct current) for the EV battery. While discharging in bidirectional mode, it does the reverse by converting DC from the battery into AC, allowing the electricity to be used by the grid or a building.
3. Additionally, a suitable Energy Management System (EMS) facilitates seamless communication between connected devices, optimizing charging and discharging to save costs.
4. Communication protocols such as CHAdeMO (version 1.1), ISO 15118-20, or IEC 15118 regulate the bidirectional communication between vehicles and charging stations.

One of the major barriers to the widespread adoption of V2G technology is the lack of standardization across equipment and communication protocols. For V2G to operate efficiently and safely, consistent requirements for EVCS and standardized communication platforms are essential. EVs connected to the power system through different interfaces (home AC, public DC fast, depots, buildings). Each interface can involve different physical connectors and communications, typically ISO 15118 between the EV and the charger, and OCPP between the charger and its back-end—while the grid connection point follows its own interconnection standards (e.g., IEEE 1547). It is crucial that plugs, infrastructure, and communication protocols are standardized. Interoperability and well-defined standards are critical for smooth bidirectional charging, with a strong focus on safety certifications and clear interconnection requirements. Grid connection standards, such as IEEE 1547 and SAE International's J3072, are vital to ensure seamless integration of V2G systems with the power grid. These standards promote global interoperability by outlining the technical specifications for the interconnection of Distributed Energy Resources (DERs) and utility-interactive inverter systems in plug-in hybrid electric vehicles (PHEVs). Additionally, communication protocols such as ISO 15118, CHAdeMO, and the Open Charge Point Protocol (OCPP) enable data exchange between V2G systems and the grid, coordinating charging and discharging operations and providing real-time monitoring and grid services. Safety standards such as UL 1741 further ensure that V2G operations meet stringent safety measures and protection protocols (Blair et al. 2023). Lack of standardization across the V2G value chain can limit access to V2G services and hinder the maximization of their social and economic benefits. To overcome these challenges, automakers and infrastructure operators must deploy equipment that adheres to harmonized standards. OCPP 2.0 represents one step in this direction, as it supports smart charging and V2G functionality. The early development of standards, particularly in emerging markets like India, is also crucial for successful V2G deployment. Indian standards such as AIS 138 Part-1 and Part-2, along with protocols like OCPP, IEEE 2030.5, and OpenADR, are paving the way for V2G integration in the region (Kalia 2021).

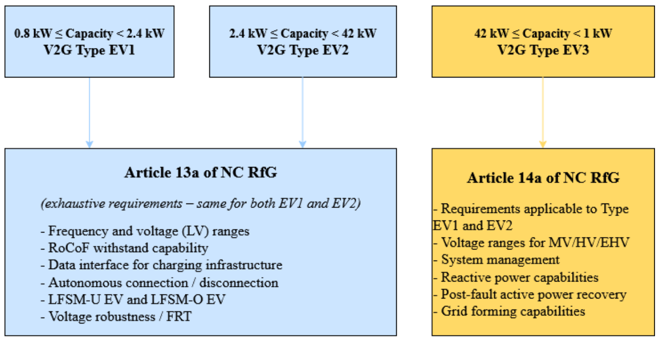


Figure 6: Overview of ACER classifications of V2G charging types and how EU Network Codes apply to each (Thomas et al. 2023)

For smooth V2G operations, grid codes must be designed to accommodate flexible loads, generation, and storage resources at the distribution and building levels. Grid codes are sets of technical and regulatory requirements that govern how bidirectional EV charging systems (including EVs and chargers) can interact with the electricity grid. These ensure that energy fed back to the grid from vehicles is safe, reliable, and grid-supportive. Many countries have already established grid codes, while others are still developing them. Table 2 presents a few country-specific examples of grid codes. In most cases, grid-connected charging is subject to the same requirements that apply to generators. Moreover, Figure 6 also explains how V2G systems are categorized under the Network Code on Requirements for Generators (NC RfG) in the EU based on their power capacity, and which regulatory technical requirements apply to each category.

Table 2: Examples of different grid codes

Country	Grid code	V2G Relevance
The Netherlands	NEN1010 (NEN 1010-8:2021	Addresses systems where users produce and consume energy. Includes Vehicle-to-Grid applications.
United Kingdom	Generation (EREC G99)	Connection of power generating modules to DNO distribution networks. Requires G99 certificate
Germany	VDE-AR-N 4105, 4110	Technical requirements for connecting decentralized energy generation systems. Compatible with low and medium-voltage networks.
Japan	JEM 1490 and METI Standards	CHAdeMO is natively supported, and bidirectional EV chargers are certified under JET/JEM standards.
Europe	EN 50549	Requirements for generators (RfG)
International	no single global or international "grid code"	Common technical frameworks and international standards IEC 61851-1 (EVSE), IEC 63110/63119 (V2G comm), IEC 63380, IEEE 1547, ISO 15118

Regulatory challenges, such as barriers to feeding power into distribution networks, must be addressed through clear frameworks and consistent standards between DSOs. Certification of V2G equipment by DSOs is essential for streamlining connection procedures, making standardized grid interfaces and clear regulatory frameworks critical for the success of V2G technology (Cristina et al. 2019).

Chapter 2: International Perspective and V2G Pilots

V2G technology is experiencing global growth as countries recognize its potential to stabilize energy grids, integrate renewable energy, and offer EV owners economic benefits. Across various regions, the diffusion of V2G is influenced by distinctive demand patterns, EV market maturity, and regulatory frameworks. V2GHub[6] provides an interactive map to locate V2G projects and pilots across the globe (Figure 7).

Europe leads in V2G initiatives, driven by its decarbonization and renewable energy goals. Countries like the Netherlands, the UK, France, and Germany are at the forefront of various pilot projects, including Powerloop in the UK and Flexitanie in France, which are integrating V2G into both residential and commercial applications. These projects demonstrate V2G's potential for frequency response, energy arbitrage, and time-shifting.

Table 3: Revenues of V2X – passenger cars

Application	Study	Annual revenue	Method
Arbitrage trading (day-ahead)	BDL project (FfE 2023)	€400 p.a. with 11kW and 100kWh battery	Simulation-based study, 2020
Control reserve	McKinsey Fleet Analysis (Fröde et al. 2023)	$7,000 to $12,000 per vehicle (heavy-duty truck, medium-duty truck, and school bus) annually	Aggregated fleet participation in secondary frequency regulation markets via TSO-certified platforms
EPEX spot market	(The Mobility House 2025)	• €650 p.a. savings after taxes • €1000 possible with tax relief	Stationary battery based on empirical driving profiles
Spot market + grid service	(Cenex 2023)	• €385 p.a. through arbitrage (2020) • up to approx. €800 p.a. with a combination of spot market+ automatic Frequency Restoration Reserve (aFRR)	Field trial in the UK (lower taxes/duties than in DE)

Figure 7: V2G projects across the globe (V2G Hub 2024a)

North America also shows significant activity, especially in the United States and Canada. V2G activities in these countries include residential and commercial trials, focusing on emergency backup power and demand-side management. The increasing EV fleet supports further integration of V2G into the grid, with pilot projects across multiple states aiming to expand its use.

Asia, particularly Japan (Global Nissan Newsroom 2024) and South Korea (Park et al. 2023), is emerging as another V2G hotspot. Japan, an early adopter, has been exploring V2G for over a decade, leveraging its high EV penetration and focus on innovation. South Korea is also testing V2G in urban and industrial systems, emphasizing its potential for enhancing grid resilience and creating economic value.

Oceania and South America are in the early stages of V2G exploration. Australia has launched several pilot projects, such as Flinders University's V2G trial (Flinders University' V2G project 2023), aimed at improving grid stability and renewable energy integration. In South America, countries like Brazil are beginning to experiment with V2G, driven by a rapidly evolving energy grid and a growing EV market.

2.1 Use Cases and Pilots of V2G Projects in Europe

Europe is home to several key V2X initiatives that are exploring the potential of bidirectional charging. The projects mentioned below are a few notable V2G initiatives currently being implemented across Europe.

BDL (Germany)

From 2019 to 2022, the BDL project deployed 50 BMW i3 vehicles across residential and commercial settings. The project focused on optimizing bidirectional charging for grid services, including energy arbitrage and time-shifting (FfE 2023). It demonstrated that bidirectional charging can significantly reduce grid strain but also revealed potential challenges if optimization is driven purely by electricity price fluctuations. Additionally, the project highlighted the importance of integrating renewable energy into the system, with V2G enabling

[6] V2Ghub: https://www.v2g-hub.com/insights#graphs

enhanced energy self-sufficiency and revenue generation by optimizing PV self-consumption .

Flexitanie (France)

Launched in 2020, the Flexitanie project in the Occitanie region of France uses 100 Nissan LEAF vehicles and ABB's bidirectional chargers (Flexitanie 2024). The project aims to enhance grid flexibility by leveraging EV batteries for energy storage and discharge, particularly to smooth out renewable energy fluctuations. By providing grid services such as peak shaving and frequency stabilization, Flexitanie has demonstrated the role of V2G in reducing reliance on fossil fuels and promoting renewable energy use. The project also focuses on understanding customer expectations and synergies between renewable energy production and EV energy storage.

EUREF Campus (Germany)

In collaboration with Audi AG, the EUREF Campus project explores the use of second-life batteries from Audi e-tron vehicles as a storage solution. With 1.6 MWh of battery capacity, the project stores excess renewable energy, such as surplus wind power, to discharge back into the grid or power campus buildings (The Mobilityhouse 2024). The 2022 field tests showed that V2G can generate economic returns for EV owners, with potential annual earnings of €650 through optimized charging schedules based on electricity market prices. This project highlights the viability of second-life batteries in supporting grid resilience and enhancing renewable energy integration.

Powerloop (UK)

A partnership between Octopus Energy and Nissan, Powerloop demonstrates the potential of V2G to stabilize the grid using Nissan LEAF vehicles. The project allows households to store green energy in their car batteries during off-peak hours and discharge it during peak times (4-7 p.m.), thus reducing the UK's reliance on fossil fuels. Powerloop also indicated that if 10 million cars participated in the program, they could theoretically power the entire UK grid during peak periods (Octopus Electric Vehicles 2024b). Supported by Innovate UK, Powerloop serves as a real-world demonstration of V2G's role in increasing grid resilience and lowering carbon emissions.

SCALE (Netherlands and EU)

Co-funded by the Horizon Europe Program, the SCALE project (2022-2025) aims to deploy 650 bidirectional charging stations across cities such as Rotterdam, Utrecht, and Eindhoven. With a €10 million budget, SCALE focuses on ensuring interoperability across different EV brands and promoting the integration of renewable energy into the grid (SCALE 2023).

By enabling EV owners to participate in energy trading and providing financial incentives for selling stored energy back to the grid, SCALE is advancing smart charging infrastructure across Europe. The project also explores frequency control, demand response, and energy arbitrage as part of its broader effort to promote sustainable energy solutions.

Nuvve (Denmark and Global)

Nuvve's V2G initiative is one of the first commercial-scale projects to provide frequency regulation services to the grid. Launched in 2016, the project involved 50 electric vehicles participating in grid stabilization efforts in Denmark (NUVVE Holding Corp 2020). Nuvve's technology allows EVs to store excess renewable energy and discharge it during periods of high demand, helping to stabilize the grid and generate economic benefits for EV owners. The company's involvement in global V2G projects, including the Flexitanie project in France, highlights the scalability and financial viability of using V2G for grid support.
In addition to the above-mentioned pilots, a number of commercial implementations have also been reported in Europe.

Renault-Mobilize & The Mobility House V2G
In France, the Renault Group (via its Mobilize brand) and the German technology provider The Mobility House have rolled out the world's first consumer-ready commercial V2G offering. Owners of the new Renault 5 (and the Alpine A290) can join a program featuring a bidirectional 'PowerBox' Verso AC charger along with a Mobilize Power energy contract. Together, they enable zero-emission and zero-cost driving, as users earn by feeding energy back into the grid (Mobilize Power: charge bidirectionnelle 2025).

Octopus Energy's "Power Pack Bundle" in the UK: Octopus Energy, alongside BYD and Zaptec, has introduced the UK's first fully integrated V2G leasing bundle. This includes a BYD Dolphin EV equipped with built-in bidirectional AC charging, a Zaptec Pro home charger and the Octopus Power Pack tariff offering free home charging by exporting energy back to the grid. Although the system is technically ready, certification for the charger is expected by September 2025. (Octopus Electric Vehicles 2025). Interested consumers can currently sign up via the official Octopus website.

City-Scale V2G Car-Sharing Service in Utrecht: Renault Group, Mobilize, MyWheels, We Drive Solar, and the municipality of Utrecht have launched "Utrecht Energized," Europe's first large-scale AC charging vehicle-to-grid (V2G) car-sharing operation. Some 50 Renault 5 E-Tech cars equipped with Mobilize's bidirectional chargers are now available via MyWheels, with plans to grow to 500 vehicles by 2025. These EVs provide about 10% of the flexibility needed to help stabilize Utrecht's solar- and wind-powered grid during peaks. This initiative showcases a significant step toward integrating shared mobility with grid-balancing services (Newsroom Renault Group 2025).

2.2 Revenue Opportunities of V2G

V2G technology offers substantial revenue-generating opportunities for both passenger cars and commercial vehicles. Passenger vehicles with bidirectional charging can generate income primarily through participating in various electricity markets, such as wholesale energy trading and ancillary services. In addition, they can save costs through optimized charging aligned with dynamic tariffs or time-of-use pricing. Below, we summarize the main electricity market-based revenue streams and supported use cases:

V2G Provides Flexibility

Flexibility in power systems refers to the capacity to manage variability in power generation and demand. As the global energy transition accelerates, there is a growing need for flexible resources such as energy storage, demand response, and V2G technology. V2G contributes to grid stability by adjusting EV charging or discharging in real time based on grid requirements. This facilitates V2G-enabled EVs to participate in load balancing, energy shifting, and emergency power supply, making them crucial assets in decentralized grid management.

Revenue Opportunities for Passenger Cars

Passenger vehicles with bidirectional charging can monetize several revenue-generating applications, allowing owners to participate in various energy markets:

Arbitrage (day-ahead market): The day-ahead arbitrage market offers owners of passenger EVs a significant revenue opportunity. Vehicles are charged during off-peak hours when electricity prices are low and discharged during peak times when prices rise. For instance, the BDL project (FfE 2023) found that a car with a 100 kWh battery and 11 kW charger could generate approximately €400 annually. Vehicles with larger batteries, or those active in the more dynamic intraday markets, could increase these earnings (Table 3).

Reserve: Participation in control reserve markets is another revenue stream. In the United States, McKinsey & Company (Fröde et al. 2023) found that frequency regulation markets hold an even greater revenue potential, particularly for high-power fleet vehicles such as school buses and medium/heavy-duty trucks. For instance, EVs using 50 kW bidirectional chargers in California could generate over $5,000 annually per vehicle, while similar vehicles in eastern US markets could earn up to $17,000 per year from frequency regulation services. However, the depth of these markets is limited, as only a few gigawatts of capacity are needed at any time, so that competition with stationary storage systems could affect earnings.

EPEX Spot Market: The EUREF Campus field trial (2022/23) highlighted the significant savings that can be made by participating in the EPEX Spot Market. By leveraging stationary batteries and responding to market signals, participating vehicles generated up to €650 in annual savings, with potential earnings exceeding €1,000 when accounting for tax relief.

Spot Market and Grid Services: The Sciurius project in the UK tested how passenger cars could generate revenue from both arbitrage and grid services. In this trial, vehicles earned an average of €385 annually from arbitrage alone. When combined with participation in Automatic Frequency Restoration Reserve services (aFRR), total earnings could reach around €800 per year. Current ongoing projects are reporting similar earnings for participating vehicles.

Revenue Opportunities for Medium and Heavy-Duty Commercial Vehicles

Commercial electric vehicles, such as trucks and buses, offer an even greater monetization potential due to their large batteries and frequent idle times. These revenues are a combination of participating on electricity markets (e.g., aFRR, FCR) and energy cost savings at fleet depots through optimized smart charging strategies. The latter reflects operational benefits rather than direct revenues from grid services, but both are enabled by bidirectional charging infrastructure.

aFRR and FCR: (TenneT 2025) examined the use of heavy-duty EVs in providing aFRR and FCR services. Long-haul trucks, retail fleets, and waste collection vehicles could earn between 1-7 EUR cents per kWh by participating in these markets. Trucks used for long-haul routes have the highest revenue potential due to their larger battery sizes and frequent periods of non-operation, allowing greater grid participation.

Depot Energy Cost Savings: Commercial EVs also provide significant opportunities for energy cost savings at depots. The (TenneT 2025) study found that a fleet of Battery Electric Trucks (BETs) could save up to €19,525 annually per vehicle through optimized charging schedules and participation in energy markets. This figure highlights the increased savings potential of bidirectional charging technology compared to traditional unidirectional systems, which only allow charging without grid interaction.

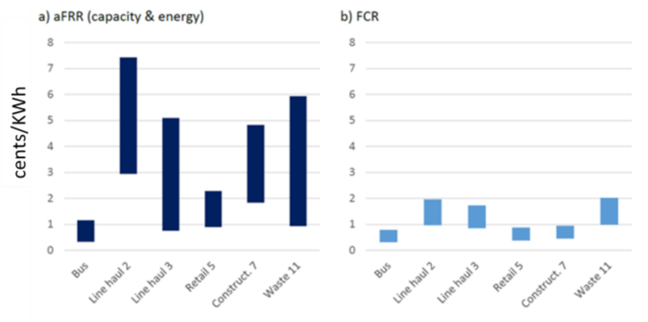


Figure 8: Range of maximum possible revenue/consumed kWh from flexibility segments (Daimler & Tennet, 2022)

Figure 8 illustrates the revenue potential from aFRR and FCR services across different types of commercial vehicles. It also highlights the energy savings potential for depots that incorporate V2X technology into their fleet operations, showing the substantial potential financial benefits for fleet operators.

2.3 How Does V2G Provide Flexibility?

V2G systems balance electricity supply and demand by aggregating electricity stored in EV batteries. EVs can store surplus energy during periods of low demand or high renewable generation and feed that energy back into the grid during peak times. This not only helps reduce the reliance on fossil fuels but can also prevent grid congestion and potential blackouts. Figure 9 illustrates this operational pattern over a 24-hour cycle, where EVs are charged during periods of high renewable availability and discharged during hours of elevated electricity prices. V2G technology supports frequency regulation by providing immediate energy injections or absorption to maintain grid stability. Additionally, smart charging can delay EV charging to off-peak hours, reducing grid strain and enhancing system efficiency.

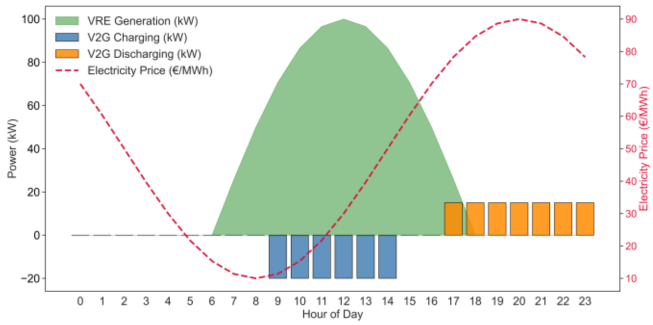


Figure 9: V2G flexibility use case: charging with renewable energy, discharging during high tariffs (Own illustration).

Advantages of V2G Flexibility

Decentralized storage: V2G transforms EVs into mobile energy storage units that act as grid assets.

RE integration: By storing excess renewable energy, V2G helps mitigate the variability of solar and wind power.

Cost savings and revenue generation: V2G enables EV owners to earn revenue through energy market participation and demand response programs while saving utilities from costly grid upgrades.

Grid stability: V2G enhances grid stability by contributing to frequency regulation, load balancing, and peak shaving, particularly during fluctuating energy supply and demand.

Stakeholders in V2G Flexibility

DSO/DNOs: Manage local grids and procure V2G services to optimize operations.

Transmission System Operators (TSOs): Responsible for system-wide balancing, frequency regulation, and wholesale market services. Aggregated V2G fleets can participate in ancillary service markets managed by TSOs, such as FCR and aFRR, serving broader stability needs across the transmission network.

Aggregators: Pool energy from multiple EVs to offer flexibility services at scale, serving as intermediaries between EV owners and grid operators.

Charging Station Oroviders (CPOs): Install and maintain bidirectional EVSE. They ensure interoperability, communication security (e.g., ISO 15118, PKI), uptime, and enable the remote control needed for V2G services.

EV owners: Benefit from offering their vehicles as flexible grid assets, earning revenue through demand response programs or by selling excess energy.

Energy suppliers: Use V2G flexibility to better align supply with demand, especially during peak periods or high renewable energy production.

Fleet operators and municipalities: Operate large pools of vehicles with predictable schedules (e.g., buses, logistics fleets), making them ideal for coordinated V2G participation in energy or balancing markets.

Policymakers and regulators: Define the legal, technical, and financial frameworks enabling V2G integration. Their role includes designing tariffs, clarifying energy resale rights, setting interoperability standards, and ensuring that V2G services are treated consistently with other flexibility assets. For example, unlike stationary battery energy storage systems (BESS), V2G-based storage may face separate regulatory treatment depending on whether electricity discharged from EVs is taxed or eligible for feed-in tariffs.

Technology providers: Develop the hardware (bidirectional chargers, inverters) and software (communication, control algorithms) required to enable reliable and grid-compliant V2G functionality.

Demonstrated Applications of V2G Flexibility

Community microgrids: In a study on community microgrids using V2G technology, cost savings reached 27.94%, with a reduction in the peak-to-average load ratio of 3.97% (Rana et al. 2021).

Congestion management in Germany: V2G has proven effective in alleviating congestion in the German transmission grid, reducing congestion management costs by up to 11% (Ruppert et al. 2023).

2.3 EV-Grid Integration Tools

EV-Grid integration tools are essential for policymakers and deliver quantitative estimates through an interactive interface. The tool can assess the impact of electric mobility strategies on power grids and the corresponding emissions. These tools also help optimize charging and simulate revenue potential, providing flexibility services. With the growing complexity of modern energy systems and the rapid expansion of EV deployment, these tools offer practical solutions to address the challenges of managing grid demand. Table 4 gives an overview of the main tools used for integrating electric vehicles with the power grid.

Table 4: EV-Grid integration tools

Tool Name	Purpose	Source
IEA Tool	Assessing charging demand and impact on the grid with visualized charging profiles.	(IEA 2023)
EVGrid Assist	Provides validated data, tools, and technical assistance to help stakeholders achieve transportation electrification goals.	(U.S. Department of Energy 2024)
V2GEL	Maintains a list of bidirectional charging equipment to facilitate V2G technology adoption.	(California Energy Commission 2022)
EVLearn	A simulation module for researching V2G and Grid-to-Vehicle (G2V) energy management strategies.	(Fonseca et al. 2024)
A Simulation Tool for V2G Enabled Demand Response	Provides a simulation tool for V2G-enabled response based on model predictive control.	(Diaz-Londono et al. 2024)
EVerest	An open-source software stack to support communications between electric vehicle (EV) charging infrastructure and other systems, facilitating interoperability and standardization in EV charging.	(EVerest 2025)
EVCC	An open-source energy management system that intelligently controls EV charging, optimizing this for photovoltaic surplus and integrating it with various home energy systems.	(evcc 2025)
EVI-DiST	Offers high-fidelity modeling and analysis for grid-scale EV charging integration, assisting utilities in evaluating the impact of EV adoption on electrical distribution systems.	(NREL 2025)
V2Sim	Open-source platform for detailed V2G analysis in coupled urban transport and power networks. Integrates traffic simulation (SUMO) with distribution grid modeling to evaluate EV charging demand, grid constraints, and custom V2G strategies at city scale.	(Qian et al. 2024)
REopt	Techno-economic optimization tool (web and open-source) for sites/fleets – now supports co-optimized planning of EV charging (smart charging, V2B, V2G) along with other energy resources. Evaluates charging load profiles, on-site generation/storage, and costs to identify optimal fleet electrification and V2G strategies.	(NREL 2024)

International Energy Agency (IEA) EV-Grid Integration Tool

The IEA Electric Vehicle Charging and Grid Integration Tool is an advanced platform that supports policymakers, grid operators, and utilities in understanding the impact of increasing EV adoption on electricity systems. It offers a comprehensive analysis of how EV charging affects national power systems and distribution networks, guiding users in managing the integration of EVs into energy grids. The tool provides insights into three main areas.

National and Distribution-Level Impact: It allows users to estimate the impact of growing EV demand on grid infrastructure and the broader energy system. At the national level, it evaluates the shape of the EV demand profile, the magnitude of demand, and how different charging strategies can affect emissions. For distribution systems, it assesses how EV demand compares with traditional grid demand, helping utilities determine how best to manage peak and off-peak demand.

Charging Strategies: One of the key features of the tool is its ability to compare unmanaged EV charging (charging whenever convenient) with managed charging strategies that optimize charging times to align with grid conditions. Managed charging can shift demand to times when energy is cheaper or when renewable energy is available, reducing the strain on the grid and improving energy efficiency.

Emission Impact Assessment:

The tool also estimates the emissions produced by EV charging. It evaluates how different charging behaviors influence CO_2 emissions depending on the power mix and timing of charging. This helps users understand how EVs can contribute to reducing greenhouse gas emissions, especially when renewable energy is integrated into charging strategies. The tool is divided into three main modules. The first module generates weekly electricity demand profiles by simulating EV driving and charging behavior, providing insights into the power the grid must supply. The second module compares unmanaged and managed charging, showing the benefits of optimized charging strategies to increase grid flexibility. The third module estimates the climate impact of different EV charging strategies, demonstrating how adjusted charging schedules can reduce emissions based on the power mix.

The tool has been successfully tested in a range of real-world scenarios. In Chile, it was applied to an intra-city bus fleet; in India, to a logistics fleet of three-wheeler vehicles; and in developed economies, to private car fleets. These case studies illustrate how it can be adapted to different vehicle types, charging behaviors, and geographic contexts to optimize EV charging schedules.

Chapter 3: Electrification of Bus Depots

3.1 Electric Transit Buses

Several charging standards and communication protocols are employed for the unidirectional charging of electric transit buses. The Combined Charging System (CCS) connector is a widely adopted standard in North America and Europe, supporting both AC and DC charging through a single port (iEVPower 2022). CHAdeMO is another DC fast-charging standard that was more common in Japan and in earlier electric vehicle deployment globally. In addition to these physical connection standards, communication protocols play a crucial role in managing the charging process. The Open Charge Point Protocol (OCPP) is a widely used open-source protocol that enables communication between charging stations and central management systems. OCPP facilitates various functionalities, including remote monitoring, control of charging parameters, and the implementation of smart charging strategies for load management and energy optimization (Electric School Bus Initiative 2022). Understanding these standards and protocols is essential for ensuring interoperability between different charging infrastructure components and for effectively managing large-scale unidirectional charging deployments for electric transit bus fleets.

3.2 Unidirectional Charging Enabled Bus Depots

While bidirectional V2G systems are emerging, the majority of electric bus systems worldwide currently rely on unidirectional charging infrastructure. For example, in Germany, the city of Hamburg is a leader in this transition. Public transport operators such as Hamburger Hochbahn (Hochbahn) and Verkehrsbetriebe Hamburg-Holstein (VHH) manage substantial electric bus fleets. One of Hamburg's largest depots spans 45,000 square meters and accommodates 236 to 240 electric buses, supported by 96 charging points equipped with Siemens Sicharge UC 200 charging stations (150 kW, CCS plugs) (Siemens AG 2020). VHH also operates multiple electric depots, including sites in Bergedorf, Schenefeld, and Billbrook. Hamburg's commitment to electric mobility is further demonstrated by its plans for the Meiendorf depot, expected to open in 2026 with capacity for 130 electric buses (Hamburger Hochbahn AG 2023).

In the United States, the Metropolitan Transportation Authority (MTA) in New York City is undertaking a broad electrification initiative across its bus depots. The Jamaica Bus Depot is being entirely rebuilt and expanded to support up to 300 electric buses (MTA 2023). This project includes the installation of automated overhead pantograph charging systems, is scheduled for completion by fall 2027, and features environmentally-friendly design elements, such as a green roof, aligning with LEED certification standards (Lepre 2018). Other MTA depots undergoing or slated for similar upgrades include the Grand Avenue Depot in Queens, which recently added 17 fast-charging pantograph dispensers, and the Gun Hill Road Depot in the Bronx, which will become the borough's first electric bus charging facility, with capacity for 225 buses. Additional sites in the electrification program include Queens Village, East New York, Jackie Gleason, Ulmer Park, and Yukon depots that are all progressing through various stages of infrastructure transformation to accommodate electric buses.

In Asia, Jakarta is advancing its electric bus program via Transjakarta, which operates BYD K9 buses with 324 kWh batteries and a range of up to 250 km (BYD 2022). Key depots such as Klender and Pupar Cakung have 35 combined charging stations, capable of fully recharging a 350 kWh battery in approximately two hours. Damri, a state-owned company, currently operates 116 electric buses, all supported by this growing depot infrastructure.

In China, major urban centers such as Shanghai utilize similar depots where buses are charged, and in some cases, the infrastructure is shared with private electric vehicles to maximize utility.

Similarly, in South America, Santiago, Chile, has integrated unidirectional charging into its broader electrification projects, contributing to the city's clean transportation goals.

3.3 Bidirectional Charging Enabled Bus Depots

Vehicle-to-Grid (V2G) technology is gradually gaining traction in electric bus depots across the globe, with several pilot projects and early commercial deployments underway.

In North America, the United States lead with numerous school bus-focused V2G initiatives. Dominion Energy in Virginia has launched the largest utility-led electric school bus program in the country, deploying over 135 "Jouley" models by Thomas Built Buses across 25 school districts, all equipped for future V2G operations.

In Massachusetts, Beverly Public Schools, in collaboration with Highland Electric Fleets and National Grid utility, have pioneered a commercial V2G program. Their two Jouley buses discharged around 7 MWh back to the grid during 32 summer peak events in 2022, using ISO 15118-compliant 60 kW DC bidirectional chargers (Thomas Built Buses 2021). Earlier efforts include a 2018–2021 pilot in White Plains, NY, involving five Lion Electric buses, three of which were retrofitted for bidirectional operation.

California's Cajon Valley Unified School District partnered with San Diego Gas & Electric to deploy eight Lion Electric buses with V2G capabilities, supported by six 60 kW DC chargers. In New York City, NYCSBUS is executing the state's largest V2G pilot at the Zerega Depot in the Bronx, where 30 electric school buses are being managed via The Mobility House's ChargePilot system, funded by an $8 million NYSERDA grant. Illinois is set to join this trend in 2025, with utility ComEd launching a pilot involving four electric buses across three districts. While transit and coach bus V2G remains limited, Link Transit in Washington has considered V2G for frequency regulation, and intercity coach operators such as FlixBus are exploring electric buses, though V2G integration is still pending (FlixBus 2024).

In Canada, British Columbia is home to the country's first medium/heavy-duty V2G pilot. Launched in 2023, BC Hydro and tourist operator Coast to Coast Experiences are testing a Lion Electric school bus with a 60 kW bidirectional charger at BC Hydro's Powertech Labs, demonstrating successful grid discharge.

Europe has also seen progress, particularly in the United Kingdom. London's landmark Bus2Grid project at the Northumberland Park Depot is a leading example, featuring 2.6 MW of bidirectional charging infrastructure and 28 V2G-capable double-decker buses. In Germany, regulatory frameworks enabling V2G were introduced in 2022. Although V2G depots are not yet operational, exploratory work continues, for example, the RheinMobil and The Mobility House trials. France, Italy and the Nordic countries are also advancing electric-bus adoption, though V2G remains mostly in pilots or lab settings. A Finnish project, for instance, is testing V2G for frequency regulation in the Nordic grid. European OEMs such as Volvo, VDL and Mercedes-Benz (eCitaro) are positioning to support V2G through compliance with ISO 15118 and related standards.

In the Asia-Pacific region, China stands out due to its massive electric bus fleet, currently exceeding 600,000 units nationwide. In 2023, the National Development and Reform Commission (NDRC) initiated 30 major V2G pilot projects, some of which are expected to include electric bus depots in cities like Shenzhen (Latief 2025). With 16,000 electric buses in operation, Shenzhen's transit authority is preparing to test V2G to supply ancillary services and integrate surplus solar power. While still nascent, these efforts indicate China's intention to harness its extensive e-bus infrastructure for vehicle-grid integration.

Overall, while V2G in electric bus depots remains in the pilot phase in most regions, the increasing deployment of bidirectional chargers and supportive regulatory developments suggest growing momentum.

3.4 Electric Buses with Bidirectional Charging

While bidirectional charging is gaining traction, the vast majority of electric bus models available today are equipped with unidirectional charging capabilities. These models are from various manufacturers across the globe and cater to different transportation needs, from urban transit to intercity travel. Appendix A provides a selection of electric bus models available in the market with both uni- and bi-directional charging features, along with their key technical characteristics. While still in the developing stages of widespread adoption, several electric bus manufacturers are beginning to incorporate bidirectional charging capabilities into their models in response to the growing interest in V2G and V2B applications. The current adoption rate of bidirectional charging technology in the global electric bus market is still relatively low, with most deployments in pilot projects and demonstrations. However, there is growing interest and momentum in this technology, particularly for specific applications like electric school buses and transit buses. Several manufacturers, including Lion Electric, BYD, Proterra, and Solaris, have already demonstrated or are offering models with bidirectional capabilities. The table in Appendix A highlights electric bus models identified in the research material that are confirmed to support bidirectional charging, along with their key technical characteristics and specific V2X features where available.

The regional adoption of electric buses and their associated charging technologies varies widely across the globe, reflecting differences in infrastructure development, and market readiness. Europe leads in the implementation of Vehicle-to-Grid (V2G) systems, with pioneering projects such as the BUS2GRID initiative in the United Kingdom and Solaris's Charging Park in Poland (Halvorson 2020).

In North America, V2G technology is currently focused on school bus electrification pilots. Manufacturers like Lion Electric and Thomas Built Buses have rolled out V2G-capable vehicles in collaboration with utilities to support the grid during peak demand periods. However, for urban transit operations, unidirectional electric buses, such as the Proterra ZX5 and New Flyer Xcelsior series, are more commonly used, indicating a dual-track development approach that distinguishes school and public transit use cases.

Asia, led by China, plays a dominant role in global electric bus deployment. BYD contributes to both V2G and unidirectional systems, with its K9 model widely used in domestic and international transit networks. While China has initiated several large-scale V2G pilot programs, other manufacturers such as Yutong and Zhongtong continue to focus on unidirectional charging solutions. However, there is growing interest in enabling V2G in shared depot environments as fleets scale up.

In South America, the adoption of electric buses is increasing but is currently centered around unidirectional models. Santiago, Chile, for example, operates BYD K9 buses as part of its public transit fleet. At present, there are no reported V2G projects in the region, which suggests that bidirectional charging is not yet a focus area.

Other regions, including Australia and the Middle East, have also begun integrating unidirectional electric buses into their transport systems. Countries such as Qatar operate models like the BYD K9, but V2G technology remains in the early stages of exploration. Barriers such as limited infrastructure, regulatory gaps, and smaller fleet sizes continue to delay broader deployment.

The previous sections presented international examples of electric bus depots and infrastructure concepts. The following section complements them by looking at how buses are actually operated within those systems. Transitioning to electric fleets changes the way operators plan routes, manage charging, and use depot space. In practice, this often means charging buses overnight in busy slots, aligning vehicle availability with grid capacity, and integrating charging into the overall scheduling process.

3.5 Operational Patterns of Electric Buses

Understanding the key operational parameters of electric buses is essential for effective fleet management and infrastructure planning. Unlike traditional depots designed for refueling and maintaining internal combustion engine buses, electric bus depots must prioritize electrical infrastructure to support their charging needs. Sufficient space is a primary consideration, not only for the buses themselves but also for the charging infrastructure, including chargers, transformers, and switchgear. Planning for potential future fleet expansion is also crucial to avoid costly retrofits down the line. Space limitations in existing depots can pose a significant challenge, sometimes requiring operators to explore innovative parking layouts or even relocate parts of their fleet.

Proximity to a strong and reliable grid connection is another critical design factor. Upgrading the grid connection to meet the substantial power demands of a fully electric fleet can be expensive and time-consuming, making the location of the depot relative to existing power infrastructure a key consideration during the planning phase.

Increasingly, there is a focus on integrating renewable energy sources, such as solar panels installed on depot roofs, into the energy supply infrastructure. This can help to reduce the depot's reliance on the grid, particularly during peak tariff periods, leading to lower energy costs and a reduced carbon footprint.

A central operational element linking these fleet strategies is the charging approach used at depots. Whether operators rely on overnight charging, plug-in sessions, or integrate load management systems, the depot remains the primary hub for energy replenishment. The following section builds on this by exploring the different depot charging options and scheduling practices used across fleets ranging from basic overnight plug-in setups to on-route charging facilities.

3.6 Depot Charging

Depot charging is the most prevalent charging strategy for electric buses, particularly for overnight charging when buses are not in service. The most common method for depot charging is plug-in charging, which involves physically connecting the bus to a charger using a cable.

Some operators use smart depot management systems to forecast energy demand and control charging loads. Others adopt simpler fixed-time charging strategies based on route length and daily mileage. While the operational setup varies by city and fleet size, the goal remains the same: ensure reliable service while making the most of the available infrastructure. This section highlights a few of these patterns observed across real-world deployments.

Due to the large battery capacity of electric buses, charging times can be substantial, often requiring several hours to reach full charge. For overnight charging, slower charging rates are generally sufficient, allowing buses to be fully replenished and ready for service the next day.

Smart charging technologies are playing an increasingly important role in optimizing depot charging. These systems utilize data connectivity and intelligent algorithms to manage the charging process based on factors such as electricity prices, grid load, and the bus's operational schedule. By shifting charging to off-peak hours when electricity rates are lower, smart charging can significantly reduce the energy costs associated with operating an electric bus fleet. Furthermore, smart charging can help to prevent overloading the electrical grid by dynamically adjusting charging rates based on the available capacity.

3.6.1 On-Route Charging

On-route charging is one way to extend the operational range of electric buses by giving them quick bursts of power during their service routes. The most common technology for on-route charging is overhead conductive charging, which utilizes a pantograph that makes physical contact with an overhead charging infrastructure. These charging systems typically operate at much higher power levels, ranging from 165 kW to 600 kW, enabling buses to receive a significant charge in a short time, typically between 5 and 20 minutes (US Department of Transportation 2023). This method is often implemented at designated bus stops or terminals where buses have scheduled layovers, allowing for "opportunity charging" without significantly disrupting the service schedule.

3.6.2 Overnight Charging at Depots

Overnight depot charging is the most traditional and widely adopted strategy for electric bus fleets, particularly suitable for operations with predictable schedules and overnight downtime. This method involves slow charging using plug-in interfaces, typically requiring between 4 to 12 hours to fully recharge a vehicle (Esposito 2016). Buses configured for overnight charging generally have larger battery capacities, ranging from 200 to 500 kWh, sufficient for an entire day's operation on short, urban routes. Examples of cities employing this approach include Hamburg and Shenzhen. Key advantages include low electricity costs during off-peak nighttime hours and the elimination of range anxiety. However, the requirement of larger battery systems adds cost and weight to the vehicle, posing financial and operational challenges.

3.6.3 Opportunity Charging

Opportunity charging is a strategic approach that leverages short periods of downtime during a bus's operational day to replenish its battery charge. This often occurs during scheduled layovers at bus terminals or at the end of a route. Charging times range from 30 minutes to a few hours, and the typical battery capacity for these buses is smaller, usually between 50 and 90 kWh, resulting in lighter vehicles and potentially higher energy efficiency. Power requirements range from 150 to 450 kW (US Department of Transportation 2023). This strategy is well-suited for longer routes or high-frequency services, as seen in Amsterdam, where buses undergo 20-minute charging intervals.

The key to successful opportunity charging is the use of fast chargers, typically with power outputs ranging from 150 kW to 500 kW, which can deliver a substantial amount of energy to the bus's battery in just a few minutes. Hyper-fast charging technologies, often utilizing pantographs (Siemens: Pantographs for e-Mobility 2025), can even charge a bus in just over an hour. The availability of opportunity charging infrastructure has significant implications for the size of the batteries required in electric buses. By strategically placing fast chargers along routes, operators can potentially utilize buses with smaller and lighter batteries, as they can be topped up more frequently throughout the day. This can lead to lower upfront costs for vehicles and reduced energy consumption due to their lighter weight.

3.6.4 Depot Charging with Energy Management

This advanced charging strategy integrates smart charging technologies, load balancing, and Vehicle-to-Grid (V2G) systems to optimize charging schedules and improve grid interaction. It is typically adopted in regions with mature energy infrastructure, such as Europe and North America. By intelligently managing energy flow, this strategy enhances operational efficiency, reduces peak demand charges, and provides ancillary services to the grid.

Chapter 4: V2G in Thailand

Thailand is committed to decarbonizing its energy sector with a strong focus on transport. To achieve this, several favorable policies are already in place. Alongside clean energy and decarbonization policy measures, Thailand has also focused on implementing innovative clean technologies, such as bidirectional charging (e.g., V2G, V2H, etc.) and smart grids to foster the emerging EV ecosystem nationwide. Bidirectional or V2G charging enables electric vehicles (EVs) to not only consume electricity but also feed this back into national and regional grids, supporting energy balancing, reducing peak demand, and enhancing grid resilience.

EV stakeholders in Thailand are actively exploring Vehicle-to-Grid (V2G) technology as part of their transition toward a smarter, low-carbon energy system. So far, the Thai government has launched supportive policies under the Energy Regulatory Commission (ERC) Sandbox to enable pilot projects by public organizations (e.g., EGAT) and private partnerships with companies like Nissan and Mitsubishi. These initiatives are testing V2G functionality and assessing its feasibility for commercial and technical implementation (Electricity Generating Authority of Thailand 2022). Additionally, Thailand's National Electric Vehicle Policy Committee is aiming for 30% of domestic vehicle production to be EVs by 2030, indirectly boosting the relevance of V2G.

Moreover, implementing V2G aligns with Thailand's goal of achieving carbon neutrality by 2050 and net-zero greenhouse gas emissions by 2065.

The electrification of buses is also gaining momentum as part of the country's ambitious plans to modernize its transport sector and reduce carbon emissions. Government policies and incentives are supporting the deployment of e-buses, particularly in major cities like Bangkok. Various pilot projects and initiatives are underway, aiming to replace the traditional diesel buses with electric alternatives. This shift not only supports Thailand's environmental goals but also aligns with its strategy to become a regional leader in electric vehicle production and technology by 2030. The move toward electrified public transport is expected to contribute significantly to the country's progress in sustainability and urban mobility. Such developments could also bring a scalable opportunity to implement V2G in bus transport.

Why is it Important?

V2G plays a critical role in Thailand's strategy to decarbonize its transport and energy sectors. As EV adoption grows, V2G offers a way to integrate these vehicles into the national energy ecosystem, transforming them into mobile energy storage units that can support renewable energy integration and reduce fossil fuel reliance. By enabling bidirectional energy flow, V2G can help manage grid fluctuations, reduce emissions from fossil fuel power plants, and enhance the utilization of solar and wind energy.

Moreover, V2G can help reduce the negative impacts on the grid of integrating renewables. This can support grid stabilization and reduce grid expansion costs. Beyond this, V2G also supports various grid services such as demand response, frequency regulation, load balancing (peak shaving), and reactive power provision. On the consumer end, V2G could increase self-consumption, and supply emergency backup power, local microgrids, and home/building appliances.

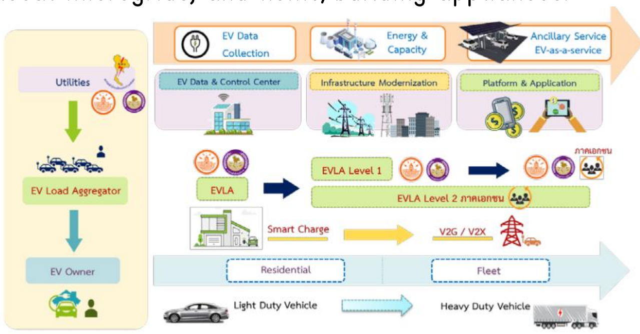


Figure 10: Thailand's medium-term smart grid implementation plan and EV-grid integration (Energy Policy and Planning Office, EPPO)

Additionally, current policy discussions in Thailand advocate a multi-level planning approach to facilitate the implementation of V2G and V2X technologies in the near future. The Thai Smart Grid initiative (see Figure 10), proposed by the Ministry of Energy, outlines several planned activities related to the advancement of V2G technology (Energy Policy and Planning Office (EPPO), Thailand 2022).

Challenges and Barriers: Despite its potential, the implementation of V2G in Thailand faces several challenges and barriers[7]. One of the main hurdles is the lack of a clear regulatory framework governing bidirectional energy flow, including rules for energy trading, grid interconnection standards and battery storage. Without clear policies, energy providers and EV owners face uncertainty, slowing adoption. Additionally, there are currently limited financial incentives or business models that make V2G attractive for consumers or fleet operators. On the technical side, concerns about battery degradation from frequent charging and discharging remain a significant barrier, especially in the absence of standardized protocols or assurances from OEMs. Interoperability of different EV

[7] A stakeholder V2G workshop was conducted in Thailand on June 27, 2024. The workshop invited multiple stakeholders to discuss ongoing progress, challenges, and barriers to the implementation of bidirectional charging in Thailand.

brands, chargers, and energy management systems also poses a technical challenge. Moreover, public awareness and understanding of V2G technology are still low.

Conclusions and Next Steps

Initial consultations with project partners and stakeholders revealed substantial interest in implementing V2G technology in Thailand. However, insights from international V2G applications are crucial for understanding the necessary steps, challenges, barriers, and best practices. This report provides global definitions and an international perspective on V2G technology. It also offers a detailed examination of electric bus usage and grid integration. Its underlying purpose is to gather and summarize the findings from ongoing implementations of V2G technology, including pilot projects, commercial tests of related business models, and technological advances.

As mentioned before, nationwide implementation of V2G technology could leverage various grid and end-user services. One example is energy system flexibility, which refers to the ability of a power system to adjust generation and consumption patterns in response to variability in supply, particularly from renewable energy sources like solar and wind.

Figure 11 illustrates a high-level use case of how flexible EV end-users can utilize renewable energy supplied to the grid. Aggregators and fleet operators also play a crucial role in demand-side management. In fact, end-users and operators can adjust their electricity consumption or output in real time, helping to balance supply and demand. Policies and regulations are key factors influencing the development of the market for energy flexibility. Ultimately, end-users benefit from optimized energy consumption, potentially lower costs and increased reliability of the power supply. Therefore, the successful implementation of V2G requires transparent data-driven business models, education, successful pilots, and consumer awareness programs to demonstrate the benefits of V2G.

The follow-up report will continue this research by focusing on the integration of V2G technology in Thailand. It will outline the current state of the Thai electric vehicle sector, analyze government policies, and map the stakeholders involved in V2G integration. Additionally, it will compile feedback from stakeholders gathered through various formats such as onsite workshops, webinars, and interviews. This feedback will be used to discuss regulatory issues, market challenges, technical barriers, and the participation of end-consumers in V2G systems.

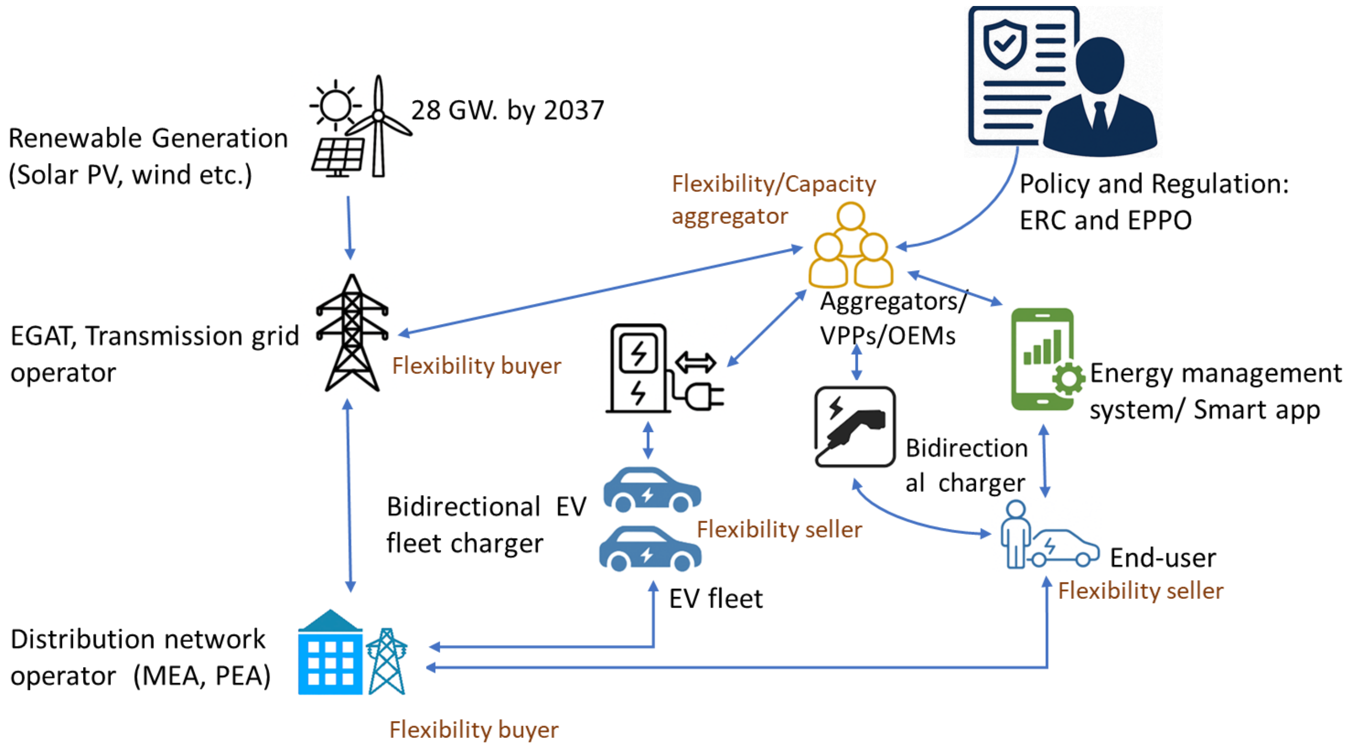


Figure 11: High-level use case of energy flexibility from implementing V2G and integrating renewables in the Thai power system.

Appendix A: List of major EV BUS OEMs

Table 5: Specifications of electrified buses and passenger cars

Manufacturer	Model	Battery Capacity (kWh)	Range (km)	Charging Power (kW)	Bidirectional Charging Feature
BYD	Double-Decker Bus (BUS2GRID)	~382	Not specified	80 (charge), 40 (discharge)	Yes
Lion Electric	LionC	150–250	Not specified	10 (discharge)	Yes
Thomas Built Buses	Electric School Bus (with Proterra)	Not specified	Not specified	Not specified	Yes
Solaris	Urbino Electric	200–470	150–300	Up to 600 (pantograph), V2G capable chargers	Yes
Yutong	U12	422	432	Plug-in	No
Yutong	E7S	134	Not specified	Plug-in	No
Yutong	E11PRO	350	Not specified	Pantograph	No
Yutong	T12E	422	500+	Plug-in	No
Yutong	T15E	630	550+	Plug-in	No
Yutong	C13E	350	Not specified	Plug-in	No
Yutong	AB14E	Not specified	Not specified	Plug-in	No
Ebusco	3.0 12M	250-500	700	Plug-in	Yes
Ebusco	3.0 18M	250-500	700	Plug-in	Yes
Ebusco	2.2 12M	>400 (>500 optional)	550	Plug-in	Yes
Ebusco	2.2 18M	>500	550	Plug-in	Yes
Blue Bird	Vision Electric	155	241	CCS1	Yes
Blue Bird	All American Electric	155	241	CCS1	No
Gillig	Battery Electric	Up to 686	241+	Plug-in, Pantograph, Inductive, Mobile	No
Zhongtong	LCK6125EV	350	250	Plug-in	No
King Long	XMQ6150AGWE	Not specified	Not specified	Not specified	No
King Long	Estar	Not specified	300+	Not specified	No
King Long	XMQ6900BGWE	210.56	Not specified	Not specified	No
BYD	K9	324	250	150	
Mercedes-Benz	eCitaro	200–400	150–350	150–300	
Solaris	Urbino 12 Electric	200–470	150–300	450 (pantograph)	
Volvo	7900 Electric	150–540	200–250	300	
Proterra	ZX5	330–660	240–330	350	
New Flyer	Xcelsior XE40 CHARGE	Not specified	Not specified	Not specified	
New Flyer	Xcelsior XE60 CHARGE	Not specified	Not specified	Not specified	

Lion Electric	LionC	Up to 210	Up to 257		V2G, V2B, V2L
Lion Electric	LionD	Up to 210	Up to 241		V2G, V2B, V2L
Lion Electric	Lion5	210	Up to 305		V2G, V2B, V2L
Lion Electric	Lion6	252	Up to 350		V2G, V2B, V2L
Lion Electric	Lion8 Tractor	630	Up to 443		V2G
Blue Bird	Type A	Not Specified	Up to 225		V2G
Proterra	ZX5+	Up to 492	Up to 483		V2G
Proterra	ZX5 Max	Up to 738	Up to 483+		V2G
Thomas Built Buses	Saf-T-Liner C2 Jouley	226	Not Specified		V2B, V2G
BYD	Type D	Not Specified	250		V2G
BYD	Type A	Not Specified	225		V2G
Solaris	Urbino Electric	Not Specified	Not Specified		V2G (with compatible chargers)
Ebusco	Energy FLEX	184 (kWh storage)	N/A	60 kW (charging)	Bidirectional energy storage

Appendix B: V2G progress in selected EU countries

Regulations driving V2G at EU level:
Electricity Directive (EU) 2019/944: Requires Member States to facilitate the participation of EVs in flexibility services[8]. At EU level, the Electricity Directive (EU) 2019/944, part of the Clean Energy for All Europeans Package, explicitly mentions the role of electric vehicles (EVs) in providing flexibility services. It highlights

"*Demand response is pivotal to enabling the smart charging of electric vehicles and thereby enabling the efficient integration of electric vehicles into the electricity grid, which will be crucial for the process of decarbonising transport.*"

Furthermore:

- **Article 15(2)** requires Member States to enable and incentivize demand response participation, including via aggregators.
- **Recital 55** highlights that electric vehicles (EVs) can contribute significantly to grid flexibility, particularly when combined with smart charging or vehicle-to-grid (V2G) technology.
-

Key guidelines for EU Member States:

1. Remove unjustified barriers for EVs to participate in electricity markets (including ancillary and balancing markets).
2. Ensure charging points and systems are smart-capable and interoperable.
3. Allow aggregators to act independently, enabling EV fleets to provide flexibility without requiring supplier consent.
4. Promote dynamic price contracts (DPC) so EV charging can respond to price signals.

In addition to the above EU-level policies and guidelines, Member States have their own measures to promote the integration of V2G technology into their national energy markets.

Table 6: V2G status table

Country	V2G Status / Projects	Regulatory framework
France	• Has launched several pilot projects since 2018. First commercially available consumer V2G Renault R5 bidirectional charging rolled out in October 2024.	France has transposed the *Electricity Directive (EU) 2019/944* into national law via: • *Code de l'énergie* (Energy Code)9 – sets out consumer rights, dynamic pricing (Article L332-7), aggregator participation, and smart charging requirements. • National transposition ensures EVs and aggregators can participate in demand response and flexibility markets. Aggregator rights • Subsequent decrees outline the framework for independent aggregators to operate in French electricity markets without requiring supplier consent, enabling the aggregation of EV flexibility for V2G services to participate in balancing and ancillary service markets.

[8] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019L0944
[9] https://www.legifrance.gouv.fr/codes/texte_lc/LEGITEXT000023983208/

United Kingdom	• EDF and Nissan EDF, through its subsidiary DREEV, partnered with Nissan to offer a V2G solution for fleet owners of Nissan LEAF and e-NV200 models • Octopus Energy and BYD: Octopus Energy has launched a V2G bundle with BYD, including a bi-directional charger, a smart tariff, and car leasing options. • Mobilize and The Mobility House Mobilize, a Renault Group brand, is partnering with The Mobility House to offer V2G services, initially in France, Germany, and the UK. The Mobility House's technology will manage the marketing of electricity on energy markets.	• UK considered most advanced in terms of regulations; licensing required for chargers >3.5 kW; policies under Ofgem • ISO 15118 adoption underway to support future interoperability.
Germany	• Pilot projects by Mobility House, Nissan & TenneT using Nissan Leafs; limited by smart meter rollout (<10%)	Legal framework in development; standardization issues; wide DSO base complicates V2G rollout. Key V2G-related guidelines are: • Charging Infrastructure Master Plan II (2022) • EnWG §14a allows variable tariffs and emergency load reduction • ISO 15118-20 adopted, OCPP 2.1 & EEBus available, standard maturity by 2027–28
The Netherlands	• Multiple projects since 2019, e.g., IONIQ 5 fleet V2G trials, Renault 5 E (Utrecht Energized pilot) and Johan Cruijff ArenA V2G pilots • We Drive Solar, in partnership with MyWheels, Renault, and the City of Utrecht, has recently launched Europe's first large-scale car-sharing service utilizing V2G technology in the Netherlands.	• Adoption of EU regulatory guidelines • Roadmap for smart charging, network tariff and market mechanisms and regulations that allow grid operators to procure flexibility from electric vehicle batteries to manage grid congestion are under development
Japan	• First V2G demo in Toyota City in 2018 with Nuvve & Chubu Electric; Nissan LEAF V2G expected commercially from ~2026	• V2G Legal framework under development. • CHAdeMO standard supports V2G; V2H available already
United States	• California is leading V2G implementation in the USA. Along with several utility-led programs, INVENT project at UC San Diego, PG&E's Vehicle-to-Everything (V2X) are notable examples of V2G pilots.	• Senate Bill 59 (SB 59): mandates bidirectional charging capabilities for new EVs sold in the state. • Interconnection Standards (Rule 21): Updates are underway to accommodate V2G • CARB's HVIP V2G Requirement (Hybrid and Zero-Emission Truck

[10] https://www.legifrance.gouv.fr/loda/id/JORFTEXT000042255722/

		and Bus Voucher Incentive Project): This requirement ensures that eligible vehicles and charging systems support V2G capabilities, enabling bidirectional energy flow between the vehicle and the grid.
Denmark	• Edison, Nikola & Parker projects from 2016–2018; fleet and grid-operated pilots tested at DTU, Frederiksberg, Bornholm. No full commercial deployment yet.	• Lack of a V2G-specific national regulatory framework • Aligned with EU V2G regulatory framework • Market-based development and collaborative approach

Bibliography

Ala, Guido; Di Filippo, Gabriella; Viola, Fabio; Giglia, Graziella; Imburgia, Antonino; Romano, Pietro et al. (2020): Different Scenarios of Electric Mobility: Current Situation and Possible Future Developments of Fuel Cell Vehicles in Italy. In *Sustainability* 12 (2), p. 564. DOI: 10.3390/su12020564.

Berylls (2024): Vehicle to Grid Readiness Worldwide. Available online at https://www.berylls.com/wp-content/uploads/2024/02/299224_Vehicle-to-Grid-Readiness-Worldwide.pdf, checked on 8/16/2024.

Blair, Brittany; Moran, Drake; Fitzgerald, Garrett (2023): The State of Bidirectional Charging in 2023. Smart Electric Power Alliance. Washington.

BYD (2022): BYD and Bakrie & Brothers Group Cooperate with Local Indonesian Body Builder Group, Tri Sakti, to Initiate Electric Bus Industrialization. Available online at https://www.bydglobal.com/en/news/2022-03-14/BYD-and-Bakrie-%2526-Brothers-Group-Cooperate-with-Local-Indonesian-Body-Builder-Group%2C-Tri-Sakti%2C-to-Initiate-Electric-Bus-Industrialization, updated on 6/13/2025, checked on 6/12/2025.

California Energy Commission (2022): Vehicle-to-Grid Equipment List. Available online at https://www.energy.ca.gov/programs-and-topics/programs/vehicle-grid-integration-program/vehicle-grid-equipment-list, updated on 2/27/2025, checked on 2/27/2025.

California Energy Commission (2024): Vehicle-Grid Integration Program. Available online at https://www.energy.ca.gov/programs-and-topics/programs/vehicle-grid-integration-program, updated on 8/15/2024, checked on 8/15/2024.

Cenex (2023): Sciurus Project - Domestic V2G Demonstration - Cenex. Available online at https://www.cenex.co.uk/projects-case-studies/sciurus/, updated on 3/22/2023, checked on 2/25/2025.

CHAdeMO (2024): Emergency response concept EV powered by CHAdeMO's bi-directional (V2X) function | CHAdeMO. Available online at https://www.chademo.com/emergency-response-v2x, updated on 8/15/2024, checked on 8/15/2024.

Colin Walker (2025): EVs keep the lights on as power outages hit – analysis. webpage. Available online at https://eciu.net/media/press-releases/2025/evs-keep-the-lights-on-as-power-outages-hit-analysis, updated on 7/25/2025, checked on 7/25/2025.

Cristina, Corchero; Manel, Sanmartí; Sara, González; Chapman, Nick (2019): V2X ROADMAP. IEA, International Energy Agency.

Diaz-Londono, Cesar; Orfanoudakis, Stavros; Vergara, Pedro P.; Palensky, Peter; Ruiz, Fredy; Gruosso, Giambattista (2024): A Simulation Tool for V2G Enabled Demand Response Based on Model Predictive Control. Available online at http://arxiv.org/pdf/2405.11963.

Electric School Bus Initiative (2022): All About Managed Charging and "Vehicle-to-Everything" or V2X, 2022. Available online at https://electricschoolbusinitiative.org/all-about-managed-charging-and-vehicle-everything-or-v2x, checked on 6/12/2025.

Electricity Generating Authority of Thailand (2022): Mitsubishi Motors (Thailand) and EGAT join hands to pilot V2G technology and Virtual Power Plant testing - Electricity Generating Authority of Thailand. Available online at https://www.egat.co.th/home/en/20221021e/, updated on 10/21/2022, checked on 2/27/2025.

Energeia (2024): Insights from the Realising Electric Vehicle-to-Grid Services Project. Final Report. Energeia Pty Ltd. Barangaroo.

Energy Policy and Planning Office (EPPO), Thailand (2022): Thailand's Smart Grid Implementation Plan, Medium Term, 2022 - 2031. Available online at https://policy.asiapacificenergy.org/sites/default/files/Master%20Plan%20for%20Smart%20Grid%20Network%20System%20Development%20in%20Thailand%202015-2036%20%28TH%29.pdf, checked on 2/27/2025.

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Ernst, Alina-sophie (2024): Vehicle to Grid Readiness Worldwide. Berylls. Available online at https://www.berylls.com/vehicle-to-grid-readiness-worldwide/, updated on 2/20/2024, checked on 8/16/2024.

Esposito, Gloria (2016): The Low Emission Bus Guide. The Low Carbon Vehicle Partnership. London.

evcc (2025): PV-Überschussladen für steuerbare Wallboxen. Available online at https://evcc.io/, updated on 2/27/2025, checked on 2/27/2025.

EVerest (2025): EVerest/EVerest: Main Repository of EVerest - an EV charging software stack. All main documentations and issues are stored here. Available online at https://github.com/EVerest/EVerest, updated on 2/27/2025, checked on 2/27/2025.

FfE (2023): Bidirektionales Lademanagement (BDL) - FfE. Available online at https://www.ffe.de/projekte/bdl/, updated on 7/5/2023, checked on 9/12/2024.

Flexitanie (2024). Available online at https://www.flexitanie.fr/projet-flexitanie, updated on 9/12/2024, checked on 9/12/2024.

Flinders University' V2G project (2023): All systems go for landmark energy project. Available online at https://news.flinders.edu.au/blog/2023/08/04/all-systems-go-for-landmark-energy-project/, updated on 8/4/2023, checked on 5/28/2025.

FlixBus (2024): FlixBus Launches First London - Cambridge Electric Coach Service | Flixbus. Available online at https://www.flixbus.co.uk/CambridgeEV#:~:text=centre%2C%20Trumpington%20Park%20and%20Ride%2C,Station%20from%20Wednesday%2014%20August, updated on 6/12/2025, checked on 6/12/2025.

Fonseca, Tiago; Ferreira, Luis; Cabral, Bernardo; Severino, Ricardo; Nweye, Kingsley; Ghose, Dipanjan; Nagy, Zoltan (2024): EVLearn: Extending the CityLearn Framework with Electric Vehicle Simulation. Available online at http://arxiv.org/pdf/2404.06521.

Fröde, Peter; Noffsinger, Jesse; Sahdev, Shivika (2023): What promise does V2X hold for fleets? In *McKinsey & Company*, 8/29/2023. Available online at https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/what-promise-does-v2x-hold-for-fleets, checked on 2/27/2025.

Global Nissan Newsroom (2020): Nissan RE-LEAF: Power when it's needed, where it's needed. Available online at https://global.nissannews.com/en/releases/nissan-re-leaf-power-when-its-needed-where-its-needed, updated on 12/9/2022, checked on 7/25/2025.

Global Nissan Newsroom (2024): Nissan to launch affordable vehicle-to-grid technology in 2026. Available online at https://global.nissannews.com/en/releases/nissan-to-launch-affordable-vehicle-to-grid-technology-in-2026?origin=channel-fd86f26fe0b756c430ee7f6c0c012766, updated on 10/11/2024, checked on 5/28/2025.

Habib, Salman; Kamran, Muhammad; Rashid, Umar (2015): Impact analysis of vehicle-to-grid technology and charging strategies of electric vehicles on distribution networks – A review. In *Journal of Power Sources* 277, pp. 205–214. DOI: 10.1016/j.jpowsour.2014.12.020.

Hackmann, Markus von Guttenberg Lea, Herbold, Bendiks (2025): Bidirectional Charging – Worth the Hype? Exploring Use Cases from Vehicle-to-Home to Vehicle-to-Grid. Available online at https://www.p3-group.com/wp-content/uploads/2025/03/P3-Bidirectional-Charging%E2%80%93Worth-the-Hype.pdf, checked on 7/25/2025.

Halvorson, Bengt (2020): World's largest V2G site: A London double-decker electric bus garage. Available online at https://www.greencarreports.com/news/1129260_world-s-largest-v2g-site-a-london-double-decker-electric-bus-garage, updated on 6/12/2025, checked on 6/12/2025.

Hamburger Hochbahn AG (2023): New bus depots. Available online at https://www.hochbahn.de/en/projects/new-bus-depots#:~:text=Two%20years%20ago%2C%20we%20opened,a%C2%A0repairs%20garage%2C%C2%A0and%20an%20administration%20building, updated on 6/12/2023, checked on 6/12/2025.

Hecht, Christopher; Figgener, Jan; Sauer, Dirk Uwe (2023): Vehicle-to-Grid Market Readiness in Europe with a Special Focus on Germany. In *Vehicles* 5 (4), pp. 1452–1466. DOI: 10.3390/vehicles5040079.

IEA (2023): Electric Vehicle Charging and Grid Integration Tool – Data Tools - IEA. Available online at https://www.iea.org/data-and-statistics/data-tools/electric-vehicle-charging-and-grid-integration-tool, updated on 2/27/2025, checked on 2/27/2025.

iEVPower (2022): The Ultimate Guide to Bidirectional Charging for Electric Vehicles. In *iEVPower*, 7/11/2022. Available online at https://ievpower.com/guide-to-bidirectional-charging-for-electric-vehicles/, checked on 6/12/2025.

Iqbal, Sheeraz; Xin, Ai; Jan, Mishkat Ullah; ur Rehman, Haseeb; Masood, Arsalan; Abbas Rizvi, Syed Asad; Salman, Salman (2018 - 2018): Aggregated Electric Vehicle-to-Grid for Primary Frequency Control in a Microgrid- A Review. In : 2018 IEEE 2nd International Electrical and Energy Conference (CIEEC). 2018 IEEE 2nd International Electrical and Energy Conference (CIEEC). Beijing, China, 11/4/2018 - 11/6/2018: IEEE, pp. 563–568.

Kalia, Shweta (2021): Electric Vehicles and Smart Charging. Charging Forward. Features.

Kempton, Willett; Tomić, Jasna (2005): Vehicle-to-grid power fundamentals: Calculating capacity and net revenue. In *Journal of Power Sources* 144 (1), pp. 268–279. DOI: 10.1016/j.jpowsour.2004.12.025.

Klobasa, Marian; Kühnbach, Matthias; Singh, Mahendra; Antretter, Michelle; Knorr, Kaspar; Schütt, Jonathan et al. (2022): Entec Digitalisation of Energy Flexibility. EnTEC - Energy Transition Expertise Centre. Edited by European Commission. Fraunhofer-Institut für System- und Innovationsforschung ISI (Fraunhofer ISI); Fraunhofer-Institut für Energiewirtschaft und Energiesystemtechnik IEE (Fraunhofer IEE); McKinsey & Company Inc.

Latief, Yusuf (2025): China sets up 30 large-scale vehicle-to-grid pilot projects. In *Smart Energy Internationl*, 4/15/2025. Available online at https://www.smart-energy.com/industry-sectors/electric-vehicles/china-sets-up-30-large-scale-vehicle-to-grid-pilot-projects/#:~:text=China%20sets%20up%2030%20large,grid%20%28V2G%29%20interaction, checked on 6/12/2025.

Lepre, Nicole (2018): Deploying Charging Infrastructure for Electric Transit Buses. Best practices and lessons learned from deployments to date. Atlas Public Policy.

Mobility house (2024): Vehicle to Grid (V2L). Available online at https://www.mobilityhouse.com/int_en/vehicle-to-grid, updated on 8/15/2024, checked on 8/15/2024.

Mobilize Power: charge bidirectionnelle (2025). Available online at https://www.mobilize-v2g.fr/fr_fr, updated on 7/31/2025, checked on 7/31/2025.

MTA (2023): Jamaica Bus Depot Expansion. Available online at https://www.mta.info/project/jamaica-bus-depot-expansion, updated on 6/12/2025, checked on 6/12/2025.

Newsroom Renault Group (2025): Utrecht becomes Europe's first city with a vehicle-to-grid (V2G) car-sharing service - Newsroom Renault Group. Available online at https://media.renaultgroup.com/utrecht-becomes-europes-first-city-with-a-vehicletogrid-v2g-carsharing-service/, updated on 4/6/2025, checked on 7/31/2025.

NREL (2024): Leap Into New Capabilities: REopt Offers Enhanced Energy Solutions. Available online at https://www.nrel.gov/news/program/2024/reopt-web-tool-offers-enhanced-energy-solutions.html#:~:text=EV%20Smart%20Charging%2C%20V2B%20and,grid%20%28V2G%29%20modeling%20capabilities, updated on 2/27/2025, checked on 2/27/2025.

NREL (2025): EVI-DiST: Electric Vehicle Infrastructure – Distribution System Integration Tool. Available online at https://www.nrel.gov/transportation/electric-vehicle-infrastructure-distribution-system-integration-tool.html, updated on 2/27/2025, checked on 2/27/2025.

NUVVE Holding Corp (2020): V2G PROJECTS - NUVVE Holding Corp. Available online at https://nuvve.com/projects/, updated on 2/13/2020, checked on 9/12/2024.

Octopus Electric Vehicles (2024a): Powerloop | V2G | Octopus Electric Vehicles. Available online at https://octopusev.com/powerloop, updated on 8/15/2024, checked on 8/15/2024.

Octopus Electric Vehicles (2024b): Powerloop | V2G | Octopus Electric Vehicles. Available online at https://octopusev.com/powerloop, updated on 9/12/2024, checked on 9/12/2024.

Octopus Electric Vehicles (2025): Power Pack Bundle. Available online at https://octopusev.com/power-pack-bundle, updated on 7/31/2025, checked on 7/31/2025.

Park, Kijun; Jang, Dongsik; Kim, Sangok; Lim, Youseok; Lee, Jungho (2023): A Grid-Friendly Electric Vehicle Infrastructure: The Korean Approach. In *IEEE Power and Energy Mag.* 21 (6), pp. 28–37. DOI: 10.1109/MPE.2023.3308232.

Pradana, Adlan; Haque, Mejbaul; Nadarajah, Mithulanathan (2023): Control Strategies of Electric Vehicles Participating in Ancillary Services: A Comprehensive Review. In *Energies* 16 (4), p. 1782. DOI: 10.3390/en16041782.

Qian, Tao; Fang, Mingyu; Hu, Qinran; Shao, Chengcheng; Zheng, Junyi (2024): V2Sim: An Open-Source Microscopic V2G Simulation Platform in Urban Power and Transportation Network. Available online at http://arxiv.org/pdf/2412.09808v1.

Rana, Md Juel; Rahi, Kamrul Hasan; Ray, Tapabrata; Sarker, Ruhul (2021): An efficient optimization approach for flexibility provisioning in community microgrids with an incentive-based demand response scheme. In *Sustainable Cities and Society* 74, p. 103218. DOI: 10.1016/j.scs.2021.103218.

Ruppert, Manuel; Baumgartner, Nora; Märtz, Alexandra; Signer, Tim (2023): Impact of V2G Flexibility on Congestion Management in the German Transmission Grid. In *WEVJ* 14 (12), p. 328. DOI: 10.3390/wevj14120328.

SCALE (2023): Home - SCALE. Available online at https://scale-horizon.eu/, updated on 1/23/2023, checked on 9/12/2024.

Siemens AG (2020): Siemens technology becoming part of state-of-the-art bus depot in. Available online at https://press.siemens.com/global/en/pressrelease/siemens-technology-becoming-part-state-art-bus-depot-hamburg#:~:text=largest%20local%20transport%20provider%20in,for%20electric%20buses%20in%20Europe, updated on 6/12/2025, checked on 6/12/2025.

Siemens: Pantographs for e-Mobility (2025): Simply reliable: On-board pantographs for eBuses. Available online at https://www.siemens.com/global/en/products/energy/emobility/charging-pantograph.html, updated on 5/28/2025, checked on 5/28/2025.

Sophie Rabasch (2022): A successful V2G model in a Danish utility, Interreg VB North Sea Region Programme. Available online at https://northsearegion.eu/access/news/a-successful-v2g-model-in-a-danish-utility/, updated on 8/15/2024, checked on 8/15/2024.

Sovacool, Benjamin K.; Kester, Johannes; Noel, Lance; Zarazua de Rubens, Gerardo (2020): Actors, business models, and innovation activity systems for vehicle-to-grid (V2G) technology: A comprehensive review. In *Renewable and Sustainable Energy Reviews* 131, p. 109963. DOI: 10.1016/j.rser.2020.109963.

TenneT (2025): Neue Studie zeigt: Betreiber elektrischer Nutzfahrzeugflotten könnten Stromkosten deutlich senken und Stromnetz entlasten. Available online at https://www.tennet.eu/de/news/neue-studie-zeigt-betreiber-elektrischer-nutzfahrzeugflotten-koennten-stromkosten-deutlich, updated on 2/25/2025, checked on 2/25/2025.

The Mobility House (2025): Größter Multi-use-Speicher Deutschlands. Available online at https://www.mobilityhouse.com/de_de/unser-unternehmen/referenzen/artikel/euref-campus, updated on 2/25/2025, checked on 2/25/2025.

The Mobilityhouse (2024): Größter Multi-use-Speicher Deutschlands. Available online at https://www.mobilityhouse.com/de_de/unser-unternehmen/referenzen/artikel/euref-campus, updated on 9/12/2024, checked on 9/12/2024.

Thomas, Jack; Heer, Hans de; Rivas, Marisú Mangino (2023): V2X Enablers and Barriers. Assessment of the regulatory framework of bidirectional EV charging in Europe. smartEn.

Thomas Built Buses (2021): Saf-T-Liner C2 Jouley Electric Bus. Available online at https://www.google.com/search?client=firefox-b-e&channel=entpr&q=two+Jouley+buses+discharged+around+7+MWh+back+to+the+grid+during+32+summer+peak+events+in+2022%2C+using+ISO+15118-compliant+60+kW+DC+bidirectional+chargers#vhid=zephyr:0&vssid=atritem-https://thomasbuiltbuses.com/content/uploads/2021/09/brochure-c2_jouley-fall-2021.pdf, checked on 6/12/2025.

Thompson, Andrew W.; Perez, Yannick (2020): Vehicle-to-Everything (V2X) energy services, value streams, and regulatory policy implications. In *Energy Policy* 137, p. 111136. DOI: 10.1016/j.enpol.2019.111136.

Transport and environment report 2022. Available online at https://www.eea.europa.eu/publications/transport-and-environment-report-2022/transport-and-environment-report/view, checked on 8/12/2024.

U.S. Department of Energy (2024): EVGrid Assist: Enabling Vehicle Grid Integration (VGI). Available online at https://www.energy.gov/eere/evgrid-assist-enabling-vehicle-grid-integration-vgi, updated on 2/27/2025, checked on 2/27/2025.

US Department of Transportation (2023): Electric Bus Basics. Available online at https://www.transportation.gov/rural/electric-vehicles/ev-toolkit/electric-bus-basics, updated on 6/12/2025, checked on 6/13/2025.

V2G Hub (2024a). Available online at https://www.v2g-hub.com/insights, updated on 9/12/2024, checked on 9/12/2024.

V2G Hub (2024b): Home: V2G Hub. Available online at https://www.v2g-hub.com/services, updated on 8/15/2024, checked on 8/15/2024.

Wan, Muchun; Yu, Heyang; Huo, Yingning; Yu, Kan; Jiang, Quanyuan; Geng, Guangchao (2024): Feasibility and Challenges for Vehicle-to-Grid in Electricity Market: A Review. Multidisciplinary Digital Publishing Institute. Available online at https://www.mdpi.com/1996-1073/17/3/679, updated on 7/24/2025, checked on 7/24/2025.

Xiao, Guoxuan; Li, Canbing; Yu, Zhicheng; Cao, Yijia; Fang, Baling (2013): Review of the impact of electric vehicles participating in frequency regulation on power grid. In : 2013 Chinese Automation Congress (CAC 2013). Changsha, Hunan, China, 7-8 November 2013 ; [proceedings]. 2013 Chinese Automation Congress (CAC). Changsha, Hunan, China, 11/7/2013 - 11/8/2013. Chinese Automation Congress; CAC. Piscataway, NJ: IEEE, pp. 75–80.