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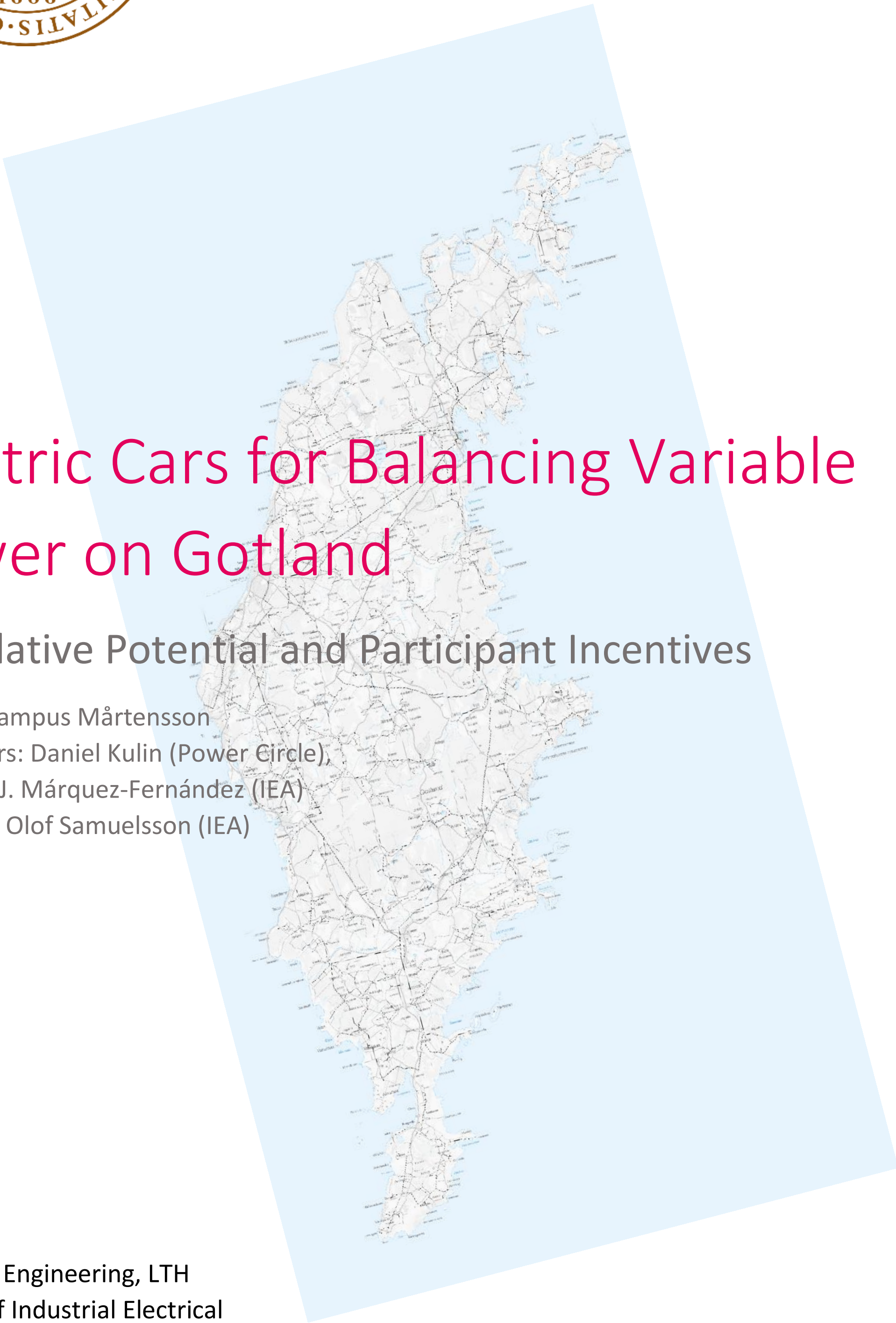
Cumulative Potential and Participant Incentives

Hampus Mårtensson

Division of Industrial Electrical Engineering and
Automation Faculty of Engineering, Lund University



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Cumulative Potential and Participant Incentives

Author: Hampus Mårtensson
Supervisors: Daniel Kulin (Power Circle),
Francisco J. Márquez-Fernández (IEA)
Examiner: Olof Samuelsson (IEA)

Faculty of Engineering, LTH
Division of Industrial Electrical
Engineering and Automation
Box 118, 221 00 Lund
Sweden
www.iea.lth.se

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Abstract

The share of renewable power grows in the generation mix, wielding promises of substituting traditional CO_2-intensive power production. In combination with the trend towards electrification of transport, opportunities are emerging to use electric vehicles for balancing the variability of the renewable power sources. This master thesis explores the potential for such balancing techniques, often referred to as smart charging (SC) or vehicle-to-grid (V2G), on the Swedish island of Gotland. For this purpose, a self-developed model is used, built to reflect the transport and power system on the island. The systems are simulated on minute scale during a year on Gotland. It is also examined, by means of a literature study, whether economic incentives and associated modes of participation encountered in scientific research are aligned with the driving forces and concerns of potential participants. The limited transmission capabilities between Gotland and the mainland together with the large generation of wind power on the island has resulted in the local energy company disallowing further installations of variable power. Therefore, examining these technologies in this context is of particular interest and the findings made here paint the picture of what is possible outside Gotland as well.

The SC and V2G systems are evaluated in three future cases with 100 percent electrification of passenger cars, altering the level of power generation between the levels of today and increased production scenarios covering 50 and 100 percent of the additional load from the electric cars, on an annual basis. It is found that suggested systems can increase the usage of locally produced power significantly for all cases and that the potential contribution grows, as variable power production is increased. Introducing a SC or V2G system and simultaneously increasing renewable power generation to cover the increased energy need from the electric car fleet, could lead to a reduction of energy import and export to and from the island. In the SC and V2G system yearly export values found from the simulations made are reduced from 4.4 GWh per year to 2.8 and 0.8 respectively and import is decreased from 612.1 GWh per year to 608.4 and 610.2 when production is increased, and the systems are implemented. The increased energy need for electric passenger cars would be equivalent to that which is provided by roughly 17 wind turbines rated at 3 MW. The amount of wind turbines are a sizeable investment but well in-line with regional and national ambitions.

The availability of the electric car fleet as a power sink is high and during the vast majority of the year the chargeable capacity is well comparable to the current transmission capacity to the mainland of 130 MW. Under current levels of power generation, the electric car fleet can be charged at rates of 189 and 191 MWh/h or more in the SC and V2G system respectively during 95 percent of the year. If the power generation is increased to cover the energy need of electric cars, the corresponding numbers are 138 and 183 MWh/h.

Furthermore, there seem to be a considerable interest in participation in SC and V2G systems. Most of the current economic incentives and modes of participation encountered in research, could likely be implemented in ways aligned with the concerns and driving forces of future electric car owners. The most commonly found concern being that of mobility restrictions resulting from participation is likely less problematic on Gotland due to the limited geographical extension of the island. Finally, it should be considered that while economic earnings are important, they only provide one of many viable paths for reaching out. Allowing for flexible modes of participation, communicating environmental benefits achieved and carefully minding data privacy issues are examples of important aspects to consider when launching SC and V2G systems.

Keywords: Smart Charging, Scheduled Charging, Vehicle-to-Grid, Smart Grid, Balancing Variable Power, Wind Power, Participation, Electric Vehicles, Gotland

Abstract in Swedish

Andelen förnybar kraft växer i produktionsmixen, med löften om att ersätta traditionell fossilintensiv kraftproduktion. I kombination med en trend mot elektrifiering av transporter uppstår nya möjligheter som användning av elfordon för att hantera variabiliteten i förnybar kraftproduktion. Detta examensarbete utforskar potentialen i att använda sådana balanserande tekniker, ofta refererade till som smart charging (SC) eller vehicle-to-grid (V2G), på den svenska ön Gotland. För detta syfte har en självutvecklad modell använts, byggd baserad på transport- och kraftsystemet på ön. Med modellen simuleras ett år på Gotland i tidsskalan minuter. Genom en litteraturstudie undersöks även om ekonomiska incitament och deltagandeformer från gjorda studier passar med de drivkrafter och orosmoment som potentiella framtida deltagare upplever.

Den begränsade transmissionskapaciteten mellan Gotland och fastlandet, tillsammans med den stora mängden vindkraft på ön resulterade i att det lokala energibolaget förbjöd ytterligare installationer av variabel kraftproduktion under 2017. På grund av detta erbjuder ön ett särskilt intressant sammanhang för teknikerna men funna resultat målar även upp en bild över av vad som är möjligt i en bredare kontext.

SC- och V2G-system är utvärderade i tre framtida fall, samtliga med en 100 procent elektrifierad personbilsflotta. I fallen varieras nivån på lokal kraftproduktion mellan dagens nivåer, ökad produktion för att på årsbasis även täcka elenergibehovet från elbilarna samt ett fall med en produktionsnivå mitt emellan de två. Resultaten visar att systemen kan öka användningen av lokalt producerade energi betydande i samtliga fall och de gynnsamma effekterna växer när kraftproduktionen på ön ökar. Om SC- eller V2G-system införs samtidigt som kraftproduktionen ökas för att täcka elbilarnas elenergibehov kan både export och import av energi, till och från ön, minskas. Exporten kan minskas från 4,4 GWh till 2,8 och 0,8 GWh för SC- respektive V2G-systemet medan motsvarande minskning av import blir från 612,1 GWh till 608,4 och 610,2. Det ökade elenergibehovet från elbilarna motsvarar produktionen från 17 ytterligare vindturbiner med en märkeffekt om 3 MW vardera, på årsbasis.

Resultaten visar även att elbilar är en resurs med hög grad av tillgänglighet och under större delen av året är den ackumulerade laddkapaciteten hos in-pluggade bilar jämförbar med exportkapaciteten i fastlandskablarna (130 MW). Under nuvarande nivåer av kraftproduktion kan elbilar laddas med 189 och 191 MWh/h eller mer i SC- respektive V2G-systemet under 95 procent av året. När produktionsnivåerna höjs för att täcka elenergibehovet hos elbilar är de motsvarande siffrorna 138 respektive 183 MWh/h.

Litteraturen visar på ett betydande intresse för deltagande i SC- och V2G-system. De flesta ekonomiska incitamenten och deltagandeformerna som återfinns i studiematerialet kan sannolikt anpassas till funna drivkrafter och orosmoment. Det mest väldokumenterade orosmomentet om mobilitetsbegränsningar är sannolikt mindre problematiskt på Gotland, på grund av öns begränsade storlek. Litteraturen tyder även på att ekonomisk vinning är en viktig drivkraft men att den är långt ifrån den enda. Möjliggörande av flexibla deltagandeformer, kommunikation av miljönyttan från systemen och noggrann hantering datasäkerhetsfrågor är exempel på aspekter som är viktiga att ta i hänsyn.

Preface

This master thesis is produced by Hampus Mårtensson, an environmental engineering student at the Faculty of Engineering, Lund University. In temporal terms, the study-period has extended from the beginning of autumn 2018 until spring 2019. The thesis is produced in cooperation with Power Circle, the Swedish organisation for electrification and the division of Industrial Electrical engineering and Automation (IEA).

There are a number of people that have provided their time and mental resources for aiding the cause of this study. Some of them deserve a particularly great share of gratitude for their sizeable contributions. First and foremost: without the perspectives and support from supervisors Francisco J. Márquez-Fernández (IEA) and Daniel Kulin (Power Circle), the quality would be considerably lower and much less interesting to any reader. For your contributions I am thankful!

Moreover, they say a model is only as good as the data you put into it. Johan Sjöndin at Gotland Energi AB have provided data as well insights on the power system on Gotland, crucial in making the model resemble reality. Thank you!

Many more have left valuable input and support and to you I am grateful as well. Contributions have come from the full team at Power Circle (including ex-team members), academics at Lund and Uppsala university (including Campus Gotland), key persons at GEAB, Vattenfall, Region Gotland and more.

Abbreviations

BEV – Battery Electric Vehicle
DoD – Depth of Discharge
EV – Electric Vehicle
GEAB – Gotland Energi AB
HEV – Hybrid Electric Vehicle
PHEV – Plug-in Hybrid Electric Vehicle
SC – Smart Charging, Scheduled Charging
SoC – State of Charge
SvK – The Swedish Transmission System Operator, Svenska kraftnät.
UC – Uncontrolled Charging
V2G – Vehicle-to-Grid

Definitions and clarifications

Aggregators - Actors accumulating the potential of many electric vehicles to aid in balancing power or other system services. The aggregator is often thought of as a middle hand, selling and buying capacity to actor responsible for the power grid functioning.

Balancing Power - Aiding the power grid functionality by using power when there is an abundance and, in some applications, supplying power to the grid when there is a deficit. In this master thesis, the grids that are considered are the regional grid and local power grids on Gotland.

Battery Electric Vehicle - In addition to being an electric vehicle as specified below, the vehicles considered here are those that only store energy in a battery, have an electric drivetrain and uses electric motors for propulsion. This means that Plug-in Hybrid Electric Vehicles, that has a traditional gas tank and an internal combustion engine in addition are not considered under this term.

Bidirectional Charging, Bidirectional Power Flow - When power is allowed to flow both ways and an electric vehicle battery is used for both charging from and supplying power to the power grid.

Chargeable capacity –The capacity for receiving power from external sources of electric vehicle batteries.

Dischargeable capacity –The capacity for supplying power to the grid, by discharging electric vehicle batteries.

Depth of Discharge – How deeply a battery is discharged as compared to complete depletion. 100 percent depth of discharge corresponds to the battery being completely depleted.

Electric Car – See Electric Vehicle. The only difference is the vehicle type being specifically a passenger car.

Electric Vehicle - In this study electric vehicle is used for any vehicle using an electric motor, having an electric drivetrain and being chargeable through plugging it in to an external power source. Electric Vehicles are differentiated from Hybrid Electric Vehicles which cannot be plugged in and is used analogous with Plug-in Electric Vehicles.

Gotland Energi AB - The local energy company on Gotland, responsible for the power grid and electricity trading on the island.

Hybrid Electric Vehicle - An electric vehicle that is not charged by plugging it into a charging station. The vehicle, however, is equipped with a battery and an electric motor. The battery is charged using the fuel in the gas tank, generally of fossil origin, or by capturing the motion energy of the car.

Nodes - Used in this study as a common name for the five largest towns of Gotland and the city of Visby, a selection made to simplify the simulations on Gotland. The nodes are: Hemse, Klintehamn, Romakloster, Slite, Vibble and Visby.

Plug-in Hybrid Electric Vehicle - A vehicle with a conventional internal combustion engine and gas tank in conjunction with electric motors and a battery for propulsion. The vehicle can switch between the two or use them in combination. Generally, the battery used for propulsion in these vehicles are smaller than those in battery electric vehicles.

Power Circle - The national organisation for electrification.

Smart Charging, Controlled Charging - The concept in which vehicles are charged during periods of an abundance of power to a larger extent than in the case of regular charging (see Uncontrolled Charging). This is accomplished by scheduling charging to periods of greater renewable power generation.

State of Charge – The energy level in a battery as a share or percentage of a full battery. 100 percent State of Charge means the battery is filled up with energy.

Uncontrolled Charging, Regular Charging - when charging is carried out in an unplanned manner, with the charging session starting as soon as the car is plugged in. The charge cycle normally lasts until the EV battery is full or the car is plugged out.

Vehicle-to-Grid - The concept in which vehicles are used to dynamically respond to the current situation on the power grid supplying services such as balancing power, frequency regulation, voltage regulation etc.

Content

1. Introduction

In response to the need for a future with renewable energy sources, the Swedish government has set ambitious goals for having no net emissions of greenhouse gasses to the atmosphere by 2045 (Regeringskansliet 2018). Constituting a small part of a large transition, the Swedish government has identified the island of Gotland as an important testbed for early implementation of a smart and renewable energy system. The progress on the island could lead to experiences and accumulation of knowledge facilitating nation-wide progress towards a fully renewable energy system (Hjalmarsson, G. 2017).

This ambition for Gotland was expressed in a press release in July 2017, however, in September the same year installation of additional renewable electricity sources was prohibited by the local energy company on the island, Gotland Energi AB (GEAB). The fluctuating electricity production associated with renewable energy sources, posed a risk for the reliability of the power grid. In short, production when at its highest could exceed the load within Gotland and the capability of the existing transmission cables to the mainland could be insufficient to transfer excess energy from the island (Nohrstedt 2017).

Since then, some policy adjustment has been made. Micro-producers are allowed to connect their production facilities and the larger producers can sign up for a queue, awaiting approval for installing generating capacity. The conditions for micro-production include that no more than 43.5 kW, 63 A can be delivered to the grid, and the producer is required to consume more than the facility is producing, on an annual basis (Region Gotland 2017A). In this way, the possibilities of increasing renewable energy installations on Gotland remain limited. This does not go well together with the ambition of making the energy system renewable. Neither is it a good combination with the aim from the municipality of Gotland, including an increase of wind power production from the 0.4 TWh of today to 2.5 TWh (Region Gotland 2018).

Meanwhile, there has been a rapid development on the electrification of transport, not least concerning electric cars. This is seen as an important part in all of the International Energy Agency's scenarios for a decarbonised future (International Energy Agency 2017). Gotland is no exception from the current paradigm of fossil intense transport with one fourth of carbon dioxide emissions caused by the transport sector, air travel and sea travel excluded. If the lime industry is excluded as well, the figure transport is responsible for half of the total emissions (Region Gotland 2016).

Electrification of transport and increasing the share of intermittent renewable energy on Gotland can be developed hand in hand. By charging plug-in electric vehicles (EVs) when renewable power is produced in abundance and/or discharging vehicle batteries onto the grid when power production is insufficient, vehicles could mitigate the consequences of the variability from renewable power sources. These technologies, referred to as smart charging (SC) when only the charging pattern is altered and Vehicle-to-Grid (V2G) when vehicles can be discharged onto the grid as well, have been shown practically possible by actors such as Renault (2016), Nissan (2016) (for more examples see *Vehicle-to-Grid and Smart Charging* in the appendix) and chargers with the possibility of scheduling charging are already available in the market (Chargestorm, n.d.). Personal vehicles are currently parked roughly 95 % of the time, meaning they could be available for system services a large share time (Gullberg 2015; Pernestål Brenden 2017).

So why are these technologies not implemented already? The electrification of transport is a rapidly growing area and the number of EVs has grown from a few hundred to thousands in a matter of years (Kulin & Andersson 2019). It is reasonable that the novelty of the technology as an option for the masses means there has not been sufficient time for really considering the potential contribution to balancing renewable power, outside the academic environment. There are also challenges to which the solutions need further examination, one example being the willingness of EV owners to be part of a SC or V2G system. In research there has been a general deficit of social and behavioural perspectives (Sovacool, Axsen & Kempton 2017; Geske & Schumann 2017). The time has arrived for putting good things to use and studying the potential and decisive aspects of future SC and V2G systems will be an important part of making them come to life.

1.1 Project Aim and Research Questions

This master thesis aims to investigate the cumulative potential achievable in a future with full electrification of passenger cars on Gotland, under three different charging/discharging system scenarios (and a no EVs case for comparison), for balancing variable power production and to allow for more of this energy to be utilised on the island. These systems are: using uncontrolled charging (UC), Smart Charging (SC) and bidirectional charging as would be used in a Vehicle-to-Grid (V2G) scenario. The limitations of the regional grid and mainland transmission link are accounted for. The focus will be on active power balancing.

Additionally, the driving forces and concerns of potential participants are examined. Economic incentives and modes of participation found in research are examined and contrasted to these driving forces and concerns. The research questions are summarised in figure 1 below:

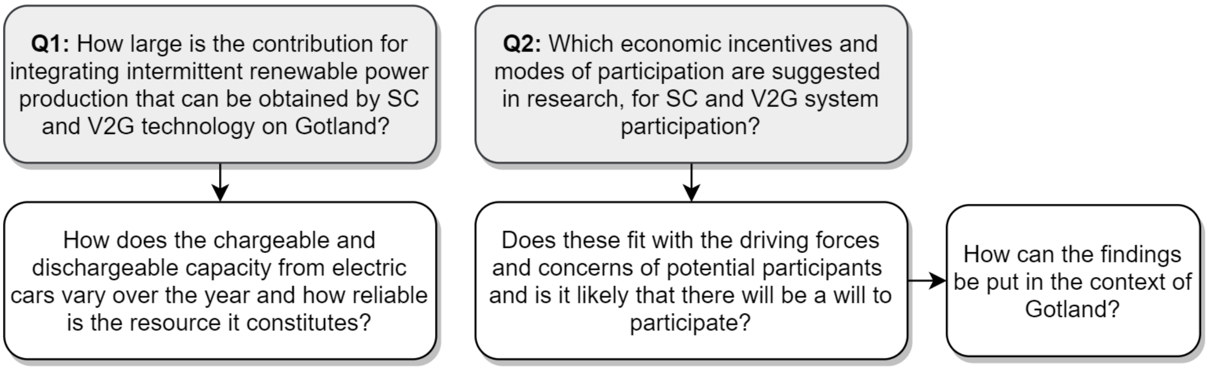

Figure 1: The research questions summarised.

To answer Q1, a self-developed model is made of the transport and power system with the time resolution at minute scale. To answer Q2, a literature study is made instead. The two different methods are described separately as well as their results and an analysis of this in the sections *The Model* and *The Literature Study*. Conclusions and discussion are made on an aggregated level, including results from both methods and research questions.

1.2 Background

In this section of the thesis characteristics of V2G, SC, the energy and the transport systems on Gotland are explained. The aim is to give the reader an understanding of the relevant features in the context of this thesis. For further information, the reader is referred to the section *Current and future situation on Gotland*, in the appendix.

1.2.1 Smart Charging and Vehicle-to-Grid

While the ideas of SC and V2G are not new, the areas have experienced an increasing momentum during the last years. An indication for the rate of progress is given when searching for *Vehicle-to-Grid* on the well-established online database *Web of Science.* Of the total amount of results, 1420 hits, 1380 are published after 2010; of these, 785 have been published after 2015. This means more than half of the articles have been published during the last three years (written 2018-09-06). The progress includes theoretical work as well as practical pilot demonstrations.

Furthermore, the introduction of the international communication standard ISO 15118, a joint effort from the International Organization for Standardisation and the International Electrotechnical Commission provides new opportunities. Built on seven groups of functions and layers, communication between EVs and charging stations can be made to respect technical requirements when supplying power to the grid. Despite the name of the standard being "*Road vehicles – Vehicle to Grid communication interface*" and the first edition being published in 2013, the V2G application is not yet enabled. Examples of mechanisms what remain to be implemented in the standard are the ones needed to ensure discharging of vehicles can be made in compliance with grid codes. There are estimations of the enabling for discharging onto the grid using the standard being ready within three to five years (Mültin 2018).

Functional SC and V2G systems are heavily dependent on there being electric cars available for participation. According to vehicle statistics from Swedish Statistics, there were more than five million passenger cars in traffic in Sweden in august 2018 (Statistics Sweden 2018A). Meanwhile, the general car stands still 95 % of the time (Pernestål Brenden 2017) and the electric car fleet could therefore be available for provision of SC and V2G services during a large share of time.

Today there are far from 5 million EVs on the roads of Sweden, yet, the numbers are increasing rapidly, and projections show that there could be 2.5 million electric cars by 2030 (Kulin & Andersson 2019). There were 71 000 EVs in traffic at the end of January 2019, with an accumulated battery capacity of over 1.3 GWh. However, the rate of adoption has been rapid from the 8400 EVs on the Swedish roads in January 2015, with a corresponding increase of 751 %. The vast majority of EVs are passenger cars (68 000) and of these 26 % are battery electric vehicles (BEVs). The remaining 74 % are plug-in hybrid vehicles (PHEVs) with a traditional internal combustion engine and a traditional powertrain in addition to the electric equivalents (Power Circle 2019).

Benefits of Smart Charging and Vehicle-to-Grid

A central part of why SC and V2G technology have been considered is due to concerns on the effect mass-adoption of EVs will have on the power grids. Many of these grids were dimensioned during a time when EVs were not considered. A large part of the challenges arising from this potential lack of network capacity can be handled by simply scheduling charging intelligently, creating a better match between when renewable power is produced and EVs are charging. How many more EVs that can be charged within the local distribution grid or the regional grid depends on the case, however, employing the aforementioned techniques has shown to have a potentially large impact.

To give an example: in their master thesis *Batteries VS cables* authors Bergstedt and Nyström (2018) show that four times as many cars can be charged in their researched systems: a residential area and an airport, if SC is used instead of UC. Support for their findings can be found in the study *Combining Models to Assess Impact of Electric Vehicles on Electric Grid* (2013) where Anglani et al use a model of an energy system and combine it with a transport model to investigate if SC can contribute to regulating power. The study finds that by using SC, the difference between peak power and minimum power transmission on the grid can be reduced to 87.1 % as compared to the UC case.

By allowing a bidirectional power flow (V2G) in addition, the strain on the grid can be decreased further. This as power can be discharged to the grid during hours of high load, satisfying some of the power need. Anglani et al (2013) examines such a scenario in parallel and the study finds a potential reduction in power peaks of 54.8 % compared to the UC case. The potential of decreasing or shaving peaks is not necessarily the most important implication. An option is to turn the focus towards a better match between peak production and peak load, which could be referred to as peak adoption. However, the findings demonstrate a considerable flexibility in the accumulated load posed by EVs.

The potential demonstrated motivates research on SC and V2G further. In fact, using EVs as a flexible active power source is not the only considered benefit from a SC or V2G system. Additional examples are shown in figure 2 below.

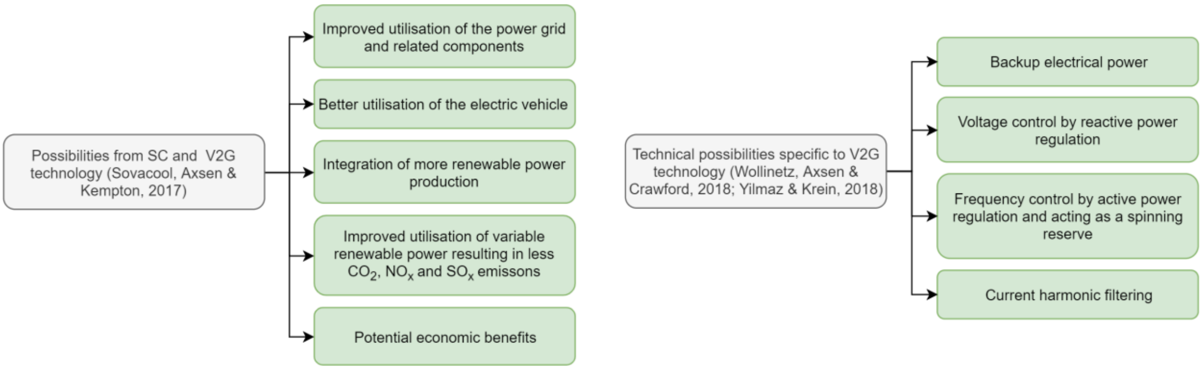

Figure 2: Benefits achievable in SC and V2G systems and the technical possibilities achievable using V2G technology specifically.

Voltage control, frequency control and providing a spinning reserve are especially sought-after services, as the share of intermittent power production increases at the expense of traditional power sources, historically assisting the power grid with these services (Svk 2015, pp. 13-29).

The potential services from batteries in general have been shown to be even larger in number. Fitzgerald et al (2015) has determined thirteen such services. It is likely that many of these could be delivered by EV batteries in a SC or V2G system as well. The services are shown in table 1 below.

Table 1: Potential services from batteries according to Fitzgerald et al (2015).

For regional transmission organisation	**For utility companies**	**Customer services**
Energy arbitrage - Possibility of purchasing electricity when the locational marginal price (LMP) is low and selling it back when LMP is higher	*Resource adequacy* - Replacing other, potentially over-dimensioned, power production sources	*Time-of-use bill* - It is possible to buy electricity when the price is low and use it or sell again when the price is higher.
Frequency control	*Distributional deferral* - Delaying or avoiding investment in the distribution system (for example the grid). This can be usable if a new building project is planned and the final load is not yet known	*Increased solar power self-consumption* - as self-produced solar power can be saved for later.
Spinning Reserve	*Transmission congestion relief* - Absorbing power from the grid when the transmission is at high levels, possibly due to high production of renewable energy, making room for more	*Backup power*
Voltage control	*Transmission deferral* - Delaying, reducing the size of or completely avoiding investing in new transmission capacity. Especially when there is a new projected growth in load	
Aiding in a blackstart - Aiding when restating the system in the event of a power failure		

In addition to the above specified benefits there might be interesting implications rising from the fact that Gotland is an island. Similarly to how EVs can assist during a black start, they could allow for shorter periods of time with the power system operating on island mode, not using the mainland connection. This could be beneficial in emergency situations, during cable maintenance work and under similar circumstances.

Due to Gotland being particularly affected by limitations of renewable energy integration, caused by the grid transmission capacity being insufficient, this master thesis will be focused on the potential contribution from SC and V2G systems for this particular aspect. Load shifting as one of the main services of interest from a V2G system is also indicated in an interview with Johan Sjöndin, Key Account Manager for electricity trading at GEAB.

Challenges for the technologies

Admittedly, there are challenges for implementation of SC and V2G technology as well. Some of these challenges can be met by implementing a system that is carefully optimised to receive the largest benefits possible from the systems.

Battery degradation

One concern is the additional wear on the battery caused by additional charge/discharge cycles, when allowing for a bidirectional power flow. This has been one of the major counterarguments for V2G technology. Some research has indicated that the concern is valid, one example being the recent study by Ahmadian et al (2018) where the authors find an accelerated rate of degradation. The system in the study is modelled in a Danish context and the EVs are mainly used as spinning reserve and for frequency regulation and the type of degradation that is considered is limited to the effect of depth of discharge (DOD). The study does find, significant in the context of Gotland, that the economic gains can outweigh losses associated with loss of battery functionality in a system with a considerable share of wind power. The same study, by Ahmadian et al keep within the margins of 20- 85 % SoC, to reduce the battery degradation in their simulations.

However, a recent study comes to a conclusion in contradiction with this, as it is shown that applying EVs in a V2G scenario might instead increase battery lifetime. The study by Uddin et al (2017) found that by using smart algorithms in a smart grid system the degradation rate of batteries can be reduced. If the battery operates between 15 to 95 % of full capacity on a daily basis, a decrease of 9.1 % in capacity fade (how much energy that can be stored) and 12.1 % in power fade (at which power levels the battery can be charged or discharged) can be expected in the studied system, as compared to the effects from simply using the vehicle for mobility. There are reductions in degradation rate even if the battery operates near depletion before charging. When the battery is allowed to go between 0 to 80 % of total capacity, the study then finds a decreased degradation rate of 4.4 % capacity fade (storage) and 9.5 % power fade (charging/discharging).

One of the important contributions to these results has been the holistic perspective in the study, accounting for multiple battery degradation mechanisms such as: calendar aging, capacity throughput, temperature of the battery, state of charge (SoC), DoD and current rate. In the study, real battery cells were used for validation, adding to the level of confidence. The shares of the total capacity used for daily transport is 21 – 38 %, while the use of capacity for discharging onto the grid is 8 – 40 % (Uddin et al 2017).

Another study, carried out by Thingvad & Marinella (2018), looks at degradation through V2G in Nordic countries. Their finding is that the effect on the battery does not differ significantly from the case where the EVs are used for transportation solely, if the energy quantity required in the service is low. In between the two binary perceptions of V2G being good or bad for battery health, there are also studies suggesting pragmatic solutions. An example is where the V2G technology is used only two hours a day to deliver the most important system services without getting a significant battery wear (U. Daim et al 2016) or designed to maximize the economic gain from the system, despite an anticipated wear (Farzin, Fotuhi-Firuzabad & Moeini-Aghtaie 2016).

The lack of scientific consensus is apparent although most studies seem to indicate some level of battery degradation associated with using EVs in V2G applications (Sovacool, Axsen & Kempton 2017). Still, the benefits could outweigh costs of degradation and for obvious reasons the consensus is lacking on this subject as well. The cost is closely related to the rate of degradation. There is a need for additional studies, clarifying how batteries can be used optimally in a V2G system.

Limiting the interval of operation for the battery to a certain percentage of the full capacity could harmonise well with participants' requirements. A lower limit is reasonable as it enables unexpected vehicle departures. The lower limit that is required by participants in the system may well be higher than the preferable lowest limit from a technical point of view. The option of doing an unexpected departure is valuable to many and even a perceived necessity to some, discussed later in this thesis. Using an upper limit as well could provide margin towards handling unexpected overproduction. This could potentially mean that the battery rarely moves outside the preferable margins.

Non-Stationary Energy Storage

The challenge of using a vehicle for providing services that need the vehicle to be standing still and plugged in, when the main purpose of it is to be used for transport should be recognised as well. As pointed out before in this thesis, vehicles are standing still for a large share of time and as the number of cars connected to the system grows, individual departures resulting in the sudden loss of capacity will have less effect as share of the total capacity. Anglani et al (2018) have studied a combined transport and energy model and found that there is a significant potential for peak shaving despite the non-stationarity of cars. Similar conclusions have been drawn from modelling work by Chioke Bem (2013), specifically for the context of Texas. There is also an interesting aspect of vehicles in that these will bring energy storage closer to the destination of the driver and the passengers.

Availability of technology

EV technology advances fast at the same time as SC and V2G systems have already been put to practice in multiple pilot projects (See appendix for examples). However, there is a lack of distributed V2G technology including computing, communication and residential V2G components which needs to be solved for mass-adoption to come true. In the study *technology roadmap for smart electric vehicle-to-grid (V2G) of residential chargers* these technologies are presented along with a roadmap describing how the necessary conditions for a V2G-system can be set. The authors of the study establish that much of the technology is on its way (U. Daim et al 2016).

On the vehicle side, a study by authors Knezović et al (2017) examines the car model *Nissan Leaf* to find out if the series-produced cars of today can be used in a future V2G system. Three system services are evaluated: voltage control, frequency control and congestion management, however, the cars can only charge intelligently and cannot discharge onto the grid. The result show that while it is technically possible, problems with current undershooting and slow response time mean there is still work to be done for a successful V2G integration (Knezović et al 2017).

As an effect of the technology being new, there is a larger cost associated with current V2G solutions. Furthermore, V2G technology requires more components than traditional chargers and EVs. This results in a higher investment cost with the potential economical earnings being postponed (Sovacool, Axsen & Kempton 2017). It has been shown that vehicle owners discount V2G technology heavily, in a study by R. Parson, K. Hirdue & P. Gardner (2014), posing a challenge for penetration of the technology into society.

Does it make financial sense?

Studies have shown a wide range of economic results regarding the earnings obtainable when participating in a SC or V2G system, numbers starting at a few and ending on thousands of euros (Geske & Schumann 2018). The economic feasibility, a subject of debate among scientists, greatly depend on which system that is considered and what assumptions that are made along the process of calculation. One parameter that has a high impact is the lacking consensus regarding battery degradation, discussed earlier. To clarify: if the battery is heavily degraded when used for ancillary services, the costs of supplying the service will go up significantly. An attempt to establish the cost driving parameters in a V2G-system, is made by authors Geske & Schumann (2018) and apart from (3) these should apply to a SC system as well:

1. The cost of creating a charging infrastructure.
2. The substitutive relationship to flexible mobility, as there might be less energy left for travel when the EVs have provided other services.
3. Compensating vehicle owners for degradation of batteries.

The question of what revenues that can be made from system participation also remains unanswered, with a patchwork of studies showing potential revenues for some local systems such as Queensland Australia and Singapore (Agarwal, Peng & Goel 2014; Marwan et al 2011).

Electricity prices and the need for system services are examples of factors that affect the profitability of the system. The impact of electricity prices specifically is examined by Agarwall, Peng & Goel (2014) who find that V2G participation can result in economic earnings of up to $2300/MWh during the vehicle lifetime when vehicles are used to supply peak power for regulation at peak power prices as high as $3000/MWh. Conversely, they find that it is uneconomical to use vehicles for this purpose with prices of $500/MWh or lower.

Finally, there is the matter of what economic compensation vehicle owners demand for the service their vehicles provide. Estimations has been made with different results, depending on the types of economic compensation and many other factors (Geske & Schumann 2018). Recent estimates of acceptable rates are ranging between $100-300 per year and vehicle (Sovacool, Axsen & Kempton 2017).

Participation in the system
The fatal question of economic feasibility, for the concept, remains unanswered and so does the question on what mode of participation vehicle owners will prefer. In a more general sense, further research is needed on the social and behavioural aspects of SC and V2G (Sovacool, Axsen & Kempton 2017). Without participants onboard, none of the systems can be realised. The chapter *The Literature Study* in this thesis is devoted to this subject.

Other Challenges
Other points of interest that could be mentioned when discussing the challenges of SC and V2G systems are:

- The effect that EV charging will have on medium voltage distribution grids, as there is a risk for the charging contributing to degradation of these grids. This risk specifically concerns low voltage transformers and line capacity violations (Sovacool, Axsen & Kempton 2017).
- The creation of a critical mass large enough to make a meaningful contribution. This has been the research topic of Agarwal, Peng & Goel (2014). Interestingly they show a considerable potential of service provision already at 2 % EV penetration.
- The impacts from increased electricity production and the mass-production of EVs if the systems are implemented. Examples of related concerns are: water scarcity, mining of rare earth metals, pollution from manufacturing and more (Sovacool, Axsen & Kempton 2017).

1.2.2 Electric power on Gotland
Below is a brief description of the power system on Gotland. It includes current aspects of energy system, plans for the future and transmission capabilities regionally as well as to and from the mainland. The information reproduced here is reflected in the design of the model produced in this

thesis. For additional aspects on the energy system of Gotland, the reader is referred to the *Additional Aspects on the Power System* section in the appendix

Electric power system and renewable power generation

The electricity used on Gotland mainly originates from two sources, each contributing with roughly 50 % of all electricity used on the island: wind power and imported electricity. The sector consuming most electricity is the industry, however, large amounts are also consumed in the service sector, households and in farming (table 2A and 2B below) (Swedish Energy Agency 2018, pp. 14-16).

Table 2A: The power sources on Gotland.

Power Source	**GWh**
Wind Power	484
Solar Power	0,6
Hydropower	0,02
Import	499
Total	**984**

Table 2B: The power consumption on Gotland, per sector.

Use	**GWh**
Industry	365
Service	260
Household	195
Farming	91
Transport	0,2
Losses	73
Total	**984**

There are several ways in which the electricity demand on Gotland might increase in the future, among these are (Ibid, p. 18):

- Electrification of Cementa, an industrial company producing concrete. This would require an additional 2000 GWh / year, increasing the total consumption on the island by a factor of three.
- Establishing of new industries (including data centers).
- The re-establishing of the military on Gotland.
- Electrification of the transport sector.
- Increase or decrease in population.

Wind Power is the greatest contributor to power production on Gotland and in the end of 2016, the installed capacity amounted to 182.5 MW and 430 GWh of electricity was produced, yielding roughly 2.4 GWh/MW installed (Region Gotland 2018). Addition of further turbines has halted due to economic reasons, as well as the lack of permission to install more capacity and to connect to the distribution grids. In 2016 there were 133 wind power turbines on the island.

Due to the presence of the military, an airport and the presence of eagles, potential sites for wind turbines are limited (Ibid). Further installations will, to a large extent, be placed where there is already wind power today. For the interested reader, the region plan and a map showing the wind power sitings of today is shown in the *appendix, Energy on Gotland*. There are also technical benefits for using the pre-existing infrastructure when installing additional power production.

The production of solar power is very low on Gotland today, however, there is potential for producing more. Campus Gotland has estimated the potential to be as high as 100 MW installed power (Swedish Energy Agency 2018, p. 19).

Power and Transmission

Normally the power demand on Gotland is in the range of 120-130 MW and it seldom falls below 80 MW. The largest load is during winter, with a peak demand of 180 MW occurring no more than a few hours per year. In contrast to the rest of Sweden, Vattenfall Eldistribution AB is responsible for maintaining the frequency in the grid, a responsibility that is accredited to the Swedish transmission system operator, Svenska Kraftnät (SvK), for the Swedish mainland. This is mainly due to historical reasons, however, the power system on the island is currently not synchronised with the mainland system (Ibid, pp. 14-16).

Currently two high voltage direct current (HVDC) transmission cables connect the grid on Gotland with the Swedish mainland, with a capacity of 130 MW each. One of the cables is used solely for importing electricity from the mainland. During 20 % of the year, the other transmission cable is used for exporting power from Gotland to the mainland. The export from the island does not exceed 55 MW meaning there is more than enough capacity, however, this state leaves the electricity grid on the island vulnerable. Should transmission via one of the two cables be hindered during export, there is risk for island-wide power failure. Starting from a blackout includes using spare power generators fuelled by gas and diesel (Ibid, pp. 14-16).

The transmission cables are estimated to endure until 2035, thereafter their technical function cannot be assured. Changing direction of the bidirectional DC-link decreases the lifespan of the transmission cables (Ibid, p. 23). Recently there has been an update of the control system allowing redirection of the this cable to be done faster, ensuring additional life time of 20-25 years and making the electricity grid more compatible for energy storage (Nohrstedt 2018A). It is also worth noting that the substation on the mainland is currently able to receive 180 MW of exported power from Gotland (Lidström et al 2018).

Gotland is included in bidding zone three for setting the price of electricity. This means the price of electricity on the island is the same as a large part of the middle part of Sweden and it does not reflect the limitations of transmission to, from and within the island. Therefore, the price-signals sent to consumers and producers of electricity do not reflect the strains on the local power system (Swedish Energy Agency 2018, p. 24).

Increased Share of Renewable Power

Region Gotland has the ambition to increase energy production from wind on Gotland from the 0.4-0.5 TWh of today to 2.5 TWh. It is their view that this will require the installation of an additional 200 turbines with an average size of 3 MW, adding up to 600 MW and requiring the current status quo to be revoked. However, it is currently estimated that only 20 MW of wind power can be installed on the island. Their ambition of producing more is in line with national planning goals of increasing the power production from wind to 30 TWh/year in 2020, roughly doubling the production from 2015 (Region Gotland 2018; Swedish Energy Agency 2017A, p. 6).

The reason behind the disallowance for further installations has been that more production would increase the need for exporting power. The mainland link was constructed during the eighties to import energy and using it for export puts the power system on the island in a vulnerable state, risking blackouts on the island (Nohrstedt 2017).

Two main ways have been discussed for handling increase in production of renewable power on Gotland: either the mainland cable is reinforced/rebuilt, or a large-scale energy storage is introduced.

SvK has investigated the possibility of reinforcing the transmission capacity, however, the conclusion has been that the benefits would be outweighed by the costs associated with the project (SvK 2017). The price is estimated by Innoenergy to reach up to three billion SEK (Nohrstedt 2018B). The final cost of the cable relates to which capacity that is installed, and other transmission capacities have been discussed as well (SvK 2015B).

The energy storage solution is estimated to be significantly cheaper for the corresponding capacity. It is estimated that the energy storage could cost 365 million SEK or even go below 300 million (Nohrstedt 2018B). An energy storage unit such as a battery can help reducing the number of redirections for the bidirectional DC-link and thus cause less exhaustion for the cable. Using a battery with 25 MWh storage capacity and 25-50 MW charging/discharging capacity can reduce the number of redirections to half of those currently needed (Lidström et al 2018). As in the case of installing new cables, the final capacity and cost of the energy storage system will require finding a trade-off point.

The multiple values of decreasing export should be emphasised here, as it in addition to indirectly increasing the utilisation of locally produced power will reduce the stress on the export cable. It is also of interest to decrease the number of hours in the more vulnerable export state and decrease the need for importing energy in various forms to the island.

Lidström et al (2018) suggests a third way of dealing with the challenge, using a combination of actions. If these measures are used, wind power production on the island can be increased by 250 MW, corresponding to an increase of 830 GWh, assuming the same energy/power ratio as done in the region targets. The suggested measures are:

- An energy storage with a maximum power of 25-50 MW and a storage capacity of 25 MWh. This is mainly to manage failures on the mainland cable. If a 25 MW / 25 MWh energy storage unit is used, Vattenfall estimates a price of 200 MSEK.
- New power production units are required to be able to regulate frequency. Potential contribution to wind power integration: 80 MW.
- The voltage in the region level grid is increased from 70 to 130 kV. Potential contribution to wind power integration: 70 MW.
- A market place for power flexibility is created, where consumers get paid for moving their consumption to hours of the day which help the Grid. Potential contribution to wind power integration: 100 MW.

In the Horizon 2020 project Cordinet, starting the first of January 2019, a local marketplace for power regulation and system services will be developed on Gotland. A pre-study has been made by Vattenfall, and their recommendations are that the marketplace should include the flexibility of reducing power consumption, flexibility of increasing consumption as well as other ancillary system services (Ibid 2018).

1.2.3 Transport on Gotland

The below depiction of transport on the island aims to describe those aspects that will be reflected in the modelling part of this thesis. The focus is road transport and mainly for passenger cars. For the interested reader, additional information can be found in the section *Additional Aspects on Transport*, in the appendix.

Cars and island inhabitants
During 2016 road transport on Gotland consumed 494 GWh and there were roughly 35 000 passenger cars on the island (Swedish Energy Agency 2018, p. 31). If these are compared to the 4 850 000 passenger cars in traffic in Sweden, they constitute 0.7 % (Statistics Sweden 2018B). With 611 cars per 1000 inhabitants, Gotland is the most car dense region in Sweden (Regionfakta 2018).

During 2015, there were 57 000 individuals registered as living on Gotland (Statistics Sweden 2018B). Region Gotland (2017B) has the ambition to increase the number of inhabitants to 65 000 by the year of 2025 and if the population was to continue increasing at the same rate until 2035, there would be 73 000 people living on Gotland that year. Assuming the same car-to-inhabitant ratio there would then be 45 000 cars on the island Indeed an increasing trend has been seen from 1970 for the population (figure 3). However, there has been significant variations with a notable dip between the years 1994 and 2015. Therefor 35 000 cars are assumed for the modelling part of this thesis.

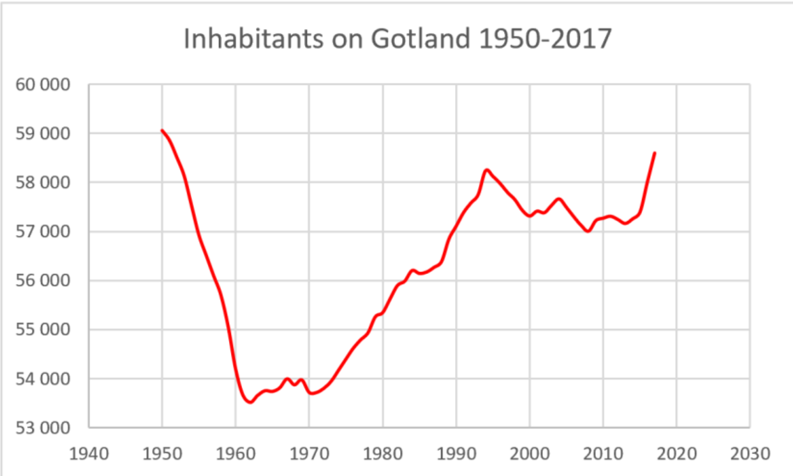

Figure 3: The yearly number of inhabitants on Gotland 1950-2017 (Statistics Sweden 2018).

To understand the transport patterns, it is of interest to know which cities/towns that are the largest in terms of people living there. Currently there are five towns and one city on Gotland with over 1000 registered inhabitants. These are, in descending order of population: Visby, Vibble, Hemse, Klintehamn, Romakloster and Slite. Visby stands out due to its significantly larger population, more than three times as many live there as compared to the following six largest towns together (Region Gotland 2017C, p. 65). These six locations will be referred to as nodes, in this thesis.

Many of the working places are in Visby, however, locations Hemse, Klintehamn, Roma(kloster) and Slite also have a positive net commuting to and from them due to the availability of work. Most of the commuting also occurs between the locations with most inhabitants (Region Gotland 2015, p. 7). An estimation of the daily number of cars in and out from these locations (and Vibble) is shown together with the number of inhabitants per location in table 3 below. For clarification on how this estimation was made, the reader is referred to the section *Method and model design* in the chapter *The Model*.

Table 3: The ten largest towns/cities on Gotland and their population according to Statistics Sweden (2018C) and the flow to and from these, estimated in the chapter *The Model, Method and model design*.

Town/City	**Population**	**Flow to and from node**
Visby	23845	29480
Vibble	1765	17200
Hemse	1701	8080
Klintehamn	1535	7180
Romakloster	1202	10750
Slite	1006	4500

More than half of the people on Gotland live in these six locations, however, a large part of the island population lives in sparsely populated areas and are more spread out than the general population in Sweden (Region Gotland 2015, p. 7).

There are busses going to and from Visby and most of the towns on Gotland (Swedish Energy Agency 2018, p. 33). However, the fact that a large part of the inhabitants live in sparsely populated areas is a challenge for the public transport and only one out of five trips are made using public transport. During 2012 there were 760 000 person trips made by regional busses and 290 000 person trips inside Visby and the towns of Gotland (Region Gotland 2015, pp. 7-9). There has been trains on Gotland as well, however, lack of profitability has resulted in changing the mode of transport to busses, leaving the rails of Gotland mainly as historical artefacts (Region Gotland 2014). To clarify: one person trip is one person doing one trip meaning collective transport can be used to complete many person trips simultaneously using for example a bus. Driving alone in a car would mean only on person trip is accomplished.

The Region of Gotland currently plans to invest in the regional transport infrastructure, however, the main changes concern transport by ferry and not road traffic. As this thesis is focused on cars specifically, these plans will not be explained further (Regionstyrelseförvaltningen 2018).

1.3 Thesis outline

Two different main methods are used in this thesis. Simulating using a self-developed model and a literature study. These are used for examining two different dimensions of SC and V2G technology: the technical potential available and the perspective of potential participants. Therefore, there are two main chapters in the thesis: *The Model* and *The Literature study*. Instead of using the traditional IMRADC (Introduction, Method, Result, Analysis, Discussion and Conclusions) it is presented in an IMRAMRACD form with own dedicated chapters to the model and literature study containing their own sets of MRA (Method, Result and Analysis). Finally, the conclusion and discussion attempt to unite the results and analysis from the two separate chapters, creating a more holistic picture of SC and V2G technology on Gotland.

The Model chapter starts with the section *Method and model design*, where the design features of the model and the data used is explained. Following this are *Limitations* where the limitations and assumptions are explained further. The *Results* then shows the outcomes from simulations. This is followed by a sensitivity analysis and finally an analysis of the result outputs is made in the subchapter *Analysis*.

The Literature Study is initiated by a *Method* section where the approach used to find information is explained. *Limitations* follows to clarifying how the study results can be used and interpreted. After this, the *Results* section sums up concerns, driving forces, economic incentives and modes of participation encountered in the study, describing them on aggregated level. Finally, the reader will find the *Analysis* section where the results from the study are evaluated.

After this, *The Model* and *The Literature Study* is again considered collectively in *Conclusions*. A *Discussion* section follows focusing on the validity of findings, the implications for the future of energy and road transport on Gotland, suggestions on future work and an attempt to put the findings in a wider perspective.

2. The Model

The model developed in this thesis is based on the energy and transport systems on Gotland. It was used to run 34 simulations, including different setups of parameters. This part of the thesis is dedicated to explaining the model build, what input data is used, the results of the simulations and the analysing of these results. The inclusion of a sensitivity analysis is done to identify the parameters that have a greater impact on the result.

2.1 Method

The model is characterised by certain design features, which are described below in *design features* while the main program and how it propagates are expanded on in *The main program*. As a basis for the simulations, a large amount of input data has been accumulated and adjusted to fit the scope of the thesis and the design of the model. This is elaborated on in *Data and data processing*.

2.1.1 Design features

The systems are simulated for three different cases, described below:

1. A base case using current power production and consumption data on Gotland (BC).
2. A future with enough additional renewable power production to cover 50 % of the energy need from electrification of transport on a yearly basis (IP50).
3. A future with enough additional renewable power production to cover 100 % of the energy need from electrification of transport on a yearly basis (IP100).

Also, the model includes a number of key objects, which interact with one-another creating the dynamic of the model. A shorter description of these follows below.

Cars

This object contains the parameters that characterize a simplified electric vehicle. Examples of properties specified are the energy storage capacity and the charge and discharge capability, to represent an onboard battery. The cars have a home node and a work node, representing the locations in-between which they travel according to a specified pattern using a predefined energy consumption per kilometre. Cars are the objects in the model that exists in by far the largest amount.

If the battery level in electric cars are below a specified SoC (see data and data processing), they charge in a regular manner and without delay. Above this SoC, cars are handled in different ways depending on if a UC, SC or V2G scenario is simulated. In UC scenarios electric cars keep charging until 100 % SoC is reached or they are plugged-out to be used for transport purposes. In the SC scenario additional charging, above the specified lowest SoC, is only made when there is an abundance of renewable power. An abundance defined after satisfying the other power needs on the island rising from the current load profile. The abundant power is distributed evenly amongst cars local to nodes with the abundance of power and if power remains after this, it is distributed evenly among the remaining cars on the island.

If a V2G scenario is considered the same charging strategy is used. In addition, plugged-in cars with SoC above the specified lowest level will be discharged to nodes in with a power deficit. The cars are first used to cover the power need in the node that they are in and are only used to satisfy the power need of other nodes if they have remaining capacity after doing so.

Estimated losses during these processes are included. If the cars lack the energy to complete a trip between home node and work node, they simply will not embark on the trip but rather stay in their current node and charging.

Nodes
Nodes represent the locations on Gotland, such as towns or the city of Visby. The nodes aggregate the power production and consumption for a specified nearby area. In this way the power system on Gotland is simplified from the many spread out locations where production and consumption occur, to consist of a few nodes. The nodes can import and export power from and to other nodes and the mainland, with the latter representing a buffer that is only used if there is an abundance or deficiency of power on Gotland as a whole. Included are regional and mainland transmission capacities to account for the limitations in these and estimated losses.

Nodes also serve the function of aggregating cars, with their individually stored energy adding up to a total energy storage level in the node. This makes the nodes comparable to giant batteries that can be used as a power sink during periods of power excess or in the V2G scenarios as sources of power during hours of deficiency. If the chargeable/dischargeable capacity in nodes are insufficient, other nodes on the island are charged or discharged and when this alternative is exhausted energy is transmitted to or from the mainland. The system is optimised in an attempt to achieve the greatest possible self-consumption on the island. For a graphical representation on how cars and nodes are connected, see figure 4 below.

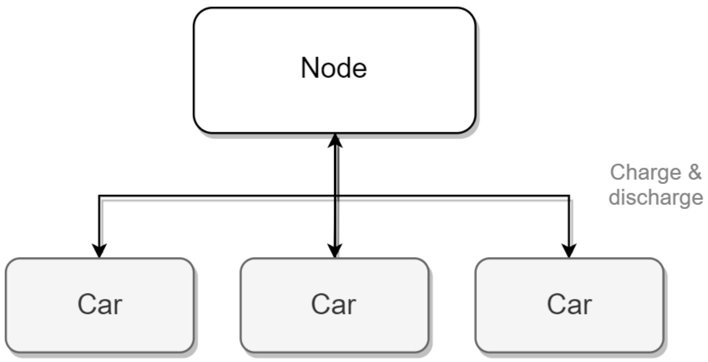

Figure 4: Illustrating the interaction between nodes and cars.

When cars are moving in-between nodes, they are temporarily disconnected from the nodes. An algorithm keeps track of how many minutes remain until arrival and how much energy is used to complete the trip.

Aggregation
Aggregation is the outermost object, acting as the aggregator for all the nodes. From it, the nodes are accessed and their contributions are accumulated. Similarly to the relation between nodes and cars, Aggregation constitutes a final giant battery, based on the individual contributions of the nodes. The interactions between Aggregation, Nodes and Cars are illustrated in figure 5 below.

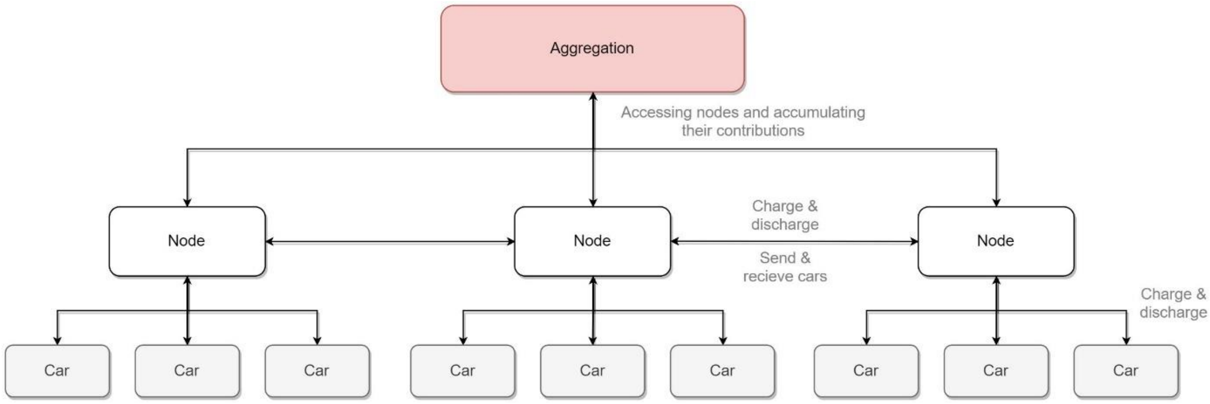

Figure 5: Illustrating the interactions between Aggregation, nodes and cars.

2.1.2 The main program

When simulations are run, the program goes through three separate phases explained in greater detail below.

Setup Phase

In this first phase, actions that need to happen before the actual simulation starts are executed. Examples include the assignment of work and home nodes to cars, reeding in external data into the model and more. New files in which the results are later stored are created.

Main Simulation Phase

This is the part of the program where the simulations occur. Cars, Nodes and Aggregation interact in largely pre-determined patterns, over a simulated year with the time resolution of minute scale. During the process, hourly average data is recorded. Each minute include a step-wise propagation where a set of actions are executed, following the order that is illustrated in figure 6 below. Values used during the simulated minutes are hourly values that are use as input to the model, divided by sixty.

1.

Sending cars on route – Cars are selected stochastically until the time it takes for all selected cars to finish their coming trip amount to the same time as is specified in a prestored list. The list value shows how many minutes cars should be travelling during the particular minute of the year. Nodes from which the cars are selected are chosen stochastically as well, with the chance of a particular node being chosen based on how many cars there are in the node. A choice of node is made again, each time a car is to be sent on route.

The cars will remain on road until there are zero minutes left until arrival. These are then assigned to to the node where they were headed initially. The number of cars that are currently in nodes are stored as an output from the simulation.

2.

Production of power and initial consumption – Hourly production and consumption values are gathered from a lists that are specific to each node. The values are stored as output from the simulation.

The model propagates through the nodes, handling one at the time and consumption values are deducted from the production values storing any excess or deficit of power in that node as a temporary result. The power that is consumed locally in the node in this phase is stored as output from the simulation.

3.

Sharing power between nodes - The total excess and deficit in all nodes are summed up. Power corresponding to the deficit is taken from the nodes with an excess and distributed to the nodes with a deficit, attempting to satisfy their demand as far as possible. If the total excess is less than the total deficit, all the excess power is distributed. A mechanism ensures that the power is supplied as evenly as possible between the nodes. The new levels of excess or deficit in the nodes are saved temporarily and the difference to former levels are stored as output from the simulation.

To respect the regional transmission limits the accumulated power that is transmitted between nodes are not allowed to be larger than a specified limit during the minute.

4.

Charging and discharging local cars - The program propagates through the nodes and any excess power is attempted to be used for charging the cars within the node. In the case of a V2G scenario, the cars are used in a similar way to discharge energy for satisfying the need of power in nodes with a deficit. There are limitations such as a charging/discharging capacity, energy storage limitations and a lowest allowed SoC for system participation specifying to what extent the cars can be used. If there is an excess of power in the node, cars are charged in order of lowest to highest SoC, in their batteries. The opposite order is used in the case of a power deficiency, where discharging is utilised. The power transferred in this step is stored as simulation output.

5.

Charging and discharging cars from other nodes – The nodes are again gone through and if there are any remaining excess power, this is used for charging the cars in other nodes. If the simulation is of V2G type, the program will try to satisfy the remaining need for consumption of power by discharging cars in the other nodes as well. One car is only used for charging or discharging one time during the same minute. The power transferred in this step is stored as simulation output.

6.

Transmission to and from the mainland - If there are an excess or deficit of power remaining when this point is reached, it is transferred to or from the mainland. In this way, the mainland link is used as a safety feature to maintain the power balance on Gotland. If there are cars left in the nodes below lowest allowed SoC, that have not been charged or discharged during the minute, these are charged with power from the mainland. The output representing export and import is stored as simulation output.

The transmission limitations in the two mainland cables are accounted for and before this phase a choice is made whether the directable cable is used for export or import based on if there are a surplus or deficit of power on Gotland as a whole.

Figure 6: Illustration of the main simulation phase in the model.

End Phase

The results that have been stored as simulation output during the main simulation phase are stored as txt-files. If errors have occurred during the simulation, these are automatically counted and stored.

Multiple simulations

There are elements of random in the model, elaborated on in *Limitations*. In order to account for these and to get reliable results, an outer loop is used, running the main program an on beforehand determined number of times with different values of the random parameters. Subsequently, the average value of the simulation output is used as the final result.

This part of the program also sums up the total annual values from the hourly results. Based on the annual values, standard deviations are calculated and stored with the annual energy values of the individual simulations and their corresponding mean values. The procedure used here is based on the Monte Carlo simulation method.

2.1.3 Data and data processing

Data used during the simulations have been gathered from a number of sources. Although the full electrification of the passenger fleet is likely to be accomplished some years from now, data describing the current status is mostly used. The single values that are used are shown below in table 4 and 5, however, transport, power production and power consumption data are hourly values that have been processed. These data and their processing are described under separate headlines below. For specification on how the single values were produced, the reader is referred to the appendix, *Design parameters*.

Table 4: Design parameters for the simulated cars in the model.

Parameter	Value	Unit
Battery capacity	54	kWh
Energy consumption per km	0.15	kWh per km
Charging capacity	6.3	kW
Discharging capacity	6.3	kW
Charging losses	9	%
Discharging losses	9	%
Chargeable Share	100	%
Allowed Lower Limit	18,7 / 34	kWh / %
Initial SoC	50	%
Number of Cars on Gotland	35 000	Cars
Share of time cars are active	5	%
Electricity for transport needs	165.8	GWh per year

Table 5: The designing parameters for the power system.

Parameter	Value	Unit
Regional Transmission Limits	250	MW
Losses for transmission between nodes	6.3	%
Mainland Transmission Limits	130 + 122	MW

How much energy that was needed for electric cars on Gotland, admittedly an important figure, was determined from running the UC scenario under base case preconditions. The additional import minus the decrease in export, as compared to the no car scenario, summed up to 165.8 GWh on an annual basis. The hourly production values were scaled up by a percentage corresponding to the increase that is needed for producing 165.8 GWh of extra energy.

Transport

The total minutes travelled during a year is calculated from the number of cars on Gotland (C_{amount}), the share of time that cars are active (X_{active}) and the number of minutes per year (equation 1 below). With C_{amount}=35 000 and X_{active}= 5 % there will be a total of 551 880 000 minutes of car travel on Gotland.

$$Min_{active} = C_{amount} * X_{active} * 365 * 24 * 60 \quad \text{(equation 1)}$$

The distribution of the transport minutes is based on traffic count data provided by the Swedish Traffic Agency (2018). The Swedish Traffic Agency provides different data sets, including full year sets at some locations. The values in these represent the share of the total yearly traffic that passing by during each hour of the year. On Gotland there are thirteen such points at the time of writing, which are used in this model. An average value has been calculated for the thirteen collection points and when values for every hour of the year are added together, they sum up to one. The idea behind this method is to mirror the traffic intensity on the island during each hour of the year. The distribution of trips is shown in figure 7 below.

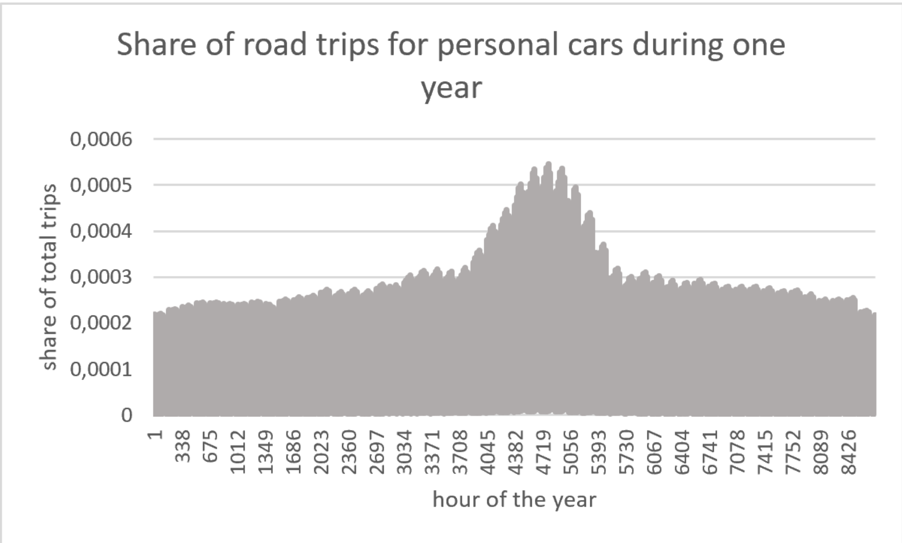

Figure 7: The distribution of trips during the simulated years.

The cars in the model move between two nodes only as a simplification, and the nodes included are the six largest towns (and in the case of Visby a city) on Gotland, with more than one thousand inhabitants. While the pairing of the two nodes in-between which the cars are commuting are chosen stochastically, the number of cars assigned to the nodes is determined by traffic flow patterns provided by the Swedish Traffic Agency, on an interactive map called *Vägflödeskartan* (Swedish Traffic Agency n.d.). The flows are shown individually, per road, and a procedure of adding flows to and from nodes are needed. Finding the flow to and from a particular node include taking screen-shots of the webpage, drawing the borders of the nodes and adding up the traffic flows entering and leaving these borders on individual roads. Screen-shots including drawn borders are shown in the appendix, in the chapter *The Model* and the section *determining traffic flows*. One example is given in figure 7a below, for the node Visby.

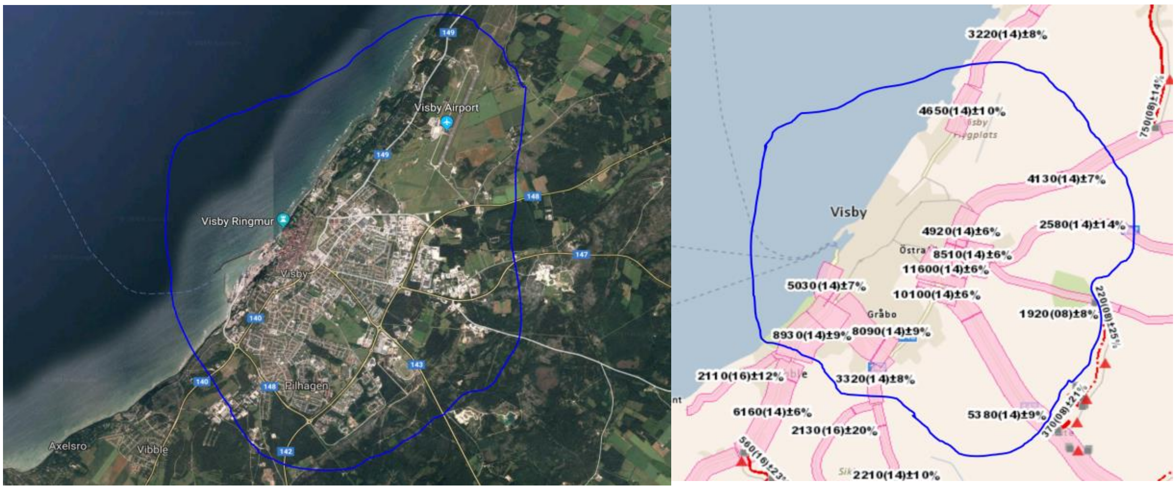

Figure 7a: The traffic flow to and from Visby, together with the drawn borders defining the node.

The share that the traffic flow to and from a particular node represents, as compared to all considered traffic flows is calculated. This share is then multiplied by the total number of cars and the resulting number of cars is assigned to that particular node. In this way, the 35 000 cars on Gotland are distributed among all six nodes. The summarised traffic flows are shown in table 6 below, together with the share they constitute as compared to the total, and the resulting number of cars that is assigned to the particular node.

Table 6: The six selected nodes, the flow to and from these nodes, the share it constitutes of the total flow to and from nodes and finally, the resulting number of cars.

Town/City	Flow to and from node	As share of total	Resulting Cars
Visby	29480	0.38	13367
Vibble	17200	0.22	7799
Hemse	8080	0.10	3663
Klintehamn	7180	0.09	3256
Romakloster	10750	0.14	4874
Slite	4500	0.06	2040
Total	**77 190**	**0.99**	**34999**

Production and Consumption of Power

Power generation data on Gotland was provided by GEAB, in spreadsheet files specifying production per hour and per production unit, for each month of the year. In these files, a corresponding code was stated, specifying the production facility. An additional file specifying the GPS coordinates to the production units based on the code was also provided. To aggregate the data points in relevant clusters, a program was made using polygons to simplify the zoning. The program used the polygon-class available through the JAVA-awt package to create zones in which the production was aggregated (Oracle n.d.A). The resulting data sets compile the hourly values from nearly all production units on Gotland to the six nodes.

To specify the extent of these zones GPS-coordinates were used, retrieved through a combined use of google maps and a self-developed map of the power grid on Gotland. This self-developed map was made from smaller pieces of the Gotland map showing the island power grid, provided by Vindbrukskollen, and pasted together similarly to the laying of a puzzle (Länsstyrelserna 2018). As the regional power grid is largely drawn in-between the nodes, the main idea behind the zoning was to include half of the cable length between two adjacent nodes, in each of the two corresponding zones. Where there were no cable in-between nodes the zone border was drawn equally far from both nodes, and where there were no adjacent nodes, the zones were extended into infinity to ensure that all data points were included. An example of the latter was in the Slite-node in the far north, extending upwards, as there were no adjacent nodes in that direction. The resulting zones are shown in figure 8 below.

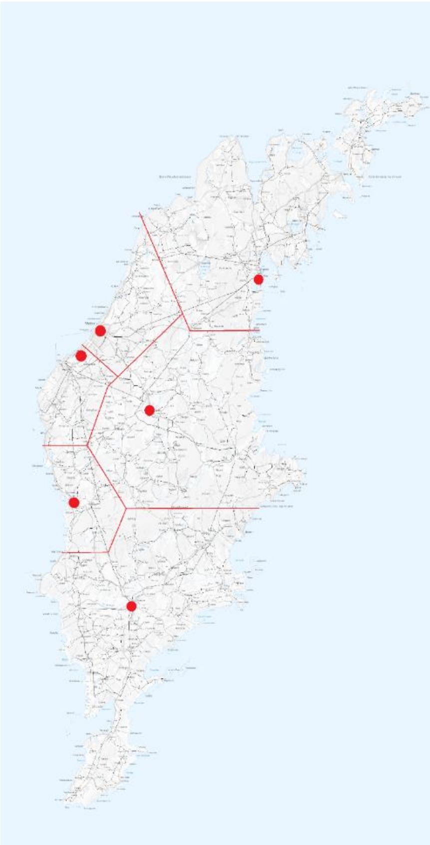

Figure 8: The zones and each corresponding node used for aggregating power on Gotland. The nodes are, from top to bottom: Slite, Visby, Romakloster, Vibble, Klintehamn and Hemse

Some production units did not have GPS coordinates assigned to their codes, resulting in 1.5 % of the total power production not being inluded. To account for this, all power production quantities were increased by 1.5 %.

The consumption data-set was not given directly but had to be constructed. One data set specifying consumption minus the production (referred to as the residual) was used together with a data-set describing production. As the residual data-set included negative values for export and positive values for import, simple addition of the two sets resulted in a consumption data-set. The residual data-set was given for 2018, substituting the December values of 2018 with corresponding values from 2017 while the production data was given for the full year of 2017.

As the residual-set included negative values during hours of export and since there were some hours during 2018 with more production than for the corresponding value in 2017, addition did occasionally result in negative values. As a negative consumption was not a useful in conjunction with the developed model and these values were replaced by the consumption values for 2017, instead of adding the two sets together. A final subtraction of 6 % was made to account for the losses on the regional grid. Processing the data in these ways resulted in the data-set being 5.4 % smaller than the values obtained from simply adding production and residual given by GEAB together.

The consumption data was retrieved on an hourly but aggregated level, for all of Gotland. The challenge was therefore, oppositely to that of the power production data, to split it up in six data-sets representing the consumption of the six nodes. This splitting up was based mainly on how large share of people that live in the nodes, as compared to the total number of people living on Gotland.

There are some industries on the island that use considerably more energy than the rest of the activities on the island. The industries needing specific consideration were selected based on a dialog with Johan Sjöndin at GEAB. The power consumption assumed for these are rough estimates rather than exact numbers. The industries were assumed to be a constant load over the year, as the number of inactive hours for these is low during a normal year. A summary is shown in table 7 below.

Table 7: Assumed constant loads and the corresponding node these are assigned to.

Node	Company	Load (kW)
Visby	Arla	1484, calculated based on the facility using 11-15 GWh per year and picking the mean value.
Slite	Cementa	50000
Slite	Nordkalk	5000

A few values in the set became negative due to the subtraction of larger industries. Where this was the case, no subtraction was made and instead the created consumption data-sets were used directly. The methodology resulted in the total amount of energy of the six data-sets being enlarged as compared to the resulting set from the previous step. Adding up the values of the final data set, however, resulted in a 3.9 % lower value than sum of the unprocessed data given by GEAB. This can be interpreted as 3.9 % less energy being used on the island according to the processed data set, if compared to the unprocessed data given by GEAB.

2.2 Limitations and assumptions

The suggested SC and V2G systems do not exist today, neither on Gotland, nor elsewhere, at any significant scale. Therefore, real observations from SC or V2G systems are not available for analysis and the development of a model was chosen as approach. Still, the model could have been made in many different ways with the final model design including a certain set of trade-offs arising from balancing the level of detail with the time available for the project. In the tables below, some of the most important limitations and simplifications are summarised. A separation is made, showing limitations and simplifications related to model design in table 8 and the corresponding ones, related to input data, in table 9. Two of the simplifications, related to time resolution and regional transmission limitations are describes below as they do not fit the table format.

The time-resolution in the simulations is on a minute basis, with hourly values for production, consumption and traffic intensity. This is a designer choice based on the data available being per hour values and with physical distances between nodes being short enough to be covered in less than one hour. Disabling cars from charging and discharging during one whole hour would lead to a significant underestimation of the potential from suggested SC and V2G systems.

While mainland transmission capacity is implemented to reflect the transmittable power over the mainland cables, the corresponding limitations within Gotland include a greater simplification. A fixed number of 250 MW is used, and every time power is transmitted over any of the regional grid cables, during simulations, a corresponding amount is deducted from that number. The idea behind this is that the regional grid constitutes a circular shape connecting the nodes, shown in figure 9 below. Included in the figure is also a regional transmission cable in the middle of the circular shape. The additional opportunities that comes with the cable is disregarded in the model.

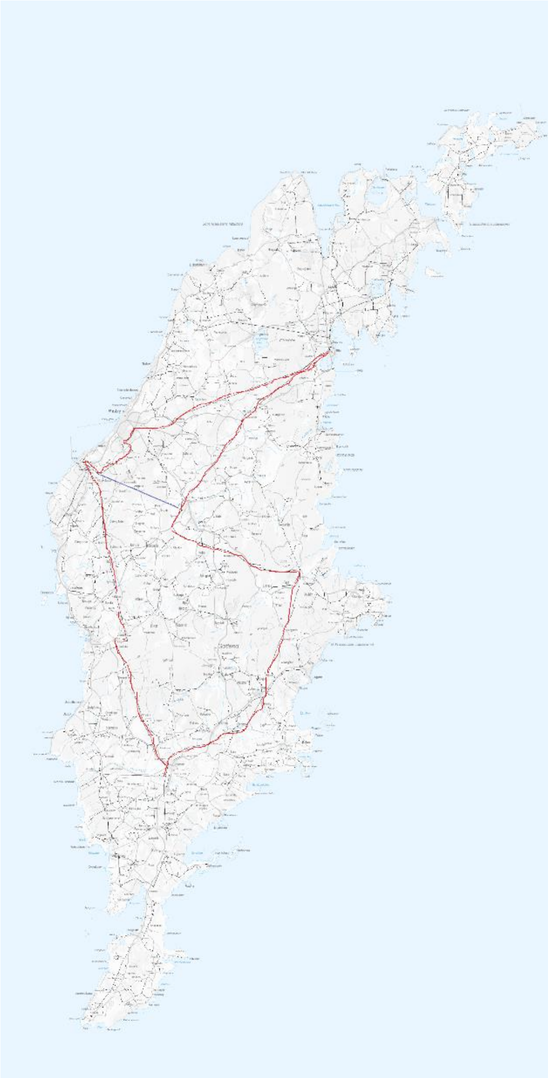

Figure 9: The part of the regional power grid on Gotland that connects the nodes. The blue line in the middle of the island represent transmission cable that is disregarded in the model.

Similarly, to how a thread connects pearls in a pearl necklace, cables join each node with two other nodes and the transmittable capacity of each cable is assumed to be 125 MW. When power is to be transmitted between two nodes, two different paths can be chosen, adding up to a transmission capacity of 250 MW. Hence, the fixed number used really correspond to an unrealistic worst case in which power always is transmitted all the way around the circular grid, through all cables each time.

In reality, transmitted power should only burden the cables corresponding to the path taken, however, for the grid to be utilised optimally the model design has to be made in a certain way. The implementation of the grid limitations was made in a late stage of the model development, resulting in insufficient time to retrofit the model. The implementation could be interpreted as a worst case, were less of the potential capacity of the power grid is utilised than would be possible in reality. Furthermore, it is shown in the appendix, *The Model*, *Validating model* that results from the simulation with no electric cars and with current levels of power production is similar to the current situation on Gotland. The transmission capacity available on the mainland and regional grid is reset at the beginning of every new simulated minute.

Table 8: Limitations and simplifications related to the model design.

Limitation or simplification	**Shorter description**
Using six nodes	The model is based on there being six nodes on Gotland in which all consumption and production is made. It is also within these nodes that all cars are harbouring. It would simply be too complex to consider all locations on Gotland, motivating a simplification such as this.
Disregarding distribution grid	The effect on and limitations of the distribution grid is disregarded altogether. The idea is to look at Gotland from a greater system perspective and going into more detailed level is not within the scope of this thesis.
The effect of heavy traffic	Heavy traffic is left out from the simulations. There was little data found on this subject during the study and currently cars make up the vast majority of electric vehicles. Introducing heavy vehicles into the SC or V2G system could be of potential interest in future work.
Simulating one year only	The simulations are carried out for one year and in reality, there are differences between years in terms of wind power production and consumption pattern. Using one specific year like this is a simplification yet it provides some link to reality.
Focusing on integration of renewable power	The focus is put on the integration of renewable power sources and EV charging/discharging capabilities when it comes to active power balance in the model. Additional services that could be provided by grid connected EVs such as reactive power or harmonic compensation are disregarded in this work.
SC and V2G system implementation	The implementation of SC and V2G systems made here are only two of the ways in which this can be done, with many conceivable options. These implementations are by no means optimal and there could be other systems performing significantly better.
Cars starting position	The starting position of all cars is in the home node and during the simulation cars are spread out, with some of them being in their home nodes and others being in the work nodes. The effect of this diffusive mechanism is not evaluated in depth
Stochastic processes	Stochastic processes are used to account for there in reality being unforeseeable events that will affect the systems. The use of these processes did not affect the result to any larger extent, with only smaller differences found between simulations. The processes are: 1. The selection of which cars that are to be sent a specific minute. 2. Assignment of the two nodes in-between which cars are commuting. The Random and Collection classes available in the Java Util package were used to generate stochastics (Oracle n.d.B; Oracle n.d.C).

Table 9: Limitations and simplifications related to input data.

Limitation or simplification	**Shorter description**
Data from the Swedish Traffic Agency	The traffic flows given by the Swedish Traffic Agency represent annual mean values and no consideration is taken to seasonal variation. Furthermore, the measurements on traffic intensity were taken between 1989 and 1991 meaning that these are already of significant age. The usage of this data is motivated by it being the best available data known to the author and the link to the real transport system that it provides.
Only accounting for native cars	The cars accounted for are the native ones, and those temporarily on the island e.g. due to tourism are not included. There could be non-native cars available for participation to a SC or V2G system in the future, however, the reliability of their sporadic contribution would be harder to estimate. Additionally, no figures were obtained specifying the seasonal variations in detail.
No battery wear	There is no consideration made for degradation of batteries. Real batteries would lose some of their capacity over time, however, this effect is limited during a shorter time perspective, such as one year.
Fully electric passenger car fleet	In the study an assumption is made that all cars are electric as this will show the potential effect of a complete electrification of the passenger car fleet. The assumption is further motivated by the system being realised some years from now, when more electric cars are likely to be found on the roads.
Electrification not affecting the transport pattern	It is assumed that electrification of transport does not have any greater impact on the pattern of transport. Presumably, there will be an effect of electrification, SC and V2G technology. However, no good way of adjusting the data sets to this effect was found by the author.

2.3 Results

In this part of the thesis, the results from the simulations are shown. The section *Model validation* is added to clarify how similar the model results in the base case with no EVs are to the real values measured by Gotland. For all of the three cases, the base case (BC), extra renewable production covering 50 % (IP50) and 100 % (IP100) of transport electricity needs, there are four simulated scenarios, including a no EVs, UC, SC and V2G scenario.

The results show residuals for all cases and for all scenarios, a residual representing the import minus the export measured at the point where Gotland is attached to the mainland cable. The available capacity for charging and discharging is shown as well. The values represent the cumulative energy that is used when charging EVs and the energy that is supplied from discharging EVs, including losses, on hourly basis. Included are losses in the distribution grids, regional grid and the losses generated in the charging equipment between the grid and the EV battery.

In all of the result, except the annual total values, the results from the first simulated week is omitted to account for the effect caused by setting an initial SoC of the cars. It is kept for the annual values as the effect there was find to be very limited (See appendix, *design parameters*).

The information presented below is rigorous and for a quicker summary, the reader is referred to the *Analysis* section.

2.3.1 Model validation

Figure 10 below shows the power residual (import – export) on Gotland given by GEAB and the corresponding values produced from the model. This data is shown as it is the final output from the model, when all stages has been gone through. The overall trend is clearly similar, however, there are some differences visible.

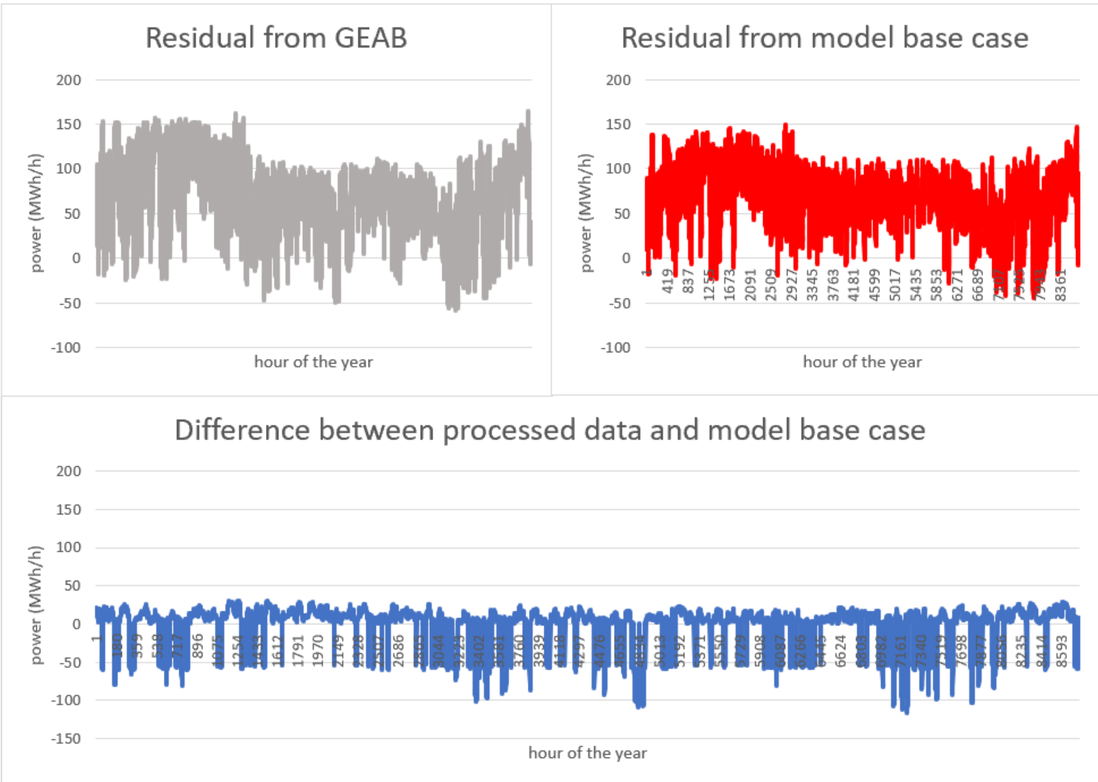

Figure 10: The residual given by GEAB (top left) the residual output from the model (top right) and the difference between the two.

Quantifying the total export, import and the residual of the processed data, the GEAB data and the model further clarifies the differences between them (table 10 below). Regarding import and residual, the similarities are high while the export values differ more.

Table 10: The import, export and import-export for the GEAB data and model results. Included are also a comparisons in percent.

	GEAB data (GWh)	Processed data (GWh)	Processed data/ GEAB data (%)	Model results (GWh)	Model results / GEAB data (%)
Import	606	556	92	612	101
Export	16	7	44	4	28
Residual	590	549	93	608	103

The export is overall low in comparison to the residual value, taking values 2.6, 1.2 and 0.7 % in the GEAB, processed data and model result cases respectively. The potential export will easily be eliminated by slightly elevated losses. As there are no stochastic elements in the model when there are no cars, the result was the same for all simulations.

2.3.2 Base Case (BC)

The base case (BC) includes the current power production levels on Gotland. Below in figure 11, the residual is shown in a duration diagram.

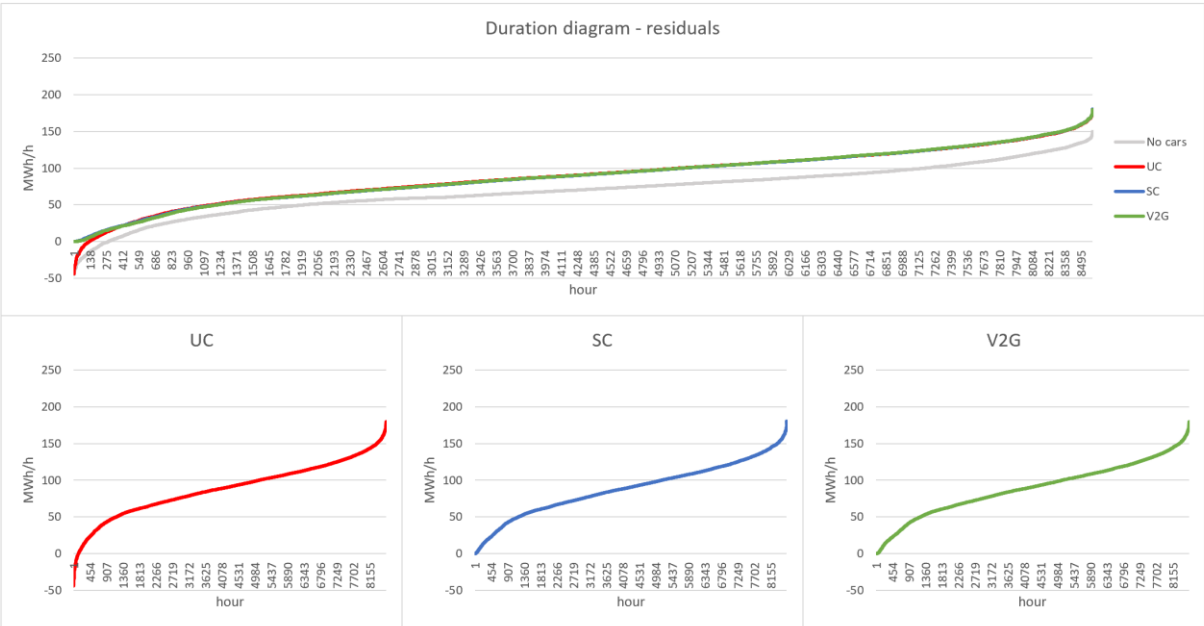

Figure 11: The residuals in the BC plotted in a duration diagram. In the top all residuals are plotted together, and the residual of the no electric cars scenario is included as reference. In the bottom the residuals are shown individually for the UC, SC and V2G scenarios.

The residuals share great similarities and all scenarios with electric cars lead to an elevated use of electric energy on average, due to the increased consumption from charging electric cars. While there are energy exports from Gotland in the UC scenario (negative values in the diagrams), the effect of SC and V2G is that there is no export from the island during any hours of the year. The energy is instead used locally on the island and some burden is released from the mainland transmission cable.

Below, table 11 shows the annual imported and exported energy as well as the local power used for charging in the four scenarios. The highest export value is found in the scenario without electric cars. Exports are lower in the UC scenario and reaches zero in the SC and V2G scenario. Energy import is highest when UC is used and second highest in the V2G scenario, one GWh higher than for the SC scenario. The utilisation of locally produced power for charging cars is highest for the SC, second highest in the V2G and lowest in the UC scenario. The number of hours with export was 291, 130, 0 and 0 for the No EVs, UC, SC and V2G scenarios respectively.

Table 11: Export, import, and charged local powerFor the BC for the no EVs, UC, SC and V2G scenarios. Included are also standard deviations to show the spread in the result. The stochastic elements relate to EVs why standard deviations are not used in the No EVs scenario.

	No EVs (GWh)	**UC (GWh)**	**SC (GWh)**	**V2G (GWh)**
Exported	4.4	1.7 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Imported	612.1	777.9 ± 0.1	774.1 ± 0.1	775.1 ± 0.1
Charged local power	0	2.8 ± 0.0	4.7 ± 0.0	3.6 ± 0.0

During 99 % of the time cars are capable of receiving 177 MWh/h or less in the SC scenario and during 95 % of hours they can receive 189 MWh/h or less. In the V2G scenario the corresponding numbers are 180 and 191 MWh/h. Note that again, results from the first week of the simulated year are omitted. The corresponding values for discharging, only viable in the V2G scenario, are close to zero and in total one GWh is discharged during the year. Below, figure 12 include histograms where the number of hours at certain levels of charging/discharging capacity are available are shown.

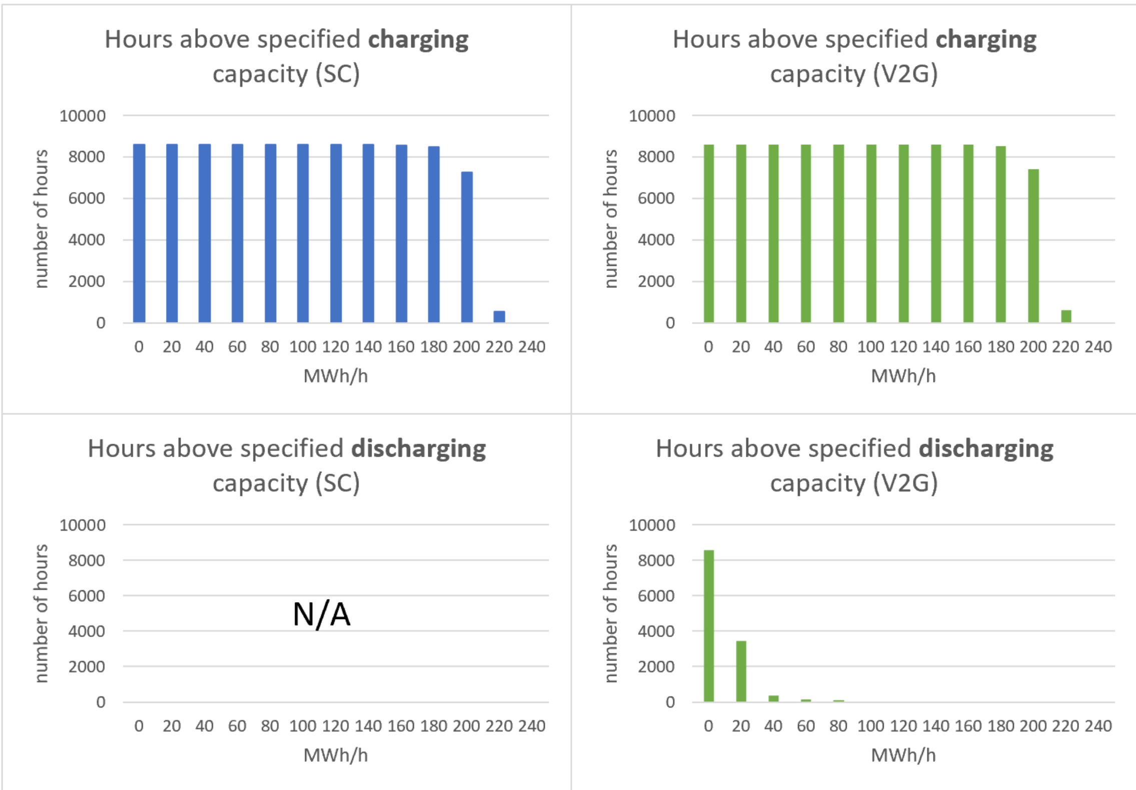

Figure 12: Histograms showing the number of hours with specified levels of chargeable capacity during the simulations in the base case. Chargeable capacity here is how much power that can be used to charge all the plugged-in electric cars on Gotland.

Finally, the energy stored in all plugged-in cars on Gotland during the year is shown in figure 13, for the SC and V2G scenarios. Apart from occasional peaks and a valley during the middle of the year, the SoC is relatively constant.

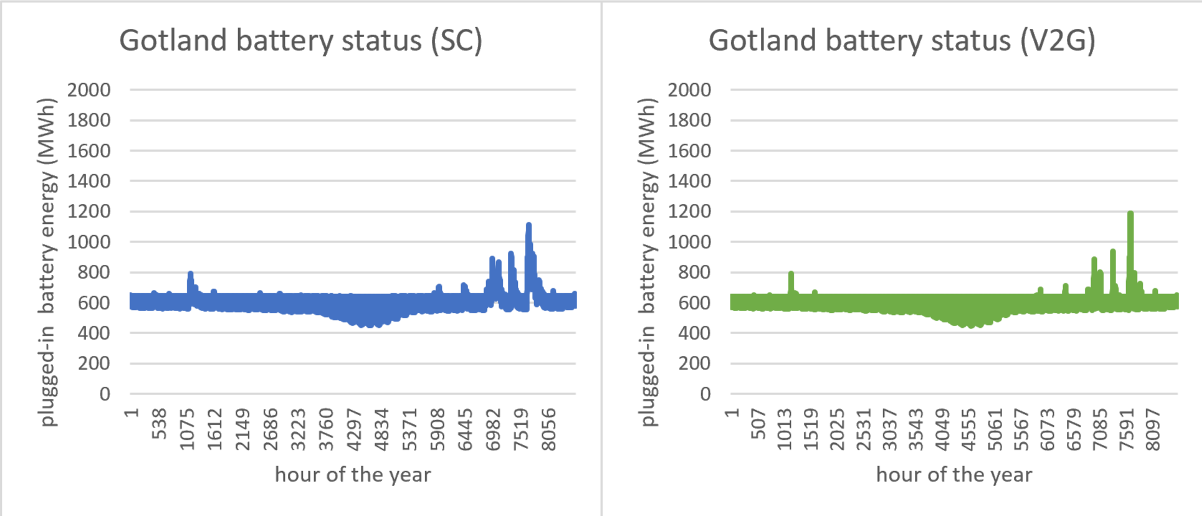

Figure 13: The energy stored in batteries of the plugged-in electric cars on Gotland during the hours of the year in the BC. Included are the SC and V2G scenarios.

The perception of thickness of the lines arise from intra-day variations as the high number of hours depicted does not allow for specific hours to be distinguished. To clarify this, the battery status during week 26 is shown in figure 14 below.

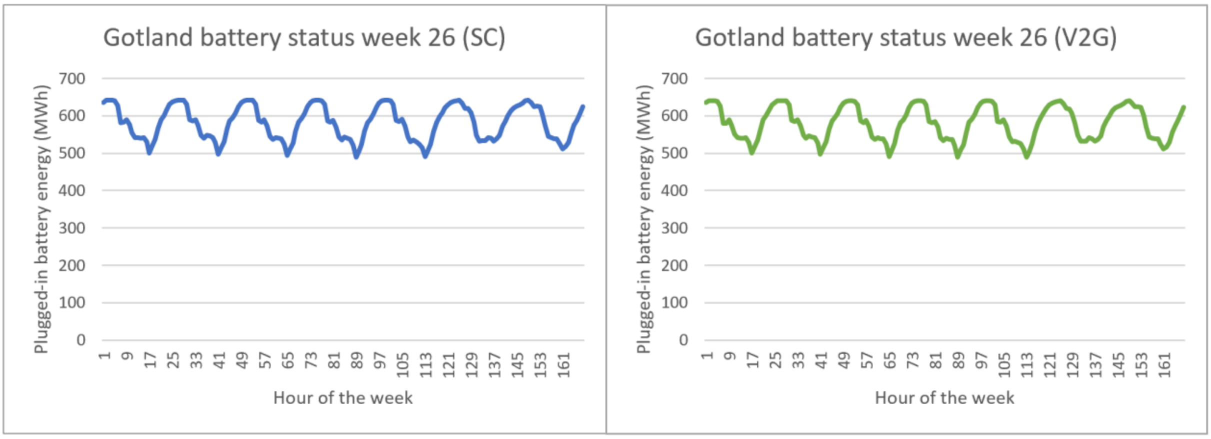

Figure 14: The energy stored in batteries of the plugged-in electric cars on Gotland during the hours of week 26 in the BC. Included are the SC and V2G scenarios.

2.3.3 Covering 50 % of transport (IP50)

Covering 50 % the electric transport energy needs (IP50) implies increasing the production on Gotland by 18 %. Apart from the addition of the electric cars the consumption values are the same. Below in figure 15, the residuals of the scenarios are shown in a duration diagram. Again, the residuals share great similarities and all scenarios with cars lead to an elevated use of energy on average.

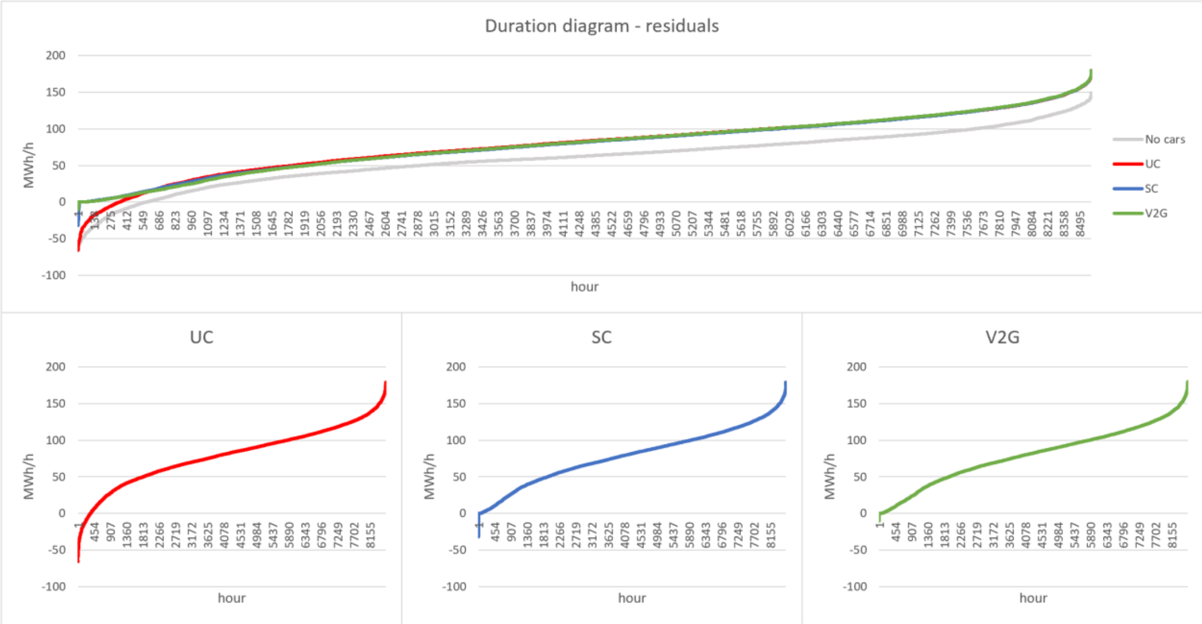

Figure 15: The residuals in IP50 plotted in a duration diagram. In the top all residuals are plotted together and the residual in the no electric cars scenario is included as reference. In the bottom the residuals are shown individually.

Below table 12 shows the total exported and imported energy and the power used locally for charging for the four scenarios. The impact of SC and V2G on export is again distinguishable. Exports are significantly lower in the UC scenario and reach zero in the SC and V2G scenario. Import is highest in when UC is used and second highest in the V2G scenario, almost two GWh higher than in the SC scenario. The number of hours with export was 569, 353, 9 and 6 for the No EVs, UC, SC and V2G scenarios respectively.

Table 12: Export, import and charged local power and the number of hours with export in IP50 for the no EVs, UC, SC and V2G scenarios. Included are also standard deviations to show the spread in the result. The stochastic elements relate to EVs why standard deviations are not used in the No EVs scenario.

	No EVs (GWh)	UC (GWh)	SC (GWh)	V2G (GWh)
Exported	12.3	6.3 ± 0.0	0.2 ± 0.0	0.0 ± 0.0
Imported	536.2	698.5 ± 0.1	690.0 ± 0.1	691.9 ± 0.1
Charged local power	0	6.3 ± 0.0	12.9 ± 0.0	10.6 ± 0.0

Regarding utilisation of locally produced power, the scenarios follow the same order as in BC. It is highest in SC, second highest in V2G and lowest in the UC scenario. What differs is how large the difference is, while there were 1.9 and 0.8 GWh more of utilised local power in BC comparing SC and V2G to the UC scenario, the corresponding values are now 6.6 and 4.3.

In IP50, during 99 % of the time cars are capable of receiving 114 MWh/h or less in the SC scenario and during 95 % of hours 182 MWh/h or less. In the V2G scenario the corresponding numbers are 171 and 187 MWh/h. Again, the corresponding values for discharging are close to zero. In total 3.1 GWh are discharged to the grid during the year. Below figure 16 include histograms where the number of hours certain levels of charging/discharging capacity are available is shown.

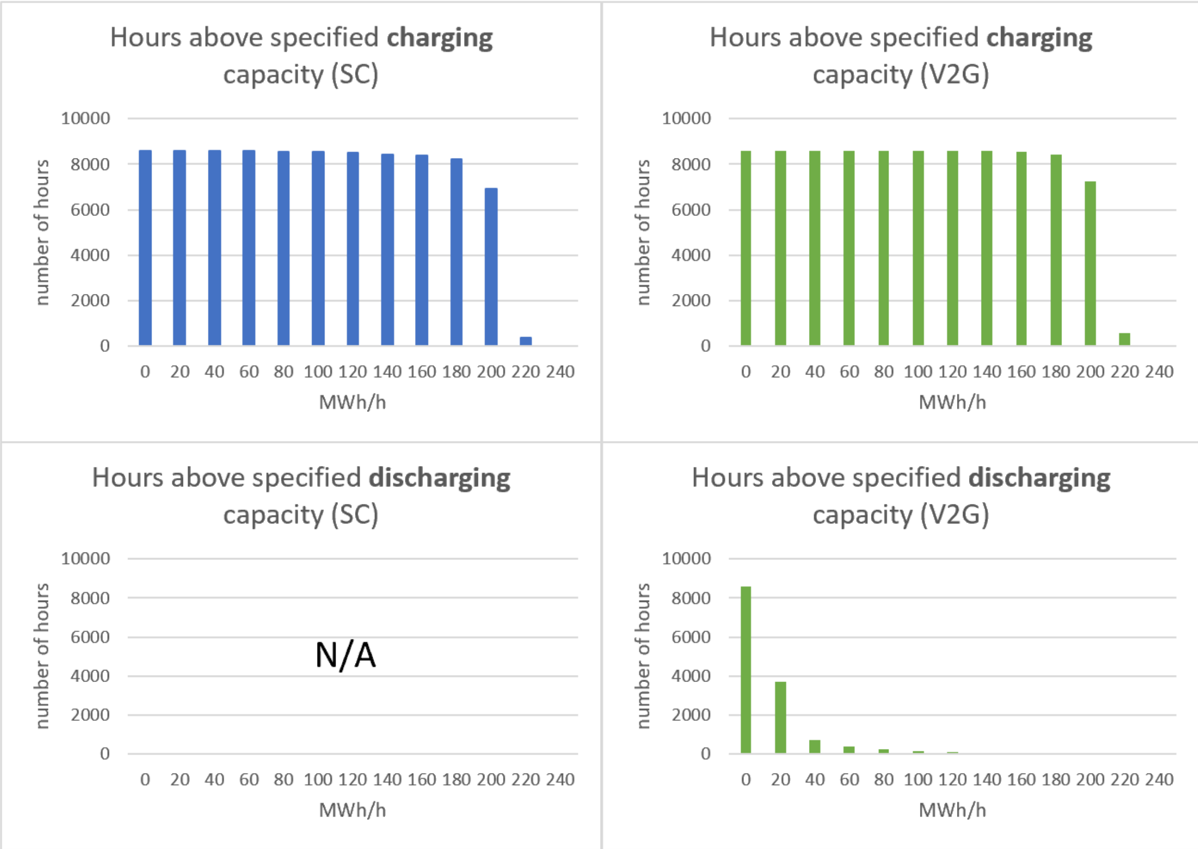

Figure 16: Histograms showing the number of hours with specified levels of chargeable capacity during the simulations in IP50. Chargeable capacity here is how much power that can be used to charge all the plugged-in electric cars on Gotland.

Finally, the battery capacity of all plugged-in electric cars on Gotland during the year is shown in figure 17 for the SC and V2G scenarios. Apart from occasional peaks and a valley during the middle of the year, the SoC is relatively constant in IP50 as well. There are more peaks than in the BC case and these also seem to be lasting longer. The perception of a thickness of the lines arise from intra-day variations as the high number does not enable specific hours to be distinguished.

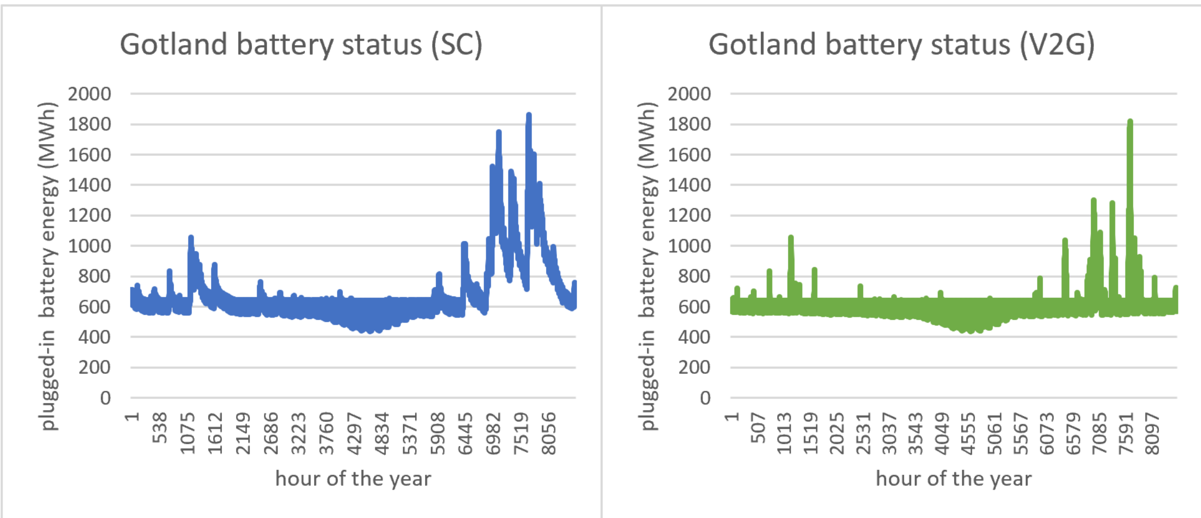

Figure 17: The energy stored in batteries of the plugged-in electric cars on Gotland during the hours of the year in IP50. Included are the SC and V2G scenarios.

2.3.4 Covering 100 % of transport (IP100)

This case (IP100) includes increasing the production on Gotland by 36 % to cover the increased need of electricity caused by 35 000 electric cars. Apart from the addition of electric cars the consumption values are the same. Below, in figure 18, the residual is shown in a duration diagram.

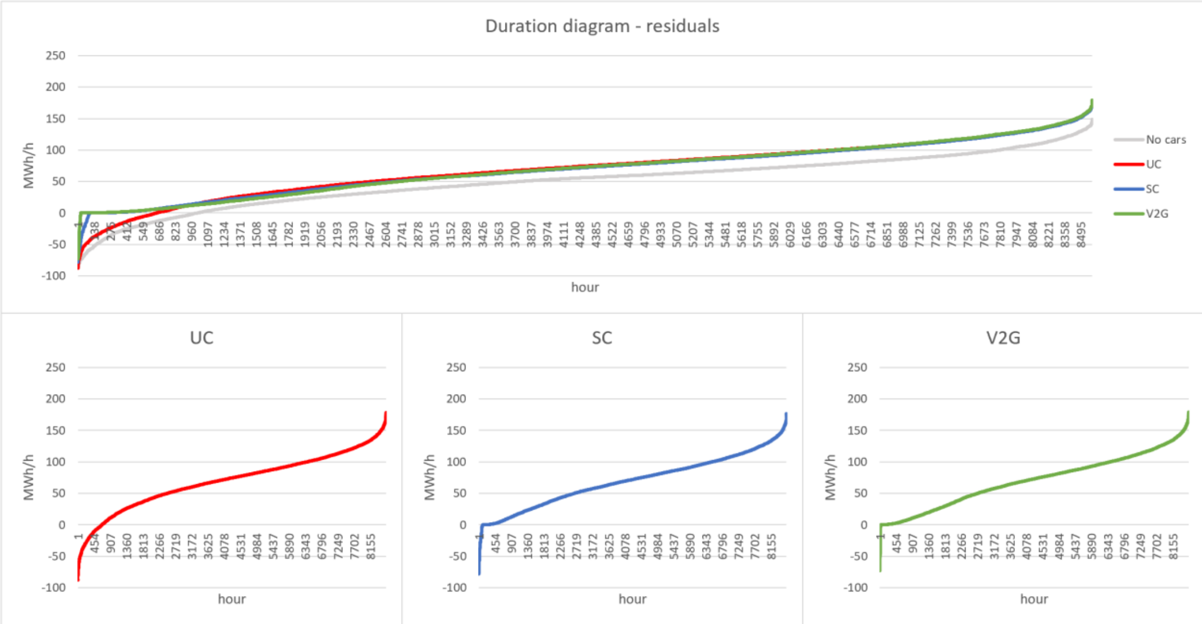

Figure 18: The residuals in IP100 plotted in a duration diagram. In the top all residuals are plotted together and the residual in the no electric cars scenario are included as reference. In the bottom the residuals are shown individually.

Below, table 13 shows the total imported and exported energy and the locally produced power used for charging for the four scenarios. The impact of SC and V2G on export is again distinguishable. The highest export value is found in the scenario without electric cars. Export is halved in the UC scenario and reaches significantly lower values in the SC and V2G scenarios. Again, the SC and V2G scenario has notably fewer hours with export (118 and 29 respectively). The number of hours with export has increased for the SC and V2G case from the corresponding 9 and 6 hours in IP50. Import is by far the highest in the UC system and second highest in the V2G scenario, where it is one GWh higher than for SC. The number of hours with export was 1013, 667, 118 and 29 for the No EVs, UC, SC and V2G scenarios respectively.

Table 13: Export, import and charged local power in IP100 for the no EVs, UC, SC and V2G scenarios. Included are also standard deviations to show the spread in the result. The stochastic elements relate to EVs why standard deviations are not used in the No EVs scenario.

	No EVs (GWh)	UC (GWh)	SC (GWh)	V2G (GWh)
Exported	27.2	16.1 ± 0.0	2.8 ± 0.0	0.8 ± 0.0
Imported	467.9	624.5 ± 0.1	608.4 ± 0.1	610.2 ± 0.1
Charged local power	0	11.8 ± 0.0	26.0 ± 0.0	23.8 ± 0.0

Looking at the utilisation of locally produced power, the scenarios follow the same order as in BC and IP50: it is highest in the SC, second highest in the V2G and lowest in the UC scenario. The differences are even greater in this case; while there were 1.9 and 0.8 GWh more of utilised local power in BC comparing SC and V2G to the UC scenario, the corresponding values are now 14.2 and 12 GWh. The difference between the SC and V2G scenario has grown from 1.1 to 2.2 GWh.

The potential of using electric cars as a power sink while charging is similar to the corresponding potential in BC and IP50, however, the capacity available during 95-99 % of the time is lower. During 99 % of the time cars are capable of receiving 36 MWh/h or less in the SC scenario and during 95 % of hours they can receive 138 MWh/h or less. In the V2G scenario the corresponding numbers are 122 and 183 MWh/h. The corresponding number for discharging in the V2G scenario are still close to zero. In IP100, 6.5 GWh are discharged during the year. Below, figure 19 include histograms where the number of hours certain levels of charging/discharging capacity are available is shown.

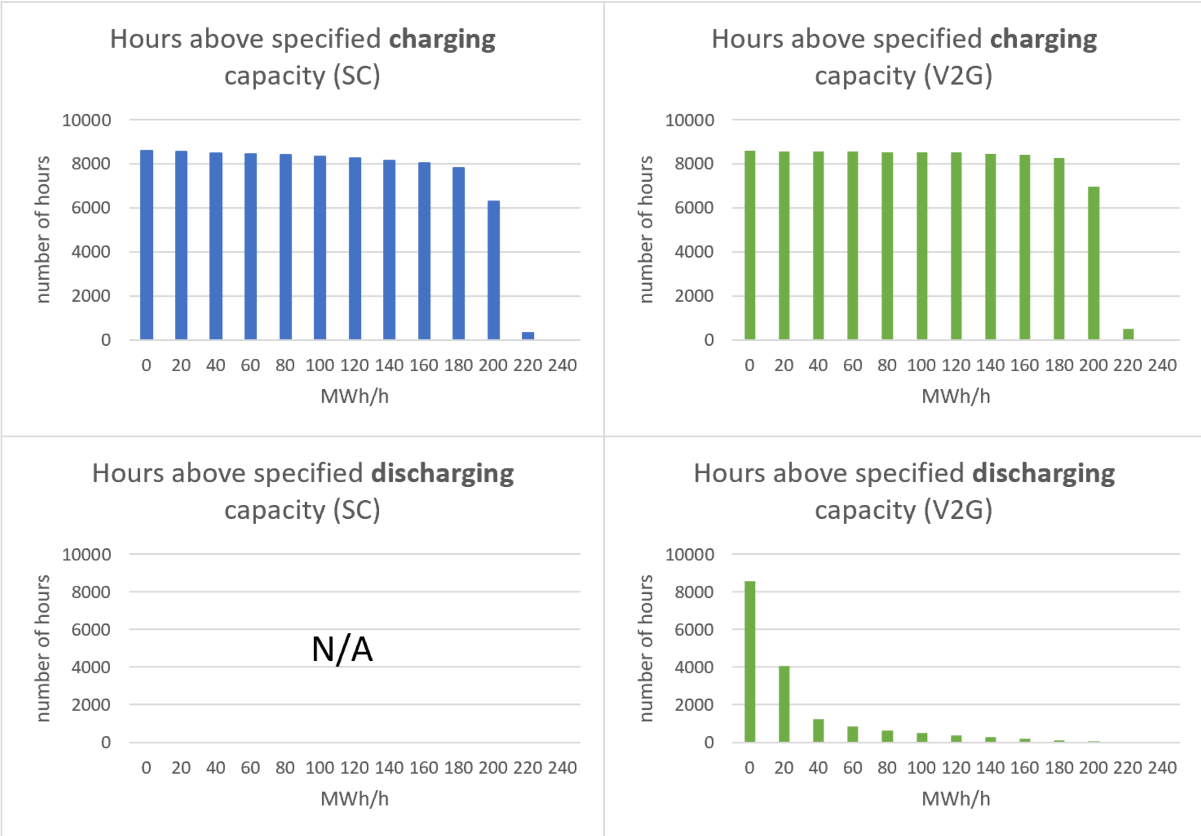

Figure 19: Histograms showing the number of hours with specified levels of chargeable capacity during the simulations in IP100. Chargeable capacity here is how much power that can be used to charge all the plugged-in electric cars on Gotland.

Finally, the battery capacity on Gotland during the year is shown in figure 20 for the SC and V2G scenarios. The number of peaks and a valleys' have increased as compared to the BC and IP50. The perception of thickness of the lines arise from intra-day variations as the high number of hours depicted does not enable specific hours to be distinguished.

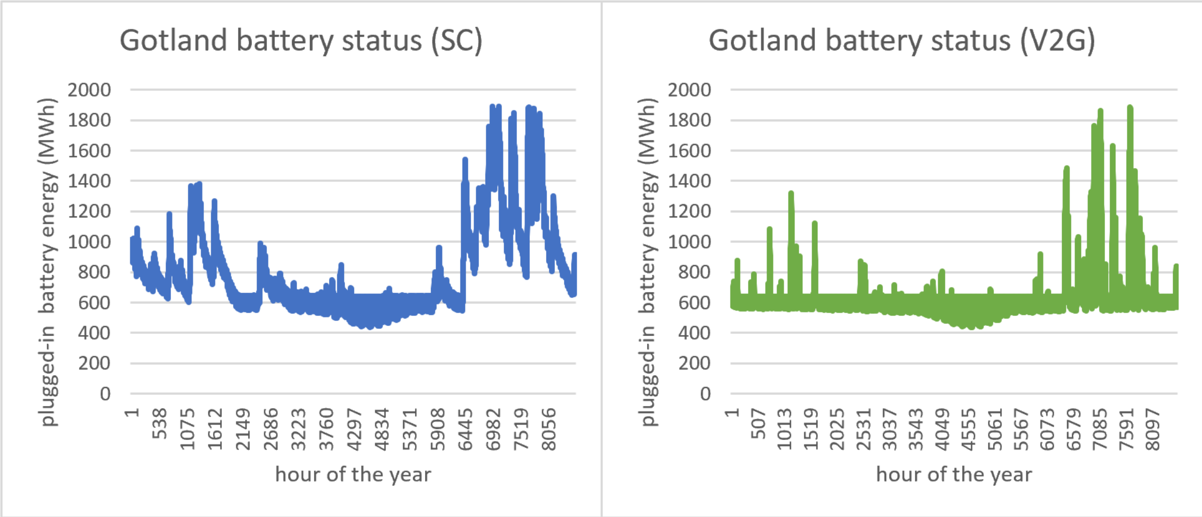

Figure 20: The energy stored in batteries of the plugged-in electric cars on Gotland during the hours of the year in IP100. Included are the SC and V2G scenarios.

2.4 Analysis

In this part of the thesis, the main results are analysed. An attempt is made to include wider trends as well as more specific differences.

2.4.1 Residuals, import and export

There are trends that are consistent throughout all cases and that differentiate the scenarios with electric cars from the ones without. The way residuals appear in duration diagrams are one example, having characteristic S-shaped figures in all scenarios and all cases for the more part of the simulated year (figures 11, 15 and 18). In general, all scenarios with electric cars result in an increase of residual values, observable as the curve-representation of these is elevated in the figures as compared to the no EVs scenario. On an annual basis, electric cars will result in increased electric energy import from the mainland, in this thesis found to be at lowest 140.5 GWh (IP100, SC scenario) and at highest 165.8 GWh (BC, UC) as compared to the no EVs scenario of today.

The residual values for scenarios with electric cars are aggregated to a large extent, in all cases. This is particularly clear during hours with more import and differences are distinguishable as Gotland moves towards export and low import hours. Differences during the export hours are expected, as a major idea behind the suggested systems is to utilise more of the locally produced power on the island and to decrease export. Decreasing export counteracts a trend of increasing export that has caused the local energy company GEAB to prohibit further installations of renewable power generation units. For all cases and all scenarios with electric cars, some energy export is avoided as compared to the no EVs scenario. This effect, however, is most pronounced in the V2G, secondly in the SC and least in the UC scenario.

To visualise the differences in residuals for the hours with export and lower import values, the 1000 lowest hourly residual values are shown in figure 21 below, for all three cases. The differences between the UC and the no EVs scenarios are close to constant during these hours (apart from the extreme export values) while the potential benefits of the SC and V2G systems grow gradually when more power production is introduced. All scenarios with electric cars reduce the number of hours when energy export is needed. This is visible in the figure as the number of hours during which the curve is below zero.

Figure 21: the 1000 lowest hourly values for the residuals in BC, IP50 and IP100 for all scenarios.

While the number of export hours are reduced to zero in the V2G and SC scenario of BC, there are still 130 hours of export in the UC scenario and 291 hours of export in the no EVs scenario. When enough electricity production to cover for full electrification of passenger cars is introduced (IP100), the corresponding numbers are: V2G: 29, SC: 118, UC: 667 and in the no EVs scenario: 1013 hours with export. Using V2G or SC technology reduce the number of export hours so that there are fewer hours of export in IP100, then in the BC scenario with no EVs, despite the 36 % increased power production.

The steepness of the curve in figure 21 represented by SC and V2G scenarios could be caused by limitations in the energy storage posed by electric cars. After a period of persistent overproduction the batteries may be fully charged, and soon after Gotland goes from almost no export to a significant export level. This could also be why the highest export values are almost the same for all scenarios in IP100. In the plots showing Gotland Battery Status, these events correspond to the highest peaks (figure 13, 17 and 20). The importance of keeping track of how large amount of energy that is stored is highlighted.

The effect on annual values from introducing electric cars to the system is exceptional as well. For comparison, EON (2019) reports on the normal electricity consumption of a Swedish villa being 25 MWh if electricity is used directly for heating and 2.5 MWh for a typical Swedish apartment (E.ON Energilösningar 2019). The avoided export of 24.3 and 26.3 GWh in the SC and V2G scenario of IP100, as compared to the no EVs scenario in the same case, would be equivalent to roughly 1000 villas or 10 000 apartments. With 57 000 persons on Gotland, this is a substantial part of the household electricity needs. In fact, SC and V2G systems compensates for the increased power production in IP100, with an annual export in the systems of 2.8 and 0.8 GWh respectively, compared to 4.4 GWh in the no EVs scenario of BC. The UC scenario also shows a potential to decrease export in all cases, but the reduction is not as strong as in the SC and V2G scenarios.

It might not come as a surprise that increased production reduces required import in general. Still it is interesting that there is a reduction in imported energy in IP100, for the SC and V2G scenarios, compared to the no EVs scenario in BC. This is despite the full electrification of the passenger car fleet. The import for the SC and V2G scenario in IP100 is 608.4 and 610.2 GWh respectively, compared to 612.1 GWh in the no EVs scenario of the BC. This means that introducing a SC or V2G system would compensate for the increased power production in terms of number of export hours, increased annual export and increased annual import.

The same is not true for the UC scenario. However, the export in the no EVs scenario of IP100 is 27.2 GWh and 16.1 GWh in the UC scenario, meaning that even a UC system could cut export, by 41 % when there are 36 % more power production on the island. The number of export hours is also reduced. Below, figure 22 shows the import and export annual values for all the scenarios in BC and IP100, please note the differences in scale of the respective y-axes.

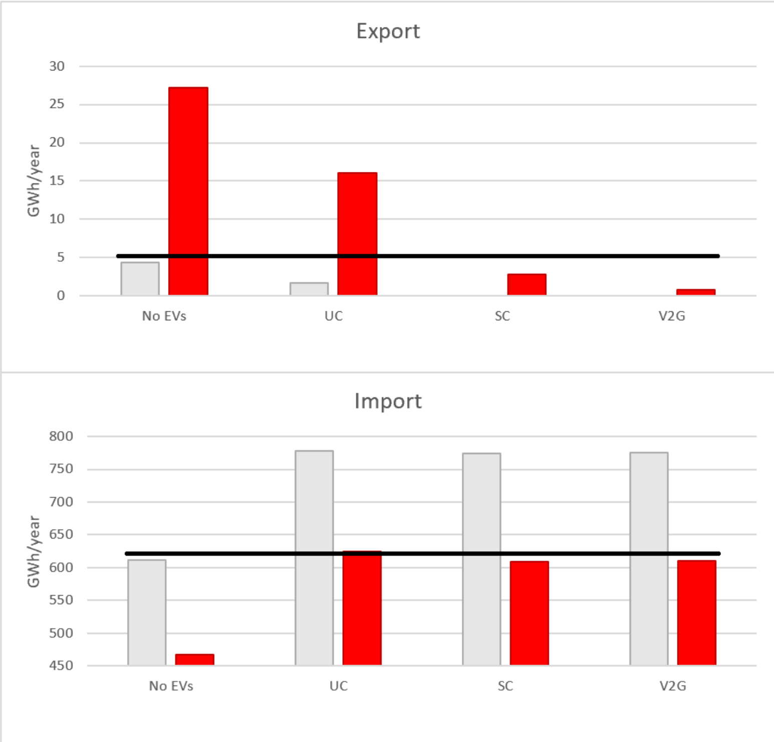

Figure 22: The export and import in BC and IP100 for all scenarios. Included are a horizontal black line to make differences and similarities clearer. Please note the different scale on the y-axes.

The amount of locally produced energy utilised in the SC and V2G scenarios as compared to the UC scenario is higher in all cases and goes progressively larger from as production is increased. While the differences, relatively seen, are modest in BC with 0.8 and 1.9 GWh more of the energy used in the V2G and SC scenarios respectively, the corresponding number in IP100 are 12 and 14.2 GWh.

Specifically contrasting SC to V2G, the differences found are small. The latter system seems to be more effective in reducing export while the former does better in decreasing import and utilising locally produced energy. The reason for the lower export and higher import in the V2G scenario is likely due to increased losses in the system, meaning that the overall usage of energy is higher. However, the reason for a lower degree of utilisation for locally produced energy is probably due to another mechanism entirely. The discharging of energy onto the grid could lead to batteries reaching the lowest allowed SoC for system participation sooner, meaning that the trips causing electric car batteries to go lower than 34 % SoC would occur more frequently. This is the condition after which cars are allowed to charge with power from the mainland in the developed model.

Rather than this being a necessary disadvantage of a V2G system in general, it could be a good reason to rethink the system implementation. For example, improving planning and using forecasting of renewable power production could help in better matching consumption (charging) and production, maximising locally produced energy utilisation. For example, if a period of overproduction is forecasted in the near future, allowing the vehicles to use the energy stored in the battery for mobility could be preferable. Letting the SoC to decrease under these circumstances will make room for storing locally produced energy later.

2.4.2 Capacity for charging, discharging and energy storage

In all cases there is a considerable potential for absorbing power in the SC and V2G scenarios. The overall reliability for this purpose is also high, as most of the cars remain plugged-in for most of the year. This indicates that electric vehicles can be trusted as a power sink and that installing more variable power on Gotland could be done if a future scenario with mass-implementation of the techniques, without taking high risks.

For the more part of the simulated year, the chargeable capacity is greater than the 130 MW that are transmittable over the directable mainland cable today. It is only in the SC scenario of IP100 that the capacity is substantially lower than the cable capacity, for more than one percent of the simulated year. The greatest availability is found in the BC, with 177 and 180 MWh/h for the SC and V2G scenario respectively during 99 % of time. To simplify the comparison between the cases, below figure 23 shows how much can be charged and discharged in all cases during 95 and 99 % of the time. Note that the scale of the y-axis in the rightmost subfigure is a factor of thousand lower.

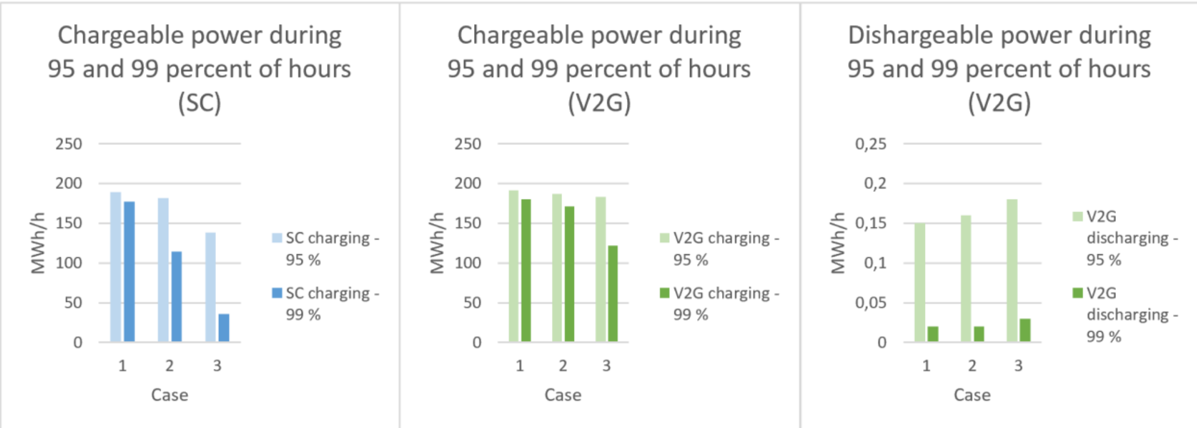

Figure 23: The capacity available for charging in the SC (left), charging in the V2G (middle) and for discharging in the V2G (right) scenario, including all cases during 95 and 99 % of the time. Note the difference in scale for discharging in the V2G scenario. In the figure the cases are represented as BC=1, IP50=2 and IP100=3.

From figure 23 it can also be seen than when more power production is introduced on Gotland, the chargeable capacity during 95 and 99 % of the time decreases. The lowest values are found in the SC scenario in IP100, at 122 and 36 MWh/h respectively. The same declining trend can be observed in figure 10, 13 and 16 showing in histograms the number of hours with certain levels of power availability.

The dischargeable capacity in the V2G scenario, on the other hand, remains low during all cases. Visible in figure 23 as well, were the scale is adjusted to be a factor of thousand lower than for the charging capacity equivalents. Notable is that the trend is opposite to the one for chargeable capacity as the introduction of more power production results in the available capacity for discharging growing. Furthermore, the energy quantities discharged to the grid are not insignificant, with values 1, 3.1 and 6.5 GWh discharged during one year in BC, IP50 and IP100 respectively. Still, employing a V2G system under the conditions in the included cases does not carry enough benefits to make it favourable over a SC system especially as it likely carries additional costs caused by the novelty of the technology, the additional complexity and the risk of battery degradation. However, this does not necessarily mean V2G is not the preferable solution but rather that doing it under the conditions here and using this form of system implementation will not make it the preferable option over SC.

Looking at the figures showing the battery storage energy on Gotland (figures 13, 17 and 20), it can be found to be 600 – 700 MWh throughout most of the year. Multiplying 35 000 cars, a battery capacity of 54 kWh and a lowest SoC for system participation at 34 %, returns a value of roughly 640 MWh (equation 2 below). This value is in-between the levels of energy stored that is found in the batteries during most of the year and is fairly close to the normal state of the system. This means that the electric cars on Gotland are close to the lowest SoC for allowed system participation during most of the year and the variations between 600 – 700 MWh is caused by cars being plugged-out for usage in the transport application. The cars being low on battery is in turn caused by the relatively low power production rate on Gotland. The power export under current production conditions are already low with most of the power having area of usage on the island. For comparison, a full battery on every car on Gotland would correspond to 1 890 MWh, if the same method for calculation is used. This higher value is only reached on rare occasions. The difference between maximum storage capacity and minimum storage capacity amount to 1250 MWh.

$$Gotland\ battery\ capacity = cars * battery\ capacity * SoC = 35\,000 * 54 * 0.34 \approx 640\ MWh$$

(equation 2)

The energy level in the system being close to minimum for allowed system participation is likely behind the high availability of chargeable power in the SC and V2G scenarios and the low availability of discharging power in the V2G scenario. While cars are ready to receive charging power during most of the time, there will not be enough energy to provide discharging power. This could also partly explain why there are no differences between scenarios in any of the cases for the hours with the highest import. The peak import hours are likely following hours of significant import and the cars may already be at lowest allowed SoC. The share of batteries devoted to system participation is simply depleted when the peak arrives and cars need to be charged from the mainland to complete mobility assignments, rather than staying idle from charging or providing discharging power.

The high capacity hours are extremes of occasional positive deviation from the normal state posed by the system SoC being roughly 34 %. While relatively uncommon in BC, an increase in number of such hours are seen for IP50 and IP100. It is also visible that hours with a battery capacity in-between extreme values become more common as the power production capacity on Gotland increases. The highest average energy level in the system is found in the SC scenario of IP100, where the trend of the system energy level staying close to 34 % is broken during half of the year. The elevated storage level is found mainly during the latter part of the simulated year and is caused by (wind) power production being high during that period.

There are also negative deviations from the normal energy level of accumulated plugged-in car batteries on Gotland. The deviation occurs during the hours of the year when traffic is most intense (figure 7). While it seems reasonable that less plugged-in time due to increased usage for mobility purposes would result in less available charging and discharging capacity from electric cars, it is not necessarily representative of the cars considered as a part of the SC or V2G system. The traffic data used does not distinguish between local cars, mainly used on Gotland, and cars that belong to temporary visitors. However, the valley corresponding to the negative deviations in figures 13, 17 and 20 provides a hint on the sensitivity of using electric cars for active power regulation if transport intensity is increased.

Another perspective to take regarding the impact of increased traffic intensity is that of system robustness to this kind of events. During no scenarios and in no cases (except for those with no EVs) the plugged-in battery capacity goes below 430 MWh during any hours of the year.

2.5 Sensitivity analysis

This sensitivity analysis includes parameter studies showing how a change in battery storage capacity, battery charging and discharging capacity, share of time electric cars can charge, the number of electric cars and how increased production to the target of 2.5 TWh annually will affect the usefulness of SC and V2G systems.

As it was found in the results that the proposed systems would contribute the most in IP100 and the aim of Region Gotland is to increase power production even further, the level of production from IP100 is used when nothing else is mentioned. The original scenario is shown in each of the analyses as a reference and it is coloured grey for comparability. The first week of simulated values is omitted where it has a significant effect on the result, due to the effect of a set initial SoC.

The main characteristics of the results are described here, for more details the reader is referred to the *The Model*, *Sensitivity analysis* in the appendix. For the reader who are in a hurry, a summary can be found in the end of this section.

2.5.1 Battery storage capacity

To find how the results are affected by changing the battery storage capacity of the electric cars in the model, simulations are run with battery capacities of 50, 200 and 300 % of the original capacity. The SoC was kept as a percentage, meaning the 34 % lowest SoC for allowed system participation does not mean the same absolute amount of energy in the different simulations.

For the SC scenario, increasing battery capacity leads to a positive contribution in decreasing export, import and increasing the share of utilised locally produced energy (figure 24, note the differences in the scale of the figure). The standard deviations were in all scenarios 0.0 GWh for export and charged local power and 0.1 GWh for import. The number of hours with export are decreased and the highest hourly export values are lowered. The highest hourly values and number of hours with extreme import remained largely unchanged.

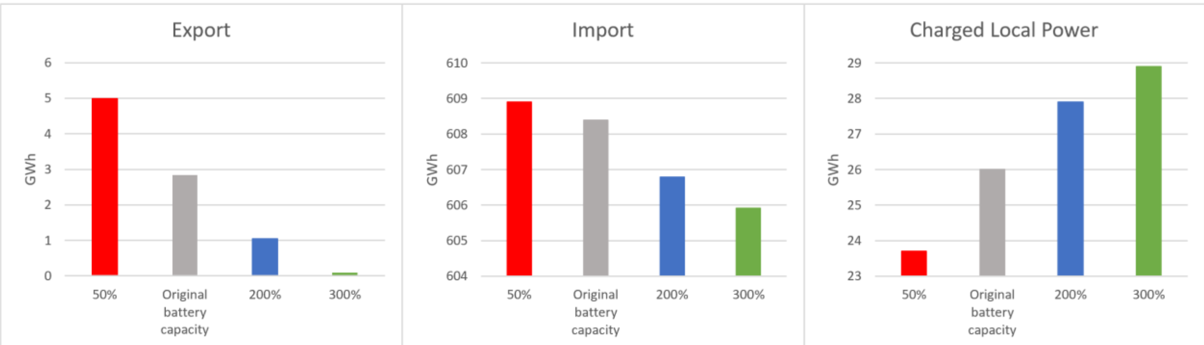

Figure 24: The export, import and charged local power on annual basis for battery capacities of 50, 200 and 300 % of the original capacity in the SC scenarios. The corresponding values for the original capacity are included as reference.

The effect on available battery charging capacity is positive, and values of chargeable capacity found during 95 and 99 % of time are higher. This is likely a result of the batteries taking longer to fill up and to empty out, meaning the capacity would be available during more of the simulated year.

Increased storage capacity can be seen on the accumulated level as well. As a result, the energy level representing the normal state is increased and periods with high production are utilised to a greater extent as battery storage capacity grows. This is visible as peaks in the curves representing the energy stored during the simulated year for the higher storage capacity scenarios, and can be contrasted to the blunter looks of the lower storage capacity scenarios (figure 25). Energy that could have resulted in peaks is instead exported in the latter scenarios. The figure also shows a deepening valley for the traffic intense months as battery storage capacity increases. Cars simply bring more energy with them when they are unplugged.

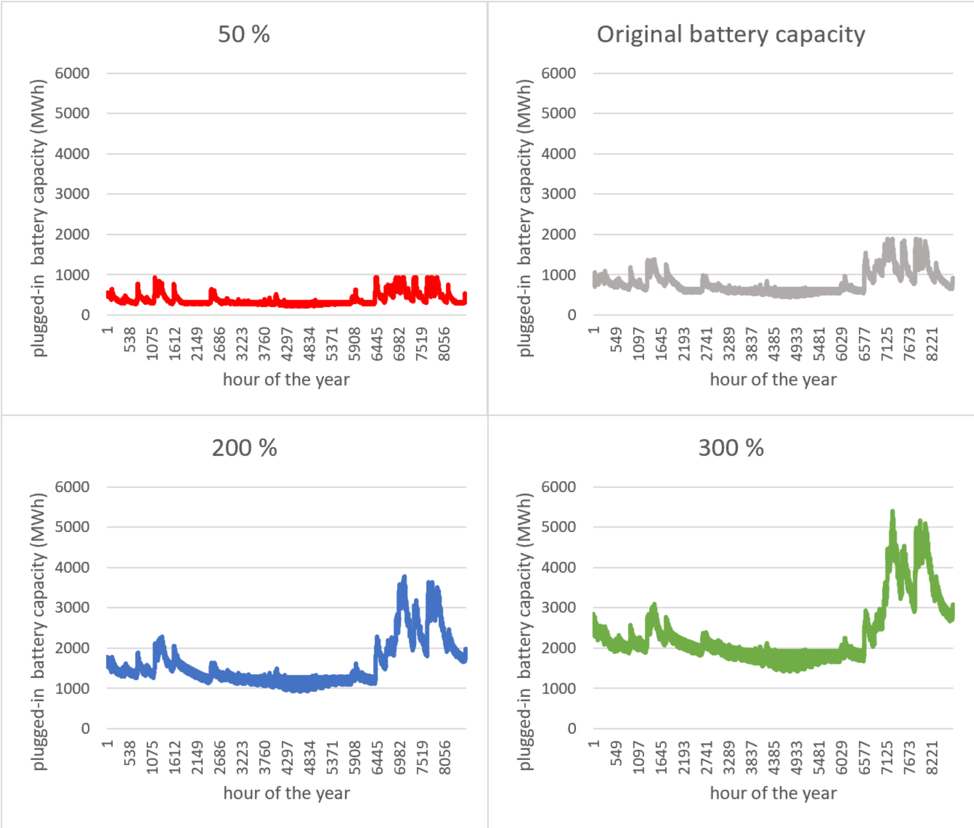

Figure 25: Energy stored in EV batteries on Gotland during the simulated year with 50, 200 and 300 % of the original capacity in the SC scenarios. The corresponding values for the original battery capacity are included for reference.

Similar trends are found for the V2G scenarios for export and import (figure 26, note the differences in the scale of the figure). The standard deviations were in all scenarios 0.0 GWh for export and charged local power and 0.1-0.2 GWh for import. However, there are no export for scenarios with batteries of 200 and 300 % of the original storage capacity and the difference in import between scenarios is low. While the difference in charged local power is small between scenarios of 100 % storage capacity and more, an unexpected finding is the slight decrease between the 200 and 300 % scenarios. The decrease, however, is less than 0.25 GWh. Again, the highest hourly values of export and number of hours with export are decreased and there are no export hours during the two scenarios with highest storage capacity amongst cars. The extreme import values remain unchanged.

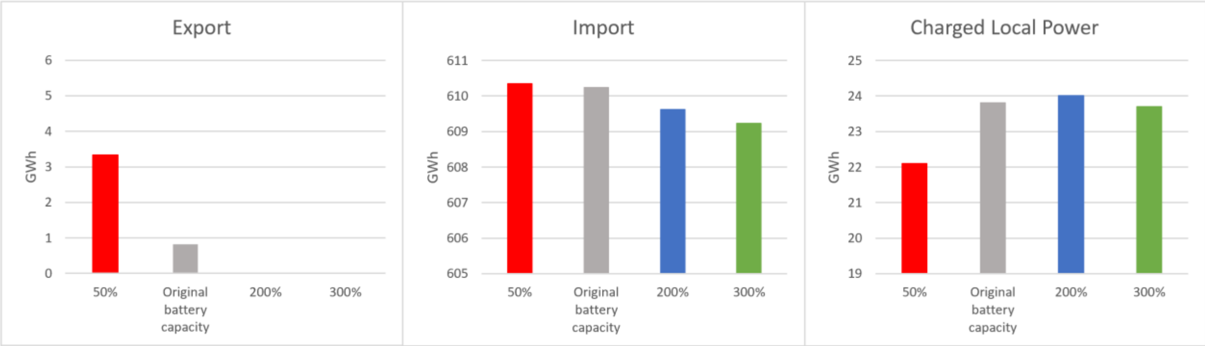

Figure 26: The export, import and charged local power on annual basis for battery capacities of 50, 200 and 300 % of the original capacity in the V2G case. The corresponding values for the original capacity are included for reference.

Again, effect on available battery charging capacity is positive, looking at values found during 95 and 99 % of time. The effect on energy stored during the year is represented by the characteristic peaks for the higher battery storage capacity scenarios in this scenario as well. However, scenarios with 200 and 300 % of original storage capacity are similar (figure 27). This implies that a point is reached somewhere between the original battery capacity and the 200 % scenario after which increased battery storage capacity is not significantly increasing usefulness in the V2G system, under the IP100 conditions. This would be expected as the annual export is reduced to zero, meaning there are no more surplus energy produced on Gotland, that are used by electric cars.

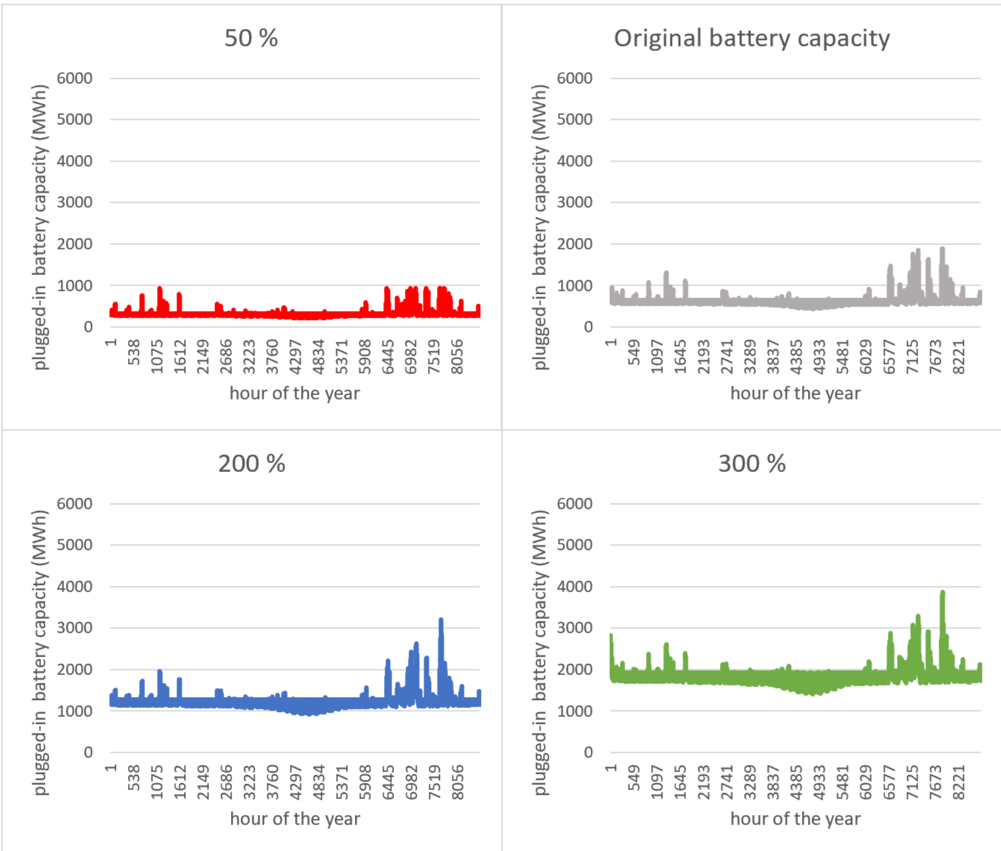

Figure 27: Energy storage level during the simulated year for 50, 200 and 300 % of the original capacity in the V2G scenarios. The corresponding values for the original capacity are included as reference.

There are no great effects on dischargeable capacity, which remains low throughout the scenarios. Discharged in the four scenarios are: 5.2, 6,5, 7,1 and 7,2 GWh as battery storage capacity is increased and a stagnating trend is again visible.

2.5.2 Charging and discharging capacity

The charging and discharging capacities that will be used in future SC or V2G systems are hard to predict today. Therefore, simulations are run with the lowest charging capacity that is commonly used (3.7 kW) and an increase of 100 % from the original value of 6.3 kW (12.6 kW). When simulated for the V2G scenario, the same capacities are used for charging and discharging.

For the SC scenario, there is no significant effect on export, import or charged local power (figure 28 below, note the differences in the scale in the figure). The differences, however, is less than 0.25 GWh. The standard deviations were in all scenarios 0.0 GWh for export and charged local power and 0.1 GWh for import. The number of export hours, extreme hourly export and import values also remain largely unchanged.

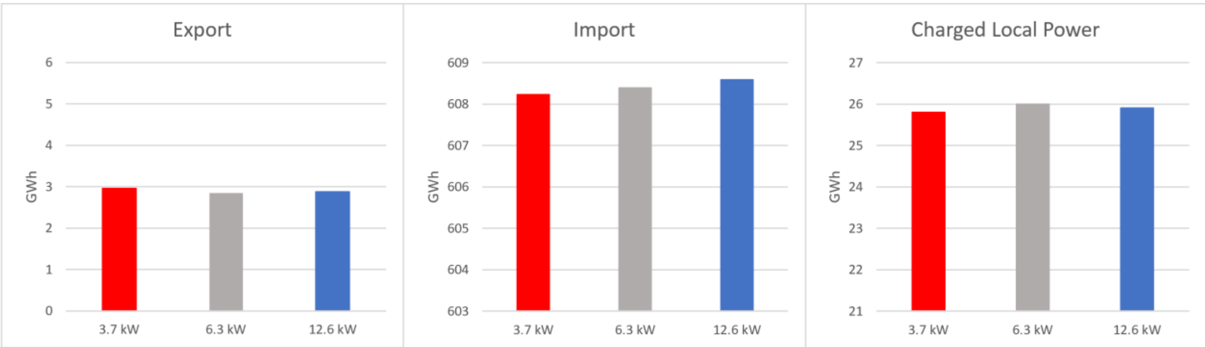

Figure 28: The export, import and charged local power on annual basis for charging capacities of 3.7, 6.3 and 12.6 kW in the SC scenarios.

The effect on available battery charging capacity is strong and positive as charging rate is increased. This is true for the chargeable capacity available during 95 and 99 % of time as well. The values for the energy stored during the year are still largely similar throughout the simulations (figure 29). It seems charging capacity is not a limiting factor for the benefits of the studied SC system under IP100 conditions, when it comes to integrating renewable energy.

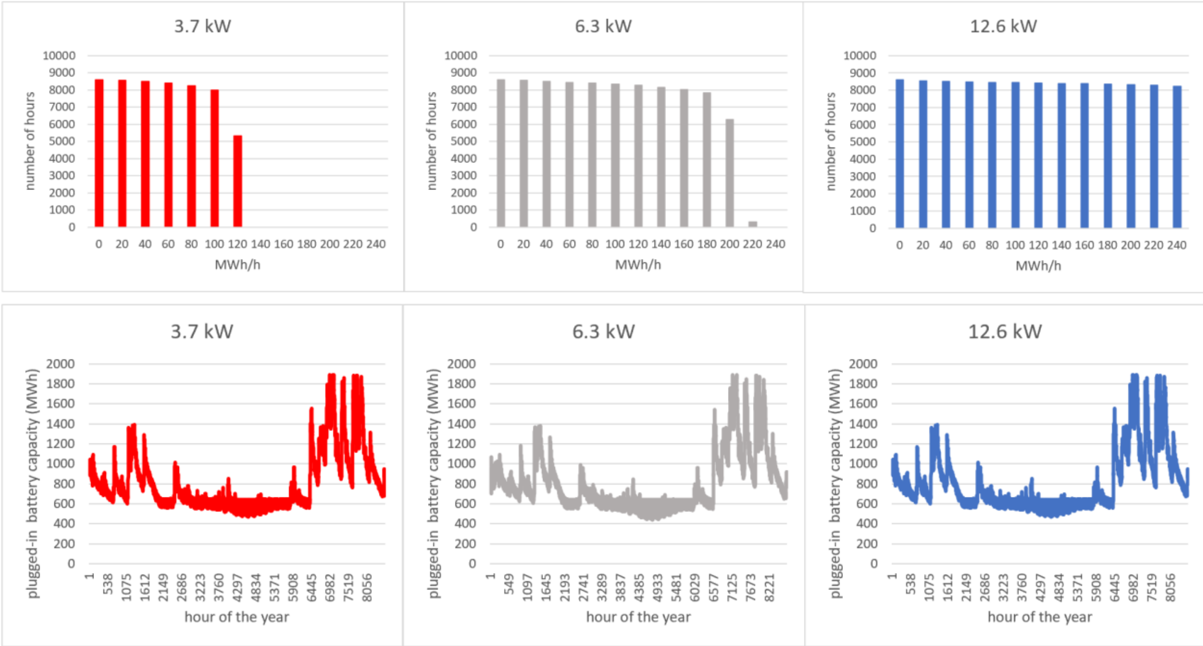

Figure 29: number of hours above certain available charging capacities and battery storage level during the simulated year for 3.7, 6.3 and 12.6 kW in SC scenarios.

While no significant differences are found for annual export values in the V2G scenario, there is an increasing trend for import and decreasing trend for charged local power (figure 30, note the differences in the scale of the figure). These differences are small, however, they could be explained through a set of mechanisms. The standard deviations were in all scenarios 0.0 GWh for export and charged local power and 0.1 GWh for import.

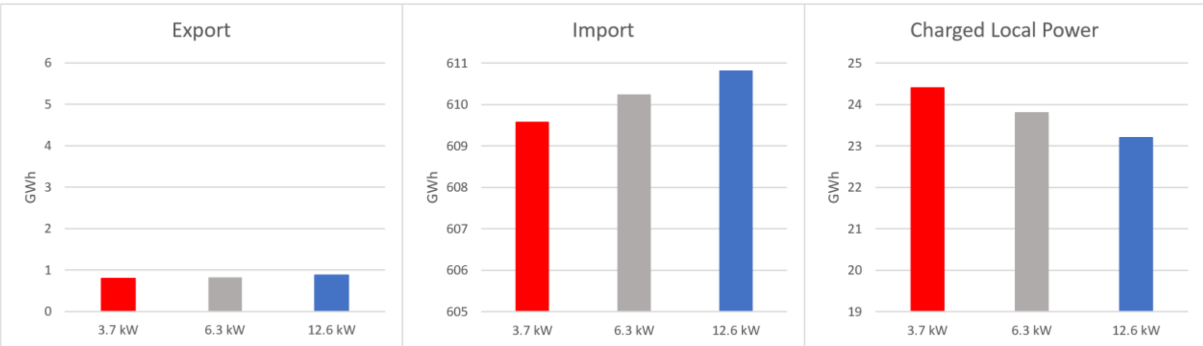

Figure 30: The export, import and charged local power on annual basis for charging/discharging capacities of 3.7, 6.3 and 12.6 kW in the V2G scenarios.

Faster discharging of batteries could result in cars having to be charged with power from the mainland more often as they rapidly empty out to the 34 % SoC lower limit, a mechanism that has been mentioned before. This could decrease the share of locally produced power used by the cars over the year. The faster charging could theoretically compensate for this, as a sudden increase of production could be better utilised, however, charging capacity does not seem to be a limiting factor. This can be seen from the SC (figure 29) and V2G (figure 31) scenarios showing that energy storage level has the same profile throughout the simulations despite the increased capacity for charging and discharging.

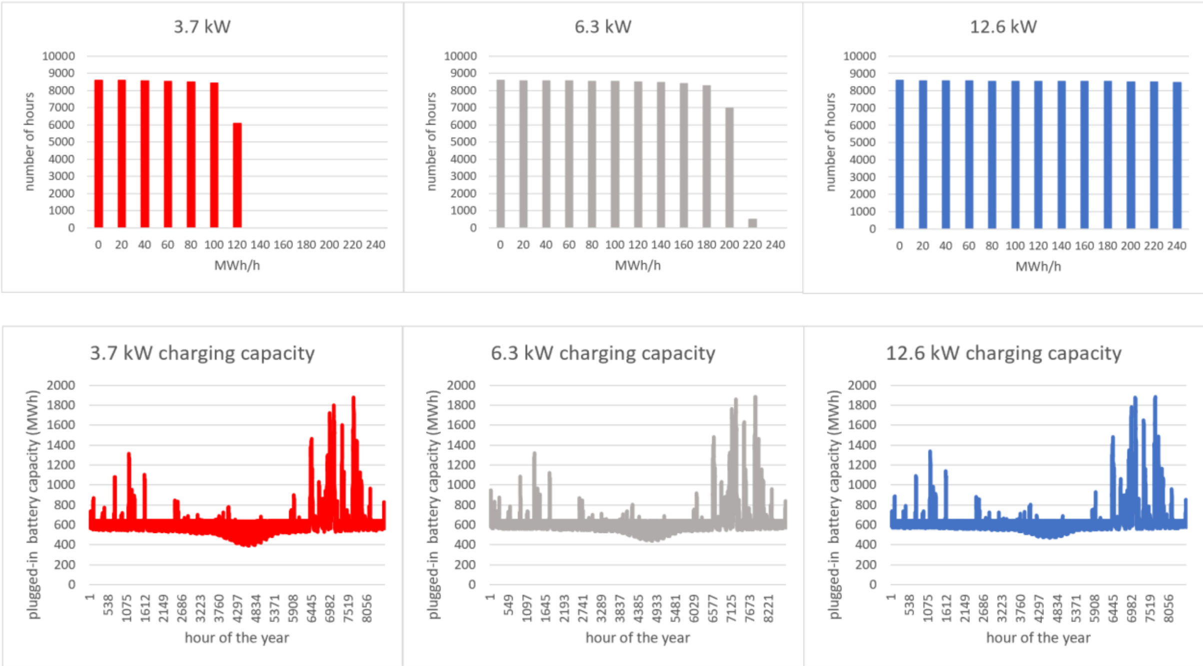

Figure 31: number of hours above certain available charging capacities and battery storage level during the simulated year for 3.7, 6.3 and 12.6 kW in V2G scenarios.

While this could explain the increased import as well, there should be more export compensating for it, to maintain the energy balance in the system. This is simply not the case and it seems the system uses more energy when the charging and discharging rates are increased. A part of the reason could be increased losses, as more power has to be imported and transmitted over the regional grid, instead of being utilised locally, within a close area.

Another part of the reason is the increased amount of energy discharged during the year (with losses). Discharged energy values for the three scenarios are: 5.3, 6.5 and 7.4 GWh. There is some improvement in dischargeable capacity as the discharging rate is increased, however, it remains significantly lower than the chargeable capacity.

2.5.3 Chargeable share

Hopefully the norm will become to plug in the car upon arrival on a new destination (or have it done automatically in the case of an automated future). If this is not the case it could affect the usefulness of SC or V2G systems. Therefore, simulations are run setting the share of vehicles that are chargeable to 50 and 75 % instead of the 100 % used in the original simulations. To clarify: cars are plugged-in both as soon as they have entered a node in the original model, here the share that is plugged-in in this way is altered.

The assignment of chargeability is done every time cars arrive to a destination and the status is very unlikely to be kept throughout the simulated year. A car that cannot be charged, cannot be discharged to the grid either, even in the V2G scenarios. In this case the risk of cars getting stuck on locations, with them unable to charge, has to be considered. However, the number of minutes cars did not embark on planned journeys due to them being insufficiently charged was found to be less than one per thousandth of the total number of journey minutes, even in the worst scenario. This implies that the number of stuck cars is very low and should only have a limited effect on the final results.

While there are smaller differences to be observed between the 50 and 100 % scenarios, the 75 and 100 % scenarios are close to identical in terms of annual export, import and charged local power (figure 32 below, note the differences in the scale of the figure). The standard deviations were in all scenarios

0.0 GWh for export and charged local power and 0.1 GWh for import. This is also the case for the number of hours with export while the extreme hourly values of export and import remain largely unchanged.

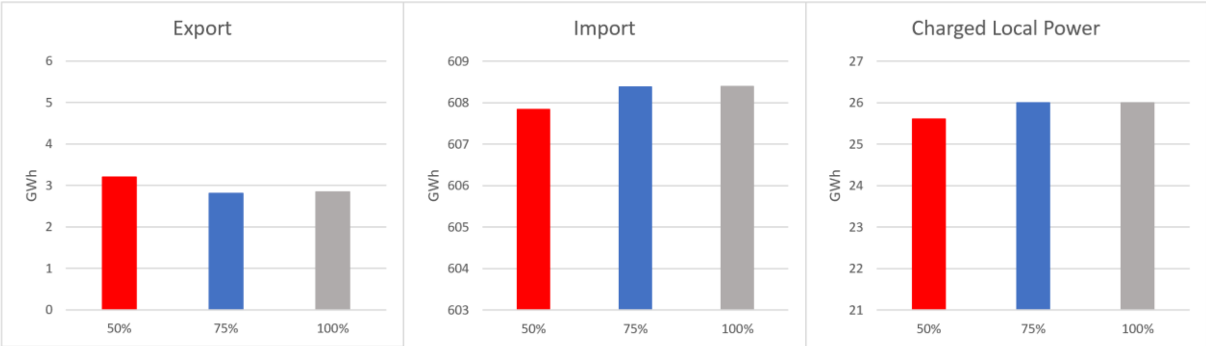

Figure 32: The export, import and charged local power on annual basis for the 50, 75 and 100 % chargeable share scenarios for the SC scenarios.

A decrease of the available chargeable capacity is visible, as the chargeable share is lowered (figure 33). There is some difference in the energy storage level during the year for the 50 % scenario as compared to the 75 and 100 % scenarios, with the latter two again sharing great similarities. The visible differences for the 50 % of cars available for charging, are seen in the peaks, which are not as high as the equivalent ones for the other two scenarios. The normal energy state in the system is somewhat increased as the system moves towards a higher chargeable share. There is some effect on the capacity available for charging during 95 % of the time while the effect on capacity available during 99 % of time remains modest.

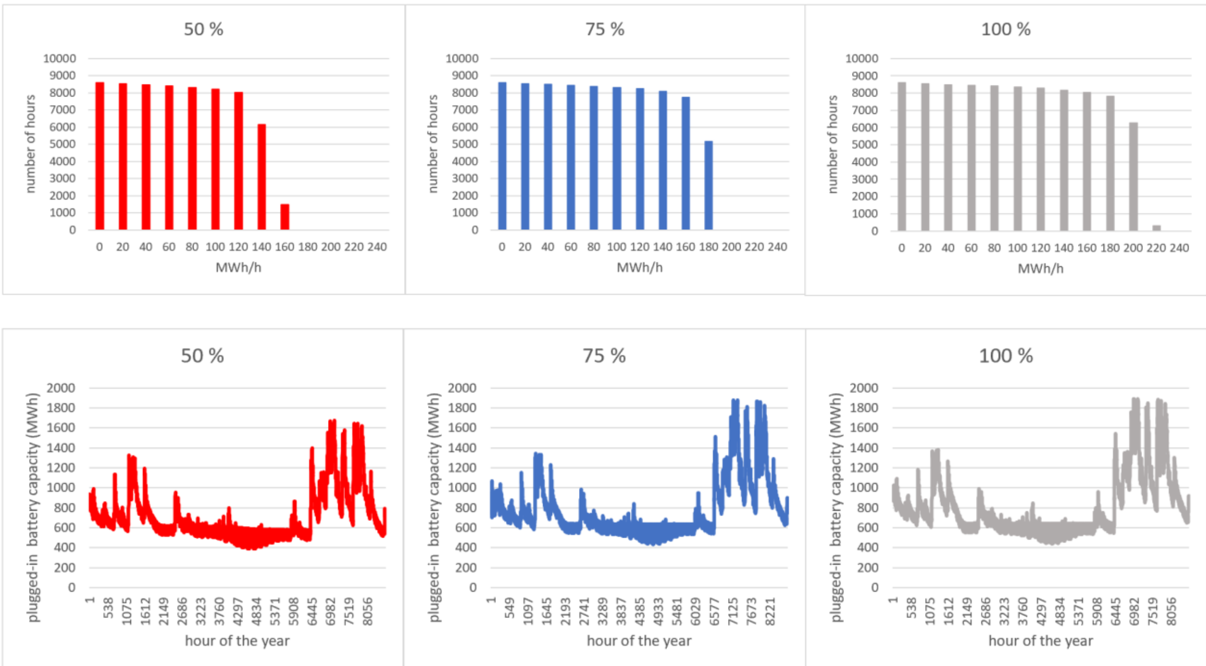

Figure 33: number of hours above certain chargeable capacities and energy storage levels during the simulated year for 50, 75 and 100 % chargeable share in the SC scenarios.

The patterns are similar in the V2G scenarios (figure 34, note the differences in the scale in the figure). The standard deviations were in the scenarios 0.0 GWh for export and charged local power and 0.1 GWh for import. While the 75 and 100 % scenarios do not differ to a significant extent, the export is somewhat higher and the import somewhat lower for the 50 % scenario. Furthermore, more locally produced power is used for charging in the 50 % case while the 75 and 100 % scenarios again does not differ significantly in this respect. The result could relate to the increase in annual discharged energy amounts being 3.3, 5.7 and 6.5 GWh for the 50, 75 and 100 % scenarios respectively. More discharged energy could mean a greater number of batteries being discharged to the 34 % SoC limit and therefore having to charge from the mainland.

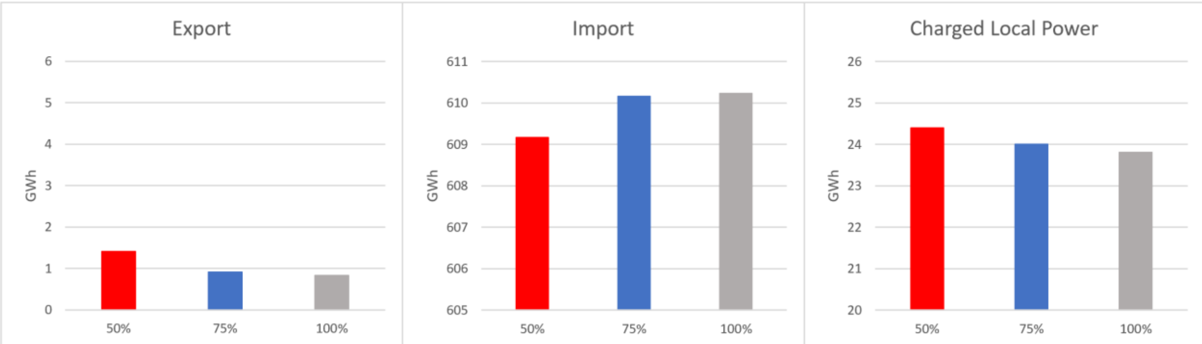

Figure 34: The export, import and charged local power on annual basis for the 50, 75 and 100 % chargeable share scenarios with V2G systems.

The effects on chargeable capacity and the energy storage during the simulated year are similar those in the SC scenario (figure 35). The effect on number of hours above certain chargeable capacity is considerable while the effect on stored energy is small for the 50 % and the 75 and 100 % scenarios. Again, differences between the latter two are insignificant. There are also only minor differences in the chargeable capacity available during 95 and 99 % of the time and the dischargeable capacity is impacted negatively with decreasing share of chargeable cars.

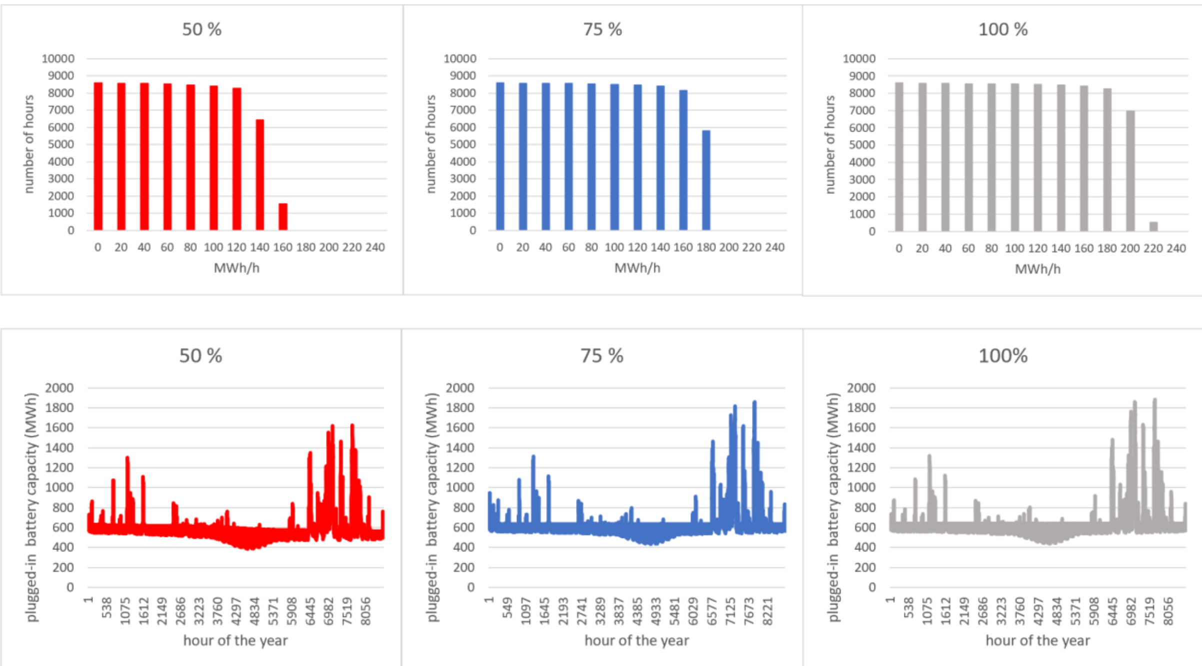

Figure 35: number of hours above certain available charging capacities and energy storage levels during the simulated year for 50, 75 and 100 % chargeable share in V2G systems.

2.5.4 Number of cars

What if all passenger cars do not go electric and only a share of them are available for SC or V2G system participation? In this part of the sensitivity analysis the number of electric cars is altered, setting the share to 33 and 67 % of the original with complete adoption of electric cars. This differs from the analysis of chargeable share: only a fraction of the car fleet consumes electricity while all cars in the chargeable share analysis are electric but just not plugged-in all the time.

Even though it is unlikely that the production level is increased to cover for 100 % electrification of passenger cars while there are only 33 or 67 % of cars being electric, the setup for IP100 is used. This is for comparability and due to higher production better showing the potential of SC and V2G systems.

In the SC scenarios, reducing number of cars effectively reduce the potential of the system to decrease export and utilising more locally produced power (figure 36 below, note the differences in the scale of the figure). A linear relationship seems distinguishable. For comparison, 16.7 and 27.2 GWh were exported in the UC and no EVs scenario of IP100 meaning that there is still a considerable potential usefulness of the suggested systems. The import, however, is reduced when the number of cars is decreased, with roughly 100 GWh reduction between the 33 and 100 % scenarios. Decreasing electric cars also increases the hours with export from 1 % to 3 % and 6 % of the year in the 66 and 33 % scenarios respectively and increase the highest hourly values. The standard deviations were in the scenarios 0.0 GWh for export and charged local power and 0.0-0.1 GWh for import.

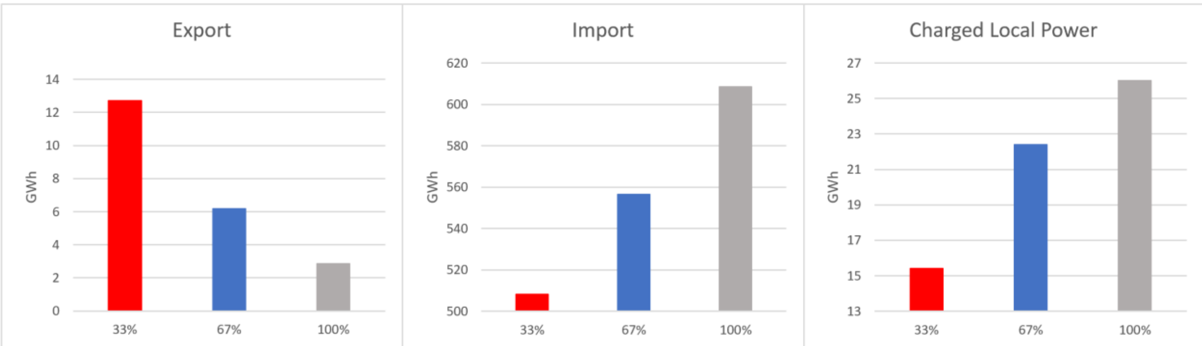

Figure 36: The export, import and charged local power on annual basis for scenarios with 33, 67 and 100 % of the original number in the SC case.

The effect on available chargeable capacity is strong as well. The scenarios with fewer cars only have fractions of the available capacity that is found in the 100 % scenario (figure 37). The capacity available 95 and 99 % of time is also decreased significantly, and the effect on energy stored during the simulated year is large as well. The normal energy level in the system become lower and peaks representing periods with more energy stored are shaved as the number of cars becomes lower. The fewer cars simply cannot fully utilise and store energy during hours of high production.

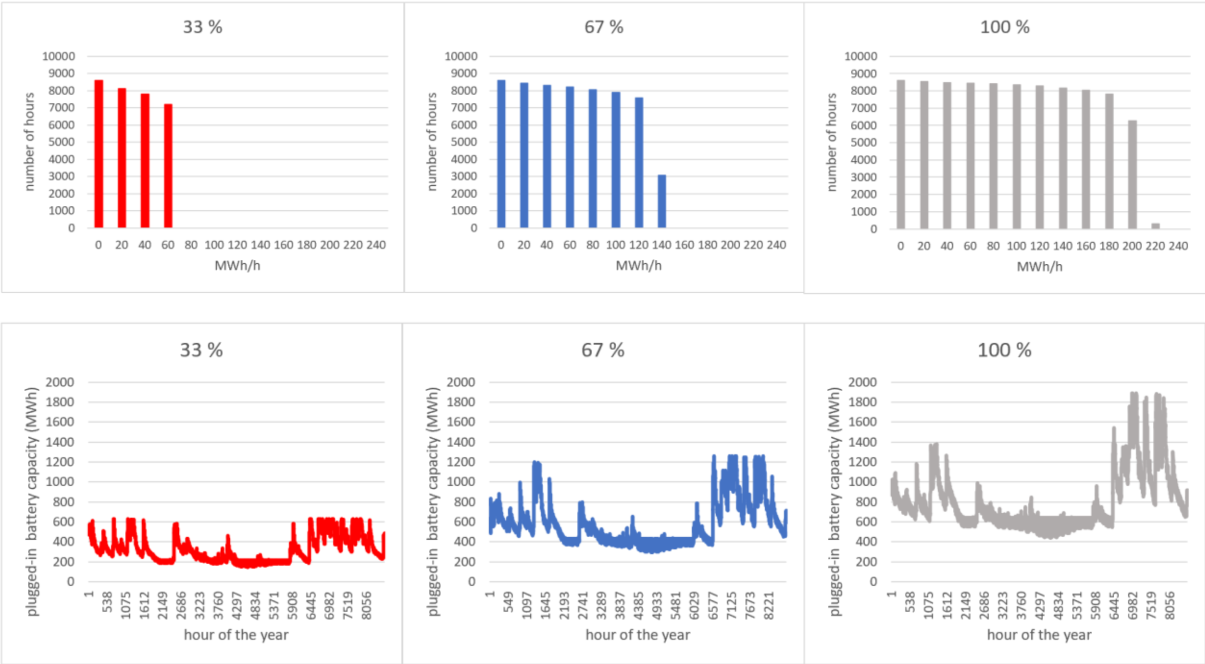

Figure 37: number of hours above certain chargeable capacities and energy storage level during the simulated year for scenarios with 33, 67 and 100 % of the original number of cars in SC scenarios.

While the overall trend is the same in the V2G scenario, the export values are lower in comparison to the SC scenarios with the same share of cars (figure 38, note the differences in the scale of the figure). The effect on number of export hours and extreme values follow the same trend as in the SC scenarios. The standard deviations were in the scenarios 0.0 GWh for export and charged local power and 0.1 GWh for import.

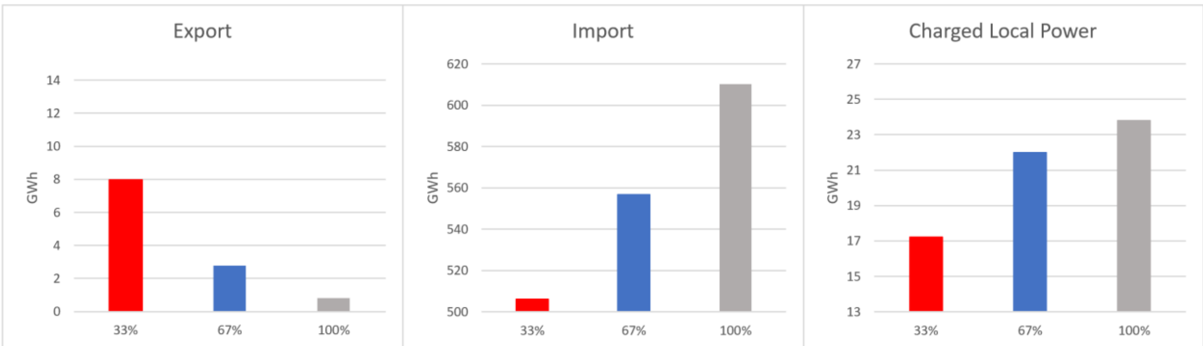

Figure 38: The export, import and charged local power on annual basis for scenarios with 33, 67 and 100 % of the original number in the V2G case.

The lower export values for the suggested V2G systems have been observed before in this thesis, yet the effect is particularly pronounced for the scenarios with 33 % of EVs, with the V2G scenario exporting 8 GWh as compared to the 12.7 GWh in the SC scenario. Also, for the first time the share of renewable energy that is utilised is higher for the V2G scenario. Possibly this could be due to the energy level in the system during the year being higher in the case of 33 % electric cars, resulting in the discharging mechanism starting to make a difference. It could be that a system with more production as compared to consumption (including the load posed by electric cars) will benefit the V2G over the SC system. For the 67 % EV adoption scenarios, the advantage of the V2G system over the SC system seem to be levelled out again, to a large extent.

The effect on the trend for available charging capacity and energy stored during the year is similar in the V2G and the SC scenarios when the number of cars is altered (figure 39). The effect is again particularly strong for the capacity available for 95 and 99 % of the time.

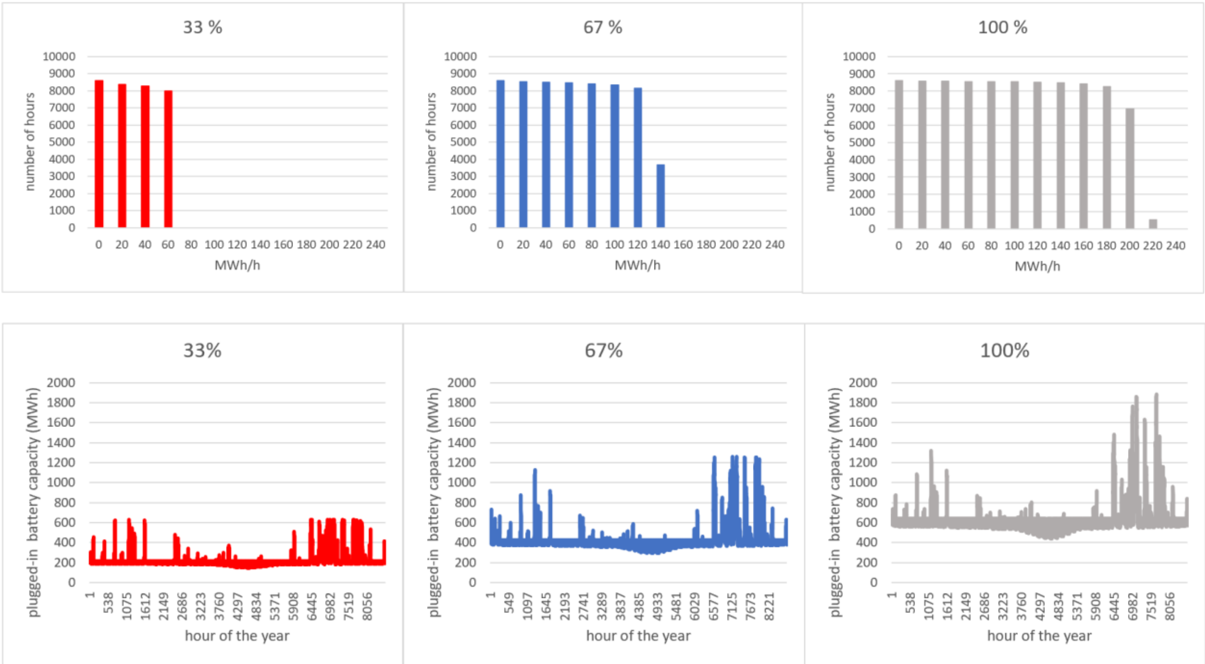

Figure 39: number of hours above certain available charging capacities and energy storage level during the simulated year for scenarios with 33, 67 and 100 % of the original number of cars in V2G scenarios.

While the capacity for discharging is low already, during most of the year, it is not improved as the number of electric cars are decreased. The energy amounts that are discharged to the grid during the year are 4.6, 6.0 and 6.5 GWh in the 33, 67 and 100 % scenarios. This results in energy amount that is discharged per car is higher, for the scenarios with less electric cars.

2.5.5 The goal of Region Gotland

The goal of Region Gotland to increase wind power production on the island to 2.5 TWh annually is ambitious. It would mean an increase of roughly 442 % from the production that exists today and to see what SC and V2G systems could contribute in a future with such production levels, simulations were run with the hourly production values multiplied by 5.42. A first attempt was made with transmission limitations included; however, more than 50 violations of these limitations where detected meaning that the energy balance was poorly maintained on the island. Therefore, simulations were run again, without limitations. The results are shown below together with corresponding scenarios from IP100 (0.624 TWh production). When deemed meaningful, the no EVs scenario in the 2.5 TWh future is included as well, for comparison.

In reality, the increased production would likely be developed together with electrification of the industry on Gotland, resulting in a different load profile. What that load profile would look like is not clear and therefore the consumption is kept unaltered.

Moving on to the results, the export is increased greatly when 2.5 TWh are produced annually, however, the difference between the no EVs and the SC scenario is large (142,8 GWh). The vast majority of the energy needed for electric cars is covered by the local production in this scenario. This can be seen in figure 40 below (notice the difference in scale), also showing the import and charged local power on an annual basis from which the same conclusion can be drawn. While the export in the SC scenario with 0.624 TWh annual production is negligible when compared to the corresponding in the 2.5 TWh scenarios, the import is significantly higher. The locally produced power used for charging is a lot larger in the 2.5 TWh SC scenario than in the 0.624 SC scenario. Standard deviations in the SC 2.5 TWh scenario were 0.1 GWh for export, import and charged local power.

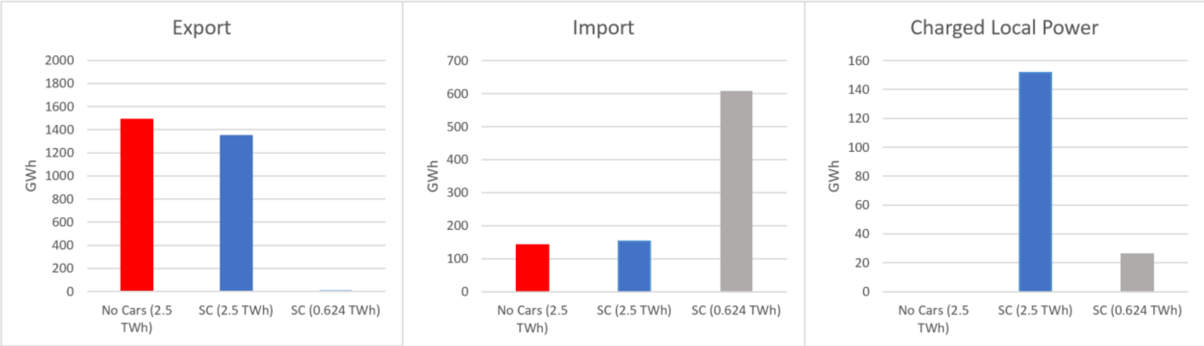

Figure 40: The export, import and charged local power on annual basis for scenarios with no EVs and 2.5 TWh annual production, SC and 2.5 TWh annual production and the original SC scenario.

The import in the SC scenario is only slightly higher than the corresponding in the no EVs scenario when the annual production is set to 2.5 TWh. It seems that under these circumstances, increasing production to the level that is the goal of Region Gotland could mean replacing imported petrol and diesel with locally produced power for transportation of passenger cars almost completely. This also provides a hint that the production scenarios used until now in this thesis might be too low to really show the potential of the SC system. However, in reality the parameters would also greatly depend on how the added load and transmission limitations would fit together with the increased production and the SC system.

A new normal state is established for the SC system with 2.5 TWh production annually. Instead of being close to the 34 % limit, the system is now close to 100 % SoC during most of the year. Instead of occasional peaks of increase, a larger number of peaks of decrease can be seen (figure 41 below). The impact on available charging capacity is grave as the cars are full or close to full during large parts of the year.

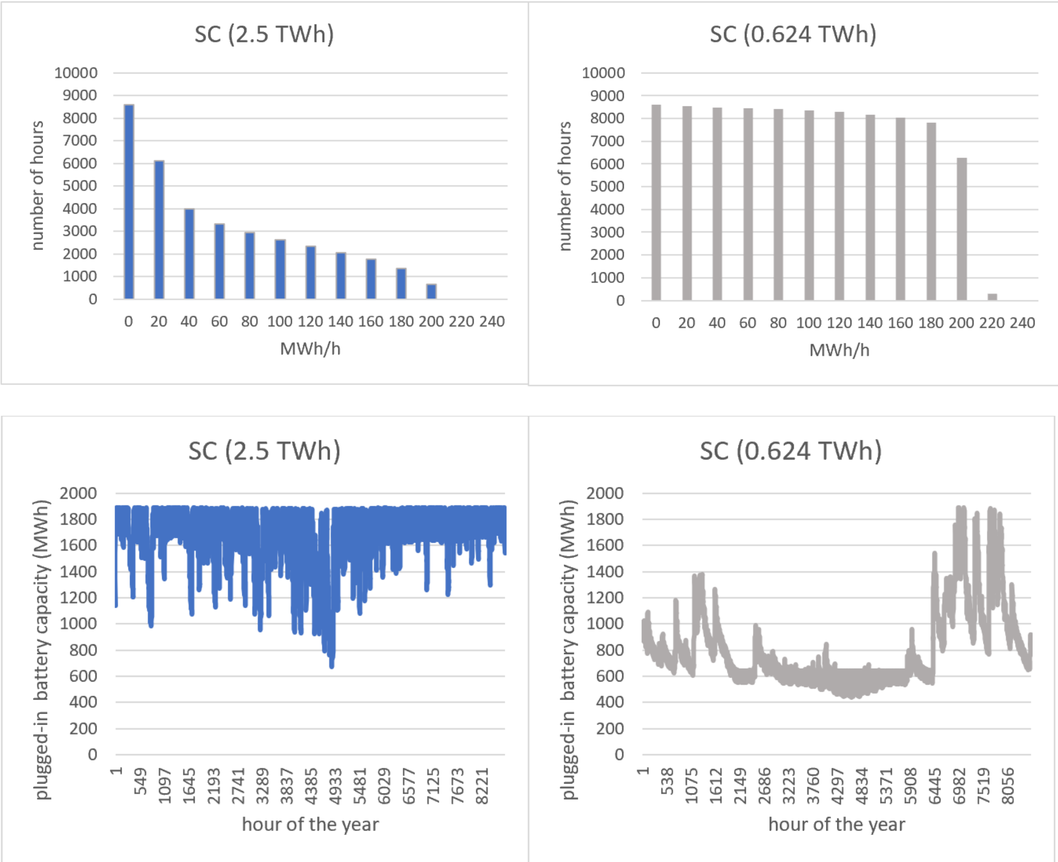

Figure 41: number of hours above certain available charging capacities and battery storage level during the simulated year for scenarios with SC and 2.5 TWh annual production and the original SC scenario.

The increased production of renewable energy shows the potential benefits from a V2G compared to a SC system (figure 42, note the differences in the scale of the figure). Standard deviations in the V2G 2.5 TWh scenario were 0.1 GWh for export, import and charged local power. The annually exported energy is decreased from 1.35 to 1.28 TWh between 2.5 TWh scenarios with the respective systems. The import is decreased as well from 0.15 TWh to 0.10 TWh, a figure that is lower than the corresponding for the no EVs scenario, which is 0.14 TWh. This is due to the high utilisation of locally produced power for charging in the V2G scenario reaching above 200 GWh, roughly 34 GWh higher than the energy used for mobility purposes. This excess energy is instead stored in car batteries and used to decrease import when the load exceeds production on Gotland. The share of time with export goes from 70 to 57 % when comparing the no EVs to the V2G scenario and while the extreme hourly values of export are decreased, the corresponding ones for import increases.

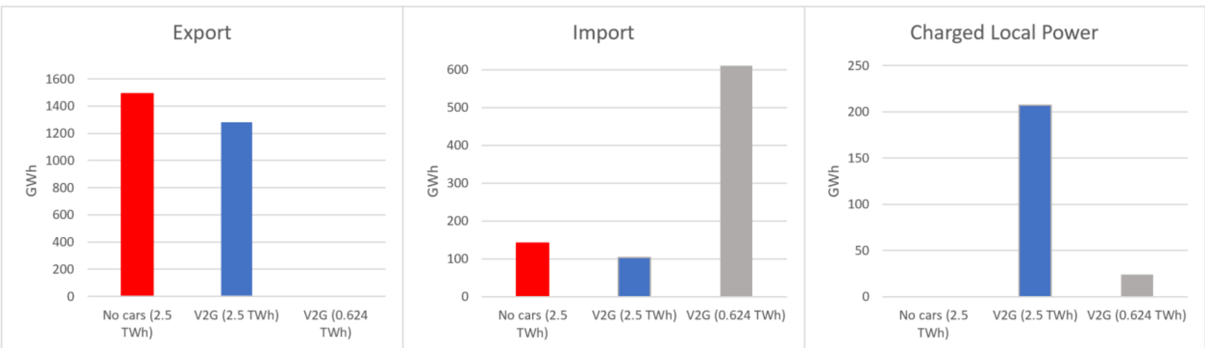

Figure 42: The export, import and charged local power on annual basis for scenarios with no EVs and 2.5 TWh annual production, V2G and 2.5 TWh annual production and the original V2G scenario.

A way of explaining the increased usefulness from the V2G as compared to the SC system can also be found in the effect on available charging/discharging capacity and the energy storage level during the year. While the 0.624 TWh scenario is characterised by a good availability of chargeable capacity and a low availability of dischargeable capacity, the situation is the opposite in the 2.5 TWh scenario (figure 43). The availability of dischargeable capacity in the latter is still far from the availability of chargeable capacity in the former, however, it is greater than the availability of chargeable capacity in the same scenario. The availability of chargeable capacity in the 2.5 TWh scenario is also greater than the availability of dischargeable capacity in the 0.624 TWh scenario and overall, the difference between chargeable and dischargeable capacity has decreased significantly in the 2.5 TWh scenario. The capacity available for 95 and 99 % of the time is now low for charging as well as discharging.

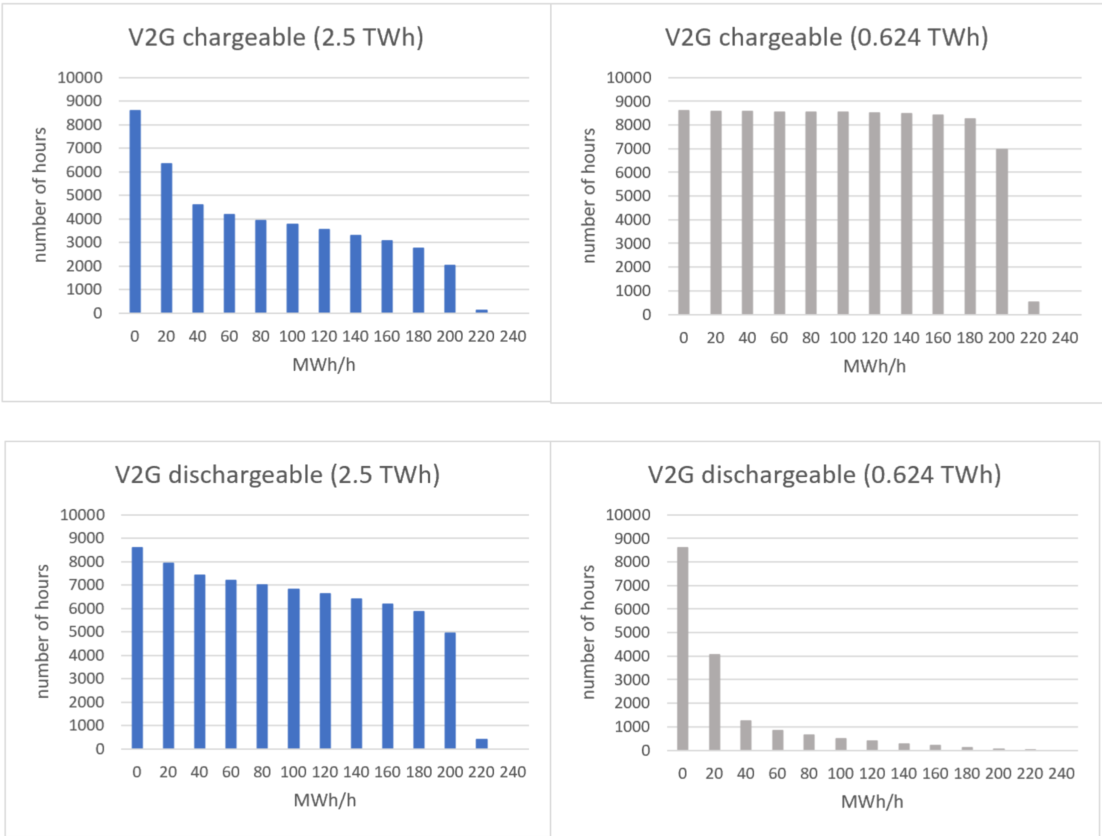

Figure 43: number of hours above certain chargrable and dischargeable capacities during the simulated year for scenarios with V2G and 2.5 TWh annual production and the V2G with 0.624 TWh of annual production.

Comparing energy storage levels during the year provide further insight into why the V2G system suddenly provides a significantly better utilisation of locally produced power (figure 44). While there exists an established normal state of energy storage level in the 0.624 TWh scenario, the 2.5 TWh scenario include numerus cycles of filling and emptying batteries of electric cars spread out over the year. Annually, 33.8 GWh is discharged to the grid in the 2.5 TWh scenario while the corresponding figure is just 6.5 GWh in the 0.624 TWh scenario.

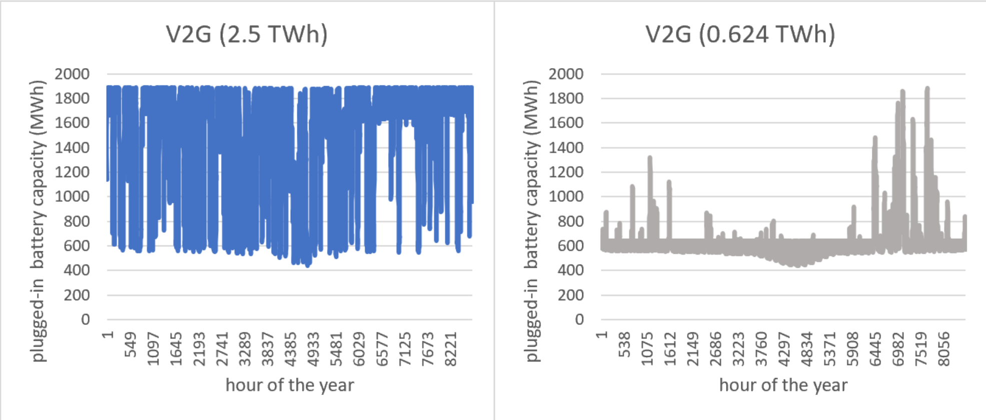

Figure 44: Energy storage level during the simulated year for scenarios with V2G and 2.5 TWh annual production and V2G with 0.624 TWh of annual production.

2.5.6 Summary

A short summary of the above sensitivity analyses is as follows:

- Increasing battery storage capacity has a positive effect on all parameters. In the V2G scenario, a threshold is reached already between 100 and 200 % battery storage capacity after which no further positive effects can be found on integrating renewable energy under IP100 production levels.
- While increasing the charging and discharging power increases the chargeable and dischargeable capacity greatly, no notable effects are found on export, import, charged local power or energy storage levels during the simulated year in the SC scenarios. In the V2G scenarios a slight negative trend is found resulting in increased import and decreased utilisation of locally produced power while the annual discharged amount of energy is increased slightly.
- Decreasing the share of EVs available for charging/discharging to 75 % does not seem to have significant effect on the usefulness of the SC or V2G systems for integrating renewable energy other than decreasing the capacity available for charging and discharging. Reducing it further to 50 % results in slightly increased export and import. The reduction will also cause slightly higher levels of utilisation for locally produced power in the V2G scenario.
- A reduction in the number of EVs on the island will affect the potential of the systems to integrate renewable power greatly, shown for the SC as well as the V2G systems. It will also affect the availability of dischargeable and chargeable capacity to a large extent.
- Increasing the power production to 2.5 TWh annually, as is the goal of Region Gotland, will result in massive export and numerous violations of the limitations implemented for the power system in this thesis. This is if nothing else is changed and the load profile of today is kept. However, a high production scenario such as the one suggested will turn the increased import from electrification of transport into a decrease in export. The high production scenario also shows an example of when an implementation of a V2G system, such as the one used in this thesis, can be significantly favourable as compared to the SC equivalent.

3. The Literature Study

Without participation, there will be no SC or V2G systems and to receive real benefits from it a few enthusiasts will not suffice, leaving the capacity and reliability of capacity too low. A low number of connected cars will not add up to significant charging and discharging capacities and a plug-out from the charger in a system with few cars will have a large impact on the accumulated power sink or usable energy storage posed by electric cars. To accomplish wide extension of the systems, penetrating deep into a diverse society, potential participants in the systems have to be considered and their driving forces and concerns understood.

The focus in this part of the study is the incentives and modes of participation found in research and how this relate to concerns and driving forces of potential participants. Participants who could offer EVs for services required by the energy system. The findings are put in the context of Gotland, creating a more holistic picture when combined with results from the modelling part, on how SC and V2G could be implemented on the island.

3.1 Method

To find literature, the online searching tool LUBsearch has been used. LUBsearch gathers a large part of the physical as well as electronic collections of information available through the library of Lund University including articles, ebooks, books, databases and more (Lund University, n.d.). To increase the number of potentially interesting results Google Scholar has been used initially as well. Google Scholar collects articles, books, ebooks from multiple academic instances (Google Scholar, n.d.).

The reason for Google Scholar only being used initially was that when the searching tool was applied to search phrases V2G, Vehicle-to-grid, bidirectional charging, smart charging and scheduled charging together with participation, it was realised that the results were too non-specific, yielding over 160 000 hits for the five categories. Keywords used for finding literature are shown in table 14 below.

Table 14: The search-phrases used in the literature study and corresponding number of “hits”. All phrases were tried out in combination with V2G, Vehicle-to-Grid, Bidirectional Charging, Smart Charging and Scheduled Charging. Therefore, the letter “X” has been used where the technology term was used together with the search phrase. The number of hits resulting from the search is showing for each combination and on the row X-participation the results from Google Scholar is included after the “,”. This is as articles found this way are included in the study.

X / Phrase	V2G	Vehicle-to-Grid	Bidirectional Charging	Smart Charging	Scheduled charging
X-participation	3, 154	3, 9	0, 9	3, 19	0, 26
X participation	66	89	7	94	15
Willing to participate X	1	1	0	1	0
Willingness X	7	9	1	26	4
Economic incentives X	26	33	4	39	2
Economic motivation X	2	3	0	4	2
Compensation X	69	80	60	64	5

A total of 40 searches generated 940 results on LUB-search and Google Scholar combined, granting a basis for which articles to include in the study. From these 940 results, articles were selected based on whether the titles carried a direct connection to the two criteria below:

- Studies concerning willingness to participate in a V2G- and/or smart charging system together with associated driving forces and concerns. The methodology of the included studies should be based on surveys, interviews or similar aimed to persons that are potential future participants of a smart charging or V2G system.

- Studies concerning economic incentives for V2G- and/or smart charging systems at least in part. The main focus of the study does not have to be these incentives, however, they need to be clearly specified.

If there was a potential connection, reading of the abstract and conclusions were used to find out if inclusion was relevant. The results where narrowed down further by inclusion only of those being available through the Lund university database or for free online. Figure 45 below illustrates the procedure of choosing relevant literature.

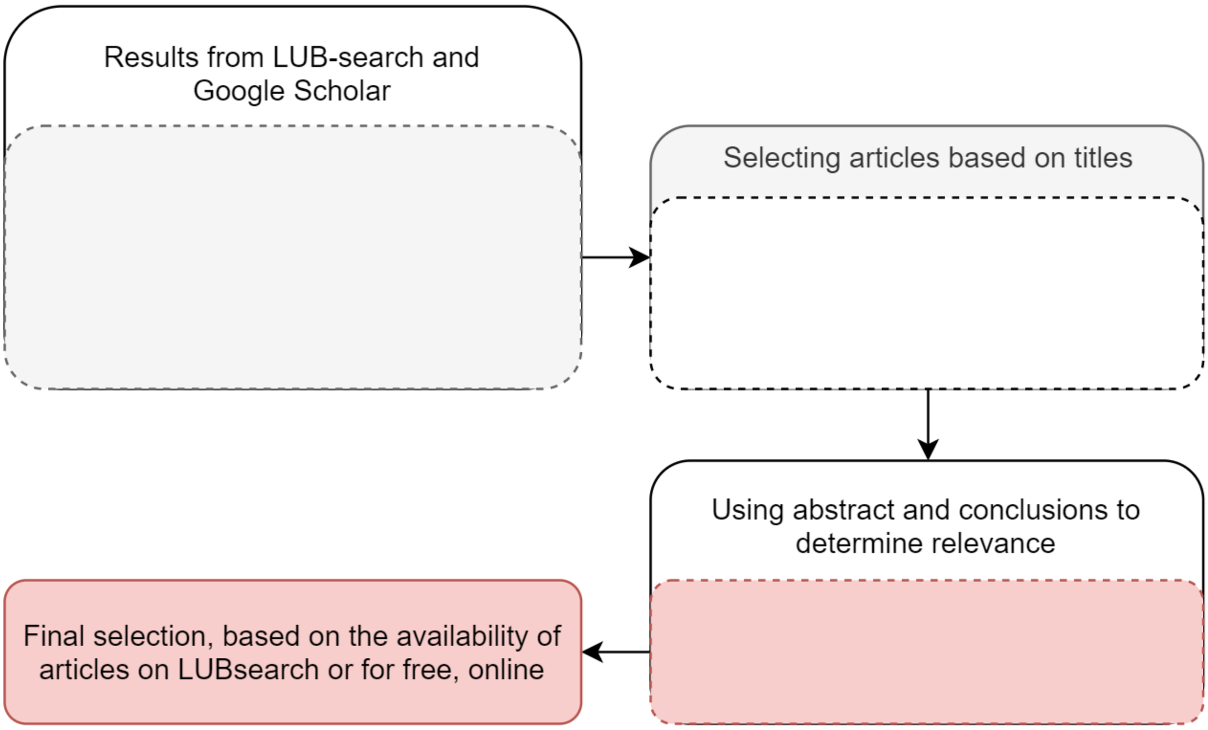

Figure 45: illustrating the procedure of choosing relevant literature.

In addition to using the phrases in mentioned databases, references from other articles have been used in order to expand the material available. The idea was that using this method could effectively lead to more relevant material.

3.2 Limitations

The using of SC and V2G is limited today and the systems remain small in number of users. The findings from the studies included to find concerns and driving forces are therefore indications made by individuals who do not know what participating in a SC or V2G system really entails. The issue of current studies on behavioural aspects of V2G being based on surveys and stated choice experiments of potential participators is pointed to by Sovacool, Axsen & Kempton (2017, p. 22).

The studies also include potential biases and samples that are not entirely representative of the whole. The latter is again pointed to by Sovacool, Axsen & Kempton (2017, p. 22), with the current target group for participation studies being pioneers with and there are indications of this subgroup behaving differently. To account for this, an attempt of transparency is made, where the biases and sample characteristics are mentioned for the studies as the result from these are summarised.

Moreover, the cultural context of the studies is not representative of Gotland, and only one of the studies include a Swedish sample. Although there might be differences, the hope is that inclusion of studies from a variety of cultural contexts will aid in catching those aspects that are relevant in a Swedish and Gotland context as well.

Moving on, there are methods used to give the reader an idea of the importance and frequency in literature for the concerns and driving forces. These are simplifications and concern using the number of studies in which a concern or driving force has been encountered and if it has been mentioned as the most important. It is quite possible that the mentioning is made in a greater number of studies without it being singled out as the most important one in any of them. Therefore, it should not be interpreted that a concern being mentioned in six studies is three times as important as a study only mentioned in two studies. Rather it means that there is more support for the first being an actual concern or driving force of potential participants.

Some of the studies from where the economic incentives and modes of participation are gathered do not have the mechanisms as their sole or main focus. Therefore, the degree to which specifications are made differs. An attempt is again made to be transparent with when this is the case, describing the aim of the studies when these are included in this literature study.

Within the scope of this study, an alternative method for examining the concerns and driving forces of potential participants would have been to survey a sample population on Gotland. However, the risk of the sample being insufficient for the drawing of conclusions applying to all of Gotland was deemed too high as the number of channels for reaching out and the time for doing so was limited. Using a more qualitative approach, exploring the positions of a lower number of potential participants at greater depth could prove misleading. There are no indications known to the author of this study, that the opinions on SC and V2G would differ less between the people of Gotland than between the samples included in the survey-studies that are used for this literature study. The larger sample accessed here is likely more relevant to finding the answer of the research question.

3.3 Result

This literature study contains nine studies regarding the willingness to participate in SC and V2G systems and fourteen studies that relate to economic incentives and modes of participation for future potential system participants. In this section, driving forces, concerns and economic incentives are summarised and an attempt is made to evaluate how well the economic incentives do in relation to the perspective of the participants. For the interested reader, summaries of specific articles are found in *The Literature Study*, in the *appendix*.

As the study "Willingness to Pay for Vehicle-to-Grid (V2G) Electric Vehicles and Their Contract Terms" contains a large sample of persons expressing their attitude towards V2G it is included in the chapter on concerns and driving forces. However, due to its focus on economic incentives, the findings made are included in the part on economic incentives as well.

3.3.1 Driving forces

Nine different driving forces for participation in SC or V2G systems are found in the study material. These are clearly echoing the promises of the technologies with expectation of increased integrability of renewable energy, increased grid stability, financial benefits and more. This is fortunate as these are largely overlapping the potential values suggested by scientists and experts. Fortunately, there seem to be no contradiction in aiding the majority of driving forces simultaneously. The driving forces are summed up in table 15 below.

Table 15: The driving forces for V2G participation along with a shorter description on what these entails, in which studies they are mentioned and the number of times they are mentioned as the most important driving force. To highlight the importance of each driving force the number of times the driving force it is mentioned and the number of times it is mentioned as most important are included. The driving forces are sorted from most to least frequently mentioned.

Driving forces	**Shorter Description**	**Studies mentioning this**	**Times mentioned as most important driving force**
Financial benefits	The opportunity to earn or save money from participation in a smart charging- or V2G-system.	(5/9) (Axsen, Langman & Goldberg 2017; K. Hirdue & R. Parson 2015; Bailey & Axsen 2015; Schmalfuß et al 2015; Geske & Schumann 2018)	
integration of renewable energy	The possibility to integrate more (intermittent) renewable energy into the energy system.	(4/9) (Bailey & Axsen 2015; Schmalfuß et al 2015; Geske & Schumann 2018; Will & Schuller 2016)	(Geske & Schumann 2018)
Power grid support	Stabilising the power grid and contributing to its functionality, largely connected to the strain posed by increased share of intermittent renewable power being distributed.	(3/9) (Schmalfuß et al 2015; Geske & Schumann 2018; Will & Schuller 2016)	(Schmalfuß et al 2015)
Environmental aspects	An interest in aiding environmental causes in general rather than in specific questions.	(2/9) (K. Hirdue & R. Parson 2015; Schmalfuß et al 2015;	
Avoiding grid expansion	Partially avoiding the need of grid expansion by implementing a smart charging or V2G system that can relieve the system.	(1/9) (Geske & Schumann 2018)	
Decentralising energy storage	Aiding in distributing energy storage as EVs spread out over the many locations of their respective owners. It can be contrasted to having one or a few larger facilities.	(1/9) (Geske & Schumann 2018)	
Emergency Power backup	Supporting ones own households with power from an EV during emergencies (i.e natural disasters).	(1/9) (Geske & Schumann 2018)	
Replacing reserve power plants	Being able to replace more expensive and environmentally harmful reserve power plants.	(1/9) (Geske & Schumann 2018)	
Reducing cost of future electricity storage	The opportunity to reduce cost of future electricity storage as the V2G or smart charging system act as such storage.	(1/9) (Geske & Schumann 2018)	(Geske & Schumann 2018)

Mentioned in five or more studies
The most frequently mentioned driving force (5/9 studies), is the opportunity to earn economic benefits from system participation. This further motivates paying attention to the economic incentives used for motivating participants, as it is a clear expectation from a significant share of potential participants.

Mentioned in three or four studies
Mentioned in 4/9 times is the driving force of integrating more (intermittent) renewable energy. This category rating high is not too surprising, it is after all one of the most popular reasons for suggesting a SC or V2G system to begin with (see background chapter). This is true for power grid support as well, a driving force mentioned in 3/9 studies.

Mentioned in one or two studies
Fortunately there are synergistic effects between driving forces, increasing the chance of there being one system fitted to appeal to multiple potential participants and/or to appeal in multiple ways. Environmental aspect as driving force (2/9 studies) will go well together with the potential to integrate more renewable energy, especially with respect to the climate issue. These two in turn go well together with the replacing of reserve power plants (1/9 studies) as the most common source of backup power today are diesel fuelled generators (Swedish Energy Agency 2017B) and a large share of diesel today is of fossil origin (Swedish Energy Agency 2017A, pp. 49-68). The driving force towards increasing grid stability are like these aspects in that it helps creating a sustainable energy system and to simplify, these will be referred to as the green driving forces onwards.

Finally, the driving forces reducing cost of avoiding grid expansion, future electricity storage, decentralisation of energy storage and emergency power backup are only mentioned in the study by Geske & Schumann (2018).

Most important driving forces
There are also three driving forces that stand out in that they have the largest number of prescribers or are emphasised as most important in one study each. These driving forces are: integration of renewable energy, power grid support and the ability to reduce the cost of future energy storage. It is interesting that these differ between studies, perhaps interpretable as a warning sign of taking the individual findings as absolute.

3.3.2 Concerns
The number of concerns found in literature are slightly higher than the corresponding for driving forces, amounting to thirteen in total. Concerns cover rather different issues and share less similarities than the driving forces. The concerns are summed up in table 16 below.

Table 16: The concerns for potential V2G participants along with a shorter description of what these entails. To highlight the importance from each concern the number of times it is mentioned and the number of times it is mentioned as the most important are included. The driving forces are sorted from most to least frequently mentioned.

Concerns	**Short description**	**Mentioned in studies**	**Times mentioned as most important concern**
Mobility restriction general	Perceived restrictions in mobility considering all possible reasons for it, including concerns that the SOC will be insufficient for sudden and spontaneous trips and range will be limited.	(7/9) (Will & Schuller 2016; Baily & Axsen 2015; Schmalfuß et al 2015; Geske & Schumann 2018; R. Parson et al 2014; Bunzeck, Feenstra & Paukovic 2011; K. Hirdue & R. Parson 2015)	
Loss of control	Loss of control when another actor (i.e utility company) determine the pattern of charging (or discharging) for the vehicle.	(4/9) (Baily & Axsen 2015; Axsen, Langman & Goldberg 2017; Bunzeck, Feenstra & Paukovic 2011; Geske & Schumann 2018)	(Axsen, Langman & Goldberg 2017)
Data privacy	The concern for what the information supplied to other actors when participating in the system will lead to and what the information will be used for.	(3/9) (Baily & Axsen 2015; Schmalfuß et al 2015; Geske & Schumann 2018)	
Distrust of technology	The concern that the technology will not hold up to its promises, potentially not charging when it should etc.	(3/9) (Schmalfuß et al 2015; Bunzeck, Feenstra & Paukovic 2011; Geske & Schumann 2018)	
Insufficient economic return	The perception that the economic return is simply too low to make up for the disadvantages from participation in the system.	(3/9) (Bunzeck, Feenstra & Paukovic 2011; K. Hirdue & R. Parson 2015; Axsen, Langman & Goldberg 2017)	(Bunzeck, Feenstra & Paukovic 2011) (for V2G)
Distrust of Utility Company	Distrusting the intention and honesty of the utility company. An example to why is the difficulty for potential participants to see if the company supplies electricity from renewable sources.	(2/9) (Axsen, Langman & Goldberg 2017; Geske & Schumann 2018)	
Effect on Battery	Concerns that there will be an increased battery degradation rate.	(2/9) (Bunzeck, Feenstra & Paukovic 2011; Geske & Schumann 2018)	(Geske & Schumann 2018)

Insufficient SoC for sudden and spontaneous trips	There being a to low SoC for making spontaneous trips or sudden trips when the need for such trips arise.	(2/9) (Bunzeck, Feenstra & Paukovic 2011; Geske & Schumann 2018)	(Bunzeck, Feenstra & Paukovic 2011) (for SC)
Need of planning	The increased need of planning as potential participator makes choices on when the EV should start charging, finish charging etc.	(2/9) (Schmalfuß et al 2015; Friis & Hanstrup Christensen 2016)	(Friis & Hanstrup Christensen 2016)
Complicated system	The complexity of the system and its requirements on user-interaction being large.	(1/9) (Geske & Schumann 2018)	
Difficult to alter charging patterns	The perception that altering the pattern of charging will be too much of a nuisance intervening in everyday life.	(1/9) (Friis & Hanstrup Christensen 2016)	
Limiting range	Lower range as the battery may not be charged fully, hence decreasing the number of destinations reachable without stopping and recharging the car.	(1/9) (K. Hirdue & R. Parson 2015)	(K. Hirdue & R. Parson 2015)
Proposed agreement is to strict	The forms of the agreement being to strict and limiting for the potential participants.	(1/9) (K. Hirdue & R. Parson 2015)	

Mentioned in four or more studies

The concern that is most commonly found is that of mobility restrictions (7/9 studies). Here it is named "mobility restriction general" to account for the different degree to which its underlying reason are specified in the study material. To exemplify: Concerns on having insufficient SoC for sudden and spontaneous trips are expressed which in more general terms are concerns of mobility restrictions. This is also the case for concerns on the limitation of range and are likely the reason for some potential participants expressing that the proposed agreement is too strict.

Therefore, the study reference is included in both rows, representing the more general category and the specific concern. The mobility restriction general also include studies exclusive to this category. The reason for keeping them separate and not combining all of them are that although the differences are small, they may carry implications for which economic incentives that are most in-line with concerns.

The feeling of losing control is an important concern, second in order, found in 4/9 studies.

Mentioned in three studies
Found in this frequency interval are the concerns distrust of technology, data privacy and insufficient economic return. Specifically, the studies are mentioned in 3/9 studies each.

Mentioned in one to two studies
The concerns mentioned in 1-2 studies cover a wide range of different issues. They consist of the following: system being complicated (1/9), Difficult to alter charging patterns (1/9), distrust of utility company (2/9), Effect on battery (2/9), insufficient SoC for sudden and spontaneous trips (2/9), limiting range (1/9), Need of planning (2/9), proposed agreement to strict (1/9).

Most important concerns
Mentioned as the most important concern by one study each are the need of planning, loss of control, insufficient SoC for sudden and spontaneous trips and limiting range and the effect from V2G participation on the EV battery. It is possible that effect on battery is not the most important concern due to the large standard deviations, however, it is again interesting to find that study results are not consistent.

3.3.3 Economic incentives

In total 22 different economic incentives have been extracted from the literature analysed. They provide an innovative range of options from the use of virtual currencies to simply allowing price of electricity to vary during the day. Some of the suggestions are more suited for system services such as frequency and voltage regulation in addition to power regulation, others are more focused towards the latter. There are mechanisms adjusted to be suitable for a SC system, while others are focused on the V2G equivalent. There are also systems suitable for both. The distribution of types of incentives are illustrated in figure 46 below.

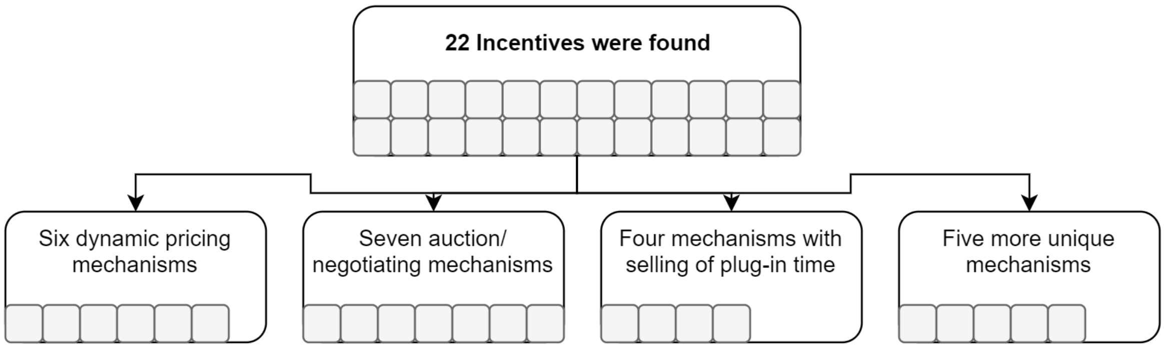

Figure 46: the incentives found distributed on four different categories: dynamic pricing mechanisms, auction negotiating mechanisms, mechanisms relating to the selling of plug-in time and five more unique mechanisms.

Although no suggestions are exactly the same, there are some underlying mechanisms that are more common than others. 6/22 incentives are based on there being a dynamic price of electricity offered, that changes with time and demand. This varying price can be based on different things such as the price of electricity in a wider region, current strain on the grid or the local electricity price. The mechanisms based on a varying price of electricity are summarised in table 17 below.

Table 17: The economic incentives found in literature based on varying price of electricity, a shorter description of them and the study reference.

Type of agreement	Short description	Reference
Arbitrage guided V2G	Charging occurs at home during off-peak hours and electricity is sold when the local electricity price is higher than the cost from charging, battery degradation and round-trip-losses.	(M. Freeman, E. Drennen & D. White 2017)
Dynamic grid tariffs	Letting prices differ based on the current situation on the grid and the support it needs.	(Kester et al 2018)
Dynamic pricing of electricity	Allowing electricity prices to differ from hour-to-hour, with great similarities to arbitrage guided V2G.	(Kester et al 2018)
Time-varying retail price	V2G participants are compensated with a dynamic retail price, changing with time, when discharging electricity. This is offered when the Electricity Reliability Council of Texas needs the extra power. EV owners specify willingness to participate, minimum SoC and if they have a maximum of allowed cycles per day when stating a session.	(Bhandari, Sun & Homans 2018)
Two-price-levels tariff system	The tariff system includes one price level for workdays between 07:00 and 23:00 and another price level for the remaining time of the week. Vehicle owners are simply supposed to answer to those prices.	(Grackova & Oleinikova 2014)
User-defined selling-prices	Charging occur at home during off-peak hours and electricity is sold at prices set by the vehicle owners.	(M. Freeman, E. Drennen & D. White 2017)

Furthermore, 7/22 of the found incentives are auction or negotiating mechanisms. In these, EV owners, aggregators or grid operators in some way form a bid on to what price they will accept purchasing of power. The mechanisms of this type are summarised in table 18 below.

Table 18: The economic incentives found in literature based on auction mechanisms, a shorter description of them and the study reference.

Type of agreement	Short description	Reference
Bidding on price from electricity provider	The EVs are responding to a price suggestion from the electricity provider. From those who accept the offer, the ones able to provide the most capacity for regulation are accepted and their owners are rewarded financially for the service. It is likely allowed for EVs to connect and disconnect on short notice, however, it is not clear in the article.	(H. Malik & Lehtonen 2016)
Dynamic-negotiating-pricing with two components	A price suggestion is communicated to the system participants on regular time intervals (i.e. hourly basis). The household and the power utility company negotiate a price until a convergence condition is met, automatically by using smart technology. The price for charging and the regular household load are separated.	(Mao, Shum & Tsang 2018)
Elastic-supply multi-level second price	EV owners place bids on to what price they are willing to purchase electricity for, to charge their EVs, for the next time interval.	(Bhattacharya et al 2016)
Elastic-supply progressive second price	EV owners place bids on what price they are willing to pay for electricity and the amount of electricity they are willing to buy, for charging their EVs.	(Bhattacharya et al 2016)
Participation in day-ahead and balancing markets via VMAs	Individual offers of capacity are based on forecasts and added together by VMAs (Virtual Microgrid Associations). The VMAs use the capacity to trade on the day-ahead electricity market. When the forecasts fall short, participants can use unsubmitted capacity to earn money in the balancing market and a penalty mechanism ensure a greater value for the capacity on the day-ahead market than the balancing market.	(Tsaousoglou, Makris & Varvarigos 2017)
Proactive demand response scheme	Demands of households are estimated automatically and curves are formed to represent the price households are willing to pay for electricity for specific usages. The curves are forwarded to the distribution system operator who aggregates the offer per substation. The wholesale market operators receive this information and determines the price to be paid. In addition to sending back the price-information, the WMOs includes which flexibilities to be utilised.	(Wei & Zhu 2015)
Two-step group bidding	Based on a load forecast from the grid operator, the EVs offers capacity to an aggregator in a bidding scheme. The aggregator accepts the preferred bids and offer the accumulated capacity to the grid operator based on a similarly designed bidding process.	(Zeng et al 2015)

Having cost of electricity varying is likely better suited for the purpose of power regulation while auction mechanisms can be adjusted for both, it depends on if it is power or capacity in another sense that is auctioned out.

In 4/22 mechanisms, the agreement revolves around selling of plug-in time rather than a price per electricity or capacity submitted. Three of these are contracts and in these EVs are obliged to be plugged-in a specified number of hours or/and can be used to a specified lowest SoC. This category of incentives is suitable for both power regulation and other system services (table 19).

Table 19: The Economic incentives found in literature based on selling plug-in time, a shorter description of them and the study reference.

Type of agreement	Short description	Reference
Four modes off participation on a parking lot	This mechanism is used during work days and includes two sets of binary options: mono- or bidirectional charging and a fixed final SoC or a varying equivalent. The compensation is set in accordance with the level of service that each mode can deliver. Vehicles are not used for discharge below 30 % SoC and are likely allowed to leave before their anticipated departure-time, however, this is not clarified in the study.	(Neyestani et al 2015)
Periodic payments	Includes a contract specifying the number of hours during which the participator has to be plugged-in, the reserved minimum range or a combination of the two. Payment is made periodically.	(R. Parson et al 2014)
Submit next departure or regular transport pattern	A contract is made between aggregator and EV owners obligating the latter to submit information on the time of their next departure or their regular transport pattern. When the car is plugged-in it can be used by the aggregator, who accumulate the capacity of the EVs to sell. The forms of participation for EV owners are not the main focus of this study.	Han, Han & Sezaki 2011)
Upfront payment	Includes a contract specifying the number of hours during which the participator has to be plugged-in, a reserved minimum range or a combination of the two. A one-time sum is rewarded the participator initially.	(R. Parson et al 2014)

Finally, there are five mechanisms that are more unique, these are shown in table 20 below.

Table 20: The economic incentives found in literature based on more unique mechanisms, a shorter description of them and the study reference.

Type of agreement	Short description	Reference
Avoiding double taxation	Avoiding double taxation of temporarily kept electricity as taxes currently apply during charge and discharge. Practice of energy storage could either be exempted from this tax regime or be subjected to net-metering based taxes instead.	(Kester et al 2018)
Compensation with 50 % of achieved profit	V2G participants submit capacity to an aggregator and are compensated with 50 % of the earnings made when the aggregator sells the cumulative services to the Electricity Reliability Council of Texas. The 50 % is split between participants evenly. The selling opportunity is offered when the Electricity Reliability Council of Texas needs the extra power. EV owners specify willingness to participate, minimum SoC and if they have a maximum of allowed cycles per day when stating a session.	(Bhandari, Sun & Homans 2018)
Fixed retail price	V2G participants are compensated with a fixed retail price when discharging electricity. This is offered when the Electricity Reliability Council of Texas need the extra power. EV owners specify willingness to participate, minimum SoC and if they have a maximum of allowed cycles per day when stating a session.	(Bhandari, Sun & Homans 2018)
Virtual currency for renewable energy consumption	Participants are awarded a virtual currency by an aggregator when consuming renewable energy. The currency can be exchanged for traditional currencies (i.e dollars) and can be used to get higher priority granting the user electricity before the lower prioritised participants.	(Zhang 2018)
Work-hour price-taker	Charging occur at home during off-peak hours and discharge during the day, at work, when the grid-operator deem a need for electricity.	(M. Freeman, E. Drennen & D. White 2017)

There are some agreements that are suggested for SC or V2G specifically, while others allow for the participants to choose in-between these two modes. Examples of these different types are cryptocurrencies for renewable energy consumption, time-varying retail price and four modes off participation on a parking lot, respectively. There are also some incentives targeting electricity storage and flexible use in more general terms such as proactive demand response scheme or dynamic grid tariffs.

Some mechanisms specify a lowest SoC (at least 4/23) below which vehicles are not any longer used for SC or V2G services. How this is done differs with examples such as 30 % SoC, 10 % SoC or are demanding or allowing the vehicle owner to specify themselves. These lowest SoCs are applied mainly when V2G application are a choice or assumed.

3.4 Analysis

In this analysis the incentives and modes of participation found in the study material will be put in light of identified driving forces and concerns. This is done in order to identify how these mechanisms perform from the perspective of potential participants.

3.4.1 Earning economic compensation

The most frequently mentioned driving force (5/9 studies) is the potential of earning economic compensation for participation. As the focus in this literature study has been specifically aimed at economic incentives, all incentives and modes of participation include ways of compensating the system participants economically. There might however be mechanisms that do not render a profit when the degradation of battery is taken into account. This was found by M. Freeman, D. Drennen & D. White (2017) examining the incentives work-hour price-taker, fixed retail price examined and user-defined selling price, finding that only the later to be profitable.

Additional battery degradation caused by V2G participation is still debated and the result will be an important part on determining profitability from all of the suggested incentives. For example, if it is shown that the degradation rate assumed by M. Freeman, D. Drennen & D. White (2017) is too low or too high, the order of profitability between incentives might change altogether. This will also be affected by the price off batteries in the future, which has been declining rapidly in the recent years (International Energy Agency 2017, p. 15). When the price of batteries decreases, so does the cost of degradation. In the case of SC, the number of charging cycles would not necessarily increase and the additional degradation from cycling is not an issue to the same extent. Few of the studies from which economic incentives have been recovered specify exact figures of compensation, which is reasonable due to the reasons mentioned above. The exact numbers would also make little sense in a Swedish context, as prices and taxes for vehicles and electricity differ.

The findings here might seem incompatible with those made by Geske & Schumann (2018), that economic incentives will have little effect on motivation for willingness to participate in a V2G system. Indeed Schmalfuß et al (2015) also found that economic incentives where not the main driving force. However, there seem to be an interest on economic earnings among potential participants and the issue seems to really be the insufficiency of these earnings (R. Parson et al 2014; K. Hirdue & R. Parson 2015). It is found by Bailey & Axsen (2015) that cost driven programmes have the largest support and by Bunzeck, Feenstra, & Paukovic (2011) specifically that economic incentives increase interest among portential participants.

A final note of interest is the irrational discount rate found by R. Parson, K. Hirdue & P. Gardner (2014). They point to the opportunity to include payment upfront for their suggested contracts, a way that could lower the demands on financial return between participants.

3.4.2 Green driving forces

The use of V2G for aiding the subject of the green driving forces is a major reason for implementing the technology and it can be seen by someone with a background in energy, how this relates to the economic incentives and modes of participation found.

Six of the incentives build on varying price of electricity, seven of them rely on auction mechanisms and four of them essentially compensate the user for plug-in time. In the first two cases the energy price will be higher when demand is high in comparison to supply or the grid is stressed. As it is expensive to use reserve power plants, the varying price could help reducing the use of these as well. In the case of plug-in time, the vehicle offers a resource that can be used as a source or sink for power or to aid with other system services.

However, to someone unused to this line of thinking, it might not be as clear how system participation will support these causes. This seem likely considering the study from Canada by Axsen, Langman & Goldberg (2017), where it is shown that 14/22 interviewees find it hard to understand how utility-controlled charging can help integrating renewable energy. It is possible that the level of understanding is higher in Sweden, still, the link between participation and the energy system benefits need to be clarified for the potential participants. This to really appeal to the green driving forces.

A similar indirect way of appealing to these driving forces applies for the remaining eight mechanisms as well, with one exception. The incentive awarding users a virtual currency for each consumed kWh of renewable energy, which provides a direct reminder on why participation is made. However, how the participant is notified on the opportunity of charging with renewable power has to be considered as well.

An appeal amongst incentives to those focused on the benefits in a local context is lacking in most cases. If variable costs of electricity build on the market prices of today, there are four (or often fewer) different regions defining the electricity price in Sweden. Differentiating prices at this scale does not respect the strain on the local power grid (Swedish Energy Agency 2018, p. 24). For Gotland, belonging to zone SE3 the limited capacity of the transmission to the mainland would also not be taken into account to any greater extent and the SC or V2G system based solely on these prices would only contribute to power grid support on a centralised level. To really appeal to these green driving forces and to get the maximum system utility, the final incentive should reflect these local challenges. The appeal to the driving force of avoiding grid expansion is assumed to be achievable with the same means.

A potential candidate for such system, could be using Locational Marginal Pricing which, according to Asija et al (2017), consists of three main parts. An energy component, a congestion component (of the power grid) and a loss component. For example: a location where the power grid is to a larger extent congested will have a higher locational marginal price which can serve as a price signal to indicate on the services needed for the power grid. However, implementing the pricing system in a way without unnecessarily high complexity for end-customers will be important.

3.4.3 Driving forces related to technology and system aspects

There are driving forces more related to the nature of the SC and V2G technology and system. Decentralisation of energy storage will be achieved when implementation is performed, regardless of economic incentive. The question is really whether enough cars participate in the system to accomplish a meaningful contribution on aspects such as renewable power integration. Similarly, the V2G application will enable a flexible use of this stored energy. Choice of incentive will therefore likely have rather little importance for this driving force, except for the indirect effect arising from promotion of the technology.

Moreover, it is hard to see how suggested incentives can, to a different extent, achieve a reduction in the cost of future electricity storage. If a cost competitive SC or V2G system can be implemented, it will likely serve this cause either way. The increased interest would likely spur on technology development and increase economy of scales opportunities potentially lowering the prices. However, these are effects related to the system implementation and technology rather than choice of incentives.

Using vehicle batteries for emergency power backup of the own household would also require bidirectional charging and is in this way connected to the basic features of the technology. However, using the car for provision of SC and V2G services would mean a SoC harder to predict by the vehicle owner and could result in a lower SoC on average. For example, the implementation made in the model part of this master thesis results in the SoC staying around 34 percent during most of the time. This could have negative impacts on this driving force, however, it is also more related to technical and functional aspects of the system than the economic incentives.

Perhaps, the driving force could be reflected better if the lowest SoC for participation was set by vehicle owners themselves, assuring that it is adjusted to their comfort level. Communicating current SoC and forecasted increase or decrease to participators might also be a way of reassuring them that there is enough capacity left. This could be done using technology such as mobile phones with apps. The trust of participants towards system operators might also play in to the lowest level of SoC that the vehicle owners feel comfortable with. If they feel reassured that there will be no technical issues or unfavourable schemes causing their SoC to be lower than necessary, and that the reason for it being low is due to the use in for example maximising societal and environmental good, they might feel comfortable with a lower SoC on average.

3.4.4 Mobility restrictions

The greatest concern, mentioned in 7/9 studies, are the mobility restrictions associated with participation. How well the economic incentives and modes of participation do in this respect differs. The reasons for this are similar to those behind concerns on the contract being too strict, which is why these will not be handled separately.

Two incentives are based on contracts specifying a minimum number of hours per day and number of days per week that the EV must be plugged-in and ready for system services or/and a lowest SoC to be set for the vehicle. Changes in these parameters affect price heavily, shown by Parson et al (2014). The same study finds that the economic revenue that can be earned under these contract forms is insufficient for potential participants, interpretable as the contract being too strict with too high mobility restrictions. The third contract found in the study material includes participants having to submit their next time of departure or their regular transport pattern. This also entails mobility restrictions, especially if these limitations has to be respected so that the EV driver are unable to do unplanned trips.

In their conclusions, Parson et al (2014) mention the possibility of having a pay-as-you go-system instead where it is possible to connect and disconnect freely and in fact most of the suggested incentives and modes of participation share similarities to such system. The six incentives building on a variable price of electricity and the seven based on auction or bidding mechanisms will not limit users from charging or force them to discharge during certain hours. Instead these will introduce the opportunity of making savings or earning compensation during these hours. Participants could choose the alternative that works best for them, weighting convenience against economic opportunities. The combination with the possibility of setting a lowest allowable SoC could reduce the anxiety from mobility restrictions even further and Geske & Schumann (2018) find that the possibility of customisation is expected by many potential participants. The five more unique mechanisms largely express a level of flexible participation, the work-hour price-taker mechanism being the only apparent case where the risk of lock-in restrictions is clear.

Depending on implementation, many of the incentives could require a level of long-standing commitment perceivable as restrictive. Most studies from where the incentives and modes of participation are found do not specify whether participants sign up for a long-term agreement or can choose to participate more flexibly. A potential participator about to sign a long-term agreement knowing that the price variations may result in restrictions on his or her mobility needs, or in a cost of charging higher than status quo, might think twice before jumping onto the deal. It is therefore interesting to see mechanisms such as the *four modes of participation on a parking lot* where the potential participant chooses the mode of participation every time they enter. This might sound demanding, however, setting some sort of default mode for participation could mean that EV owners do not have to make active decisions more often than they would have to in the case of a long-term agreement.

Flexibility could also be expressed by offering variations on agreements and hybrid versions between pay-as-you-go and contracts are mentioned by Parson et al (2014) to be an option as well. To have more options could facilitate the recruitment of those that believe to be more inflexible than they are in practice, as these could then increase their contribution gradually.

Finally, as mobility restrictions are such an important concern, implementers of a smart charging or V2G system should consider these ways of reducing anxiety and try not to cause to many lock-in effects. How this affect the usable capacity from the systems should be evaluated.

3.4.5 Loss of control

The feeling of losing control arise when the charge cycle of the EV is decided by another actor. The concern is documented in 4/9 studies and is found to be the most significant concern in one of the studies.

The most invasive mechanisms would likely be the modes of participation where another actor directly takes control over the EV. Examples where this is the case include the contracts, *the work-hour price-taker* and *the four modes of participation on a parking lot* mechanisms. There might be less of a problem in the latter case as the choice of participation is made on each occasion. These mechanisms could have a lower transparency on what is going on towards the participant and could create a feeling that they do not get to make a choice on what is to happen. In the case of a variable price or an auction mechanism, it may well be the case that the feeling of control increases as the owner can decide whether to purchase energy or simply let it be. It may also be clearer to them what their vehicle is used for. Similar opportunities are presented in many of the remaining incentives and modes of participation, as the participant can make choices there as well. This is, of course, speculation and to really understand the core of this concern and how to respond to it require further studying.

3.4.6 Data privacy

Mentioned in 3/9 of studies, this concern is not an infrequent finding and the incentives and modes of participation will perform quite differently on this issue.

Of the 22 incentives and modes of participation 15 require some sharing of information, to a varying extent and of varying type. The information to be shared may include how much capacity the EVs can contribute with, next intended departure time, the price they are willing to pay for electricity, the number of hours they will be plugged-in and ready for service, the lowest allowed SoC or the maximum number of cycles allowed by the EV owner.

The remaining economic incentives require none or little information sharing. These incentives are: avoiding double taxation, dynamic grid tariffs, dynamic price of electricity, fixed retail price, time-varying retail price, arbitrage guided V2G and virtual currencies for rewarding use of renewable energy usage. Interestingly, some of these overlap the preferable options from point of view of earlier mentioned concerns.

Reducing the amount of data submitted and choosing mechanisms that do not require the sharing of data of a certain type is not the only way to deal with the challenge of the data privacy concern. As an example, Schmalfuß et al (2015) suggest that providing information on data security could be of help.

There are likely additional ways in which this concern can be eased and if data privacy concerns can be handeld, none of the incentives and modes of participation would necessarily perform poorly.

3.4.7 Distrust of technology

Distrust of technology as a concern is rather detached from the choice of incentive and form of participation, and it is more related to general aspects of the system and the technologies. Those worried could be convinced to change their mind when the technology becomes more widespread and accepted with developed standards clarifying what can be expected. It makes sense not to address this as the primary target group in the initial stage of system deployment.

3.4.8 Insufficient economic return

The concern of insufficient economic return, mentioned in 3/9 studies, is closely related to economic compensation as a driving force and essentially the same line of argument applies. It is understandable that someone investing in SC and V2G technology or a V2G compatible car wants to feel certain that the investment is going to pay off.

3.4.9 Concerns mentioned in 1-2 studies

Finally, there are five concerns mentioned in 1-2 studies. These are: Need of planning (2/9 and as the most important concern in one study), distrust of utility company (2/9), effect on battery life (2/9), system being complicated (1/9) and difficulty to alter charging patterns (1/9).

Starting on the need of planning as a concern, this is found to be a challenge in practice for participants in a real SC pilot, studied by Friis & Haunstrup Christensen (2016) on Danish households using flexibilities. The time when charging and discharging need to occur does not significantly differ between the suggested incentives and modes of participation as they would be applied to support the power system. This will limit the preferred hours of participation to a specific set, meaning that, regardless of incentive and mode of participation used, these are the hours that participants should plan around. The study material, however, does not single out the specific hours where EV owners must participate and different options for participants could be made available, possibly awarding the highest economic return when the EVs are supplied during the most critical hours.

Most mechanisms involve more flexible modes of participation than simply saying yes or no. This could ease the burden of planning as trade-offs between potential savings or earnings and convenience could be made. These again include flexible pricing, auction mechanisms and most of the unique mechanisms such as *avoiding double taxation*, *user-defined selling prices*, *dynamic-negation of prices* and a *virtual currency awarded EV owners for using renewable energy*.

Distrust of the utility company could be a concern realised in some modes of participation. However, many of them rely on an intermediate actor in the form of an aggregator to collect capacity. The role of an aggregator is to aggregate the capacity provided by multiple EVs and make an offer large enough for the utility companies to respond to. There are no clear ways in which economic incentives are incompatible with arrangements with an aggregator, even when a utility company is suggested in the study. Therefore, if the concern posed by a distrust of the utility company turn out to be problematic, such intermediate actor could possibly be the answer.

There might be some preference towards the mechanisms that do not entail complete control from another actor over the EV during the charge/discharge cycle again weighting in favour for flexible energy prices rather than contracts and the work-hour price-taker scenario.

Another concern is the effect participation will have on the battery, and it has been argued before that this issue relates mostly to the V2G application and mainly concern the use for power regulation applications. There could be a trade-off point between this concern and the driving forces as a more extensive battery use for V2G purposes allows to integrate more renewable energy into the power system, supports the grid more and potentially provides a larger economic return. With this in mind, it is shown by M. Freeman, E. Drennen, & D. White (2017) that possible scenarios include some modes of participation providing economic return, while others fail due to the effect on the battery. In this case, the authors point to how extensive the use of the battery is as the decisive factor.

An important part of the puzzle when trying to ease this concern will be to establish the actual effect that V2G participation will have on batteries. If it can be shown that the effect is limited and this can be communicated to participants, it should ease their concern. Finding the optimal level of usage is not only of interest to those concerned about their battery health, but to anyone who wants to participate in a V2G system and make a profit.

It is in any case clear that it will be important to consider the properties of batteries and not discharge to deeply. Charging/discharging cycles should be adjusted to future findings. Batteries are expensive and the participation effect on them should be reflected in calculations used as basis for deciding the rate of economic return. Perhaps the impact on battery should be continuedly monitored and weighted in on the price paid for the service supplied. However, this will increase the complexity of the system,

There are also concerns on the system being too complicated. Looking at the incentives from the perspective of a person unfamiliar with this type of technology and the energy system, this concern is understandable. The mechanisms range in complexity from more easily understood options such as *the two-tariff-price* system to more complex systems like the *dynamic-pricing-system with two components*. The complexity of the mechanisms adds up with other aspects of the SC and V2G system, plus all the technology bits that could be hard to grasp. The participants in the Danish experiment studied by Friis & Haunstrup Christensen (2016) find that adjusting to prices on the Nord Pool Spot market was too complicated to be acknowledged by participants, even if it only is an hour-by-hour varying price for electricity. It is worth noticing that most of the incentives and modes for participation are on this level of complexity or higher.

Many of the studies from where incentives are taken include a smart meter and an energy management system to reduce the frequency of interaction in selling and buying for the users and create a more understandable interface (i.e Mao, Shum & Tsang 2018). Smart technology could reduce the perceived burden from the system but does not necessarily make the underlying mechanisms clearer to the user. Furthermore, these complex smart systems could make it hard to estimate the car charging/discharging cycles, potentially leading to increased difficulty in planning. The level of complexity that customers will accept and how the incentives and modes of participation can be made more attainable to them will be important questions to answer before future implementation.

The final concern is that of there being a difficulty in changing charging patters. The concern is likely possible to generalise to include discharging patterns: for some there could be a mismatch between how quickly they need to get their vehicle charged to fulfil their transport needs and when system services are needed (Friis & Haunstrup Christensen 2016). From what can be found in the studies suggesting the modes of participation and incentives, none of them ties the participant to certain hours of the day, when they have to participate. However, it is a prerequisite that there will be vehicles connected and ready for service when service is needed, otherwise the smart charging or V2G system will be toothless.

Non-discrete ways of participation were suggested as a helpful way of easing the concern of needing to plan ahead. This could be helpful regarding this concern as well, as it is conceivable that participants will realise that there is some compatibility between their habits and the energy system needs for plugged-in cars providing services. Furthermore, mechanisms building on varying price, auction prices and similar could again allow trade-off points to be found for participants, weighting economic return against convenience.

There being a difficulty in changing energy use patterns is found by Friis & Haunstrup Christensen (2016) to be a real challenge, however, specifically charging patterns seem to be one of the uses for electricity that actually can be easily altered. Particularly so when introducing smart technology enabling scheduling of the charging sessions.

3.4.10 Most appealing forms of compensation

Geske & Schumann (2018) also asked their respondents which incentives they found most interesting. These are summarised below in figure 47, in order of descending popularity. Significantly less interesting to the participants were privileges such as them being allowed to travel in bus lanes, having free parking or similar.

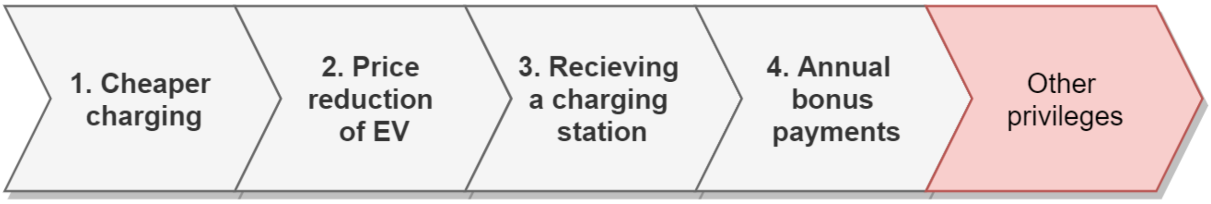

Figure 47: The order of popularity for incentives, found by Geske & Schumann (2018).

The fact that only cheaper charging and annual bonus payments really are included in the found incentives could be due to the research starting point. Rather than gathering input from participants on their preferred ways of being compensated and designing the system from there, researchers have started out on the drawing table, trying to figure out the smartest mechanisms.

Of the two incentives, cheaper charging and annual bonus payments, it does not seem farfetched to assume that the first one is more popular due to its higher level of flexibility. It is more similar to the varying price, auction and to most of the eight unique mechanisms as these will allow cheaper charging during times when the energy system is less strained. The relation to discharging is likely the same in that a varying rate of compensation is preferred to an annual remuneration.

3.4.11 Additional factors for SC and V2G integration

From the study material where concerns and driving forces were gathered, it was found that economic incentives alone will not be the superior way to encourage SC and V2G participation. They are just one (important) part of the puzzle. Geske & Schumann (2018) find that willingness to participate in a V2G system increases with the level of knowledge among potential participants. This causes the authors argue for an information campaign on V2G technology. Moreover, as there are driving forces towards other factors than economic benefits Schmalfuß et al (2015) find that a feedback mechanism should be included to show participants how they contribute to society and the environment. These perspectives should be applicable for SC and V2G acceptance and so should also the ideas gathered by Kester et al (2018). The study collects four main measures for aiding integration of V2G in addition to market mechanisms and these are summarised below.

1. Innovation and R&D – Some of the interviewed found the challenges of implementing a V2G to be something of a catch 22, in terms of pilot project and regulation tools. For example: if it is not known which technical and market arrangement that are most efficient it is hard to design such mechanisms. Simultaneously it is hard to design the right incentives if it is not

known what pros and cons the technology entails. Therefore, creating more pilots could help to start the machinery constituted by enrolling V2G technology. Pilot projects could also help building up the required knowledge in V2G companies and surrounding actors, creating awareness and more.

2. Information and awareness – The study authors state that only one percent of the respondents knows about V2G technology. Some of the interviewed also pointed to concerns of for example battery degradation from potential system participants. Informing about the technology at all levels in society may be decisive in order to gain support.

   There is more support for this finding in the material included in the literature study. Geske & Schumann (2018) found that when their study was conducted, in 2013, 87.7 % of participants did not know what V2G was. 11.3 % had heard about the concept, however, had a limited knowledge of what it implied and only 1 % knew the concept well.

3. Other policy advice – Some proposed regulations exist outside these three areas including, planning, mandate and subsidies. These can be summarised as:
   a. Planning and visions - If a strategy or vision is expressed by the government or local authorities on how the energy system will look like in the future, it may feature a need for the services that V2G technology can provide. The authors argue: "… [The strategy and/or visions] can push a market forward and/or create the stability for markets to develop products on their own".
   b. Mandate and subsidies - In addition to subsidising R&D, specifically aimed subsidies for V2G capable cars were suggested by some of the interviewed. The authors argue that this could scale up pilots to higher rates of production and increase awareness of V2G.

4. Determinism and momentum – Some of the interviewed experts believed that V2G is on its way regardless of there being an increasing amount of support mechanisms or not. This is due to continuous technology development and the effect of the current support already provided by governments. Other respondents believed that the government has a small role to play and that it should not intervene or "… give money but stay away ... ". This line of thinking also relates to the risk of destroying a functioning market.

3.4.12 In the context of Gotland

The geography of Gotland carries some implications for which incentives and modes of participation that could be utilised. As the transmission to and from the mainland is limited, it will be even more important to make the pricing mechanism reflect the local constraints on renewable power production and transmission capabilities. Simultaneously, the island is relatively small with the longest road distance on the main island from north to south extending roughly 147 km. The width is even smaller, and is never more than 52 km. If a passenger car features a battery pack with 54 kWh of capacity, as assumed in the modelling part of this thesis, roughly 34 % SoC would be enough to traverse the whole island. Therefore, the setting of a minimum SoC for participation could ease the concerns on mobility restrictions and encourage participants to join the SC or V2G purposes: they will always have enough energy to reach their destination. Even though the real figure for SoC depend on additional factors such as energy efficiency of the EV, choice of road, weather and more, a large part of the battery could still be made available for SC and V2G services.

Assuming like-mindedness of participants in the studies and the people on Gotland, the other aspects of incentives and modes of participation should be applicable on the island as well as in a wider context. Research aimed at finding if this is the case would be valuable, still, an assuring indication is found in the work of Bunzeck, Feenstra, & Paukovic (2011). There are differences in willingness to participate in SC and V2G systems between countries, however, only to a lesser degree and the Swedish respondents end up somewhere in the middle of the range in this respect. It is also found that the Swedish sample requires the lowest minimum SoC to participate in the system.

The relative cleanness of the Swedish electricity production mix will also mean that the shift from using fuels such as petrol and diesel to the use of electricity will be particularly beneficial in this context (Messagie n.d.; Swedish Energy Ageny 2017, p.6). The benefits of countries relying heavily on coal and fossil fuels for power production would not be as large in this respect. The widespread knowledge of this and the comparatively low price of electricity likely facilitate the introduction of EVs which is a perquisite for the SC and V2G system, meaning that it could indirectly supports these causes as well.

In the optimal arrangement, there should be feedback mechanisms to show the contribution made to society and the environment, an opportunity of customisability and the system interface should be simplified to the largest extent possible. With Horizon 2020 starting this year (2019), there will be a local market place on Gotland for power regulation and system services (Lidström et al 2018). A market place like this could be developed to become the type of flexible and relatively easily understood concept that overall goes well together with the driving forces and concerns of potential participants. In addition to creating a pedagogic interface for the participants, showing how they contribute to environmental and societal good, while carefully addressing concerns of data privacy could make a successful implementation.

To really be able to assess what the most beneficial incentive and mode of participation on Gotland would be, it is of interest to determine how the potential for power regulation differs across the different mechanisms. The flexible mechanism with a varying price should be compared to the more rigid forms such as the contract-based types.

4. Conclusion

A considerable potential exists in using smart charging (SC) or vehicle-to-grid (V2G) technology in a future with a full electrification of passenger cars. The local energy company GEAB has disallowed installation of additional variable power generation due to the risk of lowering the security of deliverance as the power system on the island is vulnerable during export hours. Export hours that become more frequent with rising levels of production. Electric cars charged (or discharged) in intelligent ways could reduce the energy export and the number of hours in export mode, allowing for more renewable power to be generated on the island and simultaneously allow for more power to be used locally. This is established in this thesis using a self-developed model that consider the transport and electric energy systems on the island.

If the production and consumption of power is kept at the levels of today (base case) and the passenger car fleet becomes fully electric, the export from the island can be reduced to zero if a SC or V2G system is implemented, compared to 4.4 GWh and 291 hours of export when there are no EVs. In the case of an increased production corresponding to the energy needed for electrification of all passenger cars on an annual basis (increased production case), 24.3 and 26.3 GWh of export could be prevented. The number of hours with export could then be reduced from 1013 to 118 and 29 hours for the two scenarios respectively. Using regular charging, also known as uncontrolled charging (UC), will reduce export but not to the same extent.

Changing from the conventional cars of today to electric cars without increasing the production of renewable power will result in most of the energy needed required to be imported. This is true regardless of if UC, SC or V2G is used as the major charging form and the yearly import in the three scenarios are: 777.9, 774.1 and 775.1 GWh per year and should be compared to the 612.1 GWh per year that are imported when there are no EVs, according to the model. In the increased production case, electric cars will still result in increased import as compared to the no EVs scenario, however, deployment of a SC or V2G system mean less import and export on annual basis and lower number of export hours as compared to the no EVs in the base case. The import levels in the increased production case for UC, SC and V2G are: 624.5, 608.4 and 610.2 GWh per year.

The chargeable capacity of plugged-in cars is considerable if full electrification of passenger cars is accomplished and in all production scenarios. During 95 % of the simulated year in the base case, the electric car fleet can be charged at 189 and 191 MWh/h in the SC and V2G scenarios respectively. In the increased production case the corresponding numbers are 138 and 183 MWh/h. This is despite the in-stationarity of cars and the figures are higher than the 130 MW that can be exported via the directable mainland cable today.

During the year, the implemented systems are closer to the lowest state of charge for allowed system participation than full battery capacity and increasing production lead to the stored energy increasing on average. This causes the chargeable capacity to decrease while the effect on dischargeable capacity, available in the V2G scenarios is the opposite. The discharging capacity, however, remains insignificantly low during all production scenarios in the main results due to the overall energy level in the system being low. The low energy level also leads to the energy quantity discharged during the year being restricted to a few GWh and the differences between the SC and V2G scenarios are small for the examined parameters and under the circumstances considered. To find the benefits from a V2G system over the SC equivalent, different implementations and the additional benefit of other system services should be examined.

Parameters affecting the potential of integrating renewable energy, the chargeable capacity and reliability of electric cars as a power sink positively is increasing number of cars in the system and the battery storage capacity. Increasing the rate of charging and discharging and the share that is chargeable/dischargeable mainly affects available charging and discharging capacity and the reliability of the resource.

A literature study was carried out within this study as well. In the examined literature there were 22 different economic incentives and modes of participation. Even though none of the mechanisms were exactly the same, some of them shared resemblance and they were divided in four different groups. There were seven mechanisms based on auctions and/or negotiation, six mechanisms based on a variable price of electricity, four mechanisms based on the selling of plug-in time and five more unique mechanisms that did not fit in the other categories.

Found in literature was nine driving forces and thirteen concerns from potential participants for a future SC or V2G system. The most commonly found concern was that of mobility restriction and the most commonly found driving force was the opportunity of making economic earnings. When the incentives and modes of participation are seen from the perspective of potential participants, most of them could perform well if the concerns and driving forces are considered during implementation. A few exceptions exist where the alignment between the interest of potential participants and the modes of participation is less well adjusted. Examples include stricter forms of participation such as the found contract types. Despite this, it seems likely that there will be an interest for participating in a future SC or V2G system.

The concerns and driving forces should be reflected better in the incentives and modes of participation. Communicating how societal and environmental benefits are achieved with the system, maintaining data privacy, keeping things simple and building trust towards the system operator are examples of additional aspects that need to be considered. Although, the achievable economic earnings are important to potential participants, solely focusing on them will mean missing out on viable paths to reach out.

In the context of Sweden, most of the above findings should be applicable. Only one of the found studies examining the participants perspective in a SC and V2G system included a Swedish sample. In this sample the interest in participation were as high as in the other included countries. The relative cleanness of electricity and the relatively low price in Sweden could further facilitate the introduction of EVs and indirectly support the enrolment of suggested systems.

Specific to Gotland, there are some geographical properties favouring SC and V2G systems. As the most well documented concern is that of mobility restrictions, it can be relieving to participants that even if enough energy is kept in the battery for traversing the island, there will be a substantial share left that could be of use in a SC or V2G system. Finally, within the Horizon 2020 project, a local market place on Gotland for power regulation and system services will be developed. This could be adjusted to be just the kind of flexible mechanism that makes a good match with the concerns and driving forces found in this thesis.

Conclusively, SC and V2G technology could have a large positive impact on integration of renewable power on Gotland and there will likely exist an interest for participation. There are good reasons for Region Gotland, GEAB and other relevant actors to further investigate how the technologies could fit with their plans on making the energy system on Gotland renewable. Depending on how the systems are implemented and how much additional renewable power generation is to be added to the island, employing SC technology could be sufficient. Still the applications for V2G technology could be examined further if the conditions differ from those examined in this thesis. There are no reason to postpone working with these technologies as the infrastructure for charging is established rapidly and electric cars grows fast in popularity. Investments made now will last for many years to come.

5. Discussion

The discussion includes setting the findings in relation to the coming future, some suggestion on further studies, the implications of findings for the transport and energy system on Gotland and finally how the findings can be applied in a wider perspective.

5.1 Validity of findings

The suggested systems do not exist today, neither in the context of Gotland, nor at large scale elsewhere. Therefore, the quantification of the potential contribution from SC and V2G technology in a future with 100 percent electrification of passenger cars required the making of assumptions and there are some aspects that are worth some extra consideration.

The way the transport system is implemented is a simplification to begin with and also does not consider the differences in transport pattern that will arise in the future. Even though the differences are relatively small in the shorter time perspective, the number of years before full electrification is achieved could be enough to have a significant impact. Especially in light of the data used being of some age already, with the uptake of measurements occurring between 1989 and 1991. In fact, the electrification of transport in-itself will likely impact the habits and routines of drivers.

There are also current trends towards automation of transport with actors such as the CEO of the electric car company named Tesla claiming that the company will have self-driving cars available within a few years (Ottsjö 2019). The introduction of the technology could impact the future transport patterns forcefully.

Moreover, the development of the energy system on Gotland is not limited to electrification of passenger cars and the building of wind power turbines. As was discussed in the background of this thesis electrification of Cementa, establishing of new industries, the reestablishment of the military, change in population and the electrification of ferries are some ways in which the consumption of power on the island could be altered. In relation to production, the introduction of solar power could have a great impact with Campus Visby estimating a large potential from such production techniques. Perhaps even more important is the ambitious aims of Region Gotland implying that there will be a considerable increase of wind power production.

Worth noting is also that future development does not inherently have negative effects on the potential of SC and V2G systems. It is quite possible that the careful enrolment of an energy system with SC or V2G, flexible loads, other forms of power system flexibilities and/or energy storage solutions used in combination could mean that the potential contribution from SC and V2G could be enhanced. In particular, the sensitivity analysis without limitations and with production levels equivalent to those of the aims of Region Gotland indicated that there are more potential in a V2G system, than was found in the explored main scenarios. Using other technologies in parallel could have synergistic effects with SC and V2G technology, however, these could also leave them redundant if proven to be better options.

An aspect threatening to reduce the usefulness of the findings from the model in this study significantly is the upgrading of the current transmission cables. The current estimation of technical life time for the mainland cables include that they will endure until 2040-2045, after which a major intervention could be necessary. With Power Circle estimating 2.5 million electric cars by 2030 and with current number of cars being five million, it may well turn out that full electrification of passenger cars will happen close to that year. If that is the case, the cables could be upgraded to a capacity level that makes SC and V2G systems superflous.

If the current trend towards electrification of transport is sustained, however, there will be a large number of electric cars even before that year and charging (and potentially discharging) them intelligently would be a valuable relief to the power system during the years in-between. It is also conceivable that SC and V2G systems demonstrates a potential and reliability that motivates the choice of a smaller upgrade. Installing transmission cables with less thickness and expensive materials could result in significant savings. The evaluation of the economically best performing solution would be an interesting subject for future research.

Moving on to the literature study, perception of positive and negative aspects of a technology develop with the technology. As the knowledge of SC and V2G technology diffuse into society the concerns and driving forces could increase, decrease in significance and change altogether. This development is reason for continuously monitoring the attitudes of participants and potential participants in the system, however, it does not render the research made today meaningless. The research provides a starting point for understanding what can persuade potential participants to be part of the systems and it is also the current attitude that a system implementation near in time must relate to.

A similar line of thinking can be used in relation to the low variability in the sample of examined survey-studies, with overrepresentation from people that are likely to buy cars and that are EV enthusiasts. Focusing on them during the introduction phase might really be a good way of prioritising. The difficulty to reach all segments instead of a few are reflected on by Kågesson & Berggren (2017, p. 14-15), in their case specifically pointing to the difficulty in making the EV concept attractive to those who drive shorter distances.

Interesting is also how the demand of economic incentives will develop over time. For example: sorting your trash has become the norm for most people in Sweden, something that generally does not bring on a promise of economic compensation. It is conceivable that the importance of other driving forces and concerns will result in a similar situation for the SC and V2G systems with a voluntary or close to voluntary participation. It might be a good idea to have a form of symbolic compensation initially, such as cheaper charging. This could create the prerequisites necessary for the technologies to catch on and eventually become the norm.

5.2 The future of energy and road transport on Gotland

The increased consumption of electricity arising from full electrification of passenger cars on Gotland was found to be roughly 166 GWh. Using the same power-to-energy ratio for wind turbines (3.33 GWh/MW) and the same average power rating per wind turbine (3 MW) as assumed by Region Gotland for additional wind turbines, the complete adoption of electric passenger cars on Gotland would require 17 additional turbines. This constitutes an increase of 13 % from the 133 turbines found on the island by the year of 2016 and an installed wind power capacity of roughly 50 MW. Admittedly a sizeable investment, still, there would be great potential economic and environmental savings from the avoided import of fossil fuels and the avoided usage of these. Establishing more wind power production on Gotland would also be in-line with regional and national ambitions of increased production from the power source.

Furthermore, if introduction of wind power and electric cars are made within an SC or V2G system, there would be great implications on self-sustainability and security of power supply. Gotland would go from a large importer of energy to becoming a lot closer to self-sustainability. Simultaneously, the SC or V2G system could lead to less export in total quantity and in number of hours reducing the wear on the directable mainland cable and possibly granting it years of increased life time. The full economic consequences of transitioning from the old energy system to the new would be of great interest to examine, especially in light of projections for future decrease in price of SC and V2G system components.

This master thesis has shown that the chargeable capacity available in examined SC and V2G systems is significant and even comparable to the transmission capacity of the mainland cable. A similar comparison can be made with the energy storage suggested by Lidström et al (2018) with a charging/discharging capacity of 25-50 MW and a storage capacity of 25 MWh. While the discharging capacity of the V2G system remains low in the simulations and are non-existing in the SC system, the available chargeable capacity is significantly higher than the 25-50 MW. Additionally, the 1250 MWh of storage that constitutes the difference between all cars on Gotland being at 100 and 34 percent SoC, is 50 times as high as the 25 MWh available in the suggested solution.

If SC or V2G systems are further combined with the measures suggested by Lidström et al (2018) of increasing voltage level in the regional grid, demanding frequency control to be readily available in new power production units and to create a market place for (other) flexibilities, there is good reason to believe that the energy system on Gotland can become fully renewable within a few decades. The transition could be facilitated further with the right support from the government, the region and other actors shouldering responsibility. In this way, the island could live up to the ambitions of the Swedish government for it becoming a test bed for a smart and renewable energy system, paving the way for the wider Swedish progress and even act as an inspiration in an international context.

The findings in this thesis also indicate on a will to participate in SC and V2G systems, if implemented in a way that respects driving forces and concerns. Still, there is a current lack of knowledge on the implications of the system and what the associate technologies entail. Providing information and painting the picture of what the systems could mean and contribute with are decisive for the future success of deployment. There are many ways of doing this with one interesting example being smaller projects allowing employees of Region Gotland, interested companies and/or curious private persons to experience being a part of a SC or V2G system. A smaller project like this could provide the hands-on experience that is required for convincing potential participants and lead to realisations on how the systems should be adjusted to fit in the sociotechnical context.

From where we currently are standing, electrification of transport is developing at an exponential rate, with investments in EVs and charging infrastructure done today lasting for many years to come. Therefore, the timing is right for taking action and engage in the construction of the SC and V2G systems that will become in the future. Within the Horizon 2020 project, there are already plans of creating a local market for flexibility and system services on Gotland. There are good reasons for pushing towards an SC or V2G system in conjunction as the market mechanism established within the project could provide the incentive and mode of participation that is needed for encouraging participation in the system.

5.3 Suggestions on future work

The future possibilities are endless and there are still many stones left unturned. Below are some examples of subjects that could deserve some extra examinations with the results potentially bearing important implications.

- Specific to the context of Gotland there are some matters that could enhance the understanding on how the future of transport and energy will (or can) turn out:
    - Which will be the effects on transport from the introduction of EVs and the automation of transport? Are there other large trends that will have great effect?
    - How does the introduction of solar power fit with the introduction of EVs, SC and V2G systems? It is conceivable that the production cycles are a good fit with limited battery storage capacity.
    - How can other systems services contribute to the future sustainable energy system, that are achievable from SC and V2G technologies?
    - What potential for integrating renewable power can be achieved when combining SC and V2G with other flexibility and energy storage technologies? Examples include power-to-gas, stationary battery storage, hydrogen gas storage, flexible resources in industry and households, the curtailment of wind power and more.
    - A greater acknowledgement of the economic perspective. What will be the most cost-effective solution or combination of solutions? How does these compare to investing in reinforcement of the mainland cable?
    - Studying the effect on the distribution from mass-adoption of SC and V2G technology.
- Current V2G research comprise a lack of the social perspective. Therefore, studies on this topic are needed. Some examples include:
    - Examining how different forms of participation will affect the SC and V2G system properties. Is it possible to develop a model comparing for example the use of contracts to flexible-price-models? Gaining perspectives on this could aid in establishing to what extent it is viable to develop incentives and modes of participation that are less in alignment with the concerns and driving forces of potential participants.
    - A study in a Swedish context, examining the willingness to participate in a SC or V2G system and what preferences there are towards these.
    - Possibly in combination with the above suggestion: Survey and differentiate between those who have prior knowledge on SC and V2G and those who do not. How large are the differences in willingness to participate and how do the preferences differ?
    - Who will win and who will lose on the introduction of SC and V2G systems? Will there be any groups in society that will be particularly disfavoured?
- What is the view on the SC and V2G systems of other relevant actors? Will the energy companies, companies using electric vehicles and the public sector embrace the opportunities or will they reject the technologies? Furthermore, what are their role in bringing the concepts to life?
- Further studies that can aid in once and for all sorting out what effect SC and V2G systems will have on battery degradation. The work could also include a review of charging/discharging cycles that has been suggested for diminishing the effect of degradation and specify what these can accomplish.

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Appendix

A1. The Model

The appendix complements the master thesis by going deeper into some aspects that is considered to extensive for the average reader of the report. The appendix contains four chapters:

- A1. The Model – graphic showing how traffic flow was determined, deeper explanation to chosen design parameters, explanation of the test used to validate the model and complementing data on the Sensitivity analysis.
- A2. The Literature Study – shorter summaries of the articles used to find concerns and driving forces of potential participants. Included are also summaries of articles used to find economic incentives and modes of participation.
- A3. Current and future situation on Gotland – Additional aspects on the power system and transport system on Gotland.
- A4. V2G Pilot Projects – Real world testing of V2G technology that has been completed or are currently active. The projects are included to validate the assumption that V2G is technically possible.

For further information and for those who would like to replicate the model, please contact the author of this thesis so we can decide how to proceed.

A1.1 Determining traffic flows

The process of determining what roads to include as going to and from each node is based on visually establishing the area that the constitute, by looking at satellite pictures from google maps. The traffic flow on the roads running to and from the respective specified areas were added up when calculating the flow to and from the nodes, using the traffic flow chart from the Swedish Traffic Agency (n.d.). The resulting numbers are shown below.

Table A1: Calculated traffic flows, their share of the total flow and the margin of error as there is an interval specified in the source provided by the Swedish Traffic Agency (n.d.).

Node	Total flow (to and from)	Share of total	Error margin as share of total flow	Resulting cars
Hemse	8080	0,104677	0,123614	3663,687
Klintehamn	7180	0,093017	0,123955	3255,603
Romakloster	10750	0,139267	0,129944	4874,336
Slite	4500	0,058298	0,116933	2040,42
Vibble	17200	0,222827	0,082936	7798,938
Visby	29480	0,381915	0,088704	13 367,02
Total	77190	1		35 000

Below shows the selection of roads included in for the specific nodes (figure A1-6).

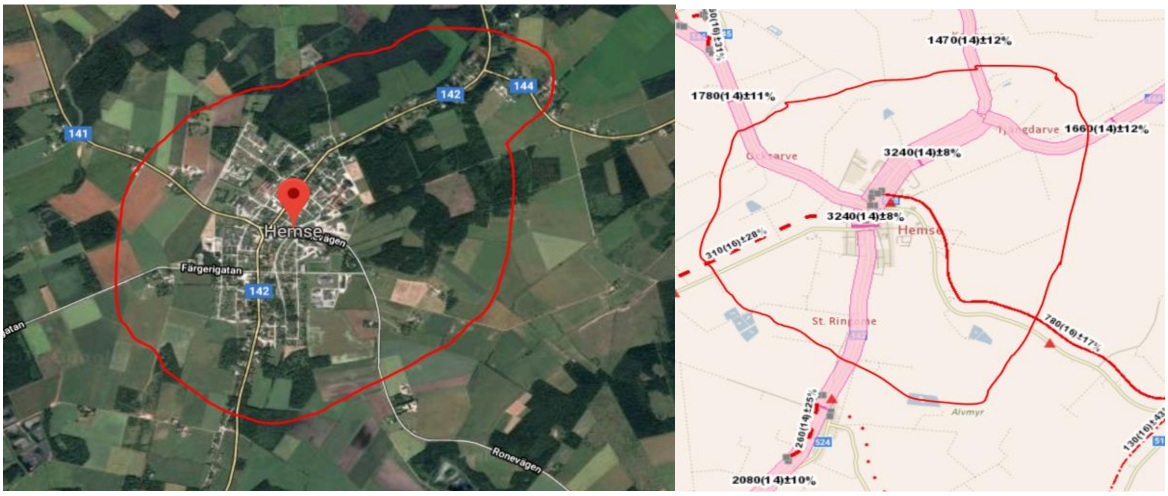


Figure A1: Hemse.

Figure A2: Klintehamn.

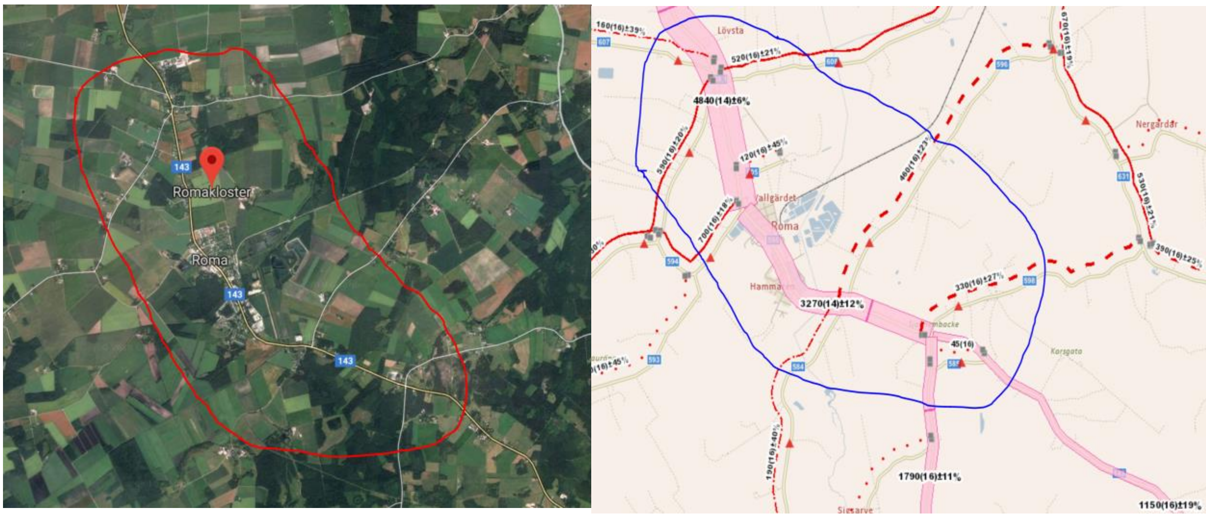


Figure A3: Romakloster.

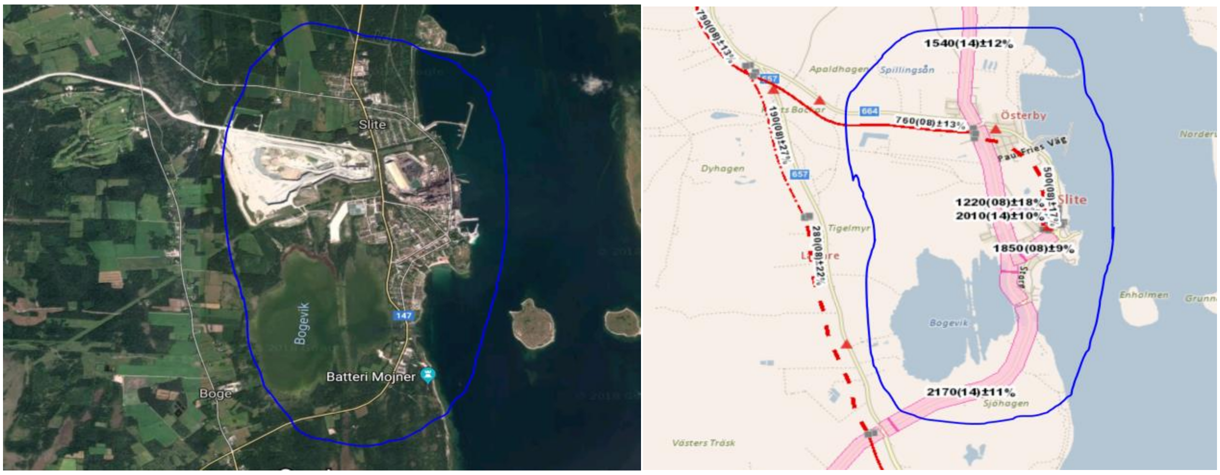


Figure A4: Slite.

Figure A5: Vibble.

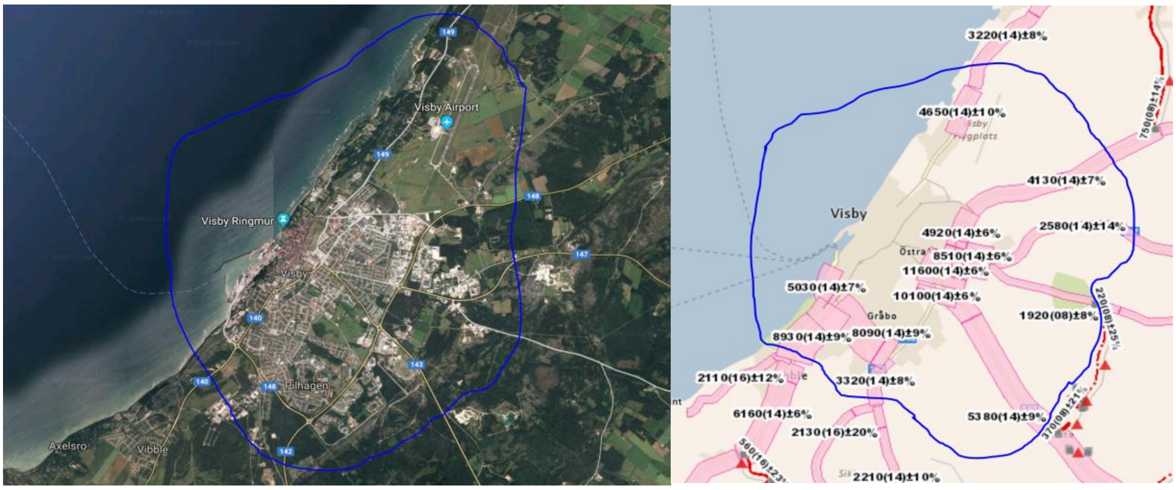


Figure A6: Visby

A1.2 Design parameters

The parameters below in table A2 constitute the base case and are used if nothing else is mentioned for the simulations.

Table A2: The parameters used during simulation.

Design parameters for cars			
Parameter	**Value**	**Unit**	**Comment/source**
Battery capacity	54	kWh	1
Energy usage per km	0.15	kWh/km	2
Charging capacity	6.3	kW	3
Discharging capacity	6.3	kW	4
Charging losses	9	%	5
Discharging losses	9	%	6
Chargeable Share	100	%	7
Allowed Lower Limit	18,7 / 34	kWh / %	8
Initial SoC	50	%	9
Number of Cars on Gotland	35 000	Cars	10
Share of time cars are active	5	%	11
Electric energy for vehicle use	165,8	GWh	12

1. Calculated mean value, using the five most common models of electric cars today with each model weighting in to the result in accordance to the share they constitute of all five car models. The cars from these five brands constitute more than 75 % of the electric cars on road in Sweden today. Se table A3 below for values.

Table A3: The five most common cars and some characteristics according to Power Circle (2018).

Most common electric cars	**Number of cars**	**Storage capacity (kWh)**	**Range (km, NEDC)**	**Energy use (kWh/km)**	**Source**
Tesla Model S	3505	75	490	0.1530	(Tesla 2018A)
Nissan Leaf	3288	40	378	0.1058	(Goldman 2018)
Renault Zoe	2846	41	400	0.1025	(bilia 2018)
Renault Kangoo Z.E	1524	33	270	0.1222	(Renault n.d.)
Tesla Model X	1001	100	565	0.1770	(Tesla 2018B)
Weighted Average		54.38 ≈ 54		0.127	

2. 0.15 kWh/km is a figure based on simulations made at LTH (J. Márquez-Fernández 2019).

   0.127 kWh/km is a calculated mean value using the same method as in (1). The values are based on the NEDC-cycle, which is an overestimation of energy efficiency. The figure serves to validate 0.15 kWh/km as the real figure should be in the same order of magnitude, yet slightly larger.

3. Based on a normal working week being 40 hours or roughly 16.8 % of the total week, a weighted average was made for charging capacity, weighting public charging for this share and using standard 3.7 kW home charging for the remaining 83.2 %. For the public charging

points, a weighted average was again made on the current installed chargers, based on statistics from Power Circle (Kulin & Andersson 2019). As it becomes increasingly common with higher charging power and home charging is possible with higher power as well, using 6.3 kW can be considered conservative.

$$P_{charging} = 0.832 * 3.7 + 0.168 * \left(\frac{= 155 * 43 + 2226 * 22 + 907 * 11 + 402 * 7{,}4 + 1948 * 3{,}7 + 50 * 162 + 254 * 125}{155 + 2226 + 907 + 402 + 1948 + 162 + 254}\right) \approx 0.832 * 3.7 + 0.168 * 19.1 \approx 6.3$$

4. Al though the real figure can be higher, such as the 10 kW used in the V2G project in Fredrikshavn (enel 2016), 6.3 kW is used as it is assumed that it will be the same power when charging as when discharging.
5. The round-trip total system losses (vehicle battery to transformer station) in a grid-Integrated Vehicle System at charge rate of 6.3 kW is in the order of 1.1 kW or 17.5 %. The one-way losses then become half of that, roughly 9 %. (Apostolaki-Iosifidou, Codani & Kempton 2017).
6. The one-way losses for discharging are estimated the same way as the charging losses in (5).
7. The assumption is made that every electric car is plugged-in when finished driving, for simplicity. A sensitivity analysis examines the effect of this choice further.
8. As the distance from the southernmost part of main Gotland (close to Hoburg) to the northernmost part (close to Fleringe) is 147 km, the allowed lowest battery level is this distance multiplied by the discharge rate on road (0.127 kWh/km), ensuring that the likelihood of not having enough energy for the trip is low.
9. Arbitrarily chosen number. The real number is unknown and even though stochastic assignment of SoC could have been a better estimate, more random elements would increase the variations in the result.

To find the impact of changing initial SOC, the base case was run six times, one time each for the three scenarios (UC, SC, V2G) with 50 % initial SOC and 100 % initial SOC respectively. The effect se altering initial SoC was found to be low and figure A7 shows the residual for the no EVs scenario (for perspective) and remaining values when subtracting the SOC 100 residuals from the SOC 50 residuals for the three scenarios. After an initial difference that affects the first days of the year, the values quickly become very similar.

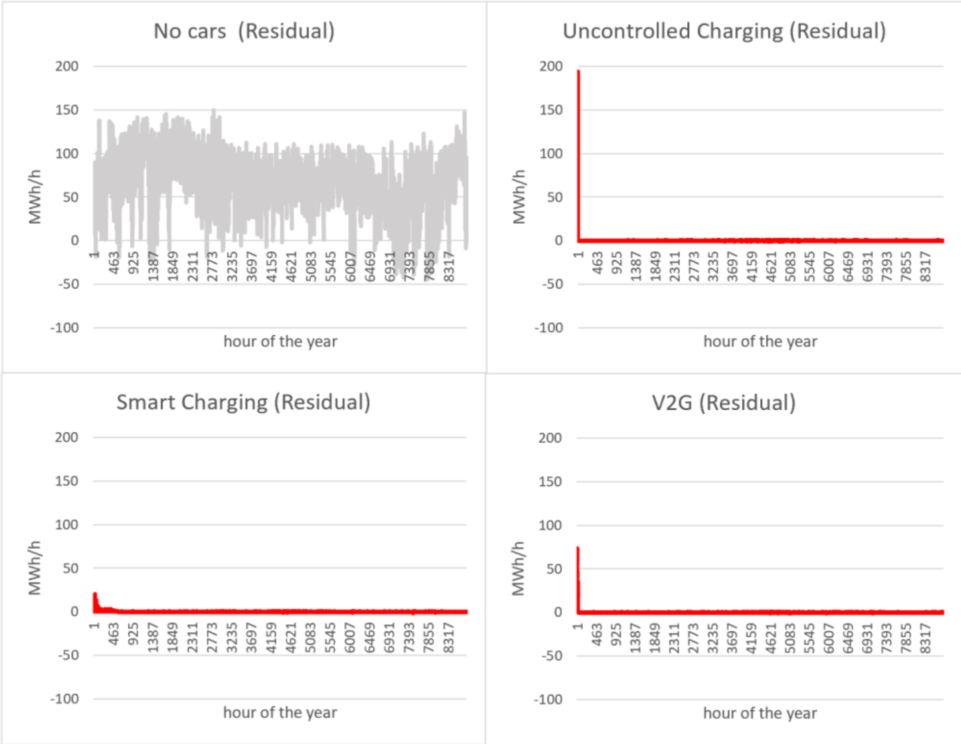


Figure A7: The no EVs scenario residual for comparison and the differences in residual for the three scenarios. This is developed from subtracting values found at an SOC of 50 % with values found at an SOC of 100 %.

Below table A4 also show the annual values for the case of 50 and 100 % initial SOC. The difference in end results is also shown. Again, the differences are small as compared to the original values, never larger than 0.16 GWh. Remember that there are random elements already in the model, meaning some difference between values will exist regardless of the impact from altering initial SoC.

Table A4: The annual values for the case of 50 (green) and 100 (blue) % initial SOC and the difference (orange) in end results.

	SOC 50			**SOC 100**			**SOC 50 - SOC 100**			
	UC	**SC**	**V2G**	**UC**	**SC**	**V2G**	**UC**	**SC**	**V2G**	**Unit**
Export	1,727784	0	0	1,727784	0	0	0	0	0	GWh
Import	777,8896	774,121	775,075	777,8896	774,121	775,075	0	0	0	GWh
Residual	0	589,3875	587,5356	0	589,3875	587,5356	0	0	0	GWh
Increased import	165,824	162,0554	163,0094	165,824	162,0554	163,0094	0	0	0	GWh
Charged Local Power	2,8	4,670164	3,602867	2,8	4,670164	3,444418	0	-9,7E-08	0,158449	GWh
Discharged	0	0	1,014741	0	0	1,096078	0	0	-0,08134	GWh
Discharging Losses	0	0	0,266787	0	0	0,302971	0	0	-0,03618	GWh

Electric power for transport	143	145,8	145,862	142,9	145,8	145,934	0,1	0	-0,07201	GWh
	SOC50			SOC 100			SOC 50 - SOC 100			

10. Although the future number of cars on Gotland is likely to be larger than the present, due to increasing population, using the 35 000 cars present today will be conservative.
11. An estimate based on multiple reports is used finding cars are parked 95 % of the time. Gullberg (2015) reports on this figure being 96 % in Stockholm (Gullberg, 2015). Pernestål Brenden researcher in traffic field at KTH report the figure to be 95 % in an interview with Swedish Television (SVT) (Pernestål Brenden 2017).
12. To find this number, the UC scenario was run in the base case preconditions. The additional import added with the decrease in export as compared to the no car scenario summed up to 165.8 GWh, assumed to be the increased need in power production on a yealy basis to compensate for 100 % electrification of personal cars on Gotland. The hourly production values are scaled up by a percentage corresponding to the increase that is needed for producing 165.8 GWh of extra energy.

    An estimation based on the 143 GWh used on road in the same simulation was also made. The figure was modified by including, in addition to the charging losses, regional and local transmission losses for all energy used for EVs resulting in the increased need of 167 GWh to cover transport. This worst-case scenario is close to reality as most power is produced in the area around Slite and Hemse and most cars are charging in Visby. It therefore seems reasonable to use the rather large number of 165.8 GWh as basis for the cases.

    To put the number in perspective, a simulation was run with unlimited power production on the island and with no limit values for transmission capacity. This was done to see how the value differed when the limitations were omitted. The energy required in this scenario was then 158 GWh.

Some parameters related to the transmission capacity is shown in table A5 below, a reference is included to the specification of why the parameters where chosen or how they were calculated.

Table A5: Power transmission capacities and losses.

Transmission capacities and losses			
Parameter	**Value**	**Unit**	**Comment**
Regional Transmission Limits	250	MW	1
Losses for transmission between nodes	6,3	%	2
Mainland Transmission Limits	130, 122	MW	3

1. The transmission capacity of the largest cables in the regional grid is estimated to 125 MW each by Per Norberg, adjunct professor in electrical engineering and Senior Technical Advisor at Vattenfall Eldistribution AB. The assumption of the 250 MW capacity, which is two times this number, is based on the ring-like structure of the power grid on Gotland. A simplification is made in that power can travel two ways from each node on 125 MW cables, adding up to

250 MW of transmission capacity. When power is transmitted in the model, the corresponding amount is deducted from the 250 MW and therefore power cannot occupy the same capacity twice during the same minute. The limitations of this method are discussed in *The Model, Limitations*.

2. Assumed after discussing a suitable mean-value with Johan Sjöndin, Responsible for power grid and sales of over 80 000 kWh/year at GEAB. On a yearly basis, the total losses in the grid of Gotland is 60 GWh during the same time period as the total consumption is 950 GWh. The percentage loss on a yearly basis will then be 6.3 %.
3. 130 kW per cable (Swedish Energy Agency 2018, pp. 14-16). Assuming 6 % losses lead to the transmission received in Gotland being 122 kW when importing, at the Gotland side of the cable.

A.1.3 Tests for validation

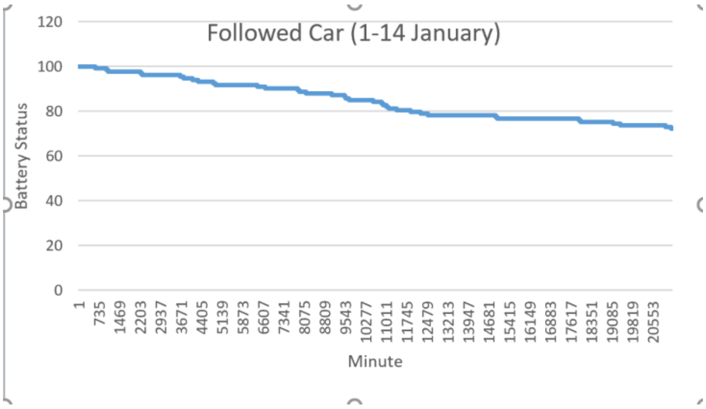
Tests runs for validation of the model:

- No EVs:
  - One node:
    - Hypothesis without transmission capacity limits, no losses and high production/ low consumption on Gotland:
      - Considerable export to the mainland summing up to the difference between production and consumption. CONFIRMED.
    - Hypothesis without transmission capacity limits, no losses and production equal to consumption on Gotland:
      - No export nor import of electricity. All that is produced is consumed immediately. CONFIRMED.
    - Hypothesis without transmission capacity limits, no losses and low production/ high consumption on Gotland:
      - Considerable import from mainland summing up to the difference between consumption and production. CONFIRMED.
    - Hypothesis without transmission capacity limits, with losses and high production/ low consumption on Gotland:
      - Considerable export to the mainland however, more energy is produced than is consumed/exported. The energy loss amount to the assigned share of losses. Disproven, in the latest implementation the losses for transmission to/from the mainland was removed as the idea was to only consider the system to be constituted by what is inside borders of Gotland, not including the distance over water to the mainland. However, the model seems to produce the right result.
    - Hypothesis with transmission capacity limits, without losses and high production/ low consumption on Gotland.
      - Blackout error and a lot less export. Blackout confirmed, however the export turns negative. Fixed.
  - A few nodes:
    - Hypothesis without transmission capacity limits, no losses and high production/ low consumption on Gotland:
      - Considerable export to the mainland summing up to the difference between production and consumption. Confirmed.

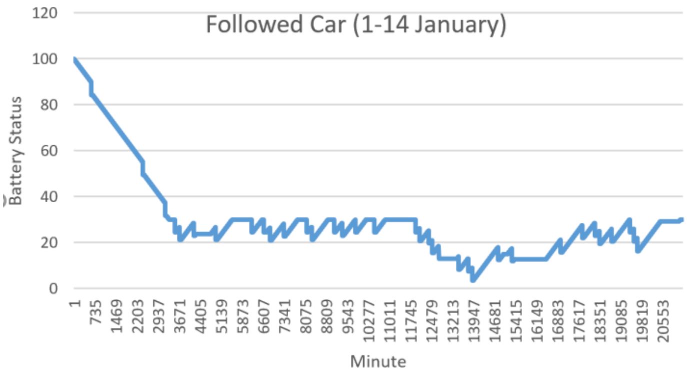
        - Hypothesis without transmission capacity limits, no losses and production equalling consumption on Gotland:
            - No export/ import and neither between nodes nor to and from the mainland. Confirmed.
        - Hypothesis without transmission capacity limits, no losses and low production/ high consumption on Gotland:
            - Considerable import from mainland amounting to the difference between consumption and production. Confirmed.
        - Hypothesis without transmission capacity limits, without losses and 50 % of nodes high production and 50 % low production:
            - No export, the overproduction from nodes will be transmitted to the nodes with lower production. Confirmed.
        - Hypothesis without transmission capacity limits, with losses and 50 % of nodes high production and 50 % low production:
            - As above, however, there is an import making up for the losses. Confirmed.
        - Hypothesis with transmission capacity limits between nodes, no losses and high production on the island:
            - Error report: the nodes cannot receive/deliver enough energy etc. The nodes are not transmitting above the limit. Confirmed.
        - Hypothesis with transmission capacity limit to the mainland, no losses and high production on the island:
            - Error report blackout. Gotland is only transmitting what is allowed by the export limit, to the mainland. Confirmed.
- One car with a giant 1000 kWh battery:
    - One node, overproduction of power:
        - Only losses from charging/discharging. The losses as a total will add up to the percentages set for the charginglosses in the in-data. The car will be close to fully charged most of the year. Disproven, the car is already at full battery and as there are no other nodes, the car has nowhere to go. This means that it will not require any energy. The model seems to produce the right result.
    - One node underproduction of power:
        - Only losses from charging/discharging. The losses as a total will add up to the percentages set for the discharging-losses in the in-data. Large rate of import, no discharge onto the grid. The car will be close to the lowest allowed limit. Confirmed.
    - One node, underproduction first half of year, then overproduction.
        - Only losses from charging/discharging. The losses as a total will add up to the percentages set for the losses in the in-data. Notable import as power is lost when charging discharging the car, no discharge onto the grid. The car will be close to the lowest allowed limit first half year and then full during the second half year. Confirmed.
    - Multiple nodes:
        - Hypothesis with overproduction of power in all nodes without losses: There should not be any charging, discharging in any node where there is no car. What is discharged en-route should equal to the energy needed to complete the total distance the car makes during a year. Energy balance on Gotland and of the car should equal to 0. Confirmed.

    - Hypothesis with losses, production=consumption of power, no losses in all nodes: There will be an import to cover the difference in energy need between how much the car battery can be discharged and how much energy is needed to complete all trips done by the car. There will be no discharge nor charge from any nodes, those will need all energy themselves. Confirmed.
    - Hypothesis with losses, production=consumption of power for all nodes as a total but with 50 % of nodes having a deficiency and 50 % an abundance, with losses in transmission between nodes: There will be an import to cover losses from in-between nodes, what is discharged enroute. There will also be some discharging from the car to the local node. – Confirmed with a slight difference. The import does not cover all that is discharged en-route as some is discharged before the car gets a low battery. This means a little less power can be discharged to the node for support during the runtime of the simulation.
    - Hypothesis with losses, production=consumption of power for all nodes as a total but with 50 % of nodes having a deficiency and 50 % an abundance, with losses in transmission between nodes: There will be an import to cover losses from in-between nodes, what is discharged enroute when the battery is getting to assigned lower limit. There will also be some discharging from the car to the local node, as the car is placed in deficiency-nodes. Confirmed. Also checked so the battery and import balance checks out.
    - Dis-allowing discharging to the power grid, with losses, overproduction of power in 50 % of nodes and underproduction in 50% in total summing up to a deficiency, meaning some energy need to be imported from the mainland. This means only charging of cars and discharging enroute is possible energy routes for the car. This means there should be no discharging to other nodes and the energy used by cars are restricted to discharging enroute. Confirmed.
    - Same as above, allowing losses. Losses equal to those done in transmission between nodes and in charging.
    - Same as above, with lower priority for cars with over 75% battery (0.5 chargerate). Confirmed
- A few cars with a 1000 kWh battery, multiple nodes:
  - Hypothesis without losses: Cars will be charged discharged within the nodes and discharged, charged to help the balancing of energy in other nodes.
    - With high production: The car will be close to fully charged and will never get stuck due to lack of power. Also cars that have be assigned homenodes will start in those nodes, similarly the worknodes will be correct and the cars will end up in these on occation. Bug detected. Due to the mechanism behind sending cars on trips, the first nodes will be the ones sending cars as long as there are cars there. This means that the latter nodes won't be addressed until late in the simulation. Bug fixed.
    - When consumption equals production, the car will lose energy every time it is on the road. After some trips the car will find a balance close to the allowed lowest battery level and will keep this limit by importing electricity from the mainland. The car will not discharge any power to nodes. Confirmed.
    - When consumption is lower than production, the car will discharge to help balancing the power equation of the nodes and hence discharge even faster than the above test case. Confirmed.

Consumption= production:

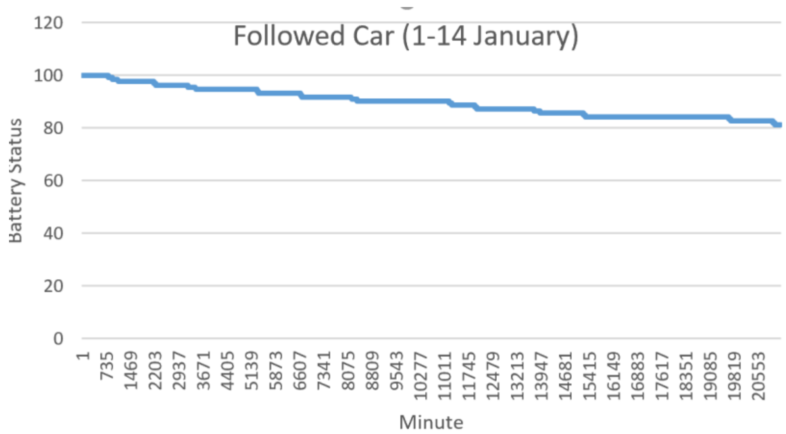


Consumption>production:

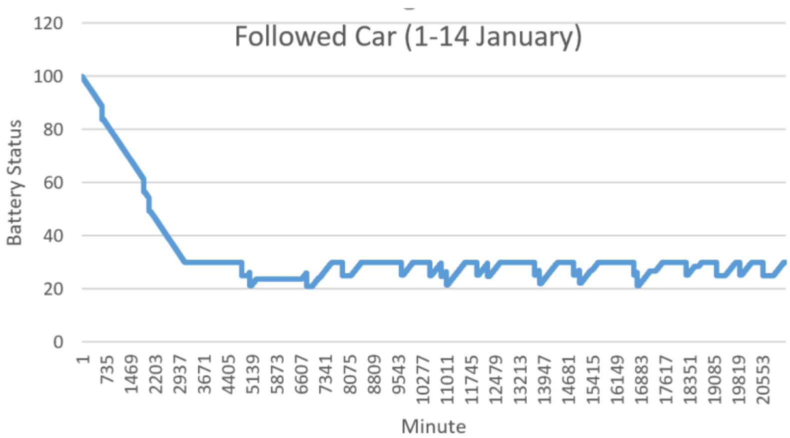


  - When consumption equals production for all nodes but 50 % of nodes overproduce and 50 % underproduce. After some trips the car will find a balance close to the allowed lowest battery level and will keep this limit by importing electricity from the mainland. The car will not discharge any power as the required energy is satisfied by overproducing nodes. Confirmed.
- Hypothesis with losses:
  - When consumption equals production for all nodes but 50 % of nodes overproduce and 50 % underproduce. After some trips the car will find a balance close to the allowed lowest battery level and will keep this limit by importing electricity from the mainland. This will happen faster than in the case with no losses. Also the losses should add up to projected shares. The car will discharge some power. Se so that there is nothing inexplainable in the error log! Confirmed. However, there is an error as cars are not sufficiently charged to carry out their trips on some occasions. A possible explanation could be that these cars have, by mere chance, been selected so many times that they do not have enough time to charge. It is in principle possible that these cars get selected for doing a new trip as soon as they have arrived, more or less. This issue should be fixed when increasing the amount of cars massively. The risk of the same car being selected multiple times is then a lot lower.

Without losses



With losses



- More cars than in reality, with losses and varying power production and consumption:
    - This will not aid in validating the model as such but will give an idea of how much computer power is needed to manage the final model. Important to check the error log! It seem to currently take roughly 8 hours.
- After changes to save time and improve distribution of cars during simulation 5000 cars:
    - Hypothesis without losses:
        - With high production: The car will be close to fully charged and will never get stuck due to lack of power. Also cars that have be assigned homenodes will start in those nodes, similarly the worknodes will be correct and the cars will end up in these on occasion. Confirmed.
        - When consumption equals production, the car will lose energy every time it is on the road. After some trips the car will find a balance close to the allowed lowest battery level and will keep this limit by importing electricity from the mainland. The car will not discharge any power to nodes. Confirmed.
        - When consumption is lower than production, the car will discharge to help balancing the power equation of the nodes and hence discharge even faster than the above test case. Confirmed.
        - When consumption equals production for all nodes but 50 % of nodes overproduce and 50 % underproduce. After some trips the car will find a

balance close to the allowed lowest battery level and will keep this limit by importing electricity from the mainland. The cars will not discharge any power as the required energy is satisfied by overproducing nodes. Confirmed.

- Hypothesis with losses:
  - When consumption equals production for all nodes but 50 % of nodes overproduce and 50 % underproduce. After some trips the car will find a balance close to the allowed lowest battery level and will keep this limit by importing electricity from the mainland. This will happen faster than in the case with no losses. Also the losses should add up to projected shares. The car will discharge some power. Se so that there is nothing inexplainable in the error log! Confirmed.

A1.4 Sensitivity Analysis – extra material

Battery storage capacity

Battery storage was altered to 50, 200 and 300 % of original capacity. Below are the residuals in a duration diagram (figure A8), histograms showing the chargeable capacity (figure A9) and a table (A6) showing the capacities over which the cars where chargeable during 95 and 99 % of the time (table A7) for the SC scenario.

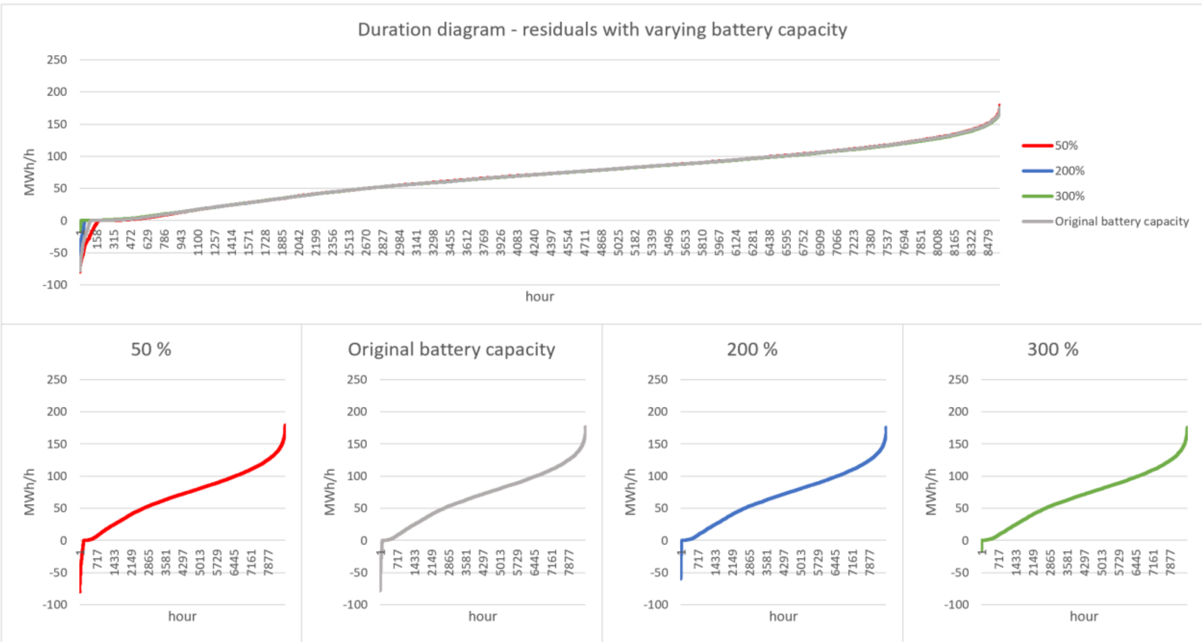


Figure A8: Residuals for the SC scenario with altered battery storage capacity of 50, 200 and 300 % of original. The residual of the original battery capacity is included for reference.

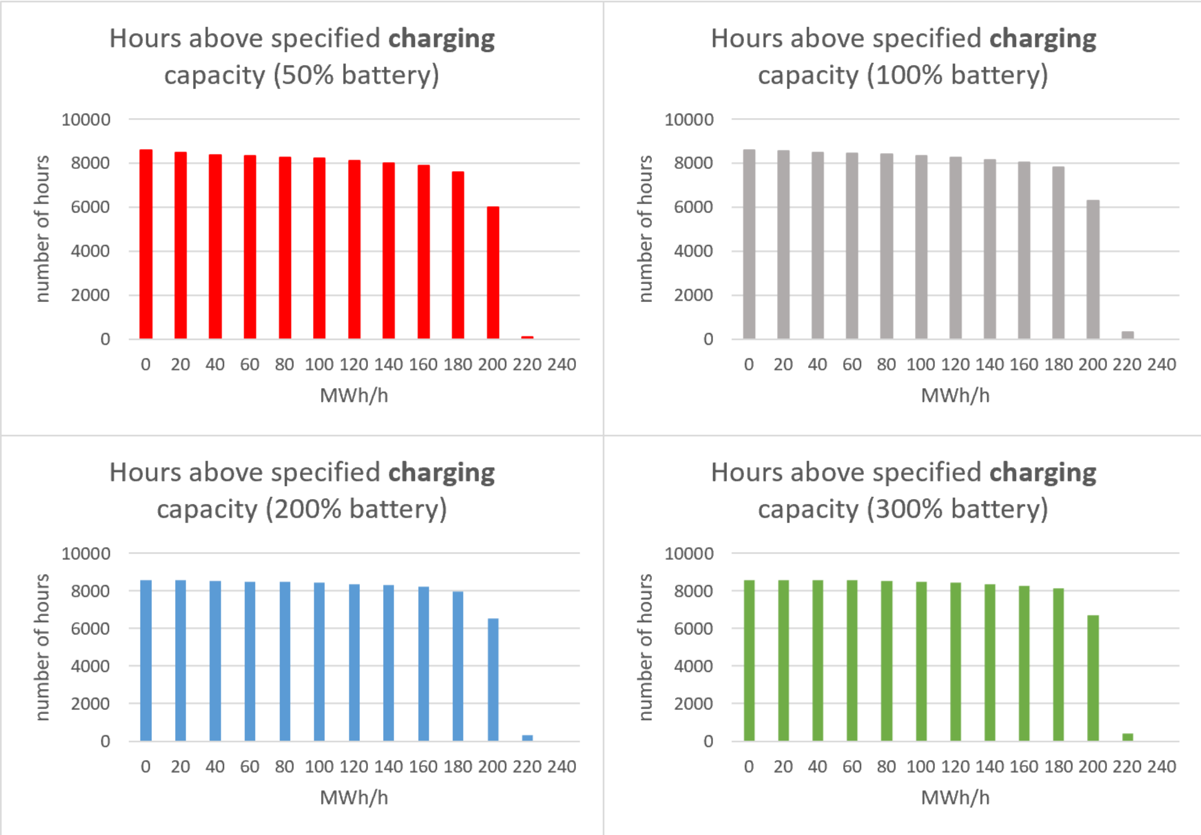


Figure A9: Hours above specified chargeable capacity for the SC scenario with altered battery storage capacity of 50, 200 and 300 % of original. The original battery capacity is included for reference.

Table A6: The capacity available for charging during 95 and 99 % of time for the SC scenario with altered battery storage capacity of 50, 200 and 300 % of original. The original battery capacity is included for reference.

Percentage of time for specified capacity	**50 % of original** (MWh/h)	**Original battery Capacity** (MWh/h)	**200 % of original** (MWh/h)	**300 % of original** (MWh/h)
95	112	138	169	177
99	14	36	65	99

Below are the residuals in a duration diagram (figure A10), histograms showing the chargeable capacity (figure A11), histograms showing the dischargeable capacity (figure A12) and a table showing the capacities over which the cars where chargeable during 95 and 99 % of the time (table A9) of the V2G scenario.

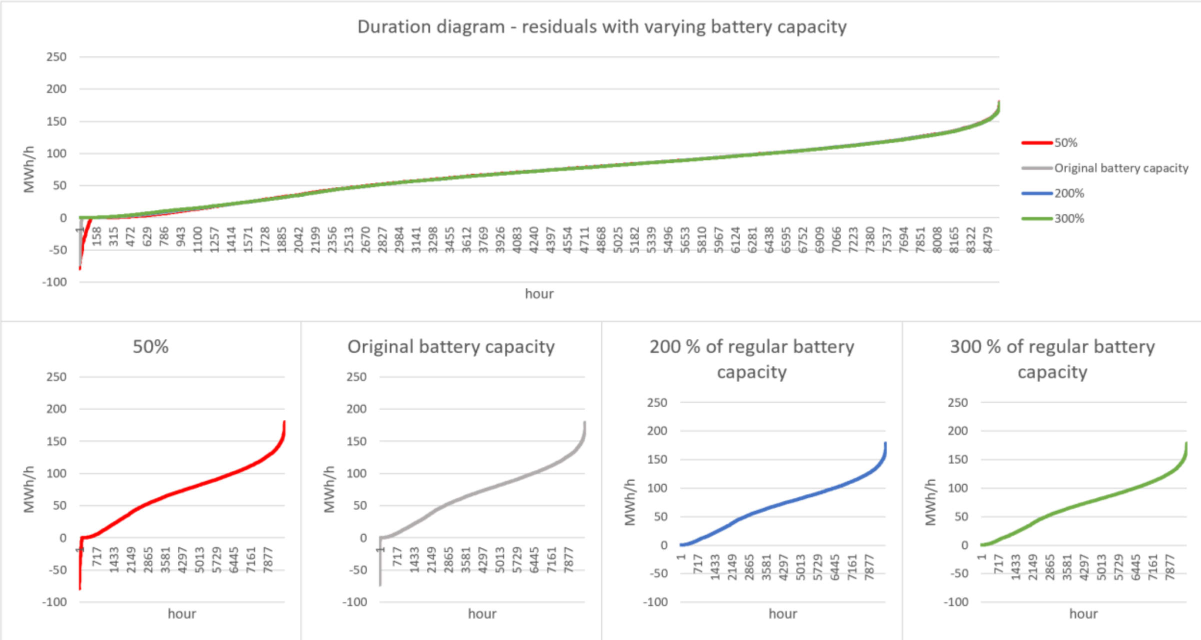


Figure A10: Residuals for the V2G scenario with altered battery storage capacity of 50, 200 and 300 % of original. The residual of the original battery capacity is included for reference.

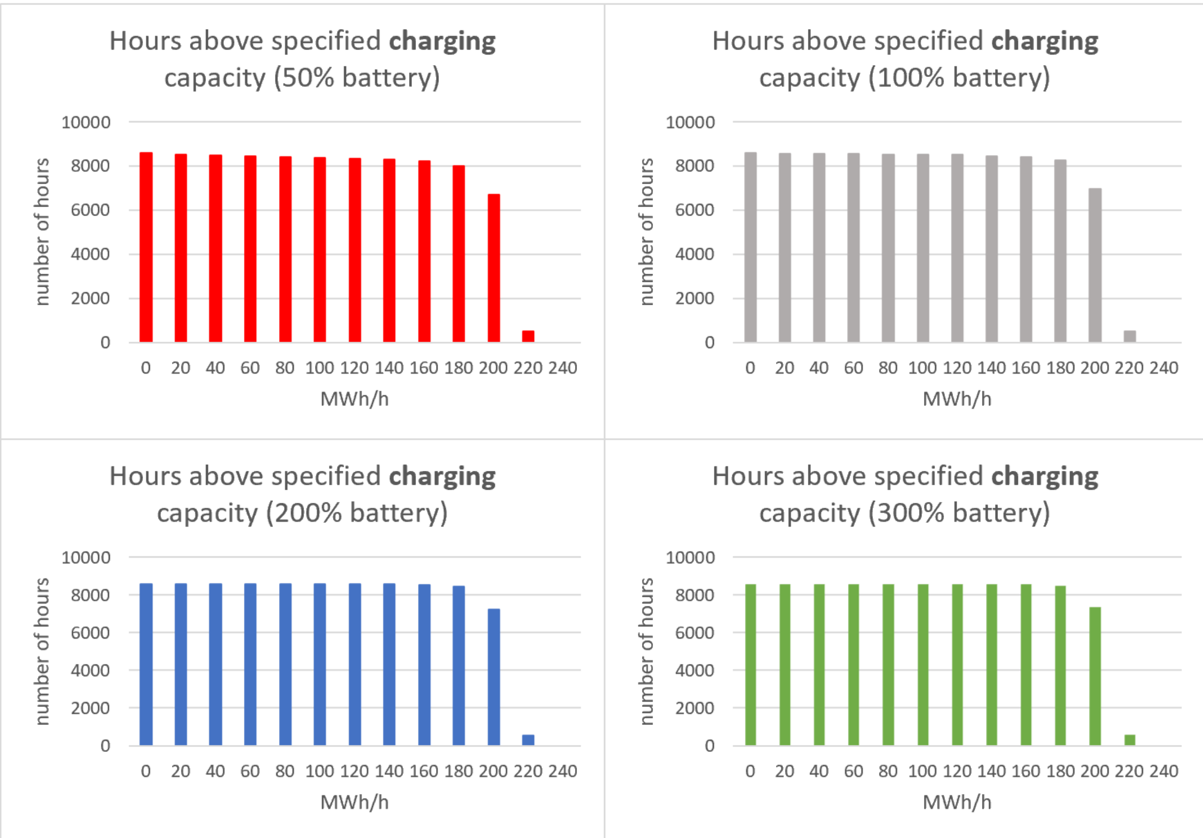


Figure A11: Hours above specified chargeable capacity for the V2G scenario with altered battery storage capacity of 50, 200 and 300 % of original. The original battery capacity is included for reference.

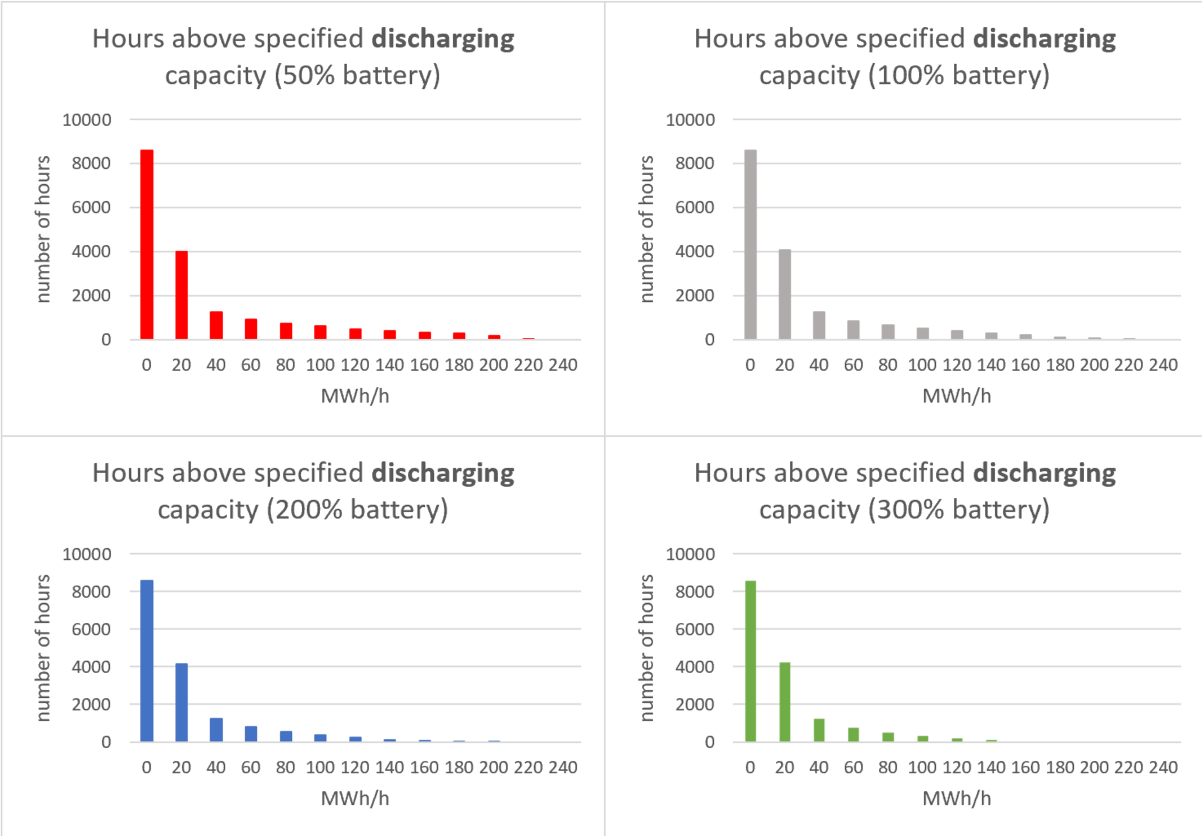


Figure A12: Hours above specified dischargeable capacity for the V2G scenario with altered battery storage capacity of 50, 200 and 300 % of original. The original battery capacity is included for reference.

Table A9: The capacity available for charging during 95 and 99 % of time for the V2G scenario with altered battery storage capacity of 50, 200 and 300 % of original. The original battery capacity is included for reference.

Percentage of time for specified capacity	**50 % of original** (MWh/h)	**Original battery Capacity** (MWh/h)	**200 % of original** (MWh/h)	**300 % of original** (MWh/h)
95	168	183	188	190
99	27	122	172	180

Charging and discharging capacity

Charging and in the V2G discharging capacity was altered to 3.7, 12.6 kW and compared to the original usage of 6.3 kW. Below are the residuals in a duration diagram (figure A13) and a table (A10) showing the capacities over which the cars where chargeable during 95 and 99 % of the time for the SC scenario.

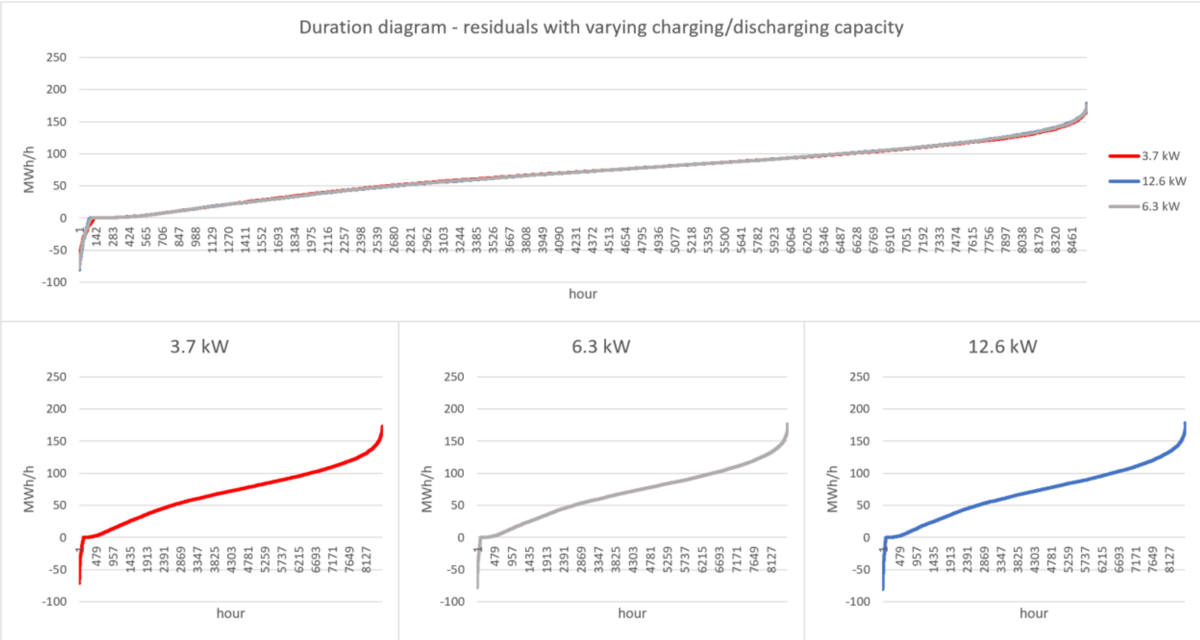


Figure A13: Residuals for the SC scenario with charge rates of 3.7, 6.3 and 12.6 kW.

Table A10: The capacity available for charging during 95 and 99 % of time for the SC scenario with charge rates of 3.7, 6.3 and 12.6 kW.

Percentage of time for specified capacity	**3.7 kW** (MWh/h)	**6.3 kW** (MWh/h)	**12.6 kW** (MWh/h)
95	87	138	256
99	37	36	35

Below are the residuals in a duration diagram (figure A14), histograms showing the dischargeable capacity (figure A15) and a table showing the capacities over which the cars where chargeable during 95 and 99 % of the time (table A11) of the V2G scenario.

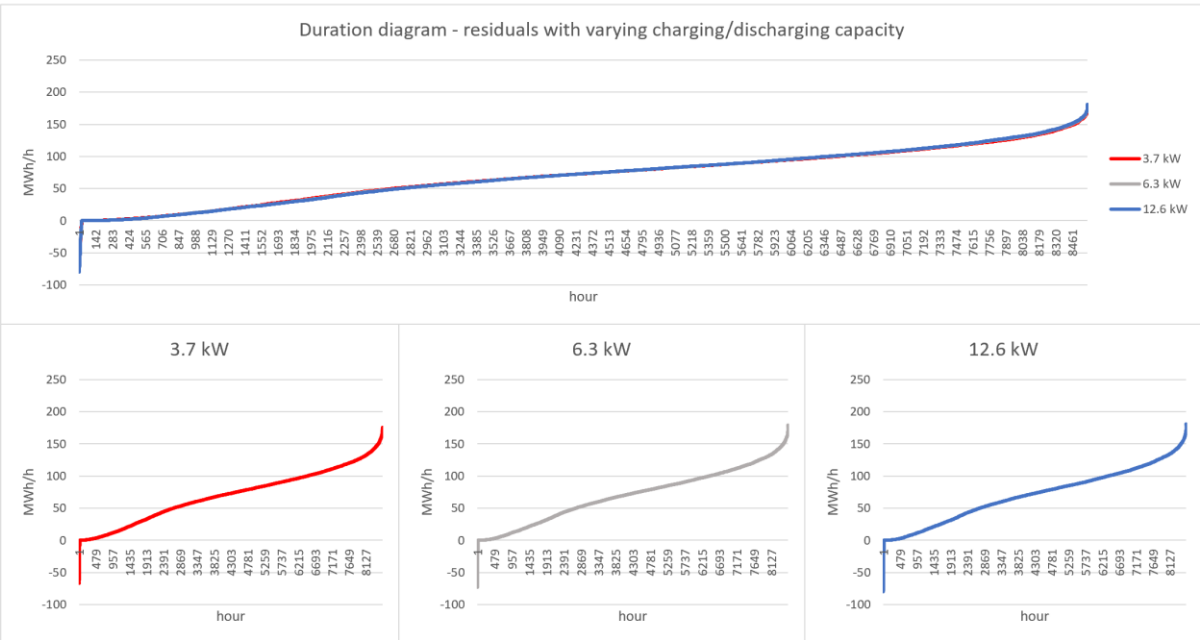


Figure A14: Residuals for the V2G scenarios with charge rates of 3.7, 6.3 and 12.6 kW.

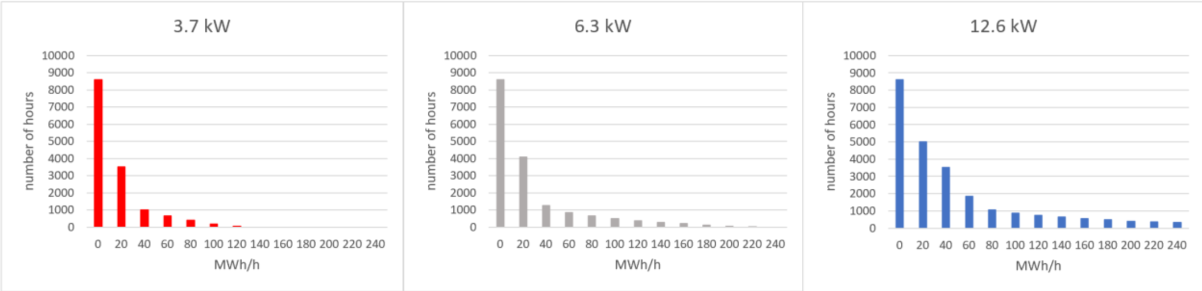


Figure A15: Hours above specified dischargeable capacity for the V2G scenario with charge rates of 3.7, 6.3 and 12.6 kW.

Table A11: The capacity available for charging during 95 and 99 % of time for the V2G scenario with charge rates of 3.7, 6.3 and 12.6 kW.

Percentage of time for specified capacity	**3.6 kW** (MWh/h)	**6.3 kW** (MWh/h)	**12.6 kW** (MWh/h)
95	109	183	362
99	77	122	231

Chargeable share

Chargeable share and in the V2G discharging share were altered to 50, 75 % and compared to the original usage of 100 %. Below are the residuals in a duration diagram (figure A16) and a table showing the capacities over which the cars where chargeable during 95 and 99 % of the time (table A12) for the SC scenario.

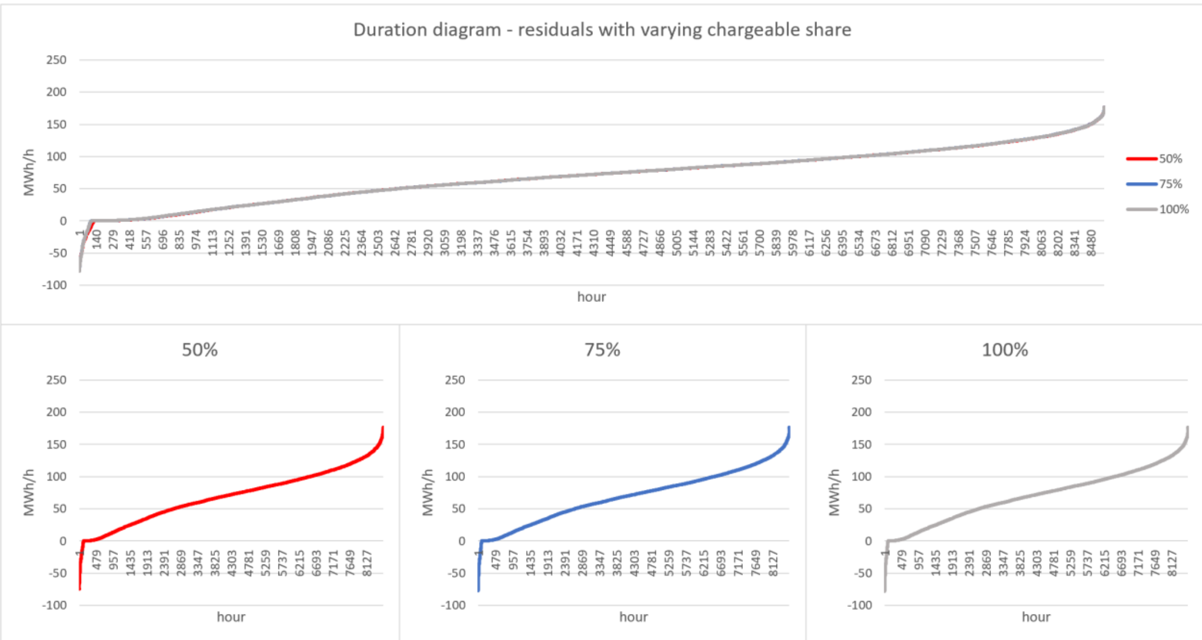


Figure A16: Residuals for the SC scenarios with chargeable shares of 50, 75 and 100 %.

Table 12: The capacity available for charging during 95 and 99 % of time for the SC scenarios with chargeable shares of 50, 75 and 100 %.

Percentage of time for specified capacity	**50 %** (MWh/h)	**75 %** (MWh/h)	**100 %** (MWh/h)
95	106	129	138
99	32	36	36

Below are the residuals in a duration diagram (figure A17), histograms showing the dischargeable capacity (figure A18) and a table showing the capacities over which the cars where chargeable during 95 and 99 % of the time (table A13) of the V2G scenario.

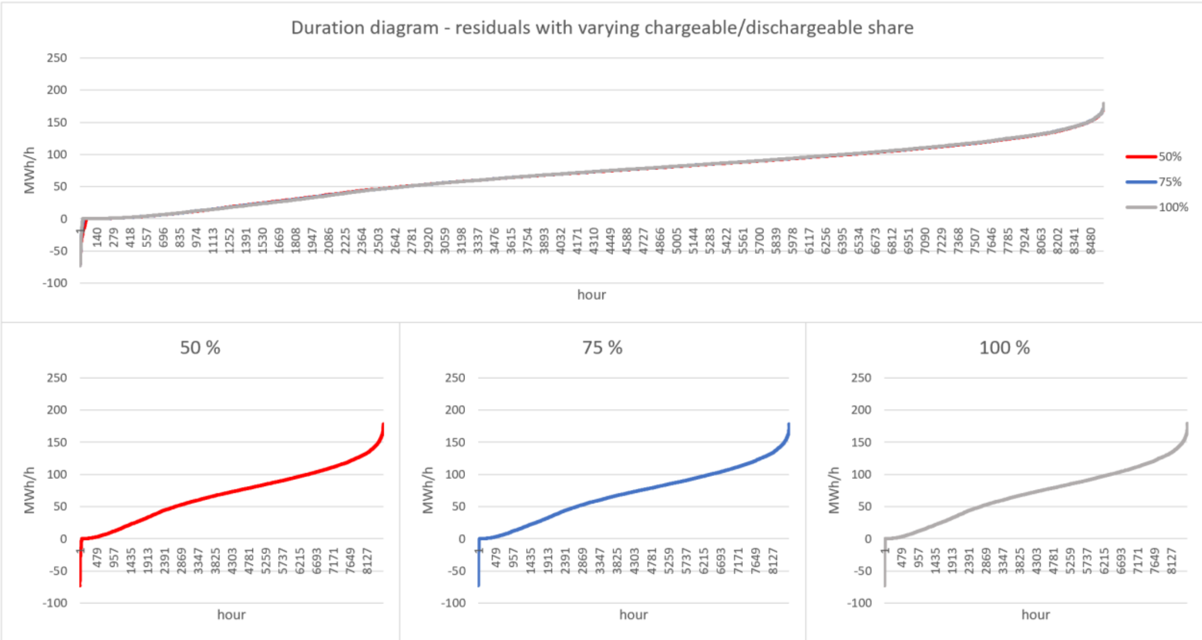


Figure A17: Residuals for the V2G scenarios with chargeable shares of 50, 75 and 100 %.

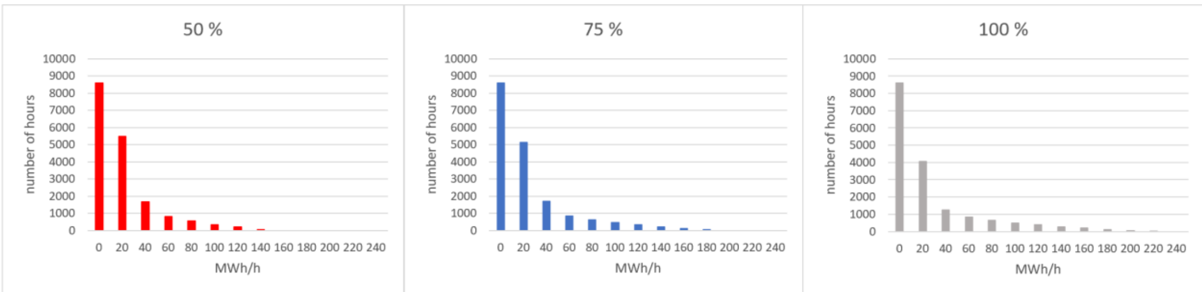


Figure A18: Hours above specified dischargeable capacity for the V2G scenario with dischargeable (and chargeable) shares of 50, 75 and 100 %.

Table A13: The capacity available for charging during 95 and 99 % of time for the V2G scenarios with chargeable shares of 50, 75 and 100 %.

Percentage of time for specified capacity	**50 %** (MWh/h)	**75 %** (MWh/h)	**100 %** (MWh/h)
95	124	159	183
99	70	98	122

Number of cars

The number of electric cars in the SC and V2G system was altered to 33, 67 % and compared to the original usage of 100 %. Below are the residuals in a duration diagram (figure A19) and a table showing the capacities over which the cars where chargeable during 95 and 99 % of the time (table A14) for the SC scenario.

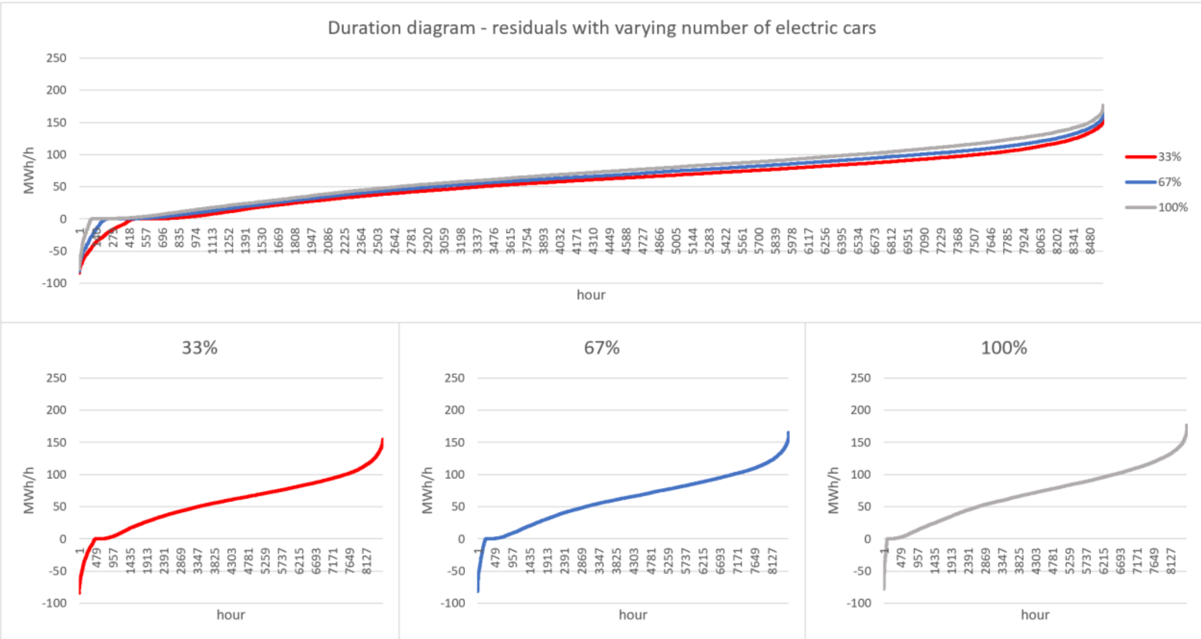


Figure A19: Residuals for the SC scenario with shares of 33, 67 and 100 % of electric cars in the SC system.

Table A14: The capacity available for charging during 95 and 99 % of time for the SC scenario with 33, 67 and 100% of the original number of cars in the system.

Percentage of time for specified capacity	**33 %** (MWh/h)	**67 %** (MWh/h)	**100 %** (MWh/h)
95	16	66	138
99	2	13	36

Below are the residuals in a duration diagram (figure A20), histograms showing the dischargeable capacity (figure A21) and a table showing the capacities over which the cars where chargeable during 95 and 99 % of the time (table A15) for the V2G scenario.

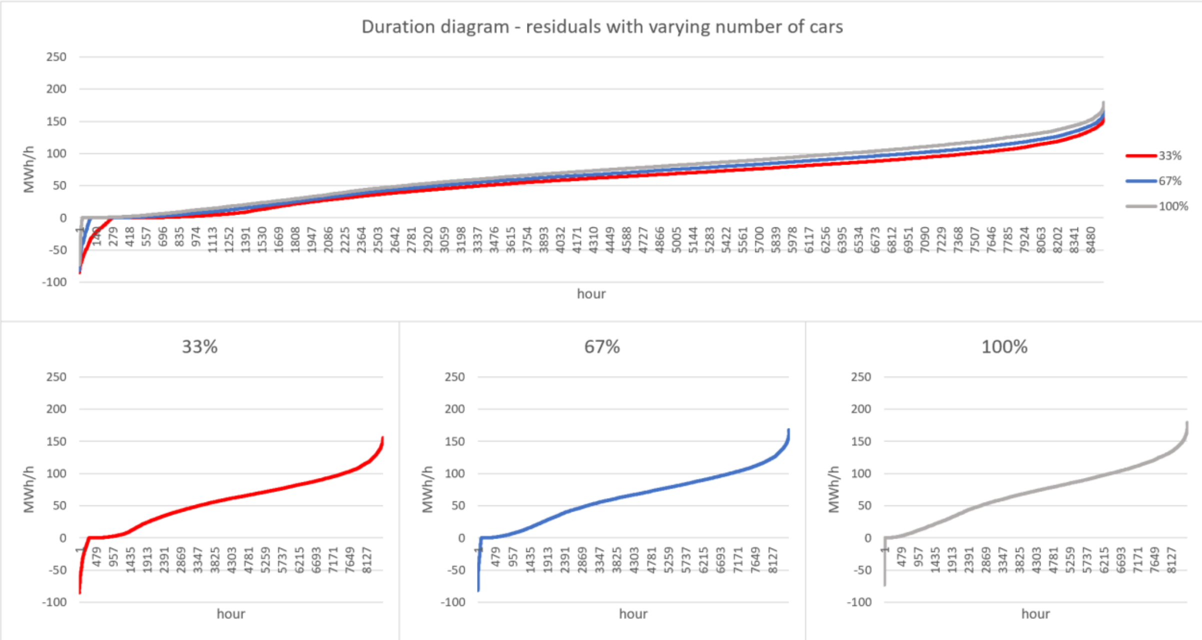


Figure A20: Residuals for the SC scenario with shares of 33, 67 and 100 % of electric cars in the V2G system.

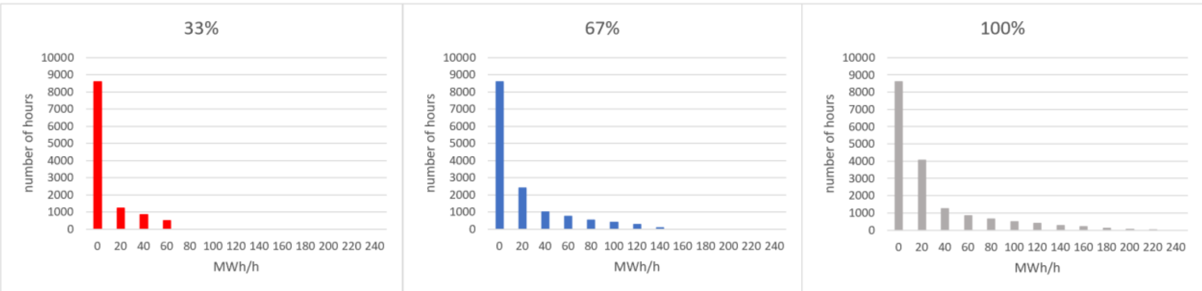


Figure A21: Hours above specified dischargeable capacity for the V2G scenario with shares of 33, 67 and 100 % of electric cars in the V2G system.

Table A15: The capacity available for charging during 95 and 99 % of time for the SC scenario with 33, 67 and 100% of the original number of cars in the system.

Percentage of time for specified capacity	**33 %** (MWh/h)	**67 %** (MWh/h)	**100 %** (MWh/h)
95	51	119	183
99	5	30	122

The goal of Region Gotland

The number of electric cars in the SC and V2G system was altered to 33, 67 % and compared to the original usage of 100 %. Below are the residuals in a duration diagram (figure A22) and a table showing the capacities over which the cars where chargeable during 95 and 99 % of the time (table A16) for the SC scenario.

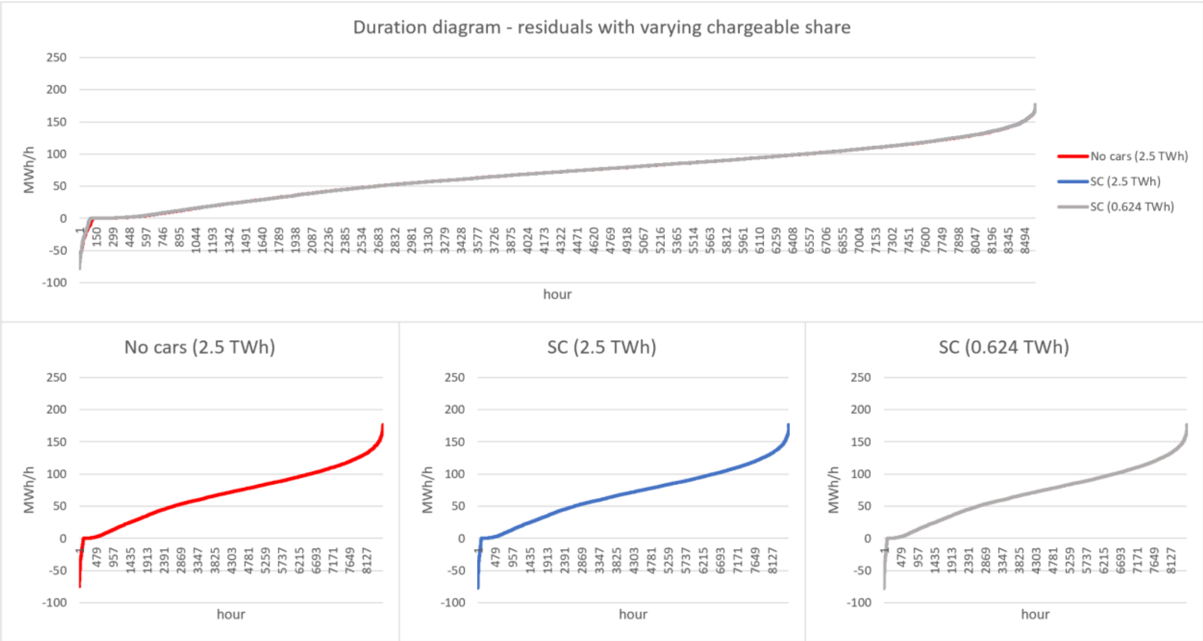


Figure A22: Residuals for the no EVs and 2.5 TWh production, SC and 2.5 TWh production and SC and 0.624 TWh production scenarios.

Table A16: The capacity available for charging during 95 and 99 % of time for the no EVs and 2.5 TWh production, SC and 2.5 TWh production and SC and 0.624 TWh production scenarios.

Percentage of time for specified capacity	**No EVs (2.5 TWh)** (MWh/h)	**SC (2.5 TWh)** (MWh/h)	**SC (0.624 TWh)** (MWh/h)
95	0	<1	138
99	0	<1	36

Below are the residuals in a duration diagram (figure A23) a table showing the chargeable capacities for the no EVs and 2.5 TWh production, V2G and 2.5 TWh production and V2G and 0.624 TWh production scenarios can perform during 95 and 99 % of the simulated year (table A17).

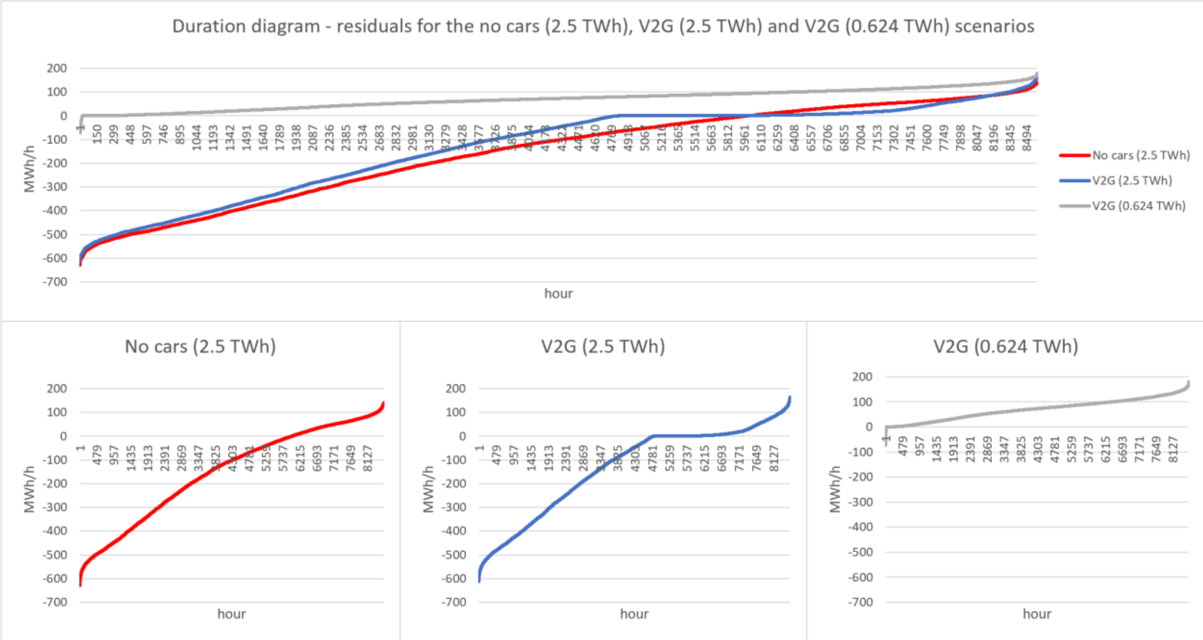


Figure A23: Residuals for the no EVs and 2.5 TWh production, V2G and 2.5 TWh production and V2G and 0.624 TWh production scenarios.

Table A17: The capacity available for charging during 95 and 99 % of time for the no EVs and 2.5 TWh production, V2G and 2.5 TWh production and V2G and 0.624 TWh production scenarios.

Percentage of time for specified capacity	**No EVs (2.5 TWh)** (MWh/h)	**V2G (2.5 TWh)** (MWh/h)	**V2G (0.624 TWh)** (MWh/h)
95	0	1	183
99	0	<1	122

A2. The Literature Study

Here, a brief summary of all the publications included in the literature study is provided.

A2.1 Concerns and driving forces in a smart charging or V2G system

Not all barriers are technical and a large penetration of a smart charging- or V2G-system requires participation of private owners and organisations. To achieve large rates of participation, a wide and diverse group of vehicle owners will have to be involved. Therefore, driving forces and concerns of potential participants have to be understood and addressed; this will be the focus of this chapter. Among the nine studies included and summarised below, there will mainly be surveys and interviews with vehicle owners that are the potential smart charging or V2G system participants of the future.

Anticipating PEV buyers' acceptance of utility-controlled charging

In the first study, the attitude towards a variation of nightly charging programs is investigated in a scenario where a utility company control the home charging of PHEVs and BEVs. Using a web-based survey, the authors have collected responses from 1470 new vehicle owners in Canada. The experiment has included stated choice questions, mapping the openness and attitude to different versions of charging programs (Baily & Axsen 2015).

Four different subgroups were identified: charge-focused (33 %), cost-motivated (27 %), Anti (proposed) charging programmes (21 %) and renewables-focused (19 %). Of those interested in buying a Plug-in electric vehicle, half of the respondents to two thirds were interested in participating in a charging program as suggested to them. Cost-incentives driven programs were found to be most interesting in the eyes of participants with 63-78 % being interested in such systems with renewable-incentives driven programs coming in second, interesting 49-59 % of participants.

Despite this, 53 % state that they would voluntarily participate – with no economic return. In addition, respondents were prepared to pay an additional $16/year for charging with 10 % more renewable energy. Notably, young, environmentally concerned and more educated participants were more willing to adopt the programmes.

Similar to using a guaranteed minimum range, the authors used the concept of guaranteed minimum charge (GMC) to evaluate the participants sensitivity to not having a full battery in the morning. The result showed that 96 % would allow the battery to be at 90 % SOC in the morning one day per week and 43 % would allow this SOC five times a week. A lower SOC of 50 % was only accepted by 68 % during any day. Using a vehicle battery level of 84 km worth of charge during the end of the day, participants considering pure EVs were on average willing to pay $59/year for an increase of 10 km range during the night. Regarding concerns, the authors find that 24 % of respondents are worried about invasion of privacy and 39 % felt that the charging programmes would ‘‘take control away from me in a way that I would not like” (hereby referred to as perceived loss of control).

The sample were assumed to have almost no prior knowledge on EVs. Hence, an initial part of the survey included explaining relevant parts of the technology and what usage of the vehicles would mean to the participants. The survey-takers are slightly older, more educated, and more likely to own a home than the general public, however, they are found representative of new vehicle owners in the English-speaking parts of Canada. The participants were granted $20 gift cards if they participated in the study and had a chance of winning an additional $500.

Confusion of innovations: Mainstream consumer perceptions and misperceptions of electric-drive vehicles and charging programs in Canada

Examining knowledge, confusion and preferences of potential buyers regarding PHEVs, BEVs, HEVs (Hybrid Electric Vehicles) and users of utility-controlled charging is important to highlight barriers and challenges for adoption of the technologies. These subjects have been studied using semi-structured interviews with 22 new-vehicle buying households in Canada (Axsen, Langman & Goldberg 2017).

A first apparent result was the low level of awareness of the vehicle types and utility-controlled charging. Respondents were confused about differences between hybrid and plug-in hybrid technology and did not understand the power sources usable for EVs well. Once the technologies were explained, the interviewees had negative and positive perceptions that where divided on three categories by the authors: perceived functional, symbolic and societal attributes. While functional attributes concern operating cost and driving range, in some sense practical issues, symbolic attributes concern the message that the technology convey and societal attributes what the technology can do for society.

None of the participants had personal experience with any plug-in electric vehicles, although some had been passengers or drivers in HEVs. Concerns perceived by participants included limitation in range, charging, operating costs, novelty of the technologies and environmental impacts. Confusion persisted when addressing the understanding of the electricity system in the part of Canada subjected to study. Most households (20 of 22), displayed only a basic knowledge of the system, specifically believing that all of the electricity came from hydropower when some of it in fact originated from fossil fuelled sources. While some participants found wind and solar to be environmentally friendly or natural, there were also concerns on the environmental impacts from solar panels during their lifecycle and wind turbines' effect on wild life and noise level.

Concerning utility-controlled charging, none of the interviewees had any prior knowledge and in 14 of 22 interviews the households found it difficult to grasp the concept. In particular, it was hard to understand how renewable energy integration could be facilitated by energy storage and even more so how altering the time of charging could aid the cause. Only one person expressed worries on the effect on batteries that the inclusion of V2G technology could have. More widespread was the concern of loss of control, with seven of the nine interviews encountering this perception specifically being related to distrust of the utility company. The motivation was mainly that they could not know if they were really charging with renewable energy and not fossil based.

A sample of households were selected that had bought a new vehicle within the last five years and had a parking space at home. The idea being that a home-parking would help conceptualising home charging. There were 17 men and 14 women and deviation from general public was found in the sample in it being slightly older, having somewhat higher income and on average having a higher level of education.

Evaluation of Economic, environmental, regulatory and social aspects, WP 3

This study has a wide range of targets and here focus will be on one of them: "the acceptance of delayed (off-peak) charging schemes and vehicle-to-grid services among potential EV-users". To gather information on this, the authors performed a multichoice online survey. The survey was available in English, German, French, Spanish, Italian, Dutch, Swedish and Portuguese, aiming to gain understanding of the wider European attitude towards the technologies (Bunzeck, Feenstra & Paukovic 2011).

The survey-takers were found to be interested in participating in a smart charging system. The total average on a scale from one (not at all interested) to seven (very interested) were 5.74. This result differed between the countries, with UK respondents averaging 6.09 making it the country with highest level of acceptance while respondents in Spain had the lowest average of 5.6. The Swedish sample averaged 5.94. The respondents were offered the possibility of charging to a given lowest SOC without delay before participating of 40, 80, 120 km, with corresponding costs of an extra 2, 2.5 and 3 euros respectively. It was found that the three option were roughly equal in popularity. The Swedish sample had the largest share preferring the first option, however, the reason behind this was not elaborated on in the study.

The most prevalent reason for not being willing to participate in a smart charging system was concerns on not being able to use the car for sudden unplanned trips, in for example an emergency. This was mentioned as primary concern by roughly 50 % of respondents. Other issues specified were the dislike of utility control, uncertainty regarding battery effects, insufficient economic gain, distrust in that the car would be charged on time and a general wish for the car to be charged without delay. None was the major concern to more than 15 % of participants by itself.

The willingness to participate in a V2G system was somewhat lower, averaging 4.38 on the same 1-7 scale as earlier mentioned, with the highest scores found in UK and Portugal. The main reason for not being interested were the economical revenues obtainable being too low (claimed by 45 % of survey-takers). Related to the result, the authors found that a higher level of compensation can increase willingness to participate. When presented with the opportunity to gain an annual check of €20, over 20 % of those that did not want to participate initially where willing, in most countries (not in Sweden and the Netherlands). When the rate of compensation was increased to €60, the corresponding share was 40 % in all countries. The report also shows some support for the interest in participation being larger with a leased battery.

Other reasons for not participating were dislike of utility control (16 %), uncertain battery effects (13%), distrust in that the car would be charged on time (13%), a general wish for the car to be charged without delay (8%) and other (5%).

Some of the limitations in the study are worth mentioning. The survey was distributed via family members, social networks, blogs, news articles and company webpages. The risk of creating bias as this type of media only reaches out to certain people is described by the authors. Recognised is also the risk that those interested in EVs will answer the survey to a greater extent and the authors did not test respondents regarding prior level of knowledge. Some information, however, were provided to the respondents along with the survey. Information such as general information on electric cars, charging, their capacity and the types of charging available. The way this information was given could have created biases as well. Finally, a limitation also resides in the limited number of responses, especially in France and the UK where less than 100 responses where collected, se table A18.

Table A18: number of survey takers per country.

Country	Respondents
France	78
Germany	148
Netherlands	216
Italy	181
Portugal	489
Spain	422
Sweden	311
UK	54
Total	1899

Characterising the sample, it was young (66 % below 45 years of age), mostly male (76%) mostly living in city areas with over 100 000 individuals (In the case of Sweden and the UK more than 40 % lived in cities with more than 500 000 individuals).

Is there a near-term market for vehicle-to-grid electric vehicles?

Just as the name implies authors Hirdue and Parson studied the potential of a near time market for V2G. This was done with an internet-based survey to 3029 car buyers in the US. They compare consumer willingness to pay for V2G-EVs (EVs that are V2G capable) for different cost of batteries and try to capture the cost of inconvenience in using the technology. An annual pay rate is granted, differing in size depending on the number of hours the responders can imagine suppling their vehicle capacity to the system. The study belongs to a series of studies including *Willingness to Pay for Vehicle-to-Grid (V2G) Electric Vehicles and their Contract Terms*, also found in this literature study (K. Hirdue & R. Parson 2015).

The findings include that willingness to pay is insufficient for implementing the system in an economically efficient way due to range anxiety, strictness of contract in addition to the costs of the technical system. In favour of V2G, there are an increased willingness to pay due to the joint value of environmental benefits and most importantly the reduced cost of fuel. Notable is that the data serving as basis for the study was collected 2009 and the lowest price of battery, projected for 2018, was $312.9/kWh. The Union of Concerned Scientists (2017) report on the price 2017 being $205/kWh and still decreasing.

There is also a mechanism implemented too adjust for the tendency of those willing to support the V2G-technology saying yes to a prosed agreement, which they would not accept in reality. Half of the sample gets the opportunity the check the box "'I like the idea of V2G–EVs … but not at these prices...". It is shown that the subgroup with this option is less willing to accept the proposed conditions, indicating that such tendency indeed exists.

The respondents are, according to the authors, representative of US households. Slightly underrepresented are male and low-educated households. The survey includes no government subsidies nor rebates, and the contract proposed to respondents include an agreed plug-in time of 20 hours per day, 25 miles (40 km) as minimum range and an annual payback of $4000.

As this study is part of a series using the same sample and there are two studies from this series in this literature study, concerns and driving forces will only be considered when these are unique for the whole series. Onwards, the driving force represented by potential financial benefits are not explicitly mention but interpreted from there being a price for which the participants are interested to participate.

The challenge of time shifting energy demand practices: Insights from Denmark

Based on an experiment including actual participants this study explores "temporal flexibility of Danish households' electricity consumption through their participation in two smart grid projects". The two projects consist of a longer project during multiple years were participants had dynamic tariffs and an overlapping shorter project were some where lent an electric car for a five-month period. Experience is collected from semi structured interviews with 18 individuals living in detached houses in Southern Jutland, Denmark, combined with analysing recorded electricity load from 159 (overlapping) households. Characterising the sample, individuals are living in middle-sized cities in an economically declining part of Denmark. The houses had a garden as well as a garage (Friis & Haunstrup Christensen 2016).

The design of the tariffs consists of a static profile were a fixed price is payed during a part of the day. Between 0.00-6.00 the price is 0.4-euro cents/ kWh while the price during peak hours 14.00 -20.00 is ten times as high (4 euro cents/ kWh). Due to a large part of the energy prices in Denmark being taxes, the actual difference to be payed is 15 %. Apart from the price differing with the tariffs, it also did so in accordance with the spot price on Nord Pool Spot market. This did not alter behaviours as it was perceived to be complicated and the impact from this mechanism was left out from the study result.

There were no significant signs of any long-term effect in shifted consumption to hours with lower prices distinguishable from analysing the load data. However, some sign of shifting could be observed, and interviewees expressed ability to change the time of dishwashing, laundering and EV charging as more achievable. While altering their routine regarding the first two carried some inconvenience, altering the EV charging time was perceived as most manageable. It was during the five months of EV use that the tariffs seem to have altered behaviour of participants to the largest extent. The reason for the perceived difficulties came from the inconveniences in altering time of carrying out everyday-life activities when already under large time constrains.

Understanding user acceptance factors of electric vehicle smart charging

In this study authors Will & Schuller (2016) consider the overrepresentation of technical studies in exploring the smart charging possibilities. To do their part in shifting this overweight, they instead focus on the main study question: "How do users perceive control interventions in their charging behaviour and what are the main factors driving the acceptance of smart charging programs?". Using a survey answered by 237 early EV-adopters in Germany they try to find connections between a set of parameters hypothesised to have a positive or negative effect on the acceptance of a SC system (Will & Schuller 2016).

In general, the survey takers demand high rebates, with an average of 20 % deducted from two price components: the variable kWh price as well as the base price on their electricity bill. Most of the participants demand this discount, however, there is a significant subgroup making no such claims. As a result, the authors find that there is no significant correlation between demanded reduction in base price or in reduction of kWh-price for acceptance of a smart charging system. However, it is argued that there is a risk that the compensation offered was too low for survey takers, either to compensate for their loss in flexibility or to matter at all in their decision. An important message recovered from their findings are: "… not to focus only on the potential economic advantages of a smart charging program but also to address other factors.".

The most common expectations on a smart-charging system was found to be:

- Allowing for a customized minimum range (77 % of survey takers). Average requested minimum range of 70 km and median of 50 km.
- Having the option of charging on demand overriding the optimal charging cycle of the system (76%).
- Including the option to submit a time of departure (71 %), supposedly adjusted for by the system.
- Assigning a threshold above which no more charging is needed (60 %).
- An option of gentle charging for better battery life (56 %).
- A variation of range around their arrival (37%).

The study examined the link to acceptance of the smart charging system provided by 13 different parameters. Of these, only the potential benefit of increased grid stability, renewable energy integration and a need for a flexible mobility option had a more significant correlation. A weaker, but noteworthy, link existed to customization on the layout of participation as well.

Notable is that there are more participants reporting on the proposed system being useful than satisfactory which according to the authors conclude: "that smart charging is indeed seen as a valid concept but so far lack optimal implementation". Finally, the authors note that there is a need for expanding this type of study to include the general public and sampling outside the borders of Germany.

Regarding the sample, the reason for choosing a group consisting of EV-adopters was that the inclusion of a more general sample would result in the need of explaining the concept, risking creating biases. The EV-adopters constituting the sample include individuals belonging to EV-associations and subscribers to EV-newsletters. Other relevant characteristics of the sample is given in table A19 below.

Table A19: Parameters characterizing individuals taking the survey.

Characteristic	Share (%)
Non-female	90
Between ages 26-35, 26-55	33, 76
Full time workers:	76
University degree	79
Owning EV, driven EV	41, 26

User responses to a smart charging system in Germany: Battery electric vehicle driver motivation, attitudes and acceptance
A field study was performed where ten private EV users tried smart charging and regular charging during a five-month trial. With interviews and questionnaires, the motivation, attitudes and willingness to participate in the charging strategy was evaluated before and after the trial. It was also examined how participants integrated smart charging into their life and how they experienced it (Schmalfuß et al 2015).

Rather than having economic benefits as main motivation, participants were motivated by feeling they did something good for the environment. Specifically, the order of relevance for the examined driving forces were: helping the environment followed by assisting grid stability, increased integration of renewable energy and then financial benefits. Furthermore, based on the study results the authors argue that there is an importance of getting feedback on made contribution to the environment and society from system participation.

Regarding concerns, loss of flexibility was found to be a perceived disadvantage, mainly resulting in the need of planning ahead but also resulting in loss of spontaneity more specifically. Other concerns were on data privacy and distrust of technological features within the SC system as some participants were unsure whether the settings they made had been successfully implemented by the system.

The group did not overall represent German car drivers, however, they offered a sample alike that of similar studies. Therefore the study authors argue that the included participants mainly consisting of highly educated middle-aged males able to charge at home would be representative of the relevant target group.

The participants applied themselves, potentially creating a bias. However, testing a smart charging system was found to only be the third most common motivation for participation with driving the new car model ActiveE, topping the list and only six of them had prior knowledge on EVs.

Willing to Participate in vehicle-to-grid (V2G)? Why not!
The ambition of Geske & Schumann (2018) is, as the title suggest, to explore what determines the willingness to participate in a V2G system. The study relies on online-surveys where EV owners and individuals interested in buying electric cars as their next vehicle state their preferences based on a set number of choices and include a sample of 611 participants in Germany. The authors offered participator contracts with a minimum plug-in time of 0, 5, 7, 10 or 14 hours of the day during 3, 4 or 5 days a week. Instead of directly asking whether the respondents wanted to participate in the system, they were offered different levels of revenue. These included, a one-time payment of €1000, 3000, 5000 or 7000 and a monthly revenue of €15, 30, 45 or 60 (Geske & Schumann 2018).

Acceptance for uncontrolled charging was the largest, however, smart charging and bidirectional charging was accepted to a significant degree as well. The most important advantages seen by respondents were, listed in descending order of importance with the first two equal in popularity, reducing cost of necessary future electricity storage, increasing renewable energy used in EVs and supporting Energiewende. Energiewende is the transformation of the German energy system (Federal Foreign Office of Germany n.d.) (Federal Foreign Office of Germany, n.d.). In addition to these, advantages were: profit from energy arbitrage, emergency power backup, supporting decentral energy storage, potentially outcompeting reserve power plants and the technology aiding to avoid (partial) grid expansion. All options were presented to the respondents by the authors.

The concerns expressed were, in order of descending importance: negative effects on battery, insufficient energy for unplanned trips, another actor controlling the charging, concern that the battery would not be sufficiently charged when starting a trip, mobility restriction, data privacy issues and the system being too complicated.

The most popular forms of economic incentives for participants was, again in descending order: cheaper charging, price reduction of EV, receiving a charging station and annual bonus payments. Significantly less interesting to the participants were privileges such as V2G-system participants being allowed to travel in bus lanes, free parking and similar.

Notable is that the standard deviations specified in the study are large enough for the real order of the advantages, concerns and economic incentives possibly being different in reality. In order to establish a reliable result, the authors have compiled the most important determinants:

1. Concern that the battery would not be sufficiently charged.
2. Consenting to the myth of nature as capricious decreases willingness to participate.

   Seeing nature as capricious means believing that no matter what we do, the environment will change in unpredictable ways, for better or for worse. Therefore, it does not matter how we, as humans, act.
3. Concerns of constrains from system participation – in freedom and independence.
4. Supporting the decentralization of electricity storage
5. partial avoidance of an electricity grid expansion
6. Current main occupation. It could be seen that students on average are more interested in participation than part time employees.

Among the findings are also that knowledge about the technology increases willingness to participate in a V2G-system. Therefore, the authors point to an information campaign as a way if increasing willingness to participate. The authors also find that economic compensation is unlikely to have a large effect on increasing the willingness to participate in the system, especially for the long-time and frequent vehicle users.

Willingness to Pay for Vehicle-to-Grid (V2G) Electric Vehicles and Their Contract Terms

In the study, the authors examine whether vehicle users will embrace the idea of selling power to the energy sector, what price they will demand and if a V2G systems could help facilitating introduction of EVs on the market. The study contains a web-based survey, aimed at US households with 3029 participants and is a part of a series of studies also including the earlier described study “Is there a near-term market for vehicle-to-grid”. Contracts tested required plug-in time (RPT) of corresponding 10,15 or 20 hours per day and a guaranteed minimum range (GMR) of magnitude 40, 120 or 200 km (R. Parson et al 2014).

Respondents are found to be sensitive to restrictions associated with the proposed V2G system. This sensitivity is also quantified in economic terms, where the option of a higher RPT or a lower GMR is compared to the negative effect it has on customer willingness to pay for a V2G EV. From this, the authors find that the difference between using a maximum or minimum GMR and RPT is in the order of thousands of USDs (Table A20 below). The effects are amplified further when a high RPT is combined with a low GMR and reaching a worst case of 16 628 $.

Table A20: equivalent negative effect on price when buying a vehicle, caused by decreasing GMR and increasing RPT.

GMR (km)	Value ($)	RPT (hours)	Value ($)
200 to 120	497	5 to 10	1411
120 to 40	4020	10 to 15	4454
200 to 40	8438	15 to 20	8504

The authors find two main types of participants: one that is more optimistic towards EVs and one that prefers the gasoline equivalent (GV). While both groups significantly discount the return given on an annual basis, the EV-friendly group, does it less. As a share this means a discount rate of 41 % for the EV-group and a corresponding 56 % for the GV-group. While these are high discount rates, even in the context of energy savings where rates generally are high, it may have to do with the unfamiliarity of the V2G technology. High rates echo the perceived high risk of making an investment in an V2G compatible EV.

Parson et al present two different types of contracts that are good interpretations of the vehicle owners requests. The use of contracts is, according to the them, the main focus of the potential economic compensation for V2G participation in research. The reason for it is the higher reliability it presents for EVs as power sources.

The first contract includes a GMR of 120 km and an RPT of 5 hours, calculated by the authors to require a one-time payment of 2368 $ (contract A). The second contract includes a GMR of 40 km and an RPT of 20 hours, this in turn would require the one-time payment of 8622 $ (contract H). The reason for the authors only including GMRs of 40 and 120 km is that a higher GMR would be to limiting as many EVs have a maximum range of 240 km or similar today.

The H contract is compared to the possible revenues achievable by a Toyota RAV4 EV, as estimated by Kempton & Tomić (2005) by the authors. Using a GMR of 32 km and a RPT of 18 hours, the obtainable revenue is found to be 2554 $, far from the 8622 $ required to get participants on board. This estimated revenue of course rely on assumptions of the value of power in a certain context.

Onwards, it is found that when designing contracts the use of a one-time payment can reduce the heavy effect from discounting made by participants. Seeing, however that the contract-approach is linked to high costs for participation in general, the authors find the pay-as-you-go approach to be an option. A solution where cars in the system can be connected and disconnected without prior warning, however, only earning money when plugged-in. The possibility of using a hybrid system is also considered, were contracts are applied for those preferring that option and a pay-as-you-go solution for others.

As this study is part of a series using the same sample and there are more than one study from this series in this literature study, concerns and driving forces will only be considered when these are unique for the whole series.

A2.2 Economic incentives and conditions of participation

Examining studies on suggested, mentioned and for modelling purposes used economic incentives and modes of participation provide a glance into which mechanisms that will be realised in future smart charging or V2G systems. By being one step ahead and analysing these before implementation, hopefully a functional and user-appealing version can be determined before an attempt is made to introduce a poorly fitted system. Below follows a summary of fourteen articles that concern economic incentives and modes of participation for SC and V2G systems specifically or consider surrounding topics forcing the authors to define such mechanisms.

As the study "Willingness to Pay for Vehicle-to-Grid (V2G) Electric Vehicles and Their Contract Terms" contains a large sample of persons expressing their attitude towards V2G it is included in the former chapter. However, due to its focus on economic incentives, the findings made are included in this part of the analysis as well.

A Regulation Policy of EV Discharging Price for Demand Scheduling

The aim of this paper is to provide a "… new V2G pricing policy by incorporating the system load condition, maximum power limit, and price rate for user load in a fair manner". The mechanism is intended to maximize the operator's economic benefit while it balances the bill and comfort level of participants (Mao, Shum & Tsang 2018).

Central to the model is the separation of a V2G power price component and a load price component. The latter is priced based on if it is home load only, home load with EV charging, and home load with vehicle-to-home (the EV can support the household with power). By determining the prices for the two components and offering updated prices on regular time intervals (i.e on an hourly basis) the utility company leads the market while customers receive price-signals telling them the momentary cost of energy. The customers respond if they are willing to buy the electricity at the current price and this information is transmitted to the utility company. Based on this, the company can send out new prices for the customers to respond to and the process is repeated until a condition of convergence is met, negotiating a price.

In this way, the authors argue that the utility company can base their price signal on how to get maximum profit and leave the customers to choose the price or comfort-level that they prefer and to contribute with V2G services under desired conditions. The authors also argue that only aggregated user load and V2G capacity is needed, therefore customer privacy can be protected. For the management of the negotiation it is assumed that the customers have Home Energy Management Systems (HEMS) and that some of their load is flexible.

Agent Based Bidding Architecture in Electricity Markets for EVs as V2G and G2V

In this article, the authors propose "… a simple bidding algorithm for energy market for EV's participation in V2G and G2V." The case is specified to EV-possibility in aiding the short-term management of power imbalances. A set of intelligent computational agents are used to determine the need of EVs as a source of or sink for power. The vehicles are determined able to participate if connected to the grid, having at lowest 10 % SoC in addition to enough remaining capacity for completing the next trip and at highest 90 % SoC (H. Malik & Lehtonen 2016).

When the EV services available have been established, an economic compensation is proposed per kWh. From those who accept, the EVs with the largest possible capacity for aiding in balancing power will be used for the next time period. These used vehicles will have their owner awarded economic return for the provided service. For further technical specifications of this system, the reader is referred to the original article.

Additional terms of participation are not specified in the article. Presumably, the authors are anticipating the system to be employed in a way allowing participants to connect or disconnect on short notice, given that the vehicles are required to keep enough energy in the battery for the next trip at any given time.

Analyzing the Effect of Various PEV Owner's Charging Tariffs on PEV PL's Market Equilibrium

This paper considers a parking lot with EVs and an actor that aggregates their capacity together with other sources and sinks for power (i.e heat pumps, washing machines etc), to act on the reserve and energy market. The EVs are given different tariff-rates depending on chosen mode for participation, chosen by the EV owner at arrival. The cumulative effect of the parking lot on the electricity market is examined. The parking lot is assumed to be used during work hours and contain 250 charging stations (Neyestani, Yazdani Damavandi & P. S. Catalão 2015).

The way the authors suggest that the EV owners' preferences are considered is by allowing four separate modes of participation. Firstly, it is possible for the EV-owners to choose between mono- and bidirectional charging. Secondly, participants choose either a fixed SoC for a planned time of departure or allow the final SoC to vary not knowing on beforehand what it will be upon departure. By combining the two sets of choices, four modes of participation are possible. The owners will be awarded different levels of compensation dependent on the value of their chosen mode of participation, in terms of what it can do for the energy and power markets. Regardless of their choice, the cars are not allowed to discharge below 30 % of SoC.

Vehicle owners are anticipating their departure time and although not entirely clarified in the article, it seems that vehicle owners are allowed to disconnect on demand. One indication for this is the use of a parameter, β, to account for departures in the mathematical model for evaluating capacity. This will of course affect the system ability to get the EV batteries to a specified SoC before their departure.

Can parked cars and carbon taxes create a profit? The economics of vehicle-to-grid energy storage for peak reduction

As put by the authors: "this article discusses a five-year, hourly economic model of vehicle-to-grid energy storage for peak reduction". The economic model involves compensating the vehicle owners for participation by using three modes of participation. The effect of a carbon tax is also examined for the scenarios (M. Freeman, E. Drennen, & D. White, 2017).

The selling and buying price of electricity is set by the local marginal price of electricity on an hourly basis (location-based marginal pricing, LBMP). Participants can communicate their commuting distance, beginning time of workday, workday length and in the final mode to what price they are willing to sell electricity. It seems to be the idea of the authors that the system will be applied during routine work days. The suggested modes of participation are:

1. Work-hour price-taker – The participants will charge at home during off-peak hours and discharge during the day, at work, when the grid-operator deems a need for electricity.

2. Arbitrage-guided – The battery is filled during off peak hours and the energy is sold when the LBMP is higher than the cost from charging, plus the cost associated with battery degradation and the round-trip-losses made when storing energy in the battery.

3. User-defined selling price – Significant similarities to (2), however, the user can choose the price to which the electricity is sold.

The carbon tax is simply added to these different modes. The authors do not consider the emissions made at the time of charging/discharging. Instead it is based on the energy displaced by EVs from the V2G service. Less displaced energy means more energy produced by fossil-based sources in the system and therefore a higher carbon tax.

The user-defined selling price is found to give the largest economical gain, with or without carbon tax if the optimal price for selling and buying electricity is used. The work-hour price taker V2G scenario generate a great cost over time due to battery degradation, however, its roughly six times as many cycles potentially allows for more peak managing during the use period. This likely has implication for the obtained renewable energy integration, grid stability services and other objectives traceable to the driving forces of potential participants. It is not specified whether vehicle owners are allowed to connect or disconnect upon demand. Neither is there a specified lowest SoC.

Economic Motivation for Electric Vehicles Participation in Power Market
In this study economic motivation for V2G participation is analysed in a Latvian context. It is stated by the authors that there already today exists an intraday differentiated price tariff for electricity. It is suggested that this is used to encourage V2G participation. The current tariff system includes one price level for workdays between 07:00 and 23:00 of 0.156 €/kWh and another for the remaining time of the week of 0,118 €/kWh (Grackova & Oleinikova, 2014).

Electricity market policies for penalizing volatility and scheduling strategies: The value of aggregation, flexibility, and correlation
The authors examine how small-scale prosumers (actors both consuming and producing) can add their capacity in order to be able to participate in the wholesale market via a "Virtual Microgrids Associations" (VMA). Participation is made on the day-ahead market and balancing market (Tsaousoglou, Makris & Varvarigos 2017).

The VMAs have agreements specifying capacity from production and flexibility submitted by prosumers. The collected capacity is used to create agreements with the energy market operators, a procedure that is repeated daily on the day-ahead market, hour by hour. When the day-ahead market closes and the hour of delivering or consuming electricity approaches, new forecasts are made, with improved accuracy they are closer in time. The prosumers have a chance to use their uncommitted capacity to make up for inaccuracies in the initial forecast and can make profit this way, however, with a lower achievable revenue. The lower revenue is a feature built in to the system as a sort of penalty for poor planning, ensuring the energy market operator that the prosumers will try to stick to the original agreement and make good forecasts.

A mechanism is also included to ensure that prosumers that do not cooperate with the VMA will be individually penalised, rather than the full impact hitting the association. This is a way of protecting the opportunity to make profit for the other participants.

Encouraging Vehicle-to-Grid participation through premium tariff rates
In this study, Richardson has gathered inspiration from the Canadian feed-in-tariff system where different levels of compensation is given based on which source of power production that are used. The services provided by the vehicles in the system include peak power, operating reserves and regulation (B. Richardson, 2013).

Compensation in the feed-in-tariff system is paid per MWh of electricity fed into the grid. Examples given in the study are: 104 $/MWh for large biogas installations and 802 $/MWh for production with small rooftop solar. The rate of return suggested for participator in the V2G system from these tariffs is 11 %. This is the same rate of return that is granted by the feed-in-tariffs of other renewable power sources. Worth mentioning are also an assumed lowest allowed SOC arising from discharging onto the grid and that all cars are to be fully charge at 6 am each morning.

Estimation of Achievable Power Capacity from Plug-in Electric Vehicles for V2G Frequency Regulation: Case Studies for Market Participation
The main objective of this paper is to suggest a method for estimating achievable power capacity (APC) obtainable by a V2G aggregator. The focus also lay in the interaction between aggregator and grid operator and not the relation between vehicle owners and aggregator. This result in the more part of the article being out of scope for this thesis. However, there will be no aggregation of V2G capacity without vehicles and a form of contract is suggested in the study to couple participants to aggregators (Han, Han & Sezaki 2011).

The contract does not bind the vehicle owners to being plugged-in at certain times of days, at a certain number of hours or impose any reoccurring restrictions in a similar way. It does, however, obligate participants to submit information on when their next departure or their regular pattern of transport. In this way the aggregator knows until when the source or sink of power, represented by the plugged-in vehicle, will be available for them to use. The idea is that during that time the aggregator will control the charging and discharging of the EV.

The article contains no specification on the form and size of economic compensation for the participation. It is also not clear at which SOC the vehicle will be left at when the plug-in session is over.

Extended Second Price Auctions with Elastic Supply for PEV Charging in the Smart Grid
In the article, two second price auction methods for EV owners are presented, for a smart charging system. These are simplified derivatives from the Vickrey-Clark-Groves (VCG) mechanism, a mechanism used to optimise social gain in terms of use of resource by using the valuation function of the participants (Bhattacharya et al 2016).

In VCG the optimisation is made from the value of energy that can be provided and subtracting the cost of supply and by recognising the charging and energy availability constraints of the distribution grid. The value of energy is determined from the valuation function of the EV owners. Unfortunately, these functions are likely not known in full by EV owners. In addition, the functions are complex, hard to communicate and changing over time. This is why the authors try to develop a new mechanism.

From the participator point of view, the mechanism is likely quite similar. They are auction mechanisms with a considerable complexity used to optimise societal gain from the system. To simplify interaction, the authors suggest the use of smart meters doing the bidding. The first mechanism is called the elastic-supply multi-level second price and starts with there being a number of bids on certain set energy levels or quantities. The second mechanism is called the elastic-supply progressive second price. Here the bid includes both an energy quantity and a suggestion of a price to which this energy is to be bought. If the participants win the bid, they are supplied with the electricity for the bidding price. For specific details the reader is referred to the original study.

Group Bidding for Guaranteed Quality of Energy in V2G Smart Grid Networks
In this article the authors propose "… a two-level group bidding mechanism for the electric energy trade between the grid and EVs". The authors also describe the mechanism as "a quantity based feedback electricity unit pricing scheme …" and are using the VCG mechanism for implementation. The mechanism is designed to minimise cost from the grid and to maximise the profit of EV owners (Zeng et al 2015).

The two levels refer to there initially being an aggregator collecting bids from EV owners who are selling their capacity for usage in the V2G system. In and second step the aggregator sell the accumulated capacity to the utility company or grid operator. The two levels result in two processes of selection: first the aggregators chose which EVs to include in their offer to the utility company, then the utility company choses which aggregators to include. The bids made by the EVs are based on an initial demand expressed by the grid operator/ utility company. This demand is in turn based on the forecast for the next period of time in combination with the historic power demand.

Proactive Demand Participation of Heterogeneous Flexible Loads in Smart Grid
In their paper, the authors present a "proactive demand response scheme" to make the most of the flexibilities presented in households, including charging as a flexibility. In the households an intelligent agent continuously estimates the flexible resources available and creates a demand curve for the

included resources that express to which price the customer is willing to buy electricity for their different flexible resources (Wei & Zhu 2015).

The curves are forwarded to the distribution system operator who aggregates the resources per substation. The wholesale market operators (WMOs) receive this information and determine the price to be paid. In addition to sending back the price-information, the WMOs include which flexibilities to be utilised.

Promoting vehicle-to-grid (v2g) in the Nordic region: Expert advice on policy mechanisms for accelerated diffusion

In this study, Kester et al (2018) have made 227 interviews with 257 electromobility experts in the Nordic region, from 201 different institutions and 17 cities involving car industry, electricity sector, academia and government. The target of the study is to "identify and prioritise the list of policies that would best address the barriers facing V2G". As this thesis is focused on economic incentives and their implications, many of these policy suggestions will be omitted from the literature study (Kester et al 2018).

The authors identify five main types of policy advice from the interviews: the restructuring of the electricity market, innovation and R&D, information and awareness, other policy advice and determinism and momentum. Many off the suggestions do not have a clear relation to economic incentives for vehicle owners and therefore they will not be considered here. Relevant policies are:

1. Avoiding double taxation - Transmitted power is subject for taxation both when bought from the grid (to be stored in the vehicle battery) and on the way back out to the grid. This tax may be misplaced as electricity are only temporarily kept in the vehicle battery and not intended for consumption. One solution proposed is to initially exclude this type of flexible system from the double taxation. Other options include instead using a one side taxation or place the tax based on net-metering.
2. Dynamic pricing – Enhancing the price differences on the electricity market between hours – beyond night and day tariffs.
3. Dynamic grid tariffs – Not clearly specified in the report, however, this most likely refer to the challenges on the grid generally ignored at present by changing a different tariff rate dependent on the current strain on the grid.
4. Flexible taxation tariffs – This is not clarified either, however, the suggestion may refer to the taxation of energy varying to create incentives for using electricity (or discharging) during optimal hours, from a system perspective. As it is not specified and the reader is left to speculate – this mechanism will not be included in future analysis.

Interestingly, the current suggested regulations are aimed at the electricity sector and not the transport sector. The authors also find that successful introduction of V2G require integration with the electricity sector. Also interesting is the finding that even a significant part of electromobility experts do not experience that they know enough about V2G-technology to be comfortable discussing its pros and cons (15 %). The share of experts offering concrete policy related suggestions in the study is only 23 %.

Smart Electric Vehicle Charging: Mitigating Supply-Demand Disparity Through User Incentives

In this dissertation, author Zhang presents a smart charging system that motivates its participants with financial as well as non-financial incentives. The aim is to increase the utilisation of renewable energy (Zhang 2018).

In the suggested system, there are "preferred" and "normal" users, with their status determined by an aggregator. Depending on their status, the participants will be prioritised to different degree and can for example receive electricity for charging before a lower prioritised user when electricity is a limited resource. This forms the non-financial incentive.

A share of the savings made by the aggregator from improved charging habits can be converted into cryptocurrencies (called SMERCOINs) and awarded the participants per kWh of renewable energy consumed. These SMERCOINs are either used to increase ones priority within the system or is exchanged for traditional currencies (i.e dollars). This exchange can be made with the aggregator for a given fixed price, ensuring the value of the SMERCOIN. A boosting mechanism can be introduced as well, allowing the lower priority user to skip in line and receive power before an otherwise more highly prioritised participator.

The use of cryptocurrencies relies on blockchain technology and for further technical details, the reader is referred to the original study. Advantageous of using the technology in this context are:

- Increased value of the SMERCOIN as opposed to a traditional currency. It has in addition to the exchanging value, a value in that it can buy the holder of the coin priority and faster charging.
- The ability to lend money from the participants as they hold on to the SMERCOINS, freeing up traditional money for the aggregator.
- There being no need of implementing additional dynamic/tiered pricing or similar price signals as an economic incentive for smart charging.

The profitability of vehicle to grid for system participants - A case study from the Electricity Reliability Council of Texas

Addressing the effect of market rules and operating costs on the profitability from V2G, the authors focus on three economic incentives: payment from a fixed retail price, a time-varying retail price and a scenario where the EV owners are compensated with 50 % of the achieved profit on aggregated level, split up between participants. For the final scenario EVs are charged at a fixed price and it is for the use of the discharging function, the EVs are awarded in this way. In all scenarios, the EVs are expected to be used in conjunction creating a Virtual Powerplant (VPP) in the parking lot, for example via an aggregator (Bhandari, Sun & Homans 2018).

The offers are made when the Electricity Reliability Council of Texas needs the extra power. For all incentives, it is assumed that EV owners assign willingness to participate, minimum SoC, if they have a maximum of allowed cycles per day, upon entering the parking lot. The EVs are supposed to know their cost function, consisting of costs from battery degradation, operational and managing costs.

A3. Current and future situation on Gotland

A3.1 Additional Aspects on the Power System

Wind power siting on Gotland

The siting of future wind turbines is to a great extent outlined in the region plans for Gotland (figure A24). The different areas that may be relevant for installation of wind power are divided into zones with different conditions (Region Gotland 2010):

- Zone type 1 – these are areas where the Swedish Energy Agency has pointed out a national interest for installation of wind power. These areas are should be prioritised for installation of wind turbines and can to some extent even outweigh other interests. The cumulative area of type one zones amount to 170 km^2.
- Zone type 2 – these zones are also of national interest for wind power installation, however, not with the same importance. These cannot override other potential interests to the same

extent. The intention is to install smaller wind power plants at these locations, ranging from 2-9 turbines.

- Zone type 3 – potential locations of single turbines pointed out by Region Gotland.
- Zone type 4 – areas where a generation shift of wind turbines should be implemented.
- Zone type 5 – areas with height limitations due to flight radar and military air traffic.
- Zone type 6 – sites where the potential of installation of wind turbines is limited due to a weather station in the interest of national defence.
- Zone type 7 – wind turbines cannot be installed as they would compromise interest of the military. Apart from these interests, the sites may have good potential for wind power generation.
- Zone type 8 – determined to be good locations for wind power at sea.

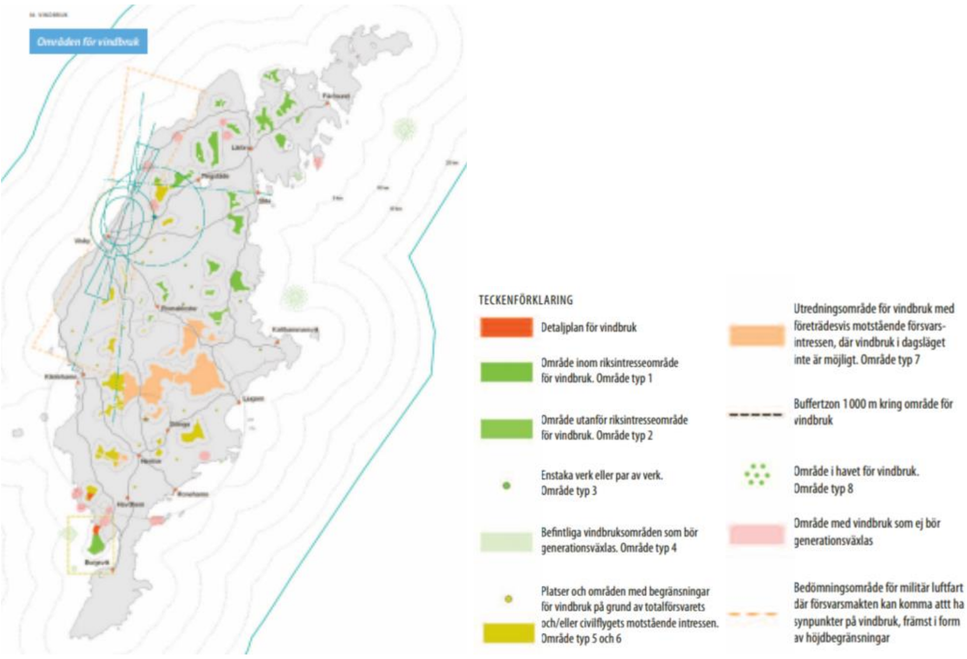


Figure A24: The potential sites of wind power on Gotland (Region Gotland 2010).

From comparing it with figure A25, it can be seen that a large part of the planned wind power is to be situated where there is already wind power today.

Figure A25: the wind power on Gotland today (Länsstyrelsen 2018).

Related projects

Smart Grid Gotland

The recently finished project Smart Grid Gotland has looked into the possibility of steering consumption using price signals. The project concerned the development of a smart grid on the island and included the installation of a surveillance system that monitored the low voltage grid on the island, providing GEAB with precise information on the status of the grid. An important aim of the project (one of three) was to examine the possibility of increased wind power production from implementing the smart grid solution. This was also found to be realisable (Gustavsson & Wedberg 2017).

The surveillance system was based on already installed electric meters and new installations in a large number of homes, providing the customer with time-specific cost of electricity in locations Bäcks and Källunge. Findings include that 10 % of the load could be moved if automatic scheduling of power applications were available. The project also showed that using new technology has the potential to increase security of deliverance (Ibid 2017).

The impacts of High V2G Participation in a 100% Renewable Åland Energy System

Released in the 23-rd of august 2018, this recent study examines the Finish archipelago of Åland. With 28916 inhabitants distributed on 6757 smaller islands, Åland presents an energy system with similarities and differences to that of Gotland. Aiming to clarify the role of Energy Storage Systems (ESS) on the archipelago the study takes place in 2030 with a 100 % renewable energy system and considers a high penetration of EVs (2750 MWhs of battery capacity). Gas storage, power-to-gas-technologies, thermal energy storage and stationary batteries are considered in addition to the use of V2G technology. The findings of the study include a considerable contribution to the total electricity use on the island from EVs participating in a V2G system (17%) (Child, Nordling & Breyer 2018). The technologies use in this article, for energy storage, should be applicable on Gotland as well.

A.3.2 Additional Aspects on Transport

Renewable transport on Gotland

The number of electric cars registered on Gotland in January 31:st 2019 is nearing 1 % of all cars, with 288 units registered on the island. To these, there are 138 public charging points (roughly to electric cars per charger). The number of electric cars has risen from 51 in January 2015, resulting in the significant increase of 464 % during three years (Power Circle 2019). Table A21 below includes some parameters clarifying the current status of EVs in the Swedish and Gotland context.

Table A21: Parameters describing the electrification of road transport in Sweden and Gotland based on statistics from Power Circle (2019).

Share of	**Gotland (%)**	**Sweden (%)**
BEVs/all chargeable passenger cars	45	26
private persons owned chargeable cars/	61	26
Passenger electric cars/ all EVs	93	96

Currently there are trends for sustainable transport without electrification as well. There are large ambitions regarding the use of biogas with aims from the region to use 30 GWh of biogas in vehicular transport per year by 2020 and a corresponding 300 GWh by 2030. Currently, the region of Gotland is buying 60 % of the biogas that is used on the island and there is a requirement to purchase biogas-driven vehicles during procurement (Swedish Energy Agency 2018, p. 31).

There has been attempts to address and decrease the use of fossil fuel in road transport on Gotland. During 2017 a campaign called *"Ratta Grönt"*, financed by the Swedish Energy Agency, attempted to increase the local knowledge on available renewable driven alternatives to the traditional means of transport. In addition to electric propulsion, it included transport using biogas (Region Gotland 2017D). In light of the campaign, information has been collected on the charging availability on Gotland and it is established that there are over 50 charging points on the island, of which four are fast chargers (Region Gotland 2017E). In these initial steps of electrifying transport on Gotland, the *"Ratta Grönt"* – project has provided the opportunity to test electric cars for a period of six months, giving the test subjects a chance to understand what their everyday life would be like if they drove electric (Region Gotland 2017F).

Another project even more specifically aimed towards electric cars on Gotland was "Elbilslandet Gotland". Financed by Solcellskompaniet and the Swedish Energy Agency, this project introduced more EV chargers on the island and provided local car rentals with electric cars. The idea was to aim the project towards tourists who had the time to and interest in trying something new, in this way the electrification of road transport would get support from commercial forces. This also lead to many chargers being installed in proximity of tourist attractions (Elbilslandet Gotland n.d.). Included in the findings reproduced in the final report on the project is a high level of customer satisfaction with 57 % stating that the experience of driving an electric car on the island is better than using the fossil based equivalent and 33 % stating that it is on the same level (90 % of customers participated in the evaluation) (Malmsten 2016).

Tourism and transport to and from Gotland

The tourism industry constitutes a significant share of the economy on the island. During 2016, 2.2 million people travelled to and from Gotland and one million hotel nights were spent in commercial accommodation facilities, mainly concentrated around the peak season. Tourism is most intense in the summer, especially during events such as Almedalsveckan (a week dedicated to politics and influencing concerning all of Sweden) and Medeltidsveckan (a week with medieval theme) (Destination Gotland 2018). During the four most intense weeks there are 130 000 people on Gotland and roughly half of the visitors are in the Visby-area (Buhre 2017).

During a normal year 0.5 million cars are transported to and from the island and it is reasonable to assume that most of the transportation by the visitors is made by car. Destination Gotland is in charge of the ferry traffic since the last procurement and in addition to transporting most of the cars to and from the island, 1.6 million people travelled to and from the island using their ferries (Swedish Energy Agency 2018, p. 33). During the summer season there are 22 departures per day while there are 6 departures per day during the winter (Region Gotland 2017C). The port on Gotland that is used is in Visby (Destination Gotland 2018).

Recently the idea of electrification of sea fare has gained momentum and some of the harbours on Gotland are working on how electricity could be delivered to boats and ships in the required amounts and power. It is challenging due to large requirements of power, frequency differences between large ships and the grid of Gotland, voltage level requirements of ships and more. Ships could represent sudden and increased loads of 0.5-8 MW (cargo ships), 4 MWs (ferries) or upwards of 25 MW (cruise ships) (Swedish Energy Agency 2018, p. 34).

The remaining part of trips to and from Gotland that is not carried out in the ferries of Destination Gotland are by flight. During 2016, roughly 0.46 million came and went via the airport outside Visby. For air travel, the peak season is again in the summer during June, July and August (Swedish Energy Agency 2018, p. 33). From the figures, it seems likely that tourism affects the overall transport patterns on Gotland.

A4. V2G Pilot Projects

The number of pilot projects on V2G are ever-increasing. A few of these are summarised below to give an idea of how such projects are carried out. As many of them are ongoing there is a lack of results from the projects. As Smart Charging is more established and proven system, no such pilots will be included below.

The SEEV4-city project

With seven operational long-term pilots spread out on six different cities in five different countries this project aims to improve energy autonomy, increase the number of ultra-low emission kilometres and avoid extra unnecessary investments. The project has smart-charging projects as well as projects where vehicles can discharge onto the power grid in addition (European Regional Development Fund n.d.A). Two examples are:

- Leicester City Hall – four EVs, a solar panel roof and a stationary battery is used in conjunction with a smart system that decides when solar energy should be charging the cars, the stationary battery, be used in the office or be discharged onto the grid. Between June 2016 and June 2017, 15 % of the produced solar power was used for charging the EVs, adding up to 2996 kWh (European Regional Development Fund n.d.B).

- Living Lab – Carried out in the UK, this is the smallest of the projects. The projects is connected to one house where incremental technology updates have been carried out stepwise in the following order: solar panels, EV, stationary battery storage and finally V2G-technology (European Regional Development Fund n.d.C).

The Aces Project
On the Danish island Bornholm a 3- year project called Aces has been launched, examining how EVs can be successfully integrated into the energy system on the island. The project will use real grid data, usage patterns and will carry out field testing. A small-scale pilot test will also be carried out where 50 publicly and privately owned Nissan cars will be used to help balancing the energy system on the island (Marinelli n.d.).

The Parker Project
A project aiming to validate that series-produced EVs can support the power grid, locally as well as system-wide. To accomplish this the project has been supported by the worlds first commercial pilot series produced V2G cars. Nissan, Mitsubishi Motors Cooperation as well as PSA Groupe participate, which means that the project shows that multiple companies can be part of the same system. The project is built on the EDISON and Nikola projects that have examined EVs potential to balance power production (Bach Andersson n.d.).

The first commercial V2G-hub is in Denmark
In Frederiksberg, a neighbourhood of Copenhagen, Denmark the first commercial V2G-hub is operated by companies Nissan, Enel and Nuvve. By using ten charging stations the ten Nissan e-NV200 used in the project can supply the grid with roughly 100 kW upon demand. The demand is determined by Energinet.dk (Nissan 2016).