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Introduction to V2G: A critical technology to enable the energy transition

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Introduction

The rapid growth of electric vehicles (EVs) and associated charging infrastructure will create fundamental challenges to energy systems without smart charging – unmanaged charging of large numbers of EVs from the grid would require major investments to expand capacity to avoid overloading the system. Conversely, if they can be widely deployed, EV battery smart charging technologies not only have the potential to solve grid capacity issues but also provide an opportunity to enhance grid flexibility, lower system costs and reduce emissions.

Charles River Associates (CRA) and Hubject Consulting (Hubject) have combined our teams of energy and eMobility experts to bring more clarity on the smart EV charging opportunity, more specifically Vehicle-to-Grid (V2G) – an idea often labelled as a 'golden solution' to enable power grids to cope with the incremental load from charging millions of EVs whilst also better integrating more intermittent renewables into the system.

In this article, we define the various types of smart charging, review the evolution of V2G, discuss current challenges and evaluate the potential of V2G. Moreover, we assess the rationale for using EVs to provide energy services, identify implications of not achieving V2G in the long term and discuss value pools and business model options for industry participants. In follow-up pieces we will highlight implications for participants and the need for higher levels of collaboration through implementation roadmaps and identification of barriers that must be overcome to unlock the true V2G potential for all participants – from consumers, to OEMs, to grid operators, to energy suppliers.

What is at stake

When assessing a future scenario where 80% of cars are electric in the EU, the European Environment Agency concluded that the share of electricity required for EVs could represent up to 25% of the total electricity consumption[1]. This will place significant stress on the system and, if ecosystem participants do not work together and fail to unlock the potential of V2G, energy grids could face significant challenges, including:

- additional generation capacity needed to avoid system failure and blackouts to meet new demand,
- higher peak electricity demand requiring grid upgrades and higher network capital costs,
- less efficient provision of balancing services, with increased renewable energy curtailment,
- lower power plant utilisation rates leading to higher operational costs,
- increased electricity rates for consumers and price spikes and
- higher grid carbon intensity and emissions – higher costs needed to meet CO_2 targets.

Defining EV smart charging

The European transport sector is undergoing fundamental change to meet ambitious environmental targets set across the continent and to support the exponentially increasing EV adoption expected through 2050. While this transition will lead to lower carbon emissions, a holistic understanding of its impacts is needed to avoid unexpected negative consequences. Specifically, there is a need to move to smart charging from unmanaged charging – where EV owners simply plug in their vehicles when charging is needed without consideration of external factors (e.g., system load, rates). Currently, in areas with differentiated electricity (or time-of-use) rates, consumers already have an incentive to manually manage charging to avoid higher rates – smart charging would do this automatically with potential to provide significant savings to customer electricity bills.

Unmanaged charging can significantly increase system peak loads creating challenges for managing energy grids at the local, national and international levels. Specifically, without significant investment, generation capacity will not be able to meet the higher demand with voltage and thermal overloading of the distribution network leading to mass blackouts resulting in significantly higher energy prices. However, smart charging can help mitigate these issues by shifting demand patterns and providing flexibility services to individual buildings (e.g., providing local back-up power) and the grid (e.g., limiting use of grid electricity at times of high demand or injecting power into the system when needed). It encompasses several other terms and can work with both uni-directional (energy flowing from the grid to an EV) and bi-directional (energy flowing both ways) chargers.

Depending on the direction of energy flow and where the value is concentrated (home, building or grid), charging can typically be classified into the following types (with each type having additional benefits compared to the previous type of charging):

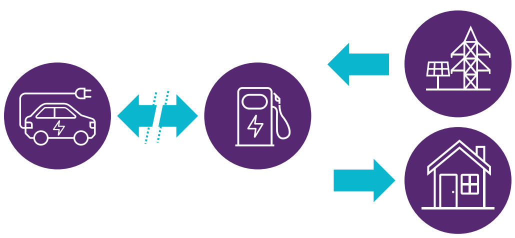
Unmanaged

Uni-directional charging that only considers recharging the vehicle. Charging starts when EV is plugged in to charger and stops when fully charged – no link for wider system demands.

Smart - V1G

Uni-directional smart charging controlled locally by a home energy management system or EV charging system to accommodate grid constraints and to limit peak-price spikes for the system (e.g., charge during periods of low grid demand or renewables over-supply or stop charging when the grid is at its limits) – requires input from the energy system operator.

Smart - V2H or V2B



Bi-directional smart charging and discharging for homes (single residential customer) or buildings (multiple residential or commercial customers) orchestrated by an energy management system (e.g., EV charging or third-party app) to utilise EVs as a source of back-up power locally.

Smart - V2G

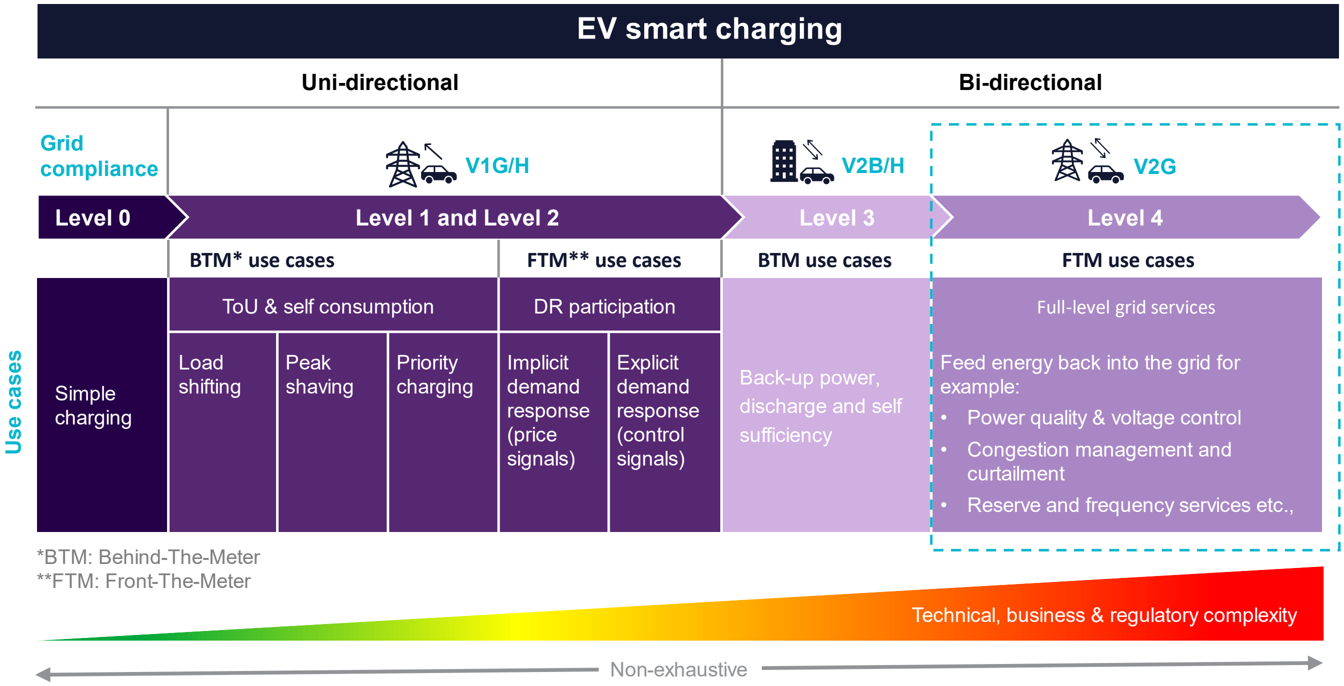
Bi-directional smart charging with energy flow that can supply power directly into the grid as needed. Managed by a more sophisticated energy management system (e.g., third-party service provider), it provides energy supply and ancillary services (e.g., frequency response) to the grid and enables consumers to earn a source of income.

NB: The broken arrows highlight the capability of the system to control (start/stop) when charging occurs

Although smart charging technically works at the individual vehicle level, the real value for the energy system will be found at the aggregated level where hundreds, thousands or even millions of EVs can be coordinated to participate in grid operations and power markets. An energy aggregator can combine EV batteries and other distributed energy assets, such as solar and home batteries, into virtual power plants (VPPs) that can supply and trade energy on electricity markets. This service would require VPP operators to compensate EV owners for energy and use of batteries.

These systems can be scaled into hundreds of megawatts (MWs) similar to traditional power plants and consequently play a key role in providing meaningful responses at a system level. This aggregation service could be provided by a number of players including distribution system operators (DSOs), EV charging companies, original equipment manufacturers (OEMs) or other third-party software firms to enable a wide range of use case and benefits to grids (front of the electricity meter) and consumers (behind the electricity meter) – see Figure 1 below.

Figure 1: Charging methods, smart charging levels[2] and use cases



Evolution of smart charging

Today, the technical feasibility of V2G has been largely proven by numerous pilot projects over the last decade conducted by OEMs, utilities, cities and academic institutions. The focus has now shifted to understanding the commercial and consumer challenges that need to be overcome in the near term. To accelerate development of the industry, future smart charging projects will need to scale beyond a few EVs, include more complex commercial and consumer benefit cases, use the latest V2G compatible hardware, include collaboration across multiple participants (e.g., DSOs, OEMs, energy suppliers and cities) in commercial trials and increase cooperation across various geographies to enable wider adoption. All in all, three key questions remain unanswered:

- Impact on EV batteries – Even though early conclusions show that V2G has no significant impact to the battery state (e.g., degradation) and additional studies will further test new use cases and over a longer time span. Also, energy losses during charging and discharging, and the rising questions around the sustainability and reliability of the supply chain are currently under further investigation.
- Commercial viability – Now that V2G has been proven to be technically feasible, the commercial viability is being further assessed (specifically questions around consumer participation and plug-in availability). For a successful deployment of V2G, effective incentivisation for end-users and increased understanding of consumer behaviours will be necessary, especially when considering private or fleet owners.
- Value chain definition and role allocation – Past pilot projects have not defined the role of the V2G aggregator. Given they will play a crucial role, ensuring interoperability and consolidation of data among the V2G ecosystem, it must be clarified whether a new player or an existing actor from the charging, transport or energy sectors will fill this gap.

These key questions should be front of mind for future projects and trials, which will improve the near-term opportunity and scalability of V2G. One key uncertainty is how regulators will enact policies across the various jurisdictions on key issues such as electricity pricing signals, charger infrastructure access and overall openness of the system. Additionally, alternative grid storage solutions are also being deployed (e.g., stationary Li-Ion battery storage, pumped hydro etc.) and investors will have competing choices for capital deployment – the sooner V2G participants can demonstrate the commercial viability of V2G, the better to address investor concerns.

Emerging trends in smart charging – participants, investments and economic pressures

Globally, looking at the automotive OEMs, there is a noticeable shift from CHAdeMO[1] charging architecture to the Combined Charging Standard (CCS[2]) as the unified standard for charging that can enable V2G. This is a noticeable trend, and OEMs continue to announce further investments in V2G based on CCS. OEMs have also been investing in smart charging technologies, for example, the recently released Ford F-150 Lightning was developed with V2H/V2B capabilities, enabling it to provide home back-up power for up to three days, using a CCS bi-directional charger. This additional feature resulted in a massive uptake in demand, with orders having to be turned down and leading to Ford doubling production capacity over the next two years[3].

Earlier this year, Porsche also demonstrated the potential of V2G through connecting five of their Taycan vehicles to the grid in a pilot with grid operator TransnetBW[4]. The pilot utilised Porsche's prototype Home Energy Manager system and focused on establishing the vehicle and grid communication requirements of enabling V2G, whilst ensuring that there were no breaches to strict conditions for storing and supplying balancing power. Tesla is also starting to run V2G pilots, launching the first VPP last month in California and participating in its first emergency response a few days later (including EVs and home storage batteries). During this event, the VPP provided close to 20MW of power to the grid, proving that such a system can work smoothly on a significant scale[5]. Beyond Ford, Porsche and Tesla, most OEMs, if not all are active in the smart charging market with sizable pilots and trials underway to further develop the technology.

Similarly, Charge Point Manufacturers and Energy System Operators (e.g., DSOs, Transmission System Operators or TSOs, energy suppliers etc.) will play a major role in the development of smart charging and have also been investing significantly to deliver V2G-enabled charging stations. These investments are also supported by energy providers given that V2G can provide key benefits to their grid operations – including leveraging customer EVs to provide grid flexibility services at minimal additional costs; mitigation of renewables intermittency challenges, avoidance of additional power generation and distribution investments; reduction of peak power prices and lowering requirements for dispatchable fossil fuel generation (e.g., coal, natural gas). Many companies have made good progress in identifying the challenges and opportunities in this space, including the pilots undertaken by Mobility House under the CharIN umbrella, which used second life Nissan batteries to participate in grid services and highlighted revenue opportunities of between €500 and €1,000 per year for the battery owner[6].

The European Network of Transmission System Operators for Electricity, comprised of 42 TSOs in 35 countries, has recently stressed that all members must promote V2G and should begin testing this technology[7]. Similarly, distribution network operators have initiated pilots around the world. For example, in 2020, E. ON UK partnered with Nissan to deploy V2G chargers to demonstrate how they can play a role in supporting the UK grid[8]. Likewise, in the US, Avangrid has been working with Bidgely to utilise EVs as a grid resource to avoid driving higher peak demand when they are charging[9].

Incentivisation and government support are also key in the move towards net zero. Successful policies have previously encouraged renewables development and provided disincentives for fossil fuels, namely with the cost of carbon rising linked to the expansion of carbon trading systems such as EU ETS, UK ETS and California cap and trade. More recently seen in the US, the Inflation Reduction Act (IRA) is likely to have a major global impact with unprecedented levels of support for EVs – such as credits for EV purchases up to $7,500, $40B in tax credits for clean technology manufacturing (including batteries and metals value chains), $2B to retool existing auto plants for EVs and $20B for new EV manufacturing plants. These support mechanisms and investments should further accelerate the adoption of EVs and deployment of charging infrastructure.

Additionally, we observe macroeconomic and geopolitical trends that are also impacting investment flows in this sector. Notably, the recent geopolitical issues surrounding the war in Ukraine have led to many countries looking

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[1] CHAdeMO is the name of the popular Japanese fast-charging standard that governs charging plug connection.

[2] CCS is the name of the fast-charging standard widely accepted throughout Europe that governs plug connection.

to become more energy independent, especially when considering how rising energy prices have significantly impacted consumer bills. In turn, this direct effect on the consumer will increase appetite for increasing renewables, create a supportive environment for further EV adoption growth and increase the demand to utilise the vehicles storage potential via V2G.

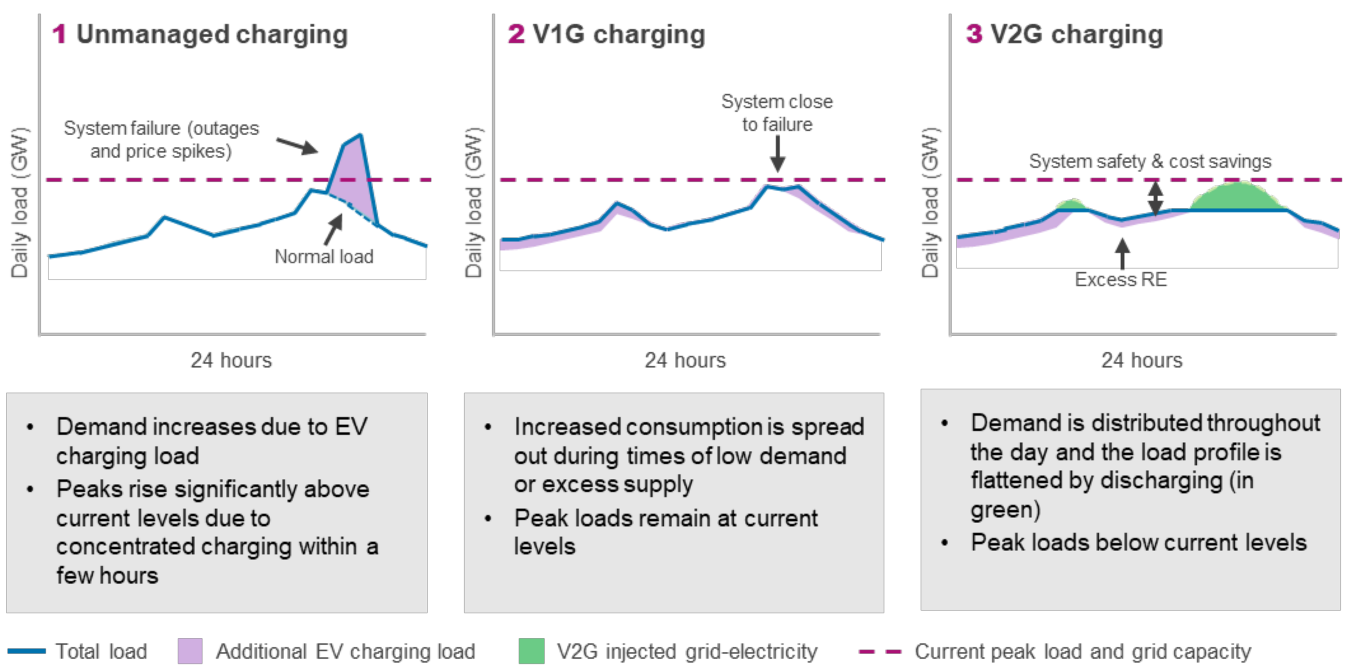
Rationale for smart charging

As briefly mentioned above, V2G has the potential to generate major benefits for power grids, and in turn protect consumers from outages and price spikes. However, it is worth discussing the key implications in more depth. Firstly, EVs represent the convergence of two previously distinct energy systems – in the near future, the power grid will also have to supply the large new energy needs of the transportation sector in addition to demand from residential, commercial and industrial electricity sectors.

Additionally, driven by climate change concerns and changing economics, the penetration of variable renewables and electrification of heating is expected to increase rapidly across most markets. Thus, the electrification of transport is, in effect, compounding the problem – meaning the grid must support far more than it used to, heightening the importance of managing EV loads via smart charging. Power grids, as they are set up today, would not be able to cope with the introduction of millions of EVs into the system.

A large number of EVs charging from the grid would result in a significant increase in overall energy demand and a much higher evening peak load – if commuters simultaneously plug in their vehicles after work which cause the energy system to fail resulting in outages and price spikes. This can be seen below in Figure 2 (unmanaged load).

Figure 2: 1 Unmanaged vs. 2 V1G vs. 3 V2G charging



The additional overall demand and peak load from the **unmanaged charging** scenario (shaded portion in graph 1) would exceed grid capacity – greatly increasing cost and causing system overload and blackouts.

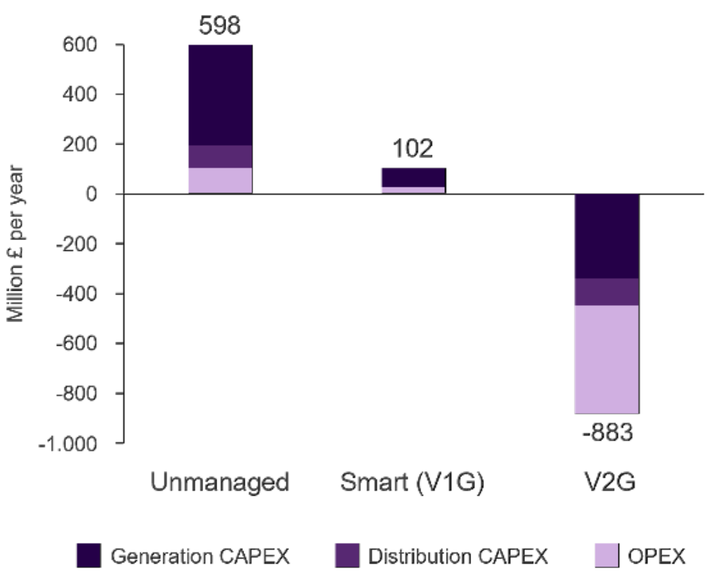
This can be mitigated with **V1G** (graph 2) by spreading out the charging profile to hours outside peak times flattening the load in a way to enable grids to cope with additional EV demand. This would be achieved through price signals from the grid to delay charging. Without smart charging, the system operator would need to build new generation capacity that can be dispatched in the evening (likely natural gas) and additional grid distribution capacity (e.g., substations, street transformers etc.).

Taking this further, by developing **V2G** (graph 3) capabilities, the grid operator can also call on EV batteries to supply energy into the grid to meet demand, similar to a dispatchable power plant – thus the EV fleet could take advantage of excess renewables (e.g., solar) during the middle of the day and offset evening grid demand. This scenario would significantly reduce overall grid costs through energy arbitrage (between low midday prices in day and high evening prices), more efficient operation of generation assets and lower need for additional grid CAPEX.

A recent study conducted by Euroelectric found that by 2035, when we have over 130 million EVs on our roads across Europe (~50% penetration), if drivers were to charge simultaneously, peak loads could increase by 86%[10]. However, this can be seen as an opportunity to reduce whole system costs and emissions of the value chain.

To put this into perspective, Figure 3 below highlights the impacts of three different charging scenarios in the UK as developed by Imperial College in 2020: unmanaged, smart (V1G) and V2G. Specifically, the incremental costs stemming from introducing one million EVs are quantified by comparing the three scenarios with a counterfactual system where there are no EVs. The V2G scenario proved to not only generate significant economic benefits but it also reduced CO_2 emissions, lowering the UK power system's carbon footprint by 12% compared to the counterfactual scenario.

Figure 3: UK power system incremental costs for three different EV charging scenarios[11]



Unmanaged charging

- Increased CAPEX for generation capacity
- Increased CAPEX for distribution reinforcement
- Increased OPEX due to less efficient generation

Smart (V1G) charging

- Small increased CAPEX for generation capacity
- No additional CAPEX for distribution reinforcement
- Increased OPEX to satisfy energy requirement

V2G charging

- Reduced generation and distribution CAPEX
- Reduced OPEX as V2G replaces frequency response

Roles of energy suppliers, system operators, OEMs and consumers

To enable the development of V2G, energy system operators will also need to invest in additional capabilities to support the two-way flow of energy and heightened level of control for an increasingly distributed system. Grids will need to continue to evolve into 'smart grids' that have the needed visibility at the edge[3] to allow V2G to function (e.g., full smart meter penetration, edge computing etc.).

Moreover, energy suppliers and DSOs will need to considerably step up their efforts to capture the potential growth associated with V2G and not lose share to new market entrants that will be targeting energy customers with value propositions that may complement or replace the existing energy supplier-to-consumer relationship.

3 The interface between the customer and the electricity supply as part of the low-voltage network.

Today, this is characterised by the "ecosystem" of meters (increasingly smart meters), energy tariffs and facilitation of billing and payment for energy consumed. Additionally, energy suppliers are regulated and have a stake in market design that would enable V2G from a regulatory perspective. Based on this context, the energy supply ecosystem can serve as a foundation for facilitating V2G with energy consumers and structure commercial offers through existing bills and tariffs and through existing collaboration with OEMs and charging infrastructure operators. Additionally, based on their knowledge of their customers' energy consumption patterns, energy suppliers could articulate specific financial benefits for their customers for typical V2G use cases. As energy suppliers develop products and solutions beyond commodity supply, V2G has potential to complement offerings around e.g., energy system participation, emission reduction or monetisation.

DSOs and TSOs are also best placed to understand the potential benefits for the grid and prioritise the infrastructure investments required to accelerate the deployment of V2G. They must play a key role in working with and educating all system participants to foster the design of a smart charging system that considers supply constraints to ensure energy security, affordability and sustainability are preserved.

EV charging operators will need to ensure that bi-directional chargers become mainstream as the infrastructure currently being rolled out tends to not be V2G compatible. In other words, most chargers currently installed will need to be replaced and strong regulatory support will be needed. For instance, in the UK, a law was recently brought into effect (June 2022) to include smart functionality in all EV chargers, thus enabling them to provide flexibility services when needed[12]. The migration to CCS chargers will also need to continue to lay a foundation for enabling wide range of V2G. Additionally, while the price of low capacity V2G chargers has fallen significantly, the high commissioning and installation costs associated with it must be addressed (depending on the power level, V2G hardware costs are around £3,700 higher than that of a V1G smart charger)[13].

A future where mass adoption of V2G is a reality will also require strong buy-in and behavioural changes from consumers, the continued advancement and digitalisation of power grids and increased collaboration between ecosystem participants. For example, for V2G to work, the right types of financial incentives from energy aggregators or grid operators (such as price signals to plug in) will need to be put in place to support consumers and give them the required comfort for allowing their batteries to be accessed when needed and to ensure EVs are plugged in whenever not in use (a pre-requisite for V2G to work). Additionally, OEMs will also need to provide sufficient warranties for batteries that give the needed assurances for consumers to participate (a mass study in the Netherlands concluded that battery implications were the second most important factor influencing consumer acceptance of V2G after compensation[14]). In parallel, effective communication of the impacts of V2G on battery degradation will be crucial, especially as current research has not shown batteries are negatively impacted by low levels of charging and discharging[15].

Furthermore, charging providers will need to design systems and offerings that provide a user-friendly customer journey to support V2G adoption from consumers (e.g., payments, roaming, accessibility etc.).

Potential V2G value pools and opportunities for key market participants

As outlined throughout this paper, V2G has the potential to provide a seismic shift to the energy system. With it comes distinct economic, environmental, consumer and social benefits to the entire energy system. The economic benefits are likely to be the catalyst for development and investment in the short term, while at a high level there is the CAPEX avoidance of not developing further generation and energy storage assets; and the lower OPEX costs given the storage is behind the meter, integrated within the consumers vehicle. However, when considering the ecosystem participants, various value pools will emerge, and it is therefore crucial to understand the key participation benefits and incentives for the various ecosystem participants.

Figure 4: V2G ecosystem and participant dynamics

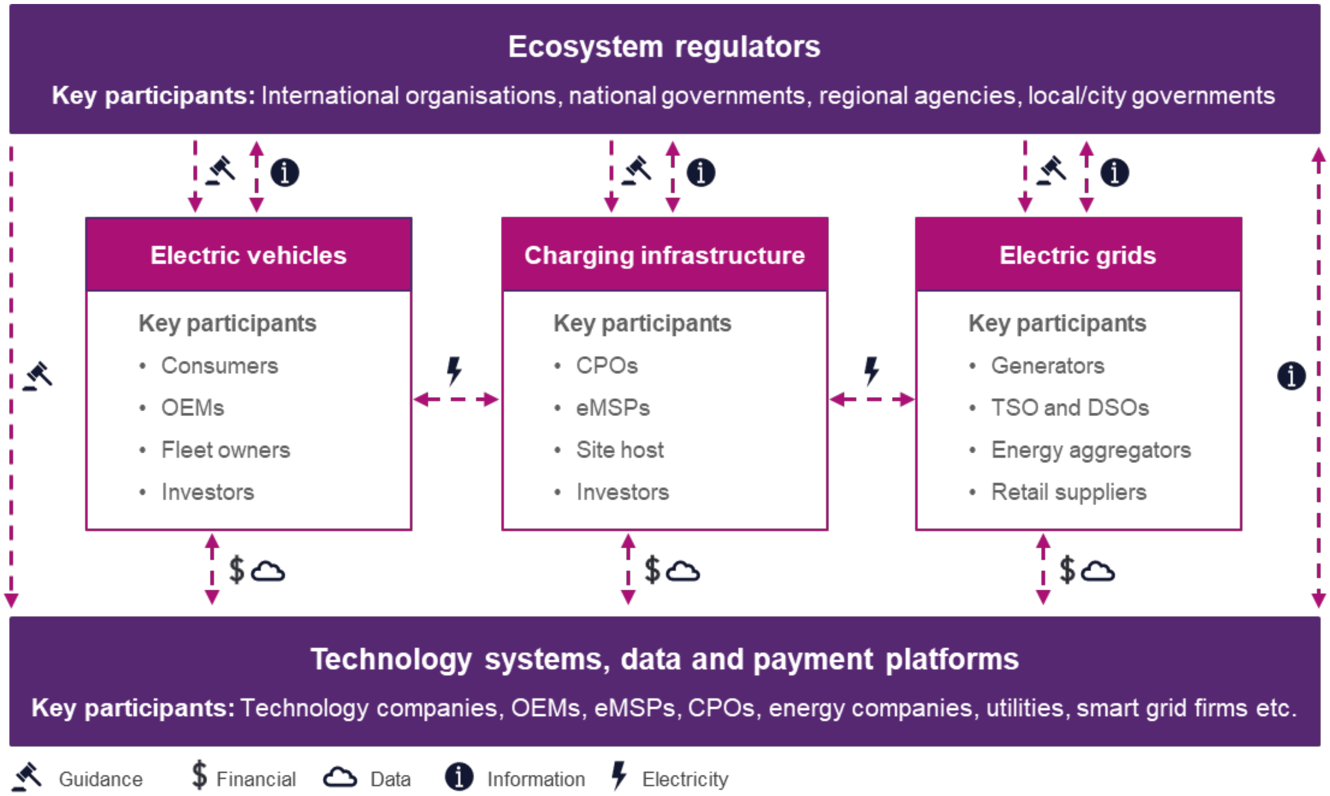


Figure 4 above gives an overview of the participants and their interactions within this ecosystem, each having varied value pools created through the provision of V2G services. As a general point, with the market still nascent in its maturity, there is ample opportunity for established participants to extend their reach through a business model extension. Some of the key value pools created for ecosystem participants include:

Consumers and prosumers, or EV owners, will be able to achieve savings on their energy bills. Firstly, by allowing their vehicle to respond to demand reduction signals (V1G) or at times go 'off-grid' (V2H/B), they will benefit from dynamic pricing tariffs meaning the energy they consume will be at non-peak times at a reduced rate. The V2H/B concept also becomes more lucrative for the EV owner if they were to pair it with a self-generation asset such as rooftop solar PV. Beyond the savings achieved, they could also benefit from additional revenue by providing supply-side services back to the grid in times of supply shortages i.e., being paid for discharging their EV back into the grid (V2G). Energy suppliers can play a key role in articulating these benefits to their customers.

Fleet owners with last-mile vans, long-haul trucks or intercity busses have similar financial opportunities to those of a consumer with optimised smart control of their EVs' charge and discharge, however their opportunity is greater given the larger aggregated capacity as a micro-grid. They have the possibility to self-generate (for example through solar PV) in parallel and could, in turn, participate in energy arbitrage markets through trading their stored energy or participating in balancing markets by means of a virtual power plant. Like other participants, these opportunities are somewhat dependant on software, hardware and regulation developments, and fleet owners would need to obtain access to energy markets.

Investors are well placed to benefit from potential returns through investment in software and hardware to accelerate technologies to unlock the next stages of smart charging. Backing a winning technology in the EV charging infrastructure industry is undoubtedly challenging, a topic CRA and Hubject assessed in a previous whitepaper[16]. However, with the V2G market having a projected value of almost $18B by 2027 with a CAGR of almost 50%[17], the potential return for investors should not be ignored.

Automotive OEMs can tap into new revenue pools through business model innovation and extensions. Firstly, they can size batteries based on consumer demands, for example a customer wanting their EV to be V2G and V2H ready, would require a large bi-directional battery, which could be priced at a premium. As opposed to a consumer who only plans to use their EV for transportation. Other opportunities such as Battery as a Service (BaaS) or battery swapping business models could emerge, in essence charging a premium to remove battery responsibility from the consumer. OEMs will also have access to more data (e.g., GPS, telematics, Battery KPIs) that could be sold to other ecosystem participants. They will also have a higher willingness to pay for batteries driven by the incremental efficiency value of using the battery for transportation and grid services. This could help OEMs improve the resiliency of their battery supply chain compared to generators with lower willingness to pay for batteries for storage only. However, securing the batteries is just the first step, OEMs will need to continue to test and improve battery efficiency to ensure that that they can deal with the additional load drawdowns from participating in V2G, for this function must be handled in an efficient way without significant operational energy losses or negative impacts to battery life.

Generators and network operators (TSOs and DSOs) can benefit from long-term CAPEX avoidance savings linked to building out their generation capacity that would be needed to fulfil EV charging demand if V2G is not achieved. In addition to the large CAPEX requirements to add capacity, it would also cause regular moments of oversupply, creating a challenge in pricing electricity. These oversupply scenarios could be managed with conventional industrial-sized battery storage, but this too would require upfront investment. V2G avoids this through utilising the EV batteries already in situ. Compared to DSO landscape, which is fragmented in EU countries such as Germany, TSOs are very well-positioned in the value chain and, thus, are of capable of kick-starting V2G developments.

Energy suppliers (also called retail utilities) will be the primary touch point for customers as they provide energy for charging and remunerate the customer for any energy discharged back to the system through V2G services. Energy suppliers need to incentivise the customer to participate and make it easy and transparent as to what exchanges are taking place. This incentivisation goes beyond the tariff – it needs to consider behaviours and motivate and nudge consumers to participate meaningfully through responding to charging signals to plug in. Done correctly, retailers will attract more EV owners that are enticed by cost savings, revenue possibility and an enhanced customer experience, in turn growing their customer base and lowering their overarching cost to serve. Done incorrectly, they could face intense competition from other market players and lose market share.

eMSPs (eMobility Service Providers) create value by providing access to multiple charging points to consumers and operating the IT platforms that include payment services. These firms are key in orchestrating charging through public charger networks and enabling availability, transparency and interoperability across different charge point operator (CPO) networks. Additionally, eMSPs can participate in V2G activities (from both the vehicle user and grid side) enabling energy requests that can be monetised. There is a large opportunity for them to partner with other ecosystem participants to help orchestrate the system and incentivise participation and use of certain CPO charging networks.

CPOs responsible for managing and operating the public charging infrastructure that innovate now and establish themselves as a market leader will likely benefit from higher footfall at their stations in years to come. They also have an opportunity to partner with eMSPs – either by vertical integration or via eMobility roaming platforms, such as Hubject – to further enhance footfall. We also anticipate CPOs to partner up with VPP operators to support the grid operator with balancing activities with associated revenues for the CPO.

Energy aggregators, or VPP operators, will be a new market participant and will benefit financially by allowing EV owners to respond to signals from the grid. They will pay the EV owners individually for their capacity availability and be paid by the grid operators for providing an aggregated capacity to the grid (V2G) or enact demand response when required (V1G). We anticipate some competition in this space from existing industry actors such as OEMs or energy companies that look to extend their business model, utilising the knowledge and data they currently own.

Regulators will benefit from having an additional tool in their armory to shape the wider ecosystems of both the transportation and energy sectors. They can leverage the potential of V2G technologies to unlock and stimulate economic growth in both sectors.

Broader society will benefit from avoided emissions due to avoidance of having to build new fossil power generation capacity to meet the additional EV charging load. Additionally, scaling V2G will be able to support further penetration of renewables – thus, accelerating fossil power plant retirements and lowering carbon emissions. Lastly, V2G technology has the potential to provide additional indirect benefits such as the creation of new businesses and jobs.

Business model options for V2G participants for different charging types

Another key consideration for each V2G system participant is the business model requirements considering different charging types: private, fleet or public. Each charging type is used by a different EV user population, each with varying goals and motivations for charging, affecting the associated V2G potential. The highest short-term potential currently sits within the private and fleet charging business models given that vehicles will be connected for a long duration, allowing the energy aggregator the largest possible window to throttle the charging and discharging accordingly.

Each charging type has specific structural challenges to be considered, for instance private charge points support single EVs which are distributed widely requiring high levels of orchestration across many EVs and locations.

Fleet charging is an important area given multiple vehicles with large batteries are connected at each depot, allowing them to create concentrated pockets of V2G power capacity, but these vehicles are business critical and typically require a high level of battery charge and may be needed at various times of the day. Lastly the public charging business model is geared towards short charging times with fast or ultrafast chargers to reduce the EV owners stop time, and if V2G were to be used, it would further prolong their stop.

These models have been summarised at a high level in Table 1 below.

Table 1: Charging types and their V2G potential

Charging type	Private charging	Public charging	Fleet charging
Types of EVs & locations	• Single passenger EV • Home or street	• Multiple EVs (passenger/vans) • Highway, destination, work	• Multiple EVs (cars, vans, trucks, busses) • Fleet depots
Charging characteristics	• Low-capacity chargers (level 1-2) • Charging for a long duration (overnight)	• High-capacity chargers (level 2+) • Charging for a short duration	• High-capacity chargers (level 2+) • Charging for a long duration that aligns to business needs
V2G considerations	• Charging time ideal for V2G • Large number of EVs ant grid edge (IT platforms) • Retail channels (B2C)	• Short charge times (<30 mins) • Aggregate EVs across DSOs and short charge times (V1G)	• Charge time acceptance for V2G • Concentrated pockets of energy capacity (fleet depots) • Higher contracting costs (B2B)

Whilst V2G has potential across all charging types, the characteristics of business model options differ significantly, and the market participants best suited to access these opportunities will likely vary. Starting with private charging, the operator will need to reach large numbers of EV users (i.e., the general public) and will need to incentivise consumers to keep their EVs plugged in at all times to access opportunities and enable V2G. Firms with strong IT platforms, data aggregation and customer reach capabilities will be best positioned in this sector – which could include large tech (e.g., Google, Amazon, Apple) or focused V2G technology players.

Regarding public charging, the V2G opportunity may be lower, however there are opportunities to enable V1G within this model. For instance, the tariffs and pricing for public charging could be varied based on a customer's willingness to participate in demand-response signals, or charge for a longer duration to lessen the demand side impacts. This business model may be suited to the CPO and eMSP that own the interaction with the customer.

Lastly in the fleet charging segment, the opportunity can allow sizeable levels of demand to be shifted (V1G) or to provide capacity directly to the grid when needed (V2G). However, this will require a more B2B-tailored solution for fleet owners/operators based on their characteristics (i.e., aggregated battery capacity, vehicle usage periods etc.). Energy aggregators or VPP operators could be well positioned through enablement of specific offers with fleet operators that can range from wholesale power trading, technology platforms, charging infrastructure installation and services, to full outsourcing solutions (including vehicles, charging and energy services).

While some aspects are taking shape, V2G still has some way to go

Overall V2G remains highly promising as a technology to help combat the challenges of the energy transition, enabling power systems to cope with the additional load from charging EVs whilst also facilitating the integration of intermittent renewables into the system. However, unlocking it will require system-wide developments and changes to technology, regulation, financing and business model innovation. A few key considerations and questions need to be front of mind as we progress forward in this sector:

- V2G represents a convergence between the Mobility and Energy sectors that will take time to fully bring together – to unlock the major benefits of the energy transition, this convergence will likely need to accelerate.
- V2G projects so far have been small with a technical focus – the various participants will need to collaborate further and expand projects to commercial scale to provide broader system, consumer and social benefits.
- The transformation of current charging sector actors (CPOs, eMSPs) and the entrance of new actors (VPPs) in the Mobility space is expected to enable users to have easier access to the energy market.
- In the past, many key players have not paid enough attention to V2G. OEMs, CPOs and Grid Operators have only recently started paving the way for more comprehensive projects.
- Consumer concerns about V2G impact on battery life, OEM warranties and convenience (EV charge levels when needed) and the implementation of adequate incentives should be addressed to ensure consumers plug in EVs.
- Similar to the transition from traditional combustion vehicles to electrical vehicles, the transition to V2G will only be reached in its full potential if all actors work together in a cooperative and aligned way.

The development of the V2G system, although in early stages, is underway. From a charging technology perspective, the shift towards CCS-based smart charging development activities in the markets can only confirm this. CCS with ISO 15118 - 20 as a guideline lays foundation for enabling wide range of V2G use cases. Targeted collaborative decision-making from all industry participants will help retain pace and progress trials further.

This being said, the charging infrastructure rollout has not been able to keep up with the rapid growth of EVs – this is especially true of smart charging. The longer it takes to achieve commercialisation of V2G technology at scale the higher the overall cost for the rollout – which will increase drastically due to the need to upgrade and replace already installed 'non-V2G-ready' infrastructure.

Moreover, if wide deployment of V2G chargers is not achieved, energy system and consumer costs will increase significantly to adapt to the rapid growth in EV adoption – major additional investments will be needed to meet climate change and energy transition targets.

To support this important endeavour, CRA and Hubject in partnership will continue to examine V2G challenges in a series of whitepapers to identify options, bring together different opinions and offer clarity to the potential value of V2G. In subsequent papers we will examine potential business models, value pools, and adoption roadmap challenges in more detail to help the industry prioritise investments in this promising sector.

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