POWER CIRCLE
Electricity for sustainable energy

What is V2G - Vehicle to Grid?

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JANUARY 2024

V2G: How electric vehicles can contribute to the grid

Updated fact sheet
This fact sheet is an update of the previous fact sheet *What is Vehicle to Grid?* from 2020. The updates are partly based on the synthesis report that Power Circle conducted in 2023 on behalf of the Swedish Energy Agency, Research and development of V2X in Sweden. The report can be read here

Fact box: Common terms
V1G: Smart charging in one direction.
Bidirectional charging: Refers to the technology that can send electricity both to and from the car.
V2H/B: Vehicle to home/building, means that the car can supply electricity back to the house/ building as needed.
V2G: Vehicle to Grid, means that the car can deliver electricity back to the grid based on the needs in the electricity system.
V2V: Vehicle to Vehicle. Means that electric cars can assist with charging another electric car.
V2L: Vehicle to Load, refers to using the car's energy to power tools, as backup power, or as a power source off-grid.
V2X: Collective name for the above concepts.

With a growing share of electric vehicles in the electricity system, there's a risk of high demand on the grid if many choose to charge at the same time. With smart charging and V2G, electric vehicles can instead provide solutions. Therefore, it's important to integrate the transport sector well with the electricity system.

In the future electricity system, the need for storage and flexibility will increase significantly, and in this scenario, the batteries and power electronics of electric vehicles can become important resources. An EV can act as a resource for energy storage or the transfer of energy. It can also serve as backup power for buildings, for charging other cars in emergencies, or as a power resource to provide support services to the power grid - given that the car is equipped for this.

The development of the technologies that allow the car's battery to be used as a power source is constantly advancing. These technologies are often named after their area of use, such as Vehicle to Grid (V2G) and Vehicle to Home (V2H). A term that is sometimes used for these solutions is Vehicle to Everything (V2X) or bidirectional charging. The difference between V2G and smart charging is that V2G enables cars to deliver electricity back to the grid. The term V2X can also refer to the exchange of information between the vehicles and the surrounding systems in other contexts.

The integration of EVs into the grid is challenging and requires innovation on many levels. The development of customer-tailored offers, new business models, and

digitalization processes are some areas that are central to enabling seamless integration. This may, in turn, require new hardware in both cars and charging stations, as well as in the grid where meters and control equipment are needed. Several market actors may take on new roles as service providers.

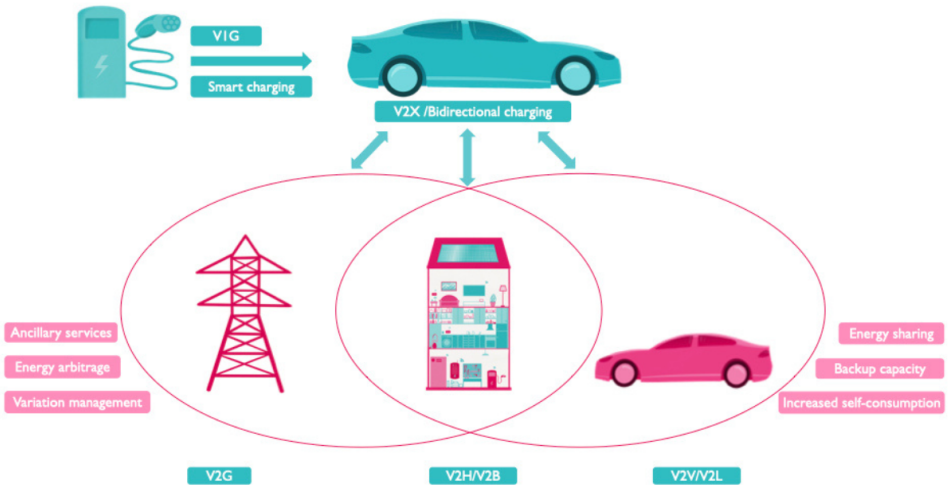


Image 1: Different types of smart charging and V2X can deliver various services and benefits, depending on whether the application is connected to the grid or not. A building can theoretically be connected to the grid or off-grid, which means that V2H/V2B sometimes can contribute to the grid and be counted as V2G.

With V2G, the EV's battery can be used as energy storage and provide energy and power back to the grid

V2G has great potential to provide broad benefits to the electricity system. The technology can improve the situation for car owners by offering increased control and efficiency in the charging process and enable economic benefits through the sale of electricity back to the grid. V2G can also handle bottlenecks for local network owners, add flexibility for those responsible for grid balance, and offer frequency regulation and other support services to the electricity system.

In this fact sheet, Power Circle highlights the potential of bidirectional charging, with a special focus on V2G. We also clarify the technical, legal, and market situation for the technology.

Theoretical and practical potential for V2G

Theoretically, bidirectional charging offers vast flexibility potential for the electricity system. According to Svenska kraftnät, around 90 percent of the installed battery volume could be located in different types of vehicles in the future[1]. Additionally, the average car is parked 96 percent of the time[2]. A NEPP2 report[3] estimated that 3.8 million chargeable cars would have a combined battery capacity of 114 GWh[4], which theoretically could supply all of Sweden with electricity for several hours. The Swedish Energy Agency estimates that 2 percent of Sweden's vehicle fleet will have V2G technology by 2025, 10 percent by 2030, and 100 percent by 2050[5].

In theory, the fleet of electric cars could power all of Sweden for several hours in the future!

In practice, the flexibility potential is limited factors like the proportion of vehicles parked at a charger, the power of the chargers, vehicles' state of charge (SOC)[6], battery temperature, manufacturers' limitations, expected stationary time, and energy needs when they are used next. Thus, the full battery capacity will rarely be available, but if a million vehicles each offer 10 kWh (about 10-20% of the battery), this can provide about 10 GW for an hour to the grid, which is more than a third of the maximum power demand we normally have, even on Sweden's coldest winter days.

[1] Svenska kraftnät, "Lagring av el – omvärldsanalys", 2022

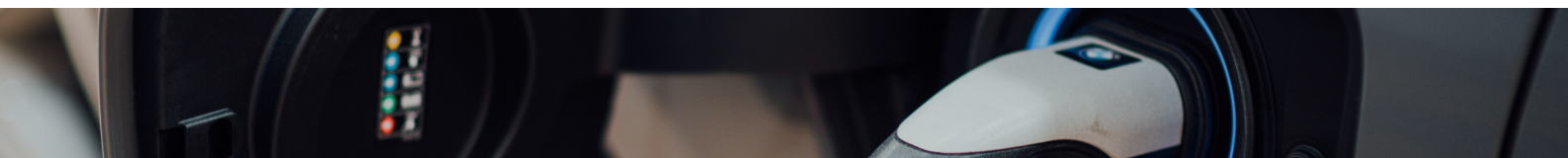
[2] KTH, "Här finns den lediga kapaciteten i storstadstrafiken", 2015

[3] NEPP, "Energisystemet i en ny tid", 2019

[4] Estimated based on an average battery capacity of 30 kWh per car. Sweden's most common EVs today have a battery capacity of approximately 60-80 kWh

[5] Energimarknadsinspektionen, "Främjande av ett mer flexibelt elsystem", 2023

[6] State of charge refers to the vehicles' charge level in relation to battery capacity.



V2G Requires Technological Adaptations

Fact box:

What is needed for V2G:

1. An electric car and a charging box that can perform V2G and have been safely installed by an electrician.
2. An electricity meter that measures output and a feed-in subscription - contact the network owner.
3. An actor who buys your output electricity and manages it in the electricity system, e.g., an electricity trader or aggregator.

V2G technology requires both new hardware and software compared to conventional smart charging to function. Regarding hardware, additional power electronics in the car or in the charging box are required to allow the current to flow in the opposite direction and be fed back to the grid. Moreover, upgraded hardware may be needed to handle the more advanced software required, compared to the existing charging boxes currently in the electricity system. The software needed must be able to exchange data between vehicles, chargers, and surrounding systems (the electricity system or the property) for V2G to be used in practice. This can be data about electricity contracts, network tariffs, billing information, energy needs, network codes, schedules, SOC, and other technical variables.

The charging needs to be adapted based on several different factors.

Which data that needs to be exchanged and how communication needs to be structured can vary depending on which service the vehicle's battery is contributing to. There are different requirements for response time from a resource in the electricity system depending on which markets an actor wants to participate in (e.g., national support service markets, energy arbitrage, local flexibility markets, or increased self-consumption of solar power). The charging also needs to be adapted based on factors such as planned use of the car and impact on battery health.

AC or DC?

The battery in the vehicle must be charged with direct current, while our electricity system is primarily based on the transmission of alternating current.

A key question issue affecting the design of the equipment is deciding if the car should use alternating current (AC) or direct current (DC) to charge and discharge. The vehicle's battery needs to be charged with DC, while our electricity system is primarily based on the transmission of AC. This means that a conversion has to happen somewhere in between, which can occur either in the vehicle via a built-in inverter, the so-called onboard charger, or in the charging station. In the latter case, the car can be charged directly with DC in the same way as occurs with higher charging powers today. Most all-electric cars today have an onboard charger installed, but it requires additional power electronics to handle bidirectional charging. The location of power electronics and control systems affects which component must handle communication and comply with the rules for feeding electricity into the grid, but also whether the increased costs for the technology end up in the vehicle or in the charging infrastructure. Currently, actors develop both types of solutions. It is also technically possible to have combined inverters for, for example, a household's solar panel system and a V2G-compatible charging station.

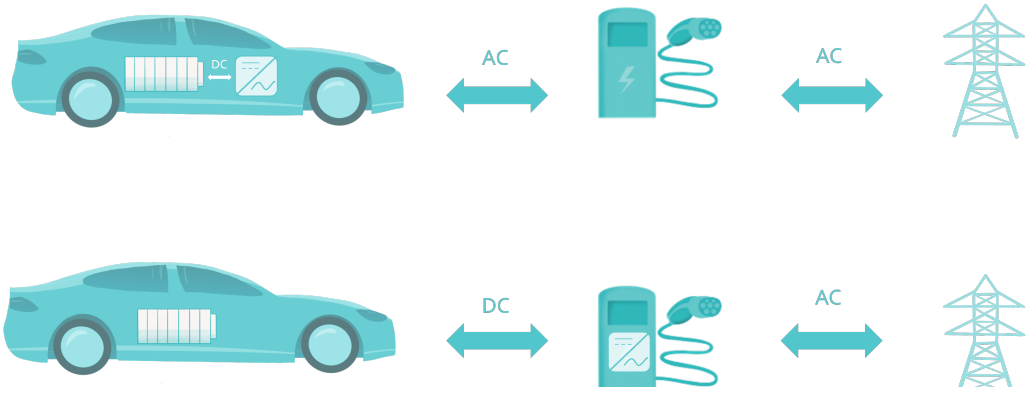
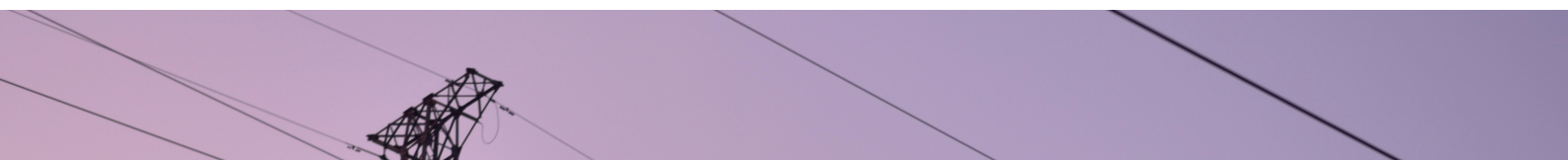


Image 2: The car's battery must always be charged with direct current (DC) while our grid delivers alternating current (AC), the inverter that converts between AC and DC and controls the bidirectional charging can be located in the car or in the charging post.



Communication and standards are crucial

Fact box: Key concepts

EVSE: Electric Vehicle Supply Equipment, a term for charging infrastructure.

CPO: Charge Point Operator, the actor who manages the operation and maintenance of a charging point.

EMSP: E-mobility Service Provider, the actor who manages customer contact and the actual charging service at charging stations. Can be the same actor as the CPO, but doesn't have to be.

ISO 15118: Technical standard for everything related to V2G technology: General use cases, hardware requirements, network protocols, hardware for connection, software for connection, and encryption.

OCPP: The structure of data communication (protocol) between a charger and a central control system (back end).

A key parameter for creating interoperability between different products, systems, and actors, but also with the surrounding system, is standards and protocols. From EV to the grid, there is a multitude of different actors, standards, and protocols that regulate both hardware and software. A holistic approach is required for V2G to function regulatorily, technically, and for the business potential to contribute with various services to the electricity system to be realized. Communication is required in several stages between the EV, charger, electricity system, and various actors in the system.

Image 3: Electric car, aggregator, DSO, TSO, charger, and service operator are all parts of a system that needs to communicate with each other.

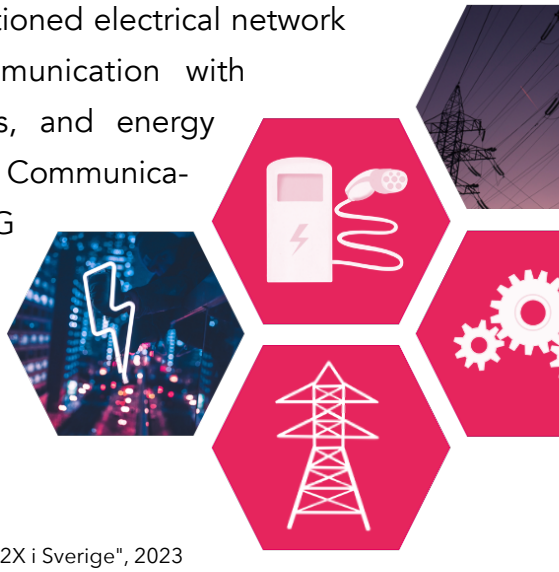
One of the most important standards is ISO15118, which gathers technical requirements for hardware and communication between the vehicle and the charger (enabling technologies like V2G, wireless charging, electric roads, and the Plug & Charge payment solution). The standard is still under development, where the next version ISO15118-20 is expected to include almost full functionality for V2G. Both chargers and electric vehicles need to have ISO15118 implemented with the same version to be able to communicate and perform bidirectional charging. Something that is not

included in ISO15118-20 is how grid codes should be handled, which is a topic that has begun to be discussed at the international level.

Consideration of the grid codes is important for vehicles to be able to move and use V2G in different grid areas and across national borders. ISO15118-20 also requires that the communication between the charger and the underlying control system supports V2G. This communication is often done according to the OCPP protocol, which is an open, unofficial standard for communication. The next version of the protocol, OCPP 2.1, will support V2G.

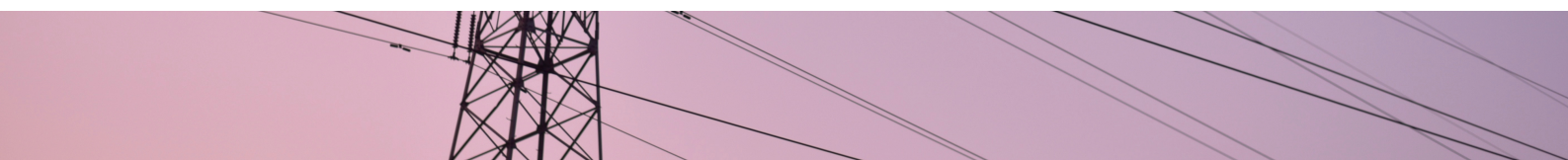
Communication with the electricity system will be a key factor for V2G to create value in the system.

Besides these standards and protocols, there are several other standards that further regulate hardware and the communication between the central control system and the customer interface or the overarching electricity system. These can be further explored in Power Circle's V2X synthesis[7]. Energiföretagen have recently launched the communication protocol OPEN ADR as an industry recommendation for communication between electrical network companies and customers to control power during conditioned electrical network connections[8]. However, communication with Svenska kraftnät, aggregators, and energy markets will also be required. Communication will be a key factor for V2G to create value in the electricity system.



[7] Power Circle, "Forskning och utveckling av V2X i Sverige", 2023

[8] https://www.energiforetagen.se/medlemsnyheter/2023/oktober/ny-branschrekommendation-openadr-foreslas-for-villkorade-natavtal/



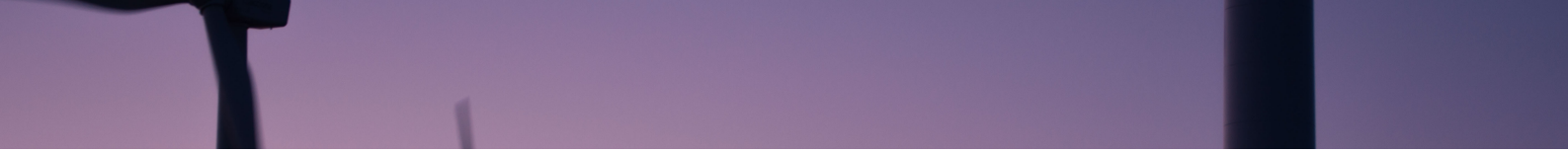
V2X - From concept to consumer

Several car manufacturers, such as Volvo, Polestar, Volkswagen, Ford, and Hyundai, are involved in pilot projects or have announced upcoming car models with support for V2G.

The concept of V2X has been discussed since the late 1990s, but its terminology has significantly evolved since then. Japan was among the earliest countries to develop and test bidirectional charging in practice, and in 2012, Nissan launched the Leaf model with the Leaf-to-Home concept, primarily as a potential backup power source. The Japanese charging standard CHAdeMO has had functionality enabling bidirectional charging since 2014. The first pilot projects around bidirectional charging were thus conducted with cars equipped with CHAdeMO charging, mainly the Nissan Leaf, which for a long time was the only car on the market supporting bidirectional charging. Today, however, virtually all car manufacturers use the European charging standards CCS (DC) and Type 2 (AC), requiring new standards and new technology for broad V2G implementation.

Several car manufacturers, such as Volvo, Polestar, Volkswagen, Ford, and Hyundai, currently have or have announced upcoming car models with V2G support. Other manufacturers have expressed concerns that the application could affect the battery's lifespan and/or function. Some manufacturers have announced models with V2G support but simultaneously limit the function to a certain amount of discharged energy or time. There are also several manufacturers whose models support V2L, which is often seen as a first step towards V2G[9].

[9] RISE, "Laddinfrastruktur och frekvensreglering, en fallstudie", 2023



Commercialization of V2G technology is expected to occur within 1-5 years!

Even though several car models with V2G support are starting to roll out, there is still a way to go before any large-scale implementation can occur. Business models, incentives, and standards need to be reviewed, and some regulations and procedures need updating. The cost of technology for bidirectional charging also needs to decrease before a large-scale rollout, but cost reductions will likely come as a result when more standards are established. In Power Circle's synthesis report, it was concluded that commercialization of the technology could likely occur within 1-5 years[10].

Business models and incentives are important factors

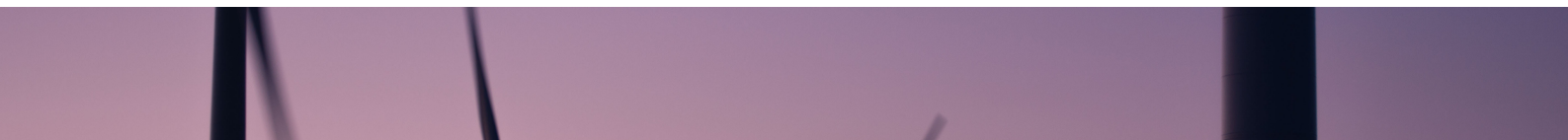
For a household, the storage potential in an EV is large compared to the increasingly common home batteries. A home battery generally has a storage capacity of around 10 kWh[11], while the battery capacity in Sweden's most common electric cars today is between 60 and 80 kWh[12]. With a larger storage capacity, a household can have a higher utilization rate of self-produced solar power, optimize control of consumption against spot prices, or contribute with support services on more markets, to name a few examples.

To increase interest in V2G, incentives for flexibility and storage need to be strengthened. The energy tax re-

[10] Power Circle, "Forskning och utveckling av V2X i Sverige", 2023

[11] https://www.solcellskollen.se/blogg/dags-att-lagra-din-solel-har-ar-det-du-behover-veta-om-batterier

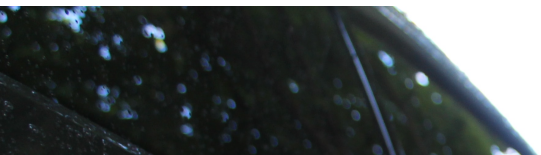
[12] https://www.car.info/sv-se/stats?from=2023-01&to=2023-12&vd=4.8.18.19.20&et0=3&tcb=registered&tcs=registered&tcf=registered

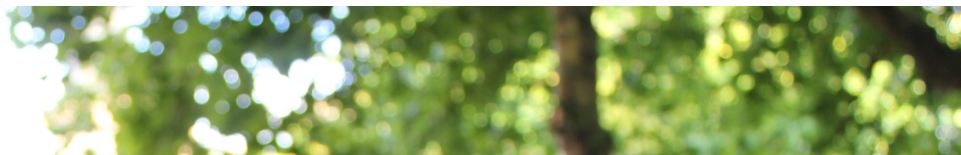


duces the small incentives that price variations in electricity provide and is designed for electricity to be used directly, not stored. This means that applications with bidirectional charging where electricity is used behind the meter have been most interesting in Sweden previously.

A possible revenue for V2G is to provide support services to the electricity system. In May 2019, several additional opportunities for batteries to participate in frequency regulation opened up. Since then, the number of batteries in the grid has increased significantly. As individual home batteries or electric cars are too small to participate directly in the various energy and support service markets, an aggregator that can gather more resources and place larger bids is needed. Today, there are actors contributing aggregated flexibility from smart charging to the frequency regulation market. However, to increase the incentives for electric cars to contribute to Svenska kraftnät's support service markets, the conditions for the aggregation of flexibility need to be further improved[13].

[13] Power Circle, "Flexibilitet för ett mer stabilt och driftsäkert elsystem", 2022





Battery degradation also needs to be considered

The extent to which a battery wears out with V2G, the so-called battery degradation, can affect the profitability of V2G. Battery degradation depends on several factors, such as cyclic aging and calendar aging. Cyclic aging is caused by charging and discharging cycles and is affected by the number of charging cycles, charging speed, the amount of energy per charging cycle, etc. Calendar aging depends on the physical age of the battery and the SOC at rest. For example, if an electric car is often parked with a high SOC, it generally accelerates calendar aging. Neither cyclic aging nor calendar aging is linear and depends on factors such as battery chemistry and temperature.

Degradation is usually very small, and the use of V2G is based on the revenues covering that cost.

Studies show that V2G can accelerate cyclic aging, but it is unclear whether V2G affects battery degradation more than other types of charging. Charging without smart technology that takes into account the car's SOC can also have a greater impact on calendar aging. There are challenges in conducting research on battery degradation over time as it, for example, takes a long time to charge and discharge a battery at low charging power. There is a great interest from electric car manufacturers to participate in research projects to evaluate, for example, how battery warranties can be designed in relation to bidirectional charging.

It's important to remember that degradation is usually very small and that the utilization of V2G is based on the revenues covering the costs.

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Regulations and laws need to be adapted

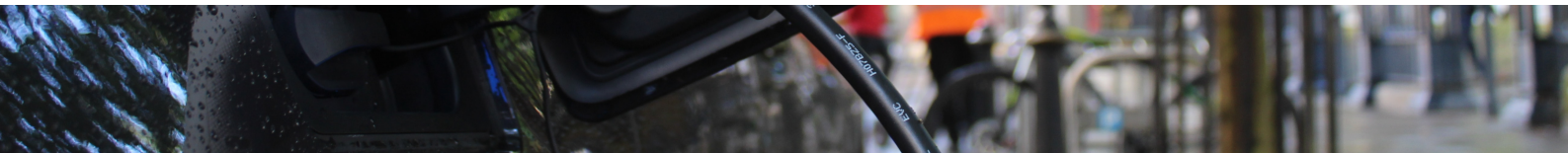
A broad market introduction of V2G requires legislation, regulations, and policy to be compatible with bidirectional charging. Today, there are several challenges that need to be further investigated to increase the understanding of if and how these affect the implementation of V2G.

There are no legal barriers, but also no specific regulation, for V2G.

There are no direct legal obstacles to feeding electricity from a car into the grid. What is required is a meter that can measure both fed-in and fed-out electricity and a feed-in subscription. Additionally, someone must buy the electricity. However, there is also no specific regulation regarding V2G or how it should be classified when connected to the grid. A possible solution is to equate bidirectional charging with a fixed electric production installation for micro production, which, for example, is being tested in the pilot project PAVE (see the next chapter). This means that an electric car and charging box supporting bidirectional charging are treated the same way as solar panels or a home battery in a property. There is uncertainty about whether and how a grid feed-in subscription needs to be differently designed for V2G and if it needs to be updated every time there is a change, for example, when the customer changes cars. Additionally, updates to industry standards are needed[14].

An alternative to viewing the car and charging box as a fixed electric production installation is to instead view the car itself as a grid feed-in point. This could give the car greater flexibility in providing V2G services

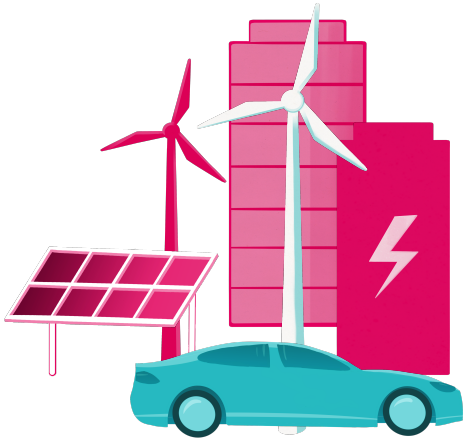
[14] https://youtu.be/kisk-dqK9QU



There is a need to review tax and VAT regulations concerning V2G and the transfer of electricity across electrical grid boundaries .

at different locations, e.g., at workplaces or public charging stations. This possibility is limited today by, for example, Svenska kraftnät's requirement for a physical address to deliver support services and DSOs' need to know where a specific resource is at a specific time. There are no explicit legal obstacles to transfer electricity from one grid to another via an electric car, but it is a legal gray area.

There are challenges related to the grid regulations for feed-in, known as grid codes. Neither existing grid codes nor those under development are adapted to handle mobile flexible resources. Furthermore, the vehicle must be able to adapt to the grid codes applicable in their current location. The ISO 15118 standard has not clarified if the car or charging box is responsible for following these codes for AC-based V2G[15].



Taxation of electricity is also a crucial issue regarding V2G. When a customer buys electricity, the electricity is taxed with both energy tax and VAT. If this electricity is stored in a battery and then fed back onto the grid to be made available for another customer to consume, this customer will also be taxed. Thus, the same electricity is taxed multiple times. The Swedish Tax Agency has introduced a possibility for consumers to apply for a refund of tax for the electricity fed back onto the grid, but this only applies to electricity returned to the same concession-obligated grid[16]. The limitation is complicating when utilizing V2G services for people who, for example, live and work in different electrical grid areas.

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[15] https://youtu.be/kisk-dqK9QU

[16] https://www4.skatteverket.se/rattsligvagledning/323435.html#h-El-som-aterforts-till-koncessionspliktigt-nat-efter-batterilagring

Pilot projects

A large number of research projects on V2G are being conducted worldwide.

Pilot projects are crucial for testing technology and business models in a real-world context and are often decisive for a solution to be implemented and launched in the market. Several V2G research projects and pilots are ongoing internationally[17]. So far, Sweden has lagged behind the rest of Europe in terms of larger pilots. Three years ago, Sweden had only two projects; one run by Örebrobostäder and one by Kungsbacka municipality. Recently, several projects have been initiated with broad anchoring in the value chain[18].

In the project **Mobility with extra services (V2X-MAS)**, Polestar is developing a bidirectional AC onboard charger, CTEK and Ferroamp are developing V2X-compatible AC and DC charging stations, Chalmers is developing advanced control algorithms for the battery, and Göteborg Energi is developing business models for various V2X solutions. The project runs between 2021 and 2024[19].

Fact box: The PEPP project runs from 2022-2024 and participants include:

Lindholmen Science Park, Johanneberg Science Park, Volvo Cars, Volvo On Demand, Chalmers Tekniska Högskola, RISE Research institutes of Sweden, CTEK Sweden, Easypark, Göteborg stads Parkering, Mölndals Parkering, Göteborg Energi, Mölndal Energi, Business Region Göteborg and MölnDala Fastighets AB.

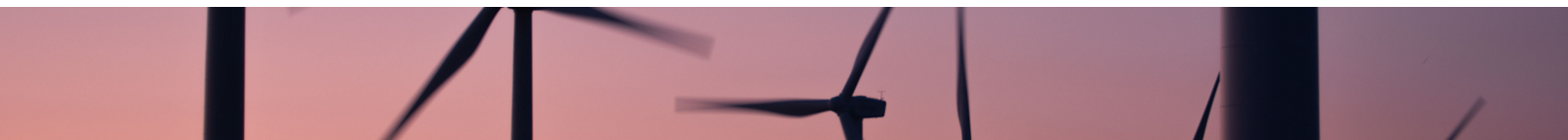
In the project **Bidirectional Charging in Public Environments (PEPP)**, the possibility of applying bidirectional charging on a larger scale is being investigated, focusing on technical systems, how people perceive and use V2G in public environments, and the value that the services create. Twelve vehicles will be used to evaluate V2G from a systems perspective in public environments, half of them in parking garages and half in a car-sharing service[20].

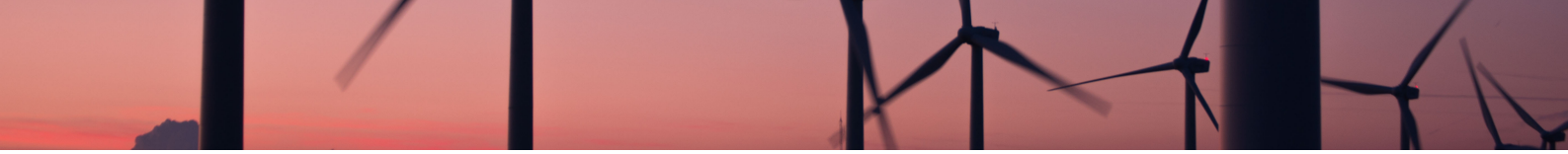
[17] See the website V2G-Hub, listing V2G projects from around the world

[18] Power Circle, "Forskning och utveckling av V2X i Sverige", 2023

[19] https://research.chalmers.se/en/project/10258

[20] https://www.lindholmen.se/sv/projekt/pepp-public-ev-power-pilots





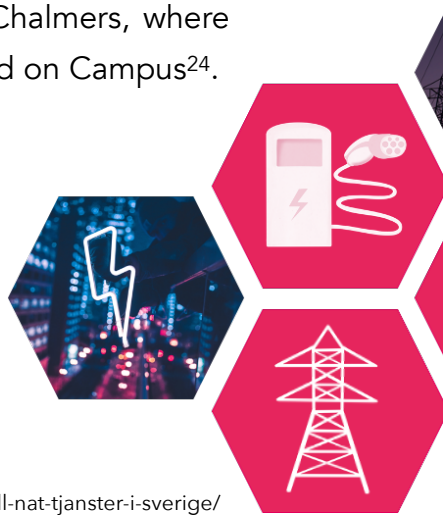
Fact box: The PAVE project runs from 2023-2025 and participants include:

Polestar, Svenska kraftnät, Göteborg Energi, Vattenfall Eldistribution, Vattenfall R&D Easee and Chalmers.

The **PAVE** project aims to introduce and evaluate the functionality, reliability, and efficiency of a V2G service for residences and workplaces in Gothenburg. The project focuses on challenges related to technology, business models, infrastructure, policy, and regulations. At least thirty vehicles and electric vehicle drivers will participate in the pilot project[21][22]. Polestar is also participating in a Vinnova-funded project in parallel, which will develop a roadmap for the implementation of V2G services in California[23].

Fact box: SCALE runs from 2022-2025 Swedish participants include Chalmers, RISE and Polestar.

SCALE is an EU project with a consortium of 29 partners from 8 European countries, including Sweden. The project focuses on reducing uncertainties around smart charging, interoperability, and V2X, whether they are technical, organizational, economic, social, or policy-related, and helping to shape a new energy ecosystem where the flexibility from batteries in electric cars can be utilized. In the project, 13 pilots will be conducted over 24 months, one of which will take place in Gothenburg under the leadership of Chalmers, where both AC and DC charging will be tested on Campus[24].

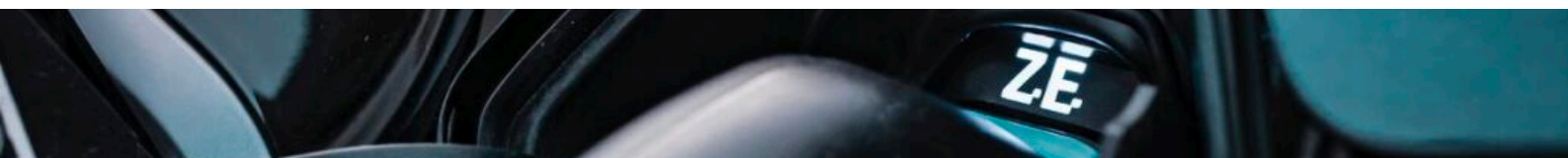


[21] https://www.vinnova.se/p/implementering-av-fordon-till-nat-tjanster-i-sverige/

[22] https://media.polestar.com/global/en/media/pressreleases/675426/polestar-initiates-v2g-projects-and-develops-virtual-power-plant-to-support-large-scale-energy-trans

[23] https://media.polestar.com/us/en/media/pressreleases/675426/polestar-initiates-v2g-projects-and-develops-virtual-power-plant-to-support-large-scale-energy-trans

[24] https://scale-horizon.eu/what-is-scale/



Other industry initiatives

There are also several initiatives and development projects in Sweden that have not been funded through research programs.

Volvo Cars is starting a new business unit focused on energy solutions and services. Volvo Cars has also initiated pilot programs with Göteborg Energi to test V2G technology with real customers. The pilots focus on home charging with AC chargers[25].

Volkswagen, in collaboration with HagerEnergy, has developed a V2H solution currently being tested in Hudiksvall. Eight Volkswagen ID.4s[26] are used for frequency regulation in the Stenberg BRF housing association in Hudiksvall. The chargers are DC chargers that charge with CCS, and the pilot project is based on ISO15118-20 in communication between charger and vehicle.

Polestar is also developing its own Virtual Power Plant (VPP) that can aggregate the capacity in Polestar cars and contribute with support services to the electricity system[27].

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25 https://www.media.volvocars.com/global/en-gb/media/pressreleases/318585/volvo-cars-launches-new-energy-solutions-business-embracing-wider-climate-potential-of-electric-cars

26 According to Volkswagen, all vehicles in the ID family with the 77 kWh battery and with software version ID. Software 3.5 or higher are compatible with V2X technology.

27 https://media.polestar.com/us/en/media/pressreleases/675426/polestar-initiates-v2g-projects-and-develops-virtual-power-plant-to-support-large-scale-energy-trans

The way forward

Interest in V2G has increased significantly in recent years, and several pilot and demonstration projects are ongoing in parallel with academic projects and various industry initiatives. Many industry actors see large scale commercialization as possible within five years.

However, some issues need to be further investigated before this can happen. Incentives need to be strengthened, and obstacles for storage, flexibility, and aggregation need to be removed. Standards, regulations, and industry practices require updates for V2G support. For example, there is a need to review tax and VAT rules. Business models and markets need to be adapted, with increased awareness both in the industry and among users. A key issue is digitalization and the design of control signals from the electricity grid. More car models and chargers need to be able to handle bidirectional charging, and the price of technology needs to drop. A technology choice may also need to be made regarding where the control should be located – in the car or in the charging box.

As more barriers are removed, V2G has great potential to lower system costs and use resources more efficiently, while car owners can earn income, either by acting on markets or increasing their self-use of solar power. There are great benefits for both car owners and the electricity system if the capacity in the cars' batteries can be better utilized in the future!

Go to powercircle.org for more fact sheets on future technologies for smart, resource-efficient, and digitalized electricity systems.

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