Norwegian University
of Life Sciences

Master's Thesis 2021 30 ECTS
Environmental Sciences and Natural Resource Management

Importance of drivers and barriers for V2G?

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Renewable Energy

Acknowledgements

With this thesis I end my master’s degree in Renewable Energy at the Norwegian University of Life Sciences (NMBU), spring 2021.

First, I would like to thank my supervisor Thomas Martinsen, for your patience, support, and guidance. I would also like to extend my appreciation to the other students I have shared many good times with during my two years at NMBU.

Eventual mistakes is the writer's own responsibility.

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31.05.2021

Abstract

To meet target CO_2 emission reductions, there is a shift in power production, where renewable energy sources are replacing conventional power generation based on carbon dense sources like coal, gas, and nuclear. Increasing shares of variable renewable energy (VRE), like wind and solar, which are unpredictable and variable, can be problematic to the electricity grid. To avoid differences in supply and demand, added flexibility and balancing factors are needed. Taking advantage of the growing fleet of electric vehicles (EVs) could be the answer. Vehicle-to-Grid (V2G) technology connects the vehicle to the grid through a bidirectional charger which allows for power flow both ways. Utilizing the EVs battery as energy storage for increased grid flexibility. This technology serves the potential to integrate more of the residual energy provided by VRE back into the power system. For owners of EVs this also presents the opportunity to make revenue, by charging the EV when demand is low and then selling it back to the grid when demand is high. While V2G can contribute to many benefits, as increased grid stability, economic revenue and reduction in CO_2 emissions, there are also drivers and barriers that will determine if V2G can be deployed on a large scale. Market-, technological-, economic- and social drivers are crucial for future V2G deployment. One of the most important barriers for V2G is the cost of bidirectional hardware. By estimating the learning curve for the bidirectional charger and the present values of future V2G revenue for different types of consumers, the maximum cost of the charger for each of the consumers is evaluated. Results show that large consumers who pay power tariffs will have more incentives to participate in V2G, and consumers who have larger batteries in their EVs will gain more profit than consumers with smaller EV batteries.

Abbreviations

AC	Alternating current
CO2	Carbon dioxide
DC	Direct current
DSR	Demand side response
EV	Electric vehicle
GHG	Greenhouse gas
IEA	International energy agency
LR	Learning rate
R&D	Research and development
SoC	State-of-Charge
SSI	Semi Structured Interview
V2G	Vehicle to grid
V2H	Vehicle to home
V2X	Vehicle to X (unknown)
VRE	Variable renewable energy

Table of Contents

List of Figures

List of Tables

List of Equations

1. Introduction

There is a worldwide consensus that anthropogenic greenhouse gases must be reduced to minimize the consequences of climate change. Reshaping power generation and energy intense sectors are valuable investments for a more sustainable future. The increasing share of variable renewable energy (VRE) generation and the reduction in conventional power plant capacity creates challenges for power system operation (Roos. and Bolkesjø., 2017). Increased variability of energy production causes expanded reserve requirements while the number of reserve providers is reduced. This creates an issue for grid operators as to how they can provide enough balance and stability in a future where electricity demand increases and the predictability of electricity production decreases.

Flexibility to ensure balance has usually been regulated from a top-down perspective, where generators have regulated their production up or down to meet demand. But the electrification of energy intense industries and sectors, like the transportation sector, makes it possible for increased bottom-up regulation, also known as demand side response (DSR). DSR participants will regulate their consumption based on signals from the grid, to meet supply and maintain balance.

Electrification of the transportation sector is one of the most valuable actions to mitigate climate change. During their lifetime electric vehicles (EVs) emit less greenhouse gases than conventional vehicles that run on fossil fuels. As of 2021 there are 10 million EVs globally and it is projected that they will range in the numbers between 150 – 250 million by 2030 (IEA, 2020). Not only will this increase the demand of electricity greatly, but it also presents the opportunity to use the EV battery as excess energy storage for the grid to help alleviate the total load.

Vehicle-to-grid (V2G) is the concept of using the EV battery as energy storage, and to sell this energy back to the grid when there is imbalance between supply and demand. V2G and its possibilities for bidirectional energy flow, can contribute to more than just flexibility. V2G can bring many social economic benefits, such as using energy storage that is already bought and paid for, ultimately reducing investment cost for more storage capacity for grid operators. For EV owners, revenue can be obtained by selling back electricity to the grid during peak hours, given that the car is charged during low peak hours. V2G can also help integrate more VRE into the energy mix, ultimately contributing to lower CO2 emissions. Although V2G presents many opportunities, it also has many drivers and barriers that influence future implementation. I will later clarify the drivers and barriers that impact the future roll out of V2G.

Importance of drivers and barriers for V2G?

2 Background

Economic growth creates new and important opportunities, but also challenges linked to scarcity of resources, climate change and other environmental issues. These challenges create driving forces in the market that lead the technological development in a more sustainable direction. To make wise decisions that affect the future development, it is important to understand the drivers that affect development. Drivers are defined as natural or human induced factors that directly or indirectly influence the viability of the technology or system.

Technology development can be uncertain, dynamic, and cumulative, and most new technologic innovations never reach the market (Martinsen, 2019). The main driver of technological development is research and development (R&D), and deployment. But what drives deployment?

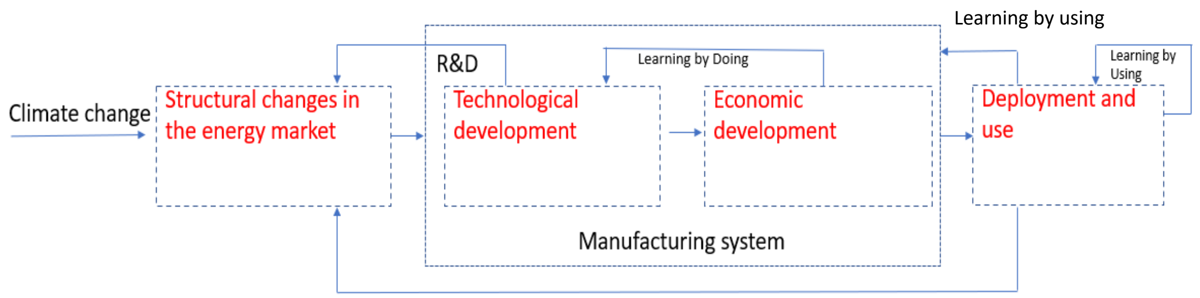


Figure 1 A simplified diagram showing system boundaries of V2G, and the different feedback loops.

Climate change and the issues it brings have caused structural changes in the energy market. More production of VRE, making electricity supply less predictive, and electrification of several energy intense sector, increasing the overall demand. The electrification of transportation is a result of international and national policies, introduced to diminish CO2 emissions caused by conventional cars. These factors make it possible for new technologies to emerge.

One of the technologies that have been granted means for R&D in the last decade is V2G. V2G can make use of the EV battery for a secondary function, by delivering balancing capacity for the grid. This area of opportunity has been studied and researched, and around 50-60 trials and pilot projects have been executed. During these trials, unit cost of production of the bidirectional charger (that allows for bidirectional power flow between the EV and the grid), have drastically decreased. From large expensive installments to a wallbox that can be deployed for domestic use.

As a technology is produced and deployed, the production process becomes easier and faster, resulting in lower cost per unit produced. This is called Learning by doing (LbD) and refers to the knowledge stock increasing as workers gain experience. If a technology is too expensive, large scale deployment is difficult. Therefore, LbD and cost reduction is important for new technologies.

When the technology is deployed, the end users will also learn from using the technology. For EV owners participating in V2G, their experience will make their own use more effective and could potentially lead to longer technology lifetime, ultimately reducing investment cost. This is called Learning by using (LbU), and is the learning accommodated by the consumers. Moreover, LbU provides important feedback to the producers, which can lead to improved changes in technology design. As V2G use both hardware (chargers and inverters) and software (apps), consumer feedback is important to simplify use and make processes more effective. This creates reinforcing feedback loops that affect accumulated deployment and unit production cost.

Not all technologies develop as quickly as others. Changes that demand broad social acceptance or changes at governmental level will happen at a slower rate than other changes (Bråten, 2017). Social resistance can limit the implementation of new technologies (Climate Policy Info, 2021).

The drivers that affect deployment of V2G is market-, technological-, economical- and social drivers. V2G will have better chances of deployment if the technology fulfils the flexibility needs of the grid in a cost-effective way. Technical difficulties must be solved for V2G to become deployed, as it affects both lifetime and cost. The value of V2G brings to the different stakeholders must be greater than the cost of V2G for it to reach large scale deployment. And without social acceptance, V2G will not be viable as its dependent on available battery EV capacity.

Each driver is presented with its barriers in the following chapters.

3 Market

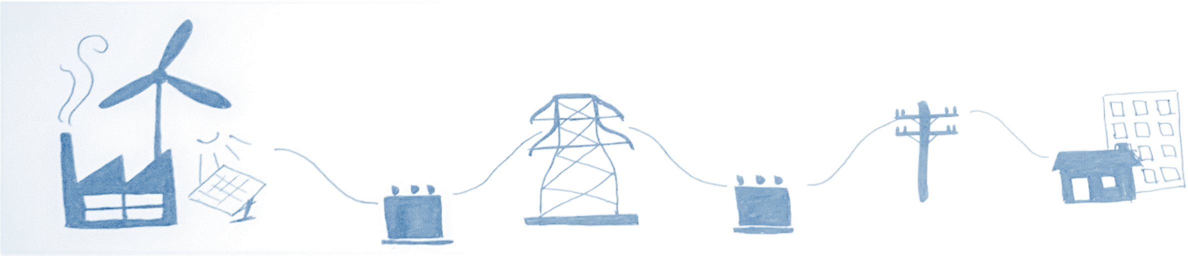


Figure 2 Illustration of the grid, from generator to end-consumer.

The grid is the electric network that runs from the power producers all the way to the end user. The grid consists of generators, transmission and distribution lines, transformers, and other electrical devices, and consumers (figure 2). It is an integrated and complex system that relies on measurement and control. Some of the processes in this system is automated and some require active operator intervention to keep the grid stable and safe (Jaffe and Taylor, 2018).

3.1 Characteristics of the Energy Market

Electricity is bought, sold, and traded in wholesale and retail markets. These markets operate similarly as markets for other products. The procurement and sales of electricity from power generators to resellers are done in the wholesale market. The purchase and sales to consumers and end users are done in the retail market (Energifakta Norge, 2019). Different from other traded goods in the wholesale and retail market, electricity cannot be easily and effectively stored. The electric grid has very little storage capacity, compared to more conventional energy delivery systems like natural gas pipelines and oil stored in barrels (Jaffe and Taylor, 2018).

Until recent years almost all electric power generation have been from fossil fuels, nuclear or hydro power plants. These all have in common that they are well integrated to the modern grid demands as they can regulate their production easily to match loads and their availability is generally high and predictable. Conventional power generation based on coal and gas are being phased out and diminishing in capacity due to national and international policies to reduce the effects of climate change. Simultaneously, the shares of variable renewable energy (VRE) are increasing. VRE such as wind- and solar power are variable on many time scales; they are often located far from the loads they serve; they may be broadly distributed installations where direct control is difficult. VRE power generation is dependent on sun irradiation, wind speed and cloud cover, which can fluctuate on all time scales, from seconds to hours, day and night, and seasonal changes. VRE are variable, unpredictable and distributed, which all can pose problems for the structure and stability of the electric grid (Jaffe and Taylor, 2018). A small fraction of VRE shares of total energy supply is no significant problem. But shares of VRE continue to increase, and so does electricity demand. Grid operators encounter the issues concerning balancing the grid, where balancing needs are growing and there is less emergency power generation capacity available (IEA, 2021).

3.2 Price Formation

Each day power producers submit bids on how much they are willing to produce and at what cost. These bids display the value they deem their production to have, also considering the running costs of production. The Retailers or aggregators also submit bids at how much they think the end users are going to consume at different price-points. The price is then decided by the equilibrium between supply (S) and demand (D), as shown in the merit order curve illustrated in figure 3. By looking at the merit order curve, one can see that when there is more renewable energy production, the equilibrium price is lower (D_{VRE}). This is because the renewable energy bids will drive down the clearing price and push out the more costly (and more carbon intense) energy production of the market. This means that when there is an abundance of VRE, like wind and solar power, the electricity price is lower. This is because the levelized cost of energy (LCOE) for VRE is lower than other electricity production methods. LCOE is the lifetime operation and investment costs divided by aggregated energy production. LCOE allows for easy comparison between different energy production technologies. Renewables like solar, wind and hydro have low LCOE, because the resources are free, low operating costs, and of course renewable. Peak loads have high operating costs, and it would be preferable to minimize the use of these.

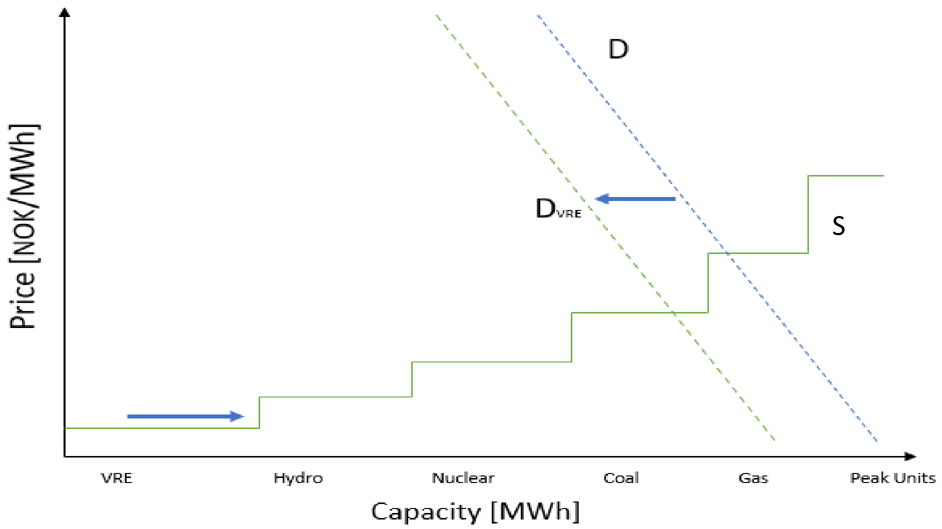


Figure 3 Merit order curve.

3.3 Balancing Markets.

If the supplied electricity is greater than the load, then electricity will circulate the grid and can potentially cause instabilities until its lost in resistive heating. If demand on the other hand is greater than the supplied electricity, then there is a risk for blackout, where all electric services stop. This can cause huge problems for society, as many important services run on electricity. Therefore, balance between supply and demand will always be the main objective in grid management. Balance in the grid is kept at 50 Hz. The grid can withstand a disturbance of 1%. Balancing factors are needed when disturbances over 1 % occurs. Most powerplants can shut down or scale up production if needed (Energifakta Norge, 2019).

If retailers have estimated the wrong load demand, and they need balancing power, which is bought one hour before delivery from power generators. Power producers can offer up- or down regulation of their production, and be paid for having balancing capacity available and the energy delivered (Ilieva and Bolkesjø, 2014, NVE, 2015).

Balancing operations have usually been regulated by the grid operators, as fluctuations have been a result of variability on the demand side of the power system. But with expected increase in electrification of several energy intensive sectors, demand side response provides more opportunities to balance the supply and demand (GridBeyond, 2019). DSR participants can receive revenue by being available for regulating and balancing services. If demand is surpassing supply, a DSR participant can downregulate their energy consumption. Those who can participate in DSR services are typically energy intensive industries, large-scale commercial consumers, and aggregators.

3.4 Ancillary Services.

Ancillary services are the services that can help the grid operators sustain a dependable and stable electricity system (Greeningthegrid). These services make sure that the energy is delivered to meet demand, but also keeping the grid stable, keeping the frequency at 50 Hz. With consistently overviewing the grid, and continuously correcting the frequency, voltage, and load, grid operators can ensure proper operation of the power grid. Frequency control and balancing is most likely the ancillary services that is used the most (Next-kraftwerke, 2021).

Frequency regulation can provide fast increase or decrease of electricity to manage the balance between production and consummation. Frequency regulation is used in short timeframes, from seconds to a couple of minutes at a time. The purpose of frequency regulation is to maintain the instantaneous balance between supply and demand, such that the frequency is kept from deviations below and above 1%.

3.4.1 How can V2G provide flexibility and help keep the grid stable?

In a short timescale, V2G can provide valuable ancillary services, that help secure reliable energy supply by maintaining stable voltage and frequency in the grid. The lithium ion batteries used in EVs have fast response times and high efficiency, which makes them ideal for grid regulation, as they can help correct any imbalances in a matter of seconds and minutes (Sarabi et al., 2014). Frequency regulation services are viewed by many as the most valuable contribution from V2G (Liu et al., 2018, Mathur and Bhateshvar, 2016, Lodberg Høj et al., 2018, White and Zhang, 2011). On time scales from minutes to days, V2G can add more storage capacity and help meet peak demand and unpredictable changes in supply and demand. In the long term, flexibility from V2G can reduce grid operating cost and investment cost.

Table 1 The type of flexibility EVs can provide. Table found in report from IEA (2019).

Flexibility type	**Ultra-short term**	**Very short-term**	**Short-term**	**Medium-term**	**Long-term**
Time Scale	Sub-seconds to seconds	Seconds to minutes	Minutes to days	Days to weeks	Months to years
Electricity market	Ancillary services		Ancillary services, balancing, energy markets	Balancing, energy markets	Balancing, energy markets
Power system issue	Ensure system stability (Voltage, transient and frequency stability) at high shares of variable (non-synchronous) generation.		Meeting more frequent, rapid, and less predictable changes in the supply/ demand balance	Addressing longer periods of surplus or deficit of power generation, e.g., driven by presence of a specific weather system affecting VRE generation.	Balancing seasonal and inter-annual availability of variable generation with power demand: meeting capacity requirements when VRE generation is low
Capability of EVs	Batteries can provide fast frequency response based on a control signal. For smart charging, increase or decrease in demand can be offered. The full EV		Ability to charge earlier or later across one day or more, or varying charging speed to better suit the system. V2G could provide system services and help meet system		Smart charging helps meet capacity needs by shifting EV demand according to system requirements

	charging load can be somewhat reduced to provide frequency support.	requirements. Aggregated charging capacities of large EV fleets can be part of a virtual power plant (VPP), either through DSR or V2X.	and can impact long-term planning of capacity.

3.5 Daily Load Curve and EV availability.

In the mornings, the demand peaks because of warming of spatial areas, coffee machines, showers, etc. During the evening, the load peaks again, as people make dinner, charge their EVs, watch television and so on. What seems to correlate with the daily peak load is peak traffic. Traffic peaks in the mornings and evenings, because of daily commuting to work, driving kids to school/practice, shopping etc., and then settles later that night. On average a car is used for driving purposes 4% of time, and stationary the remaining 96% either at home or at work (Kiaee et al., 2015, IEA, 2020). Peak traffic is between 06:00 -09:00 in the morning and 16:00-19:00 in the evening. Even though traffic peaks often at the same time as load demand, this does not mean that no cars are available for V2G participation during these times. White and Zhang (2011) found that the minimum availability is approximately 77,9% during the morning rush and the highest availability is right after midnight with approximately 99,8% availability. Statistics indicate that there are over 90% vehicles parked at any given time, including peak traffic (Brooks, 2002, Mullan et al., 2012).

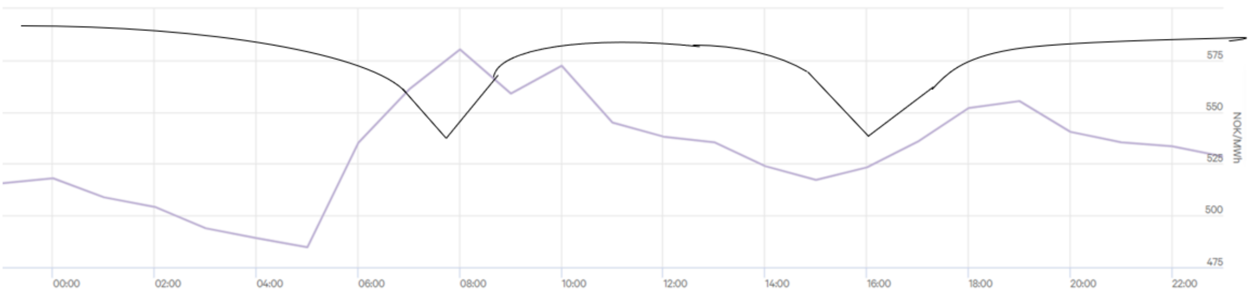


Figure 4 The graph illustrates a typical load curve (purple), and vehicle availability (black), over the course of a day.

3.6 Controlled and uncontrolled charging.

In Norway, the EV fleet will have little effect on the total electricity demand estimated for 2030. The electricity consumption for 1,5 million EVs will make up a total of 3 % of the national electricity demand. Charging an EV will however demand a lot of electricity over a short period of time, increasing the power demand (Greaker and Hagem, 2020). With uncontrolled charging the EV fleet will contribute to higher peak demand increasing stress on the grid, as showed in figure 6. Figure 5 shows a scenario of unmanaged charging. If the car is plugged in after the EV owner arrives home, the car will charge in typical peak hours and stay idle and plugged in for the remainder of the time.

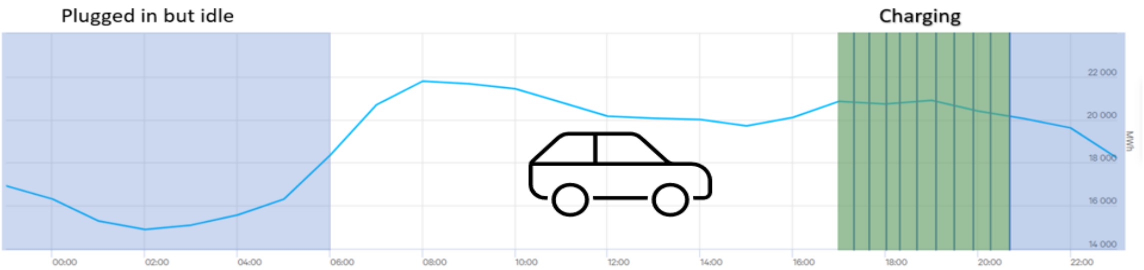


Figure 5 Uncontrolled charging.

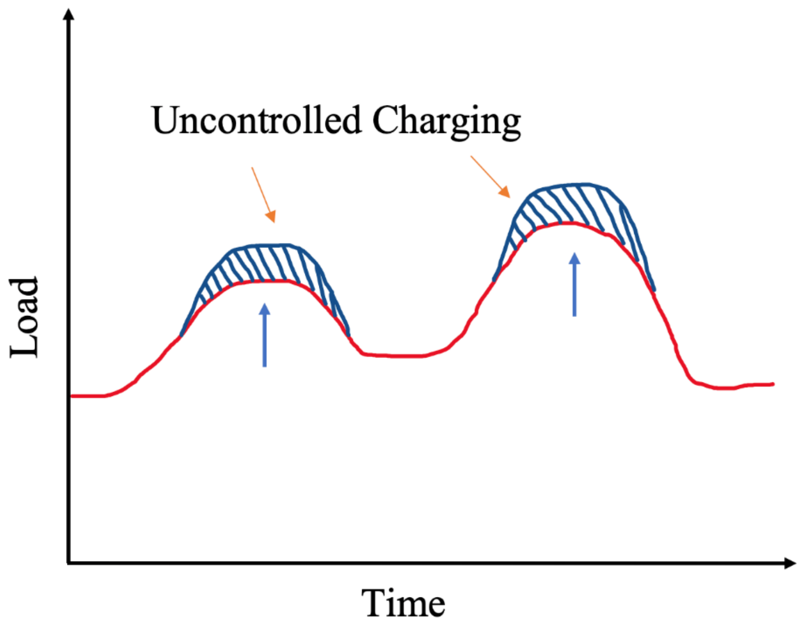


Figure 6 Uncontrolled charging contributing to increased peak demand.

Smart charging, also called V1G, is the smart and controlled charging of the vehicle. By controlling state of charge, the charge time, and accounting for time of use, charging costs can be minimized (Cross, 2020). V1G can offer flexibility to the grid by charging at low demand hours to avoid added load during peak hours, also called peak shifting, see figure 7 and 8 for illustration. V1G allows for communication between the EV and a charging operator, and this results in smart charging based on price signals from the grid (Virta, 2021).

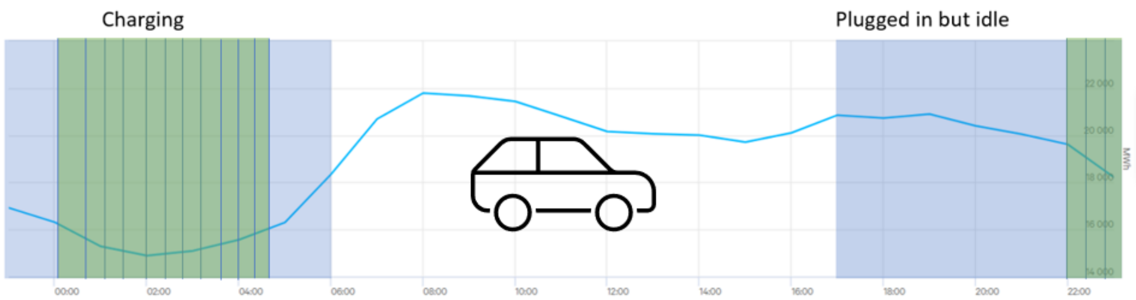


Figure 7 Controlled charging (smart charging, V1G).

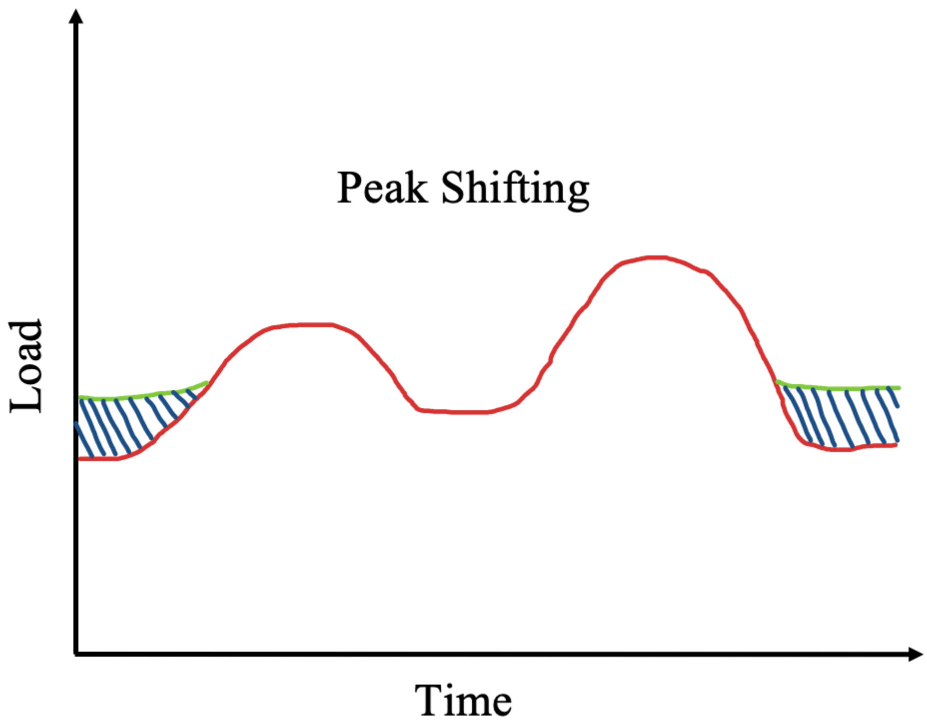


Figure 8 Controlled charging contributing to peak shifting.

V2G is a more advanced form of controlled charging. V2G will reduce charging cost and can provide additional savings by selling back electricity to the grid. V2G can contribute to peak shifting and peak shaving as depicted in figure 10. By pushing the electricity stored in the EV into a house or a building, V2H and V2B respectively, the overall demand during peak hours will decrease (Elbilforeningen, 2016).

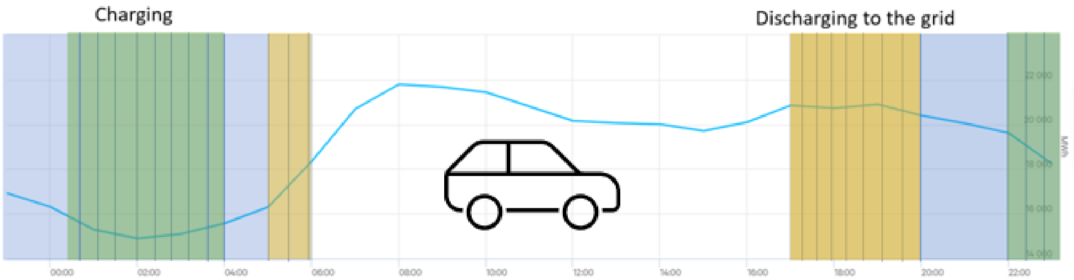


Figure 9 Controlled charging with V2G.

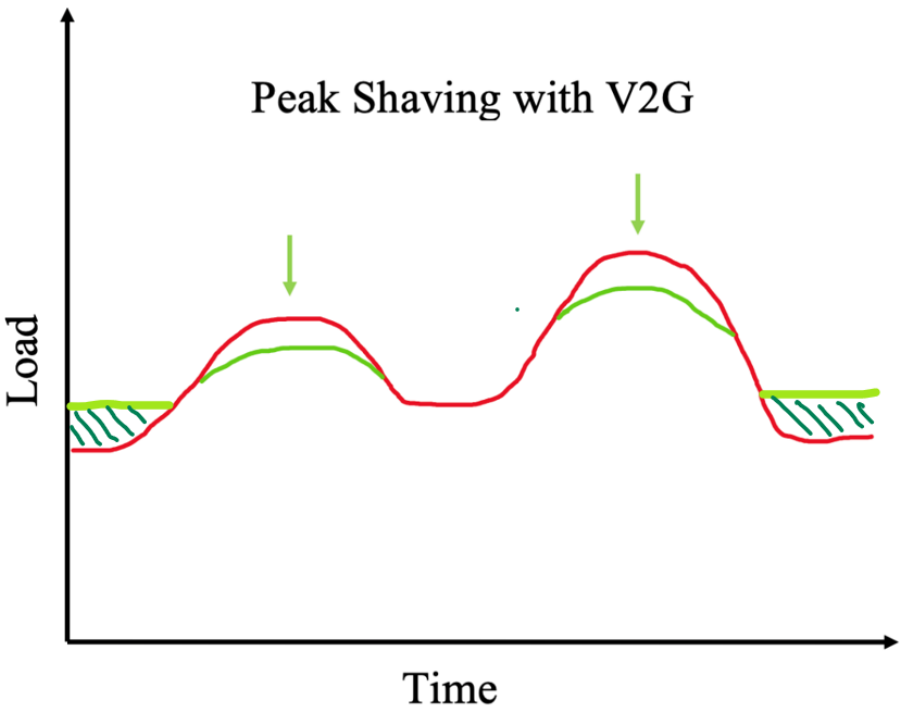


Figure 10 V2G can contribute to grid shaving.

3.7 V2G Aggregator.

An Aggregator is a company that trades a service, like electricity, for consumers. A V2G aggregator is the control centre that communicates with both the EVs and grid operators. It manages the charge-discharge cycles of each EV based on load signals from the grid, market electricity price and consumer preferences (Peng et al., 2017b, Amamra and Marco, 2019). To technically realize the V2G system, a communication chip is added to the onboard charger of the EVs to regulate the power flow between the EVs and the grid. However, designing this communication technology is expensive (Fulari and Kaa, 2021). Several studies have looked at control and dispatch algorithms to optimize a variety of different aspects of the V2G system. Algorithms can optimize grid stability, balance energy among EVs, maximize economic benefit and minimize battery degradation (Peng et al., 2017a). An illustration of the communication between the V2G aggregator, EV fleet and the grid is shown in figure 3.

The challenges that might face the V2G aggregator is to have enough vehicles in their fleet, so that they can offer enough balancing energy to the grid. In many countries the minimum capacity is 1 MW to participate in the balancing market. Meaning the aggregator would need hundreds to many thousands of EVs available for V2G, so they could deliver minimum balancing capacity.

Another barrier is to fulfil the driving demand of the EV owner while simultaneously maximizing economic benefits by contributing to ancillary services. The issue is to collect and forecast the amount of available capacity all of the EVs have for providing flexibility and for how long they can provide flexibility (Andersen et al., 2019). The balancing bids are often required a day in advance, and the unpredictability of human behaviour makes forecasting V2G capacity difficult (Noel et al., 2019). There are also no political incentives for encouraging an independent V2G aggregator in Europe to participate in demand side response, even though V2G can provide important frequency regulation and storage capacity to balance supply/demand (Andersen et al., 2019).

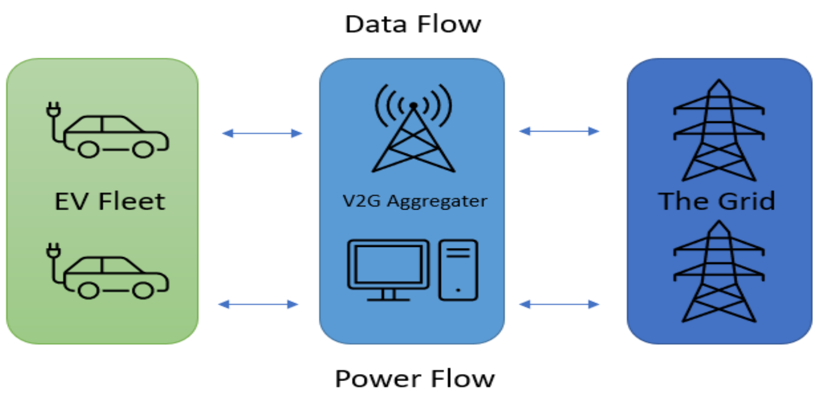


Figure 11 Illustrating the V2G aggregator. A centralized control system providing a large scale EV fleet to contribute to ancillary services.

3.9 Competition.

There are many ways to provide more flexibility to the electricity market. In markets where hydropower is the main electricity provider, the hydro power plants can offer a lot of flexibility by gearing up or down the production easily. Smart charging can also help to increase flexibility, by shifting the demand. One of the biggest competitors to V2G is stationary batteries. There is also flywheel, supercapacitors, to mention others. Like most competition in a free market, the most profitable in a societal and economic sense, will be the one chosen.

4 Technology.

The basic concept of V2G is to monetize on the battery in the EV, by selling back stored energy to the grid, and therefore also contributing to ancillary services for grid operators, illustrated in figure 12. For this to happen there are many technological obstacles and barriers that need to be overcome. Charging infrastructure that can support bidirectional power flow must be available. No unified standards and charging connectors limit the V2G deployment. Few car models that are V2G compatible and the cost of bidirectional hardware is expensive. The effect of V2G on battery health is also a debated topic.

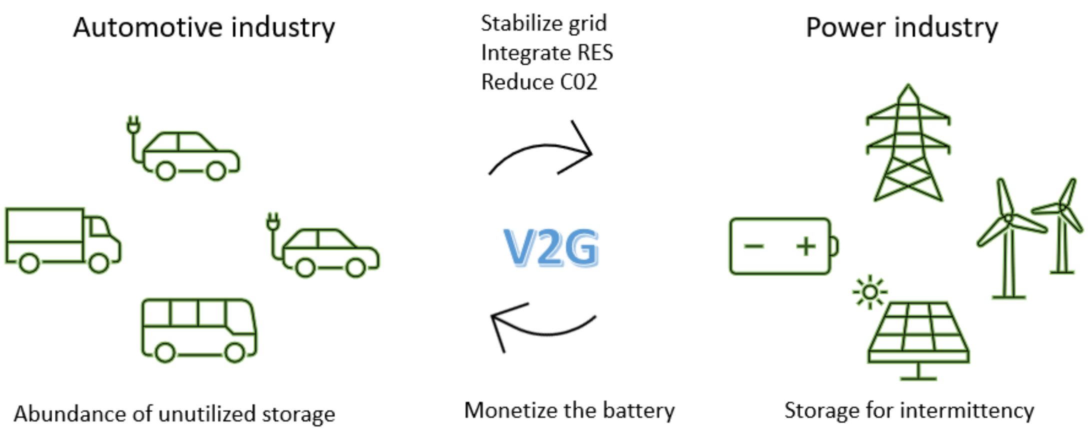


Figure 12 The concept of V2G

4.1 Vehicle-to-Grid.

Kempton and Letendre (1997) first described the idea of using the battery in EVs for storage capacity for the electricity grid. They acknowledged the fact that EVs would be growing in numbers during the following decades and an electrification of the transport sector would add more load on the grid. In addition to the rising share of renewable energy that would make balancing supply and demand more difficult. To tackle this issue, they presented the potential benefits of utilizing the EV for a secondary function than driving (Kempton and Tomic, 2005a, IRENA, 2019, Kempton and Letendre, 1997).

4.2 Charging system.

EV owners can plug their EV into a socket at home to charge their car, this is called AC-charging. The EV has an on-board charger, that converts alternating current (AC) from the grid into direct current (DC) so that electricity can be stored safely in the EV battery. The EV battery can also charge from a DC charger. The charger then converts the electricity from AC → DC and then sends it in to the EV battery. If the energy stored in the battery were to be sold back to the grid, it would have to be converted back again to AC current (Alfaro, 2020). V2G hardware are currently bidirectional DC chargers.

When converting the current from DC → AC energy will be lost in recessive heating, from 10% (for 8 kW chargers or more) to 20% (for 3 kW chargers)(IEA, 2020, Zecchino et al., 2019). Because of the high densities and power capacities of the lithium-ion battery, a battery management system (BMS) is installed, this way the battery is managed and controlled making it run more safely.

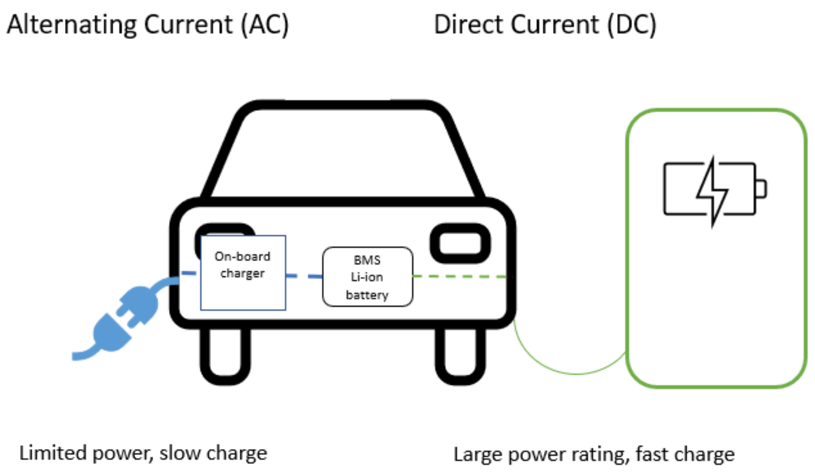


Figure 13: An illustration of the difference between AC- and DC charging, and where the current conversion occurs in the different scenarios. BMS stands for battery management system.

4.2.1 Lithium-Ion Batteries.

Lithium-ion batteries and other lithium based batteries can achieve high energy density, because of the lithium's low density and large standard reduction (Jaffe and Taylor, 2018). Over the years, Lithium batteries have experienced an increase in energy density and power capability compared to other types of batteries and therefore, lithium-ion batteries are now the preferred battery in EVs (Uddin et al., 2016, Iclodean et al., 2017). With high charge and discharge efficiency, long cycle life and high specific energy, Li-ion batteries can be viewed as an attractive energy storage technology to satisfy grid balancing needs (Chen et al., 2020). The disadvantage of this type of battery is the degradation in capacity, whether the battery is used or not (Jaffe and Taylor, 2018, Uddin et al., 2018). Ye and Li (2021), restructured the Li-ion battery during their research for Harvard, making it more stable. Their test battery had 82% of its original capacity after 10 000 cycles. This means that if the battery is going through one cycle every day, it would still have 82% capacity remaining after 27 years. Energy density also increases with their design, 630 Wh/kg compared to todays 250 Wh/kg. Fast charging with this type of charger will also become easier, faster, and not compromise the battery as much.

4.2.2 Battery Degradation.

Battery life can be categorized in two parts, cycle life and calendar life. Cycle life is the number of full charge and discharge cycles before the battery starts to degrade. Calendar life is the timeframe before a battery start losing performance (Batterywali, 2018, Tamura, 2020). Cycle life and calendar life are co-dependent and will affect each other. Other factors like ambient temperature, former cycle history, state of charge (SoC), and capacity throughput will affect the battery life (Uddin et al., 2017). In the literature there are different statements about the average lifetime of the battery, around 8 - 12 years, but might live longer if properly managed.

By participating in V2G, the battery will increase the number of charge and discharge cycles. Since EV batteries cycle multiple times when used for frequency regulation, peak shaving, and load management, the battery degradation plays an important role (Tchagang and Yoo, 2020). They also found that the deeper the depth of battery discharge is used, the more the battery degradation is pronounced. Kolawole and Al-Anbagi (2019) conclude that excessive cycles will affect the battery life to a great extent, and therefor V2G will shorten the battery life. The same does Dubarry et al. (2017), where they state that additional cycling of the battery through V2G is destructive for the battery life. In his study, he opted for maximum revenue for the EV owner, and not considering battery health. On the contrary, the same year, Uddin et al. (2017) found that it is possible for V2G to extend the life of the battery of the EV. By integrating a battery management system communicating with the smart grid, to calculate the available capacity and condition of the battery, the battery degradation could be minimized, and V2G could lead to longer battery life. Wang et al. (2016) found through different parametric simulations that V2G will have minor impact on battery degradation.

4.2.3 State of Charge.

The state of charge in a battery is the charge, ranging from 0% to 100%, that is available relative to its capacity. The battery is fully charged at 100% and fully discharged at 0% (Abdi et al., 2017). The level of SoC the battery is stored at and the depth of discharge (DoD=100%-discharge%) affects the battery life. An optimal SoC range study has been conducted by many researchers. In a literary study done by Kostopoulos et al. (2020) there was a clear agreement among researchers that a SoC range between 20% and 80% would be optimal for battery health. Operating under or above this range would prove to be harmful for the battery.

4.3 CHAdeMO and CCS.

There are currently 4 fast charger standards. CHAdeMO (Charge de move), CCS (Combined Charging System), Tesla Supercharger and 43kW AC (Figenbaum, 2020). CHAdeMO and CCS are the most common ones, and so far, the only ones that can or are willing to contribute to V2G. CHAdeMO is a fast charging standard made for the Japan Electric Vehicle Fast Charger Association, and CCS a fast charging standard for the European Automobile Association (Setec-Power, 2020). Most fast charging stations in Europe include one or both charging standards, but car models and home charging systems are made according to one of the two standards (Fulari and Kaa, 2021).

4.3.1 CHAdeMO

CHAdeMO, introduced in 2010, is a rapid-charging standard, and can provide the EV battery with energy from 6 kW up to 150 kW (Beedham, 2020a). The CHAdeMO standard was made to make a fast charging DC standard that would be used by all sectors relying on DC charging (Saarinen, 2020). There are over 32 000 CHAdeMO charge points around the world, spread out over 88 countries (CHAdeMO, 2021). To this date only CHAdeMO is available for commercial and domestic bidirectional charging (Kane, 2020, Fulari and Kaa, 2021)

4.3.2 CCS

CCS was introduced to the EV market in 2012 by German car manufacturers. It is the European and U.S markets answer to a rapid DC charge competitor to CHAdeMO. Different from CHAdeMO, CCS is an open international standard, meaning that all car manufacturers can use it (Beedham, 2020b). The charging system connector can provide the EV with power from 25 kW up to 350 kW. In Europe there are 11 000 CCS charging connector available, and in the U.S there are 2400 (Mathieu, 2020, Energy.gov, 2020). The CCS standard have their goals set on being V2G compatible within 2025 (Klingenberg, 2019, Kane, 2019).

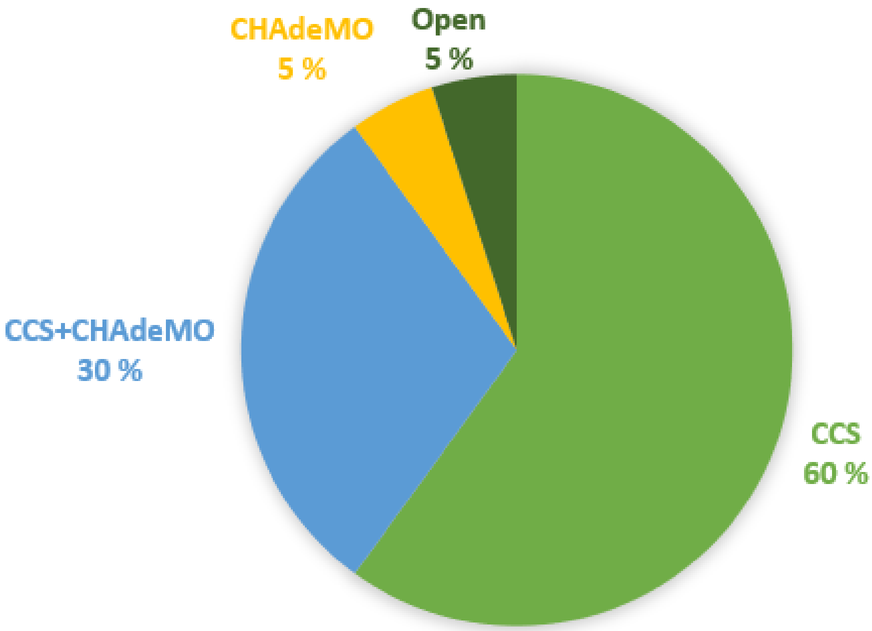


Figure 14 the share of top 20 car manufacturers who use CHAdeMO or CCS (CharIN, 2020).

Even though CHAdeMO has the most charging points set out globally, there are more car manufacturer that use CCS, see figure 14. The EU have demanded that all fast charging stations in Europe shall implement the CCS standard (Klingenberg, 2019).

4.3.3 ISO 15118.

The International Organization for Standardization (ISO) are releasing in 2021 the ISO 15118-20 which is building on the ISO 15118 *Road vehicles- Vehicle to grid communication interface.* This standard will outline the V2G communication interface for EVs to charge/discharge from/to the grid.

ISO 15118 have had some securities issues (Bao et al., 2018), but the new ISO 15118-20 addresses the safety issues concerning the large information data flow between the EV and the grid (Roman et al., 2018). In 2019, EVs which are IS0 15118-enabled, entered the market (Audi e-Tron, Porsche Taycan), but these do not support bidirectional charging as of now (Mültin, 2019). A general and applicatory framework for V2G communication has been missing until now. The ISO 15118-20 can be the push needed to scale up the V2G-technology use. A new global standard will help bring certainty to all participants, enable bidirectional charging for more EVs, and may accelerate the introduction of V2G (CHARIN, 2021, Virta, 2019).

4.4 V2G Compatible Cars and Domestic Chargers.

4.4.1 V2G Vehicles.

Table 2 Overview of V2G compatible vehicles.

Car model	Vehicle type	Connector	Estimated sales
Nissan LEAF	Passenger EV	CHAdeMO	>500 000
Nissan e-VN200	Van	CHAdeMO	>200 000
Mitsubishi Outlander PHEV	Passenger PHEV	CHAdeMO	>250 000

The Nissan Leaf is the pioneer for today's modern EVs. It was first introduced in 2010 as world's first mass-market EV (Nissan, 2020). Over 500 000 units have been sold globally. Already in 2012 Nissan made it possible for their costumers to power households with their Nissan Leaf, via V2H. The inspiration for Nissans fast adoption of V2G technology have been the rate of natural disasters in Japan posing threats for the energy system, especially the earthquake in Fukushima in 2011 (Costello, 2020). Being able for bidirectional power flow, the EVs can serve as emergency power supply. Since its launch, the battery of 24 kWh and 200 km range have now been replaced by 65 kWh battery and 458 km range. To this day the Nissan Leaf is the only passenger EV available for V2G. Nissan have also released the e-VN200, which is a V2G compatible van. The Mitsubishi outlander PHEV can also participate in V2G.

4.4.2 Car manufacturers that will participate in V2G.

BMW announced in 2019 a press release that they are starting real world trials on V2G with their i3 cars in 2021 in Germany (BMW, 2019). Audi reports, as well, that they will be available for grid integration and V2G from 2022 (Audi, 2020). Additionally, Volkswagen have reported they will participate in bidirectional charging, launching bidirectional charging in their vehicles and charging systems (Volkswagen, 2020). Volkswagen have plans to compete with energy companies and have projected that their EV fleet have 350 GWh storage available for V2G within 2025, and up to 1 TWh within 2030 (Reuters, 2020). These will follow the ISO 15811 standard and use CCS connectors. EV favourite Tesla have so far proclaimed that they will not make their cars available for V2G, this might be because they already offer a stationary battery for additional storage called the power wall.

Examples of other car manufacturers that have participated in V2G trials or are planning on participating in V2G: **Honda, Polestar, Renault, Fiat Chrysler, Jeep, Mercedes, Ford, Toyota, Hyundai, Citröen, Kia.**

4.4.3 Bidirectional chargers.

Table 3 Overview of domestic bidirectional chargers.

Producer	Connector	Price in 2020	Charge/discharge rate
Indra Renewable Technology	CHAdeMO	£ 2500	6 kW
Wallbox	CHAdeMO	$ 4000	7,4 kW

Indra released the first domestic bidirectional charger back in 2018. Although first recorded price of £15 000 when developing the charger, they now say they can deliver domestic bidirectional charging solutions down to £2 500. Wallbox, a developer of smart chargers for EVs, released their bidirectional charger, The Quasar, in 2020. At time of release, they said the cost of the bidirectional charger would be around $4000. Both chargers are connected to software, and app where the EV owners can schedule charging, update preferences and track charging history (INDRA, 2021)

Because the CCS fast charging standard is dominant in the European and U.S market, and CCS have a set goal on being available for V2G within 2025, the development of CCS chargers is in the works. Indra technologies have received a grant of £350 000 (4 million NOK) for research and development of a CCS bidirectional charger, and their goal is to have sold 20 000 of these chargers within 2025. The project is called “CCS V2X” and will end sometime in 2021 (UKRI, 2020). Volkswagen is also working on their CCS DC wallbox which can provide up to 22 kW power, it is currently under trials in Germany (Volkswagen, 2020)(Lambert, 2020).

5 Economy

There are several economic factors that affect the future growth of V2G. There are three primary interests in V2G, the vehicle manufacturers, vehicle owners, and the grid operators. Consumers must be willing to pay for the V2G capability, therefore, manufacturers should find a price range that is perceived as reasonable for the customer. The EV owner participating in ancillary services for the grid should be compensated financially and be confident in that the car can provide the necessary driving range. The grid operators must also gain benefits from V2G to recompensate for the monitoring and controlling V2G power flow (Steward, 2017). What sets V2G apart from other forms of distributed storage is its lower expected capital costs, since it capitalises on the batteries purchased for the transportation function (Lauinger and Vuille, 2017)

5.1 EV Price Development

The cost of the EV battery makes up for around 50% of the total cost of an EV. Battery costs have been reduced by a factor of 4 since 2008 and are set to decrease further (Thompson, 2018). From 2010 to 2020 the battery price of a lithium ion battery have fallen with almost 90 % , which has boosted EV sales up to 40% the last 5 years (IEA, 2021). Battery price has fallen from 1100$/kWh to 137 $/kWh, a price of 58 $/kWh within 2030 is expected (Bloomberg, 2020). When prices go under 100$/kWh, EVs will become cheaper to buy than conventional ICE vehicles. If this trend continues, the result is cheaper EVs with greater range, making them accessible for a wider variety of consumers. Price of EVs will also decrease because of increased competition between the different car manufacturers. Most car manufacturers have plans for an all-electric fleet within the next decades, as national policies demand it.

5.2 Cost of Charging Infrastructure

The Indra bidirectional charger cost was 15 000 £ (ca. 180 000 NOK) back in 2015 when the OVO U.K trials started (CENEX, 2021). This was too expensive, and they were ultimately able to deliver bidirectional chargers to their trial participants with a cost of 5 500 £ (ca. 64 000 NOK) in 2019. Sagvolden (2020) estimates a price of 54 000 NOK for the bidirectional charger. The Wallbox Quasar is said to cost 4000 $ (35 000 NOK)(Wallbox, 2020). Indra also report that their chargers now cost down to 2500 £ (30 000 NOK) per unit (Pakenham, 2020). Element Energy (2019) predicts chargers will cost around 1 000 £ (around 10 000 NOK) within 2030. This cost reduction is illustrated in figure 15.

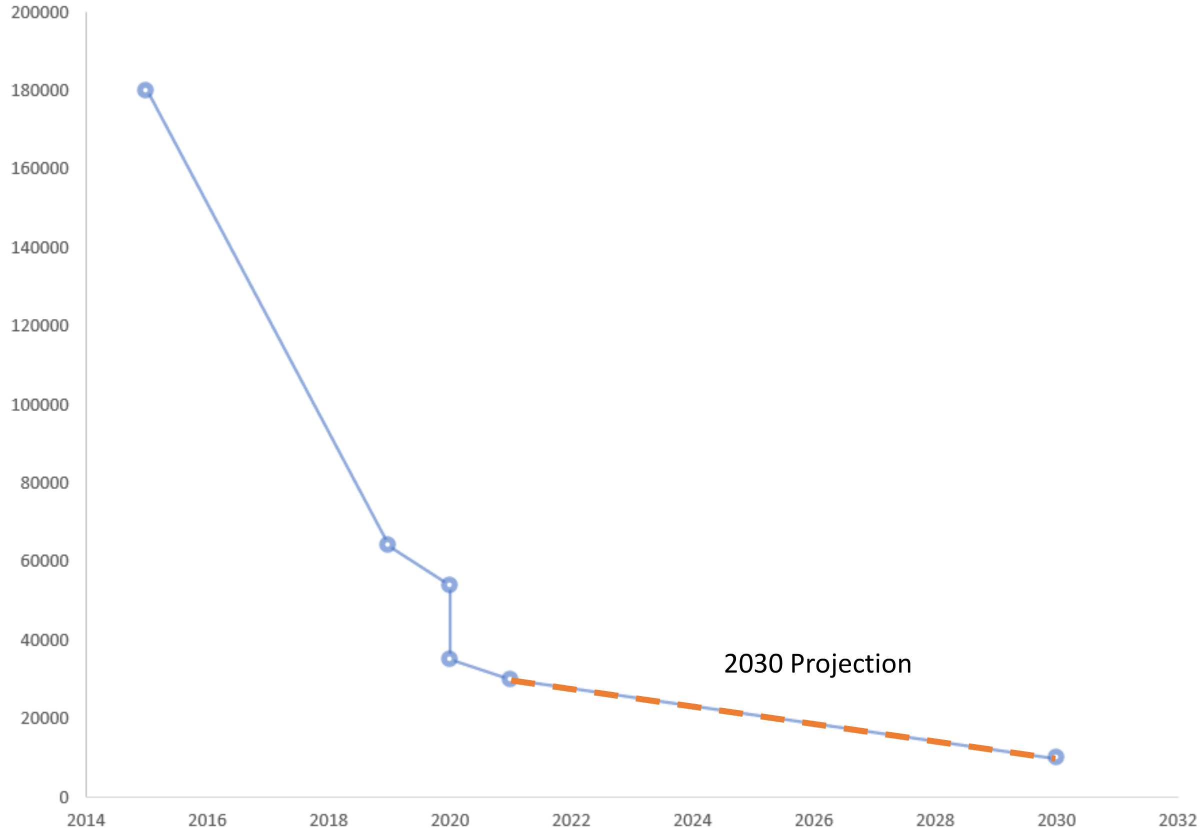


Figure 15 The cost of the bidirectional charger from 2015 to 2030. The decrease in cost/per unit produced from 2021-2030 is the estimate and projected scenario from (Element Energy, 2019).

5.3 Revenue for EV Owners and Grid Operators

5.3.1 EV Owners

In chapter 3.7 it was mentioned that smart charging can reduce electricity cost for the EV owner. V2G can not only reduce charging cost, but also be profitable in terms of revenue. There is an established agreement that the economic value using V2G compared to smart charging is considerable (Payne and Cox, 2019, White and Zhang, 2011, Schmidt, 2020). From a study in the U.K, OVO energy showed that with a plug-in rate of 75% the V2G charger could earn 436 $ a year (ca. 5 000 NOK) (Payne and Cox, 2019). The average monthly earnings from V2G participation in this study was 60 £ (700 NOK) , some earning up to 130£ (1 500 NOK) (Pakenham, 2020). Greaker and Hagem (2020) found in their study that smart charging could save up to 1 000 NOK and V2G could save up to 10 000 NOK each year by households that chose to use the energy stored in the battery themselves.

5.3.2 Large consumers

Consumers that have high demand for power and electricity, like large companies and energy intense industries, pay power tariffs. These tariffs are paid because they demand more power than other consumers and therefore take up a larger share of the load the grid can transport. These companies and industries can benefit from using V2G, as total load would reduce in peak hours, ultimately reducing the tariff cost.

5.3.3 Grid Operators

A study from the U.K found that the system operation cost could reduce from 412 – 883 million pounds per year (4 -10 billion NOK) with V2G. Smart charging and uncontrolled charging could on the other hand increase the grid operating cost with 102-150 million pounds and 567-773 million pounds, respectively, because of the higher demand placed on the grid (Oldfield et al., 2021, Grundy, 2021). As the storage capacity is already paid for by the EV owner, the grid operators save expenses when these vehicles participate in valuable ancillary services. In Norway there has been estimated a saved grid investment cost up to 15 billion NOK, if a significant number of EVs can charge their EVs in off-peak hours (Wangsness and Halse, 2020).

5.4 Externalities

A conventional vehicle that run on fossil fuels have one area of use, transportation. EVs on the other hand, offer benefits for the consumer and third parties. An externality is a societal cost or benefit that the producer/consumer is not financially accounted for. The externality can be positive or negative, and can stem from both production or consummation of a goods or service (Kenton, 2020). A positive externality of incorporating V2G is the possibility of integrating more VRE into the grid. V2G can provide storage and flexibility for renewable energy, and therefore, help displacing more conventional fuel sources, as illustrated in figure 14 (Noel et al., 2019). When demand is low (D_L) the vehicles charge, increasing storage capacity, and when demand peaks (D_P) this storage capacity is sent back out to the grid, increasing the share of renewables in the energy mix (Kempton and Tomic, 2005b).

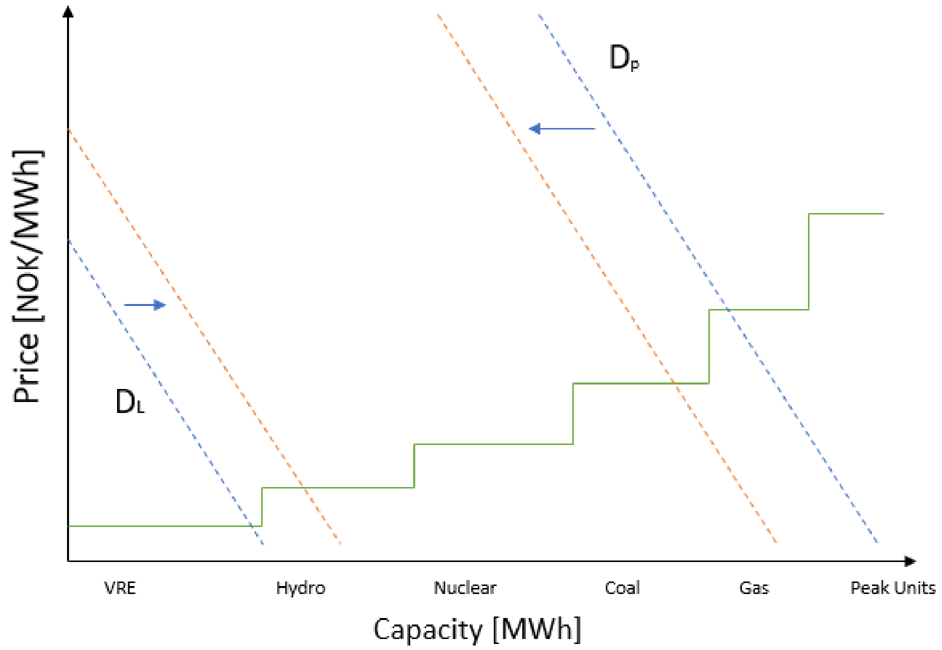


Figure 16 Merit order curve.

In the report Global EV Outlook, IEA (2020) assume that if V2G met peak demand instead of peak power generation from fossil fuels, 330 Mt CO2 emissions could be avoided globally. In the U.K a study found that more use of VRE production as a result of using V2G could amount to CO2 savings of 6 Mt each year(Cox, 2021). Oldfield et al. (2021) presume that each vehicle could contribute to CO2 savings around 60 t per year.

6 Social Acceptance

The successful establishment of V2G as a viable competitor to other flexibility sources depends not only on technology, but also on social acceptance (Burkert et al., 2021). The key to large scale deployment of V2G is the acceptance and willingness to participate from consumers. They determine the availability of the EV and therefore the availability of storage supply to the grid. The social aspect of V2G have not been explored to the same extend like other aspects influencing V2G deployment (Reynolds, 2018), and less than 3% of peer-reviewed literature investigate the social acceptance of V2G (Sovacool et al., 2018). Heuveln et al. (2021) conducted a semi structured interview to get an overview of user acceptance to V2G in the Netherlands, the two most important factors affecting their view on V2G were Range anxiety, battery degradation and low availability of charging infrastructure (Shariff, 2019). Awareness of V2G is also a challenge, not all consumers know about it and the potential benefits.

6.1 Range Anxiety

One of the biggest factors influencing social acceptance of V2G, and EVs in general, is range anxiety. There have been conducted many studies on the concept of range anxiety. In the literature there can be found several definitions, but all in all range anxiety is the fear of being stranded because of insufficient driving range in the EV. People's habits and daily commuting rarely changes, but the driving range of EVs have drastically improved the last decade. Range anxiety is also less prominent in EV owners who have other options, like multi-vehicle households, and those who own PHEVs (Element Energy, 2019).

A literature study done by Xu et al. (2020) found several sources looking at how the battery state of charge affected the EV driver. The range anxiety would negatively affect the driver as soon as the battery capacity fell below 50%. Viola (2021) points out that the public perception of EVs is that they are low-range vehicles due to limited battery capacity.

Nilsson (2011) found several approaches to mitigate range anxiety, and deployment of more fast chargers to decrease the chances of the SoC falling below a threshold of the EV driver is important. Yuan et al. (2018), like other studies, found that accessibility to charging infrastructure is important to help decrease range anxiety. Heuveln et al. (2021) found that more people were willing to participate in V2G, because the availability of fast charger infrastructure in the Netherlands reduced the concern of insufficient range. Surveys show that home charging is preferred among EV owners (IEA, 2018). Access to public charging infrastructure is still very important. It is vital to alleviate range anxiety and increase range during long trips. In cities and urban areas where most people live in apartment complexes access to public charging is crucial (IEA, 2020).

6.2 Experience

Rauh et al. (2014) found in their article “Understanding the Impact of Electric Vehicle Driving Experience on Range Anxiety” that experienced EV drivers had less negative range anxiety than inexperienced EV drivers. Burgess et al. (2013) show that the charging behaviour changes as the EV owner gain confidence in their vehicles range. Distance travelled increased with 15% as the owner gained experience and took more trips with their EV in-between charging. A study by Jensen et al. (2013) found that acceptance changed after the consumers had gained experience. From the OVO trials in the U.K with over 300 consumer participants, concerns about V2G among the participants had reduced after the trials (Pakenham, 2020).

6.3 Governmental acceptance

Governmental support is also crucial in an early market. If the cost of a technology is too expensive to ensure deployment, government can intervene and provide incentives and subsidies to help escalate roll out in the market. Incentives and subsidies can encourage deployment by making more attractive for consumers, also reducing risk for stakeholders. This is what the Norwegian government did with the EV, they relieved the consumers from road tax and toll on roads and ferries, gave them free access to parking and bus lanes and more. Norway now has the most EVs per capita. The policy contribution to the learning effect of the EV have resulted in lower costs for EV worldwide (Brynildsen, 2016). Grants can also be given for more extensive R&D, which increase learning and reduce cost.

7 Method

The relevant information and theory on drivers and barriers have been covered, and now it is time to present the methods used to obtain background information and to execute the case presented in chapter 8.

For finding drivers and barriers of future deployment of V2G; A literature review has been conducted for all categories (Market, Technology, Economy and Social Acceptance). There is also conducted a mathematical evaluation on the bidirectional charger by looking at the present-value (PV) and technology learning. A semi structured interview is also conducted to complement the literature study.

7.1 Market

7.1.1 Literary review

To identify drivers and barriers that affect viability of V2G technology a literary review has been conducted. A literature review is a critical summarization of the research already done on a selected topic. The aim of the literature review is to find out what has already been studied and provide the reader with a critical overview.

The literature review in this thesis has a thematic approach, centred around some key-topics. Studies and analysis have been done on V2G since 1997, when Willet Kempton first introduced the idea. Using the search word “V2G” in Google Scholar will result in 38 200 matches, which is too many to read and analyse. To narrow the search results, the library database for the Norwegian University of Life Sciences, Oria, was used. A search for “V2G” here, resulted in 2 827 matches. To narrow down the search even more, only articles from peer-reviewed journals from the last 10 years was chosen. Using the boolean operators AND and OR; AND when two keywords must appear together in the article, OR when the article must have either one of the keywords.

So, for finding relevant studies on V2G where the main objective is to find factors and drivers that influence the future deployment on V2G, the keywords used in Oria was: **V2G OR vehicle-to-grid, drivers OR factors, challenges OR barriers, adoption factors, market OR electricity market, Flexibility market OR balancing market, ancillary services, last 10 years.**

Various articles were chosen, based on title and abstract.

Reports from V2G trials are also included in the reference list, as they contain valuable and new insights to what the benefits and challenges to V2G are, and how the technology is developing.

7.3 Technology

Keywords used to find relevant literature on technical barriers and – development: **Lithium ion OR Li-ion, Battery degradation, Battery health AND SoC, Charging standard AND communication standard, CCS AND CHAdeMO.**

7.3.1 Technology Learning

There is constructed a learning curve, based on the cost data found in the literary review. Learning rates have also been found from the literature. A learning curve depicts the relationship between cost of a unit produced and number of units produced and is a good indicator of the technology development. The graph in figure 17 shows that initial learning will result in the most cost reduction. More units produced will subsequently result in lower cost reduction, until steady state phase occurs. At this phase cost reduction is difficult (Kagan., 2020).

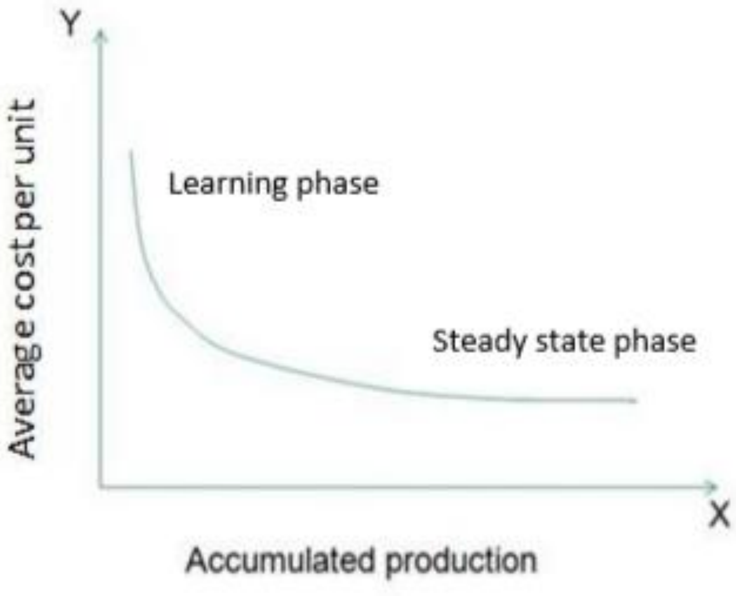


Figure 17 The Learning curve (Martinsen 2010).

The learning curve is often described by the function.

Equation 1 Learning curve.

$$C(X_p) = C_0\left(X_p/X_0\right)^{-E}$$

- C_0 is the initial cost.
- E is the learning parameter.
- X_p is the accumulated production.
- $C(X_p)$ is the resulting cost.

The learning rate is the rate of learning for every iteration of production. For every doubling of production, the costs fall with a constant percentage.

Equation 2 Learning rate.

$$LR = 1 - PR = 1 - \frac{C_0\left(2x_p\right)^{-E}}{C_0\left(x_p\right)^{-E}} = 1 - 2^{-E}$$

- $C_0(2x_p)$ is the doubling of production.
- Where 2^{-E} is called the progress ratio (PR).
- Learning ratio (LR)= $1-2^{-E}$

Since accumulated production is unknown, the learning rate has been estimated. By looking to Dutton and Thomas (1984) who found that the average learning rate is 20%, and McDonald and Schrattenholzer (2001) who found that the most common learning rates are around 8-10% and 20%. Technologies that build on other technologies that have already experienced technology learning, will often have a lower LR. (Element Energy, 2019) used the photovoltaic inverter as a proxy and estimated a LR of 11% and 15%.

Based on these, learning rates of 10% and 15% have been used in constructing learning curves for the domestic bidirectional charger.

7.4 Economy

Keywords used to find relevant literature on the socio-economic aspect of V2G: **Profit, EV owner, Grid Operator, investment cost, Bidirectional charger, Emission reduction OR CO2 reduction.**

7.4.1 Electricity cost

To find the potential revenue for the EV owner the electricity bill is an important parameter. The electricity contract from Hafslund (2020) is used for reference. This is the most popular electricity contract amongst their consumers.

Equation 3 The electrical cost over a year.

$$C_E = (fixed\ cost)\left(\frac{12_{months}}{year}\right) + \left(0{,}0695\,\frac{kr}{kWh}\right)\left(kWh_{year}\right) + \sum_i^{8760}(spotprice)_i(kWh)_i$$

The electric cost for the consumer is based on a fixed cost, a variable cost based on spot-price, and a fixed surcharge. The fixed cost will not change for the consumer if they participate in V2G or not, and the surcharge is also the same since the power used from the storage capacity in the EV during peak hours must be recharged sometime during low peak hours. Therefore, the spot price is the only factor from the electricity bill that was accounted for in the presented cases in chapter 8.

For larger consumers, the electricity contract from Elvia (2021) was used for reference.

Equation 4 Electricity cost, CE, for the large consumer.

$$C_E = (fixed\ cost)\left(\frac{12_{months}}{year}\right) + kW\left(\frac{kr}{kW}\frac{12_{months}}{year}\right) + \sum_i^{8760}(spotprice)_i(kWh)_i$$

In equation 4, the two factors being affected by V2G, is the variable cost for energy consumption and the cost for power, called a power tariff.

7.4.2 Revenue from V2G

The revenue from V2G participation can be found by subtracting the cost of electricity during low demand hours, when the battery is charged, from the electricity cost during peak demand hours, when the battery is discharged. The revenue from a private consumer was found from equation 5.

Equation 5 Revenue for a private consumer from V2G.

$$R_{V2G} = \sum_{i}^{8760} \left(spotprice_{peak}\right)_i (kWh)_i - \sum_{i}^{8760} (spotprice_{low})_i (kWh)_i$$

For a large consumer, V2G can help reduce power tariff costs ($kW_{reduced}$).

Equation 6 Revenue for a large consumer.

$$R_{V2G} = \sum_{i}^{8760} \left(spotprice_{peak}\right)_i (kWh)_i + kW_{reduced} \left(\frac{kr}{kW}\right)\left(\frac{12_{months}}{year}\right) - \sum_{i}^{8760} (spotprice_{low})_i (kWh)_i$$

7.4.1 Present Value (PV)

Present value is used to calculate the value of an investment today, based on future inflow of payments (Bøhren and Gjærum, 2016, Fernando, 2021). The present value of future yearly revenues from V2G was calculated for each case, the private consumer with a small and large battery, and the large consumer.

Equation 7 Present Value (PV)

$$PV = \sum_{n=1}^{N} \frac{a_n}{(1+i)^n}$$

Where:

a_n is expected earnings/savings in year n

i is the discount rate.

n= number of periods (years)

The number of periods for each case is equal to the estimated lifetime of a bidirectional charger.

The PV for each case was then used to find the necessary investment cost for the bidirectional charger.

7.5 Social

Keywords used to find relevant literature on the socio-economic aspect of V2G: **Social Acceptance, Consumer, Range Anxiety, barriers, experience, V2G.**

7.5.1 Semi structured interview (SSI)

Compared to a highly structured survey, which have large sample sizes, an SSI have a smaller focus group. The participants in the focus group have been specifically chosen as they have knowledge and rich insight in the specific field that is explored in this thesis. An SSI allows for open ended questions, letting the interviewee explain and go into depth about their opinions and experiences. It is a useful method when research is still in early stages and more investigation is deemed necessary. The SSI is conducted for the purpose of supplementing the literature review and to hear others' opinions on the topic. Scenario analysis can be used for estimating a products market chances (Blok and Nieuwlaar, 2016).

The focus group was chosen because they represent interests considering V2G and have extensive knowledge about the grid and electricity supply in Norway. The conversations lasted from 30 minutes to 1 hour where they explained what they thought of V2G and the possible barriers.

8 Case studies

The case studies are in the standpoints of the end-user. The potential revenues have been calculated for the private consumer and the large consumer. The private consumer uses residential parking, and a case with large battery pack and small battery pack have been evaluated. The large consumer is in this case an airport, and the cars are parked in a longtime parking garage, where 10 bidirectional chargers have been installed.

8.1 Market, Technology, Economic and Social Assumptions

The case takes base in Norway, and spot prices are collected from NordPool. Electrical prices are determined from a representative weekday during winter and summer 18th of January 2019 and 18th of June 2019. Peak prices and low demand prices are determined from each of the representative days. Assuming winter lasts 6 months and summer 6 months, these prices are used for each half of the year.

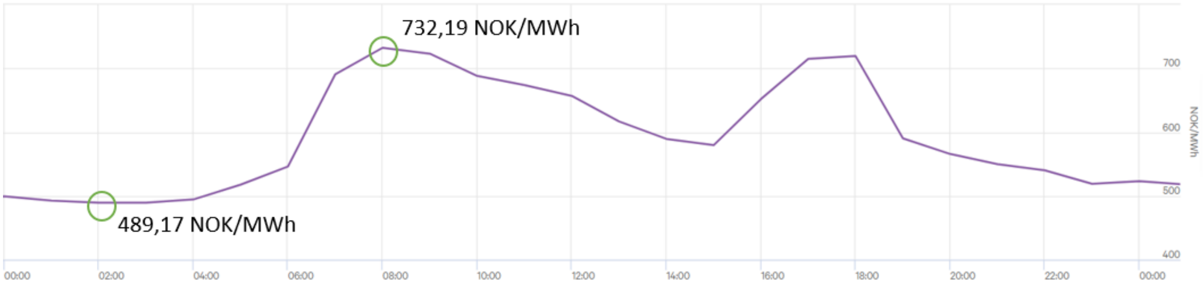


Figure 18 El-spot prices NOK/MWh January 18th, 2019, Oslo, Norway. Peak price (732,19 NOK/MWh) and low demand price (489,17 NOK/MWh) are marked with green circles (NordPool, 2021).

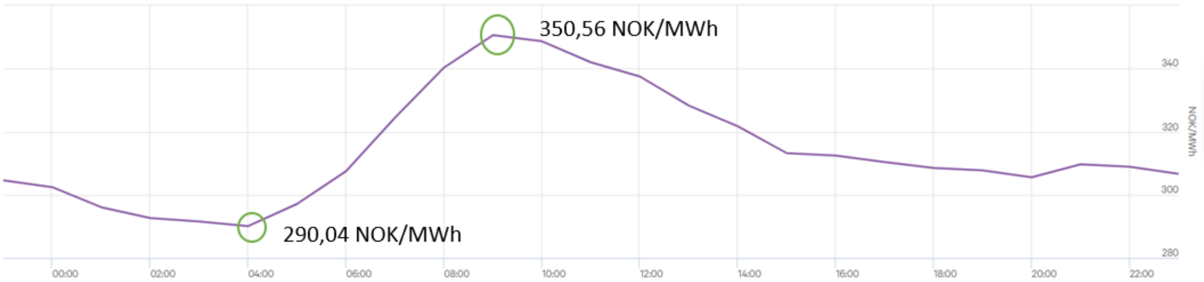
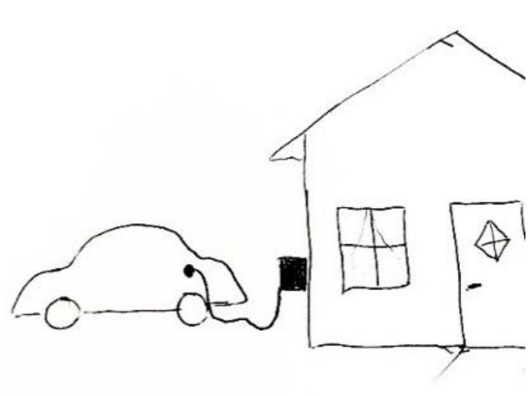


Figure 19 El-spot prices NOK/MWh June 18th, 2019, Oslo, Norway. Peak price (350,56 NOK/MWh) and low demand price (290,04 NOK/MWh) are marked with green circles (NordPool, 2021).

Assuming no battery degradation as a result of V2G participation on the basis of the study conducted by Uddin et al. (2017), this also means that vehicle is communicating with a smart grid, and the battery is kept at a SoC range between 20-80% for optimal battery health. This SoC range is chosen as it will allow for energy sold to the grid, and with the vehicle charged back up to 80% every night before the EV is used for driving, it will not trigger range anxiety. In the two cases for the private consumer, the daily average driving range in Norway, 47,2 km (Hjorthol, 2014), is accounted for.

Assuming the lifetime of the bidirectional charger to be 10 years. So, the present values from the future yearly revenues are calculated over n=10 periods. For this case, the discount rate is set at 6%.

8.2 Small consumers: Residential parking



V2G is available for home bidirectional charging for private consumers. For an EV owner, V2G presents the opportunity to participate in grid services, like peak shaving and frequency regulating. They can also use the energy stored in the EV battery to supply energy to the house (V2H) and reduce their own demand from the grid. In this case the EV owner wants to use the energy stored in the EV to supply electricity to the house.

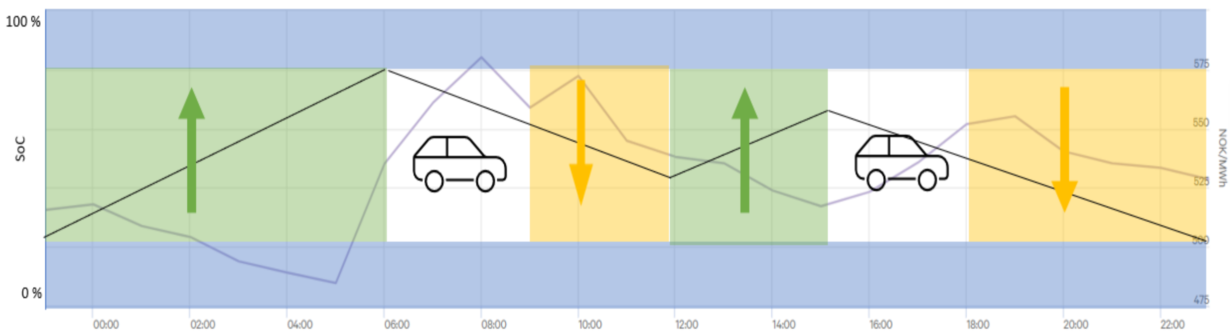


Figure 20 Illustration of the daily charge-discharge cycle as a response to price signals from the grid and a 20-80% SoC range, also taking into consideration driving needs.

8.2.1 EV with larger batter

In 2020 the Audi E-Tron was one of the most sold cars in Norway. It has a 95 kWh battery and a 446 km driving range (Brusletto, 2019). Energy use per km drive during the summer and winter is 216 Wh/km and 263 Wh/km, respectively. Considering the average daily driving range for Norway and energy use per km it is easy to find the energy left available for V2G, see table 4. In table 5 the SoC range of 20-80% and 10 % loss in DC→AC conversion is addressed, and 44,34%$_{\text{Summer}}$ and 42,25%$_{\text{winter}}$ of the total battery capacity is available for V2G.

Table 4 How much energy is left in the battery after daily driving needs.

Season	Daily driving range	Energy use/km	Energy use/day	Energy available
Summer	47,2 km	0,216 kWh/km	10,195 kWh	84,805 kWh
Winter	47,2 km	0,263 kWh/km	12,413 kWh	82,587 kWh

Table 5 The percentage of energy left to be sold to the grid considering the 20-80 % SoC range and 10% energy loss due to DC-AC conversion.

Season	% Of energy used for driving	% Of energy left for V2G services	Energy sold to the grid
Summer	10,73 %	49,27 %	44,34 %
Winter	13,06 %	46,94 %	42,25 %

Assuming the vehicle can sell to the grid or provide the household with all the power available for V2G at peak price, total savings for one day is 14,74 kr for summer and 29,30 kr for winter, as shown in table 6. Table 7 shows how much it costs to charge back up the battery the same amount of energy used for V2G, but in this case the AC→DC conversion loss is not paid for by the consumer. Table 8 shows how much it costs for charging back up the battery the same amount used for driving.

Table 6 Shows the daily savings from using the energy stored in the battery at peak price for the Audi E-Tron 55 Sportback.

	Energy sold to grid	Peak price	Savings/day
Summer	42,12 kWh	0,35 kr/kWh	14,74 kr
Winter	40,14 kWh	0,73 kr/kWh	29,30 kr

Table 7 The daily cost of charging back up the same amount of energy used for V2G.

	Charge	Low demand cost	Cost/day
Summer	46,80 kWh	0,29 kr/kWh	13,57 kr
Winter	44,59 kWh	0,49 kr/kWh	21,85 kr

Table 8 The daily cost of charging up the same amount of energy used for driving.

	Charge	Low demand cost	Cost/day
Summer	10,195 kWh	0,29 kr/kWh	2,95 kr
Winter	12,413 kWh	0,49 kr/kWh	6,08 kr

By participating in V2G, revenue made on V2G is 1 573 kr/year. The cost of charging the car back up for the same amount used for driving is 1 647,97 kr, shown in table 9. The total cost of charging that year, has been reduced to 74,82 kr for the EV owner.

Table 9 Overview of revenues and cost from participating in V2G.

Per year	Price in NOK [kr]
Earned on V2G	8 037,30
Cost of charging back up same amount	6 464,15
Revenue on V2G	**1 573,15**
Cost of charging back up for driving capacity	1 647,97
Total cost of charging	74,82 kr

Using equation 7 to find the present value where future cashflow is based on the revenue made on V2G, and a discount rate of 6%, and estimated bidirectional charger lifetime of 10 years.

Table 10 Present value of future cashflow with big EV battery.

Charger lifetime [n]	PV
10 years	11 577,41 kr

8.2.2 EV with smaller battery

Nissan LEAF is one of the most popular EVs worldwide and the only passenger full electric vehicle that offers V2G. The battery capacity used for this case is 40 kWh and it has a 270 km driving range (NAF, 2019). Considering the driving needs of the EV owner, the 20-80% SoC range and 10% DC→AC conversion loss, the available energy left for V2G participation is 16,54 kWh for summer, and 14,58 kWh for winter.

Table 11 How much energy is left after daily driving.

Season	Daily driving range	Energy use/km	Energy use/day	Energy available
Summer	47,2 km	0,119 kWh/km	5,616 kWh	34,384 kWh
Winter	47,2 km	0,165 kWh/km	7,788 kWh	32,212 kWh

Table 12 The percentage of energy left to be sold to the grid considering the 20-80% SoC range and 10% DC→AC conversion loss.

Season	% of energy used for driving	% of energy left for V2G services	Energy sold to the grid
Summer	14,04 %	45,96 %	41,36 %
Winter	19,47 %	40,53 %	36,47 %

Table 13 Shows the daily savings from using the energy stored in the battery at peak price for the Nissan leaf.

	Energy sold to grid	Peak price	Savings/day
Summer	16,54 kWh	0,35 kr/kWh	5,79 kr
Winter	14,58 kWh	0,73 kr/kWh	10,64 kr

The cost of charging up the same amount of energy used for V2G and driving during low demand price is shown in table 14 and 15, respectively.

Table 14 The daily cost of charging up the same amount of energy used for V2G.

	Charge	Low demand price	Cost/day
Summer	18,38 kWh	0,29 kr/kWh	5,33 kr
Winter	16,21 kWh	0,49 kr/kWh	7,94

Table 15 The daily cost of charging back up the energy used for driving.

	Charge	Low demand price	Cost/day
Summer	5,62 kWh	0,29 kr/kWh	1,63 kr
Winter	7,78 kWh	0,49 kr/kWh	3,81 kr

By participating in V2G, revenue made on V2G is 2 998,47 kr/year. The cost of charging the car back up for the same amount used for driving is 2 421 kr, shown in table 16. The total cost of charging that year, has been reduced to 416,43 kr for the EV owner.

Table 16 Overview of yearly revenue, savings, and cost from V2G participation for a Nissan Leaf.

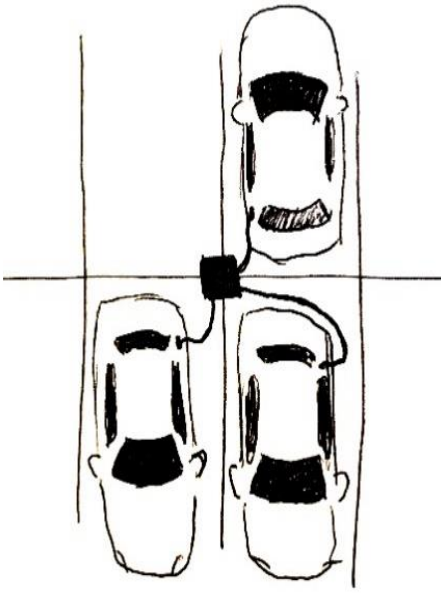
Per year	**Price in NOK [kr]**
Earned on V2G	2 998,47 kr
Cost of charging back up same amount	2 421,00 kr
Revenue on V2G	**577,47 kr**
Cost of charging back up for driving capacity	993,90 kr
Total	416,43 kr

Using equation 7 to find the present value where future cashflow is based on the revenue made on V2G, and a discount rate of 6%, and estimated bidirectional charger lifetime of 10 years.

Table 17 Present value of future cash flow with smaller EV battery.

Charger lifetime [n]	**PV**
10 years	4 250,22 kr

8.3 Large consumers: Long time parking



Airport parking is a good location for V2G. Cars are parked for days or weeks, and based on flight information, can easily be delivered with desired SoC back to the EV owner. Airports are large energy consumers, that have high electricity demands. Energy consumers over a certain size pay power tariffs, meaning they pay more because they demand more from the total load. Using V2G to reduce the power tariffs can be profitable for the large consumer.

Assuming 10 bidirectional chargers are located at the parking lot, 10 cars are always connected to the chargers. 5 Nissan Leaf and 5 Audie E-Tron. The bidirectional chargers have 10 kW charge and discharge rates. There are always 10 cars available for bidirectional charging, and it is a 100% plug in rate, meaning the chargers are plugged into a car 100% of the time.

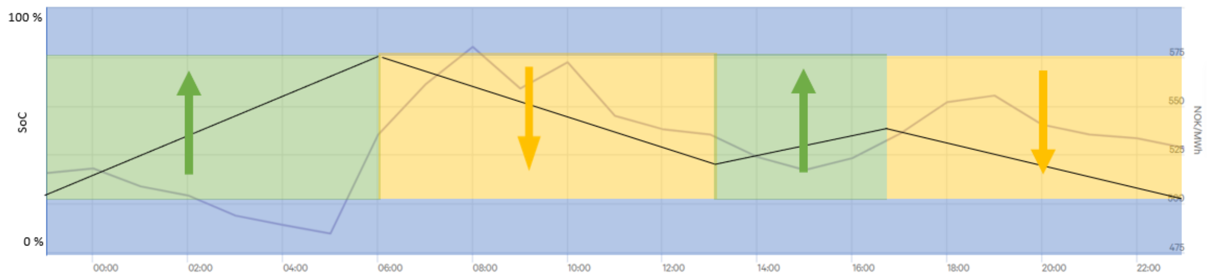


Figure 21 Illustration of the charge and discharge cycle as a response to price signals from the grid and a 20-80% SoC range.

Power tariffs are priced at 440 kr/kW for all power demand over 200 kW. The tariff is based on the highest demand over an hour (kWh/h) during the last 12 months (Elvia, 2021). A load reduction of 10*10kW in that hour of highest demand would result in a cost reduction of 44 000 kr that year. Since there is usually less demand during the summer in Norway (less energy used for heating), tariffs for the summer months are priced at 75% of maximum demand. Result in total cost reduction is presented in table 18.

Table 18 Price reduction because of lower demand.

Season	Load reduction	Power tariffs	Price reduction
Winter	100 kW	440 kr/kW	44 000 kr
Summer	100 kW	440(75%) kr/kW	33 000 kr
Yearly price reduction		38 500 kr	

8.3.1 Reduced cost from the EVs

The vehicle in this case is not used for driving and can therefore provide more capacity for V2G purposes, with a 20-80% SoC range, 60% is available for V2G for each car model.

Table 19 How much battery capacity is available for V2G considering no use for driving and SoC range of 20-80%.

	Battery size (kWh)	Available for V2G (%)
Nissan Leaf	40 kWh	60%
Audie E-Tron	95 kWh	60%

The daily revenue from participating in V2G for both the Audi E-Tron and the Nissan Leaf, during summer and winter is presented in table 20.

Table 20 Considering 10 % energy loss in conversion from DC to AC and peak prices during summer and winter, savings/day during summer and winter is calculated for the big battery car and the smaller battery car.

Season	Energy sold to the grid	Peak prices	Savings/day
Audi E-Tron			
Summer	51,30 kWh	0,35 kr/kWh	17,95 kr
Winter	51,30 kWh	0,73 kr/kWh	37,45 kr
Nissan Leaf			
Summer	21,60 kWh	0,35 kr/kWh	7,56 kr
Winter	21,60 kWh	0,73 kr/kWh	15,76 kr

The daily cost of recharging the car after V2G participation during low demand hours in summer and winter for each car model is presented in table 21.

Table 21 The total cost for charging the EV each day during summer and winter for Audi E-Tron and Nissan Leaf.

	Charge	Low demand price	Cost/day
Audi E-Tron			
Summer	57 kWh	0,29 kr/kWh	16,53 kr
Winter	57 kWh	0,49 kr/kWh	27,93 kr
Nissan Leaf			
Summer	24 kWh	0,29 kr/kWh	6,96 kr
Winter	24 kWh	0,49 kr/kWh	11,76 kr

Table 22 provides an overview of yearly total savings and revenue from participating in V2G.

Table 22 Total net revenue over 1 year for both Nissan Leaf and Audi E-Tron.

	Nissan Leaf	Audi E-Tron
Number of cars connected	5	5
Yearly earnings /per car	4 255,90 kr	10 110,50 kr
Yearly cost of charging / per car	3 416,40 kr	8 113,95 kr
Yearly net revenue/car	1 076,75 kr	2 368,85 kr
Total net savings from each model	**5 383,75 kr**	**11 844,24 kr**
Total savings from all cars	17 227,99 kr	
Savings from power tariffs	38 500,00 kr	
Total savings	**55727,99 kr**	

The total revenue per bidirectional charger is a 10th of total savings, and this value is used for calculating present value.

Charge lifetime [n]	PV
10 years	41 016,28 kr

9 Results

9.1 PV and learning curve

Table 23 Overview of present values

	Present Values
Small consumer large battery	11 577,41 kr
Small consumer small battery	4 250,22 kr
Large consumer	41 016,28 kr

The learning curve was calculated with a 10% learning rate from today's scenario. A 10% Learning based on the learning rate from (McDonald, 2001), and the low deployment learning rate scenario described in (Element Energy, 2019). A Learning curve with 15% learning rate is also presented.

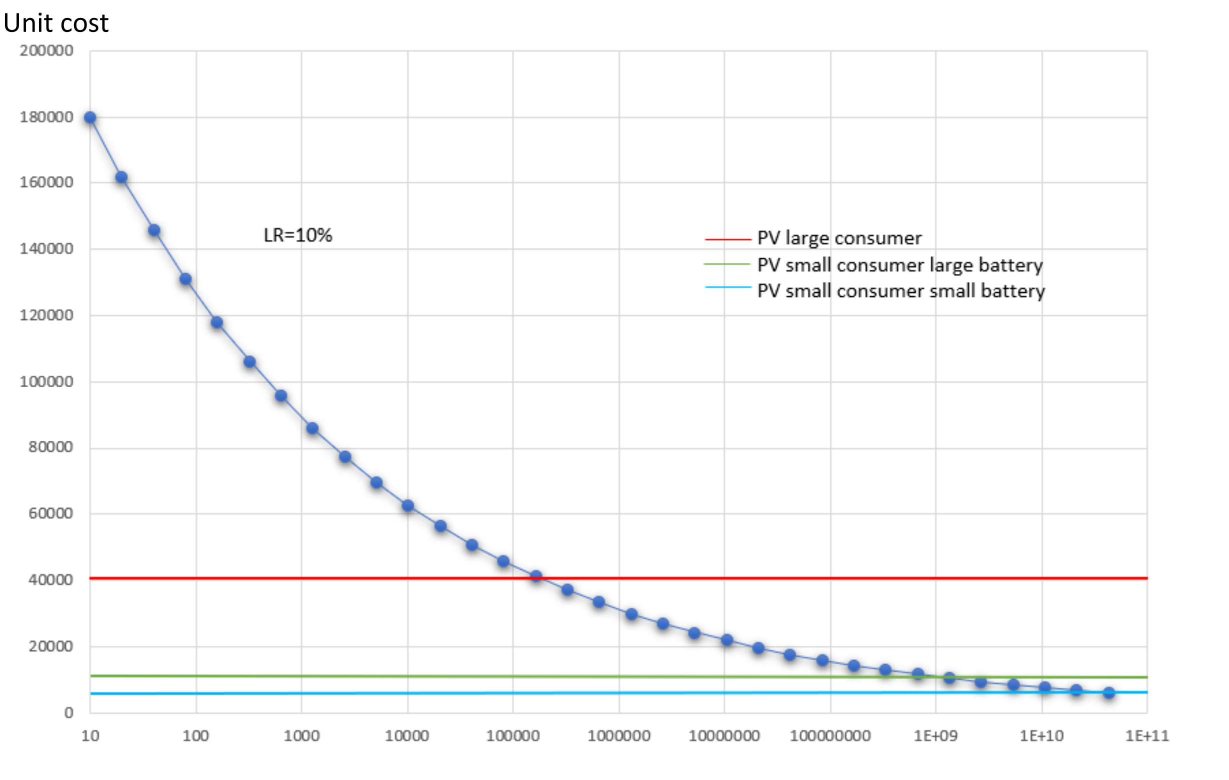


Figure 22 Learning curve where C0=180 000 NOK, X0=10 units, LR=10 %.

The learning curve in figure 22, accumulated production starts at a cost of 180 000 NOK. It is chosen 10 units produced at this price. Red line indicates the breakeven cost for the large consumer, green line is the breakeven cost for the small consumer with large battery, blue line is the breakeven cost for the small consumer with small battery. The breakeven costs are the present values from table 23. From the learning curve it shows that for large consumers, participating in V2G is profitable for charger prices below 41 016 kr. For the larger battery vehicle charged at the residence, the investment in a bidirectional charger will become profitable when the cost of a charger reaches prices under the present value of 11 577 kr. With a 10 % learning rate, it would have to be deployed around 1 billion bidirectional chargers for the cost to decrease to a sufficient level. For the small battery EV, it would not seem that V2G would be profitable for the EV owner.

With a learning rate of 15%, and all other factors alike, the profitability of V2G for the private consumer with a large battery will come at a faster rate, see figure 23. With right over a million deployed bidirectional chargers, the unit cost could reach a level profitable for the EV owner with large battery. Profitability for the small battery EV owner is also more likely. A deployment of 20-30 million chargers, could decrease the cost down to a level which would make V2G participation valuable.

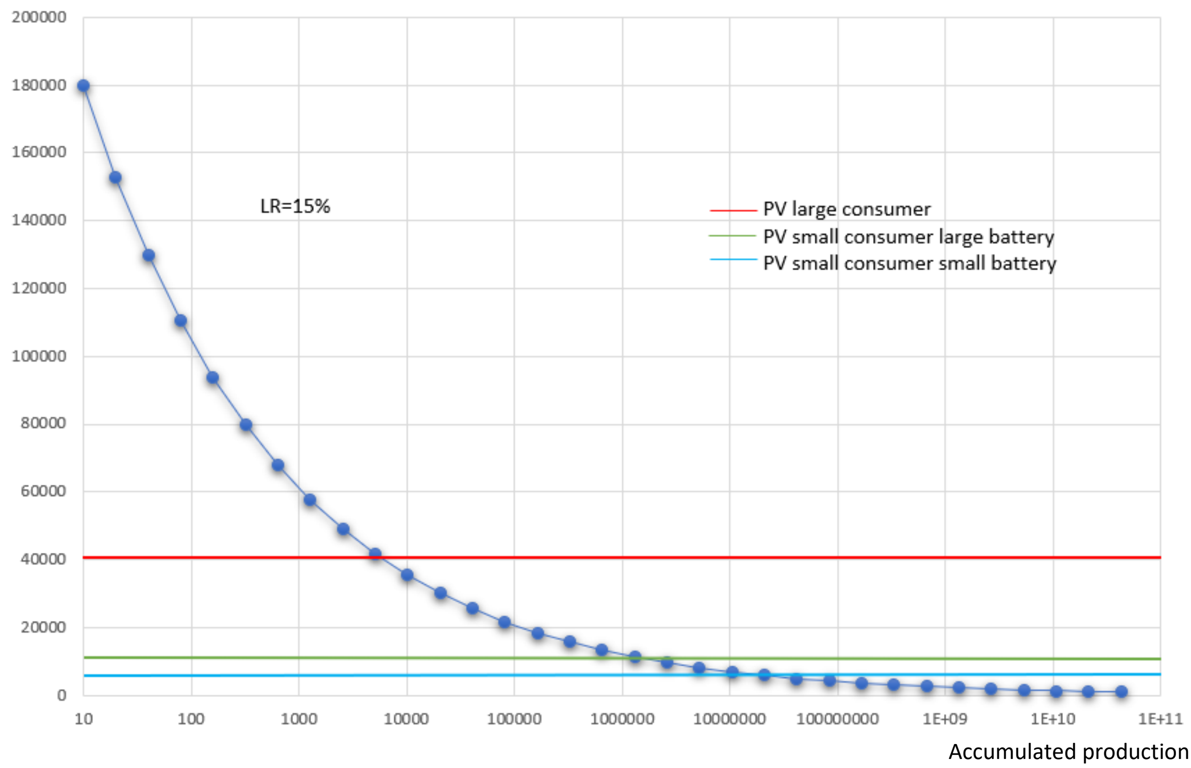


Figure 23 Learning curve where C0=180 000 NOK, X0=10 units, LR=15 %.

All consumers saved cost by participating in V2G. The large consumer will yield more net revenue from V2G than the private consumers, illustrated in the graph shown in figure 24. This is mainly due to the reduced cost of power tariff. The private consumer with the larger battery will have more opportunities to gain revenue from V2G than the one with smaller battery, assuming they have the same average driving range.

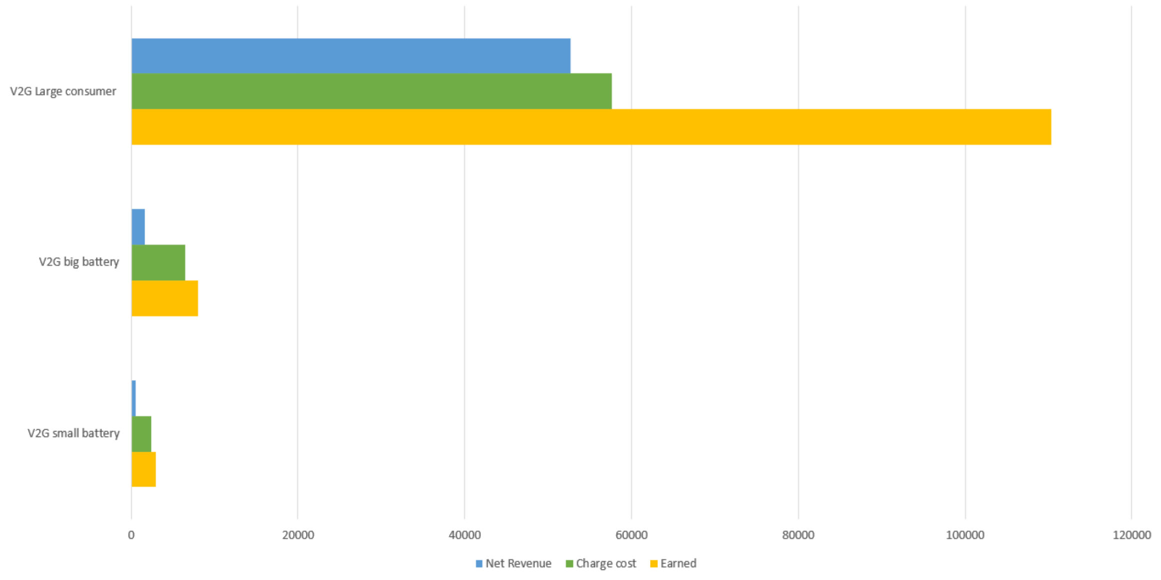


Figure 24 Comparison between the three scenarios in yearly cost and savings from participating in V2G and yearly net revenue.

9.3 Semi Structured Interview

There has been conducted a semi structured interview with 2 individuals that work in the electricity supply industry in Norway. They have extensive knowledge about the national energy system and could provide valuable insight in the deployment of V2G in Norway.

The interviewees all agreed that the most important factor for deployment of V2G was the potential revenue for the EV owner, which is dependent on the investment cost of the bidirectional charger and energy prices at low and high demand.

Interviewee number 1 (from now on called 1) mentioned that the energy prices in Norway, and the flexibility of the hydro power generators make it less profitable to participate in V2G, than in other countries. Since the Norwegian grid is dimensioned to be able to deliver Christmas dinner on the coldest days, flexibility needs will not become as prominent as in other countries that have their baseload power generation delivered by carbon intense power generation. Considering that the increased power connection to Germany and electrification of energy intense sectors will increase the electricity price range in Norway, the profitability of V2G can increase to some degree. Interviewee number 2 (from now on called 2) agrees and adds that a lot of flexibility can be offered from smart charging.

When asked if battery degradation is a barrier to V2G, 1 says that some batteries now, or soon, can do up to 10 000 cycles and in many cases the battery will live longer than the EV itself, and therefore, not be a big issue for V2G participation. 2 feels somewhat otherwise, the public perception of battery degradation will limit people from participating in V2G.

2 states that consumers who pay power tariffs have more opportunities to profit on V2G. And if small consumers would have to pay tariffs as well, this would incentivise the use of V2G for private consumers in Norway.

When it comes to competition, 2 mentions that using old batteries as stationary storage utilities can provide some of the flexibility needs that V2G also can provide. But since the battery in the EV is already bought and paid for by the EV owners, there would not be much need to invest in stationary batteries.

9.2 Barriers affecting V2G deployment.

The important barriers found in literature review is presented in table 24 below.

Table 24 Overview of barriers affecting future deployment of V2G. The results are based on SSI and literature review.

Driver	**Barrier**	
Market	The need for flexibility	V2G might not be as profitable in all markets due to variable needs for flexibility. This is dependent on what energy source provides baseload, production costs, price differences between low and high energy demand, climate, connection with other energy markets, and how much load the grid is dimensioned for.
	Competing markets	Other options can provide flexibility to the energy market besides V2G. Stationary batteries, V1G, flywheel, pumped hydro etc. The most socio-economic profitable option will be chosen.
Technology	Battery degradation	Battery degradation is inevitable, because of calendar life and cycle life will result in some degradation. But recent studies have shown that with optimized communication algorithms, V2G can help expand battery life. Others mean that battery degradation will limit V2G deployment.

	CHAdeMO or CCS?	So far only two V2G compatible EVs (CHAdeMO) but we know car manufacturers from Germany (CCS) are conducting trials and are willing to participate in V2G. More CCS cars and chargers are going to be available for V2G within 2025.
	No unified standards	ISO 15118-20 will release in 2021. This standard will help car manufacturers that use CCS to participate in V2G.
Economy	Optimizing revenue	V2G being profitable for the end user is important for future large-scale deployment.
	Cost of bidirectional charger	Bidirectional chargers have already experienced price reduction. From reported 180 000kr in 2015 to around 30 – 40 000 kr in 2021. Most use of bidirectional chargers been through trials and studies. The cost of V2G hardware is important for large scale deployment.
Social Acceptance	Range Anxiety	Average travels distance in Europe ranges from 35-50 km/day. Car models released in 2020 had an average range of 400 km. As more people are "forced" to drive electric because of national policies, experience grows, and range anxiety will most likely decrease. Knowledge about optimal SoC ranges will also help decrease range anxiety.

10 Discussion

10.1 Case results

The cases presented in chapter 8 are simplified and many assumptions have been made that does not reflect reality. The price of electricity is dependent on demand, and vary over the course of a day, week, month, and season. It is assumed that the spot-price for the winter month lasts 6 months, and the same goes for the spot-prices used for summer. It is also assumed that price is either low or high, and nowhere in between. The cases do not differentiate between weekdays and weekends, which would influence driving range, electricity price, plug in rate and ultimately revenue.

The average driving range which is used is also a simplification. Some consumers may have much smaller driving ranges and some much larger, meaning some consumers might be able to profit less or more on their V2G participation. In the cases of the small consumer, the behavior of the EV owner is assumed to be static, and that he/she never deviate from their daily routine.

The average plug-in rate is 30 %, which results in around 7 hours/day. Assuming a 10-kW charger, the Nissan leaf would achieve the same results with this plug-in rate as in the case study, but the Audi E-Tron would reduce their profit from this plug-in rate. The plug-in rate in the cases is assumed to be 75%, which would give both EVs a possibility to participate in V2G to full extent. Plug-in rate for the long parking case is 100% as it does not need to consider the behavior of the driver, resulting in higher revenue.

Assuming no battery degradation is also a simplification but based on the research of Uddin (2017) and conversations with interviewee nr 1 in the SSI. SoC range from 20-80% is optimal for battery health, and this is accounted for in the cases. As batteries are becoming increasingly better and cheaper, battery replacement cost will decrease, ultimately resulting in lower cost for battery degradation.

In the cases it is also assumed that the consumers use all the storage capacity themselves. This is If the consumers also participated in ancillary services, like frequency regulation, revenue from V2G could be higher and give the EV battery more value. In the case for the large costumer, there is not accounted for any incentives or reduced parking cost for the owners who would let their EV be used for V2G services while they are away. This would affect the net revenue for the large consumer. A cost-effective business plan would be needed in this case, so that the interests of the EV owner and the large consumer could be obtained.

10.2 Learning Curve

From the learning curve with a LR of 10 %, V2G would not be profitable for the EV owner with small battery, based on the economic and behavioral assumptions made in the case studies. On the other hand, it would "only" take a deployment of around 20-30 million bidirectional chargers for V2G to become profitable for small battery EV owner, using a LR of 15%.

It is projected by the IEA up to 250 million EVs in 2030, and element energy projects a cost of £ 1000 (around 10 000 NOK) in 2030 with a global V2G participation of 10% of the EV fleet. This would mean a global V2G fleet within 2030 with 25 million deployed bidirectional chargers. Comparing these two, LR=10% and LR=15%, the 15% LR correlates more with the projection made by Element Energy.

There are several factors that affect the result of the learning curve. The learning curve is sensitive to input parameters used to estimate the LR, which can cause large variations in the result (Martinsen, 2019). The initial unit cost might include other costs besides the charger, like installation. Accumulated production is also just an assumption. The Indra bidirectional charger was made in a R&D project before it was made available for sale, therefore, the input for accumulated production is starting at 10 units.

10.3 Barriers

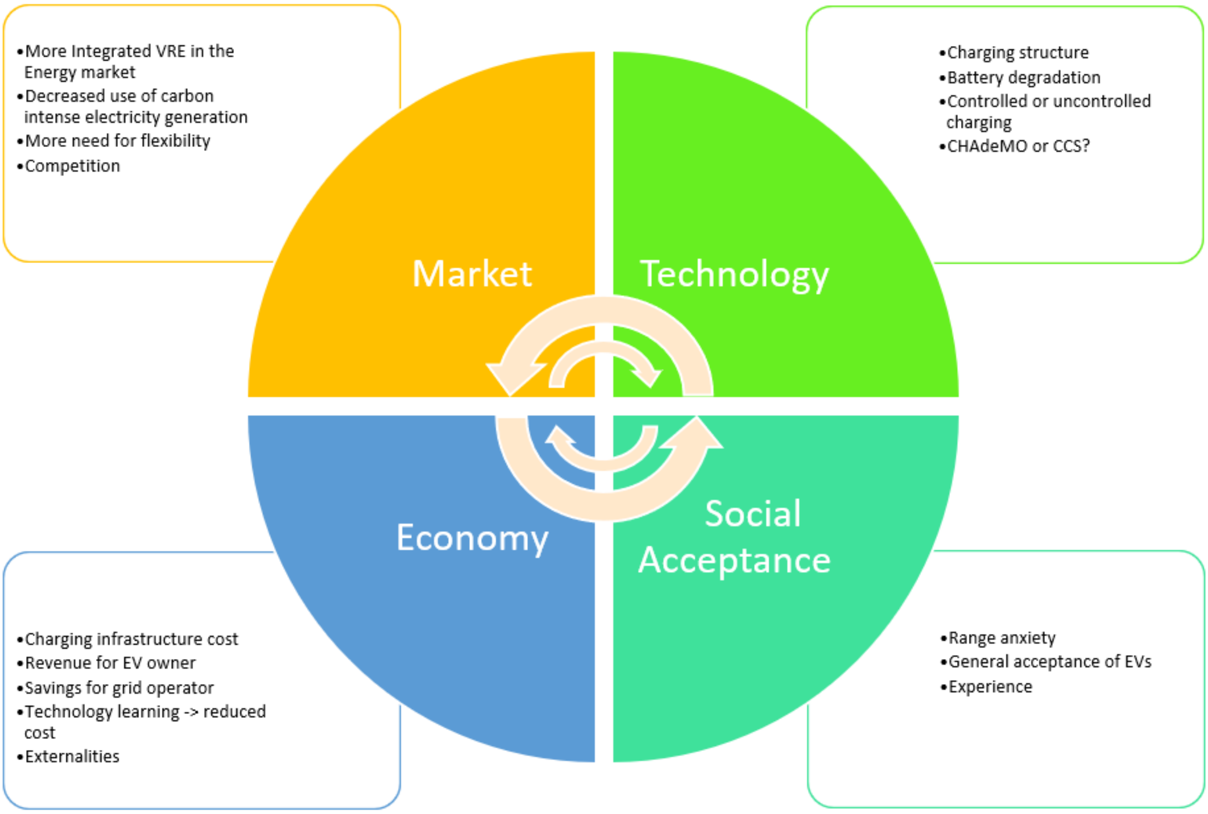


Figure 25 Simple overview of drivers and barriers affecting deployment of V2G.

Figure 26 shows a depiction of the identified drivers and barriers affecting the future deployment of V2G. Market drivers are determined by the need for more flexibility as VRE shares increase. But this need is not constant on a spatial and temporal scale, as it will differ from location, climate, what energy source is used for baseload power generation and how these are affected by more integration of VRE and electrification of energy intense industries. Norway, with 99% of power production from hydro power, have more opportunities to meet flexibility demand than for example California in the U.S, where almost 70 % of power production is generated from conventional power plants and 30 % renewable sources. These differences carry out in the energy price for consumers, which again affects the potential revenue made from V2G. Potential revenue can increase in Norway, as Norway increases its connection to other countries. In May 2021, the Nordlink power cable between Norway and Germany was announced open for operation. More power flow between countries will influence the price difference between peak price and low demand price, increasing the potential revenue made from V2G participation in Norway.

There are also other ways of meeting peak demand and instabilities in the grid. Smart charging can offer flexibility by being able to shift load away from peak demand and charging when there is abundance of VRE production. Stationary batteries are also a good alternative to V2G, but the advantage of V2G is that the battery have already been paid for when buying the EV. The cheapest option that fulfills the socio-economic needs will gain advantage.

The technological driver will influence V2G in many ways. V2G is a complex system that needs both the car and charger to be bidirectional. The car and charger should also be able to communicate with the grid to optimize revenue for EV owner and grid services, while also diminishing the battery degradation.

The deployment of V2G is also very affected by the availability of V2G compatible cars and chargers. If a consumer wants to participate in V2G now, the consumer must have a Nissan Leaf and a bidirectional charger that connects with CHAdeMO. This limits deployment and the amount of possible V2G participants. On the other hand, several car manufacturers have already participated in V2G trials and are going to participate in future trails. Volkswagen have announced that they want to butt heads at the energy companies, this could lead to other car manufacturers follow suit and act as V2G aggregators for their EV fleet. If more car models released in the market are V2G compatible, then more consumers will become aware of V2G and its potential benefits, which would lead to faster deployment. But optimized algorithms for the communication interface is still lacking, as there are many factors that need to be accounted for, like the individual habits of each EV owner, maximized profit and minimized battery degradation to name a few.

The competition between CCS and CHAdeMO limits large scale deployment to some degree, since charging infrastructure operators and car manufacturers must choose one or the other. The status to this date is that there are more CHAdeMO charging points located around the world, but many more CCS compatible cars. The Nissan Ariya SUV which will be released this year, will be delivered with CCS connector in the European and U.S market. This could mark an important shift, where CCS will be leading standard in Europe and the US. Charging infrastructure will likely follow suit, and prioritize CCS standard, since the EU commission have demanded that all charging points have CCS standards available. Building two parallel networks of both CCS and CHAdeMO charging infrastructure would seem inefficient and costly.

Another barrier is the risk of battery degradation because of more completed cycles by participating in V2G. Researchers have conflicting opinions on this topic. Some say that V2G will accelerate the degradation of the battery, while others believe that controlled charge and discharging can help extend the battery life. Through trials participants have noted that they have less concerns about battery degradation after the trial is over. This might be because experience foster learning, and when the EV owner has the possibility to monitor the charge and discharge cycles of the EV, they feel safer participating in V2G. The rate of battery degradation is first and foremost affected by *how* the battery is used, uncontrolled charging could lead to more battery degradation than carefully managed V2G. Uddin et al. (2018) states that the battery degradation of Li-ion batteries determines the viability of V2G.

Range anxiety is a barrier that have affected the uptake of EVs for quite a while. Excess use of the battery capacity might trigger range anxiety even further. Now EVs come with larger batteries and with greater range. EVs with big battery packs have more power to sell back to the grid and gain more yield form V2G participation. To help mitigate with range anxiety access to charging infrastructure is important. If charging infrastructure becomes more available, the need for such large batteries might reduce. To help with social acceptance of V2G, incentives and subsidies like free or reduced cost of parking, payment for battery degradation, or a symbolic participation "allowance" could be introduced.

The economic development is important for consumers and society to profit from the technology. The value that V2G brings must be greater than the cost. Some reports and analysis done have estimated that V2G can reduce investment cost for upgrading grid capacity. In UK, grid investment cost can be reduced with up to 10 billion NOK. Revenue for the private consumer is also researched and analysed. This is of course sensitive to the market factors that determine electricity price for peak and low demand, as discussed above, but also heavily dependent on the cost of V2G hardware. The more revenue possible to obtain, any disadvantages by V2G might be easier to accept by the consumer. There are also non-monetary benefits; V2G will support decarbonization by integrating more of the VRE produced at low demand hours and discharging this energy during high demand, reducing CO2 emissions.

11 Conclusion

There are many drivers and barriers that affect the deployment of V2G. These have been identified and discussed. The profitability of V2G is determined by price difference between low and peak demand, battery degradation and management, cost of V2G hardware, and the willingness to participate of consumers. In the last couple of years, the cost of the domestic bidirectional charger has, according to the literature, reduced with almost 80 %. As more car manufacturers have announced their willingness to make V2G available in their cars and a CCS bidirectional charger under the works, one can assume that charger cost will decrease further. V2G have awaken the interest from many different stakeholders, and with the expected growth in EVs the next years, the possibilities for V2G to unfold in the market are significant.

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