The Parker Project

Final Report - Appendices

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Technical data

<table>
<tr><th colspan="4">Accuracy</th></tr>
<tr><td>Measured values</td><td colspan="2">Range</td><td>Accuracy class*</td></tr>
<tr><td>Rms current (I1, I2, I3, Iavg, In)</td><td colspan="2">1, 5 A</td><td>0.3 (0.2)**</td></tr>
<tr><td>Maximum current</td><td colspan="2">12.5 A</td><td>0.3 (0.2)**</td></tr>
<tr><td>Rms phase voltage
(U1, U2, U3, Uavg)</td><td colspan="2">62.5, 125, 250, 500 V_{L-N}</td><td>0.3 (0.2)**</td></tr>
<tr><td>Maximum voltage</td><td colspan="2">600 V_{L-N}</td><td>0.3 (0.2)**</td></tr>
<tr><td>Rms phase-to-phase voltage
(U12, U23, U31, Uavg)</td><td colspan="2">800 V_{L-L}</td><td>0.3 (0.2)**</td></tr>
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<tr><td>Nominal frequency range</td><td colspan="2">16…400 Hz</td><td>0.02</td></tr>
<tr><td>Power angle (φ)</td><td colspan="2">–180…0…180°</td><td>0.2°</td></tr>
<tr><td>Power factor (PF)</td><td colspan="2">–1…0…+1
U = 50 … 120 % U_n
I = 2 % … 20 % I_n
I = 20 % … 200 % I_n</td><td>

0.5
0.2</td></tr>
<tr><td>THD</td><td colspan="2">5…500 V
0…400 %</td><td>0.5</td></tr>
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250
500
[W/VAr/VA]
I_n = 1 A</td><td rowspan="3">375
600
1250
2500
[W/VAr/VA]
I_n = 5 A</td><td>0.5 (0.3)**</td></tr>
<tr><td>Reactive power</td><td>0.5 (0.3)**</td></tr>
<tr><td>Apparent power</td><td>0.5 (0.3)**</td></tr>
<tr><td>Active energy</td><td colspan="2"></td><td>Class 1</td></tr>
<tr><td>Reactive energy</td><td colspan="2"></td><td>Class 2</td></tr>
</table>

* All measurements are calculated with high harmonic signals.
** Accuracy on communication

Barriers within V2G Frequency regulation in Europe

TABLE OF CONTENT

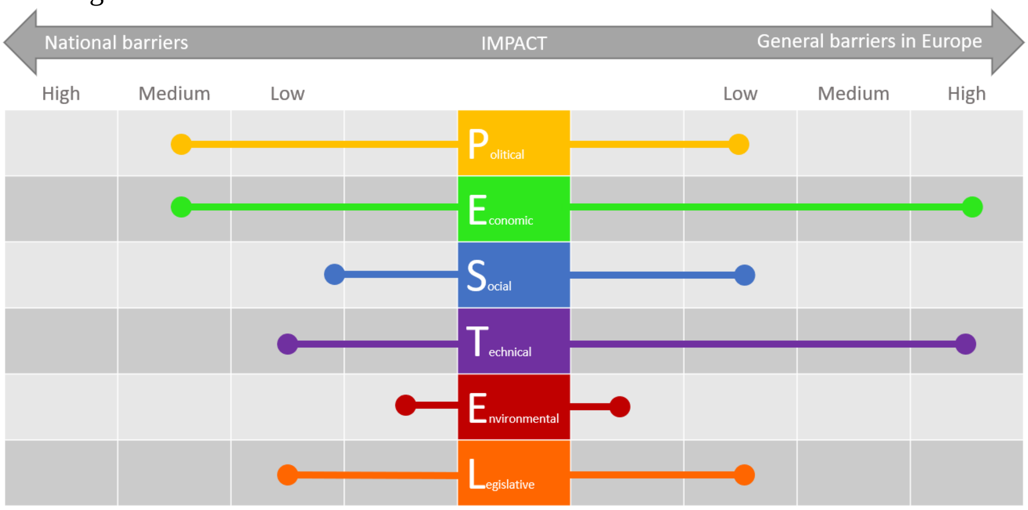
Executive Summary

The overall findings on V2G barriers are reached through an analysis and evaluation of the current and prospective market conditions, for which the PESTEL framework is used. Consequently, six themes determine the overall barriers in each particular market. The main method of the analysis includes in-depth comparative examination of literature reviews within the subject and expert interviews on V2G technology.

On a general level the research draws attention to the fact that the undergoing shift in technology produces a window of opportunities to establish a market design for commercial aggregation of frequency-regulation. Further examinations revealed that the barriers for V2G in each country vary in different areas as the market for V2G technology, in its present state, is deeply complex due to complicated market regulations and requirements. Currently, lack of infrastructure, the unknown level of battery degradation, and a limited number of V2G capable vehicles available, are the three major European barriers for large scale realization of V2G services. The analysis further reveals how the future possibilities of V2G implementation vary between each country. All in all, there are countries where V2G proposes a more optimal fit and experiences fewer barriers compared to other countries.

Apart from the above listed general European barriers, an in depth analysis has been made on four different markets to see the differences in their individual barriers. The following barriers were identified for each country:

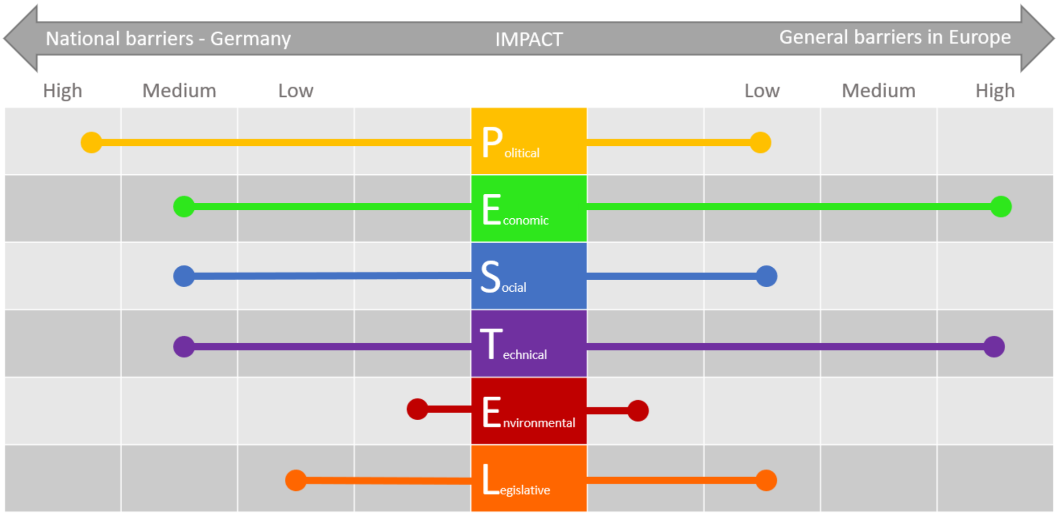
I) **Within Denmark:**
The level of barriers within Denmark have been found to be at a medium level. The core reasons for this relates to the case that the current regulation of the market does not create a positive framework for selling V2G services. This is however undergoing changes with the implementation of Market Model 2.0. To summarise the most important barriers: high electricity prices, limited size of the EV fleet and perhaps most importantly the dual taxation of V2G charge and discharge. Although the technology fits into the national framework of environmental awareness, a potential exists for improvements of the framework through political recognition and a long term policy for EVs.
The level of the different barriers in Denmark within the PESTEL framework is depicted in the figure below.



PESTEL analysis - barriers in Denmark

II) **Within Germany:**

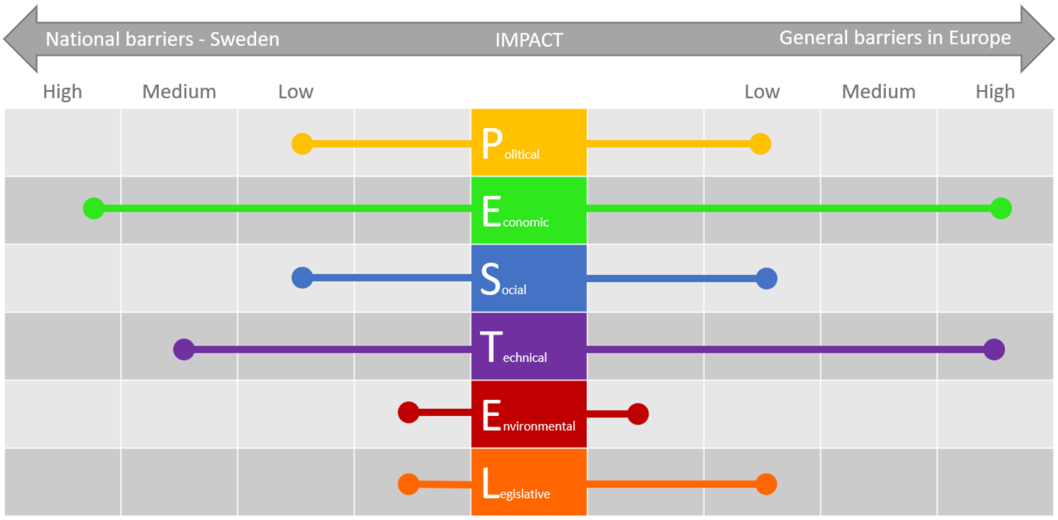
The market potential and barriers in Germany are affected by, and depending on, the political and economic factors creating noteworthy barriers to V2G implementation. So far, the German automobile industry has been hesitant to switch to EVs compared to Japanese and French producers and thereby complicating the political discussion on the topic, as it would move against the biggest industry in the country. Also, worth noticing, EVs are considered a less attractive option by the German population. The barriers in Germany are therefore quite significant and related to both national policy, industry interests, social acceptance, and technical issues with the market, as seen in the figure below.



PESTEL analysis - barriers in Germany

III) **Within Sweden:**

The Swedish power market operates well in its current state, hence is in very little need of flexibility service providers. This is a large barrier as a change on this level would require a significant change in either market setup, energy production or consumption. Secondly, the relevance for Swedish companies to participate in the FCR market is small. As a consequence, there are only a limited number of active R&D projects due to the absence of interest from grid providers. In total, the Swedish grid is regarded as adequate to its current commitment, and the demand and interest in radical change is lacking. Such limitations joined with the absence of profitable regulations from the political aspects, positions the market in a vulnerable position from a V2G viewpoint as especially the economical barriers are high, as can be seen by the figure on the next page



PESTEL analysis - barriers in Sweden

IV) **Within Norway:**

In Norway, the market seems ideal for the implementation of V2G, due to their considerable fleet of EVs. However, this is currently not the case. This is especially due to the markets self-sufficiency of hydroelectricity, providing EVs with green, stable and cheap electricity. Hydroelectricity bidding on the frequency regulation markets, leaving very limited space for a new technology such as V2G, is another barrier. A tendency to implement more wind in Norway could change this balance, however in the next five years, this development is expected to be limited. The level of barriers in Norway within the PESTEL framework is depicted in the figure below.

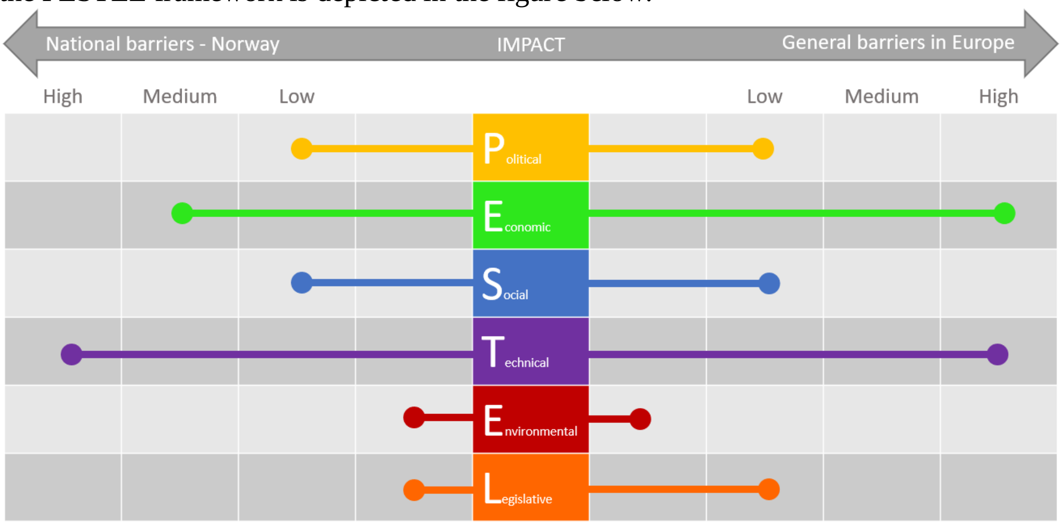


Figure 57 - PESTEL analysis - barriers in Norway

With the advance in the market share of EVs, the price of the technology decreasing and the potential of the V2G technology increasing, thereby reducing both the general technical, and economic barriers. The speed with which this happens differs from country to country. However, some countries have low enough barriers to start considering implementation of V2G.

1. General barriers towards European markets

The V2G technology provides flexibility service by electric vehicles. According to NUVVE and DTU V2G has seven main barriers for providing ancillary service. The barriers for V2G Frequency regulations vary in the four European countries; Norway, Sweden, Germany and Denmark. The V2G market is currently part of a highly complex context due to complicated regulations, market requirements and the involvement of several actors, which is now experiencing a dramatic change. The undergoing shifts in the technology mix with an increased share of renewables, demand-side response, and storage technologies create a window of opportunities to develop a market design for frequency-regulation to aggregators. Denmark leads the way in Europe for developing a frequency-regulation reserve markets to aggregators with primary reserves [38]. A commercial aggregator has the potential to participate in the existing electricity markets by unlocking flexibility to Frequency Containment Reserves; FCR and secondary (Frequency Restoration Reserves; aFRR) for balancing the grid. Tertiary reserve is not a relevant market for an aggregator, as the Tertiary reserve requires larger amount of available capacity over a longer service period [38], [1]. The Parker project focuses only on providing flexibility to primary reserve market. Thisreport identifies market barriers for the introduction of V2G in four European countries. It seeks to identify different concerns across market actors through the PESTEL framework. Each of the four countries accounts for the six factors in the PESTEL framework. The general aspects, which exist in the four European countries are defined in the following. The identified market barriers for each country are divided into national barriers and general barriers seen in Europe.

1.1. Political factors

As addressed in EU 2050 Transport Strategy Plan, to improve the energy efficiency and handle climate change, Electric Vehicles (EVs) are considered as the future of the automotive industry as they have the capability to produce motive power from electricity instead of power from a traditional combustion engine. The fast growth of EVs renders significant impacts on power systems, particularly in the distribution level and demand side [2]. In general, different political winds, opportunities like barriers can affect the implementation of V2G, for instance, subsidies, industry dependency and relation, and market types. These factors are defined for each country in following chapters.

Importantly, like several previous technologies that have provided to a technological paradigm shift, V2G and electric vehicles require various forms of government support such as subsidies for reaching their market potential [3]. Government assistance is a way for the car industry to eliminate entry barriers for EVs and V2G. However, EVs can also provide with valuable flexibilities for the power system by V2G technology, as EVs' charging rate is possible to control within a short response time, if the EVs are available for a charger most of the day [34].
In this context, to make full use of EVs connected to private and public charging infrastructure, V2G technology is maturing in the recent years. Currently, several national projects are exploring the new opportunities such as the Net-form project in Birmingham [4].

One of the political barriers for V2G in Europe is that none incentives are available for encouraging an independent, commercial V2G aggregator to participate in the existing electricity markets [22] in spite of the fact that V2G services can cover ancillary service, such as primary reserve, and voltage support etc. In order to implement the technology, it is necessary to define the role and responsibility of the DSO. As aggregators (new entrants) must be able to aggregate flexible units among multiple DSOs as EVs can consume/supply electricity from areas of different DSOs [38]. The contract of the flexibility service can be based on bilateral between the DSO and the prosumer, or DSO and commercial aggregator. This results in transaction costs for the prosumer or the commercial aggregator, or it is possible to develop an open and transparent flexibility market platform for just trading flexibility products [34]. For example, a V2G aggregator is required to contract with the BRP bilaterally and/or an energy supplier for negotiating the service price and capacity, which can create difficulties and conflicts of interest for current energy market actors due to high transaction costs. Therefore, it will reduce economic barriers for the commercial aggregator to develop a new trading market for flexibility products.

1.2. Economic factors

A commercial aggregator, which offers V2G flexibility for energy market actors, seeks to maximise its profit and market share by submitting bids and reducing operating cost. General factors, which can impact the economy of the aggregator are market reform, investments and expenses. These factors are defined for each country in following chapters.

According to C. S. King, asymmetrical bids are preferable market products for a commercial V2G aggregator [5]. If asymmetric bids are acceptable by the reserve market, separate auctions are required to generate asymmetric V2G reserves, i.e. one auction is for upregulation reserve (EV discharge), and the other is for downregulation reserve (EV charge). Development of asymmetric V2G reserves requires significant market reform changes and TSO investments. To trade in a reserve market, each bid has specific requirements, e.g., bid timing, service duration, bid size, etc. [1]. Thus, a V2G aggregator should have the ability to collect a considerable number of EVs, as in the four European countries the threshold of FCR bid size is a significant barrier. Therefore, the TSOs will require commercial aggregators to provide with a minimum product capacity (more than 0.3 MW in Denmark and Sweden and more than 1 MW in Germany and Norway) for participating in the market, cf. 1.6. Legislative factors.

Physical V2G services are provided by individual EVs but traded as a whole by the aggregator in the existing market. Thus, the TSO and especially the DSOs face difficulty in monitoring activations of aggregator transparently. In addition to the main meter, which measures energy consumed by the EV, a smart meter (also installed by a DSO) will measure energy consumption by the EV for down-regulation and energy delivered from the EV to the grid for up-regulation. The two meters must satisfy requirements by TSO on measurement precision and delivery time. Thus, it is required that the meters record, verify and control both power charged and discharged, the unlocked flexibility provided from each EV to the TSO for implementing proactive grid management [34]. Another barrier with the energy settlements is the data measured by smart meters. Whether they are both used for data documentation for consumer's energy bill and data documentation for BRPs for energy traded from prosumers for up- or downregulation. In the future, it will be necessary to separate measurement of energy consumption,flexibility provided and energy for balancing the grid for securing reliable data collection. The investment of metering systems will be a barrier for prosumers with small flexibility units (small available capacity e.g. home chargers) due to high installation and operation costs. However, V2G is also a valuable resource for providing distribution services, such as congestion management, voltage support, power quality maintenance, emergence handling, and black start [6].

Infrastructure investments are fundamental in the context of successfully implementing V2G into the energy market. V2G charging systems are currently expensive to incorporate into the grid, as it requires bi-directional charging and it is often costlier to install due to new wiring, metering system and communication between the prosumer, commercial aggregators and the grid operator. A V2G connection, which provides with a capacity of 6.6 kW costs 340 € and an upgrade to 15 kW costs additional 1.600 € [7]. An alternative investment for a DSO is grid reinforcement. Therefore, it is relevant that the DSOs conduct a cost-benefit analysis both in the case of grid reinforcement and V2G implementation and compare the results for investigating the best way to utilize the public investments [34].

The most critical barriers for V2G applications in Europe are high EV charging cost because of high electricity prices. Figure 1 illustrates electricity price statistics for EU countries, and Figure 2 illustrates the percentage of taxes on electricity in EU countries. Figure 1 & Figure 2 illustrate that Denmark and Germany have the two highest electricity prices in EU due to high taxes and levies. Whereas Norway has the lowest electricity price, percentage of taxes and levies on electricity paid by consumer compared to the three other countries.At the same time the Norwegian electricity price is under the average of European electricity price, which provide V2G aggregators an opportunity to enter the electricity market in Norway.

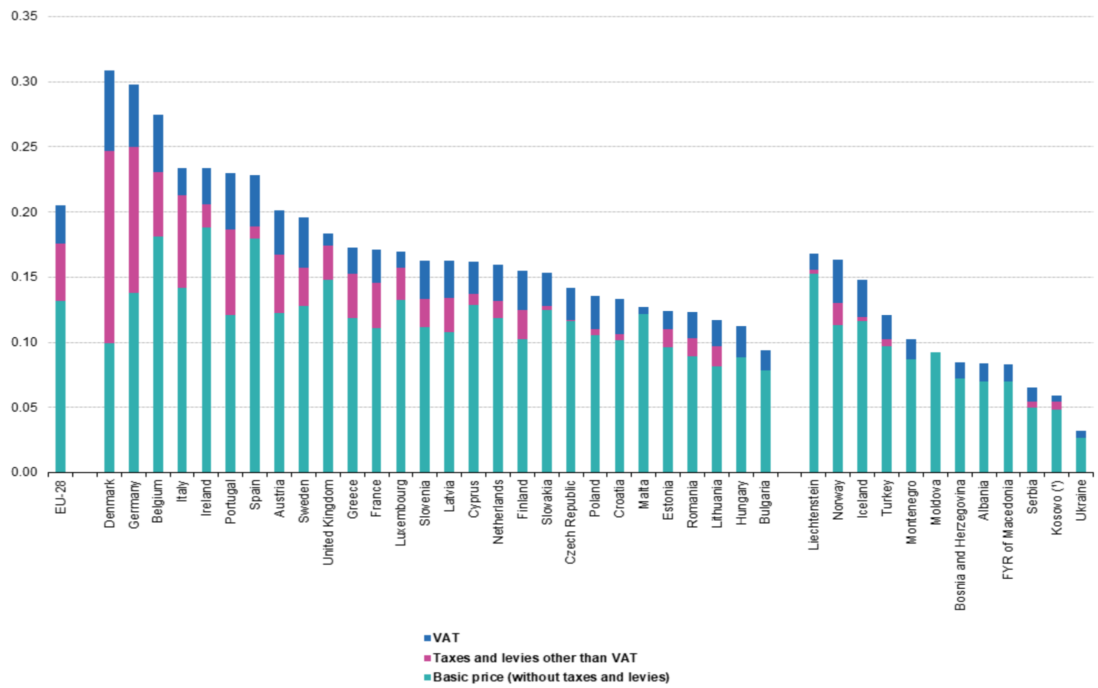


Figure 1 EU electricity prices for household consumers (€/kWh) in 2016. Source: Eurostat

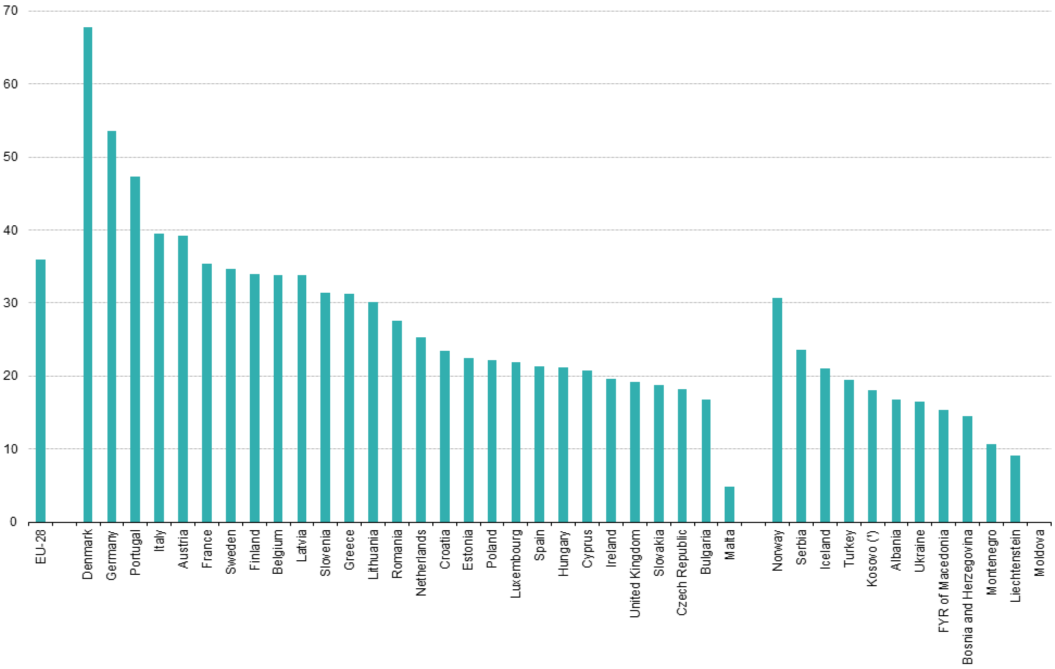


Figure 2 Percentage of taxes and levies on electricity paid by household consumer (%) in 2016. Source: Eurostat

1.3. Social factors

Successful implementation of EVs in Europe depends on social factors such as customers attitude, interest, and purchase opportunities, as the factors can mould the market demand for V2G. There are different social factors, which can impact the implementation of V2G, e.g. motivation and needs, and user behaviour. These factors are defined for each country in following chapters.

The motivation for BEV owners to use the V2G technology is likely to be a combination of advantages balanced with risks and consequences. The most challenging part is that driving patterns (of individual EV) owners are varied and dispersed [8], and thus it is more complicated for the technical aggregator to calculate the surfeit of flexibility in the proposition to the driving needs. Furthermore, the user can be uncertain about the accessibility of the EV, as the V2G operation of the EV can appear inflexible compared to their everyday need for driving. EV availability is an important concern to address as it determines the user behaviour of an EV. No EV owner or fleet manager will be motivated to sign up for V2G if it means their vehicle will be unviable at unexpected periods. The overall V2G setup must guarantee enough flexibility in its operations, as customers' needs are above all other requirements. Furthermore, the operator must be able to give the customers the certainty that the system will manage the charging most reliably, leaving the EV with the needed amount of range to drive in the next operational trip [3]. In general, by using the technology, the prosumer will potentially experience economic benefits if the business model allows it. The generated benefits must be compared against vehicle availability, potential lifespan reduction of batteries, warranty, and overall convenience. Acceptance of V2G is fundamental and customers (and thus potential prosumers) need to understand and adapt if the V2G concept is going to be successfully implemented. Prosumers must be properly instructed in applying the technology. Information regarding off-peak charging and load stabilisation is essential while subjects such as the electricity flow from the EV to the grid are secondary [9]. A proper introduction to V2G can create an understanding about V2G and thus increase the acceptance, as it reduces the hesitancy and doubts about the usability and security of V2G as technology [3]. Another important subject to address is payment security and the financial aspects. Prosumers will need to be informed about financial advantages as flexibility provider, as it will impact their decision regarding lending their battery to the grid or not. In the future, as the trust towards V2G increases, well-informed prosumers can work as ambassadors for the technology and arouse a keen interest and market demands for this option.

1.4. Technological factors

The transition from fossil fuel to renewable energy and the overload on European electricity grids provide critical technical challenges for the Distribution System Operator [10]. The DSOs are challenged by the implementation of distributed generations and EVs, as it causes to both an unpredictable and a significant power capacity during peak periods and bi-directional flows of electricity. Therefore, it is important for the market to manage the flexibility for avoiding both energy losses and high grid operating costs [34].]. Based on various technical setups, such as problems vary from country to country as output and regulation differ within each nation.

The full potential of the V2G in the European energy market has not yet been identified. In many ways, the V2G market is far from being entirely in place. Moreover, there are some challenges which inhibit a still fragmented market from becoming a significant reserve provider for the TSOs while delivering the full value package to the customers. The V2G technology has introduced some considerable difficulties mainly towards standardisation of the markets across, e.g. Europe [1].

Technical factors, which can impact the implementation of V2G are potential battery degradation, discharging process called two-way energy loss, management of the technology and long duration frequency bias. These factors are defined for each country in following chapters. According to Knezovic´ et al. (2015), DSOs require some technical barriers to be handled before they are interested in flexibility services from V2G. One of the barriers is how usable the service is for the electricity market which depends on the type of service it is possible to provide. An example is direct load control and price-based control. Therefore, the commercial aggregator should forecast and inform about activation frequency during the contracting period, maximal power/capacity from the EV (kW), duration of the active service, and quality of service comprising accuracy ramping and maximum activation time. Another technical barrier with the V2G technology is to collect and forecast the availability of the EVs on the basis of the needs and habits of the prosumers and thus ensure the DSOs to provide with flexibility capacity when needed [34]. Another very relevant barrier is the uncertainty of the number of the available EVs with a surplus of flexibility to provide for the grid. It is not possible to determine exactly how many EVs will be available, when and for how long time. It is therefore not possible to predict the particular capacity to provide from V2G.

One technical barrier for connection EVs to the V2G is the two-way energy loss. When the battery provides energy to the FCR reserve by charging or discharging cycles, the power converters in the charger have an appreciable amount of energy loss due to inefficient bidirectional charging. Bidirectional charging with lower power level than charger capacity results in energy loss. When V2G connection provides with the highest amount of power capacity, the best efficient bidirectional charging is 90%. Energy losses can result in high operational and energy costs for prosumer.

Another technical barrier is that the V2G can potentially lead to battery degradation during the discharge/charge cycles. Thus, EV drivers and car OEM’s can be worried about warranty and hidden costs because battery replacement is expected to be expensive not only with current technologies but also in the upcoming future. The battery capacity loss is caused by size and rate of power drawn, as well as cycling frequency [9]. A research team from the University of Hawaii, Natural Energy Institute, has investigated the impact of bi-directional charging between EVs and the grid. According to the study, V2G used twice a day increases battery degradation by 75% and resistance by 10% and decreases the lifespan of batteries to just five years with a constant connection to V2G [5]. Researchers at the University of Warwick demonstrated a new “smart grid” system which showed that a new approach could potentially lead to an increase in longevity of battery in EV [7]. Deep discharging of the car batteries should be avoided as it damages the battery severally. The BMS system should be able to prevent this, but standard protocols regarding charge limits between cars and power receiver could reduce the risk of battery degradation even further [10].

A technical barrier is that the current EV’s manufacturers may redesign their models as the majority of existing EV models are incompatible with the present V2G infrastructure [11]. V2G is limited by the lack of both the charging infrastructure and the EV models regarding bi-directional charging, as it is essential for V2G to function that the EV models have bi-directional charging. Furthermore, the charging infrastructure has to include bi-directional chargers, especially for the “daily” charging, in parking areas where the EVs are parked most of the time. V2G implementation will complicate the EV technology even further and resulting in increased vehicle and infrastructure cost. Price is already a barrier for EVs, as EV costs significantly more than conventional cars. Also, the lack of AC & DC standards for V2G-capable designs across European electricity markets makes it difficult for car OEM’s to produce EVs that complies with regional standards, leaving the customers with a much smaller assortment of car model to choose. In all propability, the lack of AC & DC standards will negatively affect the total number of compatible cars. Current customer demand seems insufficient compared to the expenses and risks which are followed by the development of new car models. Another barrier is that the current grid infrastructure is limited by seizing, current geographic location, and V2G technology as many charging station models are currently not ready for facilitation of bi-directional V2G charging [12]. Another issue is the charging process: a random number of batteries with random energy demand present a demand side management issue [2].

1.5. Environmental factors

The V2G technology must address ethical and sustainable issues by using the technology. Comprising prosumers will demand that the product is environmentally friendly. One of the main arguments for the use of V2G is the improved environmental performance, as it reduces the need for fossil fuels when balancing the electricity grid. In general, following factors can affect the implementation and environmental performance of V2G technology; Customers’ choice of purchase, load management, subsidies for EVs and battery lifetime. These factors are accounted for each country in following chapters.

Environmental and grid benefits are anticipated to be secondary to financial motivations for most potential prosumers. Several prosumers are interested in taking environmentally responsible actions, but only if it is inexpensive and suitable for them [3]. Nonetheless, a significant group of the early adopters of EV technology are people that are environmentally driven. Consequently, it could be assumed that those same early adopters would be among the first users of V2G technology as they are familiar with the technical background and its environmental value. A significant penetration of EVs could have an impact on the performance of the existing electricity grid, as higher system loading could affect the overall system reliability. Uncontrolled or concentrated charging of massive fleets of EVs can result in increased power consumption and thereby increase the peak loads propably in the evening periods. The effect of unstructured EV charging could result in a demand for energy provided from generators in order to stabilize the grid when renewable energy systems cannot cope with the demand from the energy market [13].

Furthermore, studies have shown that subsides creates excuses for acquiring a second car and EVs are used to replace short trips that otherwise would have been done with means of transportation, such as public transit, cycling or walking [3]. Thus, the EV technology can result in bad driving habits and negative environmental impacts. The possible battery degradation caused by the use of V2G technology has negative effects on the ethical and sustainable performances of V2G and EVs. As a consequence, the V2G technology must be proved with no reasonable doubt that such arguments are false.

1.6. Legislative factors

V2G has only been the object of research and demonstration projects, and the technology has not yet entered the market on a commercial basis. Hence, no legislation exists that directly regulates V2G in the four European countries. However, V2G must obey the general electricity legislation for being applicable for the energy market. V2G can be considered part of smart grids for which challenges exist regarding legislation and barriers. The legislation of electricity supply has to undergo changes to meet future challenges with more fluctuating renewable power in the electricity system [14]. Among others, there is a political wish to ease the conditions for smart grids in EU [10]. Factors, which can impact legislation on V2G in Europe are; entering the market, data security, supply- and charging security and ownership issues. These factors are defined for each country in following chapters.

The electricity supply and its markets in Europe and legal regulation are complex. The electricity market shall obey both national- and EU laws. The electricity supplier holds the responsibility for electricity supply, economics, environment, consumer protection and low prices for the consumer/prosumer into account. Supply and demand regulation is regulated by electricity services that different players can bid on the electricity market. Seen, electricity service bids can be divided in two: (1) Day ahead market which constitutes a basic electricity production next day based on forecasts & (2) on the day (Intraday market), market actors can trade capacity close to real time to balance the grid within short time.

The electric vehicle (EV) has the advantage that it can react very fast if there is a need for flexibility and hence it is well suited as a reserve in the electricity market. The challenge is that a commercial actor must bid at least 1 MW (1000 kW) to enter the market [14] except from the Danish and Swedish market, where the actor has to bid with a minimum of 0.3 MW. The minimum bid of 0.3 MW requires commercial aggregators to pool several EVs, as one EV cannot provide with a capacity of 0.3 MW. This means that a number of EVs must be pooled by an aggregator, e.g. 100 EVs with 10 kW chargers. According to Knezovic´et. al. (2015), the minimum capacity should be reduced for implementing demand response, or bitless markets are an opportunity, as it is possible for prosumers to bid its minimum capacity to real-time price signals [34]. Currently, there is no clear legislative definition of energy storage in the EU legislation, leading to a series of unintended barriers creating an uncertain investment environment [14].

2. Barrier analysis for V2G implementation in Denmark

Regularly identified as a first mover towards decreasing climate change, Denmark has many success stories, such as the intensive instalment of wind power. Historically the decarbonising of the transport sector has lingered behind, but the application of EVs is optimal in proposition to the population figure. Currently, the greatest obstacles towards V2G implementation in Denmark is the EV prices, tax system and the general lack of political will. Nevertheless, Denmark is among the first countries in the world to have a commercialised V2G pilot project [15]. Furthermore, West Denmark has a need for frequency regulation and this can create the best economic potential for a V2G aggregator.

2.1. Political factors

The political barriers to implement V2G in Denmark has been summarized in Table *1*, and the national barriers have been explained in-depth below.

Political barriers for V2G in Denmark		
General barrier in Europe, cf. Chapter *1.1. Political factors.*	Independent V2G aggregator	Interest may lose if a V2G aggregator is stipulated to contract with the BRP and consumers/prosumers without incentives
National barrier	EV purchase subsidies	Lack of consistent incentives weakens the sale of EVs and indirectly restrains V2G services and the development of EV charging infrastructure.

Table 1 Political barriers for V2G in Denmark

However, EVs also provide valuable flexibilities for power system operation. In this context, to make full use of EVs, charging infrastructure at residentials, commercial and industrial buildings need to be further developed, and thus V2G technology has matured in the recent years.

Till now, V2G is identified as a critical enabler of demand response, power security, and renewable integration. In Denmark, the registration tax exemption on EVs expired in 2015 and replaced by several different incentives that should slowly decrease the taxation of EVs [15]. The lack of consistent incentives is the primary barrier for EV expansion. This results in a limited amount of EVs for providing potential V2G services to the power system.

2.2. Economic factors

V2G is a valuable flexibility service, as the V2G is useful for the TSO to participate in the existing electricity market by providing with frequency regulation [15]. The economic barriers for implementing V2G in Denmark has been listed in Table 2.

Economic barriers for V2G in Denmark		
General barriers in Europe. The barriers are explained in chapter, *1.2. Economic factors*	Market reform	Current bidding rules are not suitable for achieving the cost-effective use of small-scale V2G aggregators.
	System investment	Update of monitoring and metering systems request a significant amount of investment which shrinks the interests from the DSOs.
	High charging cost	High electricity price increases V2G charging cost dramatically.
	Emerging market	Public distribution-level market is necessary to realize various V2G services for DSOs
National barrier	Dual taxation	High tax rate for both V2G charging and discharging limits V2G potential

Table 2 Economic barriers for V2G in Denmark

In Denmark, primary reserves requires asymmetric bids, which are preferable for the V2G aggregator. To incorporate V2G aggregator into the Danish FCR market, although the current daily auction and gate timing are suitable, the threshold of FCR bid size (0.3 MW) in a period of 4 hours is still a significant barrier. The current bidding rules are not suitable for small-scale V2G aggregators, as a V2G aggregator should have the ability to collect a considerable pool of EVs. This bidding limit weakens the interests of small-scale (less than 0.3 MW) V2G aggregators to engage in the FCR market.

The most critical barriers for V2G applications are high EV charging cost with electricity price and dual taxation for both EV charging and discharging. Referring to EU electricity price statistics, the Danish electricity price is approximately 0.31 €/kWh including taxes, levies and VAT, cf. *Figure 1* and the Danish consumers pay about 67% of taxes, levies and VAT in the total electricity price, cf. *Figure 2*. Despite the V2G aggregator is authorised to trade directly in the existing markets, it is still challenging to take a profit due to high operating costs. Furthermore, there has not been developed financially viable business models for commercialising V2G in Denmark due to high competition, and market restrictions [15].

2.3. Social factors

The integration of V2G to the Danish grid depends on social factors as they determine customers attitude, interest, and opinions. Therefore, it is essential that these barriers are dealt with efficiently as they mould the market demand and conclusively determine the buying behaviour towards EVs. The social barriers to implement V2G in Denmark has been summarized in Table 3.

	Social barriers for V2G in Denmark	
General barriers in Europe, cf. 1.3. Social factors	User behaviour & instructions	Consumers need guidance and directions in the new technology in order to gain public acceptance
	Vehicle availability	Access to the vehicle is a concern towards V2G implementation, from the customers' point of views, as their needs are essential. V2G must ensure flexibility in its design, leaving room for practical use
	Trust in the technology	The technology must be able to give customers the confidence that the system will operate reliably and leave the car sufficiently charged whenever needed
	Lack of motivation	Consumers are potentially not motivated to lend their battery to the grid if the business case is too complicated and economic insufficient, which results in lack of grid availability.
National barrier	The government does not support the sale of EVs	The lack of Danish subsidize to purchase an EV results in lack of public support.
	Lack of communication	Lack of communication about V2G and its opportunities for the society.

Table 3 Social barriers for V2G in Denmark

According to the research by AU, one of the social barrier for the Danish consumer is aware of the taxes for electric vehicles, but has not gathered information about the different types of EVs on the market and the charging infrastructure [15]. Another barrier is the unsupportive strategies from the government and taxes on EVs, as the consumer prioritises the social welfare higher than green transport alternatives, which causes less economic support from the government to market penetration

of EVs [15]. A third barrier is that generated knowledge from Danish research activities within V2G is not shared with the external environment, which results in the public does not know about the V2G project results, battery capacity and the financial contributions etc. [15].
The most challenging parts for V2G are EV owners need of flexibility and varied driving patterns. Vehicle availability is an important concern to address as it determines the practical use. No car owner or fleet manager will be motivated to sign up for V2G if it means their vehicle will be unviable at unexpected periods. The overall V2G setup must guarantee enough flexibility in its operations so that customers' needs are above all. Furthermore, the operator must be able to give the customers the certainty that the system will manage the charging reliable, leaving the vehicle with the needed amount of range to operate for the next operational trip. Therefore, it is important to give the prosumer instructions about the availability, use and handling of the technology for avoiding technical problems and dissatisfied customers.

2.4. Technical factors

At the time, Denmark has a small market potential for EVs. In June 2017, the total population of BEVs reached 8.872 in total, and PHEVs represent a small part of the total share. Technological barriers for implementing V2G in Denmark has been summarized in Table 4. The technical barriers have been explained below.

	Technological barriers for V2G in Denmark	
General barriers in Europe, cf. chapter *1.4. Technological factors*	Discharging process	Some of the present BEV models are not designed for bi-directional charging.
	Battery lifetime	Insecurity about the effect of V2G on battery lifetime.
National barrier	A small market potential for EVs	The market potential for V2G is limited by the slow movement in purchasing EVs.
	Charging infrastructure	In Denmark, the government has focused on implementing public EV charger infrastructure, but there is a need for building private chargers besides of residential, office and industry buildings, cf. chapter 2.6. Legislative factors.

Table 4 Technological barriers for V2G in Denmark

One of the primary barriers to successful implementation of V2G technology is the lack of EVs. In the future, where fossil fuels have been phased out, the amount of EVs will increase, but as of now, the EVs accounts for less than 1% of the total market share in Denmark, including PHEV vehicles. The number is below 8% for the Nordics combined that includes Norway being the world leader [16]. The "purchase anxiety" for EVs creates the classic "chicken-and-egg" dilemma: Will the grid providers install the essential charging infrastructure before customers buy the EVs? Building a comprehensive system of charging infrastructure will open up new possibilities for EV drivers to use V2G.

The concerns towards battery degradation are, however, not the only technology dilemma introduced with the potential use of V2G. Current EV's models must add new functions to their design as the majority of existing models are incompatible with the present V2G infrastructure. The V2G implementation will result in an increased vehicle and infrastructure cost. Price is already a barrier as EVs suffers from the problem of costing significantly more than comparable conventional cars, often as much as twice the price such as the Volkswagen Up with a current price differentiation of 13.200 €.

Danish charging operators such as Clever and E.ON are facing significant risks regarding investments if the purchase movements of EVs continuous to disappoint due to unknown customer demand and behaviour. Such risks and potential losses might discourage investors from investing in the technology in the future.

2.5. Environmental factors

V2G is regarded as cleantech, as it can result in a reduction of the need for fossil fuels in the production of electricity. The environmental barriers for implementing V2G in Denmark has been summarized in Table 5.

	Enviromental barriers for V2G in Denmark	
General barriers in Europe, cf. chapter *1.5. Environmental factors*	Customers' choice of purchase	Most customers want to have a green profile and be environmentally responsible, however, only if it is inexpensive and convenient for them.
	Battery lifetime	The technology must demonstrate that V2G does not significantly contribute to battery degradation as it would damage the environment.
	Few early adopters	Early adopters are most likely environmentally driven and represent only a minor part of the total customers

Table 5 Environmental barriers for V2G in Denmark

In the first quarter of 2017, the purchasing power of consumers were dismal, as the EV stock in Denmark has decreased for the first time since the introduction of the modern EV models. Therefore, the potential number of early adopters (potential EV consumers with environmental purchasing interest) have been small in the first quarter compared to other countries in Europe [16].

2.6. Legislative factors

There is a political wish to ease the conditions for smart grids in both Denmark and EU. The legislative barriers for implementing V2G in Denmark has been summarized in Table 6.

Legislative barriers for V2G in Denmark		
General barriers in Europe. Cf. Chapter *1.6. Legislative factors*	Magnitude of the electricity traded	It is a condition that a minimum amount of electricity can be made available to the market. This and the legal regulation of the market is explained below.
	Data security	V2G are dealing with private consumers who shall be agreed on the procedure for protection of personal data.
	Ownerships issue	There are no clear rules towards the ownership of energy storage systems
National barrier	Building Regulation	Building regulation should be changed for positive affect the development of private charger infrastructure in the future.

Table 6 Legislative barriers for V2G in Denmark

Energinet is the TSO in Denmark. Supply and demand regulation are regulated by electricity services that different players can bid on the electricity market. The most significant trades take place on the Nord Pool electricity exchange owned and driven by the Nordic TSOs.

As mentioned in chapter 2.2. Economic factors, EVs can provide flexibility to the primary reserve market with asymmetric bids. Whereas, secondary reserve requires symmetric bids, but in DK secondary reserve is not relevant market for aggregators to enter, as DK has a long-term contact with Sweden for provision of secondary reserves and secondary reserve is only open for aggregator by breakdowns of the interconnection between Sweden and Denmark [38]. However, the technical barrier for an EV is that it must bid at least 0.3 MW (300 kW) to enter the dayahead market. This means that a number of EVs must be pooled, e.g. 30 EVs with 10 kW chargers. It is likely that the energy provider or a BRP will aggregate the EVs and organize the bid on Nord Pool.Other market players approved by Energinet, such as an independent commercial aggregator or an aggregator, which cooperates with an energy provider and/or a BRP may do this as well [37]. The advantage, besides the lower entrance bid, is that it is less costly to provide this service. The disadvantage is that the electricity is not as well paid as the price for the reserve electricity. The price is the market price of the activation day on Nord Pool.

According to an interview study by Aarhus University (AU), the Danish Building regulation should support the EV transition by developing incentives for installing charging stations at houses, apartments and private companies and public buildings instead of making incentives for extending the public charging infrastructure [26].

2.7. Sub-conclusion for barriers in Denmark

West Denmark, also called DK2, has the highest need for flexibility capacity and thus the area, a commercial aggregator can get the best economic potential to provide with frequency regulation. The Danish TSO creates opportunities for opening frequency-regulation reserve markets to commercial aggregators, especially FCR-market. However, some of the obstacles are high electricity prices, lack of EV fleet and dual taxation on V2G charge and discharge. Despite the barriers mentioned above, Denmark is environmentally conscious and first mover on R&D projects regarding V2G. With an extensive production of wind energy and public environmental awareness, V2G fits into the national framework but it requires political assistance in order to create a promising business case for V2G.

3. Barrier analysis for V2G implementation in Germany

Germany is well-known for the car industry, and some of the German car manufacturers have been impacted after the emission scandal related to higher emission of gases from new diesel vehicles than reported. However, the German automobile industry has not followed the technology development of EVs.

The PESTEL analysis has been composed on the basis of a literature review. The analysis will be compared with interviews answers in writing, as partners in the Parker project will answer specific questions related to the macro analysis.

3.1. Political factors

The political barriers to implementing V2G in Germany has been summarized in Table 7, and the national barriers have been explained in-depth below.

	Political barriers for V2G in Germany	
General barrier in Europe, cf. chapter *1.1. Political factors.*	Independent V2G aggregator	Interest may lose if a V2G aggregator is stipulated to contract with the BRP and consumer/prosumers without incentives
National barriers	EV purchase subsidies	Purchase subsidies are limited to last for a maximum of 400.000 cars in total or the period for subsidies will end in 2020.
	Industry dependency	The German automotive industry has for the past decades continuously developed ICE technologies while lobbying against the growth of EVs. The government continues to support the car industry despite the emission scandal with diesel vehicles.
	Cooperation with other industries	Various industries have to cooperate in the future, as the automotive and utility industry may establish the necessary grid and vehicle technology for implementing the V2G technology
	Decentralized market	Characterised by being decentralised and diverse, the German market has multiple interests varying from one state to another

Table 7 Political barriers for V2G in Germany

Till now, V2G is recognized as a potential enabler of demand response, power security, and renewable integration. From an environmental point of view, EVs are considered as a promising solution to remove ICE vehicles. However, the levels of EV market penetration have been low, as out of an estimated pool of 46 million vehicles in Germany, only 75.000 were EVs by the end of 2016 with a current market share below 1 %. Purchase subsidies play a significant role in the acceptance of the drivers. In Germany, the purchase subsidies will expire by the end of 2020 or at the 400.000 sales mark. EVs purchased before the end of 2015 got Ownership Tax exemption for the following ten years, and EVs purchased after that date got exemption of five years until the end of 2020 [17]. Lack of consistent incentives is the primary barrier to EV expansion as it depends critically on the political environment. The gate results in a limited base amount of EVs for providing potential V2G services to power systems. Germany is one of the biggest car producers in the world and home for several of the largest car OEM's in the world. The industry has a significant impact on the future direction of technology and mobility in Germany and to some extent the global market.

Historically, these car manufacturers have been focusing on the development and improvement of ICE vehicles and investing in an enormous amount of money in R&D, but with a limited interest in EVs and potential V2G technology. Consequently, limited awareness in the alternatives vehicles, the

German car OEMs will impact the transmission to cleaner alternatives negatively. Even with the massive diesel emission scandal where German car giants potentially colluded with emissions, Germany's federal government continues to support the industry stating that they are against individual states and cities banning cars with diesel engines [18], despite several warnings from EU officials regarding high levels of air pollutant. The reason for support from the government could be that one in seven jobs are directly or indirectly linked to the car industry, and the importance of the sector is enormous. Overall, there are various associations of interest connected with protecting the business, and their concerns are often looked after by the government due to the high economy sensitivity [19].

The fundamentals needed to implement EVs as regulating power involves collaboration between two major industries that previously have had very little in common: the German automotive industry and the utility industry. An important question to address is; Who will invest in the infrastructure: the car manufacturers or the utilities? However, if the charging infrastructure is primarily installed without V2G, it might be difficult to modify the infrastructure in the future.

3.2. Economic factors

There has been identified following economic barriers for V2G in Germany, cf. Table 8. The barriers have been explained below.

Economic barriers in Germany		
General barriers. The barriers are explained in chapter, *1.2. Economic factors.*	Market reform	Current bidding rules are not suitable for achieving the cost-effective use of small-scale V2G aggregators as they are designed towards symmetric bids instead of preferred asymmetric bids, cf. general economic factors.
	System investment	Update of monitoring and metering systems requests a significant amount of investment which shrinks the interests of the DSOs. The penetration of smart meters was only 1.6% in Germany and it is not expected to increase due to negative cost-benefit results [34].
	Emerging market	Public distribution-level market is necessary for realise various V2G services for the DSOs. However, in Germany, the authority has not offered a public distribution-level market, where DSOs and independent V2G aggregators can trade efficiently
	High charging cost	High electricity price results in high charging cost, why V2G can cause to high expenses for both the prosumer and the commercial V2G aggregator
National barriers	Type of innovation	The German automotive industry focuses on incremental innovation and optimizes ICE vehicles.
	German GDP highly depends on the car industry	The automotive sector is important for the German economy, because of its GDP share

Table 8 Economic barriers in Germany

The German car industry has for several decades been world market leader in the automotive field. However, their expertise is concentrating on ICE vehicles and based on that they developed a tool of skills with networks of component suppliers and manufactured while only to a limited degree create innovation towards the development of EVs. The German car industry has focused on incremental innovation by optimizing ICE vehicles instead of innovate radical, as it demands to extend the network for generating new knowledge for entering a new market. The automotive industry has announced dedication to the development of electric vehicles in the long term. However, the short-term focus on CO2 reduction is based on the improvement of ICE vehicles as radical innovation requires large investments. Environmental focus is less important for the industry as electro-mobility is not considered as a threat to the current core business but rather a new field to conquer when the time is right according to the industry [5].

The power of the German car industry is evident when compared to its contribution to Germany's gross domestic product. The sector managed to achieve combined annual sales of 385 billion € last year equal to 14 % GDP of the total 14% of GDP.

The most critical barriers for V2G applications are high EV charging costs due to high electricity prices. According to EU electricity price statics, the German electricity price is approximately 0.30 €/kWh including taxes, levies and VAT, cf. *Figure 1*. Therefore, it is challenging for the potential V2G aggregators to make a profit in Germany due to high operating expenses.

3.3. Social factors

There has been identified following social barriers for implementing V2G in Germany, cf. Table 9. The social barriers have been explained below.

	Social barriers in Germany	
General Barriers in Europe, cf. Chapter *1.3. Social factors*	User behaviour & instructions	Prosumers need guidance and education to V2G in order to gain public acceptance
	Vehicle availability	Access to the vehicle is a major concern towards V2G implementation from the prosumers' point of views, as their needs for driving are essential. V2G must ensure flexibility in its design and leave room for practical use
	Trust in the technology	The technology must be able to give prosumers the confidence that the system will operate reliably and secures the car is fully charged or charged as required whenever needed
	Lack of motivation	Prosumers are potentially not motivated to lend their battery to the grid if the business case is complicated and economic insufficient
National barriers	Lack of public interest	In Germany, it is not popular to drive an EV.

Table 9 Social barriers in Germany

One important barrier addresses the consumer's lack of interest in EVs in Germany as the EV penetration is essential to the active practice of V2G. As stated in 3.1. Political factors, EVs currently only account for less than 1% of the total car market, primarily caused by social barriers created by history. In decades, Germany has been a nation of ICE vehicles, why EVs have not been fully adopted by consumers. Furthermore, studies have identified evidence which indicates a direct link between consumer acceptance and adoption of new technologies with the degree of political support [3]. Modern EV models are deemed as a secondary product, even when estimating fuel cost savings. They offer shorter range and longer refuelling times at a noteworthy price premium. The German consumers evaluate EVs against the same standards as ICE vehicles, as consumers expect an equivalent product. Even with the undergoing development of EVs, the alternative will not be attractive to the majority of the potential users in the short term [8].

In Germany, two customer segments have been recognised as potential users of EVs, as they might prefer EVs rather than ICE vehicles. Younger, less educated, and very environmentally aware customers are more likely to invest their capital in modern technologies such as EVs and in general, while PHEVs are more appealing to the old and technical customers of large cars. Poor fit between potential buyers and the current technology standard is, to some extent, a barrier as EVs are currently more expensive than ICE vehicles, which makes it harder for younger consumers to afford this type of vehicle [9].

3.4. Technological factors

There has been identified following technical barriers for implementing V2G in Germany, cf. Table 10. The technical barriers have been explained below.

	Technical barriers in Germany	
General barriers in Europe, cf. chapter *1.4. Technological factors*	Battery lifetime	Frequent charging and discharging activities caused by utilising V2G could potentially decrease battery lifetime
	Discharging process	Some of the present BEV models are impracticable with the current V2G infrastructure as they are not designed for bi-directional charging
	Capacity of EVs	Compared to other energy resources, EVs are completely mobile and limited by battery size
National barriers	Demand side Management issue	Uncertainty regarding the number of batteries available with random energy demand requires active management solutions
	User-driven charging issues	There are two types of charging; User-driven charging and Cost-driven charging. By operating V2G, cost-driven charging is utilised on a larger scale. This charging method addresses important issues towards the CO_2 emissions.

Table 10 Technical barriers in Germany

Current customer demands seem insufficient in Germany compared to the expenses and risk which are followed by the development of new car models. German charging operators such as EnBW are facing high risks investments if the deployment of EV's continuous to disappoint and the risks might discourage investors from investing in the technology in the future. Since 2015, the power consumption of EVs in Germany has been limited compared to the overall energy demand. The level is assumed to remain flat in 2020 with a power requirement of only 0.1-0.2 % of the total power consumption. Focusing on 2030, an increase in energy consumption will result in EVs being responsible for 1.6 % of the total consumption according to studies [13].

A commercial aggregator has two different ways to charge an EV, User-driven charging and Cost-driven charging. In Germany, the environmental impacts of two different charging methods have been investigated, cf. 3.5. Environmental factors. The choosen charging approach will influence the reliability of the flexibility provided, as actual charging loads will vary and occasionally become relatively high if the charging is uncontrolled. In general, user-driven charging is separated in three daily load peaks, which vizualize daily driving activities by user-driven charging. Frequently, the load equation does not include evening periods of cars being fully charged due to the "fast charge goal". Whereas, cost-driven charging focuses on limiting the cost of energy by charging in time periods with a small degree of power demand and thereby cause to flatten impact on the electricity grid [13].

Given the significance of a stable and secure power system in Germany, V2G as a regulating power solution requires a high degree of capacity reliability. An aggregator cannot know exactly if a particular vehicle will be accessible at a given time or guarantee constant availability. Also, the storage capacity of each battery is restricted, and when full, no more down regulation can be delivered. V2G is a complicated technology, as many small units need to be activated simultaneously and in order to accommodate the necessary bid size required by the grid. The threat given by this barrier will decrease as the penetration of EVs grow along with the development and improvement of existing aggregator technologies [6].

3.5. Environmental factors

The environmental barriers in Germany, which can impact the future of V2G, has been defined in Table 11. However, the factors are comparable with the investigated current and future environmental barriers in Denmark.

	Environmental barriers in Germany	
General barriers in Europe, cf. chapter *1.5. Environmental factors*	Customers' choice of purchase	Most customers want a green profile and are environmentally responsible, however, only if it is inexpensive and convenient for them. Therefore, the environmental effect does not increase the fiscal value of a product.
	Few early adopters	Early adopters are most likely environmentally driven and represent only a minor part of the total customers of EVs.
	Battery lifetime	The technology must demonstrate that V2G does not significantly contribute to battery degradation as it would profoundly damage the environment.
	Load management	Load control is necessary. Uncontrolled charging of EVs can cause more rapid peak periods into the grid
National barriers	EV subsides	EV owners mainly use the lucrative subsides as an excuse for acquire a second car

Table 11 Environmental barriers in Germany

A significant penetration of EVs will have an impact on the performance of the existing electricity grid, as higher system loading could affect the overall system reliability. Uncontrolled or concentrated charging of massive fleets of EVs may lead to higher peak loads mainly in the evening periods. The effect of uncoordinated EV charging could result in the use of fossil-fueled energy resources in order to stabilise the grid as the peaking phase is shifted away from the optimal hours of solar and unreliable shifting winds from wind generation [9]. Efficient use of load management throughout a smart grid solution within the existing system of the electric grid is a necessity to prevent such uncontrolled energy sparks.

From an environmental point of view, cost-driven charging is favoured as peak loads are environmentally damaging, and with the potential of even larger penetration of EVs, increases the impacts on the grids. The focus of V2G technology points at cost-driven charging, as that charging approach can cause to reduced impacts on the power system. However, modest relaxation of user-driven charging strategy restricts the "fast charge goal" and the strategy will result in a considerably flattened load profile, and thus omitsone of the advantages of cost-driving charging as the adverse effect of the power grid is reduced. In fact, among the two different charging strategies in Germany, the cost-driven strategy always leads to major CO2 emissions compared to user-driven charging. Cost-driving charging combined with the power plants which mostly consists of emissions-intensive generators cause to high environmental impacts, as it allows for rearranging some charging actions toward hours in which fossil energy resources are under-utilised, whereas the user-driven charging frequently appears in times in which fossil resources are already entirely used [13].

3.6. Legislative factors

Table 12 defines important barrier for the German energy market and the implementation of V2G in Germany. The barriers are summarised below.

	Legislative barriers in Germany	
General barriers in Europe. Cf. Chapter *1.6. Legislative factors*	Magnitude of the electricity traded	It is a condition that a minimum amount of electricity can be made available to the market. The legal regulation of the market is explained below.
	Data security	V2G are dealing with private consumers who shall be agreed on the procedure for protection of personal data.
National barrier	Ownership issue	There are no clear rules towards the ownership of energy storage systems

Table 12 Legislative barriers in Germany

In Germany, TransnetBW, Tennet TSO, Amprion and 50 Hertz Transmission are responsible for the electric transmission grid [20]. The German TSOs and local DSOs are impacted by unclear EU legislatives regarding energy storage system, as it is unclear if they can own or control storage systems in general. The ownership of storage systems allows them to balance the grid by using renewable energy efficiently [21].

Supply and demand regulations are regulated by electricity services that different players can bid on the electricity market. The most significant trades take place on the International PFC cooperation electricity exchange owned and driven by TSOs from German, Belgian, Dutch, French, Swiss and Austrian markets with a total demand of over 1250 MW is created. It is likely that a German commercial aggregator (both current and new energy market actors can act as a commercial aggregator) will aggregate the cars and organise the bid on International PFC, service and accounting, but other market players approved by the TSOs may do this as well.

3.7. Sub-conclusion for barriers in Germany

Highly depending on the political and economic factors, successful implementation of V2G in Germany is facing significant barriers. The current moderate degree of EV penetration combined with the general interest from the car industry in keeping ICE vehicles affect the political will to move towards new energy alternatives within the automotive sector called Energiewende, as the expenses towards infrastructure are high. Furthermore, EVs are in general considered less attractive compared to other vehicle options. Despite the fact that the German government insists on R&D and is, to some extent, shifting towards a desirable environment for EVs, V2G is not of a status as a developing technology that pushes towards commercialisation in Germany.

4. Barrier analysis for V2G implementation in Sweden

Acknowledged its modern electric power system and consequent pledges to promote decarbonization, Sweden is ideally suited to shift from ICE vehicles to EVs and thereby has the opportunity to implement V2G successfully. However, the electrical power system poses a challenge for the country, as nuclear power plants are phased out [22]. The Swedish section is mainly based on previous interviews with several of the Swedish grid providers carried out by the university of Uppsala [33]. The PESTEL analysis has been composed on the basis of a literature review. Furthermore, the analysis has been compared with one interview answered in writing, as the partner in the Parker project has answered specific questions related to the macro analysis.

4.1. Political factors

The political barriers for implementing V2G in Sweden has been summarised in Table 13.

	Political barriers for V2G in Sweden	
General barrier in Europe, cf. chapter 1.1. Political factors.	Independent V2G aggregator	Interest may lose if a V2G aggregator is stimulated to contract with a BRP and a consumer/prosumer without incentives.
National barriers	EV purchase subsidies	Purchase subsidies are limited to 2.100 € for PHEVs and 4.200 € for EVs with an emission of maximum 50 g/km. The amount for PHEVs was halved in 2016. The rebate was introduced in 2012 and was designed to cover 5.000 vehicles but has been extended for the past years. However, Swedish EV customers do not obtain the discount at the points of purchase.
	Industry dependency	The Swedish automotive industry (mainly Volvo) has for the past decades been favouring the continuous development of ICE technologies.

Table 13 Political barriers in Sweden

The purchase subsidies in Sweden (*supermiljöbilspremie*) is the spine of Sweden's EV policies. EV consumers obtain approximately 4,200 euros in a reduction for the acquisition of a new vehicle that emits no more than 50 grams of carbon dioxide per kilometre. This means that BEVs and most PHEV models are qualified for the discount, even though it was halved for PHEVs in 2016. Initially, the discount was designed to cover 5000 vehicles when it was introduced in 2012. However, a high number of vehicles was already reached by the mid-of 2014. Consequently, the subsidy program has been extended for the past five years. Such continuous extension is a barrier as dependability is affected. For each extended year, the Swedish government estimates a determined amount of funds for the discount. These resources are continually drained before the government commits to continue the program. Therefore, the funds are moving into the market at a faster paste than the Swedish government will provide them. Furthermore, the Swedish EV owners do not obtain the discount at the point of sale. In fact, the Swedish Transport Agency observes EV purchases for providing incentives to potential consumers to invest in an EV. Upon receiving the legal paperwork, the agency releases the discount to the EV owner [23].

4.2. Economic factors

As mentioned in chapter 1.2. Economic factors, a V2G aggregator can participate in the existing market, while it seeks to maximise its profit by submitting bids and reducing cost.
There has been identified following economic barriers for V2G in Sweden, see Table 14.

	Economic barriers for V2G in Sweden	
General barriers in Europe. The barriers are explained in the chapter, *1.2. Economic factors*	Market reform	Current bidding rules are not suitable for achieving the cost-effective use of small-scale V2G aggregators.
	System investment	Update of monitoring and metering systems requests a significant amount of investment which shrinks the interests of the DSOs
	Emerging market	In Sweden, the authority has not offered a public distribution-level market, where DSOs and independent V2G aggregators can trade efficiently.
	High charging cost	High electricity price increases V2G charging cost dramatically.
National barriers	Infrastructure investments	V2G implementation demands large investments in infrastructure. Currently, the Swedish government supports the development of the charging infrastructure.
	Lack of pricing incentives	The industry is not willing to invest in the R&D of the technology due to the economic incentives
	Small variation regarding load demand pricing	Small price difference between high and low load demand

Table 14 Economic barriers in Sweden

An economic barrier for V2G in Sweden is the system investment. For V2G to be a part of the Swedish system a lot of investment has to be made. The monitoring and metering system has to be updated, and the related high investment costs can lower the interest from TSO and DSO. In order to enable Sweden in accommodating V2G, the authority has to offer a public distribution-level market, where DSOs and independent V2G aggregators can trade efficiently. The public distribution-level market is necessary for realising various V2G services for the DSOs.

It is recommended that Sweden should implement a bonus-malus system, where the system alternately rewards (bonus) or penalises (malus) the EV users. Citizens with EVs and prosumers will be rewarded economically. If the industry is not willing to invest in the development of V2G, the economic incentives are too weak. Several actors within the V2G development find it too expensive and complicated to develop the technology, as a collaboration between the industry, the academia and the government is highly complex and time-consuming. The actors have to make profit of their work in the future for creating value of V2G [32].
One of the most critical barriers for V2G implementation is high charging cost. The charging cost is affected by the high electricity price and the dual taxation for both EV charge and discharge. In Sweden, the electricity price is 0.19 €/kWh including taxes, levies and VAT and consumers pay approximately 32% of the taxes, levies and VAT out of the total electricity price, cf. Figure 1 & Figure 2. The high electricity price can make it very difficult to make it profitable to implement V2G.

The infrastructure is also an important barrier for implementing V2G. The Swedish government supports the development of charging infrastructure, but it can be a major factor that private EV owners gets support as well for implementing chargers at home. Many of the grid providers in Sweden argued that there is a need for pricing incentivise to invest in V2G duo to the geographic positioning and high level of grid advancement in Sweden. The absence of electrical pricing incentives causes the price of electricity to be stable and reliable. The small difference regarding pricing within high and low load demands does not increase the expenses [33].

4.3. Social factors

There has been identified following social barriers for implementing V2G in Sweden, see *Table 15*. The barriers have been explained below.

	Social barriers in Sweden	
General barriers in Europe, cf. chapter 1.3. *Social factors*	User behaviour and instructions	EV owners need guidance and education to V2G in order to gain public acceptance.
	Vehicle availability	The EV owners are concerned about the access to the car during V2G implementation, as their needs for driving are essential. V2G must ensure flexibility in its design and leave room for practical use. The EV owner must trust the technology, and the system will operate reliably and leave the car charged as required whenever needed.
	Lack of motivation	The EV owners are not motivated to lend their battery to the grid if the business case is economic insufficient.
National barriers	Public interest	Currently, EVs are considered important in Sweden, with a relatively high level of public acceptance. However, The EVs are still very expensive compared to the ICEs.
	Conservative market	The Swedish industry consider the electricity market to be conservative

Table 15 Social barriers in Sweden

The first barrier to address is the EV owners concern about the availability of the vehicle. It is essential for the EV owners that the EV is available with a charged battery when they need it. Therefore, the technology of V2G must be reliable in order to gain the EV owners' trust. Sweden is a country that is ideally suited for transit to EVs as they have a low-carbon electricity power system and they have a strong commitment to further decarbonization. The Swedish government consider EVs as an important part of the future, and the public has accepted it to some extent. One of the biggest barriers in Sweden regarding EVs is the price, and therefore the high price does affect the public and their acceptance. Another social barrier that affects the publics acceptance of V2G is their level of knowledge about the matter. The public needs guidance in V2G in order to understand the advantages and possibilities that occur in an electricity market with V2G implemented.

Another important social barrier is the lack of motivation for the EV owners to lend their battery to the grid. As mentioned above, the EV owner has concerns about the availability of their cars when working with V2G. Even though some EV owners drive EVs because of the environment, the economy has a higher priority. No EV owner would lend their battery to the grid without economic benefits. Therefore, the business plan for V2G has to be economically profitable for the EV owner [22].

Large corporations in Sweden such as ABB consider the electricity market to be, to some extent, conservative and old fashioned overall. They believe the concern and scepticism regarding extended communication in the grid are restricting possible innovation and approval of new technological opportunities. According to the industry, the technical barriers to implementing V2G and other smart grid solutions are second to the opinion related to it. Furthermore, the lack of demand from the customer side is ultimately removing any market potential for V2G in Sweden. The lack of public interest might be caused by the large production of non-carbon electricity in Sweden; they simply consider the current situation to be acceptable [32].

4.4. Technical factors

There has been identified following technical barriers for implementing V2G in Sweden, see Table 16. The national barriers have been explained below.

	Technological barriers in Sweden	
General barriers in Europe, cf. chapter *1.4. Technological factors*	Discharging process	Several of the EV models and chargers in Sweden are not designed for bi-directional charging, and the EVs can therefore not accommodate the requirements for V2G.
	Battery lifetime	It is still unknown how it will affect the lifetime of the battery if it gets charged and frequently discharged by utilizing V2G.
	Capacity of EVs	Compared to other energy resources, EVs are completely mobile and limited by battery size.
National barriers	Charging infrastructure	There is a limited amount of charging infrastructure in Sweden. In order to V2G to work, the “daily” charging (such as chargers at home, work places etc.) has to be improved and available for all EVs.
	Demand side management issues	It is uncertain how many batteries are available at a specific period, which gives a random flexibility supply through V2G.
	Lack of demand	Sweden has only a small need for new ways of generating power.
	Grid design	The current grid is designed towards supporting few but big producers of electricity
	Risk of overload	Local power production could lead to the potential for overload due to the high-power generation from other sources

Table 16 Technical barriers in Sweden

In Sweden, Svenska Kraftnät is the TSO and five regional companies manage the distribution grid with approximately 170 companies, which are responsible for the local networks. Another technology barrier that concerns the Swedish interviewees is that it is unknown if the frequently charging and discharging of the battery will affect the lifetime of the battery. If the V2G technology shortens the lifetime of the battery, it can be very costly for the EV owner, and therefore not profitable. The interviewees were divided into two groups when talking about the issues of the capacity of EVs [22]. One group could see the benefits of V2G and thought it was an interesting technology. The other group was more sceptical, as they could not see how V2G should be beneficial to Sweden compared to second-hand purpose-built (stationary) battery storage. As the capacity of the latter can be bigger than the capacity of an EV.

Sweden does not need alternative ways of producing electricity to the grid, as more than 99% of the Swedish people could have unlimited access to electricity from CO2 neutral sources (hydro, nuclear and wind). Besides this Sweden is a net generator of electricity with ideal and carbon free electricity typically produced by hydrogen and nuclear power. The redeeming of nuclear power is advancing at a slow pace affected by the export of electricity to other countries. Furthermore, another limitation towards removing nuclear power out of the equation is the fact that wind power and solar energy are conditioned on geographical positioning and weather and V2G cannot fully support the power transition from nuclear to renewable energy due to lack of capacity. An additional barrier is the current grid design. Originally designed to be centralized and to support only a few, but large power producers, the current state of electricity is flowing one way, downstream, and should change in order to make room for smaller electricity providers [32].

With the expansion of local power providers, energy supply is more stable in peaking periods as the energy transportation is shorter, which in many ways is excellent. However, with a more common production of local energy comes the risk of decreasing the efficiency of the providers as previously experienced in Gotland, where they had to stop the local wind production to prevent overload in the electricity system. V2G is also more unstable and harder to regulate than hydro power due to a series of factors [32] mentioned in chapter 1.4. Technological factors.

4.5. Environmental factors

Sweden has a goal of being independent of fossil fuels by 2020, and the aim for the transportation system is a reduction of 70% carbon by 2030 (compared to 1990 levels). Several experts say: "*the central benefit of V2G would be to "save" hydro capacity for services it was better suited for, given battery's suitability for short-term balancing*" [24]. The V2G technology has to address the sustainable issues followed by using the technology. There has been identified following environmental barriers for implementing V2G in Sweden, see Table 17.

	Environmental barriers for V2G in Sweden	
General barriers in Europe. See chapter *1.5. Environmental factors*	Customers' choice of purchase	Most EV owners buy an EV because they want a green profile and are environmentally responsible, but only if it is inexpensive and convenient for them.
	Few early adopters	The early adopters of EV are most likely environmentally driven, but only represents a small part of the total customer group.
	Load management	Charging of a large quantity of EVs can cause more rapid peak periods into the grid.
	Battery lifetime	It must be demonstrated that V2G does not contribute to a significant degradation of the lifetime of the battery, as this will damage the environment.

Table 17 Environmental barriers in Sweden

The risk of a potential degradation of the battery lifetime caused by the use of V2G technology is that the technology is not sustainable. The V2G technology has to be proven that it will not affect the battery lifetime significantly and thus a clean technology to utilise for providing with the flexibility to the electricity grid.

4.6. Legislative factors

V2G has only been an object of research- and demonstration projects in Sweden and has not entered the market on a commercial basis yet. Sweden has only had few projects with V2G, and there is currently no legislation that directly regulates V2G as technology. However, V2G is part of the general electricity legislation and it has to obey these legislations. There have been identified following legislative barriers for implementing V2G in Sweden, see Table 18.

Legislative barriers for V2G in Sweden		
General barriers in Europe. Cf. Chapter *1.6. Legislative factors.*	Magnitude of the electricity traded	There is a condition that a minimum amount of electricity can be made available for the market. An aggregator can, therefore, be a link between the EVs and the DSO/TSO.
	Data security	V2G are dealing with private consumers who shall be agreed on the procedure for protection of personal data.
	Ownerships issue	There are no clear rules towards the ownership of energy storage systems

Table 18 Legislative barriers in Sweden

As mentioned in chapter 1.1 Polictical factors, the Swedish transmission system operator, Svenska Kraftnät, is responsible for the electric transmission grid. Most of the electricity consumption is in the south of Sweden, while most of the production takes place in the North [25]. There is a minimum amount of electricity which can be delivered to the grid. On the ancillary market (reserve market) the capacity provided should be more than 1 MW. On the energy market (spot market) the capacity provided should be around 10 MW. Therefore, a commercial aggregator can be the link between the EVs and the DSO and/or the TSO.

Data security is an important issue to consider. V2G deals with private consumers, prosumers, whose personal data shall be protected. There are no clear rules towards the ownership of energy storage systems. However, rules of ownership of energy storage systems can be made in the future when V2G becomes commercial.

4.7. Sub-conclusion for barriers in Sweden

V2G has market opportunities in Sweden as the country is environmentally friendly and in various ways moving in the direction of creating the foundation for utilising the technology as EV sales are continuing to increase, however, the surrounding market aspects are creating essential barriers. First, the Swedish power market operates excellent in its current state with an environmentally friendly production securing almost unlimited power to the grid while leaving very little room for new providers. The barrier creates an insecure market to invest in which leads to the absence of R&D projects. Second, the immature market conditions create significant barriers for the technology as both the grid and customers lack both interest and demand in new technical opportunities, as they prefer to keep "business as usual". In total, the Swedish grid is considered adequate to its current obligation, and the need and interest in radical changes are missing. Such conditions combined with the lack of beneficial regulations from the political aspects leave the market in a weak position from a V2G standpoint.

5. Barrier analysis for V2G implementation in Norway

Norway is stated as a clean country, as approximately 98% of the electricity is provided from hydropower. The electricity market is satuated with green energy which results in low electricity prices. Furthermore, Norway is a global frontrunner within electromobility due to the highest share of BEVs in the world, and the BEVs are provided with green electricity, and thus BEVs provide to a good environmental performance at national level [26], [36]. The barrier analysis is based on survey analysis from 2017 conducted by AU and Noel et al. (2017), which has interviewed experts about status, challenges and opportunities for EVs and V2G in Norway [27].

5.1. Political factors

Both the public transportation system and the private transport are challenged by Norway's geography, winter conditions and its varied topography. Therefore, it is difficult for the government to meet the public's needs and at the same time deal with the environmental problems.

The political barriers to implement V2G in Norway has been summarised in Table 19**Error! Reference source not found.**, and the national barriers have been explained in-depth below.

Political barriers for V2G in Norway		
General barrier in Europe, cf. chapter 1.1. Political factors.	Independent V2G aggregator	Interest may lose if a V2G aggregator is stipulated to contract with the BRP and consumer/prosumers without incentives
National barriers	Need investments in charging infrastructure	Need investments in high-speed DC chargers for allowing the opportunity for long distance driving
	Need to increase the knowledge about charging opportunities	The government needs to support the regulations and information about charging infrastructure in local communities.
	Bottom-up regulation for implementing V2G	The industry may support the V2G development due to lack of perceived need for flexibility

Table 19 Political barriers for V2G in Norway

According to AU, experts state that the Norwegian government should not take a role in the development of V2G, but instead create market conditions for V2G. For market conditions, cf. 5.2. Economic factors. The industry may develop the V2G technology, and thus the technology may be pushed into the market by bottom-up regulation and thus create a need for flexibility service. However, it is only relevant for Norwegian market to participate in V2G projects, if the local DSO has a potential need for stabilise the grid [27].

5.2. Economic factors

The Norwegian electricity market does not need flexibility provision by V2G due to the surplus of produced electricity by hydropower. As mentioned in the quotation in Noel et al. (2017), "Norway's substantial hydroelectric capacity in many ways obviates the need for V2G" [27, p. 3]. The self-sufficiency of power results in low electricity prices, which gives non-incentives to develop new cleantech in spite of unexploited resources [27]. There has been identified following economic barriers for V2G in Norway, cf. Table 20.

Economic barriers for V2G in Norway		
General barriers in Europe. The barriers are explained in chapter, *1.2. Economic factors*	Market reform	Current bidding rules are not suitable for achieving the cost-effective use of small-scale V2G aggregators.
	System investment	Update of monitoring and metering systems requests a significant amount of investment and expenses which shrink the interests of the DSOs.
	Emerging market	The government has not offered a public distribution-level market, where DSOs and independent V2G aggregators can trade efficiently.
National Barriers	Infrastructure investments	V2G implementation demands high investments in infrastructure. However, the government develops public charging stations, which are free to use for all E-cars.
	Market conditions and structures	Both the current market conditions and structure are a barrier for V2G to inter the electricity market.
	Different market interests	TSO and DSO have a different interest in the development of V2G technology due to different perceived needs.

Table 20 Economic barriers for V2G in Norway

In Norway, green cars are promoted with economic incentives. BEV and hydrogen cars are exempted from vehicle registration tax, and the tax on hybrid cars is reduced due to low emission of CO_2 and NO_x BEVs are also exempted from 25% VAT. Furthermore the incentives for EVs make the purchase price for BEVs competitive with prices of ICEVs [36]. Furthermore, the electricity is cheap, and thus the charging costs are not as high as in Denmark, Germany and Sweden. Therefore, Norway offers public free power charging stations for e-car owners [26]. The electricity price is 0.165 €/kWh and consumers pay 30.5% of the taxes and levies on used electricity.

According to AU's informants, the current Norwegian market conditions are a main barrier for the V2G implement. It is seen that the V2G technology will be useful for Norway if the export of electricity will be increased by decreasing the import of nuclear energy from Sweden and not store the energy in domestic water heaters, but instead utilise EVs for flexibility provision [27]. Furthermore, the market for primary reserves is based on both *daily and weekly reserves* market for securing sufficient primary response in the system compared to the other countries, which only have daily reserves, cf. 1.6. Legislative factors. The weekly market is running before the power spot market in NordPool, called "Elspot market", and the daily market may provide with the rest demands in the power spot market and demands from TSOs. Norway has a weekly market for securing reorganization of planned production in the "Elspot" market and secure sufficient reserve volumes [35]. Therefore, *daily reserves* can provide with the flexibility to the electricity market, if it is demanded, and at the same time increase the competitiveness, whereas the *weekly reserves* secure primary reserves, but the actors can be locked to supply of power and the price of electricity in the proposition to the scheduled electricity production. The manual reserve market is therefore difficult to enter as commercial V2G without market changes, as the need for flexibility provision to the daily market is not at the same scale as for the three other countries, because of the planned weekly reserves.

The market structure mentioned above can be the reason for market actors have different interests in the development of V2G technology. TSO may not be interested in V2G services with the existing market setups, such as reserve market, regulating power market, day-ahead market, etc. Whereas, DSOs may be interested in V2G services for balancing the local grid by local congestion management and power loss reduction due to the geographically long-distance power delivery in Norway.

Therefore, V2G can provide distribution grid services in the case of power loss for the local DSOs to the local communities. However, it demands that the TSOs and DSOs cooperate and share information for developing a common, proactive grid management, as distribution grid services can result in the need for system-wide services [34].

5.3. Social factors

Norway is challenged by the goals of reducing air pollution and at the same time meet the people's needs for transportation. There has been identified following social barriers for implementing V2G in Norway, cf. Table 21. The national barriers have been explained below.

Social barriers in Norway		
General barriers in Europe, cf. chapter 1.3. *Social factors*	User behaviour and instructions	EV owners need guidance and instructions in V2G in order to gain public acceptance.
	Vehicle availability	The EV owners are concerned about the access to the vehicle during V2G implementation, as their needs for driving are essential. V2G must ensure flexibility in its design and leave room for practical use. The EV owner must trust the technology, and the system will operate reliably and leave the car charged as required whenever needed.
	Lack of motivation	The EV owners are not motivated to lend their battery to the grid if the business case is economic insufficient.
National barriers	Expectations of cheap power	Consumers expect cheap power and power security without conducting new energy efficiency initiatives
	User participation	V2G integration may be supported by the consumers for increase the market for V2G technology [28].

Table 21 Social barriers in Norway

A main social barrier for Norway is the consumers' expectation of 99% security of electricity supply in the whole country and cheap power supply [28]. The consumer's expectations can be challenged by the expansion of domestic electrification and an increase of power export, as the electricity prices or the taxes will increase [27]. However, since the 70s the electricity savings have been more important for Norwegian consumers, because of environmental values and not cost-efficiency concerns [28]. The increased share of EVs in Norway is an indication for consumer's environmental awareness. However, some consumers prefer conventional cars such as SUVs due to lack of different models of EVs [27]. Therefore, the design is an important factor in consumers' purchasing decision and a way for EV producers to improve for increase the market share and develop a market opportunity for V2G.

It is important with a transparence and open communication with the public about Smart Grid, and V2G impacts on their everyday life and the opportunity for profit performance by V2G connection to their EVs. In addition, it is relevant to inform the public about economic consequences by V2G connection to EVs in the aspect that the electricity consumers are going to pay for the costs related to installation of smart meters by an increase in the transmission tariffs to the network companies. Lesson learned in smart grid implementation in other countries is that it is important to inform the public about the related costs to secure their endorsement for V2G implementation. It is possible by creating room for user participation by open communication, dialogue and discussions for creating an understanding of the public's needs and their considerations about the technologies' implication on their social life and creating a common understanding and decisions about the technology and its impacts on the community [28].

5.4. Technical factors

Norway has been ambitious about electrification of personal vehicles, but reticent about participating in V2G development, as the potential in V2G is small compared to the robustness of electricity system and storage capacity in hydroelectric [27].

There has been identified following technical barriers for implementing V2G in Norway, see Table 22. The national technical barriers have been explained below.

Technological barriers in Norway		
General barriers in Europe, cf. chapter *1.4. Technological factors*	Battery lifetime	It is still unknown how it will affect the lifetime of the battery if it gets charged and frequently discharged by utilising V2G.
	Capacity of EVs	Compared to other energy resources, EVs are completely mobile and limited by battery size.
National barriers	Renewable energy source	Hydropower is the main electricity source in Norway, and they do not have a perceived need for flexibility to balance the grid.
	V2G projects	Norway will learn by current pilot projects before participating in V2G projects

Table 22 Technological barriers in Norway

In Norway, there are plenty of pumped hydro plants. The hydro plant has both a high environmental and economic performance, as it provides a stabile electricity production on a large scale, it is possible to store energy and quite flexible to function as a regulating power [29]. Therefore, the main barrier for V2G is that there is little need for flexibility provision from EVs in spite of the fact that the country has potential to utilize V2G capacity from EVs due to a high EV penetration. In 2016 the market share of BEVs and PHEVs was 29.1% in total [31]. EVs will be a valuable, flexible service provider with a V2G technology, as the EV can provide with electricity within very short response time and the EV can be connected to the charger during the working hours etc. [34]. Furthermore, Norway has a need for improving the charging infrastructure with DC fast chargers for securing a rapid charging of EV usable for commuters and increase the availability of chargers at housings due to Norway’s geography, dispersed population and strong weather conditions. Otherwise, EVs limited battery capacity can make it difficult to avoid ICE for long transportation, why Norway is dependent on technology improvements for a green transport transition. The third barrier for V2G is the need for system investments for avoiding grid congestion on the local distribution grid, which is an opportunity for DSO to extend the grid infrastructure. In the south of Norway, the local utility grid may be optimised by investing in smart charging and stationary batteries, but in the North, both the local and regional grid cannot handle the load, which makes it difficult to implement V2G. Furthermore, the V2G technology could be relevant for housing with distributed generations, as the EV stores the produced power or provides with emergency backup power [27].

The market does not have a perceived need for flexibility provision by V2G due to the surplus of electricity production, why Norway does not invest in technology development of V2G [27]. According to research by Aarhus University, Norway will instead learn from the Danish research results and optimise its technology research in the future [27]. Therefore, the Norwegian electricity market is not ready for innovation within V2G. However, it is seen by the researchers that Oslo municipality is part of one V2G project, SEEV4-City[1].

5.5. Environmental factors

Norway is mostly self-provided with hydropower, but the goal of the Norwegian government is to improve the air quality by reduction of particulate matter emissions and decarbonization of the transport sector, as during the 45 years, the transport industry has provided to 80% of the increased CO2-emissions. Therefore, the transport sector may improve the environmental performance by decarbonising the industry. There has been identified following environmental barriers for implementing V2G in Norway, cf. Table 23.

	Environmental barriers for V2G in Norway	
General barriers in Europe. See chapter *1.5. Environmental factors*	Customers' choice of purchase	Most EV owners buy an EV because they want a green profile and are environmentally responsible, but only if it is inexpensive and convenient for them.
	Few early adopters	The early adopters of EV are most likely environmentally driven and represent a small part of the total customers.
	Load management	Charging of a large quantity of EVs can cause more rapid peak periods into the grid.
	Battery lifetime	It must be demonstrated that V2G does not contribute to a significant degradation of the lifetime of the battery, as this will damage the environment.
National barriers	Hydro power	The environmental performance of the electricity market is good in Norway to do to clean hydro power.

Table 23 Environmental barriers for V2G in Norway

The Norwegian government has focused on making EVs competitive with ICEs for improving Norway's environmental performance, as EVs reduce CO_2 with renewable energy and provide energy-efficiency, energy security, and reduce local air and noise pollution [36]. However, the environmental performance of the EV depends on the source applied for generating the electricity. The V2G can help with improving the environmental performance, as V2G technology should reduce the need for generating energy at power stations, but instead use the available flexibilities from EVs. The interest for the V2G technology could be created by investigating the environmental performance of the V2G technology for which the market actors can compare the environmental performance and the economic performance of the investments for infrastructure improvements.

According to chapter 1.5. Environmental factors, the primary EV user is young with environmental conscious. According to Bjerkan et al. (2016), the general EV owner is a private, multihousehold, young and an affluent person. The typical EV users in Norway are primary men at the age of 30 to 60 years, high educated with high income and owner of multi-cars household [36].

5.6. Legislative factors

There have been identified following legislative barriers for implementing V2G in Norway, see Table 24.

[1] SEEV4-City project: http://www.northsearegion.eu/seev4-city/about/

	Legislative barriers for V2G in Norway	
General barriers in Europe. Cf. Chapter *1.6. Legislative factors.*	Magnitude of the electricity traded	There is a condition that a minimum amount of electricity can be made available for the market. An aggregator can, therefore, be a link between the EVs and the DSO/TSO.
	Data security	V2G are dealing with private consumers who shall be agreed on the procedure for protection of personal data.
	Ownerships issue	There are no clear rules towards the ownership of energy storage systems
National barriers	Democratic legitimacy	Strengthen the cooperation with the public before V2G is going to be implemented

Table 24 Legislative barriers for V2G in Norway

In Norway, Statnett is a system administrator and responsible for the electricity transmission grid. The V2G technology can provide a commercial aggregator with EV flexibility for being able to bid on the reserves markets.

There are no rules about the ownership of energy storage systems, but it is relevant to focus on both technical and social aspects of the technology if V2G becomes commercial. In that perspective, democratic legitimacy is relevant in cooperation with the public for strengthening the legitimacy of the technical innovation of V2G and the cooperation process for implementing the technology [28].

5.7. Sub-conclusion for barriers in Norway

Norway has the largest EV market share in the world and is self-sufficient with hydroelectricity, why the electricity prices are low, and the EVs are provided with green power. The main barriers for V2G in Norway is that they are self-sufficient of water power, and V2G implementation may result in system investments for avoiding congestion of local distribution grids. However, Norway needs DC high charging stations for securing EVs usable for longer transport distances and especially in cold weather conditions. Furthermore, the V2G can increase the market share of EVs and thus improve the environmental performance of the country. The industry may develop the V2G technology and create market opportunities in the current electricity market for creating a demand by the net system operators.

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Value System Analysis

The Value System Analysis identifies market actors, their roles and interaction of values among the actors in a V2G system in the Danish energy market. The analysis accounts for a comprehensive, high-level conceptual business description of a value system according to the Smart Grid Coordination Group Model (SGAM, 2014). In SGAM, high-level concept cases on business level are recommended to define actors and their roles, functions and responsibilities. Furthermore, SGAM recommends analysing risk impacts. Firstly, the report accounts for identified actors and their mutual roles and functions in a V2G system with a Multi Agent System (MAS). Afterwards, the transport of value between the actors are analysed by identifying a Value System based on one of the four MAS models. The four MAS figures have been developed based on each market models illustrated in MM2.0 and IEC 61851.

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1. The Multi Agent System

A Multi Agent System (MAS) has been developed to provide a framework for actors, their roles and relationships within a V2G system. The network architecture of the energy market is changing from a radial and one-way structure to a more complex bidirectional architecture (Kieny, Sebastian, Miquel, Bena, & Duretz, 2015). The V2G architecture composes of several actors with various roles and functions for developing an operative system. Actors in a V2G system can assume various functions when providing flexibility service from EVs for which reason, a V2G system can consist of few or several actors depending on actors' competences, products and strategies.

The MAS visualises both the physical energy transport between energy actors, which is illustrated with *blue* boxes for actors and *blue* arrows for relations between the actors. The market actors regarding pricing, sale and purchasing of electricity, and sale of equipment to the V2G system are illustrated with *red* boxes and related arrows. Furthermore, the MAS figures illustrate one case for which a BRP or an energy supplier take an aggregator role and three cases for which an aggregator is an independent, third-party actor. Actors, which can take an aggregator role are illustrated with *green* boxes and relations to other actors are defined with green arrows. An EV OEM and an EVSE have also been included in the V2G system, as it is relevant for the function of the system that the aggregator software can communicate with charging station and EV.

The actors' function and roles are relevant to investigate for developing sustainable business models based on V2G as technology. By introducing a V2G system into the electricity market, the commercial aggregator will be placed at the grid side of the MAS and the aggregator will cooperate with the different actors providing flexibility services to ancillary services.

Table 1 contains the description of each actors and their roles visualised in the four MAS figures. Furthermore, Table 1 refers to specific models in Market Model 2.0.

Actor	Description of actor's role in V2G system	Related to specific model in MM2.0
Distributed Generation Operator	Distributed Generation Operators produce electricity due to production demands from production BRPs.	Relevant for all four models (Model 0, 1, 2 & 3)
TSO	Transmission System Operator operates transmission grids and ensures grid stability.	
DSO	Distributed System Operator operates local distributed grids and ensures power quality.	
EVSE	Electric Vehicle Supply Equipment (EVSE) is a charging station. The EVSE is an electrical interface between the EV and the grid, and a communication channel from EV to Charge Point Operator (CPO) and the grid operators.	
EV fleet	In a V2G architecture, an EV is the flexibility unit and the EV owner is the main actor in the V2G system. An EV fleet can consist of several EVs, which are usable for both transportation and flexibility services.	
BRP	Balance Responsible Partners balances the grid by buying electricity on the Wholesale market and selling electricity to the Retail market and power on the Flexibility market.	
Electricity Provider	Electricity providers are also called energy supplier or energy utility. An electricity supplier secures electricity to consumer by purchasing electricity at the Retail market and has the responsibility for electricity transport and handles bills for electricity consumption by consumer/prosumer.	
CPO	Charge Point Operator (CPO) secures the charging of EV by EVSEs.	
EMSP	E-Mobility Service Provider (EMSP) communicates and handles billings of the EV owner and clearing house.	
EV owner	EV owner puts theirEV at disposal of the aggregator for flexibility service due to owner's daily habits and driving demands.	
Clearing House	The Clearing House handles charging/roaming and the billing processes of using chargers provided by various CPOs/EMSPs.	
EV OEM	The Original Equipment Manufacturer manufactures Electric Vehicles, and OEMs have the role as technology enabler for the V2G system.	
Aggregator	An aggregator pools EVs for providing flexibility services to grid operators by delivering a specific amount of required capacity. An aggregator can operate V2G-connected EVs via EVSEs to charge/discharge in proposition to demands from grid operators and EV owner.	
BRP_{AGG}	The third-party aggregator cooperates with or has registered a partnership with a BRP, called BRP_{AGG}.	Model 2
Electricity $Provider_{AGG}$	The third-party aggregator cooperates with an electricity provider for handling prosumers' revenues from flexibility provided.	Model 3

Table 1 Identified actors and description of actors' roles and functions in MAS figures

1.1 Flexibility Opportunities for present actors

Figure 1 illustrates the Multi Agent System of a V2G system based on *Model 0 in MM 2.0, Flexibility Opportunities for present actors* called MAS 0. In model 0, present market actors can take the role as aggregator, or a commercial aggregator can cooperate with a BRP or an electric supplier. Energy intensive industries in the current market can deliver unlocked flexibility. Table 2 contains the description of each arrow in MAS 1 for Figure 1.

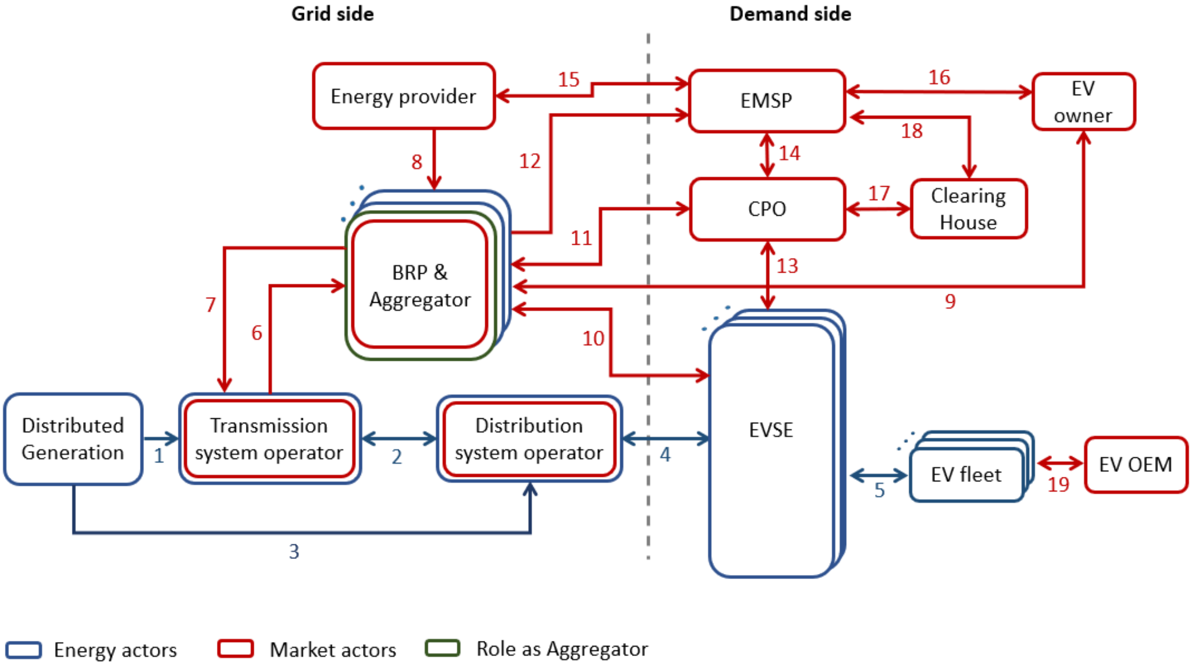


Figure 1 The Multi Agent System 0 for V2G and Model 0 in MM2.0

1.2 Frequency Stabilisation

Figure 2 illustrates the Multi Agent System of a V2G system based on *Model 1 in Market Model 2.0* called MAS 1. In the case of market model 1, the aggregator delivers frequency stabilisation (FCR-D) to the transmission grid. The aggregator is an independent commercial actor in the current market does not cooperate with a BRP or energy provider, as the aggregator only delivers small amounts of flexibility to the TSO. Table 2 contains the description of each arrow in the MAS 1 for frequency stabilization.

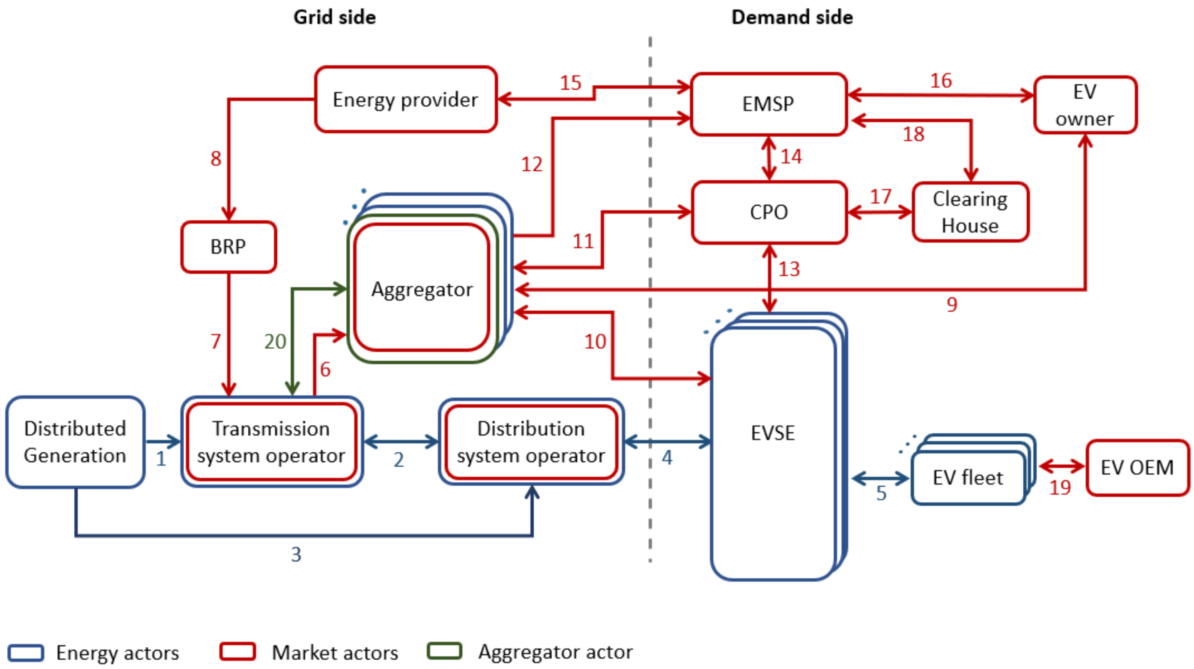


Figure 2 The Multi Agent System 1 for V2G and Model 1 in MM2.0

1.3 Supplier of flexibility

Figure 3 illustrates the Multi Agent System of a V2G system based on *Model 2 in Market Model 2.0* called MAS 2. The aggregator can provide larger amounts of flexibility to ancillary services, as the aggregator cooperates with a third-party BRP, which can handle balancing of flexibility for the aggregator. The BRP is the aggregator's collaborator and is referred to as BRP_{AGG}. The arrows illustrated in MAS 2 are defined in Table 2.

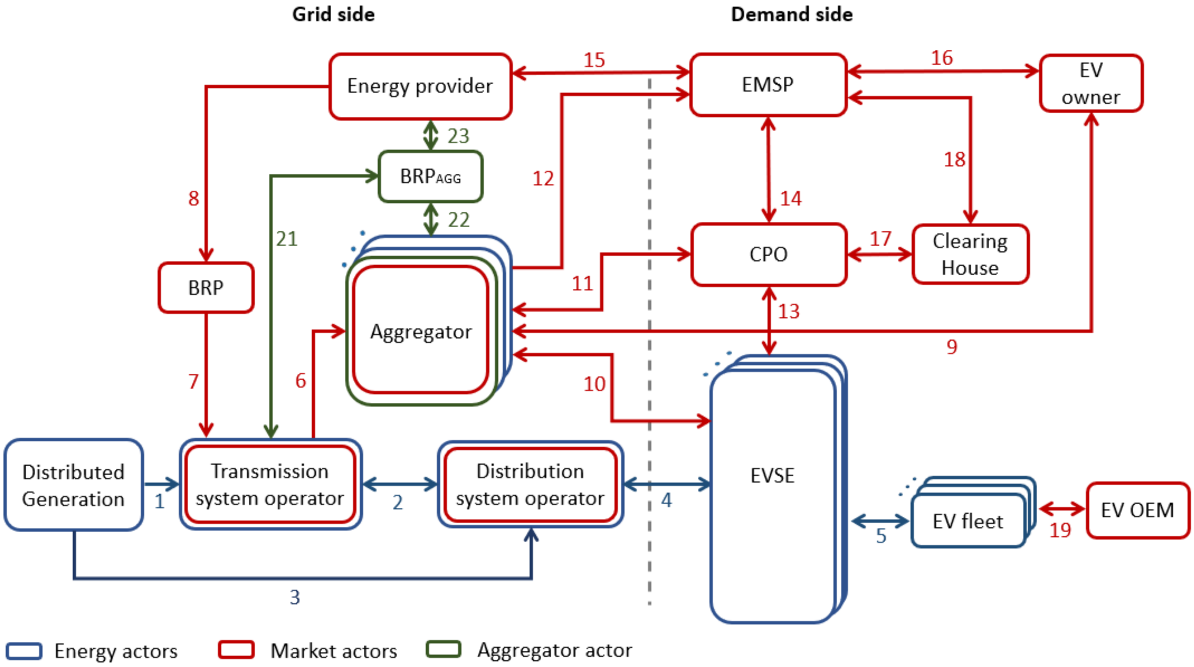


Figure 3 The Multi Agent System 2 for V2G and Model 2 in MM2.0

1.4 Flexibility and Service

Figure 4 illustrates the Multi Agent System of a V2G system based on *Model 3 in Market Model 2.0* called MAS 3. A fleet owner can act as an aggregator and deliver flexibility from EVs, and thus the fleet owner can trade in the ancillary service market. The aggregator collaborates with its own BRP and energy provider, which are referred to as BRP_{AGG} and energy $provider_{AGG}$. The arrows between actors in MAS 3 are defined in Table 2.

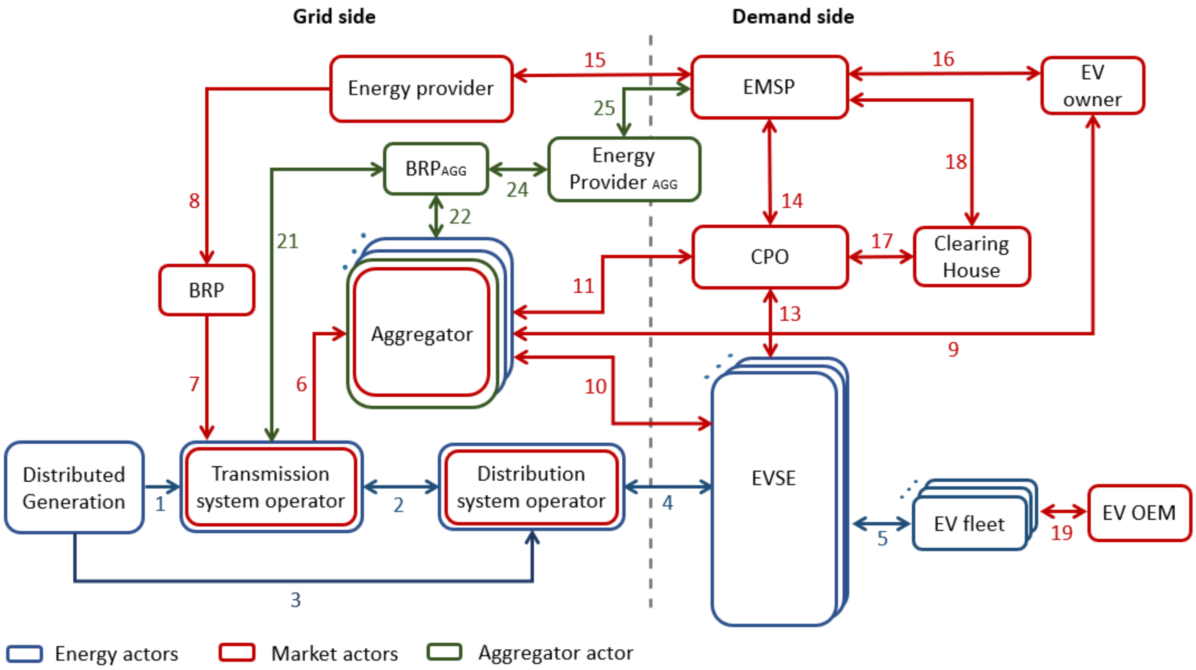


Figure 4 The Multi Agent System 3 for V2G and Model 3 in MM2.0

1.5 Description of each process between actors in the four MAS figures

Table 2 defines each arrow in the four MAS figures and describes each process between actors in the four figures, cf. Figure 1 to 4.

Arrow	Description of processes between actors	Relevant MAS models
(1) Blue arrow	In the electricity market from the grid side, electricity producers supply electricity via the transmission grid operated by the TSO.	Relevant for all four models (MAS 0, 1, 2 & 3)
(2) Blue arrow	High-voltage electricity is physically transported and transformed through the TSO grid to the DSO grid.	
(3) Blue arrow	Smaller Distribution Generations such as photo voltaic systems can supply medium voltage electricity directly to the DSO grid.	
(4) Blue arrow	**To the right:** Physical electricity transport and transformation of medium voltage to low voltage electricity is supplied through the distribution grid to the EVSE. **To the left:** The EVSE can deliver low voltage electricity to the DSO grid from the EV fleet.	
(5) Blue arrow	**To the right:** An EV consumes electricity via a charger cable connected to EVSE. Additionally, the EVSE sends signals about start or end of charging to each EV in an EV fleet. **To the left:** The EV delivers stored electricity to the grid via the EVSE. In addition, the EV sends measured data about the charging level (SOC) on the battery and technical conditions of the EV to the aggregator via EVSE.	
(6) Red arrow	The TSO sends information about the frequency level on the transmission grid to the aggregator.	
(7) Red arrow	When needed, the TSO balances the transmission grid by buying services from BRPs to ensure grid stability. Flexibility service is a supplement to the present approach to balance the transmission grid. In MAS 0, a BRP (or the energy provider) can take the role as aggregator, and the aggregator can sell flexibility to all markets. Activation of flexibility will be handled internally between aggregator and BRP, as the BRP sends price signals to the aggregator.	
(8) Red arrow	The energy provider buys electricity to the EVSE for consumers or prosumers from the BRP and electricity is supplied via the distribution grid.	

(9) Red arrow	**To the left:** The EV owner provides the aggregator with information about planned availability of the EVs for aggregation. The EV owner can communicate directly with an aggregator or with a CPO. **To the right:** The aggregator sends information to the EV owner via a communication platform about SoC-level on EV battery. The aggregator will always fulfil the EV owner's driving needs.	(MAS 0, 1, 2 & 3)
(10) Red arrow	**To the left:** The aggregator controls the active power status of EVs, and analyses performance of each EV by investigating three performance indicators, comprising directionality (Uni- or bidirectional energy transport), granularity (setpoint range [W] & step size) [Var], responsiveness of activation of V2G [W/s], ramp time [Var/s], and accuracy and precision of delivered and requested response rate [%]. The aggregator receives data about SOC-level etc. from the EVs via the EVSEs. **To the right:** Based on the information about frequency level on the grid (cf. *(6) Red arrow*), the aggregator platform regulates the bidirectional flow by sending operation signals to either EVSE or EV. Signals can be sent as required ampere-level [A], effect [kW] or percent [%] to EVSEs depending on the charger.	
(11) Red arrow	Aggregator and CPO cooperate for securing communication between the V2G software and EVSE software.	
(12) Red arrow	The aggregator sends the EMSP information about metered data on provided flexibility to grid, and the EMSP can send the information to the EV owner.	MAS 0, 1 & 2.
(13) Red arrow	**Upwards:** EVSE sends metered data about electricity consumption and flexibility to CPO and informs the CPO when it needs service. **Downwards:** CPO services the EVSE and maintains the functionality of the EVSE for providing flexibility service.	Relevant for all four models (MAS 0, 1, 2 & 3)
(14) Red arrow	**Upwards:** CPO informs EMSP about metered data and conducted services for EVSE and EMSP sends EV owner invoices based on consumption and flexibility service provided. In addition, EMSP and CPO can also communicate via a hub called "Clearing House" for roaming service. **Downwards:** EMSP contacts CPO, when EVSE needs service beyond regular servicing.	
(15) Red arrow	**To the right:** The energy provider communicates with the EMSP and sends information about electricity consumption of the EV fleet metered with the primary meter. **To the left:** The EMSP pays the energy provider for the electricity consumed by the EVSE including tariffs to both TSO and DSO. In MAS 0, the existing electricity meter is utilised to meter flexibility, which sends data to the energy provider about delivered flexibility services to the TSO.	
(16) Red arrow	**To right:** The EMSP communicates and sends the EV owner invoices for used electricity, provided flexibility (revenue stream) and the CPO service. The EV owner can own one or several EVs. **To left:** The EV owner pays the electricity bill including tariffs and service costs to the EMSP. In addition, the EV owner contacts the EMSP, when the EVSE needs service.	
(17) Red arrow	The CPO communicates with the Clearing House for handling clearing of payments for EV roaming at chargers provided by other CPOs. This report does not investigate the impacts of clearing houses.	
(18) Red arrow	EMSP communicates with Clearing House for securing payment for CPO service, comprising communication between EVSE and EV fleet across borders or communication between other EMSPs and their services.	
(19) Red	EV OEM manufactures EVs and thus provides the flexible unit with storage capacity relevant for the V2G system. The EV OEM may	(MAS 0,

arrow	cooperate with CPOs for securing an optimal charging process of the EV. Two main charging protocols have been developed for communication between EV and charger when providing V2G, the IEN 15118 and the CHAdeMO 2.0 protocol.	1, 2 & 3)
(20) Green arrow	In MAS 1, the aggregator communicates and settles directly with the TSO when providing flexibility stabilization service, but currently the aggregator must settle with a BRP in correlation with market regulations (Energinet.dk, 2017, s. 7).	MAS 1
(21) Green arrow	In MAS 2 & 3, the commercial aggregator cooperates with a specific BRP called BRP_{AGG} for handling balancing of flexibility provided from EVs for the TSO.	MAS 2 & 3
(22) Green arrow	In MAS 2 & 3, the BRP_{AGG} sends price signals for primary reserve market to the aggregator to deliver flexibility service.	MAS 2 & 3
(23) Green arrow	In MAS 2, the prosumer's energy provider handles metering of both electricity consumption and flexibility provided by the EV fleet. Energy provider handles settlements for the aggregator, comprising electricity consumption for charging and deducts flexibility provided from the EV fleet from electricity bill.	MAS 2
(24) Green arrow	In MAS 3, the aggregator collaborates both with a third-party BRP and a third-party Energy provider called Energy $Provider_{AGG}$. The Energy $Provider_{AGG}$ handles metering and settlements of the EV fleet, but the EMSP still communicates and sends the bill to the EV owner.	MAS 3
(25) Green arrow	In MAS 3, the Energy $Provider_{AGG}$ sends the EMSP information about metered flexibility provided to the grid. Unlocked flexibility is measured by a submeter installed on a flexibility unit for which the energy provider and the energy $Provider_{AGG}$ separate electricity consumption and delivered flexibility of the unit by serial-metering or parallel metering.	MAS 3

Table 2: Description of all four Multi Agent Systems for V2G system and the related four Market models from MM2.0.

2. Value System for V2G

The Value system for V2G has been visualised with a value flow diagram based on the MAS figures. The value flow diagram illustrates identified tangible and intangible values, which are released, transported and shared between the actors in the V2G system, which makes it is possible to identify incentives for energy market actors to be part of a V2G system.

Figure 5 illustrates value flows between the various actors for a market model for flexibility and service, comprising Model 3 in MM2.0. In MAS 3, electricity consumption and flexibility service are metered by two different certified meters. Primary electricity consumption is measured by the DSO with a main meter, and flexibility service is metered by a submeter provided by a commercial aggregator. Five central values have been identified in the system which are shared, delivered, received and captured among the actors. The identified values are; Money, Data, Service/product, Energy transport and Information. The first includes money exchanged between the actors and cooperation with signed contracts.

The types of value flows have been defined in the table 3.

Value flow	Abbreviation	Colour	Definition of value
Money	**M**	**Green**	The money flow, such as payment for physical transport of electricity and services, and including contract signing.
Data	**D**	**Blue**	Transport of data. E.g. Measurement data of electricity consumption etc.
Service or product	**S/P**	**Purple**	A service is e.g. installation and maintenance of EVSE. A product delivered from one actor to another is e.g. flexibility provided from an aggregator to TSO.
Energy transport	**E**	**Orange**	Transport of electricity and unlocked flexibility
Information	**I**	**Red**	Information between the actors comprising information, communication and knowledge sharing between the actors in the V2G system.

Table 3: Definition of the five values

Each value flow between the actors are described in Table 4 to 34. The numbering of value flows on Figure 5 are inspired by the processes between the actors defined on the four MAS figures, cf. Chapter 1 - The Multi Agent System. Given that the Value Flow diagram is an illustration of MAS 3, the report does not account for the relation between two actors regarding arrow 12 (Model 0), arrow 20 (Model 1) and arrow 23 (Model 2). The distributed generation is defined as electricity producer in Figure 5. Furthermore, the Clearing House as a roaming actor is mentioned in Figure 5, but the report does not look deeper into the Clearing House. However, it is relevant for future V2G perspectives, why the Clearing House has been included in the Value System for V2G system.

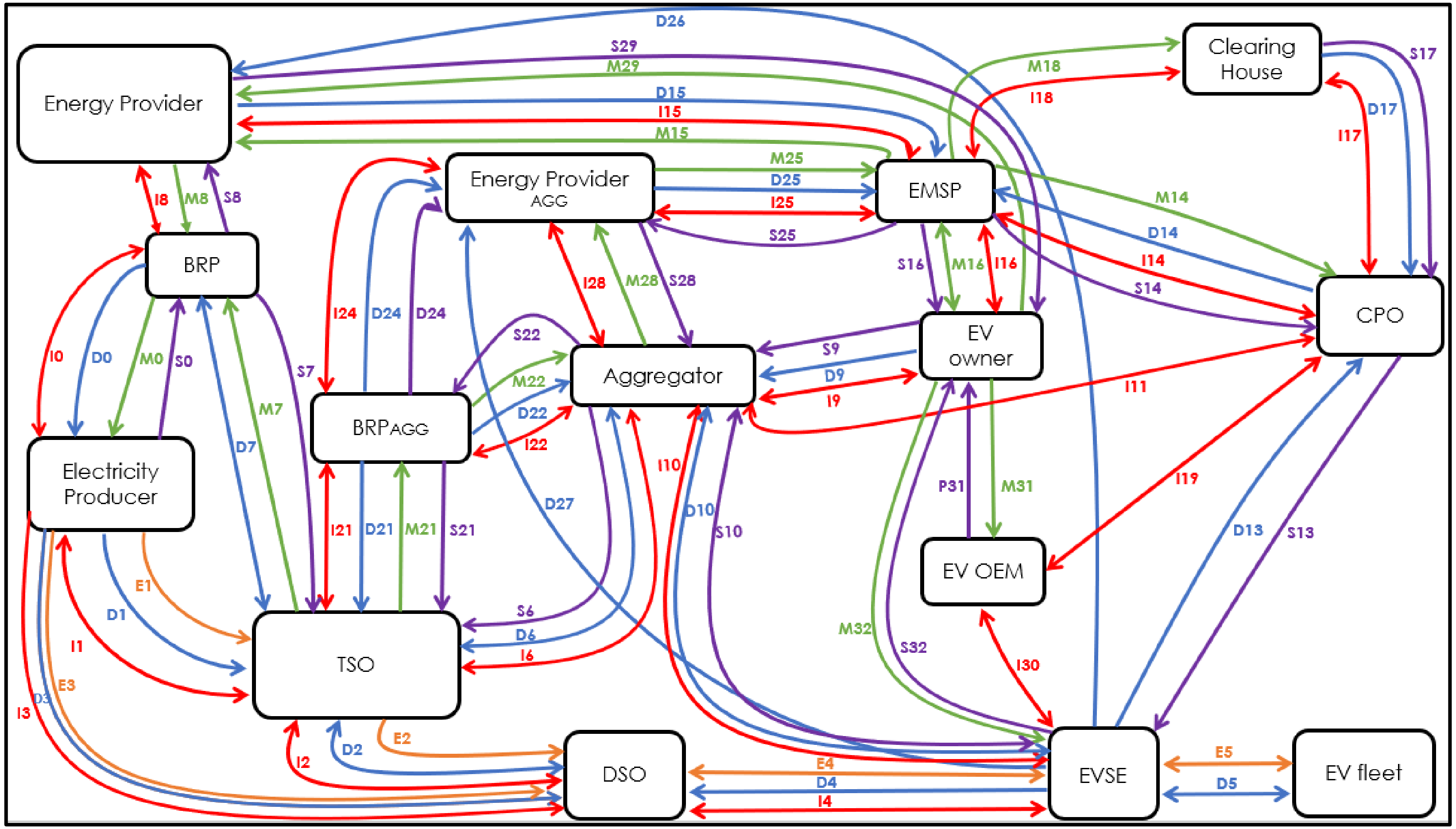
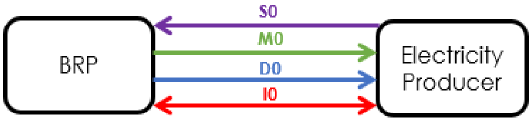


Figure 5 – A Value Flow for a commercial aggregator according to MAS 3, model 3 in MM2.0



Interaction	Flow type	Code	Definition
BRP → Electricity Producer	Money	M0	BRP pays for electricity produced by electricity producer.
	Data	D0	Sends data of needed energy capacity [W] at transmission grid
Electricity Producer → BRP	Service	S0	Electricity Producer generates electricity to transmission grid (E1).
BRP ←→ Electricity Producer	Information	I0	BRP and electricity producer communicate when energy capacity (frequency capacity) is needed at grid for securing electricity supply.

Table 4 Value flow between BRP and Electricity Producer

Interaction	Flow type	Code	Definition
Electricity Producer → TSO	Energy	E1	Electricity producer generates energy to TSO grid.
	Data	D1	Sends data about delivered energy capacity to TSO grid.
Electricity Producer ←→TSO	Information	I1	Electricity producer and TSO communicate for securing electricity supply to transmission grid.

Table 5 Value flow between Electricity producer and TSO

Interaction	Flow type	Code	Definition
TSO → DSO	Energy	E2	TSO operates physical energy transport to DSO grid. High voltage electricity is physically transported and transformed to medium voltage electricity.
	Data	D2	Sending data about present status of the transmission grid.
DSO → TSO	Data	D2	Sending data about present status of the distribution grid.
TSO ← → DSO	Information	I2	TSO and DSO communicate for securing physical electricity supply between transmission and distribution grid.

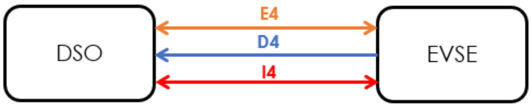
Table 6 Value flow between TSO and DSO

Interaction	Flow type	Code	Definition
Electricity Producer → DSO	Energy	E3	Medium voltage electricity can also be directly transported from distributed generation to DSO grid.
	Data	D3	Sends data about delivered energy capacity to DSO grid.
Electricity Producer ←→DSO	Information	I3	Electricity producer and DSO communicate for securing electricity supply to transmission grid.

Table 7 Value flow between Electricity Producer and DSO

Interaction	Flow type	Code	Definition
Electricity Producer → TSO	Energy	E1	Electricity producer generates energy to TSO grid.
	Data	D1	Sends data about delivered energy capacity to TSO grid.
Electricity Producer ←→TSO	Information	I1	Electricity producer and TSO communicate for securing electricity supply to transmission grid.

Table 8 Value flow between Electricity Producer and TSO

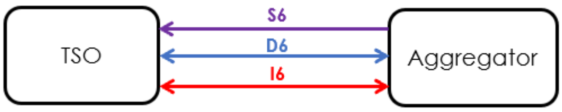


Interaction	Flow type	Code	Definition
DSO → EVSE	Energy	E4	DSO operates one directional physical electricity transport of medium voltage electricity and transforms it to low voltage electricity. The energy is transported through distribution grid to EVSEs.
EVSE → DSO	Energy	E4	EVSE delivers physical low voltage electricity to distribution grid via DSO grid.
	Data	D4	Electricity consumption data is measured with main meter by DSO but EMSP or EV owner's energy provider presents the consumption data to EV owner, cf. Code D26.
DSO ←→ EVSE	Information	I4	DSO informs about maintenance. E.g. via letter or phone call. EVSE can sent fault report in case of lack of electricity supply.

Table 9 Value flow between DSO and EVSE

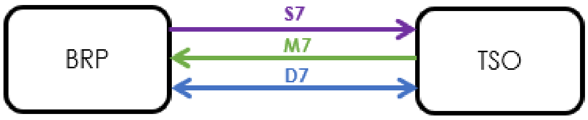
Interaction	Flow type	Code	Definition
EVSE → EV fleet	Energy	E5	EV is supplied with low voltage electricity via charger cable to EVSE.
	Data	D5	Sends signals about start and end charging of battery, comprising plug-in and plug-out state of V2G cable to EVSE.
EV fleet → EVSE	Energy	E5	EV provides flexibility by bidirectional electricity flow via a V2G cable connection to EVSE.
	Data	D5	**D5A:** EV sends data about battery energy status, comprising SOC-level and battery capacity [Wh] to aggregator via EVSE.
			D5B: Sends data of measured A-level [A] at EV.
			D5C: Sends status of active power transport, comprising activation of uni- or bidirectional energy transport [W] by V2G connection to EVSE.
			D5D: Sends ID number of EV and plug-in state.

Table 10 Value flow between EVSE and EV fleet



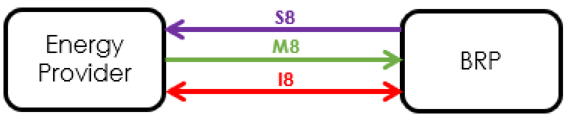
Interaction	Flow type	Code	Definition
Aggregator → TSO	Service	S6	**S6A:** The aggregator provides flexibility services to the TSO operator, when the TSO needs frequency regulation.
			S6B: The commercial aggregator maintenances and optimizes the technical aggregator, which aim is to aggregate V2G services.
			S6C: The technical aggregator can forecast potential delivery of flexibility, the time span and the price for the flexibility service in cooperation with BRP_{AGG}. The forecasts are based on EV owner's driving demands, weather conditions, pricing history and the TSO's expected need of flexibility etc.
	Data	D6	**D6A:** Prediction of the available power capacity.
			D6B: Sends measured data of flexibility provided to the grid.
			D6C: Reporting of performance indicators, comprising setpoint range [W], activation [W/s] and response rate [%].
	Information	I6	The aggregator will confirm the flexibility service, if possible to provide the needed capacity. The BRP_{AGG} will also be informed about this bid, cf. code I22.
TSO → Aggregator	Data	D6	Sends data about present frequency level on transmission grid.
			Sends data about the need for flexibility, comprising power [W].
	Information	I6	Informs aggregator when frequency regulation is needed to balance the grid.

Table 11 Value flow between TSO and Aggregator



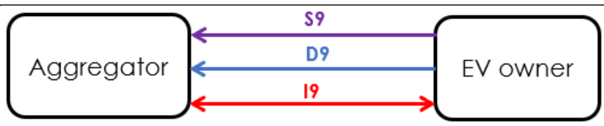
Interaction	Flow type	Code	Definition
TSO → BRP	Money	M7	TSO pays for balancing services and frequency regulation.
	Data	D7	TSO sends data about energy demand on grid.
BRP → TSO	Service	S7	BRP balances transmission grid. BRP trades energy on spot - and intraday market and ancillary services for TSO.
	Data	D7	**D7A:** Sends data about measured frequency level on grid
			D7B: Prediction of production and demand of electricity capacity and the actual price signal.
			D7C: Reporting of performance indicators, comprising setpoint range [W], activation [W/s] and response rate [%].

Table 12 Value flow between BRP and TSO



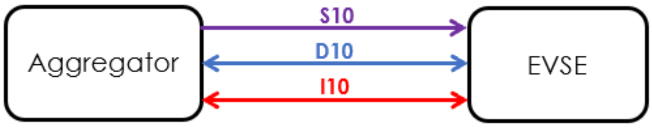
Interaction	Flow type	Code	Definition
Energy Provider → BRP	Money	M8	Payment for purchased electricity provided to consumer (EV owner) including tariffs to the grid operators and Energy Provider handles consumer settlements.
BRP → Energy Provider	Service	S8	BRP buys electricity from electricity producer and sells it to energy provider based on marginal pricing.
BRP ←→ Energy Provider	Information	I8	BRP informs Energy Provider about marginal price for electricity provided from transmission grid to distribution grid.

Table 13 Value flow between Energy Provider and BRP



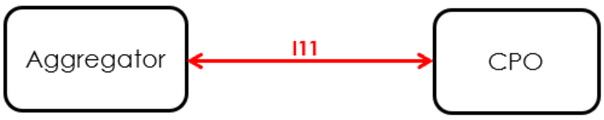
Interaction	Flow type	Code	Definition
EV owner → Aggregator	Information	I9	EV owner informs the aggregator about driving needs.
	Data	D9	Sends data about expected ToD via a communication platform.
	Service	S9	The EV owner provides the technical aggregator with accessibility to the energy stored in the EV fleet. The commercial aggregator provides the EV owner a revenue from the connected EVs through the EMSP.
Aggregator → EV owner	Information	I9	**I9A:** The aggregator informs the EV owner about basic information via a communication platform, e.g. an app.
			I9B: The aggregator informs the EV owner, when flexibility is needed by grid operators for securing a specific amount of EVs registered for aggregation.

Table 14 Value flow between aggregator and EV owner



Interaction	Flow type	Code	Definition
Aggregator → EVSE	Service	S10	An aggregator counsels and operates flexibility capacity of EV fleets for EV owners and secures the EV owner a revenue from parked EVs.
	Data	D10	**D10A:** The aggregator sends operation signals (set points) to the EVSE controller or the EV to handle the V2G connection. The aggregator sends the required setpoint of SoC-level [Wh] on the battery at a specific time to confirm with the EV owners driving pattern.
			D10B: The aggregator sends operation signals to the EVSE controller or the EV based on the frequency level on the grid (data of frequency level is sent from TSO, cf. Code D6). The setpoint is sent as a required A-level [A], [kW] or [%] at a specific time.
			D10C: Sends signals for start and stop charging in proposition to the need of flexibility service.
EVSE → Aggregator	Data	D10	**D10A:** EVSE sends data about batterySOC-level [%] and battery capacity [Wh].
			D10B: Measured data about A-level [A] at EV.
			D10C: Status of active power transport, comprising activation of energy transport [W] by connection to the EVSE. The EVSE sends data of power consumption measured by the main electricity meter, and flexibility provided by the EVs measured by sub meters. Data is applied to define historic consumption and predict future consumption and available power from EVs.
			D10D: Sends ID number of EV and plug-in state of the EV.
Aggregator ↔ EVSE	Information	I10	Aggregator and EVSE cooperates for securing interaction between software platform of aggregator and EVSE by use of IEN 15118 or CHAdeMO protocol.

Table 15 Value flow between Aggregator and EVSE

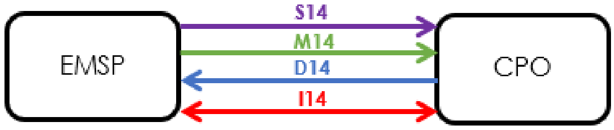


Interaction	Flow type	Code	Definition
Aggregator → CPO	Information	I11	Aggregator sends information to CPO in case of communication problems with the EVSE.
Aggregator ←→ CPO	Information	I11	Aggregator and CPO apply IEN 15118 or CHAdeMo protocol for securing interaction between software of aggregator and EVSE.

Table 16 Value flow between aggregator and CPO

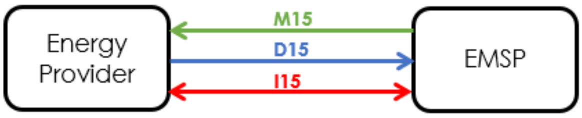
Interaction	Flow type	Code	Definition
CPO→EVSE	Service	S13	CPO is responsible for service of EVSE for maintaining its functionality and conducts installations.
EVSE → CPO	Data	D13	**D13A:** EVSE sends data of electricity consumption of EVSE metered with main electricity meter.
			D13B: A submeter measures flexibility provided to the grid and sends data both to the CPO and the aggregator's energy provider.
			D13C: The EVSE sends a signal to the CPO, when it needs a service.

Table 17 Value flow between CPO and EVSE



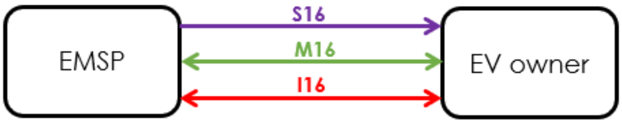
Interaction	Flow type	Code	Definition
EMSP→CPO	Service	S14	EMSP handles invoicing for the CPO to the EV owner, when the CPO has serviced the EVSE.
	Money	M14	EMSP pays the CPO for service of the EVSE.
	Information	I14	The EMSP informs the CPO, when the EVSE needs a service beyond regular servicing.
CPO → EMSP	Data	D14	**D14A:** Sends metered data of electricity consumption from the main meter.
			D14B: Sends metered data of flexibility provided measured by a submeter.
	Information	I14	Sends information about conducted services of the EVSE, cf. code S13 and the associated billing to the EMSP for the provided service.

Table 18 Value flow between EMSP and CPO



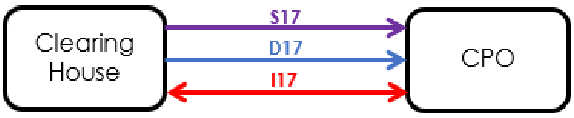
Interaction	Flow type	Code	Definition
Energy Provider →EMSP	Data	D15	Sends data of metered electricity consumption of the EV fleet.
	Information	I15	Informs the EMSP of the payment for electricity consumption, if the EMSP handles settlements with EV owner, Code M16. The EMSP sends consumption settlements including tariffs, when EV owner has paid for electricity consumption.
EMSP → Energy Provider	Money	M15	EMSP pays for electricity consumed by charger(s), and the energy provider pays tariffs to grid operators via the BRP.

Table 19 Value flow between Energy Provider and EMSP



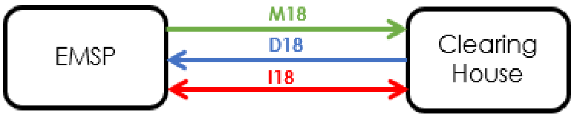
Interaction	Flow type	Code	Definition
EMSP →EV owner	Service	S16	The EMSP settles prosumer's settlement of electricity consumption and subtracts prosumer's revenue for provided service.
	Information	I16	EMSP has signed a contract with the EV owner for handling settlement of prosumer's flexibility capacity.
EV owner → EMSP	Money	M16	There are two opportunities to settle V2G service. One opportunity is that the EMSP handles settlements for both electricity consumption and flexibility service (Code M16), and the second opportunity is the EV owner pays electricity consumption of EVSE directly to Energy Provider and handles flexibility service with the EMSP (Code M29). The opportunities of settlements have been defined in chapter 2.1. For M16, EV owner pays for both flexibility service provided by aggregator, EVSE service, electricity consumed by the EV fleet, and gets a revenue from the flexibility capacity provided by the EV fleet.
	Information	I16	The EV owner contacts the EMSP, when the EVSE needs a service etc., cf. code I14.

Table 20 Value flow between EMSP and EV owner



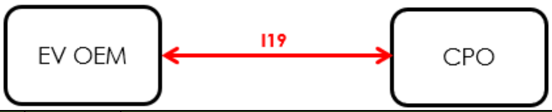
Interaction	Flow type	Code	Definition
Clearing House →CPO	Service	S17	Clearing House provides roaming service for EV owners by allowing the CPO to sell service.
	Data	D17	Clearing House sends metered data of provided roaming service.
	Information	C17	Clearing House informs CPO, when Clearing House has provided roaming service. Clearing House sends settlement for roaming service to EMSP, cf. code M18.

Table 21 Value flow between Clearing House and CPO



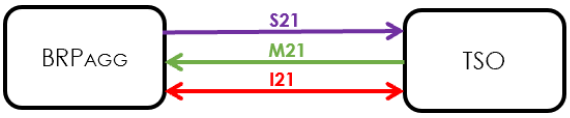
Interaction	Flow type	Code	Definition
EMSP → Clearing House	Money	M18	EMSP pays for roaming service of EV.
Clearing House → EMSP	Data	D18	Clearing House sends metered data of provided roaming service to CPO or EMSP, when EVs charge across borders.
	Information	I18	Informs about settlement for roaming service provided.

Table 22 Value flow between EMSP and Clearing House



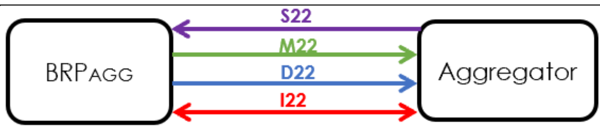
Interaction	Flow type	Code	Definition
EV OEM ←→ CPO	Information	C19	EV OEM may cooperate with CPO for securing an optimal uni- and bidirectional charging process.

Table 23 Value flow between EV OEM and CPO



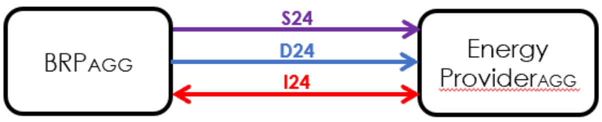
Interaction	Flow type	Code	Definition
BRPAGG → TSO	Service	S21	BRPAGG balances transmission grid in cooperation with an aggregator. BRPAGG trades on FCR-market.
	Information	I21	BRPAGG informs TSO, when flexibility will be provided from aggregator by pooling a specific amount of EV fleets.
TSO → BRPAGG	Money	M21	TSO pays for flexibility service by frequency regulation provided by aggregator.
	Information	I21	Informs BRPAGG, when flexibility service is needed to balance the grid.

Table 24 Value flow between BRPAGG and TSO



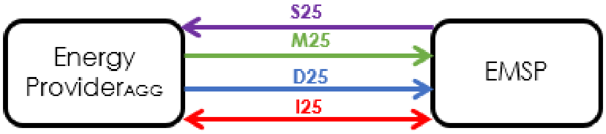
Interaction	Flow type	Code	Definition
BRPAGG → Aggregator	Money	M22	BRPAGG pays aggregator for flexibility service.
	Data	D22	Sends price signals to the aggregator for calculating flexibility signals for primary reserve market (FCR market).
	Information	I22	Informs aggregator about needed balancing of TSO grid.
Aggregator → BRPAGG	Service	S22	Aggregator provides flexibility service.
	Information	I22	Aggregator will confirm the flexibility service, if it is possible to provide the needed capacity, cf. S6A for aggregator service.

Table 25 Value flow between BRPAGG and aggregator



Interaction	Flow type	Code	Definition
BRPAGG → Energy ProviderAGG	Service	S24	BRPAGG handles price settings of flexibility services for Energy ProviderAGG.
	Data	D24	Sends price signal for flexibility capacity.
BRPAGG ←→ Energy ProviderAGG	Information	I24	The two actors communicate, as Energy ProviderAGG will handle settlement of flexibility service.

Table 26 Value flow between BRPAGG and Energy ProviderAGG



Interaction	Flow type	Code	Definition
EMSP → Energy Provider$_{AGG}$	Service	S25	The EMSP handles consumer settlement for the Energy Provider$_{AGG}$ and communicates directly with the EV owner.
Energy Provider$_{AGG}$ → EMSP	Money	M25	Payment for EMSP service, as EMSP handles consumer settlement for the aggregator.
	Data	D25	Sends data of flexibility provided to grid metered by submeter installed on charging point, cf. code D27. Thus, electricity consumption and delivered flexibility provided from EV is separated by serial-metering or a parallel metering.
Energy Provider$_{AGG}$ ←→EMSP	Information	I25	The two actors communicate for securing data validity of metered electricity consumption.

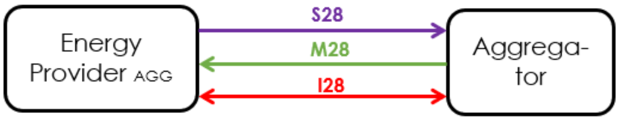
Table 27 Value flow between Energy Provider$_{AGG}$ and EMSP

Interaction	Flow type	Code	Definition
EVSE → Energy Provider	Data	D26	The DSO measures consumption data of each EV with a main meter installed on the EVSE. The data is documentation for the electricity supply, but the Energy Provider presents the consumption data to customers, cf. Code S29.

Table 28 Value flow between Energy Provider and EVSE

Interaction	Flow type	Code	Definition
EVSE → Energy Provider$_{AGG}$	Data	D27	The Energy Provider$_{AGG}$ measures flexibility provided by EV fleet with a sub meter, as documentation for flexibility services.

Table 29 Value flow between Energy Provider$_{AGG}$ and EVSE

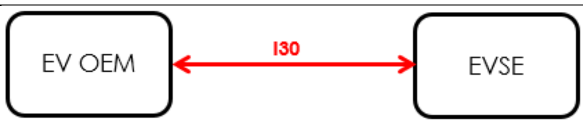


Interaction	Flow type	Code	Definition
Energy Provider$_{AGG}$ → Aggrega-tor	Service	S28	Energy Provider$_{AGG}$ meters flexibility capacity (bidirectional transport) with a submeter and settles both flexibility service and revenue for EV owner depending on the business model of the aggre-gator. The settlement is sent to EMSP, cf. code I25 and D25.
Aggregator → Energy PRovider$_{AGG}$	Money	M28	The aggregator pays Energy Provider$_{AGG}$ for handling metering of flexibility and settlement of flexibility service.
	Information	I28	The aggregator informs Energy Provider$_{AGG}$, when an EV fleet has been utilized for flexibility services for securing a settlement.

Table 30 Value flow between TSO and DSO

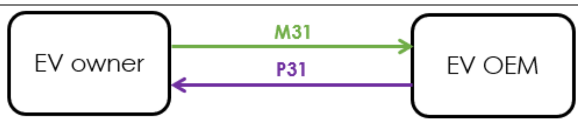
Interaction	Flow type	Code	Definition
Energy Provider → EV owner	Service	S29	Sells electricity to the EV owner (prosumer) consumed by EV fleet. Electricity consumption is metered with main meter, cf. Code D26.
EV owner → Energy Provider	Money	M29	**M29A:** As mentioned for code M16, the second opportunity for prosumer settlement is EV owner settles electricity consumption di-rectly with its energy provider, and EV owner settles EMSP for flexi-bility service provided by aggregator.
			M29B: Pays for electricity consumption, transport of energy and energy taxes.

Table 31 Value flow between Energy Provider and EV owner



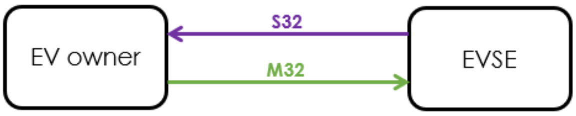
Interaction	Flow type	Code	Definition
EV OEM← → EVSE	Information	I30	The two actors apply IEN 15118 or ChaDeMo protocol for com-munication between a charger and an EV.

Table 32 Value flow between TSO and DSO



Interaction	Flow type	Code	Definition
EV OEM → EV owner	Product	P31	The EV OEM provides the EV owner's with EVs to the EV fleet and thus provides the storage capacity relevant for the V2G system.
EV owner → EV OEM	Money	M31	The EV owner pays the EV OEM for the EVs provided.

Table 33 Value flow between EV owner and EV OEM



Interaction	Flow type	Code	Definition
EVSE → EV owner	Service	S32	EVSE manufactures a charger including V2G capabilities.
EV owner → EVSE	Money	M32	EV owner pays for chargers provided by the EVSE manufactures.

Table 34 Value flow between EV owner and EVSE

The identified value flows for a V2G system with focus on providing flexibility service by inspiration of model 3 in MM2.0 indicate that V2G can provide a TSO with flexibility services via aggregation of EV fleets. The identified value flows are usable for development of business models for actors looking to utilize the V2G technology.

2.1 Settlements for flexibility services

Settlement of the Aggregator service handled by the EMSP

The aggregator provides aggregation as service, and the flexibility service is priced with formula 1 for which E is an abbreviation for expenses, M is money and R is a revenue. *Formula 1, 2 and 3* refers to value flows visualized at Figure 5. The EV owner gets a revenue due to provided flexibility service, defined as $M_{16.Downward}$, which refers to the downward money flow at Figure 5.

$$Profit_{Aggregator} = Payment_{TSO} - E_{BRP_{AGG}} - E_{Energy\ Provider} - E_{EMSP} - R_{EV\ owner} \qquad \textbf{Formula 1}$$

$$\Downarrow$$

$$Profit_{Aggregator} = M_{21} - M_{22} - M_{28} - M_{25} - M_{16.Downward}$$

For the first scenario, the EMSP communicates with the EV owner, and the EMSP handles electricity consumption of the charger with the prosumer's Energy Provider, see *Formula 2.*

Consumer settlement

There are two opportunities to settle the consumers' V2G service, which are visualised at the value flow (Figure 5) with value flow M29 and M16. One opportunity is the EV owner pays the total costs directly to the EMSP (Code M16 in Figure 5), and the second opportunity is the EV owner pays the electricity consumption of EVSE directly to the Energy Provider (Code M29 in Figure 5). For Code M16, the EMSP pays for the electricity consumption of EVSE, cf. Code M15, and the prosumer settlement is handled by the EMSP. The settlement includes variable expenses for consumed electricity, a revenue for provided flexibility and fast expenses for CPO service. Energy Provider does not settle the EV owner's revenue for the flexibility capacity provided from the EV fleet, but instead the EMSP settles flexibility with the EV owner, cf. Code M16.

First scenario; EMSP handles settlement for both electricity consumption and flexibility service

For the first scenario, the EV owner pays the prosumer settlement directly to EMSP, Formula 2 is applicable. EV owner's payment sum is defined as $M_{16.Upward.1}$, which refers to upward money flow at Figure 5. The EV owner can get a revenue due to provided flexibility service, defined as $M_{16.Downward}$, which refers to downward money flow at Figure 5. Therefore, the EV owner has to pay following to the EMSP, see *Formula 2.*

$$E_{EV\ owner} = E_{Charging\ EVSE} + E_{CPO\ service} + E_{EMSP} + E_{Clearing\ House} - R_{EV\ owner} \qquad \textbf{Formula 2}$$

$$\Downarrow$$

$$M_{16.Upward.1} = M_{M15} + M_{14} + M_{EMSP} + M_{18} - M_{16.Downward}$$

For M_{EMSP} is the cost related to service provided by the EMSP.

The second scenario; EV owner pays electricity consumption to the Energy Provider

For the second scenario, the EV owner pays for the electricity consumption of the EVSE directly to their self-elected Energy Provider, and the payment sum to the EMSP does not include electricity consumption of the charger. The EV owner gets a revenue due to provided flexibility service, defined as $M_{16.Upward.2}$, which refers to upward money flow at Figure 5. The EV owner's revenue due to flexibility service is defined as $M_{16.Downward}$, which refers to the downward money flow at Figure 5.

Therefore, the EV owner has to pay the EMSP for services provided and the Energy Provider for electricity consumption, see *Formula 3*.

$$E_{EV\ owner} = E_{CPO\ service} + E_{EMSP} + E_{Clearing\ House} - R_{EV\ owner}$$
$$\Downarrow$$
$$M_{29} + M_{16.Upwards.2} = M_{14} + M_{EMSP} + M_{18} - M_{16.Downwards}$$

Formula 3

For M_{EMSP} is the cost related to service provided by the EMSP.

2.2 Value system for Parker

Parker is an example of a commercial case with use of the V2G technology for providing flexibility services to grid operators, in an aggregator model comparable to MAS 0. A simple architecture of Parker is illustrated at Figure 6. Parker uses Frederiksberg Forsyning as a test facility and as a fleet owner with 10 EVs connected to bidirectional charging stations. Nuvve has developed an aggregator and acts as an EMSP instead of collaborating with an Energy Provider$_{AGG}$. Enel has provided charging stations and Nissan has provided EVs. Furthermore, NEAS is both BRP and energy provider. One electricity meter measures the total amount of delivered flexibility from the EV fleet, also called portfolio metering, which sends data to the consumer's energy provider about delivered service to TSO.

The grid operators pay NEAS for balancing the grid with flexibility services provided by Nuvve by aggregation of the EV fleet at Frederiksberg Forsyning. Frederikberg Forsyning pays Nuvve for both EMSP and CPO service and charging of EVs. Frederikberg Forsying gets a revenue from providing accessibility to their vehicles. Frederiksbjerg Forsyning has paid Enel for provided chargers and Nissan for the EVs.

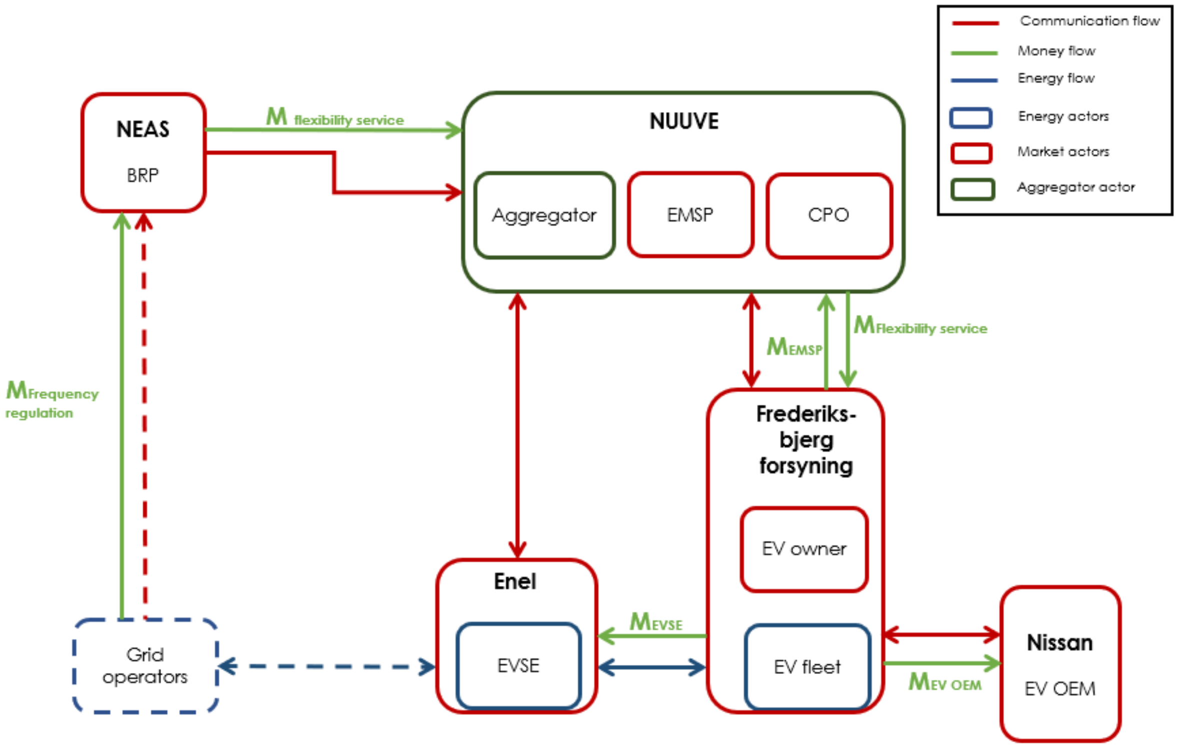


Figure 6 Architecture of Parker project

3. Discussion

In the previous chapters, the MAS and Value System for flexibility services via V2G have been defined, but the question is whether it is possible to develop a viable business model for a commercial aggregator or is it more profitable for a new actor to sell an aggregator as a technical product. Before developing business models for V2G, it is relevant to analyse the relation between the actors. The MAS architecture illustrates a comprehensive model for a V2G system with several actors. In practice, the actors can take on several roles and thus the V2G system will include fewer actors than illustrated at MAS figures, cf. Chapter 1. However, it is important that the functions are handled by the actors in the system for securing a balanced system. It is important to secure market competition and righteous market conditions, which is the reason why MM2.0 has been developed with four opportunities for market models, comprising present actors, BRP and Energy Provider or a new commercial aggregator with or without collaborators (Energinet.dk, 2017).

3.1 Relevant actors for developing a viable V2G system and their market interests

A sustainable V2G system is dependent on all roles visualised in the Value Flow for a commercial aggregator according to MAS 3, figure 5. An actor can take several roles without impacting the system. Furthermore, the market actors may have monetary, environmental and social interests for providing flexibility capacity to the energy markets. Table 34 defines the relevant roles in the V2G system and the important actors for a balanced system. The relevance of the Clearing House will not be covered.

Function/Role	**Relevant actors for the specific role**
Customer of flexibility	• TSO • DSO
Balancing service	• BRP • BRP_{AGG}
Settlement of electricity consumption and flexibility supply & communication with customer	• Energy Provider • Energy Provider $_{AGG}$ • EMSP
Aggregation	• Commercial aggregator • Energy Provider • BRP • EMSP
Flexible units	• EVs
EV manufacturer	• EV OEMs
EVSE manufacturer	• EVSE OEMs
Operation of EVSE	• CPOs • EMSP • EV OEMs • EVSE OEMs

Table 35 Definition of roles and relevant actors for the specific role

As defined in Table 34, flexible units, EV- and EVSE manufacture and customers are relevant for developing a viable V2G system, as the system is dependent on provided flexibility from EVs and its technical supply and TSO's demand for flexibility. Aggregation of flexible units is one of the most essential functions of V2G system, as it is not possible to deliver the required minimum flexibility from EVs without pooling a quantity of EVs due to limited energy in batteries. An aggregator can connect flexible units to the grid by help of EVSEs and secure bidirectional transport. In a V2G system, it is important that a commercial aggregator has responsibility for handling aggregation of flexible units and takes the related business responsibility, otherwise other actors can assume the role of the commercial aggregator, cf. table 34, due to the market position and it is possible to buy an aggregator as a software product. Parker is a practical example of actors that can take several roles without impacting the systems or collaborate with different actors, cf. Chapter 2.1 Value System for Parker. Nuvve has three functions and respective roles, comprising aggregation of EVs (aggregator), settlement of flexibility (EMSP) and operation of EVSE (CPO). Parker showcases that a commercial aggregator can have a strong cooperation with other actors than current energy actors such as an EMSP for providing flexibility service, and NEAS (BRP) pays Nuvve for securing delivery of flexibility service for balancing the grid.

According to Rubens et. Al. 2018, on one hand consumers have monetary interests in the system, but on the other hand, they are worried about the lack of flexibility for using the EV, when an EV is V2G connected (Rubens, 2018) due to practical reasons. One of the EV owner's motivation parameter is an economic reward for providing flexibility to the system. An EV owner pays for electricity consumed by the EV fleet and expects to get a revenue from V2G connection. The revenue depends on the business model of the aggregator and the amount of bidirectional energy supply to the grid. The best case is if the prosumer gets a revenue for V2G connection of the EV fleet, and the worst case is if the prosumer has a high driving demand, and thus cannot provide flexibility to the grid. Another worse case is that the V2G connection can result in high expenses for the prosumer due to major electricity consumption, high electricity prices or taxes. An EV owner must see documentation for reduction of costs by providing flexibility capacity from EV fleets for receiving the highest possible revenue stream. Prosumers want compensation for charging and battery degradation as they are not interested in participating in V2G system if their expenses are higher than the perceived revenue. Otherwise, prosumers do not have incentives to participate in the system and V2G technology does not have a market potential. Therefore, it is necessary to mitigate technical disadvantages for EV owners such as degradation of battery, vehicle availability etc. for reducing barriers for prosumers to invest in an EV and V2G connection.

Furthermore, charging costs are possible to reduce by implementing variable price settings for which EV owners are impacted by price-signals, also called implicit demand response (SEDC, 2017). Coordinated charging at low price periods should secure reduced impacts in high electricity consumption periods (reduce peak periods). Otherwise the aggregator can change the consumption by explicit demand response (SEDC, 2017). However, lack of knowledge about EVs and V2G system are relevant barriers for potential prosumers to invest in V2G, and range distance and battery life time are as well barriers for investing in an EV and V2G connection. Therefore, it is important to improve external communication and the value provided by V2G focusing on both experts and consumers for achieving understanding about the opportunities of V2G.

Balancing services have also an important role for the V2G system, as an aggregator cannot bid on the energy market without BRPs. A new commercial aggregator can handle aggregation in the new market model, however a BRP or an energy provider can also take a role as aggregator or at worst make a forward integration of the commercial aggregator business for increasing its market share.

An energy provider has opportunities as a commercial aggregator, as they have a customer database with potential prosumers and the energy provider have the opportunity to pool their customer's EV capacity, if the customer is interested. The market models (Model 0, 2 & 3) from MM2.0 indicate that the BRP role is important for balancing the grid when the flexibility capacity is high for avoiding intended impacts of the grid. A commercial aggregator as a new actor in the energy market may take the risks that it can be difficult to cooperate with current energy actors. Given that a commercial aggregator aims to take a market share of electricity generators if the aggregator provides flexibility service. Furthermore, it can be difficult for an aggregator to create a customer database due to market competition. Therefore, it is relevant for a commercial aggregator to create a strong relationship with current market actors such as Energy Providers and BRPs. Settlement of electricity consumption is conducted by an Energy Provider and flexibility consumption is settled by an EMSP or Energy $\text{Provider}_{\text{AGG}}$, but in the case of collected metered data of both electricity consumption and flexibility supply the three actors can in practice conduct the same work. Therefore, an EMSP can take responsibility of flexibility settlement for the commercial aggregator, which can involve a low risk of a backward integration of Energy $\text{Provider}_{\text{AGG}}$, as an Energy $\text{Provider}_{\text{AGG}}$ handles only settlement of flexibility provided without public relations.

The advantage of a commercial aggregator is the side effect in improving the green developments by adaptive charging service, as it can help energy actors with improving their green profile and securing energy to end-users by adjusting energy consumption and supply in proposition to supply of wind power, energy prices and emission of CO_2-emissions. A substantial risk for an aggregator is the probability that the prosumer may use the EV when the EV has been planned for flexibility services, but an aggregator will take precautions against adverse events. Another risk is currently the aggregator cannot pool enough EVs in Denmark due to a small market penetration and consumer exercises cautions about V2G. The risks for V2G can be handled by improving external communication about business opportunities of V2G. The V2G market actors may overcome consumers' prejudices against capacity of EVs and flexibility of V2G connection.

Besides the CPO, operation of EVSE can be handled by an EMSP, an EV OEMs or an EVSE OEMs, as they have the technical competences to develop a platform to service EVSEs. The advantage of the EV OEMs or the EVSE OEMs to take the responsibility of the CPO is that they can adjust the development process of chargers in correlation with development of EVs, but the disadvantage of OEMs is they can increase market growth by forward vertical integration and retard the rate of development processes of V2G technology, if the consumers are not willing to deliver energy by bidirectional transport. However, the EV OEM can have interest in improving their sustainable performance by investing in technological development of EVs and V2G. Besides the EV owner is a fleet owner, the EV owner can with advantage assume other roles in the V2G system such as CPO and own EVSEs. An EV owner can take the role as CPO, as it can be profitable to own the V2G charging infrastructure and securing service of the EVSE.

The TSO is the final customer of V2G and has monetary interests for energy supply and actors must have the knowledge about V2G for providing flexibility service. Furthermore, a TSO can have non-monetary interests in V2G such as reducing environmental impacts by supporting fluctuating energy from renewable resources and reducing the need for energy from power stations (Sovacool, 2018). Furthermore, TSO can improve its social responsibility by impelling the green transition and V2G can be a way to improve the transition in Denmark. Other actors in a V2G system, such as the BRP and Energy Provider can as well have interest in a V2G collaboration for improving their green profile. In addition, DSOs can have disinterest in V2G, if flexibility services congest the distribution grid with bidirectional energy transport, without the DSO having influence on the energy transport. Therefore, a DSO is dependent on information about charging and discharging periods from commercial aggregator for being able to forecast electricity consumption and avoiding an unintended shutdown of electricity provided from distribution operator.

3.2 The commercial aggregator's relation to collaborators

In MAS 2 (Model 2 in MM2.0), the aggregator is only dependent on one actor, BRP_{AGG}, which can be visualized as a dyad, and the aggregator will pay the prosumer's energy provider directly for delivered flexibility, cf. Figure 7. The aggregator's relation to BRP_{AGG} and Energy $Provider_{AGG}$ in MAS 3 (Model 3 in MM2.0) can be illustrated as a network of three actors called a triad, cf. Figure 8, for which the three actors impact one another in the network.

In MAS 3, the commercial aggregator is dependent on a BRP_{AGG} and an Energy $Provider_{AGG}$, but the BRP_{AGG} and the Energy $Provider_{AGG}$ are independent of the aggregator, as they can cooperate with other energy actors. They have the opportunity to take the responsibility of the aggregator in a working relationship due to their competences and network in the current energy market. Furthermore, the BRP_{AGG} and the Energy $Provider_{AGG}$ can work independently, as BRP_{AGG} can handle settlements to TSO and Energy $Provider_{AGG}$ can settle flexibility for the aggregator by which the aggregator's role is only providing technical aggregation of flexible units. On one hand, it is important that the aggregator built its cooperation to a BRP_{AGG} and an Energy $Provider_{AGG}$ on trust and transparency and addition, the aggregator has the business responsibility of the cooperation and secures knowledge sharing between actors. On the other hand, the aggregator can substitute its collaborators with competitive actors, and BRP_{AGG} and Energy $Provider_{AGG}$ have competitive advantages by cooperating with an aggregator, as they can create a broader value proposition by gained competences within flexibility service. In the Value Flow, Figure 5, the TSO pays directly to the BRP_{AGG}, but it is also an opportunity that TSO pays directly to the commercial aggregator by which the commercial aggregator can strength its responsibility and thus being a more important actor, as the BRP_{AGG} just handles marginal price setting for FCR-products for the aggregator.

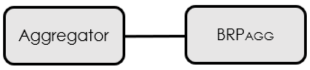


Figure 7 Aggregator and its collaborator based on MAS 2.

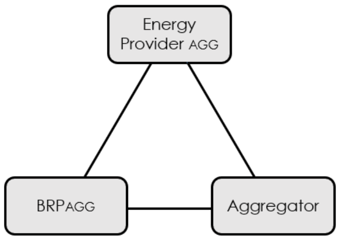


Figure 8 Aggregator and its collaborators based on MAS 3.

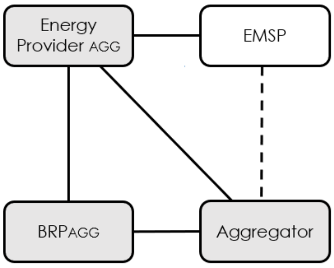


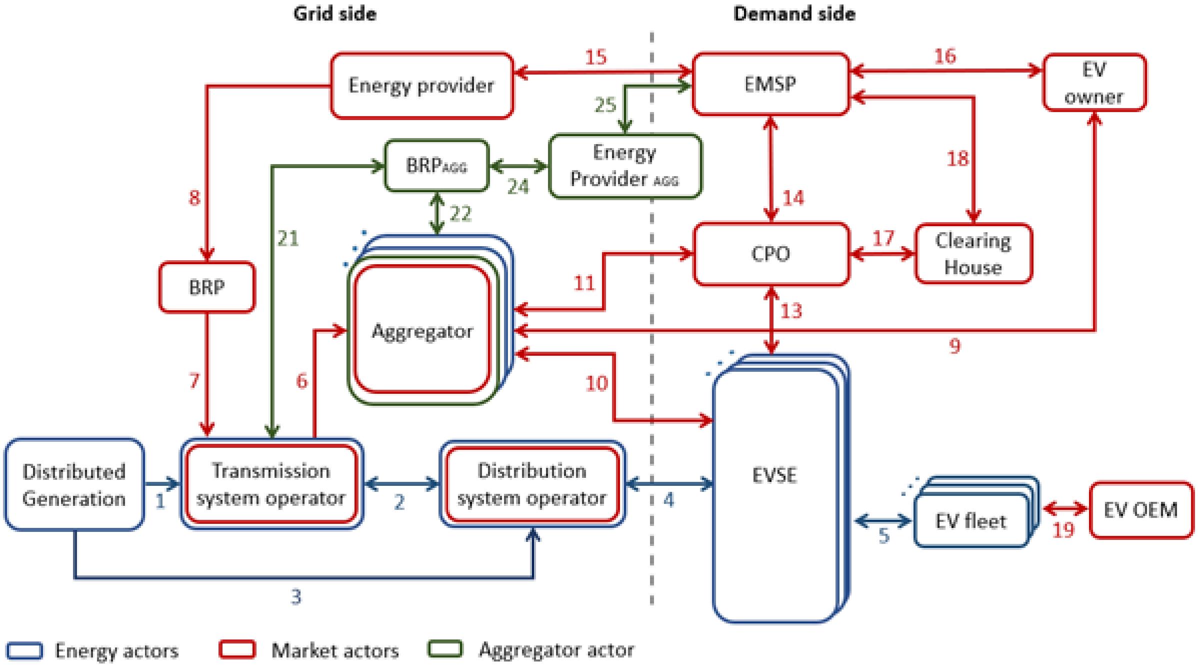
Figure 7 Combined V2G system based on MAS 3.

In a V2G system based on MAS 3, the aggregator's energy provider has comparable roles with the EMSP, as they both handle consumer settlements and collect meter data of flexibility from a submeter, cf. Figure 9. Furthermore, the EMSP has the direct contact with the prosumers and sends settlements of flexibility, why the EMSP is a necessary actor in the V2G system, but a competitor to Energy Provider$_{AGG}$, as they have comparable competences. An Energy Provider$_{AGG}$ can take responsibility for V2G by taking the roles of the EMSP, however an Energy Provider$_{AGG}$ can be seen as an unnecessary actor (especially in MAS 3), if an EMSP can act as energy provider for an aggregator. Another opportunity is that the aggregator can handle consumer settlement and control metered data for securing competitive advances by cooperation with an Energy Provider and a BRP, as the aggregator's relation with its own energy provider can be stronger than a cooperation with a competitive EMSP.

4. Conclusion

The background for analyzing the value system as a part of the replicability evaluation finds its main cause in the need to showcase, that the complete value system is in place and does support an increase in the number of EVs to be aggregated, services to be delivered and money to be transferred between stakeholders.

In order to provide a graphical overview of the connections, a multi agent system figure has been created of the full value system for V2G services, see the figure below.

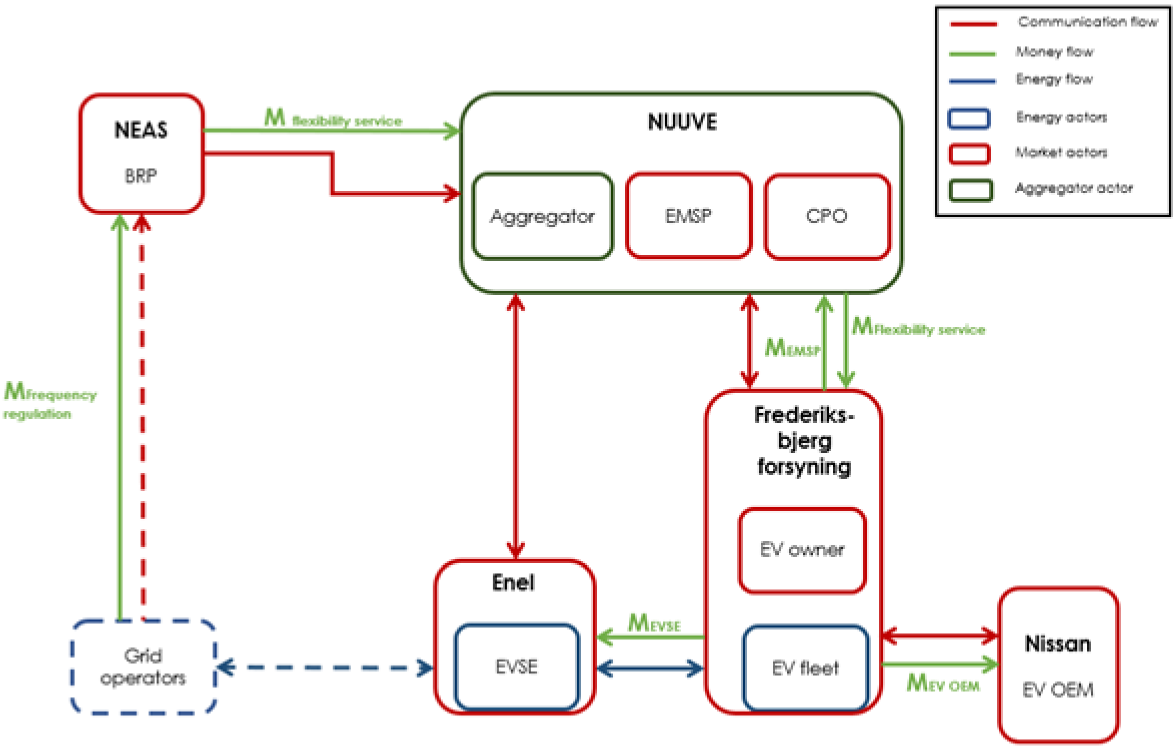


Value system depiction of MM2.0 – model 3

From the model it can be seen that the aggregator role becomes central for the delivery of V2G services to the grid but will still depend on collaboration with a BRP – own or third party – for selling into the TSO market. The aggregator is the center for communication for the complete demand side, where they balance the technical capabilities of each car through communication with the EVSE and the EV. This is calibrated with the needs of the EV owner, with whom the aggregator has direction communication through a digital platform. Finally, control signals are coordinated with the CPO, who allows for access of this through their communication system.

In general, all roles in the Value system have an interest in the delivery of V2G services, which means that they expect a compensation for providing of their services, which endangers the profitability of V2G, if the profits are to be split equally among all involved parties. How this is handled, depends on the business model created by the individual aggregator.

When transferring the model to the Frederiksberg Forsyning case, the main strategy for managing of the value system has been integration of several roles in the aggregator company, as can be seen from the figure on the next page.



Value system applied in the Parker Project

Comparing the two figures with each other, the simplicity of the latter is very clear. This is partly due to the fact, that it pictures the current market model, but also and more importantly due to Nuvve having taken several roles in the value system, which simplifies communication, reduces the number of stakeholders to share profit with, and lastly reduces risks for all involved stakeholders.
To which extent integration of several roles per actor is possible is defined by the legislation in each country and the willingness of the individual actor to increase responsibility and define their business model with respect to collaborators.

The value system analysis has shown that the different potential market models all consist of known roles, where the aggregator will be the new and enabling actor, that will bridge EVs and grid with each other, when providing services. The number of roles for an aggregator and the business model will be decisive for the construction of an attractive value offering to the remaining actors in the value system and is therefore an important consideration to make before entering a new market.
There is however nothing in the construction that prevents the technology to be replicable or to scale.

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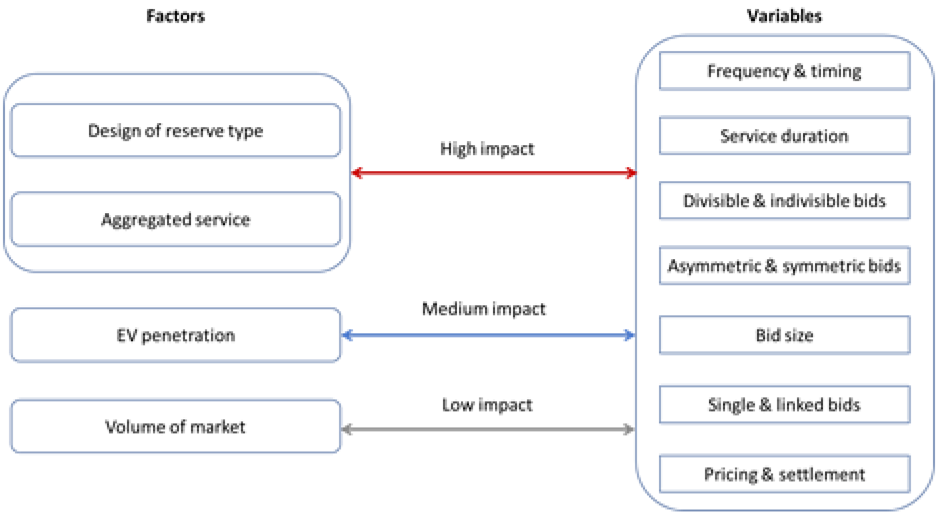
WP 5.1 – White paper of power grid variables

Executive Summary

To exploit the potential of V2G aggregation, it is important to understand the markets and the variables it is constructed upon, as they influence the ability to participate in the FCR market. In this section, seven key variables in the FCR market design have been identified and evaluated as to show how they could be optimized to support the V2G technology. The market design is, however, not the only parameter which influences the potential for V2G services for a given market. Parameters such as available capacity in the form of EVs and the volume of the market are central in creating a viable business implementation. To create a simple overview of the market potential, a framework that can be used to assess the maturity of FCR markets when introducing V2G aggregators has been developed.



Framework to assess market maturity

The survey addresses the complexity of the markets, as no country currently has a design that is completely optimised for a V2G aggregator. Further information can also be found in the references [48]–[54]. The assessment of the parameters creates a weighted score that can be used to rate the markets and identify which ones represents the most favourable cases for the implementation of a V2G aggregator considering the current state of the market. These results reflect the current condition of each market, and they will differ in time as regulations and the framework develop, thereby resulting in new evaluations for each country.

Regardless of whether the parameters are weighted or not, Norway comes out on top as the most attractive FCR market structure (Figure 63) when evaluating their score on the three parameters. This is primarily a result of Norway achieving the highest given marks in Design of reserve type and EV penetration, whereas Aggregated service only reaches a medium score.

France is second in the non-weighted score and third if the scores are weighted, which is a result of very good Aggregated services and a high EV penetration, however, the most important parameter, the Design of reserve type, is where France scores the lowest.

Finland switches position with France when going from the non-weighted to the weighted score, which is a result of a well implemented Design of reserve type and development of Aggregated services.

Denmark currently has a good Design of reserve type, but it only brings them up to a fifth place behind Sweden, which is caused by a mediocre development of Aggregated services compared to the best European countries. The development of Aggregated services is currently undergoing major changes with the implementation of market model 2.0, which would increase the score and bring Denmark closer to the top in Europe.

In general, the non-weighted scores achieved by the different countries outside of the top five, are very close to each other, which is a result of generally well-established market structures for Aggregated services but lacking market Design of reserve type, leaving differentiation between the markets to the EV penetration. With closer integration between the market structures in Germany, Benelux, and France, this is a tendency that is expected to continue.

Country score

1 Introduction

Vehicle-to-grid (V2G) technology creates mutual benefits between EVs and the power grid. Steps to enable EV aggregations to provide grid services are already underway in the U.S.A. As an example; the Parker project aims to demonstrate the V2G potential for trading in the Frequency Containment Reserve (FCR) market. A V2G aggregator plays an essential role as an interface to provide reserves for the transmission system operator (TSO) by managing EV portfolios. To this end, this whitepaper focuses on analysing the relevant power grid variables within the FCR market across various EU countries. The result is an overview of the framework and potential for V2G in the analyzed countries. The major contributions are threefold:

1) Identify variables and elaborate impacts on the V2G aggregator and the TSO.
2) Present the mapping of variables from TSOs in 11 countries.
3) Evaluate 11 markets based on the market variables and current EV market uptake.

2 Trading in the FCR market

The FCR market is already existing and primarilly supported by large energy companies with large energy ressources. The market structure has therefore been designed to fit current technologies. With the evolution of digitalization and EVs the intelligent use of multiple EVs now provides a completely new opportunity to provide services towards the electric grid, however, whether this is realistic is highly dependent on the market structure where seven variables have been identified as relevant to evaluate, when accessing whether a market could be relevant for V2G implementation in the FCR market.

2.1 Frequency and timing

When trading in the FCR market, a V2G aggregator needs to determine its auction frequency and timing. Low trading frequency (e.g., weekly) with the TSO results in long lead times and makes it difficult for an aggregator to forecast accurately and manage the EV portfolios corresponding to grid conditions. Therefore, a premium may occur in the aggregator’s bid. On the contrary, high trading frequency (e.g., daily or hourly) can shorten lead times and secure EV scheduling and operation. This is also beneficial in order for an aggregator to build and optimise its bidding strategies (a set of price and capacity pairs).

Also, auction timing should be aligned with the current gate opening time (GOT) and gate closing time (GCT) of the FCR market. On the other hand, TSOs confront a particular risk on the FCR auction failure or capacity insufficiency. In this case, backup solutions should be considered for the FCR procurement.

2.2 Service duration

Service duration of a V2G aggregator highly depends on the auction frequency. In general, a higher auction frequency leads to a shorter service duration. A long service duration challenges the aggregator to adjust diverse charging status for individual EVs and is especially a challenge for storage resources in areas with frequency bias. Further, the availability for EVs may vary between day and night, which is why long duration (e.g. 24 hours) bidding size may be limited by the hour where most EVs are used for driving. The potential operational risk of the aggregator becomes more critical when providing a longer unidirectional reserve for the TSO, e.g., only for upregulation or downregulation. All these elements are contributing to an aggregator choosing to provide lower bids to be prepared for worst-case scenarios.

However, power systems are modernising to accommodate important renewable energy sources (RES). To deal with the RES stochasticity, if a shorter service duration is regarded, a V2G aggregator can provide more flexibility in the FCR market by bidding upward regulation reserves or downward regulation reserves or preferably both. In this case, the TSO needs to schedule reserves between conventional producers and individual aggregators.

2.3 Bids

2.3.1 *Divisible and indivisible bids*

To participate in the FCR market, bids submitted by the V2G aggregators can be divisible or indivisible. Divisible bid allows the TSO to accept a partial capacity from the aggregator’s bid, while indivisible bid forces the TSO to accept the whole capacity or not. Thus, divisible bids allow the lower volume to be accepted by the TSO. With indivisible bids, aggregators can guarantee their benefits, plan utilization in a simple way, and secure economic revenue better. If indivisible bids can be included in the FCR procurement, the TSO may prefer to limit the bids with an upper and/or a lower bound to be able to construct the optimal procurement package.

2.3.2 *Asymmetric and symmetric bids*

Since EVs are mobile storages, charging status varies during the full timespan. Discharging and charging of each EV is featured in switching between producing and consuming behaviours, which gives the aggregator opportunity to supply both symmetric and asymmetric services. For instance, power producing is perceived to cover upregulation, and consuming covers downregulation. The symmetric market structure will allow for a higher utilization rate of the EVs since they will (in theory) never be completely charged or depleted, hence they will be able to constantly provide balancing services. Therefore, symmetric bids are preferable for the V2G aggregators. In the case of asymmetric bids being acceptable to the FCR market, separate auctions can take place to render asymmetric V2G reserves, i.e. one auction is for upward regulation reserve, and the other is for downward regulation reserve. Currently, in the EU countries, the FCR markets are built by symmetric bids.

2.3.3 *Minimum bid size*

It is worth noting that the FCR bid limits vary among the EU countries. For instance, in Denmark the minimum size is 0.3 MW, while in Germany it is 1 MW. As for the V2G aggregators, they may be blocked out by the current market rules due to their comparatively low capacity in the current market, at least until sufficient EVs can be aggregated. A possible solution is to reduce the minimum bid size to a certain level, remove this limitation, or for the aggregator to collaborate with conventional providers if allowed by regulations. On the other hand, an aggregator acts as a representative to take part in the FCR market, while physical reserves are delivered by individual EVs. In this situation, the TSO also faces difficulties in monitoring the activations of the aggregator in a transparent manner.

2.3.4 *Single and linked bids*

As an FCR provider, a V2G aggregator can submit single bids into the market pool at any time. Referring to Section 2.2, if a shorter service duration is achievable, linked bids can be applied in the FCR market. In regard to EV charging characteristics and residual requirement(s?), an aggregator can provide two or more bids, which is available at differing time slots. However, these bids are interrelated with each other. In this case, the TSO needs to decide to accept all of them or none. Currently, this variable does not contain any preference when it comes to V2G aggregation as both may be supported by the technology without any advantage compared to the competing technologies.

2.3.5 *Pricing and settlement*

The payment structure on the FCR market consists of two payment elements, where the bids accepted are honoured with an availability payment for being accessible for activation. Secondary, when activated, a payment for the regulation energy provided is also added to the availability payment. The largest of the two payments is the availability payment.

Two separate pricing mechanisms are applied in different regions, i.e. pay-as-bid (PAB) pricing and uniform pricing. The first usually considers bids to be just below the marginal price, and the second regards bids to come with exact marginal costs. Comparing with the conventional reserves, the marginal cost of a V2G aggregator is much lower. Therefore, it is suitable for an aggregator to participate in either PAB pricing or uniform pricing, however, marginal pricing structure would be preferred, as the V2G aggregator can expect often to win a bid. It is relevant to note that, if an aggregator is involved in the PAB pricing, a decision-making tool is needed to anticipate the FCR marginal price to ensure its profit. The TSO governs the settlement for each aggregator but also faces the same difficulties as mentioned in Section 2.3.3.

2.4 Perspectives

When correlating the seven identified variables with the usability and functions of a V2G aggregator on a FCR market, no clear perfect market exists, as this depends on the number of EVs, competitors, and other technologies available. In order to pinpoint the markets with the most relevant setup of variables for a V2G aggregator, the variables are evaluated on their V2G relevance individually.

As used in Denmark, daily auction and gate timing[1] are suitable for a V2G aggregator, as the long-term availability of EVs is highly uncertain, which is why high flexibility is preferable. The service duration provided by a V2G aggregator can be on an hourly basis.

[1] Implementation of a specific time, where bids have to be sent in for the coming period

For other TSOs in different countries, 'peak duration only[2]', 'off-peak duration only' as well as 'hours or day service' are also preferable. This depends on the available capacity to aggregate. In an early market situation, a shorter service period is preferable.

The bid size highly depends on the number of available EVs associated with an aggregator. To encourage the V2G aggregator to engage in the FCR market, the size of the bidding limit is expected to be 0.1 MW or less. When it comes to the divisibility of the bids, it should be preferred that they are indivisible and single to guarantee the profitability of the aggregator at the current stage. In the future, if a V2G aggregator can manage and operate EVs with high capacity, divisible and linked bids can be considered progressively.

Given the FCR market can be reformed to adapt to the V2G services, symmetric bids are more profitable for aggregators. Otherwise, symmetric bids need to be generated by a secondary market to serve the TSO. The marginal pricing would be preferred in the FCR market to associate with the V2G flexibility. Also, to be able to make a daily settlement between the TSO and aggregators, an extra metering system is required to record and verify the V2G service provided from each EV.

3 Impact factors in EU markets

Given the FCR market architecture and the current number of EVs on the road, the V2G aggregator has a fundamental challenge in building EV portfolios and gets acceptance to trade with the TSO as a new entity. The demands for the aggregator include the ability to handle a broad diversity of EVs and bid(s?) into the FCR market profitably. Although FCR seems to be the market with the highest potential currently, it should not be the only target for V2G aggregators. Aggregator-based service and reserve design are interdependent factors and highly affected by the variables identified in Section 2, as shown in Fig.1. In general, high EV integration could proportionally render larger size of V2G aggregation but has limited impacts on the other variables. Thus, EV penetration has a medium impact on priority and level of the variables. However, increasing requirements of general reserve capacity cannot guarantee a high utilisation of V2G services. The reason is that the TSO may favour conventional technologies (e.g., hydropower) with large capabilities in the current setups rather than V2G aggregators. Consequently, the volume of the reserve market has a little impact on these variables. Based on the context above, in this section, 11 EU countries, Denmark, Germany, Belgium, Great Britain, Norway, the Netherlands, Sweden, France, Ireland, Finland, and Switzerland, are selected to analyse the status of the impact factors and thereby the market attractiveness for V2G. Detectable progress towards the enabling of Demand Response [1] was the reason for selection of the examined markets as Demand Response is fundamental to utilize V2G technology.

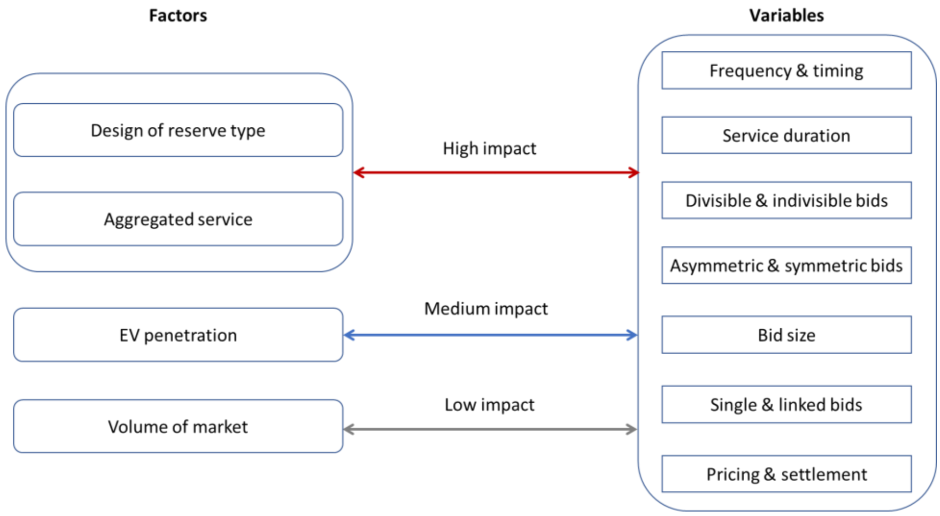


Fig. 1. Impact factors and levels for FCR variables

3.1 Influencing parameters and weighting

When evaluating the importance of the factors for the relevance of an FCR market, it has been decided to prioritize the factors when making the final assessment of the market relevance. Markets, which are already applying demand/response and accepting aggregated resources, are closer to create the right market conditions, which is an essential parameter. The EV penetration is deemed slightly less important but still has a large importance for the individual aggregator. If the number of EVs is at a minimum, it is

[2] FCR services are applied only in hours that can be defined as peak durations, in Denmark between 17.00 and 19.00

complicated to implement V2G, as both minimum bids and product duration are hard to convey with when balancing resources are scarce.

The three influencing parameters have been evaluated and prioritized based on interviews with several experts, resulting in the following priority in the evaluation of the chosen markets.

I. Design of reserve type (50%)
II. Development of aggregated services in general (30%)
III. EV penetration (20%)

The three parameters impact towards a successful implementation of a V2G aggregator in the FCR market works as a benchmark for each weighting. The most important parameter is by far the design of reserve type. With no proper design of the reserve type, it will not matter if the rest of the measures are at an acceptable level. Achieving a successful V2G implementation will become difficult unless the design leaves room for the technology's potential and functionality.

3.1.1 Design of reserve type

This factor is by far the most complex and decisive parameter as it consists of all the regulatory and practical factors concerning FCR reserves. In Section 2.1, in-depth descriptions of the variables and their influence can be found. In this section; focus is towards the most important variables which affect the design of reserve type such as product duration, minimum bid size, symmetry in bidding, and auction method, etc. When developing an overview of the different design of reserve types across Europe, a survey has been compiled regarding the variables and requested the TSOs in each of the 11 countries to answer combined with comparisons of external reports conducted by ENTSO-E and others [5][6][7][8]. This choice of methodology makes it possible to determine and evaluate the reserve types effectively based on the data sources. Considering all the factors, this has been translated into a Likert-Scale from 1-5 where 5 is the most suitable Reserve type design, and 1 is the least appropriate reserve type design.

Overall the European FCR market is divided into sections with following ENTSO-E teaming up with each other by creating or adapting similar designs of reserve types with minor differences. Central Europe is centred around the German design and includes the Netherlands, Switzerland, Belgium, and since late 2016 also France [6]. Characterised by high product duration and long lead times this section makes a less favourable case for integrating an EV aggregator compared to the Nordic region design. Successful integration of an EV aggregator seems more likely to occur in the Nordic region within Denmark, Sweden, Norway, or Finland as the design of reserve type is more flexible for this with short lead times and production durations leaving room for a more durable case. The British Isles are using another way to deploy reserve services, with a poor match for EV aggregators.

TSO response across examined European markets											
Interviewed TSO	DK2 – Energinet.dk	GER – 50Hertz Transmission GmbH	BEL- Elia	GB – National Grid	NOR - Statnett	NL - TenneT	FIN - FINGRID	FRA - RTE	IRE – Eirgrid	SWI – Swissgrid	SWE – Svenska Kraftnät
Auction frequency	Daily	Weekly	Weekly	Daily	Daily	Weekly	Daily	Weekly	Daily	Weekly	Daily
Service duration	1-6 hours	1 week	1 week	1-9999 min	1 hour	1 week	1 hour	1 week	N/A	1 week	1 hour
Linked bids possible	Yes – 6 hours	No	Yes	No	No	No	No	No	No	No	Yes
Divisi-ble/Indivisible bids	Indivisible	Divisible	Divisible	Divisible	Indivisible	Indivisible	Indivisible	Divisible	Divisible	Indivisible	Indi-visible
Bid Symmetry	Symmetric	Symmetric	Symmetric /Asymmetric	N/A	Symmetric	Symmetric	Symmet-ric	Symmet-ric	Symmet-ric/Asymmetric	Symmet-ric	Sym-metric
Minimum bid size	0,3 MW	1 MW	1 MW	N/A	1 MW	1 MW	1 MW	1 MW	1 MW	1 MW	0,3 MW
Pricing and	Pay-as-bid	Pay-as-bid	Pay-as-bid	Pay-as-bid	Marginal pricing	Pay-as-bid	Marginal pricing	Pay-as-bid	Regulated price	Pay-as-bid	Pay-as-bid

settlement											
Design score	**3**	**2**	**2**	**2**	**4**	**2**	**4**	**2**	**1**	**2**	**4**

Fig. 2. Examined design of reserve type markets

For *Design of reserve type*, each market receives an individual score based on their combined performance on the seven influencing variables. In practice, each parameter is not equally weighted and the *Design score* of each market is calculated by adding all the factors together. For evaluation, each variable was evaluated based on a 1-5 Likert Scale. In the case of a binary result, the most desirable outcome, when considering V2G implementation, was rewarded the score of 5 while the score of 1 was rewarded to the counterpart, based on the findings in Section 2.0. The importance and weight of each variable are defined below.

Highly important variables: The category is defined by variables with significant impact on the overall design of reserve type as they, to some extent, determine whether a market could be relevant for V2G implementation. Included in this category are the following variables *Service duration*, *Bid symmetry*, and *Pricing & settlement* with a combined influence worth 66% of the design score.

Average important variables: The category consists of variables with some impact on the market evaluation. Included in this category are the following variables *Auction frequency* and *Minimum bid size* with a combined influence worth 24% of the design score.

Less important variables: The category represents a group of variables with a low degree of impact on the overall evaluation of the market relevance regarding V2G implementation. Included in this category are the following variables *Divisible & indivisible bids* and *Minimum bid size* with a combined influence worth 10% of the design score.

3.1.2 Development of aggregated services in general

The development of aggregated services has already been assessed in the SEDC´s report "Mapping Demand-Response in Europe Today – 2017" and therefore creates the foundation for the evaluation of this factor. The report also supported the framework for market selection as the report only includes those nations identified to have progress. From the investigated countries, a handful of markets were selected based on their overall scores from the four categories: consumer access, programmed requirements, measurement & verification, and finance & penalties. SEDC evaluated each country with a score between 1 to 5 within each of the categories mentioned above equals to an overall max score of 20 combined.

For comparison in this analysis, this score has been translated to a 1-5 Likert-Scale, with 5 being the most developed markets, and 1 being the least developed markets:

Development of aggregated services (SEDC scores)	Markets	Likert Scale
Legally impossible	Switzerland	1
10	Denmark, Germany, the Netherlands, Norway, Sweden	2
12	N/A	3
14	Belgium, Great Britain, Ireland, Finland	4
18	France	5

Fig. 3. Overview of development of aggregated services

3.1.3 EV penetration

To utilize the V2G technology a sufficient number of EVs is key. If the number is too small, the minimum bid size cannot be reached, thus prohibiting the EVs from being utilized. Accelerated increase in the total number of EVs in use would have a significant influence on the expected attractiveness for V2G as the capacity increases [4]. Therefore, emphasis is put on the total number of new BEVs registrations between 2010 and 2017 in the given country, but also by considering the average market share of BEVs in the period.

Again, an operationalizing of these data is using a Likert-Scale from 1-5, where 5 represents the highest EV penetration, and 1 accounts for the lowest EV penetration.

Market	**Total number of BEVs sold**	**Average market share of BEVs**	**Likert Scale**
Finland	975	0,15%	1
Ireland	1.700	0,22%	2
Belgium	7.000	0,23%	2
Germany	43.062	0,26%	2
Portugal	2.500	0,26%	2
Great Britain	38.000	0,27%	2
Sweden	9.500	0,51%	3
Switzerland	11.000	0,62%	4
Denmark	8.700	0,63%	4
France	75.000	0,66%	4
Netherlands	16.250	0,68%	4
Norway	92.000	10,69%	5

Fig. 5. EV stock and market share

4 Evaluations of implementation possibility

The following section provides an evaluation of the implementation possibility for each market based on the results of previous chapters summed up as an overview. In Fig. 6 is a summary of the markets and the accumulated weight in each category.

Country	Design of reserve type – (50%)		Development of aggregated services – (30%)		BEV penetration – (20%)		Total score	
	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted
Germany	2	1,0	2	0,6	2	0,4	6	2,0
Switzerland	2	1,0	1	0,3	4	0,8	7	2,1
Ireland	1	0,5	4	1,2	2	0,4	7	2,1
Netherlands	2	1,0	2	0,6	4	0,8	8	2,4
Belgium	2	1,0	4	1,2	2	0,4	8	2,6
Great Britain	2	1,0	4	1,2	2	0,4	8	2,6
Denmark	3	1,5	2	0,6	4	0,8	9	2,9
Sweden	4	2,0	2	0,6	3	0,6	9	3,2
France	2	1,0	5	1,5	4	0,8	11	3,3
Finland	4	2,0	4	1,2	1	0,2	9	3,4
Norway	4	2,0	2	0,6	5	1	11	3,6

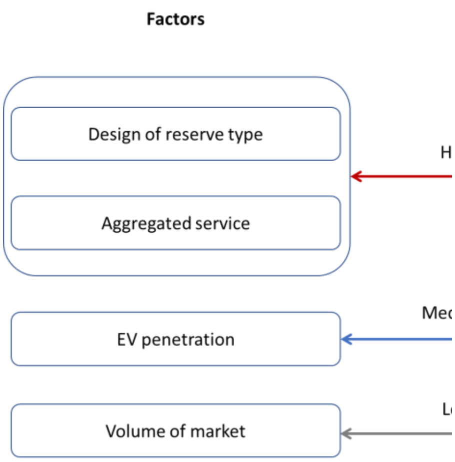
Fig. 6. Final country scores

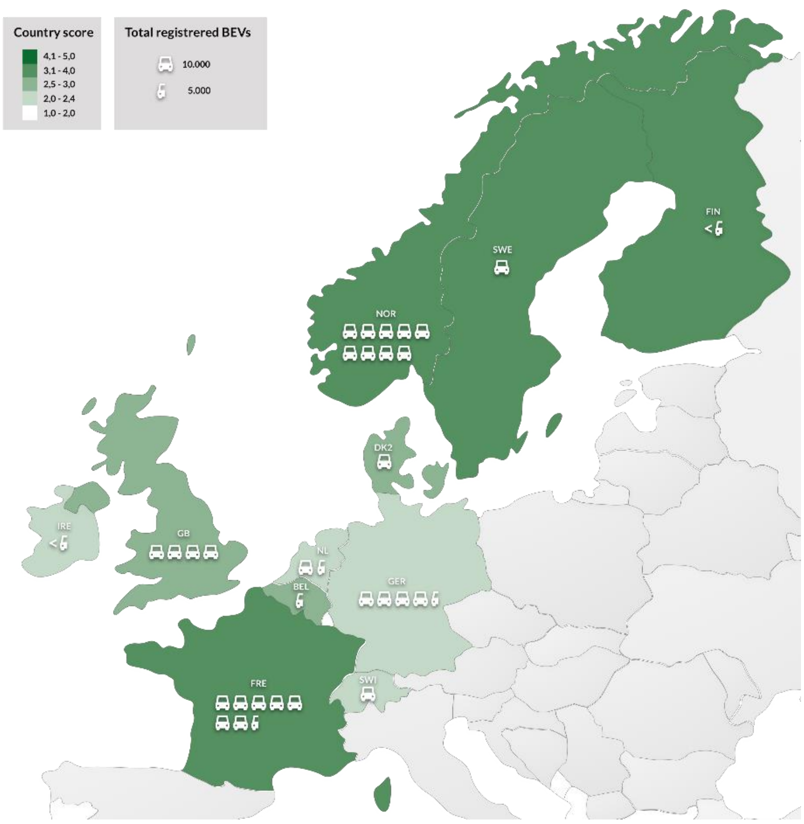
Based on the overview, the results show that the examined markets vary significantly across the three parameters. The importance of the design of reserve type was stated clearly at an early stage and clarified as the countries were assessed by the variables addressed in Section 2. An unfortunate design of reserve type caused by traditional balancing resources, according to this paper's point of view, creates the foundation for massive barriers towards a future V2G aggregator implementation and possibly making it impossible as the fit is non-existing. This analysis indicates that a large share of the examined markets has in some way a suitable design of reserve type while others have significant issues mainly towards longer lead times and service durations.

Secondly, there is a no direct link between the development of aggregated services and design of reserve type. Nations who admitted their product specifications to Demand Response also tend to enable participation from aggregated loads [1]. However, this does not create a perfect positive correlation between the two parameters where one high score will naturally result in the other scoring high too, which can be seen by the examples of France and Norway. This signifies the importance of investigating both parameters before entering a country with a V2G based business model.
Third, the preconditions for a successful operation of V2G aggregators are within the EV penetration, as they deliver the necessary resources for sustainable business cases. Consequently, a low score in this parameter will likely affect the potential timing of V2G implementation negatively, as the prerequisites limit the potential value at its current state. Successful implementation depends on the case and combination of variables, and as this study show, the current markets vary significantly from each other when comparing total scores.
All parameters matter, for instance, while Denmark is granted the highest score in the most important variable "Design of reserve type" the final score ends on 2,9 in total caused by mediocre performances in the other categories. Important to note, with the regular introduction of new laws and regulations within each market, the current situation can change very fast. Also, future technology and tax incentives continuous to affect a more rapid progression towards BEV in some areas.

5. Conclusion

To exploit the potential of V2G aggregation, it is important to understand the markets and the variables it is constructed upon, as they influence the ability to participate in the FCR market. In this white paper, seven key variables in the FCR market design have been identified and evaluated on how they could be optimized to support the V2G technology. The market design is, however, not the only parameter that influences a markets potential for V2G services. Parameters such as available capacity in the form of EVs and the volume of the market are key for creating a viable business implementation. To create a simple overview of the market potential, a framework that can be used to assess the maturity of FCR markets when introducing V2G aggregators has been developed.





The survey addresses the complexity of the markets, as no country currently has a design that is completely optimised for a V2G aggregator. The assessment of the parameters creates a weighted score that can be used to rate the markets and identify which one represents the most favourable cases for the implementation of a V2G aggregator within the market's current state. These results reflect the current condition of each parameter, and they will differ in time, thereby resulting in new evaluations for each country.

Regardless of whether the parameters are weighted or not, Norway comes out on top as the most attractive FCR market structure when evaluating their score on the three parameters. This is primarily a result of Norway achieving the highest given marks in Design of reserve type and EV penetration, whereas Aggregated service only reaches a medium score.

France is second in the non-weighted score and third if the scores are weighted, which is a result of very good Aggregated services and a high EV penetration, however, the most important parameter, the Design of reserve type, is where France scores the lowest.

Finland switches position with France when going from non-weighted to weighted score, which is a result of a well implemented Design of reserve type and Development of aggregated services.

Denmark currently has a good Design of reserve type, but it only brings them up to a fifth place behind Sweden, which is caused by a mediocre Development of aggregated services compared to the best European countries. The Development of aggregated services is currently undergoing major changes with the implementation of market model 2.0, which would increase the score and bring Denmark closer to the top in Europe.

In general, the non-weighted scores achieved by the different countries outside of the top five are very close to each other, which is a result of a generally well-established market structure for aggregated services but lacking market design of reserve type, leaving differentiation between the market to the EV penetration. With the closer integration between the market structures in Germany, Benelux, and France, this is a tendency that is expected to continue.

Reference

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[2] *O.B.M. Petit and Y. Perez, "Provision of frequency-regulation reserves by distributed energy resources: Best practices and barriers to entry," 2016.*

[3] *L. Hirth and I. Ziegenhagen "Balancing power and variable renewables: Three links," Renewable and Sustainable Energy Reviews," vol 50, PP 1035-1051, June, 2015.*

[4] *T.U. Daim, X. Wang, K. Cowan, T. Shott, "Technology roadmap for smart electric vehicle-to-grid "V2G") of residential chargers", Journal of Innovation and Entrepreneurship, 5:15, 2016.*

[5] *C. Hewicker, O. Werner, H. Ziegler, "Qualitative Analysis of Cross-Border Exchange of Balancing Energy and Operational Reserves between Netherlands and Belgium," DNV KEMA Energy & Sustainability, pp 7, August, 2013.*

[6] *P. Ladouchette, C. Edwige, H. Gassin, Y. Padova, J-P. Sotura, "Decision of the French Energy Regulatory Commission of 2 June 2016 concerning guidance on methods for the procurement of Frequency Containment Reserve for ancillary services," Commission de Régulation de L´énergie, June, 2016.*

[7] *"Survey on Ancillary Services Procurement, Balancing Market Design 2016, ENTSO-E WGAS, March 201.7*

[8] "*FCR cooperation potential market design evolutions,"Public consultation, January, 2017.*

New Market Design

The European countries have implemented different market designs for demand response due to different market requirements. Some European countries have implemented capacity market for regulating the wholesale market instead of strategic reserve as applied in Nordic countries. Danish energy actors have developed four market models for implementing aggregation in Denmark, and the actors are reflecting the way to structure the market in the future. V2G has potential to be implemented in several European countries, and for that reason it is relevant to look at the market models in countries, which have experiences with demand response such as Netherland, UK, and Finland. The purpose of the “New Market Design” analysis is to identify;
How to develop a market design for TSO markets with respect to optimal usage of V2G technology?

The report accounts for the new Danish market models for aggregators. Hereafter, the report discusses the usability of the Danish market models for the V2G system in the future. The findings have been discussed with experts’ statements based on their experiences in the energy field and V2G as technology. The purpose of “New Market Design” is to identify sustainable value systems for the implementation of a V2G system.

Content

1. Implementation of demand response in European countries

According to SEDC 2017, the European countries, Finland and Great Britain among others, have developed frameworks for demand response. The two countries are commercially active within explicit demand response whereas the Danish electricity market does not have a broad experience with demand response due to the small flexibility demands. Furthermore, the actors in the Danish energy market need experience and knowledge about flexibility (Dansk Energi, 2017) (SEDC, 2017, pp. 196, ll. 1-4).

At present, Denmark is placed in a conflict of interest for choice of reserves. On the one hand, the Nordic countries and Germany work for a uniform energy price structure. Norway, Finland and Sweden have implemented a strategic reserve market, and for that reason the Danish TSO, Energinet, is also interested in implementing a strategic reserve (SEDC, 2017, p. 199), as Denmark can improve its future cooperation with the Nordic countries and Germany (Dansk Energi, 2017). On the other hand, the Central West Europe has implemented a capacity market. Therefore, it is interesting to explore the development of demand response in Central West Europe and their regulation methods. The research focuses on three countries comprising Netherland, Great Britain, and Finland as their markets are ready for the implementation of a V2G system.

Parker wants to investigate the opportunity to deliver flexibility to ancillary service comprising frequency stabilization, called FCR-D in DKK2, as an EV is able to meet the requirements for FCR services due to a fast up- and down regulated battery and FCR is able to provide an interesting business case for V2G.

1.1 The overall market barriers in European countries

The market barriers have been defined as relevant in the Danish energy market and the results in Figure 1 are based on a questionnaire study for which TSOs from several countries have been requested to identify market barriers for V2G in Europe. The study indicates that the V2G market is immature due to a great uncertainty of barriers. Figure 1 illustrates that one of the most relevant barriers for V2G is that few EVs are driving on the roads and the lack of intelligent electric metering for bidirectional charging. Moreover, TSO and DSOs have difficulties in handling submetering for each prosumer such as fleet owners and bidirectional charging is costly for prosumers, as investment costs are higher than electricity savings. The three least relevant barriers, for which some parameters have been identified as non-barriers for the market, are; the V2G technology is not mature for the market, the price structure is not developed for demand response (non-variable prices and tariffs) and the lack of hourly settlement for end users. According to the results, the market is first ready for V2G technology when intelligent electric metering has been improved for metering flexibility capacity and the market share of EVs increases.

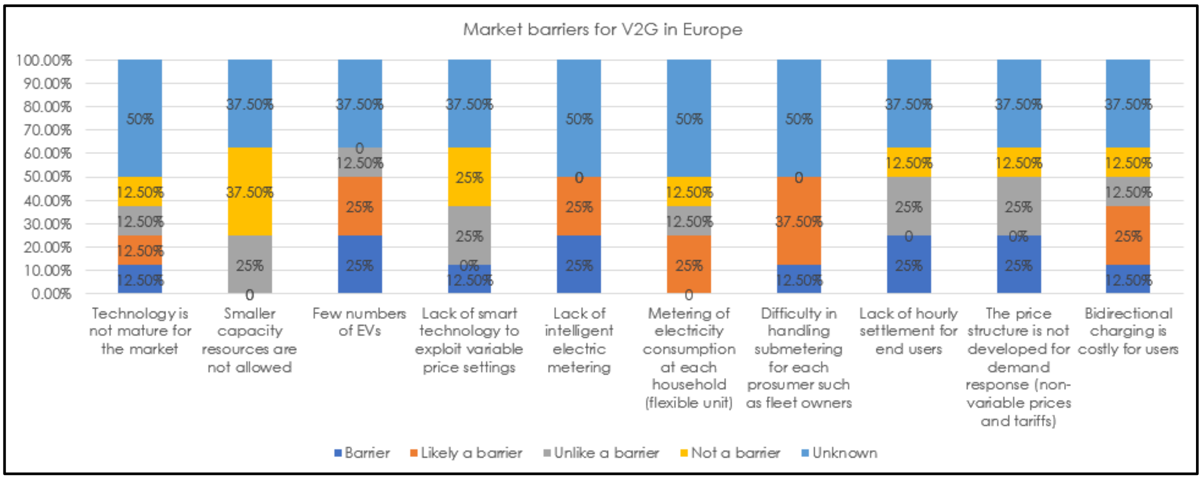

Figure 1 Market barriers for V2G in Europe

1.2 Finland

In the Nordic countries, Finland leads the way with the implementation of demand response, as demand response is legal in all current energy markets. Prosumers have high potential in providing flexibility as there is no required size for consumer participation and technical requirements for flexible units, but the pool of flexibility load has to fulfil all requirements by a pre-qualification, which an aggregator can manage for prosumers (SEDC, 2017, p. 196). In Finland, both the energy provider, which collects surplus of electricity from installed generation capacity, and a commercial, independent aggregator can work as a flexibility service provider in wholesale, retail, and reserve markets (BestRES, 2016, p. 70).

An independent aggregator can provide flexibility capacity to the primary reserve without cooperation with a BRP or an energy provider. Moreover, the Finnish TSO has increased the demand side of primary and tertiary reserves. However, Finland has some market barriers for aggregators. Demand response can only provide with large scales in FCR-D with a minimum bid on 1MW and mFRR has a minimum bid on 5MW. Some pilot projects with load curtailment can participate in FCR-N with a minimum bid on 0.1MW, and the minimum bid sizes on other balancing and ancillary services are a hindrance for aggregators to provide capacity on all markets (SEDC, 2017, p. 78). An independent aggregator can bid on FCR-D markets, and consumers and prosumers can select a Demand Response service provider in the FCR-D market, but an aggregator has to cooperate with the prosumer's BRP or energy provider for entering other markets than the FCR-D. In addition, an individual aggregator must be the owner of balancing resources, a retailer, or a BRP. An aggregator, which pools capacity from prosumers with different BRPs, can only bid on the FCR-D market despite that the aggregator has investigated how the BRPs can reduce balancing risks. However, none demand response pilot projects have yet participated in the aFRR market with a minimum bid size on 5MW (SEDC, 2017, p. 73).

One of the challenges for an aggregator in Finland is that a DSO does not have incentives for demand-side flexibility for reducing congestion in distribution grids due to the price structure; high time tariff during day time with high electricity demand. The opportunity for unlocked flexibility load is highest during night time when the time tariff is low resulting in lower energy prices, but the demand for flexibility is highest during day time with high energy and tariff prices. However, implicit demand response has been successfully implemented in Finland, as the consumer is able to lower their energy consumption by reacting to dynamic electricity prices. Thus, the DSOs can reduce costs as implementation of demand-side flexibility will require investments in communication technology (SEDC, 2017, p. 76).

V2G Pilot projects
In October 2017, Finland got its first public, bidirectional charging point for EVs installed in Helsinki. The V2G charging point is part of a V2G pilot project and is developed in cooperation between the following companies; Helen, a distributed generator, Virta,a charging operator, and Nissan, the EV OEM. The charging point is installed at a site with both a PV and a energy storage system[1][2].

1.3 The Netherlands

The TSO in the Netherlands, TenneT, has challenges with energy transition and needs capacity from decentralized energy units, which can provide flexibility to the grid. In the Netherlands, actors as energy producers, BRPs, and energy providers act as aggregators, and consumers are large industries and greenhouses (BestRES, 2016) (SEDC, 2017). A third-party (independent) aggregator is a BRP's service provider, and an aggregator is obligated to cooperate with the consumer's BRP and retailer to provide flexibility to the grid. Thus, an aggregator is dependent on cooperation with BRPs and retailers, and for that reason it is complex for a new, independent aggregator to enter the market under the current market conditions. Furthermore, an aggregator may only sell services to mFRR compared to the demand-side response, which can also provide to aFRR (SEDC, 2017, pp. 137-139).

BRPs in the Netherlands have an opportunity to provide demand response, as BRPs will be rewarded for balancing the whole system if imbalances arise. This is called "passive balancing". BRPs will be rewarded for passive balancing as the TSO has developed a price structure for demand-side flexibility based on real-time market signals (SEDC, 2017, p. 140). In that way BRPs can either handle this flexibility service with their current resources, otherwise an independent aggregator can help the BRP with imbalance services. In this case, an independent aggregator has an opportunity to pool demand-side resources from greenhouses and hospitals and load shedding capacity for passive balancing of the grid. Aggregation is only allowed in mFRR with a minimum bid size on 4MW, thus, the BRP with an aggregator role conducts the pre-qualification measurements for the consumer and provides a quality control of the flexibility capacity. One of the challenges for an aggregator in the Netherlands is that a DSO does not have financial incentives to buy demand-side flexibility, and therefore more interested in optimizing the grid infrastructure (SEDC, 2017).

As in Denmark, current energy stakeholders investigate how to improve the market conditions for an independent aggregator, and the team has developed market models for progression of demand response and investigated three new models for the Dutch energy system (SEDC, 2017, pp. 139-140):

1. The market roles of an independent aggregator
2. The independence between retailer and BRP
3. The customer can choose energy actors by choice such as BRP, retailer, service providers, etc.

Furthermore, ongoing demonstration projects for changing fixed tariff regulation to hourly basis for creating incentives to demand response in the future are in progress (BestRES, 2016, p. 72).

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[1] https://cleantechnica.com/2017/10/24/finland-gets-1st-public-bidirectional-v2g-charging-station/
[2] https://www.helen.fi/en/news/2017/first-two-way-charging-point-in-finland-to-be-installed-in-helsinki/

V2G Pilot projects
The energy provider and aggregator, Vandebron, collaborates with TenneT in a pilot project. Vandebron pools prosumers' EVs to provide balance maintenance[3]. The aggregation method is explicit demand response, as TenneT can manage the aggregation and prosumer will get payments for flexibility service. Furthermore, V2G aggregation has been implemented in Amsterdam where the CPO, NewMotion, cooperates with TenneT, Nuvve provides aggregator software, and Enel provides charge point hardware[4].

1.4 Great Britain

Great Britain has been the first mover in Europe for demand response for different services, but the development of operational requirements for demand-side resources has been delayed, thus, the market has not yet taken advantages of demand-side capacity. In Great Britain, an independent aggregator can provide flexibility to ancillary service, but the balancing mechanisms and the wholesale market are only open for independent aggregators if they sign a bilateral agreement with the consumers' energy provider (SEDC, 2017). Aggregation for which the energy provider takes the role as an aggregator and delivers frequency stabilization is called *supplier led aggregation*. Therefore, demand response has only been accessible for larger private and commercial customers, but the existing market mechanisms are being overhauled to open demand response to small scale customers.

England has potential for V2G due to an increased use of renewables and the grid must be balanced[5]. The UK government has the vision that all cars are zero emissions by 2050, and V2G can provide a more flexible and cost-efficient energy system for consumers. Therefore, the UK government invests in V2G pilot projects.

V2G Pilot projects
In January 2018, the UK government has funded the world's first, large-scale V2G demonstration project with £9.8 million, which is one third of the £30 million the UK government has invested for identifying new business models for bidirectional transport from EVs in different research projects. During the next three years, 1000 V2G chargers will be installed in the UK, and the project can result in aggregated flexibility across the East side of UK and provide ancillary services for disconnected sectors. The project will apply 10kW V2G chargers and each charger can store 40kWh. In total, the project can provide with 10 MW power capacity and store 40 MWh energy[6]. The project partners are EV OEM, Nissan, the two DSOs, Northern Powergrid and UK Power Networks, the TSO, National Grid, the V2G aggregator platform, Nuuve, as well as academics from Newcastle University and Imperial College in London. The bidirectional charging should result in reduced energy bills for consumers[7].

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[3] https://www.tennet.eu/news/detail/electric-vehicles-replace-power-plants-to-maintain-supply-demand-balance-on-high-voltage-grid/Finland
[4] https://www.enelrussia.ru/en/media/news/d201710-enel-brings-vehicle-to-grid-technology-to-v2g-hub-in-the-netherlands.html
[5] https://www.danskenergi.dk/nyheder/flere-elbiler-skal-saelge-ydelser-til-elnettet
[6] http://www.ncl.ac.uk/press/articles/latest/2018/01/v2grollout/
[7] https://www.electrive.com/2018/01/31/1000-v2g-charge-points-gb-nissan-uk-government/

1.5 Summary of barriers for a commercial aggregator in the three countries

Table 1 presents the different aggregator types, the energy market, and barriers for commercial aggregators in the three countries, Finland, the Netherlands, and Great Britain.

Parameters	Finland	Netherland	Great Britain
Aggregator type (balancing market)	Resource owners of flexibility or an independent aggregator.	An aggregator must collaborate with consumer/prosumer's BRP and BRP's retailer. Thus, the aggregator is a service provider for BRP.	An energy provider takes the responsibility as aggregator and is called *"Supplier-led-aggregation"*.
Wholesale- and Ancillary Market	Flexibility capacity is legal in all markets by cooperation with a consumer/prosumers' BRP. An aggregator can provide flexibility capacity in FCR-D, and aggregation of resources from different balancing groups is legal in FCR-D.	Both demand Response and aggregation can sell electricity to mFRR, but only demand-side response can bid in aFRR market.	Aggregation is open for all services, but an aggregator must collaborate with an energy provider to provide services to balancing services and wholesale market.
Barriers	The current price structures are a barrier for an aggregator to compete with the current market actors.	An aggregator must cooperate with a BRP, thus, it is difficult for new actors to enter the market as an aggregator. Emergency Power program is difficult to reach for an aggregator due to a minimum flexibility load on 20MW.	The market is opaque due to bilateral contracts, which can result in risks for new entrants.

Table 1 Aggregator type, relevant energy market, and barriers for a commercial aggregator in Finland, the Netherland and Great Britain.

2. Introduction to Market Models 2.0

The working party comprised of the Confederation of The Danish Energy Association, Energinet, the Confederation of Danish Industry, and the Danish Intelligent Energy Alliance have developed four Danish market models for implementing commercial aggregators in Denmark. The models focus on providing flexibility services in Europe for balancing the grid by developing a commercial actor without focusing on the aggregator as a technology. The identified models have been inspired by *Universal Smart Energy Framework (USEF)*. The developed report behind the models is called Market Model 2.0 (MM2.0). Today the Danish TSO needs flexible energy consumption for balancing the grid due to the increased use of renewable energy systems and to reduce electricity supply from power stations. According to MM2.0, electricity generators deliver flexibility to the existing market but there is an opportunity that consumers, small and medium-sized enterprises, can provide flexibility. The MM2.0 focuses on developing sustainable flexibility models/approaches and market opportunities for commercial aggregators in Denmark within the current market conditions and legislations at the whole sale market etc. Existing energy players such as BRP, the electric supplier, or power plants can take the role as an aggregator, and an independent actor with or without cooperation with established energy actors such as a BRP or both a BRP and an energy provider has also the opportunity to enter the current energy market as an independent aggregator. The aggregator models accounted in MM2.0 are defined in table 2.

The report by the Confederation recommends a stepwise implementation of the four market models for commercial aggregators to provide responsibility to a commercial aggregator by cooperation with current energy actors. The developed market models are generic and usable for flexibility units and commercial actors.

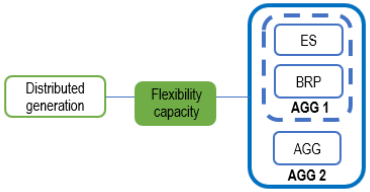
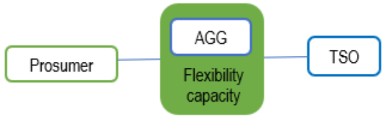
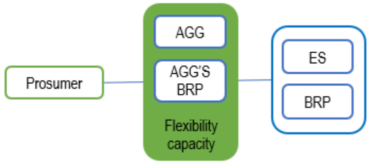
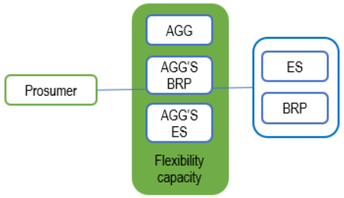
Model	Definition	Specifications
Model 0 - Flexibility opportunities for existing actors 	The model is used today, and existing market players as energy providers and BRPs can take the role as an aggregator (AGG 1). Otherwise, an aggregator can cooperate internally with a BRP and/or an energy provider by having bilateral agreements regarding balancing the grid and regulating electricity consumption (AGG 2).	**Role:** Present market actors or aggregators can cooperate with a BRP and/or an energy provider. **Value proposition:** Energy intensive industries and EV fleets have a potential to unlock flexibility by cooperation with existing energy actors. **Metering system:** The existing electricity meter installed at EVSE measures the provided flexibility to the grid. **Demand response:** Both implicit and explicit flexibility
Model 1 - Frequency stabilisation 	The aggregator is a new, independent actor in the market and delivers FCR services to the TSO without cooperation with a BRP. *Model 1* is developed by inspiration from Parker for which several EVs deliver FCR-D to the DK2 market without an online meter measuring the provided flexibility from EVs.	**Role:** An independent, commercial aggregator, which does not cooperate with a BRP or an energy provider. **Value proposition: The** aggregator delivers only a small amount of power to the TSO. The aggregator trades only frequency stabilization (FCR products) without having responsibility for electricity delivered to the prosumer. **Metering system:** Portfolio metering by installing a secondary meter or an electricity meter. **Demand response:** Implicit flexibility
Model 2 - Aggregator delivers flexibility 	The aggregator is a new market player, which cooperates with a specific BRP to provide unlocked flexibility to all electricity markets	**Role:** The aggregator cooperates with a BRP (a contractual model), which balances flexibility for the aggregator. The BRP and the prosumer's energy provider handle supply and settlement of flexibility. **Value proposition:** The aggregator can provide a larger quantity of flexibility to all electricity markets. **Metering system:** Main electricity meter at EVSE measures both the electricity consumption and the provided flexibility of EV. **Demand response:** Explicit flexibility
Model 3 - Supplier of flexibility and service 	The aggregator can provide with a service e.g. EV car sharing and at the same time be a new player as aggregator.	**Role:** The aggregator provides services for prosumers. The aggregator cooperates with both a BRP and an energy provider to handle unlocked flexibility to all electricity markets. **Value proposition:** The aggregator provides transport with EV as primary service and unlocked flexibility to the prosumer as secondary service. **Metering system:** Electricity consumption and flexibility provided by flexible unit are divided by a serial metering point. The flexibility from EV is measured by a submeter. **Demand response:** Explicit flexibility

Table 2 Market Models for commercial aggregators in Denmark

3. Implementation of V2G in Denmark by applying MM2.0

In Denmark, the implementation of aggregation is an ongoing process for which companies, universities, and municipalities cooperate to develop profitable aggregation projects potential for commercial applicability. Partners from Parker and externals energy actors from the MM2.0 working group[8]; Energinet, Dansk Energi, and Intelligent Energi participated in a workshop concerning Parker and the four market models for a commercial aggregator called MM2.0, cf. Chapter 2. The aim of the workshop was to identify opportunities and weaknesses of MM2.0 in regard to usage of V2G technology in the future and investigate whether there is a need for a new Danish market model with respect to optimal use of flexibility from EVs.

3.1 Does flexibility service meet the needs of the grid operators?

In Denmark, flexibility service can be relevant for Eastern Denmark and surroundings, called DKK2, as they have stabilization problems, and flexibility service is a way to combine fluctuating renewable energy. However, the TSO does not have a perceived need for flexibility, as it is not expected that flexibility is a cost-efficient solution for supply of power. Furthermore, the TSO has to stay politically neutral to production of electricity, as they cannot favour cleantech due to regulation of electricity production and the Nordic countries cooperate which makes it impossible to control the energy source. However, the DSO can benefit from flexibility service to secure supply security. However, the DSO can have certain reservations about the activation of flexibility from flexible units and at the same time provide power to high-power technologies via the distribution grid. This is due to congestion management as the grid can be congested with power from flexibility units. The development of flexibility service can be improved by top-down regulation to secure flexibility services and 100% green energy. Furthermore, the TSO mentions that Denmark must cooperate with other TSOs (other countries) to make changes within demand response, as there are a few barriers for the flexibility service, such as non-developed standards for V2G and too small market penetration of EVs. V2G implementation can be improved by new technology developments of EVs and smart-grid innovation for the DSO grid, several ancillary service opportunities, and business incentives which reduce consumers' electricity consumption. The working group of MM2.0 has suggested some initiatives and furthermore suggests reduction of energy consumption by increasing the electricity price gap, which can give a more transparent energy management, and therefore a supplement for flexibility service.

One of the main problems to provide flexibility in the future emphasizes that the DSO meter is a challenge due to the rules about DSO metering, meter installation, and technical qualities, as it should be possible to get access to the meter and test the meter during its operation period. Furthermore, a company should accept bidirectional transport on a meter from another company and secure a high metering quality and reduce the costs. Another problem is the lack of cooperation between the TSO and the DSO due to conflicts of interests according to investments in electricity grid infrastructure and bilateral agreements with other actors and communication problems. The aggregator and the TSO may handle the communication problem to provide flexibility services, which leaves the question whether the DSO has responsibility to lock flexibility and act according to the TSO. An aggregator is exposed to a high risk, if a prosumer gives two different aggregators accept to control charging and discharging of the EV, or the prosumer has signed a contract with two different aggregators to handle two different flexibility units, which demands a serial metering system. This is relevant if the prosumer provides flexibility from an EV and unlocked flexibility from a heat pump. According to the experts, taxation of flexibility service will not be a problem when flexibility service is provided.

[8] MM2.0 working group participants have developed the four market models accounted in MM2.0.

3.2 Usability of the four market models for V2G

Table 3 presents strengths and weaknesses of applying the four market models in MM2.0 to implement V2G in the current Danish energy market for to provide flexibility to grid. The definition of the four models in MM2.0 is represented in Chapter 2.

Model	Strengths	Weaknesses
M0	M0 is implemented in the current energy system in Denmark, where the current energy actors act as aggregators. Furthermore, the aggregator cooperates with the consumer's BRP or both the BRP and the energy provider.	The system leaves little room for an aggregator to act as an independent flexibility provider in the market, making them dependent on BRPs to provide their service thereby reducing possible revenue.
M1	M1 only works with a small amount of power for which it is not necessary to balance the unlocked flexibility with a BRP, as the FCR results in unnoticeable imbalances in the grid.	The requirements state that it is not possible to regulate imbalances without a BRP. Implementation of M1 requires that the regulations will be changed in the future for which it is possible to regulate a small amount of power without a BRP. The question is what the cost is for regulating the flexibility without a BRP?
M2	M2 is based on metering both flexibility supply and electricity consumption with a virtual meter, which creates a legal settlement in the market structure. It is not necessary to install a submeter, as there is developed a settlement between the BRPs (The aggregator's own BRP and consumer's BRP).	M2 is the most complicated model, which needs to be simplified for commercial use. However, M2 is possible to implement due to the costs of submeters, and if the virtual meter meets the quality of meter data. There is a non-commercial push for M2, as it is not relevant for the actors such as car manufactures to secure flexibility service from V2G.
M3	The model is workable for commercials with other services than aggregation. M3 is available for e.g. carsharing, as the meter data of the energy consumption and flexibility provided are separated and of high quality. Therefore, it is easier for the energy actors to handle flexibility service. M3 is relevant for the flexibility market, if M3 can provide required power to the grid.	Model 3 requires another DSO meter, but maybe it is possible to simplify the serial metering process, as flexibility supply is metered on a submeter and electricity consumption is metered on a main meter. Furthermore, the installation of submeters can be complicated and the meters are expensive. Another barrier is that the delivery of data can take 5 days, if the number of meters is limited.

Table 3 Identified strengths and weaknesses of MM2.0 models.

3.3 Which market model to choose?

The actors in a V2G system have different requirements to V2G implementation in proposition to their business experiences and legal aspects, cf. Table 4. The aggregator, Nuuve, is interested in model 3, as it enquires an extra meter due to legal security. DTU prefers model 2 due to a more intelligent and scalable metering software system to reduce system costs. The Danish TSO, Energinet.dk, is interested in testing the flexibility service by receiving a minimum bid for 1MW and/or 5 MW power. Model 2 and 3 have the potential to be implemented in the Danish energy market, but the question is who owns the smart meters when prosumers switch commercial aggregators due to market competition and voluntary choice of electricity provider and aggregator?

Experts	Model	Implementation opportunities
Aggregator, Nuuve	M2	Model 2 can imply risks for several aggregators, as the measurements are only based on virtual but legal settlements between energy actors and the metered data is not separated.
	M3	Model 3 is the recommended model for a V2G aggregator, as the model is applicable for the market, which separates the electricity consumption and the flexibility provided. The model is seen as valuable for the market, as it is an easy way to provide the grid with power when needed.
TSO, Energinet	M1	Energinet.dk recommends implementing model 1 as a start and afterwards expand to model 3.
	M2	Model 2 is the most complicated model and not usable for the market due to potential issues with settlement of measurements of consumption and unlocked flexibility.
	M3	Model 3 is the most usable model for stakeholders, as the metered data of electricity consumption and flexibility are separated, which can result in increased data security.
Electro expert DTU	M0	DTU recommends first to implement an aggregator with the use of M0, as it is possible to test the practicability of Parker.
	M2	Afterwards, DTU recommends developing a commercial aggregator with the use of M2. M2 is recommended due to future technical opportunities with a virtual meter based on legal settlements metering one- and bidirectional transport in spite of several actors which handles the power transport. Furthermore, it is possible to increase the scalability with a virtual meter due to its agility.

Table 4 MM2.0 models and their relevance for a commercial aggregator with focus on V2G

Generally seen, the market models are implementable for flexibility service with V2G technology in the future, but the models have different problems to handle to be usable in the energy market. Model 2 can result in a future-proofing of electricity metering systems, as implementation of model 2 requires development of a smart meter, which measures both electricity consumption and flexibility capacity. When a smart meter is implemented for metering electricity consumption and flexibility, different actors may cooperate to monitor data and separate related settlements. Model 3 is easier for the commercial actors to implement in proposition to financial and legal aspects, as electricity consumption and flexibility provided by the prosumer will be metered by different meters and the meters are monitored by different actors due to organized responsibility of the meters. The Danish TSO is interested in the V2G technology, but they must investigate if they want flexibility as power resource by following the evolvement of V2G in the existing market. In the future, the TSO is interested in testing the V2G system developed in the Parker project based on market model 0 or 1 in order to investigate the profitability of the V2G system.

4. Implementation of the Danish market model for optimal usage of V2G

V2G as technology to provide bidirectional energy transport is possible to implement at the energy market, if an aggregator is able to pool the required capacity from EVs. The new Danish market models, MM2.0, can provide new market opportunities for both third party aggregators and current energy actors taking the role as an aggregator. The Danish market models can result in both opportunities and threats for the V2G technology. The strengths and weaknesses of V2G as a technology providing flexibility, and the opportunities and threats of the market are defined in table 5. V2G covers both technical aspects such as technical capability of bidirectional power flow and business aspects such as the flexibility service that V2G can support. Therefore, an aggregator is defined as both a technical aggregator, which handles flexibility units, and a commercial aggregator, which sells flexibility services to grid operators.

Strengths	**Weaknesses**
• Countries with a high penetration of renewable energy and/or EVs can benefit from a V2G service. • V2G can result in improved environmental performance, if EV drives on green energy. • V2G is workable for EVs, which are connected to V2G chargers, and V2G is usable for both private EV - and EV fleet owners and carsharing actors. • V2G can provide fast frequency regulation for TSOs by unlocking power from EVs. • V2G can improve the utilization of an EV, as the battery in the EV can be employed for storage and the battery is quickly up- and down regulated. • V2G can result in low preliminary expenses, and the prosumers can get a revenue from V2G service depending on the business model of the aggregator. • The Danish government contributes to development of technical requirements such as the development of a Grid Code.	• Research indicates that bidirectional charging can result in degeneration of battery, but the variable costs related to degeneration is unknown. • V2G is expensive to install in EV due to the lack of support from OEMs. • Lack of an EU standard for communication between EVSE and Cloud platform for V2G installation. • V2G can result in an increased use of fossil fuels to electricity production, if V2G is installed in areas without renewable energy systems. • V2G contributes indirectly to environmental impacts, as batteries in EV contents environmentally unfriendly liquids. • Installation costs to install a new electricity meter near the charger.
Opportunities	**Threats**
• Countries with a high penetration of EVs can benefit from V2G service to provide service for grid providers. • The Danish TSO has a mission to reduce numbers of grid shutdowns to tighten the energy security. • The four models defined in MM2.0 can create improved market conditions for a commercial aggregator with focus on V2G – and MM2.0 will increase the market competition between the current electricity actors. • The new Danish energy initiatives give market opportunities for V2G, as one of the initiatives is to decrease the electricity prices, which gives consumers incentive to invest in an EV due to reduced costs to propellant and the consumer can be a potential V2G participant. • Besides of V2G, EVs can also be connected to buildings with V2H technology and other vehicles via short-range wireless signals with V2X technology[9].	• A third-party aggregator can have difficulties in entering the energy market without changed market conditions, as aggregators can create conflicts of interests by energy producers, energy provider, and BRPs due to market competitions. • Regulatory barriers do not give market opportunities for an aggregator at ancillary service, only at primary reserve, due to required provided capacity. An aggregator may expect implementation costs to enter the electricity market. • Other technologies like storage can be competing technologies to V2G. • Lack of knowledge and different understanding about technical and business potentials of both aggregation and V2G. • Market penetration of V2G depends on the available EVs and EV users' driving demands. • EV users can connect EVs to a charger owned by a CPO, which collaborates with another aggregator than the EV user, which requires the two aggregators to collaborate to secure efficient smart charging of EV.

Table 5 Strengths and weaknesses of V2G and opportunities and threats for V2G provided from externals

[9] Downloaded the 6 of October 2017: http://www.investopedia.com/terms/v/v2x-vehicletovehicle-or-vehicletoinfrastructure.asp

4.1. Strengths & weaknesses of V2G technology

V2G technology can improve the green transition in Denmark, as V2G can supplement fluctuating energy sources with fast and valuable flexibility from EVs in periods with high electricity consumption when transmission grid stability is needed. V2G can result in reduced environmental impacts, if EVs are charged with renewable energy, but energy production based on fossil fuels will worsen the environmental impacts (Sovacool, 2018). The greatest strength of V2G is that the storage capacity of an EV will be utilized by V2G, as a battery is capable to up and down regulate for flexibility service within a short time. In the Parker Project, an EV connected to V2G consumes 10MWh electricity, uses 1 MWh for driving, losses 3 MWh over the grid, and supplies with 6 MWh to the grid during a month. V2G can increase the potential of EVs and, furthermore, V2G can increase competition in the energy market, as it is possible for aggregators to provide flexibility as a service. V2G is applicable for households with an EV, EV fleet owners, and carsharing actors.

According to MM2.0, an aggregator has the opportunity to offer flexibility capacity at the day-ahead- and intraday market, but there are some regulatory barriers to enter the balancing and ancillary services due to demand on symmetry and high offer size, which requires the aggregator to pool many flexible units. Furthermore, the TSO will tighten the regulative for DKK1, if it cooperates with Germany to provide primary reserves, as it will require both a symmetric offer and a higher offer size in the future (Energinet.dk2, 2015, p. 55). However, currently the primary reserve requires a minimum offer on 0.3 MW which requires of the V2G aggregator to have a fleet of at least 30 available EVs under their control to provide the flexibility service. The benefit of primary reserve is that frequency stabilization service is the highest paid ancillary service due to the shortest activation periods (ENERGINET, 2017). An EV battery can provide flexibility service within 10 and 15 seconds to FCR-D and FCR, respectively, cf. *Parker - Grid Readiness Certification*. According to Energinet, the activation in DK1 fulfils the requirements for frequency stabilization but in DK2, the EV will only meet 50% of the supply requirements, as the first 50% of supply may be delivered within 5 seconds (ENERGINET, 2017, p. 21). However, the barrier for a V2G aggregator is that the BRPs must handle imbalances by proactive operation planning by activating mFRR instead of frequency stabilization, as mFRR is a cheaper service to reserve and activate than FRR and aFRR (ENERGINET, 2017).

The transmission grid can be affected by periods of fluctuating renewable energy and/or a high electricity consumption for which the TSOs needs assistant to stabilize the grid. A commercial aggregator can help with stabilizing the grid, but an aggregator needs to operate a critical mass of EVs or EV fleets. An aggregator may pool a larger quantity of EVs (batteries), which are possible to utilize for aggregation to offer flexibility as a service due to market limitation at the ancillary service market. An aggregator may pool at least 30 EVs to deliver flexibility to frequency stabilization. On the one hand, it is difficult to forecast driving demands, the amount of accessible EVs for aggregation, and the required capacity from energy operator, but on the other hand, an aggregator can plan EV users' driving demands based on history of EV users´ use patterns. Therefore, the security of supply with V2G is built on uncertainties, and for that reason it is necessary with a buffer of available EVs. A commercial EV fleet has a stable driving pattern, but private EV users can have unpredictable use patterns for which it is important to have a buffer.

On the one hand, an aggregator can offer destabilization of the local grid by massive connection to the distribution grid, if an aggregator does not organize flexibility capacity provided by EV fleets. On the other hand, V2G can result in a fast and cheap flexibility solution by handling imbalances for the net operators and can result in reduced socio-economic costs by reducing the need for investments in grid installations following the needed power demand. However, flexibility service requires an installation of a new electricity meter by a cut-in on the electricity grid for measuring flexibility provided, which is an expensive installation for the prosumer. If the aggregator applies Model 3 as business model, a flexibility meter is needed, and an aggregator with use of Model 2 requires a smart meter, which is a combined electricity- and flexibility meter.

Research indicates that one of the disadvantages with V2G is that a battery can be abraded within a shorter time due to bidirectional charging, and the variable costs related to degradation of the battery are unknown at the time. According to Dubarry et. Al. 2017, bidirectional charging will shorten the lifetime of Li-ion cell batteries with less than five years. Furthermore, the lifetime of the battery will be affected in warmer climate by delaying the charging for reducing the impact on the power grid in peak periods (Dubarry, 2017). Another weakness of V2G is that battery production has a high environmental impact due to content of environmental unfriendly liquids, which will affect waste deposit after the period of use of the battery. Therefore, it is important to extend the lifetime of the battery to reduce the impacts on the environment.

Despite potential degradation of battery and related costs, research indicates that prosumers can make a revenue on V2G connection, as preliminary expenses and marginal costs are low (Sovacool, 2018). One of the strengths of V2G is that it can cause reduced system costs through the regulation service for system operators, and an aggregator gets reduced costs and creates revenues by V2G services. The prosumers can in some cases get lower prices for electricity and parking and create a revenue by offering flexibility from EVs (Sovacool, 2018, p. 10). The question is what are the costs for a prosumer to charge and discharge the battery over a period when providing V2G services compared to total revenues? Commercial actors with carsharing as value proposition can be connected to V2G for which an EV fleet is seen as both a car service and flexible unit. In practice, carsharing can also take the role as a commercial aggregator. However, a commercial aggregator without EV ownership avoids fixed assets for investments in vehicles and electricity consumption costs.

Current actors in the car industry comprising of Charge Point Operators (CPO), aggregators, and OEMs have diverging market interests in the development of V2G technology, as OEMs do not have interest in developing EVs for bidirectional charging. V2G connection requires installation of either an AC bidirectional charging connected directly in the car (using IEC 61851) or a DC V2G cable (using CHAdeMO) for which the charger can be installed to bidirectional charging. An AC connection can result in high costs for an EV user, as EVs are not manufactured with an V2G installation to reduce expenses, as a prototype for an AC bidirectional charging costs 60.000 DKK. Therefore, the market price for an AC V2G connection should be reduced to be competitive with DC-cable at the Danish market.

The diverging interests of V2G development indicate that the market actors need changes of legislation on chargers, a so-called top-down regulation, from Danish Legislation for improving development and adaptation of V2G. At the time, the Danish government contributes to development and technical requirements such as the development of Grid Code. There is a lack of an EU standard for charging V2Gs, as charging stations have different charging types, which impacts the adaptation of V2G technology, negatively. The lack of requirements for the different charging methods complicates the charging for EV users and makes it less attractive for customers to select an EV instead of a fossil fuelled vehicle under a purchase decision. Therefore, it is relevant to develop a standard for V2G chargers for flexibility perspectives, if an EV user should find it desirable to provide flexibility via V2G.

4.2 Opportunities & Threats based on impacts from external attributes

In countries with a high market share of EVs, V2G has a possibility to be implemented due to larger market share, users are comfortable with the use of EVs, and the countries have a well-functioning charging infrastructure. In general, flexibility is to balance the grid and reduce risks for energy actors. The TSO wants to balance the transmission system and, like a DSO, handle the congestion. Therefore, it is relevant for the TSO and the reserve market that unlocked flexibility can balance the grid (MM2.0, p. 6), whereas a DSO can use flexibility to optimise and operate the local grid system. However, the cooperation between the TSO and DSOs are based on conflicts, as the two actors have different demands and requirements for flexibility provided, which can cause threats for an aggregator. The DSO and TSO can end in situations where they oppose each other, as the TSO demands provided capacity from flexibility elements, which can create problems for the DSO to stabilize the voltage level or it creates an electricity blockage of the grid when the aggregator unlocks flexibility, and for that reason the DSO is hesitant with flexibility service.

One of the best opportunities for implementation of V2G is aggregation as the technology has been identified as market mature for entering the day ahead market and ancillary services (Energinet.dk2, 2015, p. 54). Several technologies can improve the potential for aggregation of flexibility, but the potential depends on available effects, durations, reactivities, investments, and activation costs. Besides EVs, back-up power systems and individual heat pumps are two technologies, which are relevant to provide flexibility in periods of shortage of effect (Energinet.dk2, 2015, pp. 52-53). Today, back-up power systems offer 30MW to manual reserves, but it is possible to increase the capacity from small plants. Both back-up power systems and heat pumps have a high potential as flexibility provider due to a large effect potential over a longer activation period, such as 300MW in an unlimited period for back-up power and 600-700 MW over 3 hours for a heat pump. Furthermore, the costs per provided kWh is smaller for a back-up power system than an EV, comprising 1.5-2 DKK per kWh compared to 1-10 DKK per kWh for both an EV and a heat pump (Energinet.dk2, 2015, p. 137). EVs can react within the same brief time period (<15 minutes) and the investments are insignificant compared to the two other technologies. However, activation and investments costs are not possible to estimate for both EVs and individual heat pumps due to a small market penetration in Denmark (Energinet.dk2, 2015, p. 145).

In Denmark, MM2.0 and the new market requirements can improve market conditions for flexibility, but the disadvantage is that aggregation demands changes of the electricity market design (Energinet, 2017, p. 35). MM2.0 can give aggregators (specialized within V2G) some opportunities to affect the market system to implement flexibility services, which can give incentives for prosumers to unlock flexibility from EVs. The regulatoin requires that flexibility from flexible units is registered in the electricity market or a third-party aggregator via a BRP or an aggregator is certified as BRP to offer flexibility from its prosumers. The aggregator must have a contract with all 13 BRPs in Denmark to offer flexibility to the energy market (Energinet.dk2, 2015, p. 56).

Another threat for implementation of aggregation is the economic barriers which can affect actors such as companies and prosumers, as unexpected events with necessary use of EV is difficult for an aggregator to forecast. Furthermore, an aggregator may anticipate costs to organize a company, business models, and trading in the market, and prosumers may invest in new meters for metering flexibility provided, and the aggregator may pay a fee to the BRP to use the platform to offer flexibility on ancillary service (Energinet.dk2, 2015, p. 54). Therefore, the following four market models have been developed to eliminate barriers for a third-party aggregator.

M0	The benefits of *M0* can cause economics of scale, as current actors can pool larger consumer

	units together and it is possible to reduce costs and there are few competitors in the market. The disadvantage is that current actors lacks knowledge to provide aggregated flexibility (Energinet, 2017, p. 37).
M1	*M1* focuses on delivering frequency regulation without the need for a BRP. V2G can result in small, unnoticeable imbalances for BRPs, as the aggregator delivers FCR directly to the TSO without balancing flexibility with a BRP (Dansk Energi, 2017). Implementation of M1 requires changes of market requirements for which the aggregator can trade at the market without a BRP, as the regulation requirements require that the wholesale- and retail market inform about customers' electricity consumption via a BRP (Energinet, 2017, p. 56). At DKK2, prosumers can provide frequency regulation with V2G connection, if an aggregator applies M1 for its business model (Energinet, 2017, p. 38). M1 can provide a disposable income, if the aggregator can provide a competitive offer for the FCR. The weakness of M1 is the measurement of flexibility, as the aggregator measures at portfolio level, and the expenses is too high with metering flexibility on each unit, and furthermore, the measurement will be controlled with random check (Energinet, 2017, p. 39).
M2	*M2* is a complex model, as M2 can result in cases with several aggregators and/or BRPs having the responsibility for different flexibility units at a household or company, but the actors measure flexibility provided on one meter and sends data to the Datahub (Energinet, 2017, p. 40). This can result in different interests for settlement of imbalances between actors. Therefore, the metered data must be validated by actors to balance the market. In *M2*, the balance responsibility shifts in activation periods of flexibility and up- and down regulation is corrected according to activated flexibility by the actual BRP, which handles flexibility and regulations based on an expected baseline to avoid imbalance costs (Energinet, 2017, p. 40). It is possible to reduce expenses for metering, as the consumption and flexibility service are metered by one meter. The costs can be divided by bilateral contracts between the actors (a contractual model), the TSO with a Central Settlement Model, or by a Net Benefit Model. According to MM2.0, selected Danish actors expect M2 to be complicated to implement in practice, thus, it is necessary to test the model in practice (Energinet, 2017, p. 34).
M3	*M3* is best for prosumers with a large flexibility potential, as energy consumption and flexibility provided is metered with different meters by installing several measurement points per customer (serial metering), which can result in installation up to 15000 DKK. The transaction costs can at the highest be 2000 DKK due to two or several meters connected to one household or company. Therefore, it is necessary to regulate the financing to reduce the costs to implement the meters. The strength of M3 is that an aggregator cooperates with both an energy provider and a BRP, which can work across the customer portfolio. Furthermore, the aggregator can offer flexibility service on the three markets; Day ahead, Intraday and ancillary services based on current market conditions, as the meter data is included in balance settlements (and not necessary to be adjusted) (Energinet, 2017, p. 43). According to MM2.0, selected Danish actors find M3 transparent and easy understandable for customers.

Energinet's strategic goal for energy security, also called effect sufficiency, has been tightened to secure high performance internationally, which can cause a new opportunity for V2G. The ambition has been tightened to a maximal duration of grid shutdowns for the customer to 5 minutes to secure energy security. The ambition for effect sufficiency will increase the market opportunities of V2G, as the effect demand has been forecasted to increase in the future due to a reduction of power plant capacity. Therefore, the TSO is dependent on fast delivered flexibility in the future (Energinet.dk2, 2015, pp. 26-27).

BRPs can be a threat for a third-part aggregator, as they can have conflicts of interest in a new actor to enter the energy market. In Europe, BRPs went into imbalances in settlement of consumption, as aggregators could unlock flexibility without active offering flexibility in the market and the BRP could not modify consumption prognosis (Energinet.dk2, 2015, p. 56). Market model 1 can provide BRPs with imbalances due to unnoticed flexibility, but Model 2 and 3 can give rise to cooperation with BRPs to offer flexibility on current the energy market for fair market competition.

MM2.0 recommends to increase the price limit of electricity to reduce the electricity consumption by the end-user. It can affect the customer to decrease the electricity consumption and thus reduce the need to establish a strategic reserve. A rise in the electricity price can push peoples' habits, mobility needs, and thus, reduce the probability for burn outs. Increased electricity prices can also improve the green transition, as it gives building owners incentives to invest in self-sufficient, renewable energy systems to private homes, smart cities etc (Energinet.dk, 2017, p. 12). The treats of the repealed cap of electricity price can increase the energy actors' income, if consumers do not regulate their electricity consumption despite high prices and in scarce situations. Both demand for EVs and V2G will be affected by increased electricity prices, as the EV users' operation costs will increase, which gives the EV user incentives to reduce their driving demands.

In May 2018, the Danish government presented initiatives to a new Danish energy policy, which recommends decreasing the electricity prices instead of increasing the prices as defined in MM2.0. The new initiatives give market opportunities for V2G, as one of the initiatives is to decrease the electricity prices to secure private households and companies to invest in green energy systems such as wind- and solar energy. Furthermore, the government will increase the share of renewable energy by installing several offshore wind turbines (Berlingske, 2018). Reduction of electricity prices can give customer incentives to invest in EVs in Denmark, as lower energy prices can reduce costs to charging EVs. Furthermore, one of the disadvantages for an aggregator and V2G is a fixed price structure. The electricity price will be repealed in periods of shortages, and the other Nordic countries may agree on the price strategy in the spot market. A sustainable business model demands fluctuating electricity prices. Otherwise, aggregation is too expensive to activate and competition on the Nordic electricity market will decrease electricity prices, as both Finland, Sweden, and Norway can bid on the Nordic Wholesale market (BestRES, 2016, p. 73).

One barrier for implementation of V2G is customers' lack of knowledge about technical- and business potentials of aggregation on the energy market, as customers may be informed about the opportunities to provide flexibility. Furthermore, larger customers may be informed about variable price settlements instead of fixed price settlements when using electricity when production is high (Energinet.dk2, 2015, pp. 53-54).
Thus, in the future it would be interesting to investigate users' motivation, culture, and driving demands by a societal study, as such aspects can affect the implementation of V2G, if the V2G actors do not pay regard to users' driving demands etc (Sovacool, 2018, p. 15). A quantitative study from Aarhus University indicates that experts are sceptical on V2G technology due to grid operators' lack of perceived need for V2G. Especially, countries with waterpower (Norway, Sweden, and Iceland) do not need large amounts of flexibility services. Furthermore, the technical consequences of V2G such as battery degradation, securing availability of sufficient EVs, and lack of market regulation for V2G makes it difficult for an aggregator to collect EVs to provide flexibility. Furthermore, experts do not see business opportunities with V2G as a result of low customer accept, increased expenses, and no business case has been found sustainable (Rubens, 2018). However, a literature study by Aarhus University indicates that V2G service to the TSO and DSO will give the best economic incentive for con-

sumers compared to the benefits of using V2G combined with renewable energy and V2H, which some experts see as the best incentives for customers (Rubens, 2018). Therefore, it is relevant to create a better understanding on the technical-, environmental-, social- and economic performance of V2G to improve its market entry.

Another threat for an aggregator is if an EV user connects V2G to a CPO, which collaborates with another aggregator than the prosumer has signed a contract with regarding flexibility service. Thus, the two aggregators have to cooperate to aggregate the capacity from the EV. To summarize, the development of V2G can stabilize the TSO grids and can contribute to green growth, and results in various future technical potentials and the development of Smart Cities. A prosumer can contribute to the surplus of flexibility from EVs to balance the grid. One threat for an aggregator is if a prosumer will utilise its flexibility capacity to own private consumption (V2H) in a situation of increased demand for electricity instead of provided capacity via V2G.

5. Conclusion

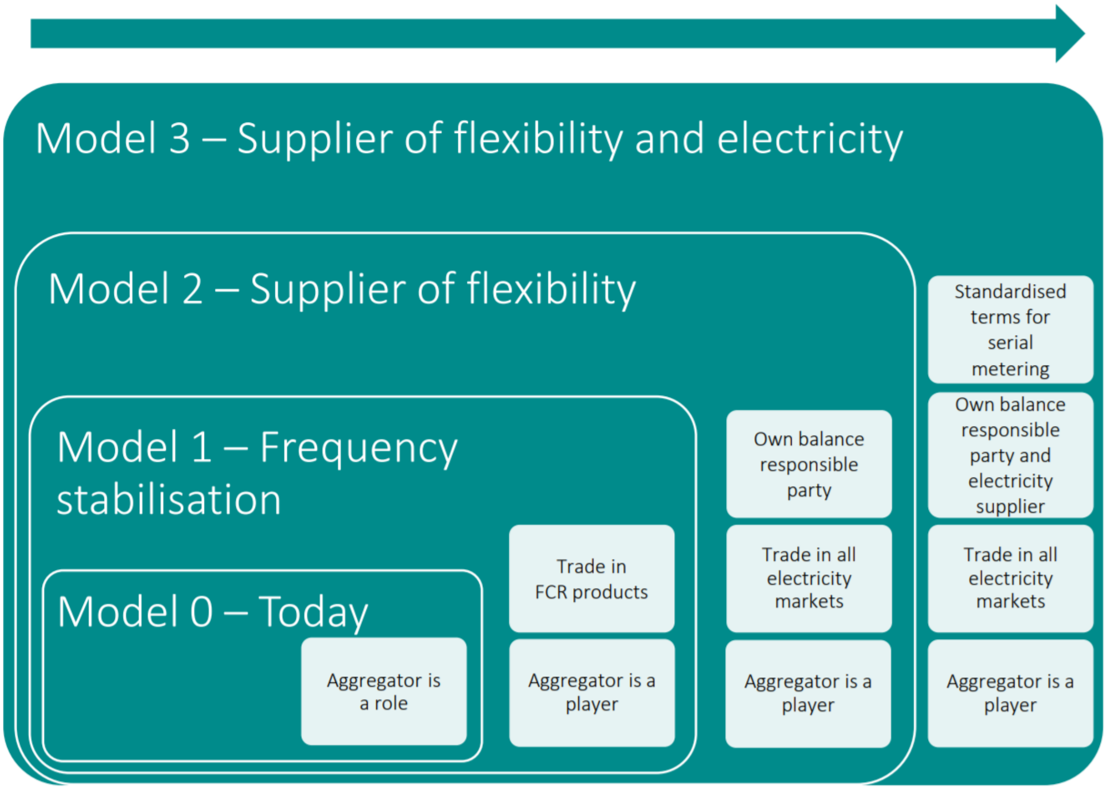
In order to define the optimal market design for implementation of the V2G technology in a TSO market, a comparative study has been conducted on three European markets, where regulations contain relevant differentiation points compared to the current Danish regulations. These international conclusions have been compared to the new market model being implemented in Denmark, the Market Model 2.0 (MM2.0) to see what would comprise the optimal market setup.

The three international markets investigated were Great Britain, where energy providers and aggregators have to collaborate closely, the Netherlands, where the aggregator mainly works in the mFRR market and in collaboration with a BRP, and lastly Finland, where the aggregator can act independently on the markets available. The main conclusions can be found in the table below.

Parameters	Finland	Netherlands	Great Britain
Aggregator type (balancing market)	Resource owners of flexibility or an independent aggregator.	An aggregator must collaborate with consumer/prosumer's BRP and BRP's retailer. Thus, the aggregator is a service provider for BRP.	An energy provider takes the responsibility as aggregator which is called *"Supplier-led-aggregation".*
Wholesale- and Ancillary Market	Flexibility capacity is legal in all markets by cooperation with a consumer/prosumers' BRP. An aggregator can provide flexibility capacity in FCR-D, and the aggregation of resources from different balancing groups is legal in FCR-D.	Both demand Response and aggregation can sell electricity to mFRR, but only demand-side response can bid in the aFRR market.	Aggregation is open for all services, but an aggregator must collaborate with an energy provider to provide services to the balancing and wholesale market.
Barriers	The current price structures are a barrier for an aggregator to compete with the current market actors.	An aggregator must cooperate with a BRP, thus, it is difficult for new actors to enter the market as an aggregator. Emergency power program is difficult to reach for an aggregator due to a minimum flexibility load on 20MW.	The market is opaque due to bilateral contracts, which can result in risks for new entrants.

TSO market design for V2G, main conclusions

In Denmark the MM2.0 was developed to create a more flexible market structure for the TSO market and lower the barriers for new actors, such as aggregators, to take part in the value system. The model actually consists of four different models with different technical and regulatory setups seen in the figure below. Model 0 is the current status on the market, where the aggregator is a role, that can be assumed by any player in the market. In model 1, the aggregator itself becomes a player, who can trade in FCR products, which partially has resembled what has happened in the Parker project. Model 2 includes a more autonomous role for the aggregator and allows it to trade in all electricity markets; furthermore, all metering of services will be conducted based on virtual meters between BRP, TSO and Aggregator. In the final model, model 3, the major change from model 2 is the introduction of standardised terms for serial metering, which creates closed and consolidated environments under control of each party active in the market.



Expansion philosophy of Market Model 2.0

When confronted with the four sub-models of MM2.0, the experts tend to disagree on which of these would be the ideal model for V2G implementation. Model 3 is recommended by commercial actors, as serial metering is currently possible to implement and simplifies all aspects of legal discussions as the aggregator has its assets secured behind a meter. Model 2 is recommended by researchers due to technical future perspectives and the potential flexibility incorporated with digital meters.

The New Market Design analysis of TSO services indicates that the V2G technology has the potential to become a player in the new market models that are already under implementation in Denmark. At present it is possible for an aggregator to provide flexibility to the grid operators, as a third-party aggregator has the opportunity to provide a larger amount of flexibility to the current FCR market in collaboration with a BRP. When evaluating the market models found in Great

Britain, the Netherlands and Finland, they do not pose more perspective in the setup than what has been identified in the coming MM2.0, which therefore can be seen as a benchmark for future integration of aggregators in a TSO market.

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DSO market structure

Market structure

In order to find the most potential future DSO market model for flexibility services, several steps have been taken. The process was defined as the following:

1. Identification of possibilities

The market structure will be a connection between a buying option and a market place. The buying options are the ways to buy/sell the flexibility services under contractual conditions. The market places are where/how the buyer and seller interact with each other.

The first step of the process was a mapping of the potential buying options and market places.

Buying options	Market places
Long term contracts	Nordpool 4 DSO (double sided auction)
Short term contracts	Call for tenders (single sided auction)
Auctions	Free market
Service contracts (leasing)	Negotiations (bilateral contracts)
Blockchain	Dual sourcing (Di-opoly)
Coupons	The phonebook
	Aggregator push (e-bay)
	Dynamic tariffs/services (stock market)

Table 1: Potential buying options and market places

The result of the process was an identification of six buying options and eight market places, as can be seen in Table 1.

In the second step of the process, the buying options were matched with the market places creating 54 theoretical market structures. These have then been evaluated whether they were considered theoretically realistic. Some of the buying options matches all the market places, and some only few of them. The connected scenarios are the potential market structures seen in the table below.

	Buying options	Market places
1	Long term contract	Call for tenders
2	Long term contract	Free market
3	Long term contract	Negotiations
4	Long term contract	Dual sourcing
5	Short term contract	Nordpool 4 DSO
6	Short term contract	Call for tenders
7	Short term contract	Free market
8	Short term contract	Negotiations
9	Short term contract	Dual sourcing
10	Short term contract	Aggregator push
11	Short term contract	Dynamic tariffs/services
12	Auctions	Nordpool 4 DSO
13	Auctions	Call for tenders
14	Auctions	Free market

15	Auctions	Dual sourcing
16	Auctions	Aggregator push
17	Auctions	Dynamic tariffs/services
18	Service contracts (leasing)	Call for tenders
19	Service contracts (leasing)	Free market
20	Service contracts (leasing)	Negotiations
21	Blockchain	Free market
22	Blockchain	The phonebook
23	Blockchain	Aggregator push
24	Coupons	Call for tenders
25	Coupons	Free market
26	Coupons	Negotiations
27	Coupons	Dual sourcing
28	Coupons	The phonebook
29	Coupons	Aggregator push
30	Coupons	Dynamic tariffs/services

Table 2: The connected market structures (Buying options and market places)

The total result of theoretically relevant market places was 30 market structures which created the basis for the following evaluation and selection.

2. Evaluation and Selection

The target of the Evaluation and Selection phase was to reduce the amount of market structures from 30 to 4, that could be presented for an expert panel in order for them to provide feedback on the relevance of each market structure.

In the first round of the process the goal was to decrease the 30 market structures to 9 market structures. The selection was made based on what the most realistic market structures are for the Danish market under consideration to the existing working methodology in the energy market and other public market places.

	Buying options	Market places
1	Long term contract	Call for tenders
2	Short term contract	Call for tenders
3	Auctions	Nordpool 4 DSO
4	Auctions	Dual sourcing
5	Service contracts (leasing)	Call for tenders
6	Service contracts (leasing)	Negotiations
7	Coupons	Call for tenders
8	Coupons	The phonebook
9	Coupons	Aggregator push

Table 3: The 9 market scenarios were chosen

In the second round of the selection process, the 9 market structures were decreased to the four most realistic market structures. The process in doing this was an evaluation on securing a diverse representation of market structures, where especially buying options were relevant to diversify. The four structures chosen have been described in detail below.

1. Long term contract	**Call for tenders**	**2. Service contracts (leasing)**	**Negotiations**
A market structure where the DSO sends out their requirements and the aggregator respond with tenders. The DSO makes the decision on which tender they accept and a contract is made between the DSO and the aggregator which are based on months/years cooperation.		A market structure where two actors – one DSO and one aggregator negotiate and agree on a service contract. The DSO pays a monthly fee to the aggregator and the aggregator gives then the DSO the service of flexibility whenever it is needed.	
3. Auctions	**"Danishpool" 4 DSO**	**4. Coupons**	**Call for tenders**
A market scenario where both DSOs and Aggregators from around Denmark can bid on the flexibility. All DSOs and Aggregators can offer and ask for flexibility, if the flexibility is in the area where the DSO are.		A market structure where the DSO sends out their requirements and aggregators/customers respond with tenders. The accepted tenders are settled with a type of coupon, e.g., a reduction of electricity price for flexibility providers in a valid period.	

Table 4: The four most realistic market scenarios

3. Expert review

The next step of the process was to identify the market structure with the highest potential of short-term implementation. In order to find the most realistic and potential market structure, five experts were interviewed and asked to provide feedback on all four models and evaluate their relevance in the future Danish energy and flexibility market. The group of experts included a BRP, researchers, DSO's and a policy maker. The different backgrounds provided a holistic evaluation of the four market structures, which increases the relevance of the final chosen market structure.

1. Long term contract	**Call for tenders**
2. Service contracts (leasing)	**Negotiations**
3. Auctions	**"Danishpool" 4 DSO**
4. Coupons	**Call for tenders**

Table 5: The four potential market structures

3.1. Resumé of meeting

Six external experts were contacted for an interview regarding the four market structures above.

3.1.1. Kim Kock-Hansen, Project Leader, Bornholms Energi og Forsyning (DSO)

In the interview, Project Leader from Bornholms Energy og Forsyning, Kim Kock-Hansen, attend the problem statement that if 1% of the cars on Bornholm are electric cars, they will get problems with the grid. The maximum load is currently 50-55 MW.

It is important that there is a close cooperation between the DSOs and the aggregators building on flexibility and not only price setting. The aggregator has to help charging the EVs when it is most beneficial for the grid (regarding the availability in the grid). This is the reason why Kim Kock-Hansen sees scenario 1 as the best solution. He sees problems in both the product and the distribution of the electricity, as there is not enough electricity in the specific timeslots. This challenges the DSO as they have situations where they cannot deliver the right amount of power. In these cases, they have to move around the power and for this, there could be other solutions than only price regulations.

3.1.2. Søren U. Schmidt, Lead Business Developer, Radius (DSO)

In the interview with Lead Business Developer at Radius, Søren U. Schmidt, a question was raised: How mature is the market for demand response and flexibility? Radius believe that both scenario 1 and 2 could happen in the near future. Scenario 2 will be the best scenario for the first step. It is about starting a bilateral communication with an aggregator. Radius would like to learn from an implemented aggregator by a bilateral talk. It is a way for both the DSO and the aggregator to learn a lot. They think it is very important to get to know the pitfalls before systemizing the whole system. The right settings have to be made in the market and the economy can be talked about after the settings are set.
If the "Winterpackage" is enacted in EU, there will be some of the right settings for the scenario no. 1. Where the DSO shall request demand response if it is cheaper for the grid (and cheaper than to dig cables down). Scenario 1 can be happening legally if the Winterpackage is enacted.
Scenario 3 could only happen on long term. There is market difference at DK1 and DK2. So, there are some fundamental issues in the market that have to be adjusted before scenario no 3 could happen. There can also be other customers for the aggregator than the DSO. It can also be BRP or other aggregators. The scenario can give the opportunity for the BRP to buy balance instead of paying for imbalance.
Scenario 4 is interesting in Radius perspective regarding the way of paying. They will consider it regarding the principle of price. Flexibility to bigger users can be paid with negative tariffs. They can base their price setting to pay the actors who can help in specific situations.
If a customer uses an aggregator, a new market has to be looked into. But if it happens around the aggregator, the negative tariffs can be used as a tool. (either strongly reduced distribution tariff or negative tariff). It depends on the development of a tariff model, where it will be possible systematically to see the dynamics in the tariff and principle of price. It will be easier to reduce the tariff than to pay people for their flexibility. An opportunity could be to have geographical difference in prices.

3.1.3. Peter Harling Lykke, Program Manager, Smart Energy, Aarhus University (researcher)

The interview with the Program Manager of Smart Energy at Aarhus University, Peter Harling Lykke, focused on the problem regarding the penetration of EVs and Heat Pumps, as Denmark is not as far as expected. Therefore, many DSOs believes that they will change the cables before the EVs and HPs will become a problem. This can postpone the need of an aggregator. The DSO is the last market actor to engage and the TSO could be interested before the DSOs. Therefore, it could be an option to skip the DSO in the first round however, the DSO will still have to collaborate with the TSO, energy providers and the EMSP hence be affected by future flexibility services. The DSOs don't see the threat yet. But if the taxes were reduced on EVs and they get an increased driving range, the development can go fast. It can be expensive for the DSOs to be late. The DSOs are using supervision of the meters to be able to see if the houseowners are using more than they are allowed to.

The TSO could cooperate with either TADAA! or the Parker project, by using the EVs that are connected when the Windmills gives less electricity. However, there has to be pooled several EVs or HP to get enough power to make a difference. Heat pumps are easier working with than EVs. You can shut them down in 2-4 hours without people finding out. In the weekends, they can shut down completely at schools. A combination of both EVs and Heat pumps could be the best solution. EVs can draw a lot of electricity and fast (up to 65 amphere). EVs and HPs: Is the two parts that draw the most electricity at the individual houses.

When it comes to the market structures, market structures 3 is not seen as possible right now. Teslas can only take the peak load over very short time. Market structure 2 can be for time contracts (for example Monday to Friday – you can only charge after 9 am. It is a normal business where it is the actor with the best price and the fastest reaction time which will win the deal.

NRGi has bottlenecks around Juelsminde and Horsens. There was a trial with 3-5 EVs charging on the same time (3 phase – 33 amphere). That was the max for the grid. If it can be handled in a smart way by flatten the charging, the grid would have been able to handle up to 30 cars.
What does the electric companies do if their system is overloaded? They do as they are doing now, turning off the power.

A very important issues to address is, how to get people to connect the EV with the charger? When do the cars have to drive again? and how far will they drive? The cars have to be able to give back electricity to the charger and grid.
A scenario can be that the market is purely about EVs (and not including HP) and the EVs have to be connected to the charger. People could get a bonus when it is registered that the car is connected (and where it is connected). The EV owners have to make a cooperation with actors that can use the flexibility. The users would want some economical benefit to connect the EV every day.

Market structure 2 is the basis solution for this scenario. But what if everybody brings their EV to the summer cottage where they can't connect their EV (for example in the holidays). And then there are no wind that day (autumn holiday, a lot of sun, cold and no wind). The aggregator has to talk to the people who would like to give away their electricity. Can there be a better price if 90% of the EVs stands still and are available for flexibility. Furthermore, there has to be laws. In Sweden, there is a safeguard for how long the people can be without electricity; otherwise the DSO gets fines.
The future mission can be in the small cities, where EVs can be the solution for ensuring electricity in the small towns. There is the trend of wanting to be independent, also electricity wise.

3.1.4. Peter Bach Andersen, PhD, Senior researcher, DTU Elektro (researcher)

The interview with senior researcher at DTU Elektro, Peter Bach Andersen, gives an overview of the primary parts to be taken into consideration when talking about the market structure. It has to be made a product - a universal product – and the product has to be flexible. It has to be a mix of demand and output and the load part has to be made with economical incitement – the voltage could be a demand.
Furthermore, the reactive effect has to be considered. In Germany there is a law that the owners of solar cells have to be able to give a reactive effect.
The market structure chosen has to be the function of the number of potential suppliers, e.g. a complex auction market structure would not work with only one potential supplier. Many projects are looking at market structure 3. It is according to Peter the best long-term solution. There are few suppliers that will be able to offer at this market structure. Therefore, market structure 3 is a future scenario and the ultimate solution. Market structure 1 and 4 are two variations of the same idea; Call for tenders. For this to be realistic there must be several suppliers. Contrary, market structure 2 only has to include few suppliers and this is the most realistic market structure at the moment. The first opportunity is market structure 2 with a bilateral contract. The setup could be that the aggregator is forced to help the DSO and the DSO is forced to give economic incentive.
Peter Bach Andersen sees two negative scenarios that could challenge the DSO:

1. overload – where the cables get to warm when they are overloaded by too many devices using electricity.
2. voltage – the voltage decreases when there is a high consumption. If the last house on a street has a Tesla, the voltage can drop for all houses.

Currently, Radius are allowed to have their own aggregator as a test. Further to this, they have at Nordhavn a large battery, that is to be used for providing flexibility services. When there is a high demand, they use the battery for peak shaving and low frequency regulation. But what if they had to buy the battery capacity from somebody else, how would the contract be and how the product look like? How would they document that the aggregator is not creating a problem which they have to solve? What kind of agreement has to be made – regarding the peak shaving? In the project, Parker, the frequency regulation is probably the worst thing for the DSOs. The cars can show consideration for the local grid and DSO, while they offer flexibility to the TSO grid, if controlled in the right way.

3.1.5. Mads Lyngby Petersen, Special Advisor, Centre for Energy Administration

In the interview with the Special Advisor of the Centre for Energy Administration, Mads Lyngby Petersen, it was concluded that market scenario 2 is the most realistic scenario as a start where there are few providers. Market scenario 2 will start with a bilateral talk with those who are interested. Mads sees scenarios 1, 3 and 4 as more realistic opportunities in the future where there are more providers on the market. He sees market scenario 1 as the most obvious in a long-term perspective. Market scenario 3 with Auction as the buying option requires several players – several aggregators – and double-sided offers, which Mads cannot imagine will happen. Call for tenders seems as a more realistic scenario in the future. However, market scenario 3 gives the opportunity for an international market where the DSOs in the Northern Germany and Sweden could bid on the market as well.

The timing is important when talking about market scenarios, as the DSO market has to be ready for the market scenario.

3.1.6. Lotte Holmberg Rasmussen, R&D Project Manager, NEAS Energy

The interview with the R&D project manager at NEAS Energy, Lotte Holmberg Rasmussen gave an overview of the role of the BRP (Balance Responsible Partner) in the market. The BRP is active on all markets and it is crucial to coordinate with the BRP, when the DSO wants to change the demand. Regarding the cooperation with end users with a Heat Pump or EV, the BRP finds the aggregator as a perfect solution. The BRP do not want to cooperate directly to all the end users, so they can see the opportunity of having the aggregator as a link to the end user.
However, they are concerned on what will happen if an extra market is added upon the existing market. What will happen if one actor wants to turn up for the flexibility and the other actor will turn down, so they are working against each other? This is a question that is analysed in projects like the DREM project (Distributors role in the energy market).

3.2. The rating of the four market structures from the experts

The table below show, in short, how the six experts rates the four market structures.

	1. Long term contract/call for tenders	2. Service contracts/ Negotiations	3. Auctions/ “Danish pool” for DSO	4. Coupons / Call for tenders
Kim Kock-Hansen	The best solution.			
Søren U. Schmidt	It can happen if the Winter package is enacted – it could happen in the near future.	Best scenario – most realistic in the near future.	On long term – some fundamental issues in the market have to be changed.	The price principle is very interesting in Radius’ perspective.
Peter Harling Lykke		Could be used for time contracts	Is not possible right now	
Peter Bach Andersen	This could be on the road for reaching #3	The first opportunity, in the near future.	A future scenario – the ultimate solution.	This could be on the road for reaching #3
Mads Lyngby Petersen	In the future when there are more providers. Will probably be	Very simple as a start	In the future when there are more providers (could be made	In the future when there are more providers

	the most obvious in the future		with international aspect as well)	
Lotte Holmberg	No clear conclusion was reached			

Table 6: The rating of the four market structures

4. Choice of market structure

Most of the experts agreed on one of the market structures as the most realistic market structure for the DSO market in short term, the market structure 2 “Service contracts (leasing) and Negotiations”.

1. Long term contract	**Call for tenders**
2. Service contracts (leasing)	**Negotiations**
3. Auctions	**“Danishpool” 4 DSO**
4. Coupons	**Call for tenders**

Table 7: The chosen market structure out of the four final structures

Market structure 2 is a market structure where two actors – one DSO and one aggregator, who bilaterally negotiate and agree on a service contract. The DSO pays a monthly fee to the aggregator and the aggregator then provides the DSO the service of flexibility whenever it is needed. Most of the experts sees this solution as the first opportunity in the near future as it is simpler to start with then there are few providers. This solution also resembles existing collaboration agreements in the B2B market hence, it is easy to comprehend and work with-.

Where market structure 2 is the preferred short-term solution, the experts in general consider market structure 3 as one that could be the model in the future, once there are several aggregators offering the service on a national and international level. Both market structure 1 and 4 could be applied as a transition towards market structure 3. None of the experts were able to give any inputs on the time horizon for expected implementation of such market structures, however several public funded projects are experimenting with creating such setups.

Before market structure 3 can become a reality there are some fundamental issues in the market that has to be changed. This market structure can only happen in the future where there are more providers and the market will be mature. Furthermore, the regulations and controls of the DSOs should incentivize choosing the cheapest/most intelligent solution to avoid the current situation, where only infrastructure investments make sense.

PARKER

Business Case Evaluation

WP 5

September 2018

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Executive summary

Previous studies on the potential of V2G have mainly focused on the potential revenue generated by the technology, but with the first commercial activities happening, the profits become more interesting than the revenue.

In order to evaluate the potential profits of V2G, theoretical calculations have been made on a scenario similar to the test setup at Frederiksberg Forsyning. This limits the calculations to FCR-N services where the TSO purchases primary power reserves on a market from service providers, who receive an availability payment. The geographical limitation of the calculations is DK2 and they are based on figures from 2017.

During activation of the power reserve, energy is exchanged with the mains. During upregulation power is supplied to the mains and vice versa during downregulation. The service provider settles the energy with an energy trading company with prices for purchase and sale, which might be different.

The variables in the calculator can be seen in the table below and will shortly be explained below.

Formula symbol	Variable	Unit	Single calculation
Sync	Synchronous area		DK2
Mept	Market entry power threshold	kW	300
EvFleet	EV fleet	units	10
CmxPw	Charger max power	kW/EV	10
BatCap	Battery capacity (usable)	kWh	21
EVmil	EV Mileage	km/month	250
EVee	EV Energy efficiency	kWh/100km	18
MxUdirEnEx	Max unidirectional energy exchange (% of Charger max power)	%	30%
ChEngPr	Charger energy production	kWh/EV/month	350
ChEngLos	Charger energy loss	%	30%
ElConPrc	Electricity consumption price	DKK/kWh	1,00
ElProPrc	Electricity production price	DKK/kWh	0,20
BatFcrW	Battery FCR-related wear	DKK/year	0
ChDeprec	Charger (bi-direc additional cost) depreciation	DKK/year	0
FcPC	FCR-N price change factor for sensitivity analysis	%/year	0,0%
SocOfsWd	SOC offset for sensitivity analysis, weekdays	%-points	0,0
SocOfsWe	SOC offset for sensitivity analysis, weekends	%-points	0,0

Variables in the calculator for V2G potential

The calculations are based on an average fleet approach, which means that all cars are considered equal with similar battery size, mileage, energy efficiency, battery wear, availability during the days (weekday/weekend), and SOC (weekday/weekend). The latter two are defined in separate tables in the calculator, hence not included in the table above.

The chargers also define a number of variables for the calculations including level of power exchange, depreciation, price of charger, and energy loss.

Apart from the availability payments the market also dictates the pricing of energy, both for consumption and production. Finally, the complex factor of unidirectional power exchanges needs to be estimated. The unidirectional power exchange is the maximum percentage of time during one hour where the regulation is purely one-sided. This latter factor is important to include as batteries are limited in size, hence can completely deplete or charge to full if the energy flow is one-sided, given that the period is too long.

Lastly, a number of parameters have been included in order to create predictions and create scenario analyses. These are a price factor when estimating price increases/decreases compared to 2017 numbers and a change factor to the SOC on weekdays/weekends.

The uncertainty is high on several parameter values. There is little knowledge about the pattern for activation of the power reserve and the amount of energy exchanged with the grid. The impact on the estimates of the profits are significant since the energy settlement prices typically are asymmetric. Besides, the energy exchange causes losses in the charger to be paid by the provider. The market for bi-directional chargers is very small and prices are prone to drop as a result of the scale of production.

In order to evaluate the full potential of FCR-N services, V2G information from the Frederiksberg Forsyning was entered into the calculator and estimates of the profits for three situations were made: typical, best-case and worst-case. In the latter two, parameter values are chosen to reflect the uncertainties described above and to take into consideration expectations regarding the developments in technology and prices. The results on the calculations of profits are:

- 'Typically'=> 3.500 DKK/EV/year or 468 €/EV/year
- 'Best-case'=> 17.000 DKK/EV/year or 2.304 €/EV/year
- 'Worst-case'=> -7.000 DKK/EV/year or -955 €/EV/year

Particularly the depreciation of the additional cost for a bi-directional charger, and the FCR-N availability prices, have high impact on the results. The charger losses are expected to be small in future chargers and will hence have an increasingly insignificant influence on the profits.

1 Introduction

As part of the Parker project an evaluation of the profitability of EV's used to provide primary reserves to the FCR market as one out of several possible V2G-services is developed. The target group for the evaluation is companies, who request appropriate methods to estimate the profitability of offering flexibility to the electricity supply system by intelligent control of a portfolio of EV's.

1.1 Background

To maintain the grid frequency stable at 50 Hz the TSO must be able to activate fast reacting power reserves for up- or downregulation, called primary reserves. The TSO buys primary reserves on a market. One solution is to have a generator running at a part load somewhat higher than minimum and somewhat lower than maximum. This means that a significant part of the generator capacity is not utilized during a period of time in which the generator is required to be available when fulfilling a commitment for the TSO.

EV's can withdraw or inject considerable power to the grid at a very short notice when connected to a bi-directional charger and can hence potentially contribute to the frequency stabilization of the grid. Due to their low energy capacity, EVs are less suitable as a long-term power reserve.

However, providing primary reserves on a commercial basis from portfolio control of EV's is a new market under development. Technology, market structure and the legislative framework is still developing.

For market players like consultants and aggregators it is important to have the right tools at hand to evaluate the business case before offering primary reserves to the FCR market.

1.2 Objective

The objective is to through development of a simple calculator to make a preliminary evaluation of the business case before offering EV-based primary reserves to the FCR market.

The model should include several basic input parameters, e.g.:

- Market entry power threshold [kW]
- EV fleet [units]
- Charger max power [kW/EV]
- Battery capacity, usable [kWh]
- EV Mileage [km/month]

- EV Efficiency [kWh/100km]
- Max unidirectional energy exchange, % of Charger max power [%]
- Charger energy production pushed back [kWh/EV/month]
- Charger energy loss [%]
- Electricity consumption price [DKK/kWh]
- Electricity production price [DKK/kWh]
- Battery FCR-related wear [DKK/year]
- Charger (bi-direct. additional cost) depreciation [DKK/year]

Besides information about FCR-N market prices, State-of-Charge (SOC) for the battery and driving patterns of the EVs must be provided.

1.3 Method

The development of the calculation model is based on theoretical considerations as well as experiences from a pilot demonstration project carried out in another work package of Parker.

The calculator is finally verified by using it on the case from the demonstration project for the year 2017.

Finally, a few simple sensitivity analyzes are carried out by making changes in some of the basic input variables. Estimates are performed for three situations: 'Typical', 'Best-case' and 'Worst-case'.

1.4 Scope

The scope of the calculator is the ancillary service in DK2, 'Frequency-controlled Normal Operation Reserve' (FCR-N), which is a primary reserve.

2 Parameters and assumptions

The profitability of EVs providing FCR-N power reserve can be calculated based on estimates of the hourly values of the following parameters:

- FCR market data [dkk/MW]
- Energy purchase rate [dkk/kWh]
- Energy sale rate [dkk/kWh]
- Energy fed into the charger from the grid [kWh]
- Energy consumed for transport [kWh]
- Energy pushed back to the grid [kWh]
- Energy loss in charger/battery [kWh]
- Connected to grid (availability) [Y/N]
- Gridconnected, but dumploading [Y/N]
- SOC [% of usable energy storage capacity]

Furthermore, the following should be known or estimated:

- FCR-related EV Battery wear [dkk/year]
- Depreciation of the additional cost for a bi-directional charger compared to a standard charger [dkk/year]

The input variables of the calculator model are described, including assumptions and simplifications when applied in the calculations.

2.1 The market for Primary Reserves, FCR

Rules for participating in the FCR-market are set by the TSO, Energinet and described in some publications, among others:

- "Introduktion til Systemydelser.pdf", Energinet.dk, 2017-03-10 [1]
- "Ancillary services to be delivered in Denmark – Tender conditions", Energinet.dk, 2017-12-20 [2]
- "Specification of requirements and test of FCR-N in DK2" [3]

The rules applying for DK2, which is the scope of the calculator, are described in chapter 2.1.1.

Historical data of FCR-N prices can be downloaded from the internet. This is described in chapter 2.1.2

2.1.1 Rules for participating in the FCR market

The rules applying for DK2 are described briefly here. In appendix 1 selected paragraphs from the publications of Energinet are presented to give a deeper understanding and for the comparison with DK1.

1. The supplier can submit bids hourly or as block bids.
2. The regulation should be maintained continuously throughout the contract period.
3. The threshold capacity for players to participate in the FCR market is 300 kW.
4. The bids must be symmetric.
5. FCR-N is procured as a symmetrical product where the supplier must provide upward regulation power (in case of under-frequency) and downward regulation power (in case of over-frequency).

1.2.1.1 Requirements

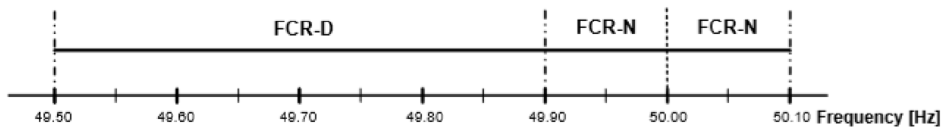


Figure 1 - Activation frequencies for FCR-N.

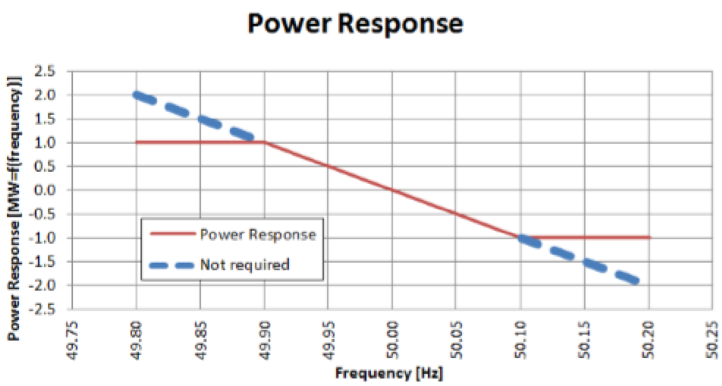


Figure 2 - Power response for FCR-N.

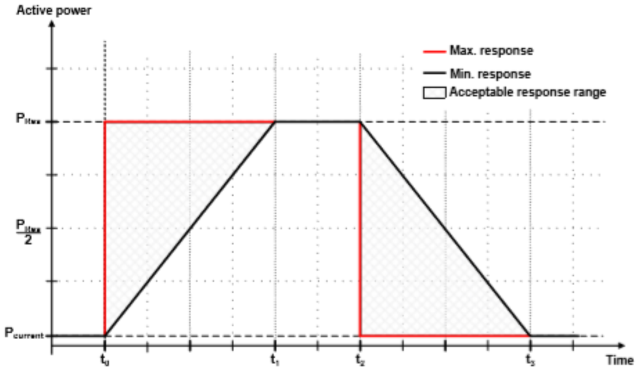


Figure 3 - Random FCR (FNR) activation response sequence in DK2.

Table 1 specifies the response times of Figure 3.

Time parameters	Time
t_0 - t_1	150 seconds
t_1 - t_2	Frequency imbalance length, at least 15 minutes
t_2 - t_3	150 seconds

Table 1 - Time parameters for response sequence described in Figure 3.

Figures from Specification of requirements and test of FCR-N [3]

The FCR service provider undertakes to provide a power reserve of equal size for up-regulation and down-regulation.

In theory, there may be a significant deviation in frequency from 50 Hz, which in worst case would trigger activation of the full committed power reserve in one direction throughout the contracted duration time of an FCR-N service. This is an extreme and hardly realistic situation, but the service provider must pay attention to the risk that the net energy exchange for a contracted duration time may differ from 0. This is especially important for service providers that base the business on battery technology such as aggregators. The smaller the ratio between the battery energy capacity and the charger power capacity, the more conservative the service provider should be in the assessment of the size of the FCR reserve to bid to the market in order to avoid the risk of not being able to fulfill the commitment.

2.1.2 FCR-N regulation prices

Historical data for availability prices of FCR-N regulation in Eastern Denmark can be downloaded from www.energidataservice.dk.

Prices are hourly and in DKK/MW.

An example of downloaded data:

HourUTC	HourDK	FCR-N_PriceDKK	FCR-D_UpPriceDKK
2017-11-16 08:00	2017-11-16 09:00	85,37	27,91
2017-11-16 07:00	2017-11-16 08:00	88,27	28,58
2017-11-16 06:00	2017-11-16 07:00	155,85	35,65
2017-11-16 05:00	2017-11-16 06:00	156,82	34,83
2017-11-16 04:00	2017-11-16 05:00	157,94	34,16

2.2 Energy consumption/generation and losses

2.2.1 Energy consumption and generation

The energy consumed by the charger during a day goes to:

- Transport
- Loss in the charger and battery
- Energy delivered back into the grid

During the time block of delivery of an FCR service energy is exchanged between the grid and the charger. The amount depends on the deviation of the grid frequency from 50 Hz and on the frequency of activation. During upregulation energy is delivered back into the grid, and during downregulation energy it is consumed by the charger. Overall, more energy (related to the FCR service) is consumed by the charger than is delivered back because of the losses in the charger and the battery.

Knowledge of the energy flow is important for two reasons. The higher the exchange of energy during an FCR block, the larger the losses in the charger and battery. In the case that purchased and sold energy is not settled at the same price (typically the price for sold energy is lowest), it would be useful for the aggregator to have a method to calculate the energy flow hour by hour.

The revenue is the sum of payment for the available FCR power reserve and for the energy delivered back into the grid. In a grid with a normally very stable frequency the revenue for power reserve will be dominant as there would be little exchange of energy. However, in the synchronous area DK2 the frequency is relatively unstable leading to a significant energy exchange, and in the case of asymmetric settlement prices that might have a significant negative impact on the profitability of FCR service from an EV.

It has not been possible to identify a general model of the flow of energy during a block of time of FCR service. Until more experience is gained with the frequency of activation and the typical duration and magnitude of power, the user of the calculator must input estimated figures for either the energy consumption or the energy delivered to the grid, assuming that the mileage of one EV and the EV energy efficiency is known. With knowledge of the relative losses in the charger and of one of the parameters, total energy consumption or energy delivered to the grid, the unknown parameter can be calculated.

2.2.2 Energy loss

The chargers used in the Parker demonstration have a rather poor efficiency (70 to 75 %) and the loss should not be neglected when estimating the profitability of EV's participating in the FCR-market. The next charger generation using Silicon Carbide technology should be closer to 90% round trip efficiency [5].

The losses are related partly to the transport service and partly to the FCR-service and when calculating the profitability of an FCR-service only the FCR-related losses should be accounted for. Energy pushed back into the grid during FCR upregulation passes through the charger twice while energy for transport only flows in one direction through the charger. Hence, in the model when splitting the losses, the FCR-related energy consumption is given a weight of 2/3 and the transport related consumption is given the weight 1/3.

2.2.3 Transport

The energy used for transportation is calculated based on the defined monthly millage and energy efficiency of the EV. Losses from the charger are the automatically added to the calculations in order to define the complete energy consumption.

2.3 State-of-Charge (SOC), battery energy capacity and charger power

SOC is here defined as the ratio of the actual stored energy in the battery to the energy stored when the battery is fully charged. It is specified in percent.

Depending on the asymmetry in energy content between upregulation and downregulation the SOC might change during the hour of an FCR-N service. At the beginning the SOC of the battery must be lower than 100 % and higher than 0 %. For instance, if it is 0 % the battery will not be able to deliver any power for upregulation and vice versa. Before placing a bid on the market, the service provider must estimate the value of SOC at the beginning of the hour. As the bid must be symmetric the lowest absolute value of SOC and (100%-SOC) restricts the size of the available power reserve. The closer the average value of SOC is to 50 %, the smaller the restriction on the size of the available power reserve.

In worst case with a large deviation from 50 Hz in the grid, the energy exchange could go in one direction at the full committed power throughout the entire hour. If the energy capacity of the battery is small compared to the charger power, the SOC would change substantially or even hit the limit (0 or 100 %).

This worst-case scenario is not realistic, yet the service provider should assess a maximum energy asymmetry. A 'Max unidirectional energy-exchange'-factor is introduced in the calculator model, which enables the service provider to take that issue into account. The factor is specified as a percentage of the max charger power. If it is set to 100 %, the service provider assumes the worst-case situation that the full committed power, e.g. the max charger power, flows unidirectional throughout the hour. Whether he can fulfill his commitment in that situation is determined by the ratio of the battery energy capacity to the charger power and the SOC at the beginning of an FCR-N hour. If the factor is set to 0 % the user assumes that the energy exchange even in any short time slot is insignificant.

The calculations are based on an average EV that is representative for all vehicles, which means that e.g. the battery size is defined at an average size (the usable and not the rated energy capacity) in kWh and the maximum charger power in kW. The calculator model uses this information in combination with the aforementioned energy exchange factor to estimate the size of power reserve that can be bid to the market.

The same estimate model is used for SOC values in the calculator, where an average level is defined by the hour over a week. The estimate may be a challenge without some experience from real-life. However, the user typical knows when the SOC is full as this is usually required up to hours, where the EV must be available for transport. In a simple model all weekdays could have the same hourly distribution of SOC values with no seasonal variations. And the same for weekend days, possibly with deviations from weekdays because of another driving pattern of the fleet of EV's. The calculation model assumes that the SOC is the same for all of the Evs.

It is important to mention that losses in praxis affects the SOC, but this is ignored in the above considerations.

2.4 Availability

V2G availability means the EV available time for providing FCR services. That is closely connected to the driving pattern of the EV.

At a given time (hourly basis) the EV can be:

- Delivering transport service (not grid-connected)
- Available for delivering FCR service (grid-connected)
- Dump-charging (grid-connected) to ensure sufficient SOC before a time block allocated for transport

An EV is available when connected to the grid and not dump-charging.

User patterns of vehicles differ from day to day therefore, the calculator introduces two factors that estimate the availability of the EV's. The analysis is conducted on a representative fleet approach, where a connectivity pattern for the representative car is filled out hour by hour for a week. On top of this, a regularity factor is introduced, where a scale from 0 to 1 defines the regularity of the availability of the EVs. If set to 0 there is no regularity to the EVs and they cannot be considered available. If the value >0 the vehicles will follow the driving patter at a representative percentage of the time. The reason that the availability should always be set to a value lower than 1 is, that in praxis the EV's in the fleet have different driving patterns. If the availability is set close to 1, then the user assumes very small variations in driving pattern between the EV's. It is up to the user to specify the availability based on his knowledge about the fleet.

2.5 Other input values

Delivering FCR services might cause an increased wear of the battery and hence a reduced lifetime. In the existing model extra battery wear caused by delivering FCR service can be specified as an amount of money per EV per year. No default value is given as there is generally some uncertainty to the order of magnitude.

An additional cost for a bi-directional charger compared to a standard uni-directional charger can be specified as an annual depreciation in DKK per EV per year. The default value is set to 0 DKK as such chargers are not off-the-shelf goods, and a value must be based on the individual case.

2.6 Other assumptions

To investigate the aggregator-based V2G potential in the FCR market, the offering price (marginal cost) of the V2G aggregator is assumed to be zero, which means its offering capacity for up/down regulation reserves can always be accepted by the TSO.

Furthermore, the calculator is constructed in a way, where it calculates the full potential of the turnover and associated profit/loss. This means that as a basic assumption all bids are won.

3 Calculator user interface and formulas

The user interface and the formulas in the calculator (excel) are presented and explained.

3.1 User interface

The user interface uses different colors.

Input data:	XXX
Result of calculations used in other formulas:	*XXX*
Output result:	XXX
Warning (text):	XXX

Formula symbol	Variable	Unit	Single calculation
Sync	Synchronous area		DK2
Mspt	Market entry power threshold	kW	300
EvFleet	EV fleet	units	10
CmxPw	Charger max power	kW/EV	10
BatCap	Battery capacity (usable)	kWh	21
EVmil	EV Mileage	km/month	250
EVee	EV Energy efficiency	kWh/100km	18
MxUdirEnEx	Max unidirectional energy exchange (% of Charger max power)	%	10%
ChEngPr	Charger energy production	kWh/EV/month	350
ChEngLos	Charger energy loss	%	30%
ElConPrc	Electricity consumption price	DKK/kWh	1,00
ElProPrc	Electricity production price	DKK/kWh	0,20
BatFcrW	Battery FCR-related wear	DKK/year	0
ChDeprec	Charger (bi-direc additional cost) depreciation	DKK/year	0
FcPC	FCR-N price change factor for sensitivity analysis	%/year	0,0%
SocOfsWd	SOC offset for sensitivity analysis, weekdays	%-points	0,0
SocOfsWe	SOC offset for sensitivity analysis, weekends	%-points	0,0
SocAvWd	*SOC modified day average for sensitivity analysis, weekdays*	%	*79,8%*
SocAvWE	*SOC modified day average for sensitivity analysis, weekends*	%	*80,0%*
TrEngCon	*Transport energy consumption*	kWh/EV/month	*45*
ChEngCon	*Charger energy consumption*	kWh/EV/month	*564*
TotLos	*Total losses*	kWh/EV/month	*169*
FcrLoss	*FCR-related losses*	kWh/EV/month	*159*
FlFcrRevY	Fleet FCR Revenue (year)	DKK/year)	87.636
FlFcrRevM	Fleet FCR Revenue (month)	DKK/month	7.303
EvFcrRevY	EV FCR Revenue	DKK/year	8.764
EvEngRevY	EV Energy Revenue	DKK/year	840
EvEngCstY	EV Energy Cost	DKK/year	6.109
EvOthCst	EV Other costs	DKK/year	0
EvProfY	EV Profit/year	DKK/year	3.495
	Profit positive		**Profit positive**
	Warning		**EV fleet power reserve < 'Market_entry_power_threshold' in 5736 out of 5736 available**

3.2 Formulas

Some of the formulas behind the cells in the table refer to cells in other sheets.

Calculations are made on an hourly basis, indicated with an index *h* in some of the variables. *h* varies between 1 and 8760.

TrEngCon = EVmil * 100 / EVee

ChEngCon = (TrEngCon + ChEngPr) / (100% - ChEngLos)

TotLos = ChEngCon - TrEngCon – ChEngPr

FcrLoss = ChEngpr * 2 / (TrEngCon + 2 * ChEngpr) * TotLos

FlFcrRevM = FlFcrRevY / 12

EvFcrRevY = FlFcrRevY / EvFleet

EvEngRevY = ChEngPr * ElProPrc * 12

EvEngCst = (ChEngPr + FcrLoss) * ElConPrc * 12

EvOthCst = BatFcrW + ChDeprec

FlRevY = $\sum_{\mathrm{h=1}}^{8760} Fleet\_Revenue_h$

EvProfY = EvFcrRevY + EvEngRevY – EvEngCst - EvOthCst

$$FleetRevenue_h = FCRN_h * EVMaxPowerBid_h * EvFleet$$

$$EVMaxPowerBid_h = Minimum\left(\frac{BatteryEnergyCapacityAvailForFCRN_h}{CmxPw * MxUdirEnEx}; 1\right) * CmxPw * FleetPattern_h$$

$$BatteryEnergyCapacityAvailForFCRN_h = Minimum(100\% - SOC_h;\ SOC_h) * 0{,}01 * BatCap$$

3.3 Comments on size of EV fleet and power reserve

If the EV fleet is small, the total power reserve might not be above the FCR-N market entry power reserve threshold (which is currently 300 kW). In that case the access to the market is blocked.

The calculation model calculates the profit per EV in the fleet regardless of the number of EV’s and the total power reserve. Instead it provides a warning that the power reserve is too small.

Whether the power reserve is above threshold or not in a given hour depends, besides on the size of the fleet and the charger power capacity, also on the actual SOC. This means that in some hours during the year the power reserve criteria might not be fulfilled. The model calculates the number of hours and gives a warning with this number.

In the present version of the calculator all costs and revenues of the EV fleet are linearly proportional to the number of EV’s in the fleet.

4 Case: Frederiksberg Forsyning

The calculator is verified against a case, here called the FF case, because it is based on an EV fleet owned by the Danish utility Frederiksberg Forsyning.

At the headquarters of FF, ancillary service, is being provided by an aggregator, the Parker project partner NUVVE, by controlling the bidirectional power exchange between the grid and a fleet of 10 EVs owned by the utility. Each EV can be connected to the grid via a bidirectional V2G charger, which is controlling the charging and discharging of the battery.

The service is delivered in synchronous area DK2.

The example is valid for 2017.

4.1 Data

The following is a specification of the input parameters to the calculator. Technical data are provided by NUVVE [5].

4.1.1 Fleet, charger and battery

<u>EV fleet</u>
10 Nissan e-NV200 vans.

<u>Charger</u>
10 Enel V2G bi-directional charging units are installed to enable EVs to charge and discharge when plugged. Each of the 10 units has 10 kW capacity, which gives a total available power of 100 kW.

The efficiency of the FF chargers is low, estimated to 70 %. The newer charger generation using Silicon Carbide technology should be closer to 90% round trip efficiency [5]

<u>Battery</u>
The EVs have 24 kWh batteries with a usable energy storage capacity at around 21 kWh.

4.1.2 FCR-N regulation prices

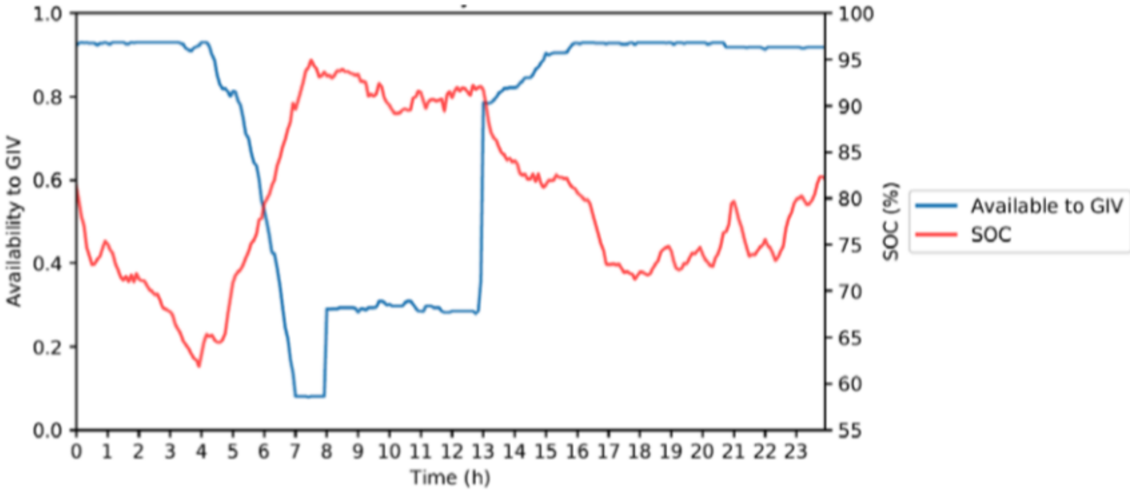
The hourly prices for FCR-N in DK2 is found as described in the chapter 2.1.2 for the year 2017.

4.1.3 SOC and Availability

An analysis of SOC and fleet driving pattern of the FF EV fleet is made by the project partner DTU and described in the section ”Utility Electric Vehicle Fleet

Usage Patterns – Understanding and optimizing aggregator participation", May 2017 [4].

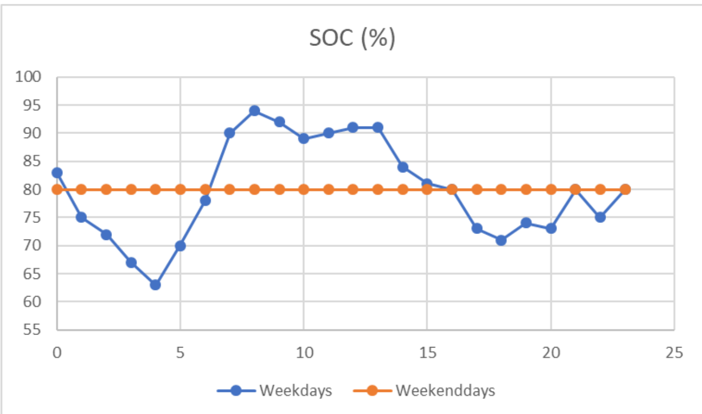
The following graph [4] shows the average availability and SOC of one EV in working days for each hour of the day.



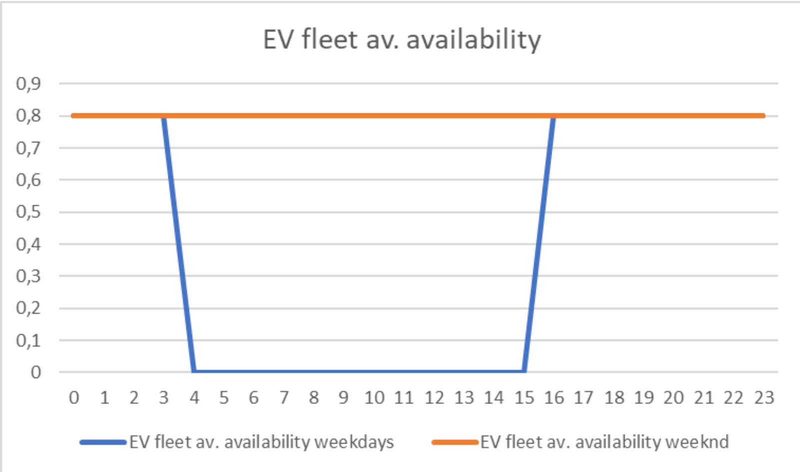
Average availability to GIV vs SOC behavior of one EV in working days.

The available to GIV behavior is very similar to the fleet behavior.
The information found in the report is translated into the following tables.

Hour	Weekdays SOC (%)	Weekends SOC (%)
0	83	80
1	75	80
2	72	80
3	67	80
4	63	80
5	70	80
6	78	80
7	90	80
8	94	80
9	92	80
10	89	80
11	90	80
12	91	80
13	91	80
14	84	80
15	81	80
16	80	80
17	73	80
18	71	80
19	74	80
20	73	80
21	80	80
22	75	80
23	80	80



Hour	EV fleet av. availability weekdays	EV fleet av. availability weeknd
0	0,8	0,8
1	0,8	0,8
2	0,8	0,8
3	0,8	0,8
4	0	0,8
5	0	0,8
6	0	0,8
7	0	0,8
8	0	0,8
9	0	0,8
10	0	0,8
11	0	0,8
12	0	0,8
13	0	0,8
14	0	0,8
15	0	0,8
16	0,8	0,8
17	0,8	0,8
18	0,8	0,8
19	0,8	0,8
20	0,8	0,8
21	0,8	0,8
22	0,8	0,8
23	0,8	0,8



The average values of the SOC in the FF case are 80 % on weekdays and the same for weekends. The closer to 50 % the smaller the restriction is on the size of the available power reserve. For the purpose of the sensitivity analysis two offset parameters, one for weekdays and one for weekends, for the SOC is introduced in the calculator model. By entering an offset value x in percentage points, adjustments can be made to each of the hourly values of SOC with x [%]. The absolute variations in the SOC values are thus maintained.

SOC and availability are assumed to have the same patterns on holidays as on weekend days. For that reason, a table has been added, in order to specify the dates of the holidays during the calendar year of the calculations.

4.1.4 Frequency stability in DK2 and energy exchange

Compared to DK1 the frequency stability in DK2 is often said to be significantly lower. However, it is impossible here to quantify the difference, neither with respect to frequency of deviations from the nominal value 50 Hz, with respect to the order of magnitude and hence the power flow in the charger nor with respect to the max unidirectional energy exchange during each hour of contracted FCR-service.

As described in an earlier chapter, the aggregator can specify a 'Max unidirectional energy-exchange'-factor. In short it describes the maximum deviation of the energy content from the starting value that might arise during one hour of FCR-N service. In this example it is set to 20 %. This means that the maximum unidirectional energy exchange for one hour is estimated to be: 1h * 10 kW/charger * 20% = 2 kWh. This is probably rather conservative but can be fine-tuned when more experience is gained from praxis.

4.1.5 Energy consumption, production and losses

The following figures are provided by NUVVE:

- Mileage of each EV is about 250 km/month
- The energy efficiency of the EV is 5 to 6 km/kWh.
- The energy production (energy delivered back to grid) is 350 kWh/month
- Efficiency of the charger is 70 %
- The rated battery capacity is 24 kWh and the usable capacity is 21 kWh

From these figures it can be deduced that the energy consumption for transport is 45 kWh/month.

The total energy consumption of the charger is (45+350)/0,7 = 564 kWh/month.

The total losses in the charger amounts to 169 kWh/month.

Using the formula for calculating the split of the losses related to transport respectively to FCR-N service, the latter amounts to 159 kWh/month.

4.1.6 Energy prices

The following description of settlement costs for electricity and revenues is based on information from the aggregator (NUVVE).

Electricity consumption for V2G is exempt from electricity tax (elafgift) and VAT.

The produced energy (upregulation) is sold back to the grid at spot pricing + balance on a regular basis as it is today, but other models could be developed in the future.

The settlement cost components in DK2 is shown in fig. 4.1

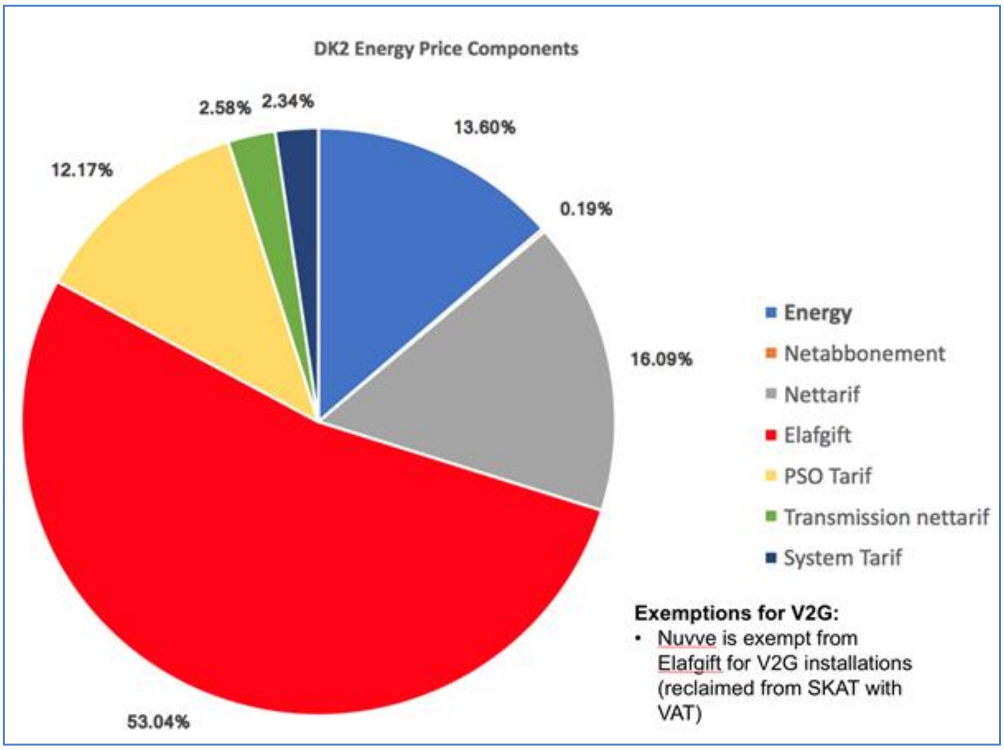


Figure 4.1: DK2 settlement cost components

NUVVE has stated the following average settlements:

- 1,0 DKK per kWh for consumption
- 0,2 DKK per kWh for production

4.1.7 Other costs

Additional battery wear related to FCR-N is set to 0 DKK/year.

Depreciation of additional costs related to the bi-direction property of the charger is set to 0 DKK.

4.1.8 Result of a calculation on the FF case

Based on the specified parameters and assumptions in the FF case the **profit is calculated to be 3.495 DKK/EV/year.**

The table in chapter 3.1 shows the inputs and results of this calculation.

The power reserve is far too small to reach the threshold for market entry. In order to reach the threshold, Nuvve need to aggregate a larger EV fleet or increase the power of the chargers utilized.

5 Scenarios

A sensitivity analysis is made with the FF case as reference. Parameter values are varied one-by-one.

The resulting EV profits are compared with the reference result: 3.495 DKK/year.

In the end, a worst-/best-case calculations are made, where several parameter values are changed from the reference case values.

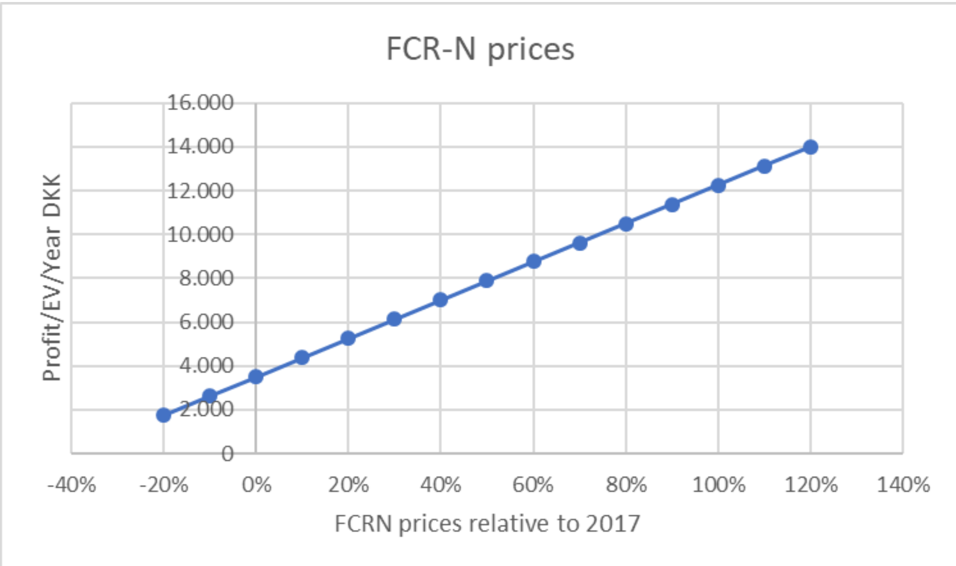
5.1 Number of EVs and 'Market entry power threshold'

In the reference case the number of EVs is 10. However, that is much too low to pass the 'Market entry power threshold' of 300 kW in all of the available hours during the year. The required number is calculated to be minimum 38 EVs. This number depends on the *Maximum unidirectional energy-exchange*. If the grid frequency variations are considerable and might trigger FCR-N activation in one direction for a longer period of time, then there is a risk, that the SOC might reach 0 respectively 100 % during the FCR-N service, unless the number of EVs is increased.

5.2 FCR-N prices

In the year 2017 the precipitation was extremely high in the Nordic countries and the energy production on the hydro power stations reached a high level which was reflected in relatively low prices for FCR-N.

The year 2018, so far, has been extremely dry and the produced hydro energy has been substantially lower than normal resulting in higher FCR-N prices.

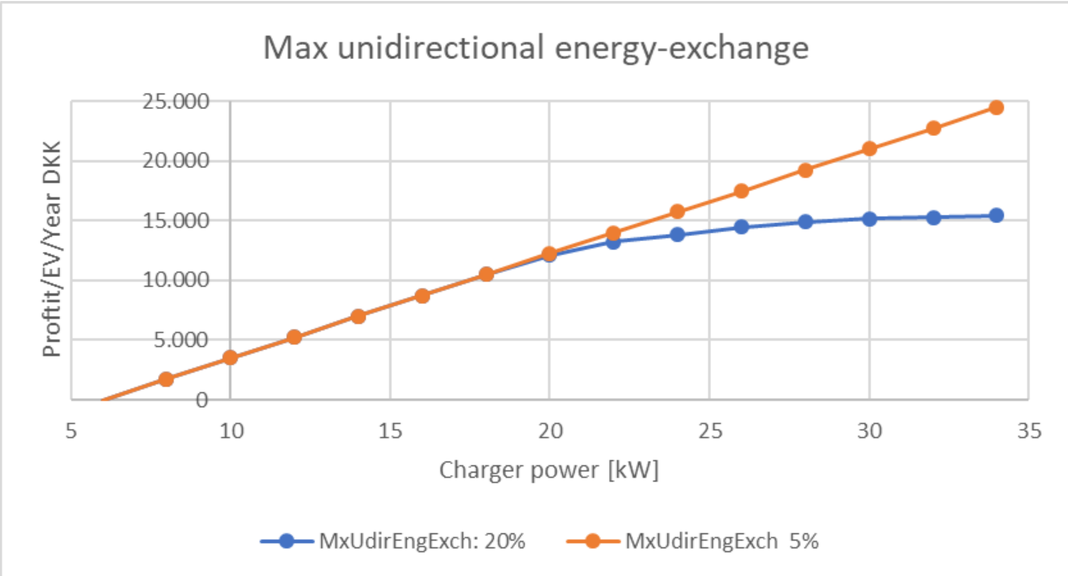


The profit is strongly dependent on the FCR-N prices. An increase of 20 % in the FCR-N prices results in 50 % increase in profit.

5.3 Charger power

The reference value of the charger power is 10 kW.

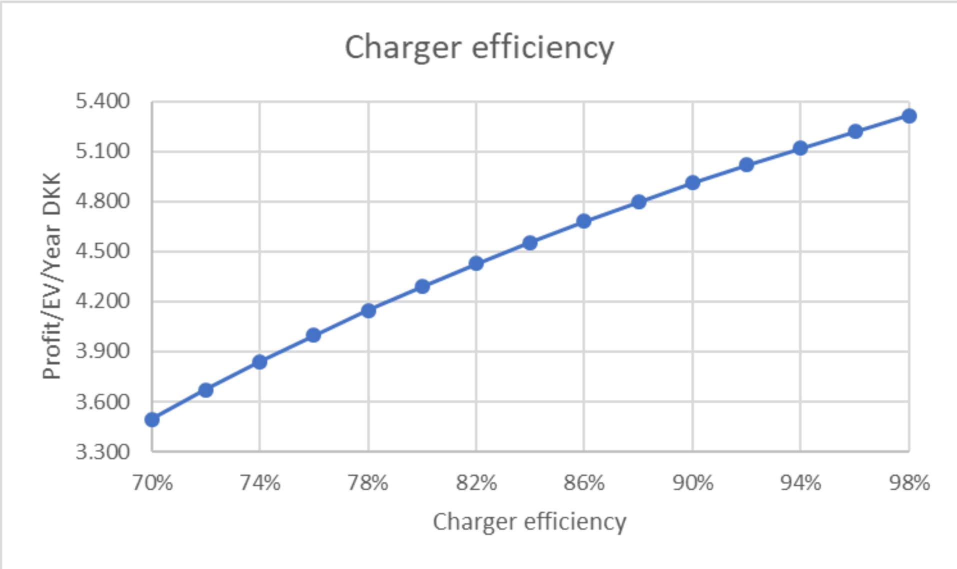
The charger power has significant influence on the profit. The profit increases with about 25 % of the reference profit per kW additional charger power.



In the reference calculation the 'Maximum unidirectional energy exchange'-factor (MxUdirEngExch) is set to 20 %. This is an indication that the user estimates that there is a risk that the request for power will be unidirectional for up to 20 % of the time in a given hour. As a rule of thumb, the MxUdirEngExch should be set to a high value if the ratio (charger power / battery energy capacity) is high and/or if it is assumed that the grid frequency often deviates substantially from 50 Hz, to minimize the risk that the calculated profit is too optimistic. If it is reasonable to assume that the grid frequency deviates insignificantly from 50 Hz the MxUdirEngExch can be set lower. In the diagram an example is shown with the MxUdirEngExch set to 5 %.

5.4 Charger efficiency

Reference value charger loss: 30 % => Efficiency: 70 %



The efficiency of the FF chargers is 70 %.

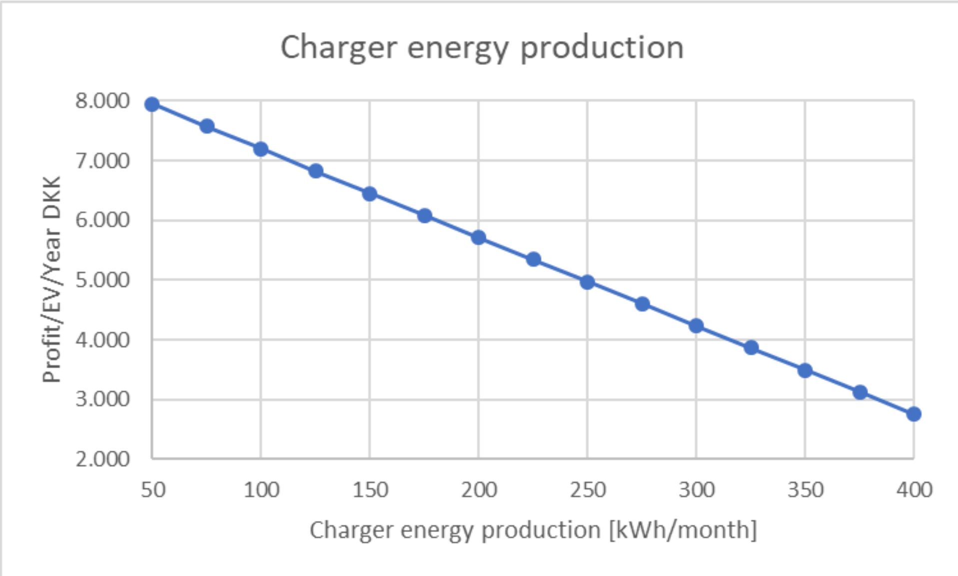
Next generation of the chargers are expected to have an efficiency about 90 % roundtrip.

Replacement of the present chargers with next generation chargers increases the profit from about 3.500 to about 4.900 DKK ~ 40 %.

5.5 Charger energy production

Reference value for charger energy production (energy delivered back to the grid during upregulation): 350 kWh/month.

The frequency in the DK2 fluctuates much more than in DK1. That also means that the primary power reserves are activated more frequently in DK2 and that the energy exchange between the charger and the grid is higher. As mentioned before, it is in the interest of the aggregator that the energy exchange is as small as possible to minimize losses; especially if the price for consumed energy is higher than for produced energy per kWh as in the FF case.



If the energy produced to the grid falls from 350 kWh/month to 100 kWh, which is considered realistic in DK1, then the profit is doubled.

5.6 Worst-case and best-case

In order to explore the potential business risk and gain within the FCR-N market for balancing via aggregated EVs, an expected best case and worst-case scenario have been defined by the Parker project partners. The input values for the reference case, a best-case and a worst-case and the results, profit/EV/year are shown in the table.

Variable	**Unit**	**Reference Scenario**	**Best case**	**Worst case**
EV fleet	units	10	10	10
Charger max power	kW/EV	10	20	6,6
Battery capacity (usable)	kWh	21	60	21
EV Mileage	km/month	250	250	250
EV Efficiency	kWh/100km	18	12,5	18
Max unidirectional energy exchange (% of Charger max power)	%	20%	10%	30%
Charger energy production	kWh/EV/month	350	350	350
Charger energy loss	%	30%	10%	30%
Electricity consumption price	DKK/kWh	1,00	0,70	1,40
Electricity production price	DKK/kWh	0,20	0,70	0,20
Battery FCR-related wear	DKK/kWhUp	0	0	1.200
Charger (bi-direc additional cost) depreciation	DKK/year	0	0	4.000
FCR-N price change factor for sensitivity analysis	%/year	0,0%	0	0
SOC offset for sensitivity analysis, weekdays	%-points	0,0	0,0	0,0
SOC offset for sensitivity analysis, weekends	%-points	0,0	0,0	0,0
Profit/EV/Year	**DKK**	**3.495**	**17.187**	**-7.128**

The best-case scenario is constructed around the expectations that EVs in the future will be more energy efficient and with larger batteries. The same development is expected with the chargers, where charging power could increase to 20 kW and energy efficiency will move towards 90 %. For the pricing of power supplied to the grid and re-bought a net metering framework could happen, which will influence the profitability significantly.

The expectations in the worst-case scenario are centered around expectations to cars not evolving in available battery capacity for this type of vehicles and not on energy efficiency either. For the chargers, expectations are that smaller home chargers will be installed to save money for the EV owner, but energy efficiency will remain at the current level. On the demand side, there is an expectancy that unidirectional loads will increase as a result of the higher level of fluctuating energy sources. Energy prices are expected to increase due to reduction in incentives and fewer large thermal plants. Lastly, a 2% depreciation on the battery as a result of V2G services, corresponding to 1.200 DKK/Year[1] and 4.000 DKK depreciation cost on the charger have been applied

The analysis shows that the influencers with large impact are the parameters, 'Battery FCR-related wear' and 'Charger (bi-direc additional cost) depreciation'. The batteries are expensive components, and there is great uncertainty to the impact on the life-time caused by providing FCR-N services.

The additional cost for a bi-directional charger compared to a standard uni-directional charger is at present very high, and if this amount of money is attributed only to the FCR-N service and not to other V2G services, then the profitability of participating in the FCR-N market is questionable.

The charger power plays also a significant role for the profitability, which has been shown in chapter 5.3.

The better EV efficiency in the best-case has very little impact on the result.

[1] A replacement battery by Nissan is priced at 60.000 DKK, where a 2 % decrease will correspond to 2 % of the battery price.

6 Conclusion

The report describes a model and a program for calculating the profits of a supplier that provides a primary power reserve (FCR) from a portfolio of electric vehicles to the TSO for frequency support to the grid.

The analytical work in defining the calculation model has led to the definition of 15 variables to evaluate when conducting scenario calculations for the potential of V2G services on the FCR-N market. These variables are supported further by vehicle data based on an average vehicle approach, where all vehicles are considered alike in terms of driving pattern, battery and charger capacity, availability and state of charge. These decisions have been made to reduce the complexity of the calculator and for the maturity of the EV and V2G market, they are considered sufficient for the evaluation.

From the evaluation conducted on the business case for FCR-N balancing via utilization of V2G ready EVs, conclusions can be made that the viability currently is very fragile due to several factors.

- Energy efficiency of the V2G chargers is very low, which causes a large energy loss and thereby added costs.
- Pricing of FCR-N is very volatile and hard to predict years ahead, which has a large impact on the revenue and thereby also the profits.
- The analysis conducted is a potential analysis, hence does not distinguish between bids won and lost. Bids won at low prices with high energy exchange will be costly.
- Excessive costs related to a V2G ready charger and battery wear will be deducted directly from the profits, hence can shift the balance from good to bad business case.

The model has been tested on a concrete case; the pilot project with 10 EV's owned by Frederiksberg Forsyning. These are operated by an FCR-N service provider in the synchronous area DK2. Information from this project was entered into the model and estimates of the profits for three situations were made: expected case, best-case and worst-case. In the latter two, parameter values are chosen to reflect the uncertainties described above and to take into consideration expectations on the developments in technology and prices. The results on the calculations of profits are [DKK/EV/year]:

- 'Expected case'=> 3.500 DKK/EV/year
- 'Best-case'=> 17.000 DKK/EV/year
- 'Worst-case'=> -7.000 DKK/EV/year

To further develop the calculation model, some of the following elaborations could be made:

1. Extend FCR market data to 3-5 years in order to find out market tendency, e.g., forecasting for next year.
2. If possible to get the EV data, new/specific driving pattern and SOC can be used to replace the default values.
3. Verify the EV cost, e.g., hourly-based consumption, possible reduction, incentives or allowances.
4. Generate more scenarios to test EV profitability.
5. Apply matured EV calculator to other balancing markets.

7 References

1. “Introduktion til Systemydelser.pdf”, Energinet.dk, 2017-03-10
2. “Ancillary services to be delivered in Denmark – Tender conditions”, Energinet.dk, 2017-12-20
3. “Specification of requirements and test of FCR-N in DK2’”, Energinet.dk, 2017-10-10
4. ”Utility Electric Vehicle Fleet Usage Patterns – Understanding and optimizing aggregator participation” (Parker_D3.1.pdf). DTU, May 2017
5. Marc Trahand, NUVVE

8 Appendix 1: The market for Primary Reserves, FCR

Rules for participating in the FCR-market are set by the TSO, Energinet.dk. Selected paragraphs relevant publications from Energinet.dk are presented.

The scope of the calculator is DK2, but for the sake of comparison the rules applying in DK1 are also presented.

The report "Introduktion til Systemydelser.pdf", Energinet.dk, 2017-03-10 [1], describes system ancillary services applied to maintain the frequency in the Danish electricity supply system:

1. 2.4.1, FCR DK1:
    a. FCR skal alene levere effekt indtil aFRR (sekundære reserver) og mFRR (manuelle reserver) tager over. Leveringshastigheden skal ligge indenfor 15-30 sekunder og reserven skal minimum kunne forblive aktiv i 15 minutter. Aktivering af FCR foregår automatisk ved frekvensafvigelser"
    b. "Indkøbet af FCR er opdelt på indkøb af opreguleringskapacitet og nedreguleringskapacitet"
2. 2.5.1 FCR-N, DK2:
    a. "I modsætning til den vestdanske FCR skal reguleringen kunne opretholdes kontinuerligt over hele aftaleperioden"
    b. "Reguleringen leveres jævnt med fuld aktivering efter 150 sekunder og skal kunne køres symmetrisk – det vil sige som både op- og nedregulering".
    c. "Aktørerne kan indgive bud på timebasis eller som blokbud"
    d. "Buddene skal være symmetriske"

Requirements to be met by suppliers of ancillary services are described in the report "Ancillary services to be delivered in Denmark – Tender conditions", Energinet.dk, 2017-12-20 [2]:

1. 1.1.1.1, FCR, DK1:
    a. "It must be possible to maintain the regulation until the automatic and manual regulating reserve can take over; however, minimum 15 minutes"
    b. "Following the end of the regulation, the reserve must be re-established after 15 minutes"
2. 1.1.2, FCR, DK1:

a. “Energinet procures two types of primary reserve, upward regulation power (in case of underfrequency) and downward regulation power (in case of overfrequency).”

b. “For the purpose of the auction, the 24-hour period is divided into six equally sized blocks of four hours each”

3. 1.4.2 FCR-N, DK2:

   a. “Frequency-controlled normal operation reserve is procured as a symmetrical product where the supplier must also provide upward regulation power (in case of underfrequency) and downward regulation power (in case of overfrequency).”

   b. “The supplier can submit bids hourly or as block bids.”

The report “Specification of requirements and test of FCR-N in DK2”, Energinet.dk, 2017-12-20 [3], describes the fundamental requirements for FCR-N and required ancillary service tests to be done before the installation can participate/be of use in the market:

1. 1.2.1 for FCR-N, DK2:

   a. ”Regulation is performed as a fast-reacting proportional control, often delivered from 'running/rolling’ installations at part load.”

   b. ”Installations tasked with supplying FCR-N must measure frequencies and automatically activate reserves on their own accord, as they will receive no external activation signal.”

   c. Power response to frequency fluctuations must be supplied at frequency deviations of ±100 MHz relative to the reference frequency, i.e. in the range 49.9 - 50.1 Hz

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1.2.1.1 Requirements

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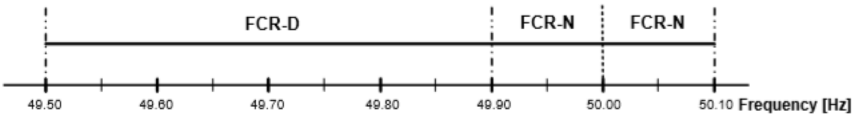

Figure 1 - Activation frequencies for FCR-N.

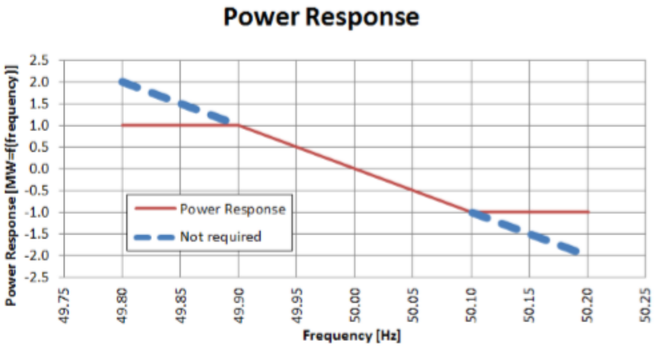

Figure 2 - Power response for FCR-N.

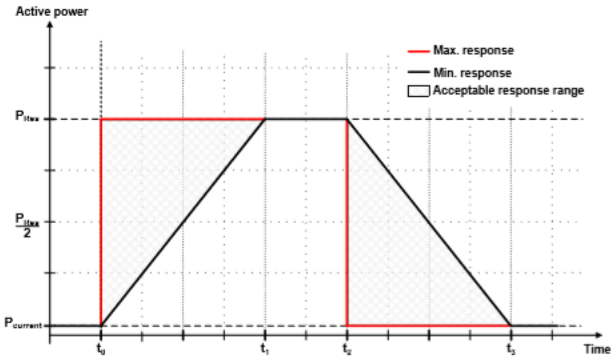

Figure 3 - Random FCR (FNR) activation response sequence in DK2.

Table 1 specifies the response times of Figure 3.

Time parameters	Time
$t_0 - t_1$	150 seconds
$t_1 - t_2$	Frequency imbalance length, at least 15 minutes
$t_2 - t_3$	150 seconds

Table 1 - Time parameters for response sequence described in Figure 3.