The Parker Project

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1 Nomenclature

BEV	Battery Electric Vehicle
CDF	Cumulative Distribution Function
DER	Distributed Energy Resource
DSO	Distribution System Operator
DSS	Distribution System Service
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FCR	Frequency Containment Reserves
FME	Frequency Measurement Equipment
GIV	Grid Integrated Vehicle
ICE	Internal Combustion Engine
IEA	International Energy Agency
LV	Low Voltage
MEF	Marginal Emission Factor
POP	Preferred Operating Point
SGU	Smart Grid Unit
SOC	State-Of-Charge
TOU	Time-of-Use
TSO	Transmission System Operator
VGI	Vehicle-Grid Integration
WP	Work Packages
WT	Wind Turbines

2 Introduction

The Parker project was a Danish demonstration project focused at Vehicle-Grid Integration (VGI). The primary aim of the project was to demonstrate that contemporary electrical vehicles could participate in advanced smart grid services including the use of Vehicle-To-Grid (V2G).

Parker builds on two previous projects, the EDISON and Nikola projects, which already laid the foundation for understanding the electric vehicle's potential in supporting the power system.

The project utilized a number of contemporary electric vehicles and V2G DC chargers provided by its industrial partners and used them to carry out a number of tests and demonstrations in PowerLabDK - an experimental platform for power system research.

Further, the project partnered with the world's first commercial pilot (the Frederiksberg Forsyning V2G hub) where electric vehicles provided frequency containment reserve, located in greater Copenhagen.

The project used the above assets to investigate three key topics: grid applications, grid readiness as well as scalability and replicability.

This document describe the main findings of the project within the above three topics and reference the scientific publications (Parker produced papers) which are listed in chapter 4.

Partners in the project were **Nissan, Mitsubishi Corporation, Mitsubishi Motors Corporation, PSA ID, Nuvve, Frederiksberg Forsyning A/S, Insero A/S, Enel X and DTU Electrical Engineering.**

The project was supported by the Danish EUDP program.

3 Executive summary

This section summarizes the findings of the Parker project divided into the three main topics investigated.

The project has investigated the **grid applications** that contemporary electric vehicles (EVs) can provide to power systems. To this end the project systematically listed potential power and energy services in a so-called ‘service catalog’. From this list a subset was chosen and then demonstrated using the EVs available to the project - the emphasis was on frequency regulation services since they are not only the most demanding (reaction time and need of V2G) but also the most commercially interesting services currently available in Denmark. It was proven that project vehicles and charging infrastructure is presently technically able to provide all frequency regulation services used in Denmark. It was concluded that V2G technology is scalable both in terms of number of EVs, type of FCR service, OEM brands, TSO regions, battery sizes and duration. Besides from FCR-type services, the project also supported and tested a new Marginal Emission Factor (MEF) signal, describing the marginal emission produced to service additional consumptions at a given time - a service directly aimed at supporting renewables in the power system. Further, under the same topic, the Frederiksberg Forsyning (FF) commercial V2G hub was investigated. Here, two years of data has proven that the electric eNV200 vans included in the trial have successfully, under temporarily relaxed market terms, been able to provide FCR services. The service has been provided for a total of 13,000 hours for a single car, with an average revenue of 1,860 Euro car/year. A study of the driving behavior at FF has shown that it is possible to optimize market participation without adverse effects to driving - with proper analysis of customer behavior. Further, a study on battery usage has shown that the energy throughput and cycles depends heavily on the service provided. The type of Frequency Containment Reserves (FCR) provided at FF (FCR-N) is by far the most demanding service of the ones investigated. Finally the grid impacts of V2G have been investigated by installing a Smart Grid Unit (SGU) at FF. The measurements have shown the power peaks generated by the EVs, which adds to the FF building demand. It was concluded that this presently is not a challenge to the distribution grid in question - but will be for other, weaker distribution systems when scaling up the number of EVs providing FCR.

The project’s second topic has been the development of a **test protocol** aimed at the technical capabilities needed in EVs and charging infrastructure in order to support V2G and the services listed in the service catalog. To this end, the project has developed ‘grid keys’ which is a list of requirements towards controllability, observability and performance when controlling the power exchanged between the EV and the grid. These grid key requirements have then been compared to the present capabilities supported by the standards and protocols connecting EV and Electric Vehicle Supply Equipment (EVSE) which include IEC 61851, IEC 15118 and CHAdeMO. It was found that CHAdeMO is the only standard which presently supports V2G - but also that other capabilities, such as reaction time when altering a power setpoint, granting access to battery State-Of-Charge (SOC) and vehicle identification through the EVSE need to be considered by all standards to fully support VGI. Further, the project developed a test pattern used to evaluate the performance of the vehicles included in the project. Based on the tests, seven different measures of performance were evaluated including activation time, setpoint granularity, accuracy and precision. The tests showed a good performance for the vehicles tested (Nissan Leaf, Nissan Evalia, Peugeot iOn, Mitsubishi Outlander PHEV) and can serve as a benchmark for upcoming car models and standards. The reaction time were measured to 5-6 seconds (including the communications delay) using an aggregator - down to a few seconds when controlling charger and car directly. Ultimately the performance depends on the design of the power electronics as well as the software and protocols used to control it. The project concludes that V2G capability works well for a subset of contemporary EVs today, using a DC V2G charger and CHAdeMO, but further work is needed to make the technology universal and to enhance performance to a degree which will make entirely new services possible (e.g reactive power provision and sub-second response).

Finally, the project explored the topic of **scalability and replicability**. To understand the scalability of the FCR service presently being provided at the pilotsite of FF, the project analysed the potential earnings for performing such services. The expected profit was found to be highly depended on a set of parameters including FCR prices, V2G charger cost and efficiency, energy costs (incl tax and tariffs) and battery degradation. The expected profit went as high as 2304 Euro pr car/year for the best case down to -955 Euro pr car/year for a worst case, showing that the business case is highly sensitive to a number of factors. Conclusions made were that both the value system and market are ready - but that there is no clear answer on the universal viability of the business case and that customers may not be ready yet to adopt the technology. Further the supply chain is currently not in place as few V2G capable cars and chargers are on the market. Further, as part of the replicability study, barriers for providing FCR using V2G where described using a PESTEL Analysis, which showed that most countries are battling a general barrier of few V2G capable EVs, market structures not ready for EV aggregation, and market frameworks not developed for the new decentralized energy market. When assessing the individual barriers in Denmark, Norway, Sweden and Germany, the country with the lowest barriers currently is Denmark followed by Sweden. Finally, an analysis described the most interesting markets in Europe to approach when introducing FCR based on V2G. The analysis used seven variables and four main factors to describe the suitability of each market. The study found Norway, Sweden and France to be some of the most interesting markets to consider for EV aggregators providing FCR-type services. Another subtopic investigated was the possibility of developing and providing new services aimed at the distribution system - so-called Distribution System Services (DSS). Such services include congestions management, load shifting, peak shaving and voltage control. Through a case study it was found that reactive power provision with efficient chargers could minimize grid losses and allow for 50% more EVs in a grid without additional investments. It was also investigated how services may be combined to provide services aimed at both Distribution System Operator (DSO) and Transmission System Operator (TSO). It was argued that the provision of FCR may readily be combined with reactive power provision - in order to simultaneously support both the system-wide frequency and the local voltage. The study found that some of the simpler DSS services, like voltage regulation with active power, may start becoming mature midterm (>2 years) while more advanced services, including provision of reactive power, could be viable long term (>5 years).

The general conclusions of the project are as follows:

1. It has been validated that the Parker portfolio of EVs (PSA, Mitsubishi and Nissan) together with DC V2G chargers (Enel X) support V2G and are ready to provide advanced services to the grid.
2. A field-test in Copenhagen has proven that it is possible to commercialize this technology though the provision of FCR.
3. Further steps must be taken to allow for universal support of V2G and VGI services across all EV brands, standards and markets.

The next step for the technology is to be tested through large-scale demonstrators which will mature the technology to a degree where it is ready and accessible for private EV owners.

The main recommendations, aimed at decisionmaker in Danish organizations, are as follows:

Transportation electrification, Denmark should have an ambitious, clear and consistent plan towards a full electrification of the transportation sector as it goes hand-in-hand with the nation's role in R&D.

Research, development and demonstration, National funding programs, such as EUDP and Innovation fonden, should consider emphasising VGI research as an area of interest.

Test zones and pilots on new market designs, Pilot projects and test zones supported by the Danish government and TSO, Energinet, may prove an effective way of identifying market-based and regulatory barriers for demand flexibility - but also to explore entirely new ways of using and incentivising flexibility.

International collaboration, It is important that Denmark collaborate internationally, both within market and standard harmonization - as well as within research. This means that funding should be made available for such collaboration.

Finally, a listing of publications and downloads can be found on the projects webpage : www.parker-project.com

4 Parker publication list

2019

Arias, N. B., Hashemi, S., Andersen, P. B., Træholt, C., Romero, R. (2019). Distribution System Services Provided by Electric Vehicles: Recent Status, Challenges, and Future Prospects. *in: IEEE Transactions on Intelligent Transportation Systems, pages: 1 - 20.*

Sousa, T., Hashemi, S., Andersen, P. B.(2019). Raising the potential of a local market for the reactive power provision by electric vehicles in distribution grids. *in: IET Generation, Transmission & Distribution*

2018

Andersen, P. B., Sousa, T., Thingvad, A., Berthou, L. S., & Kulahci, M. (2018). Added Value of Individual Flexibility Profiles of Electric Vehicle Users For Ancillary Services. In *Proceedings of IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids* IEEE.

Andersen, P. B., Hashemi, S., Sousa, T., Sørensen, T. M., Noel, L., & Christensen, B. (2018). Cross-brand validation of grid services using V2G-enabled vehicles in the Parker project. In *Proceedings of 31st International Electric Vehicles Symposium & Exhibition & International Electric Vehicle Technology Conference 2018* IEEE.

Hashemi, S., Arias, N. B., Bach Andersen, P., Christensen, B., & Traholt, C. (2018). Frequency Regulation Provision Using Cross-Brand Bidirectional V2G-Enabled Electric Vehicles. In *Proceedings of 2018 6th IEEE International Conference on Smart Energy Grid Engineering, SEGE 2018* (pp. 249-254). [8499485] IEEE. DOI: 10.1109/SEGE.2018.8499485

Christensen, B., Trahand, M., Andersen, P. B., Olesen, O. J., & Thingvad, A. (2018). *Integration of new technology in the ancillary service markets*. Technical University of Denmark, Department of Electrical Engineering.

Soares, T., Sousa, T., Andersen, P. B., & Pinson, P. (2018). Optimal Offering Strategy of an EV Aggregator in the Frequency-Controlled Normal Operation Reserve Market. In *Proceedings of 2018 15th International Conference on the European Energy Market* (pp. 1-6). IEEE. DOI: 10.1109/EEM.2018.8469922

Zecchino, A., Thingvad, A., Andersen, P. B., & Marinelli, M. (2018). Suitability of Commercial V2G CHAdeMO Chargers for Grid Services. In *Proceedings of EVS 31 & EVTeC 2018.*

Banol Arias, N., Hashemi, S., Andersen, P. B., Traholt, C., & Romero, R. (2018). V2G enabled EVs providing frequency containment reserves: field results. In *Proceedings of 2018 IEEE International Conference on Industrial Technology* (pp. 1814-19). IEEE. DOI: 10.1109/ICIT.2018.8352459

2017
Knezovic, K., Marinelli, M., Zecchino, A., Andersen, P. B., & Træholt, C. (2017). Supporting involvement of electric vehicles in distribution grids: Lowering the barriers for a proactive integration. *Energy*, *134*, 458-468. DOI: 10.1016/j.energy.2017.06.075

Rezkalla, M. M. N., Zecchino, A., Martinenas, S., Prostejovsky, A., & Marinelli, M. (2017). Comparison between Synthetic Inertia and Fast Frequency Containment Control Based on Single Phase EVs in a Microgrid. *Applied Energy*, *210*, 764-775. DOI: 10.1016/j.apenergy.2017.06.051

5 Grid applications

This part describes the results for the grid applications topic.

The Parker test environment consisted of the Frederiksberg Forsyning (10 Nissan e-NV200) and the Reference Configuration described in section 5.1.4. All EVs were connected to Enel V2G chargers and controlled by a Nuvve Aggregator.

The Parker project showed that aggregated EV solutions can be scaled in different dimensions to support various grid services with high fidelity. The tests involved cross-brand EVs from different manufacturers and it was shown how each EV can follow a request for power signal with different degree of fidelity (section 5.2.2). The tests were guided by an overall test plan (section 5.1.2) and in order to describe the Parker services a Service Catalog 2.0 was produced (section 5.1.1) to primarily provide a systematic overview to understand the value of the services to the EV owner.

The user patterns were analyzed and methods to optimize the service revenues from a coalition of EVs were devised (section 5.3.3).

The energy flow to support different services in different synchronous areas were analyzed and show a large variance in energy flow between the services, with DK2 FCR-N constituting the largest energy flow (section 5.2.4).

Finally the barriers for entry as well as the business potential were analyzed - section 5.5.

5.1 Grid services

5.1.1 Service catalog 2.0

Prior to Parker, the Nikola project had produced a Service Catalog 1.0 describing the services that can be provided by aggregated EVs. It was the result of stretching out and identifying services that can be provided to:

1. The system-wide grid (TSO)
2. The distribution grid (DSO)
3. The user

A number of studies were conducted in the beginning of Parker - immediately following the work done in Nikola. These studies are described in the papers[1]–[5].

In Parker the service catalog was further developed into the service catalog 2.0. The goal was to provide a systematic overview to understand the value of the services for each constituent. The services are grouped into 3 domains: 1) Region, 2) neighborhood and 3) Building/Home.

The catalog is focused on the owner of the EV and based on his/her willingness to share the battery of the EV for energy services.

The concept Vehicle-Grid-Integration (VGI) was adapted in the project to align with primarily US (California) used terminology. Figure 1 shows the VGI with the EV owner in the middle. Based on his/her demands (economics, conviction to going green or functionality) the grid services can be broken into domains like services for the region (TSO), the neighborhood (DSO) or the building (home, business behind the meter).

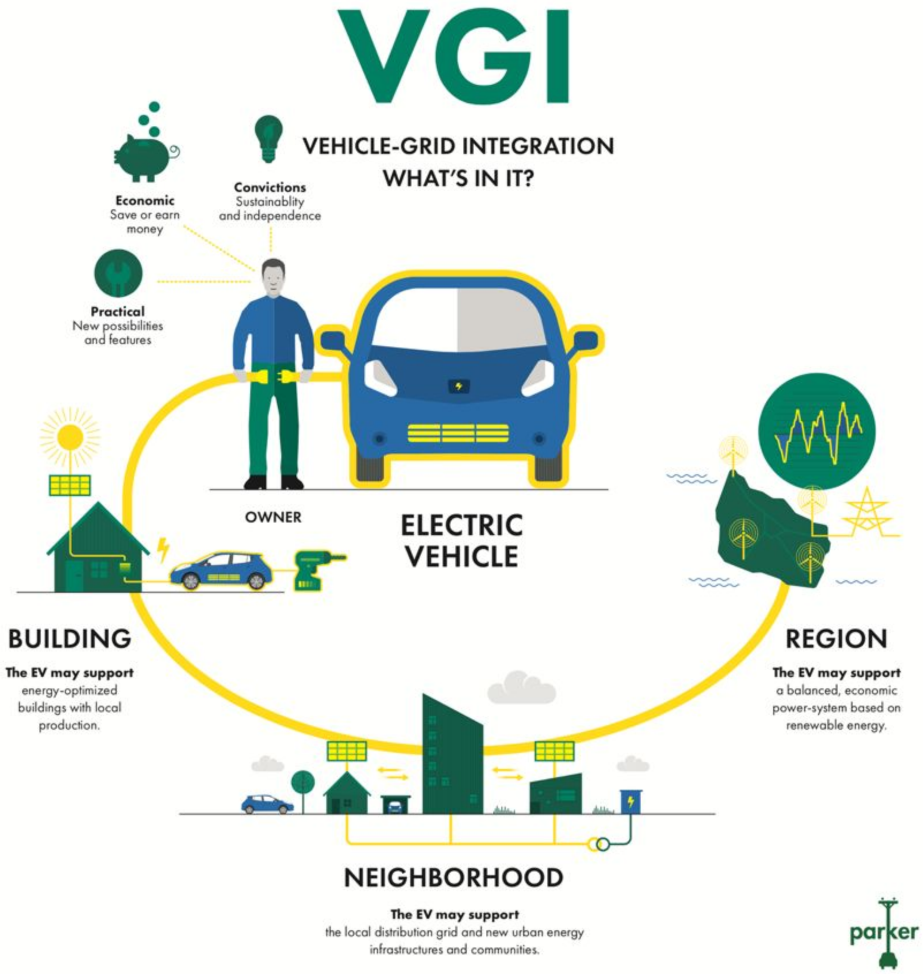

Figure 1 - VGI Overview

The Service Catalog 2.0 is shown in Figure 2.

The domains (Region, Neighborhood , Home) are mapped into Categories (e.g. Ancillary Services) which again are divided into service examples (Frequency containment reserves) and a short description of the service. The required equipment functionality is then described for each Category in form of performance and active/reactive power support. On the far right is shown the owner's incentives for sharing his battery to perform the services.

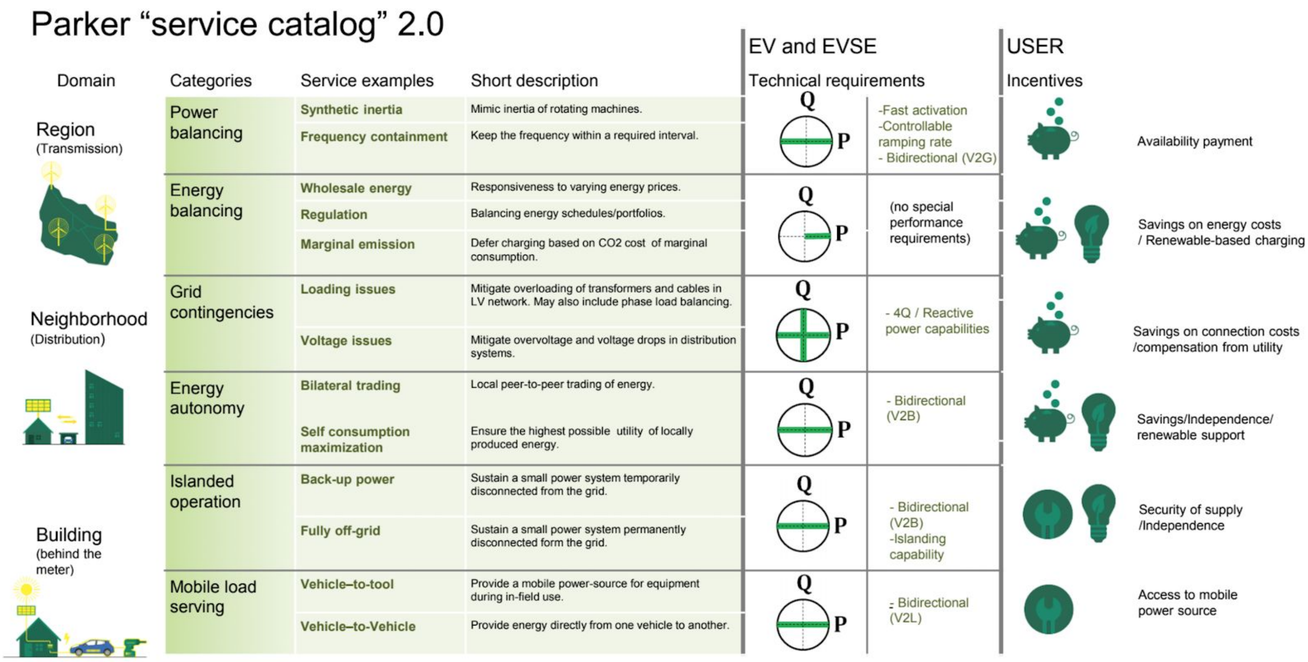

Figure 2 - Parker service catalog 2.0

5.1.2 Test plan

From the Service Catalog 2.0 a representative subset of services were selected based on technical value or novelty. These services were selected for testing in the Reference Configuration. see Figure 3.

The purpose of the test plan was to provide a common framework for all the Parker WPs (Work Packages) as to the sequencing and timing of the service tests.

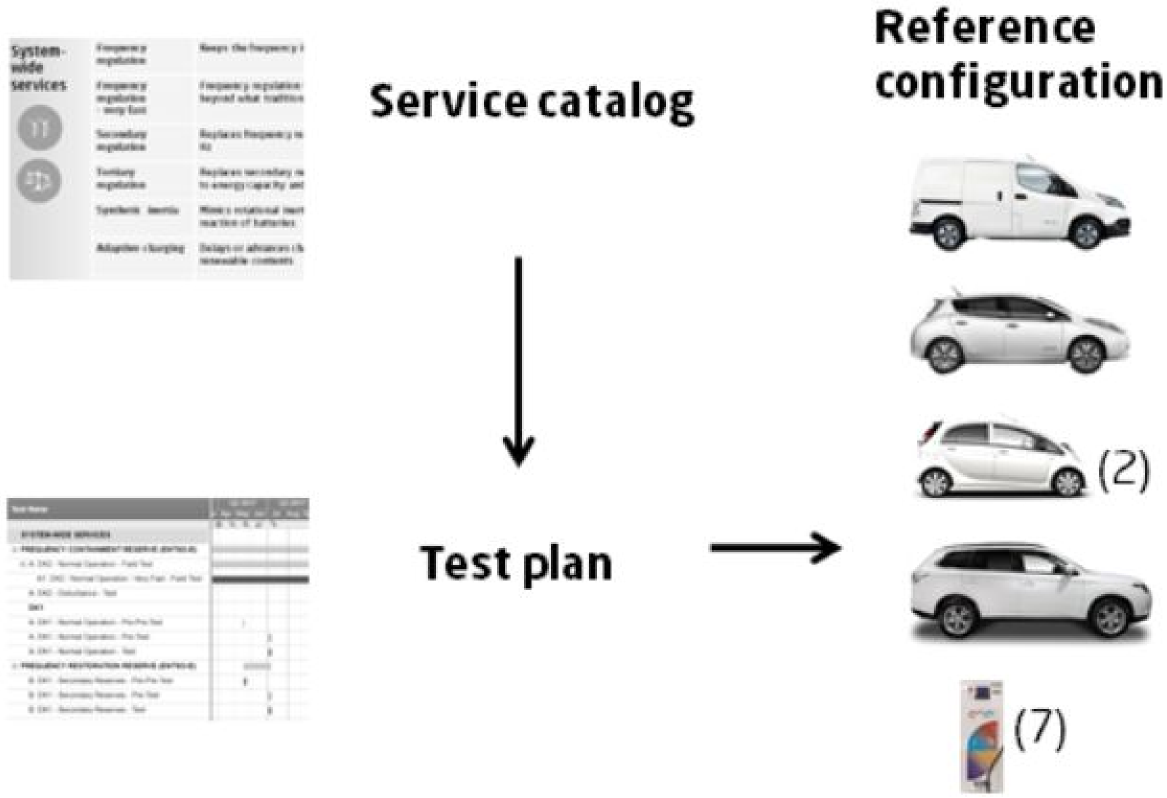

Figure 3 - Overall Test Plan

5.1.3 Service descriptions

In order to better understand the selected services it is important to understand the Danish electric grid. Denmark's electric grid is divided into two separate synchronous areas:

DK1 (West Denmark)
Connected to the European Continental synchronous grid

DK2 (East Denmark inclusive Copenhagen)
Connected to the Nordic synchronous grid.

Since the Parker project was conducted in the DK2 area (DTU campus and Frederiksberg Forsyning) we were only able to test Frequency Regulation live in the DK2 grid.

For test of DK1 services we used recorded signals from the DK1 grid (Frequency, LFC). By testing in both the DK1 and DK2 area we covered the Nordic synchronous region as well as the Continental synchronous region.

The following services were tested:

MEF Marginal Emission Factor - Charging minimizing CO2 emission

An explanation of the Marginal Emission Factors is shown in Figure 4. and in text below-

FCR-N Frequency-controlled normal operation reserve, DK2

FCR-D Frequency-controlled disturbance reserve, DK2

PFR Primary frequency reserve, DK1

aFRR Secondary reserve, DK1 (aFRR)

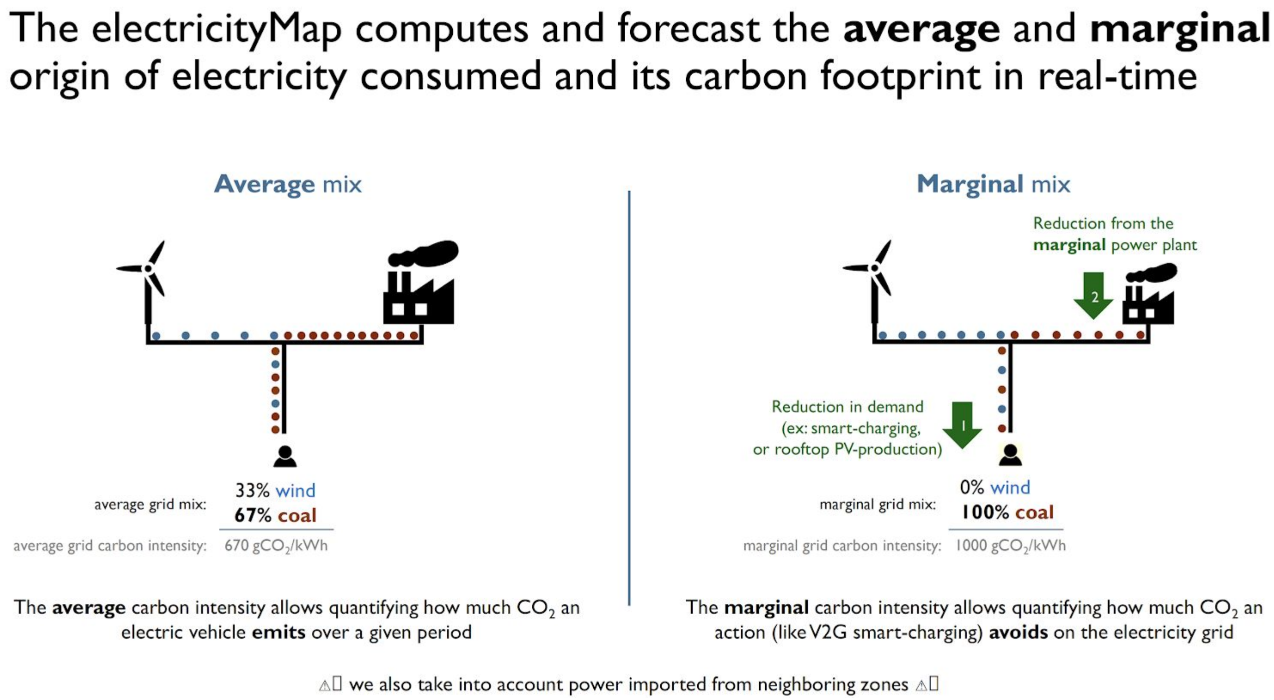

Figure 4 - Marginal Emission Factor

Electrification is seen as an important measure in reducing CO2 emission due to the continuous addition and integration of renewable energy in the power system. Short term, however, a new demand for energy from e.g. the transportation sector, may increase emissions if such demand will necessitate an increased use of peaking power plants which traditionally are based on carbon-intensive fossil fuels.

It should therefore be considered how new demand may be delayed to times where a low-carbon energy surplus is available in order to limit the use of fossil-based peaking power plants.

Managing such consumption may be especially relevant in regions with a high penetration of renewable energy as the CO2 intensity of electricity consumed may be highly variable as a function of the intermittent nature of e.g. wind and solar, but also depending on the production mix of neighboring region which may be used for cross-border imports.

Consuming an additional unit of electricity will not trigger all production units to increase their production proportionally. Typically, systems that can ramp up quickly (such as gas turbines or diesel engines) will be used to supply the additional load.

For this reason, the carbon intensity of that load differs from the carbon intensity of the load already supplied. This service has focused on the marginal emission factor (MEF) of the electricity grid, which represents the additional carbon emissions of each additional unit of electricity consumed.

With sufficient energy production data and advanced forecasts it may be possible to create a model capable of predicting such fluctuations

5.1.4 Test environments

Two different test sites were available in the Parker project.

A. Frederiksberg forsyning site (FF)
The FF site is an actual operational customer site consisting of 10 Nissan e-NV200 EVs and 10 Enel V2G chargers controlled by a Nuvve aggregator providing Frequency Regulation (FCR-N) to the Danish DK2 grid. Since this is an operational customer site it limited the tests we could perform at this site without disturbing the FF business.

The aggregator collected data from the FF operation and recorded the grid frequency on a second by second basis. These recorded data were used to test the Frequency Controlled Disturbance Reserve (FCR-D) with the DTU Reference configuration. The FF configuration is shown in Figure 5.

Figure 5 – Frederiksberg Forsyning Site

B. Parker Reference configuration

The Reference configuration consisted of a dedicated test environment with different brands of bi-directional EVs, Enel V2G chargers, and a dedicated Nuvve aggregator. Most of the services tests were done in this environment either using the actual grid frequency or using canned (recorded) signals to conduct the tests.
The Parker reference configuration was located at DTU Risø Campus. (Table 1 and Figure 6)

Vehicles		
Parker Vehicle ID	**Vehicle Brand/Model**	**Battery size (kWh)**
DTU Leaf	Nissan Leaf	30
DTU Evalia	Nissan Evalia	24
DTU Outlander	Mitsubishi Outlander	12
DTU iOn	PSA iOn	16
DTU iOn2	PSA iOn	16
EVSEs	**Enel V2G Chargers**	**+-10kW**
Freq. Measurement	**DEIF MTR-3**	
Aggregator	**Nuvve GIVe**	**Cloud based**

Table 1 – Parker reference Configuration

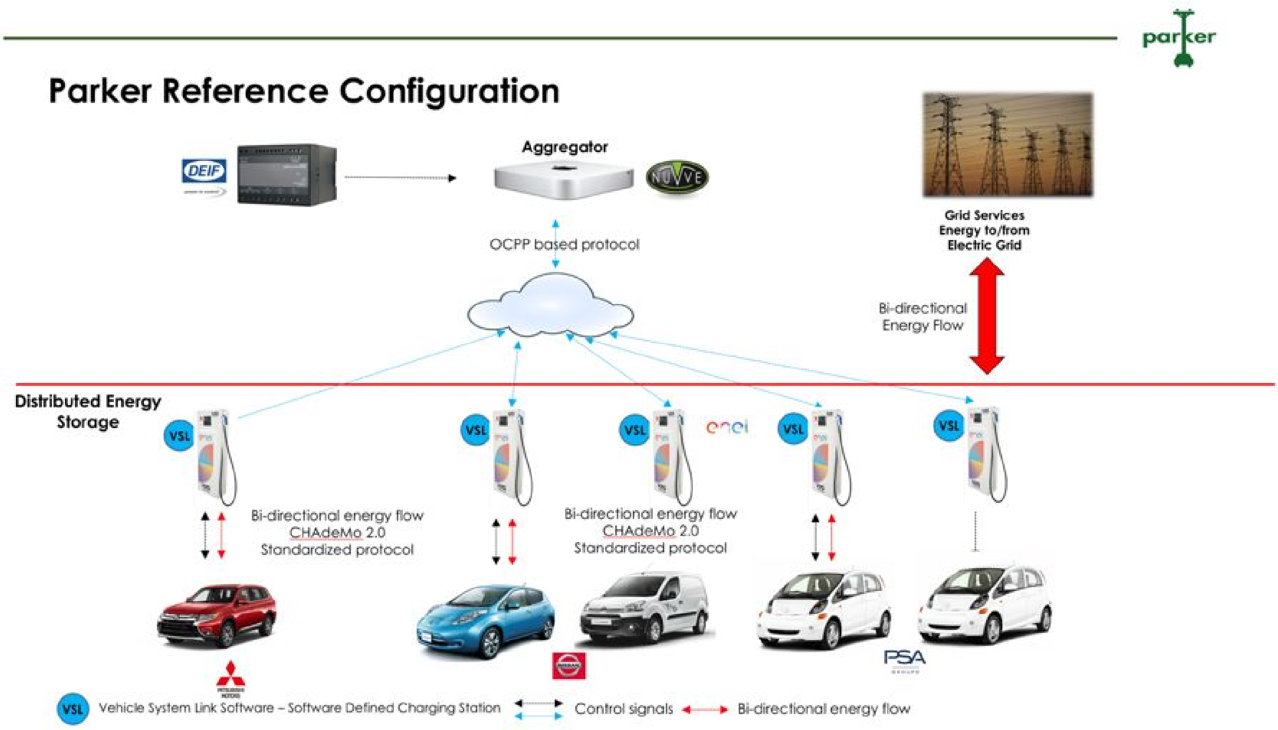

Figure 6 – Parker Reference Configuration

5.2 Demonstration outcomes

5.2.1 Scaling in different dimensions

A goal of the Parker project was to investigate and demonstrate how a fleet of V2G EVs can be scaled to different EV brands - referred to as cross-brand testing. A result of the testing was that it additionally demonstrated that the configuration could be scaled in seven different dimensions.

Figure 7 show how the project set out to scale in seven different dimensions.

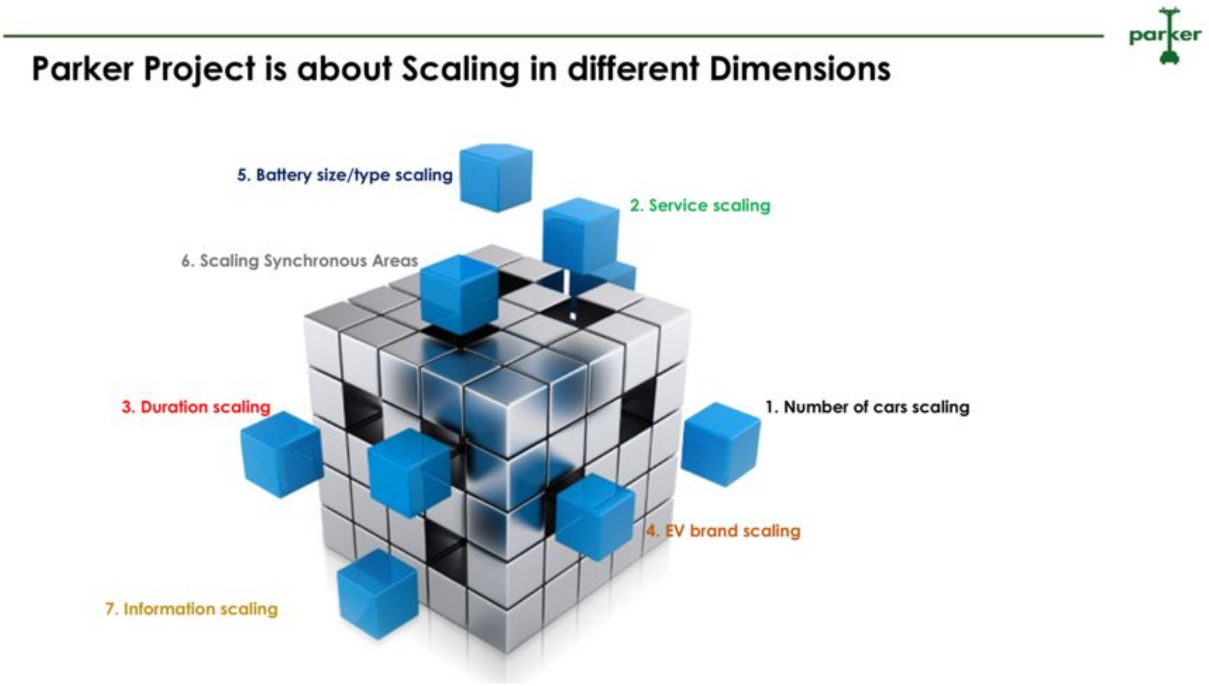

Figure 7 - Scaling in different dimensions

The Nikola project only had 2 EVs/EVSEs available and tests were only performed in the DK2 Nordic synchronous area. In the Parker project we were able to substantially scale in different dimensions. Table 2 shows how we were able to demonstrate the scaling through actual tests.

Project	1.Number of cars	2. Services	3. Duration	4. Car brands	5. Battery sizes	6. Synchronous areas	7. Data volume
Nikola	2	FCR-N DK2	16 hours	Nissan Leaf & Evalia	24 kWh 24 kWh	Nordic grid	MB
Parker	4 10 4-5 4-5 4-5 4	MEF FCR-N DK2 FCR-D DK2 PFR DK1 aFRR LFC DK1 Grid Keys	 360 hours 360 hours	Nissan Leaf and Evalia. Mitsubishi Outlander. PSA iOn	24 kWh 12 kWh 16 kWh 30 kWh	Nordic grid Nordic Grid Nordic Grid Continental grid Continental grid NA	GB

Table 2 - Scaling through actual tests

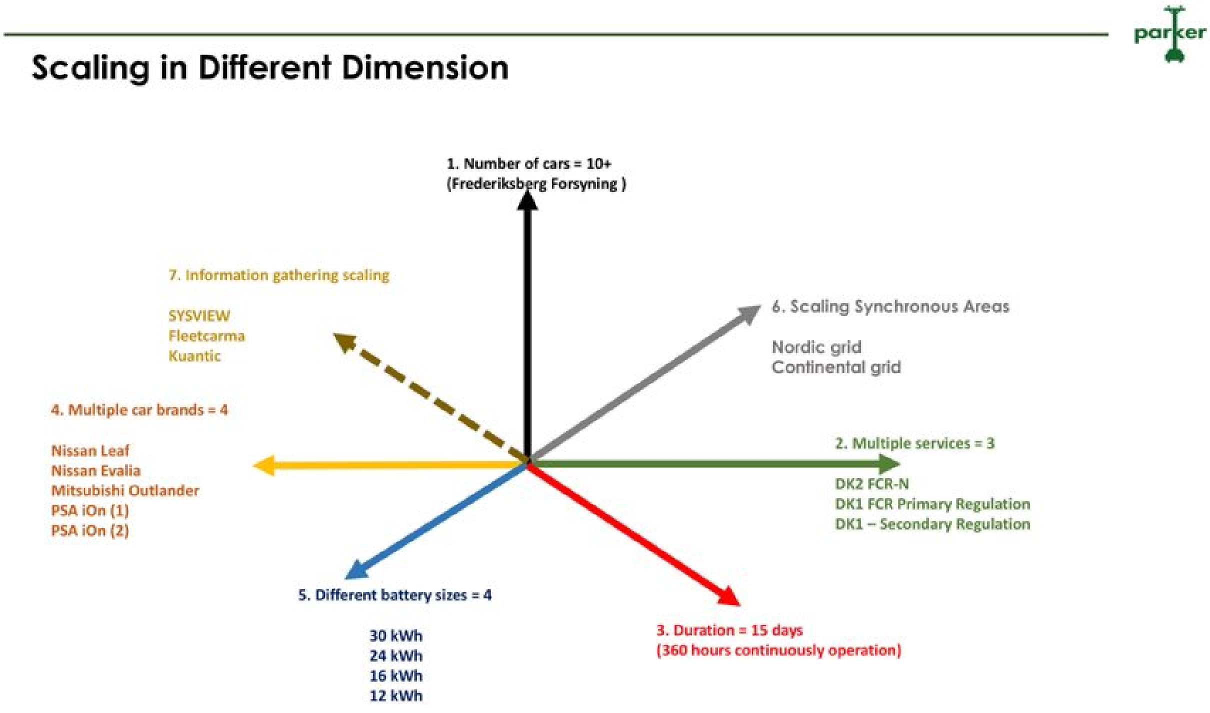

Figure 8 - Actual scaling tests in different dimension

Figure 8 and Table 3 sums up how the tests were scaled in different dimensions.

1	Number of cars
2	Different services
3	Service duration (up to 15 days continuously)
4	Different EV brands and models
5	Different battery sizes
6	Operation in different synchronous areas
7	Collecting GB instead of MB (Nikola Project) of data

Table 3 - Scaling dimensions

5.2.2 Cross-brand test summary

The services were tested with a cross-brand of different vehicles from different manufacturers. This work is described in a Parker paper[6].

The purpose was to test how individual cars respond to a requested power signal from the aggregator. The services were tested with up to 4 cars from the reference configuration as shown in Table 4.

SERVICE	Outlander	Evalia	Leaf	iOn
MEF	X	X	X	X
FCR-N DK2	X		X	
PFR DK1	X	X	X	X
aFRR LFC DK1	X	X	X	X
FCR-D DK2	X			

Table 4 - Cross-brand testing different services

FCR-N DK2, PFR DK1, aFRR DK1,MEF Services

In the following pages the individual car's response to the requested power for each service is illustrated. The requested power signal is shown with the thick black curve and the individual EV's responses in different colors. In general the individual car brands follow the requested power signal well for the FCR-N DK2 service. For the DK1 services (Figure 9, Figure 10, Figure 11 and Figure 12) there are some differences between the requested power and the car responses. It is not clear why these differences occur; it may be a combination of a dynamic POP (section 5.3.2) or high or low SOC of the cars. This remains to be investigated in subsequent projects. As for each individual EV response capabilities to a controlled signal, see Chapter 6. The provision of FCR services is described in the Parker papers[7], [8].

A. Marginal Emission Factor (MEF)

The MEF methodology described in section 5.1.3 results in a timeframe where charging the EV results in the smallest CO2 increase. This shown in Figure 9.

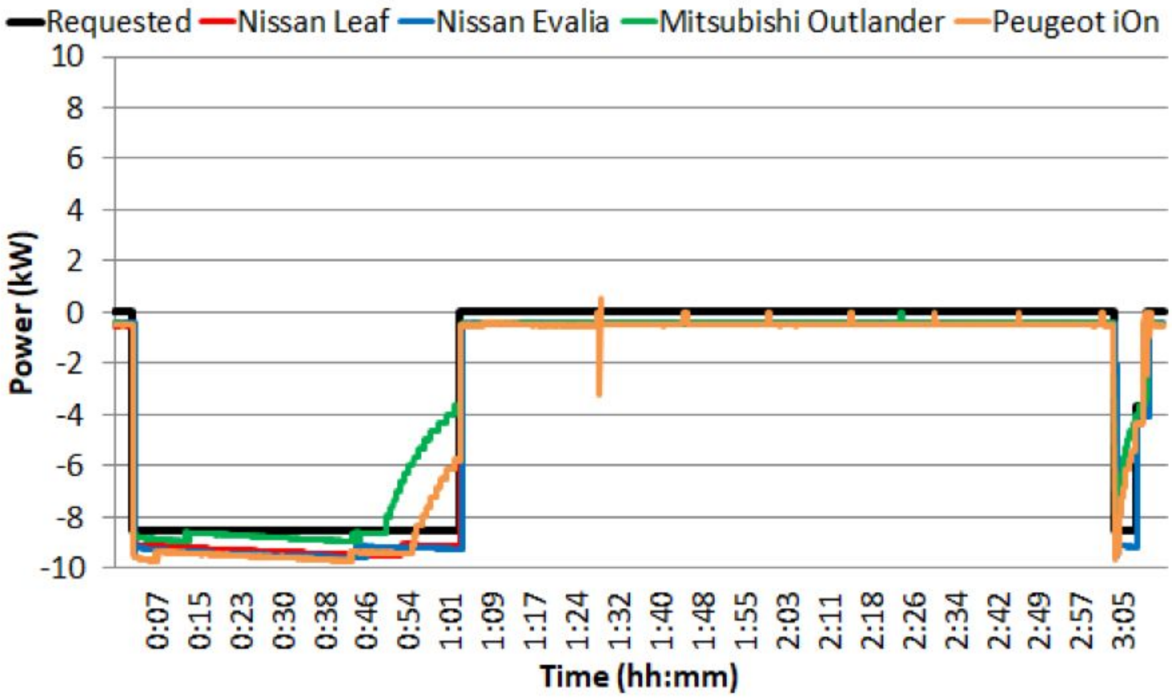

Figure 9 - MEF Test

B. FCR-N DK2

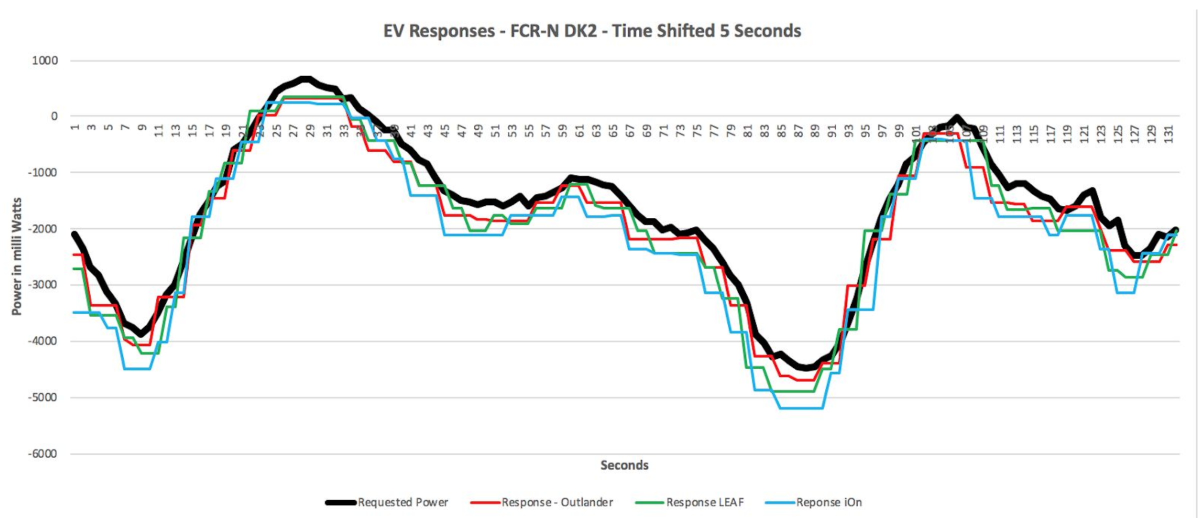

Figure 10 - FCR-N DK2 Test

C. PFR DK1

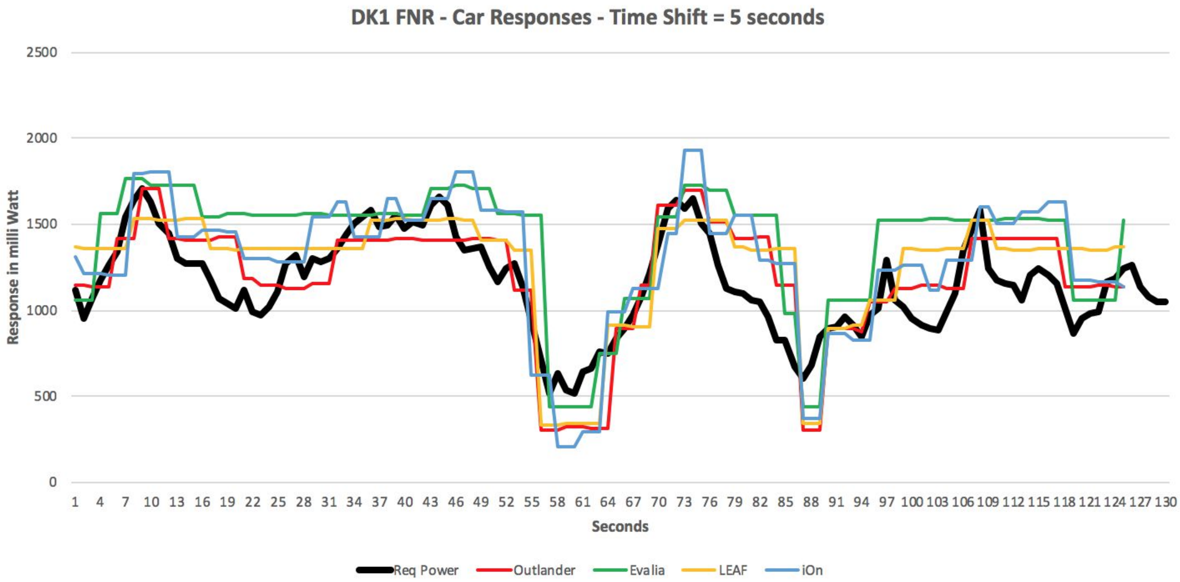

Figure 11 - FCR DK1 Test

D. aFRR DK1

This service includes some net energy being exchanged.

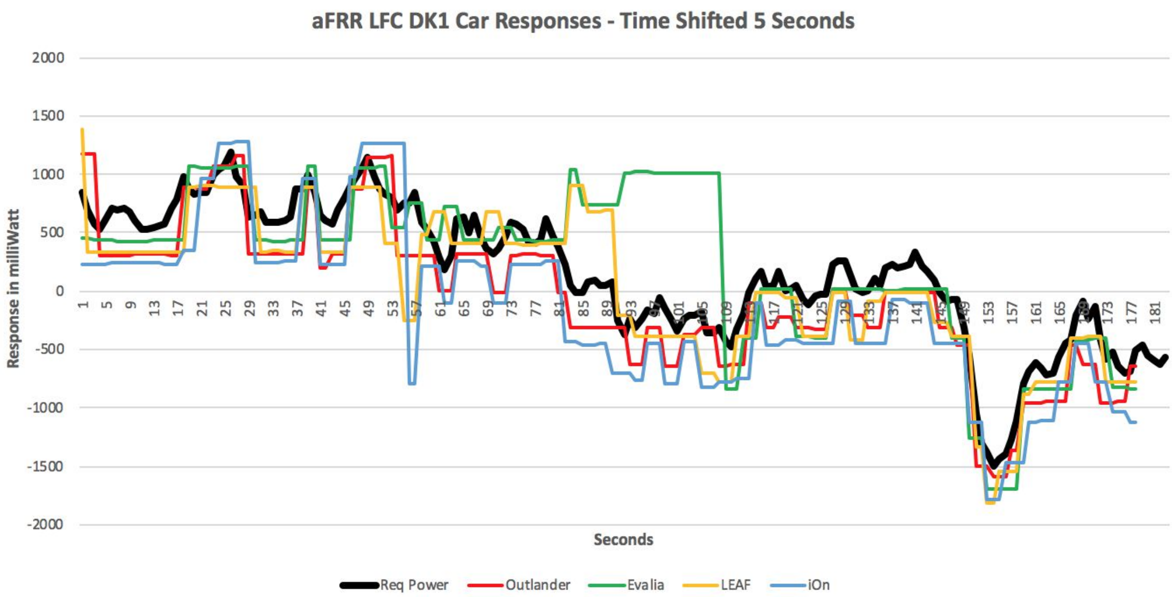

Figure 12 - aFRR DK1 Test

FCR-D DK2 Service

The FCR-D DK2 services were tested using a canned frequency recorded from the DK2 grid. The frequency was measured over a period of 452 days (39 million samples). The longest time spent in the frequency interval between 49.900 Hz and 49.500 Hz was identified (998 seconds) and this canned signal was used to test the service.

Only one charger was working during this test. The EV response (Outlander) can be seen in Figure 13 and the detailed analysis can be seen in Figure 14. The energy content is quite low with 0.4 kWh per car for the 998 seconds interval.

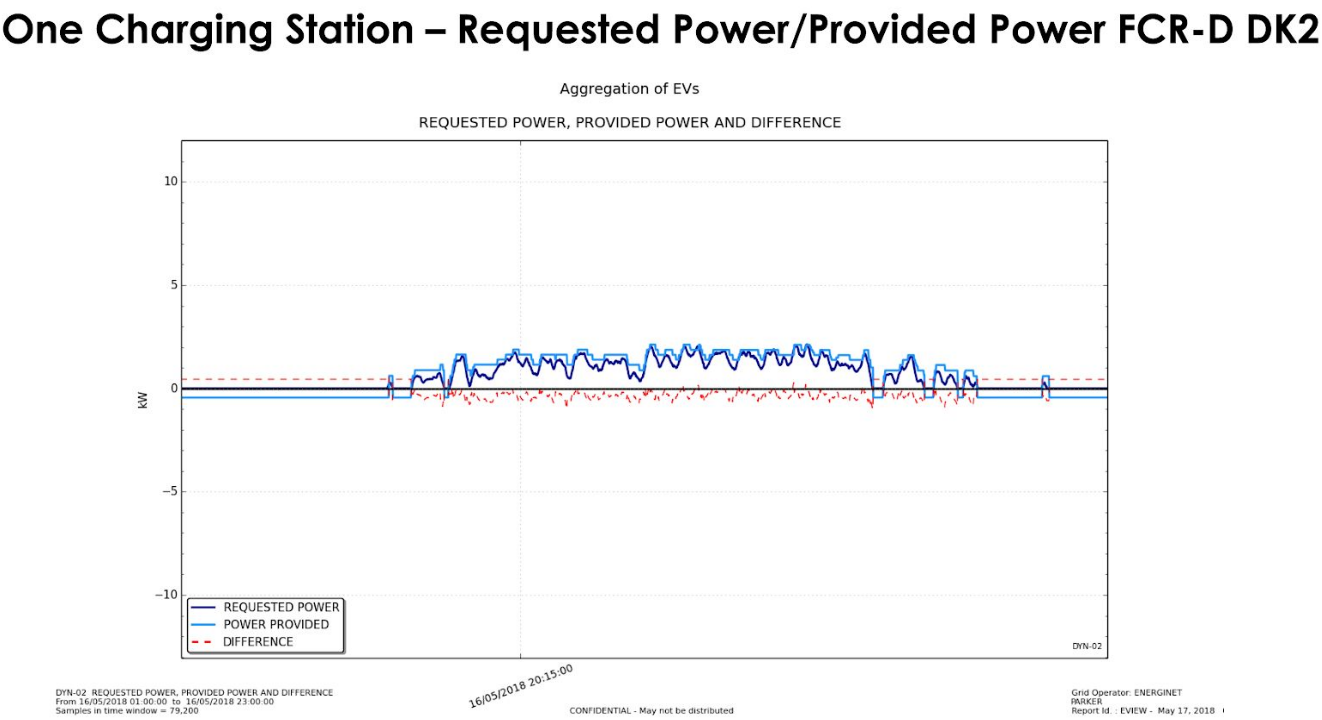

Figure 13 - FCR-D DK2 Outlander EV Response

FCR-D Frequency Analysis – DK2

01/10/2016 – 31/12/2017

ANALYSIS PERIOD

Analysis Period Start =	01/10/2016 00:00:00
Analysis Period End =	31/12/2017 00:00:00
Analysis length =	452 Days
Total Samples =	39,101,841

FREQUENCY ANALYSIS

Frequency >= 50.100	617,288
Frequency <= 49.900	518,546
Frequency >= 50.010	17,826,341
Frequency <= 49.990	17,356,803

FDR ANALYSIS

Total period seconds =	39,101,841	
Total FDR seconds =	407,937	
Percent of total time =	1.04327 %	
Total FDR events =	22,063	
FDR events per hour =	2.0	
Total FDR energy =	47.47465 kWh	
FDR energy per event =	0.00215 kWh	
Average FDR event duration =	18.0 seconds	
Longest FDR event duration =	998.0 seconds	From 08-13-2017 19:05:06 To 08-13-2017 19:21:43
Longest FDR event energy =	0.4 kWh	

Figure 14 - FCR-D DK2 analysis

5.2.3 Testing special conditions

In real life conditions errors or special conditions are bound to occur.

Below are listed several conditions which may have various consequences for the operation:

A. **Reliability of system**

Single point of failures and their consequences (system resilience):

- Failure of Frequency Measurement Equipment (FME) (or lack of external signals)
- Failure of communication link between FME and aggregator
- Failure of aggregator
- Failure of communication link between aggregator and charging stations
- Failure of a charging station to respond
- Failure of an EV to respond

B. Normal events

- EV drives away

C. Security

- How secure is the system against hacking?
- Threat analysis of system and all components
- Stability

It was considered outside the scope of Parker to address the above-mentioned conditions.

5.2.4 Energy patterns

Different services have different energy profiles. Frequency Regulation in DK2 is the most challenging, since the frequency varies a lot and requires a high energy flow to fulfill requirements.

Figure 15 shows the normalized energy flow for three different synchronous areas for the Frequency Regulation service (Nordic set to 100%):

- Nordic synchronous area (DK2)
- UK synchronous area
- Continental synchronous area (DK1)

As seen in Figure 15 the energy content is by far the highest for the Nordic area (+-100 mHz regulation interval, no dead band, highly variable frequency) and lowest for the Continental area (+-200 mHz regulation interval, +-20 mHz dead band, highly stable frequency).

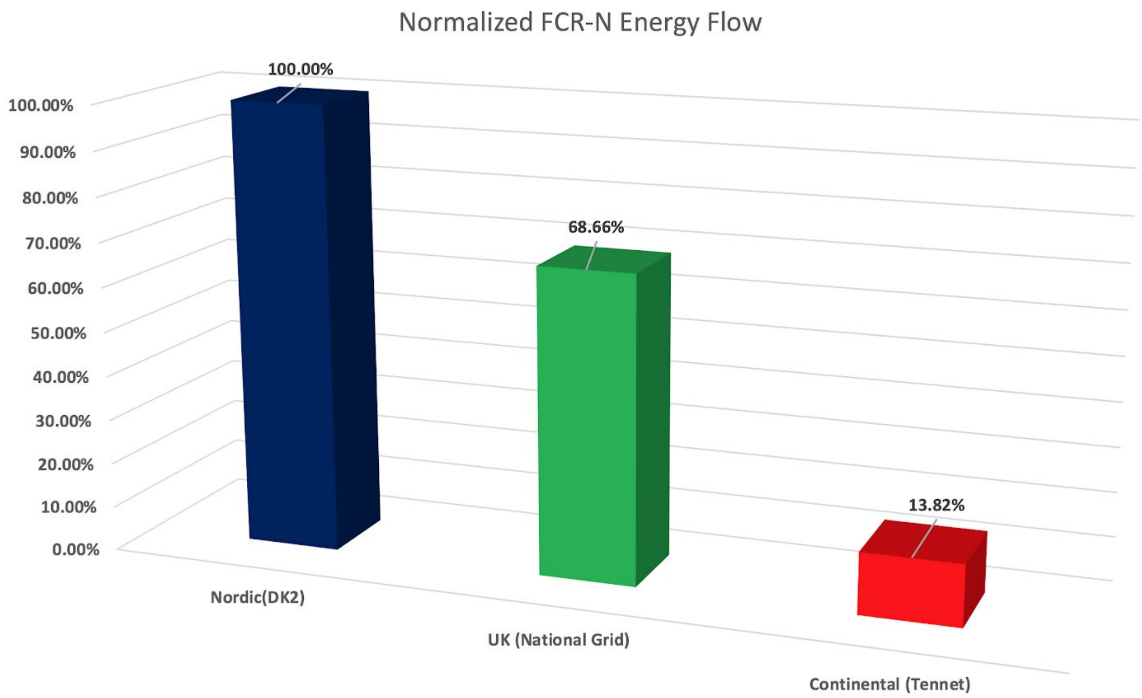

Figure 15 - Normalized energy flow – FCR-N in different synchronous areas

The emergence of higher capacity EV batteries will make the relative energy flow/battery size smaller.

Other services will have different energy flow profiles depending on how often they are called upon, the power capacity, the energy flow and the duration of the activation. Figure 16 shows an illustrative example of the potential energy flow for different services. In the figure the benchmark is Vehicle-to-Home service (in red) activated every day for a total daily energy flow of 10 kWh. As seen in the figure the worst-case scenario in DK2 FCR-N. A comprehensive analysis of different frequency regulation strategies and their energy patterns is done in [9].

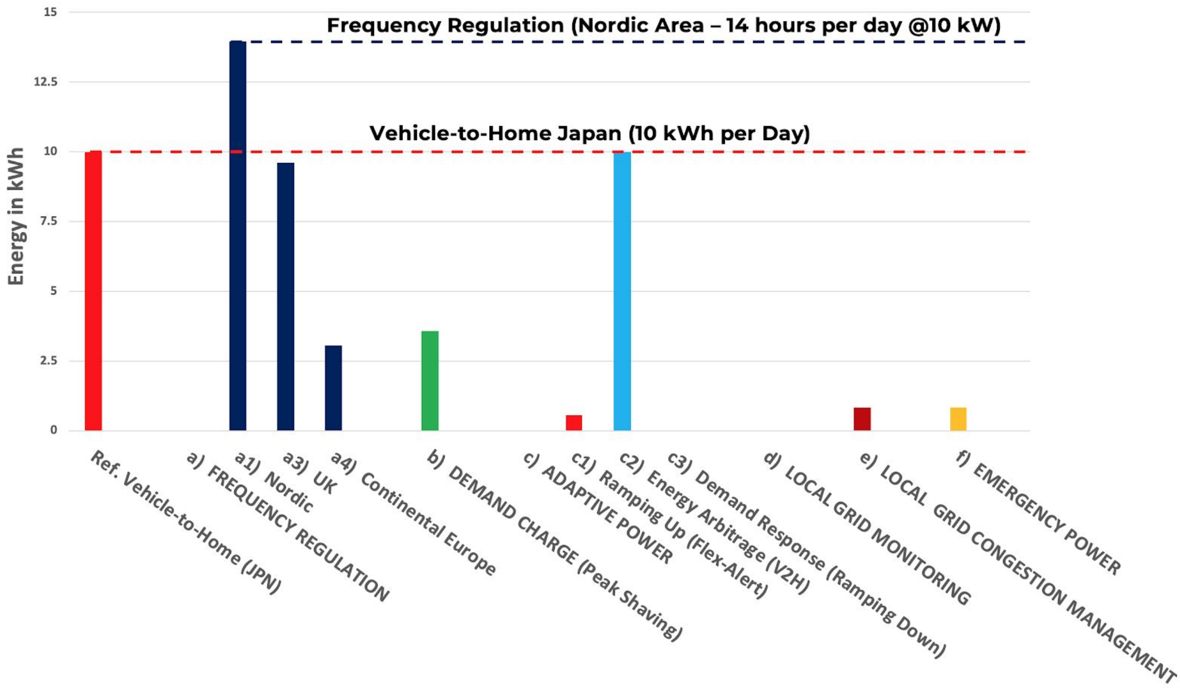

Figure 16 - Example of service energy flow

5.3 Frederiksberg Forsyning 1 - Introduction, FCR provision and EV usage.

5.3.1 Short case description

The field study was performed at the site of Frederiksberg Forsyning (FF). FF is a utility company that provides the services:

- Domestic gas
- Tap water
- District heating
- Sewage

It serves approximately 100,000 customers in a part of greater Copenhagen.
In 2016 Frederiksberg Forsyning took delivery of 10 Nissan eNV-200 standard electric vehicles equipped within 24kWh batteries as well as 10 Enel V2G charging stations rated at 10kW (up and down). The vehicles are used for serving the customers, driving out in the morning and returning to base in the afternoon. The cars are not used in the weekends.

The participants in the V2G operation at Frederiksberg Forsyning (FF) were Nissan, Enel and NUVVE and FF. The FF commercial pilot is connected to Parker through its partners and the sharing of data. The pilot is described in the parker paper[10].

The technology used for the pilot activities was based on standard equipment with no additional technical modifications made such as Nissan eNV-200 electric vehicles and ENEL V2G charging stations.
The aggregation was made through Nuvve's Aggregation Platform which was also used in the NIKOLA project at DTU to demonstrate the capabilities of V2G aggregation for FCR-N product delivery.

Figure 17 shows the architecture for FCR-N provision in DK2.

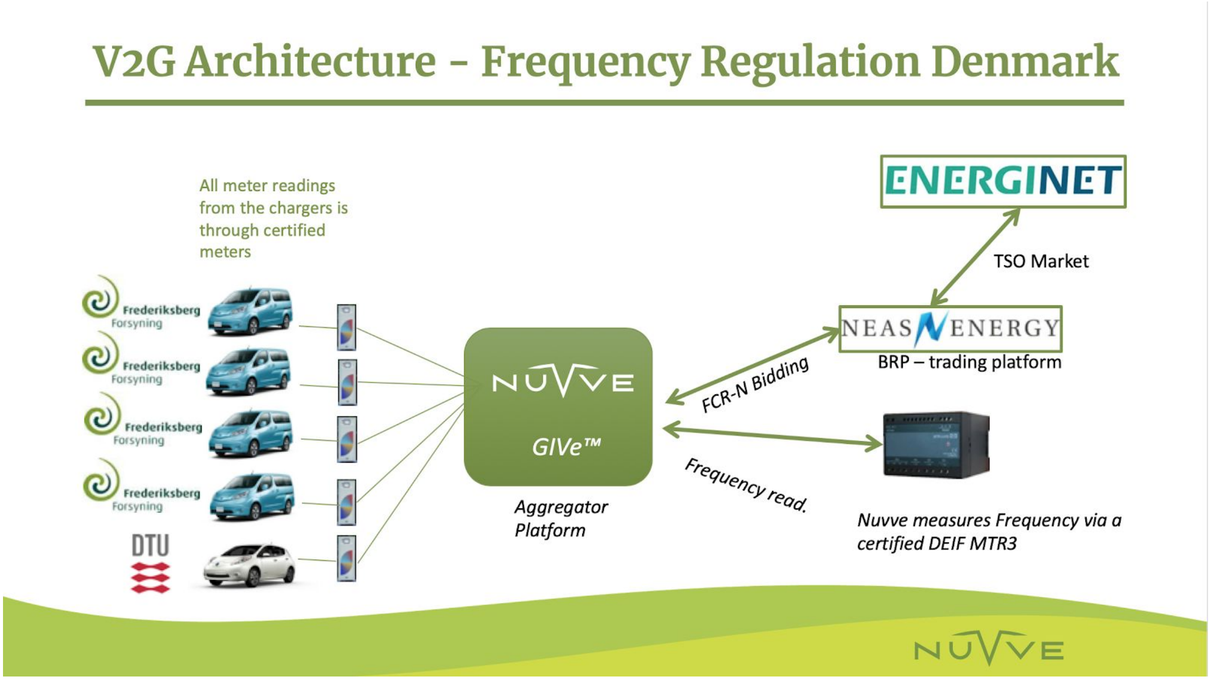

Figure 17 - Project V2G architecture for FCR-N in DK2

The aggregator receives dynamic capacity information from the distributed storage resources, and uses that capacity, plus operator experience, to determine how many kW or MW to bid. At the simple level, when cars unplug, capacity decreases, when cars plug in, capacity increases. Capacity will also increase or decrease depending on planned trips, state of charge, temperature and other variables. As one example, if the battery becomes fully charged, regulation up capacity stays the same but regulation down capacity drops to zero.

On a one second basis, the aggregator receives frequency signals from the DEIF MTR-3 device, and uses an optimization routine to dispatch a combination of EVs, at differing power rates. Because the aggregator keeps its capacity estimate updated continuously, the combined set of cars and any other resources will provide the requested kW total, by the time requirements of the service. The MTR-3 specifications are shown in the Appendix "MTR3 data sheet".

5.3.2 Field test results

Variances over the year

The FF operation collected data for a full calendar year. These data were analyzed in order to investigate if there were seasonal variances in the frequency pattern or the availability payments.

The test data were collected for 4 separate weeks during 2017 as shown below:

- Feb 06-13, 2017
- May 22-29, 2017
- Aug 07-14, 2017
- Nov 06-13, 2017

The frequency average for 2 of the weeks are shown in Figure 18 and Figure 19. As seen there are only minor variances in the frequency over the year. The frequency mean varies between 50.01 and 50.02 Hz and the variance is 0.02 Hz for all 4 weeks.

However, the difference in FCR payments for the 4 weeks were substantial and are shown in section 5.5.2.

Frequency – Feb 06-13, 2017

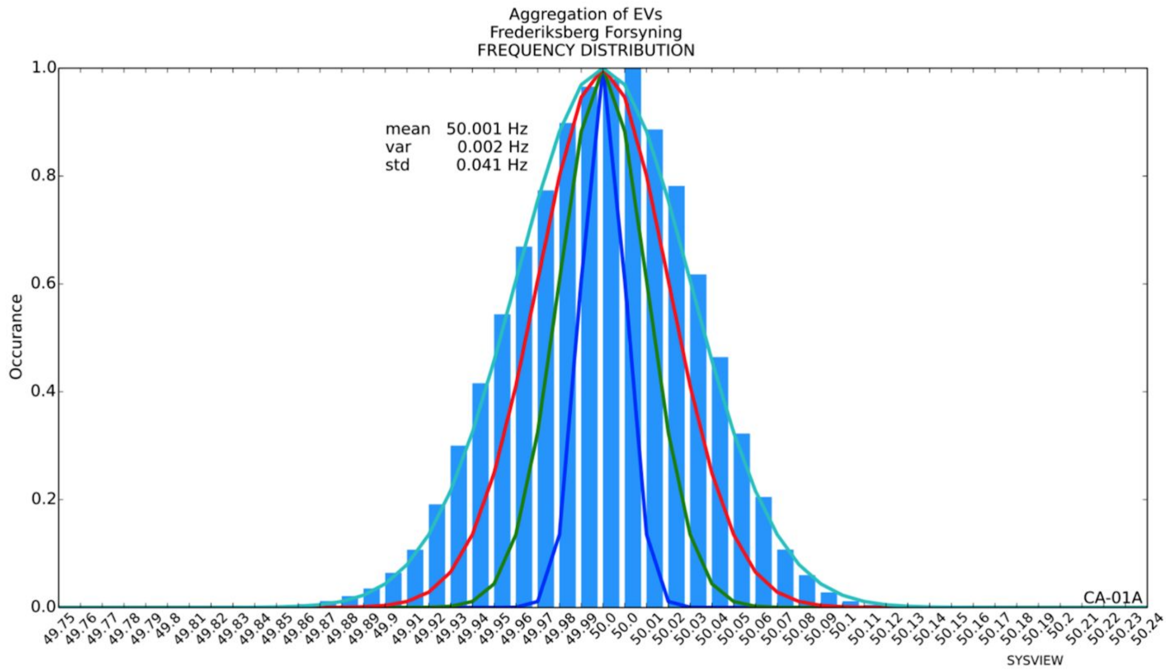

Figure 18 - Frequency february

Frequency – Nov 06-13, 2017

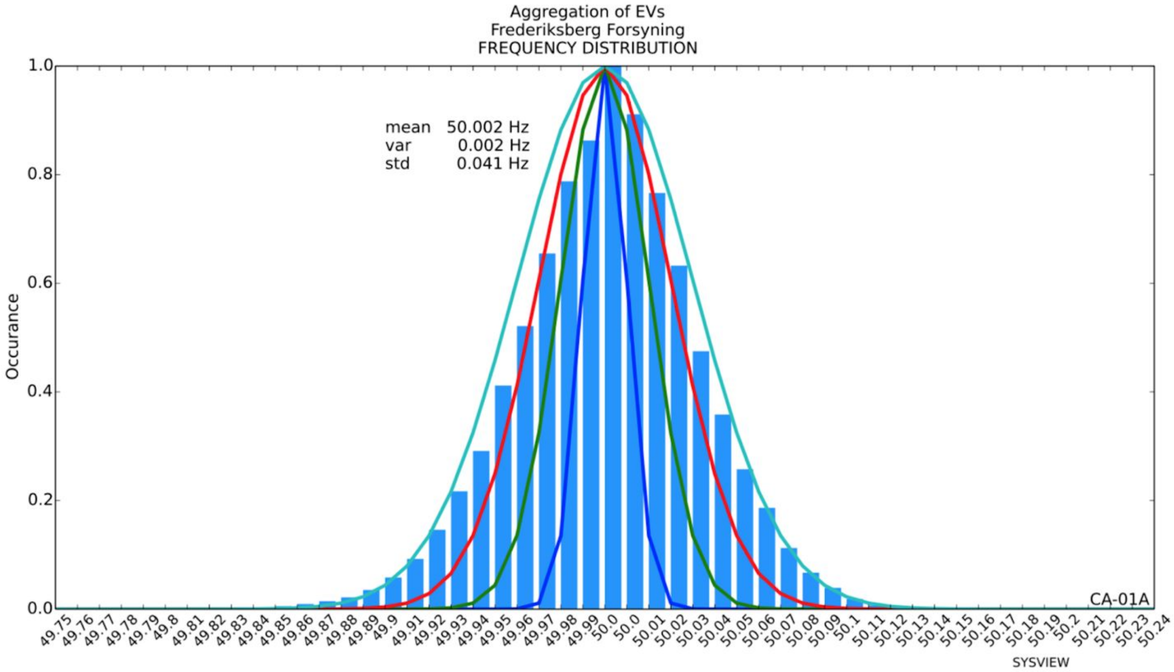

Figure 19 - Frequency november

Verification of Services

The verification of the tested service was done using a dynamic test and a static test to show the fidelity of the delivered service. The following graph shows this.
Figure 20 shows a 6 seconds shifted dynamic response (dark blue) to the frequency changes (light blue) and the available capacity up and down (red dashed line) and shows that aggregated EVs follow the frequency inversely proportional with high fidelity.

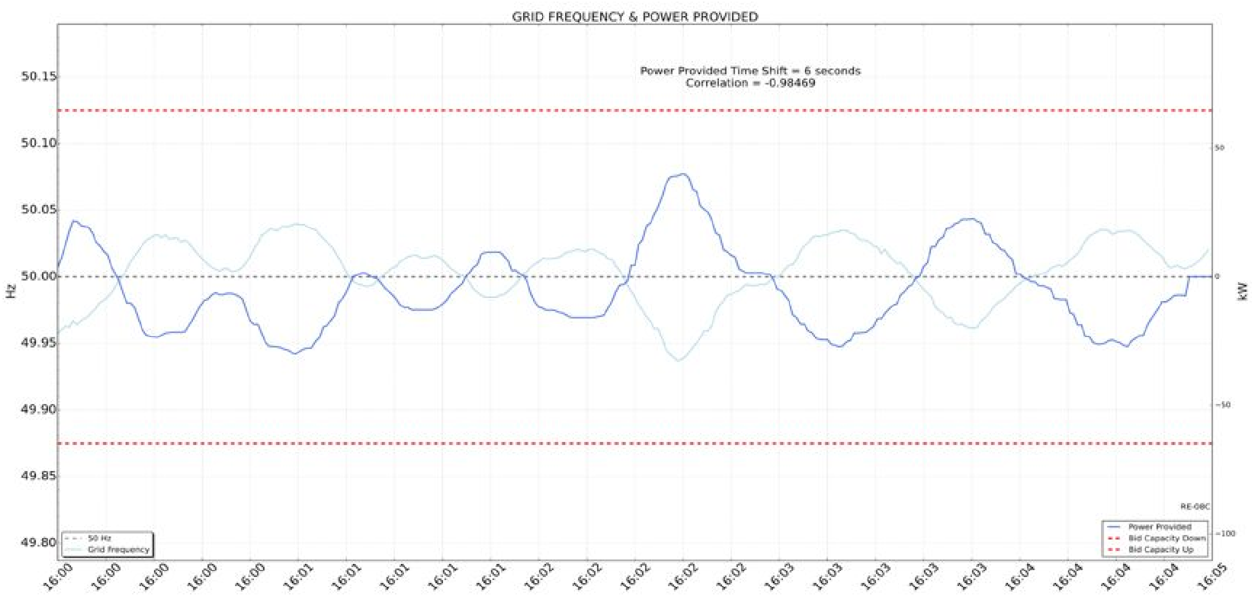

Figure 20 - Dynamic test - frequency and response mapped against time (5 min)

The static response of the system over a 14 hours period is shown in Figure 21. The frequency is mapped against the provided power (green dots) and the straight blue line indicates an ideal response - again high fidelity over time.

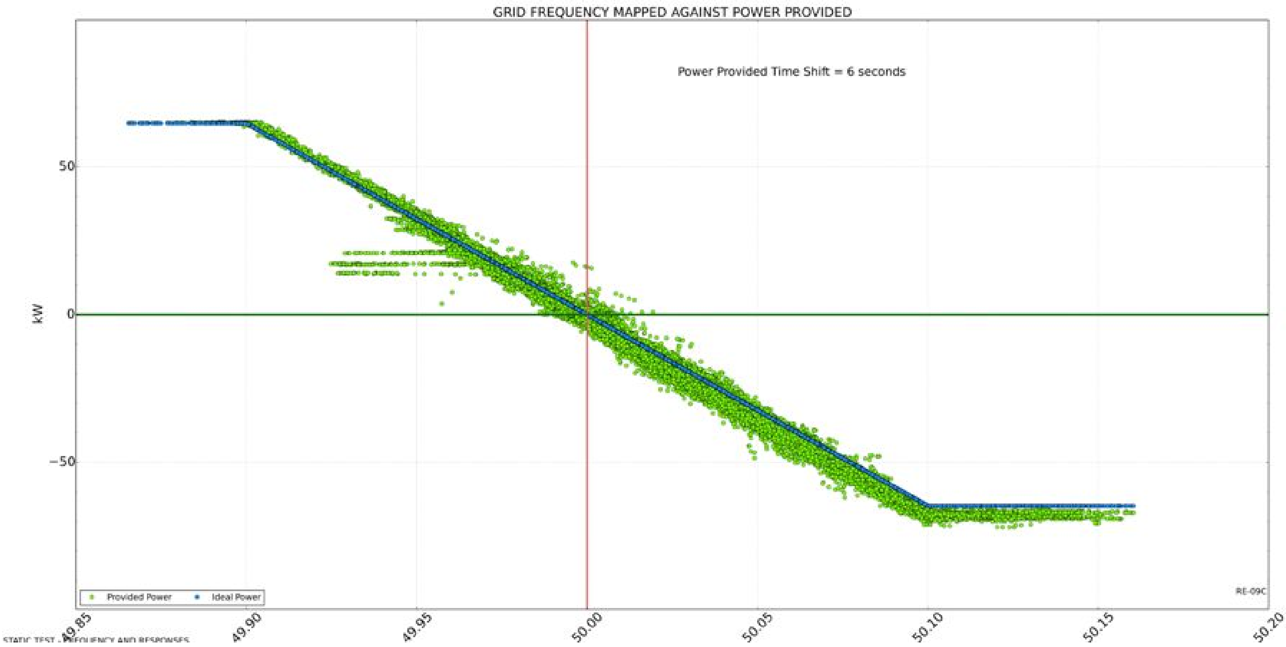

Figure 21 - Frequency vs power provided 14 hours

The response time of the aggregated EVs is shown in Figure 22. The provided power (light green) is shifted 1 second at a time until the correlation with the requested power (dodger blue) reaches its maximum; this yields the system response time. In this case the response time was 6 seconds The magenta curve indicates the difference between the requested power and the provided power.

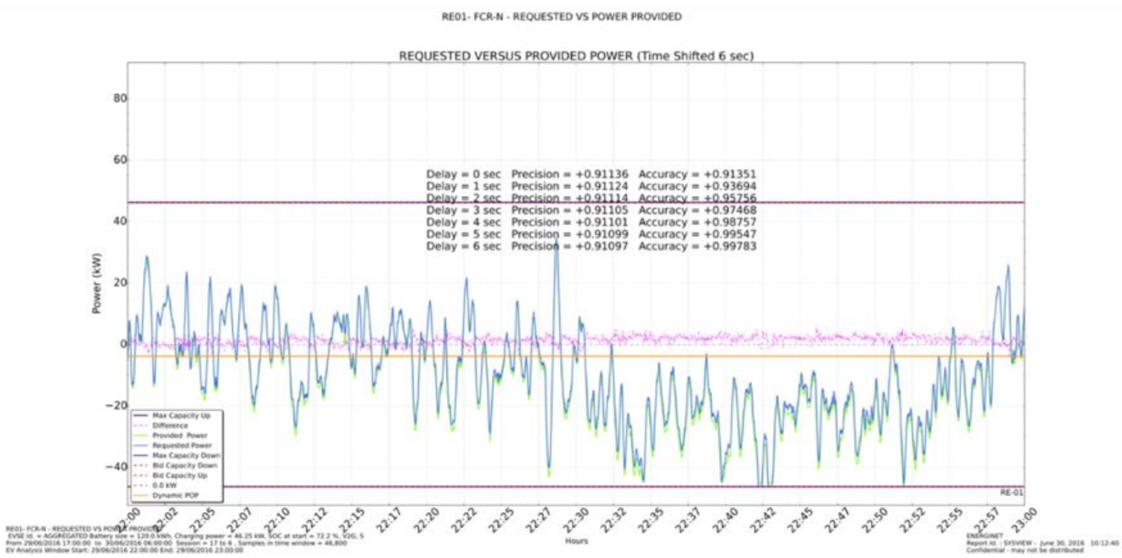

Figure 22 - System response delay - 6 seconds optimal correlation

EV batteries are by nature limited in capacity. They can only be charged until they are full or discharged until they are empty. This is in contrast to traditional power plants which can be operated at full capacity by shoveling more fuel into the plant. As long as the frequency is “balanced” over a certain time e.g. one hour, the battery will retain its SOC and can participate in the service.

In the Nordic synchronous area occurrences of over or under frequency periods do occur for longer periods. For example the frequency can be dominantly greater than 50 Hz over many hours. This poses a problem for the EV battery since it will eventually fill up. The mechanism to handle these situations are to bid conservatively and use a mechanism called dynamic Preferred Operating Point (POP).

The Nordic grid frequency shows long periods of over or under frequency (> 50 Hz or < 50 Hz). Figure 23 shows that in 2017 there were 4 periods where the frequency was high for 9 consecutive hours and 2 periods where it was low for 9 consecutive hours.

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[1]The dynamic POP mechanism is proprietary to Nuvve and is therefore not described further.

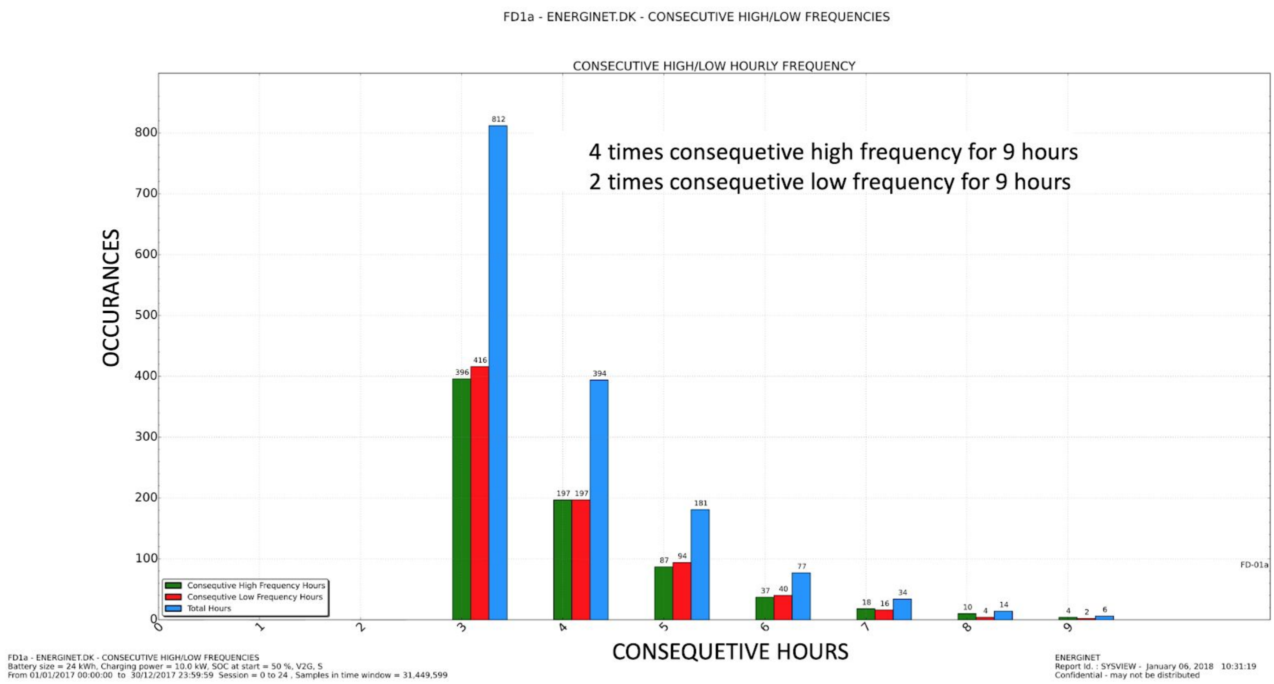


Figure 23 - Consecutive periods of over or under frequency

In order to cope with the consecutive periods of over/under frequency two methods are employed.

First the bid will be conservatively submitted to ensure that there is a reserve capacity available to fulfill the bid. This is shown in Figure 24 with the cyan color indicating the static overcapacity reserved.

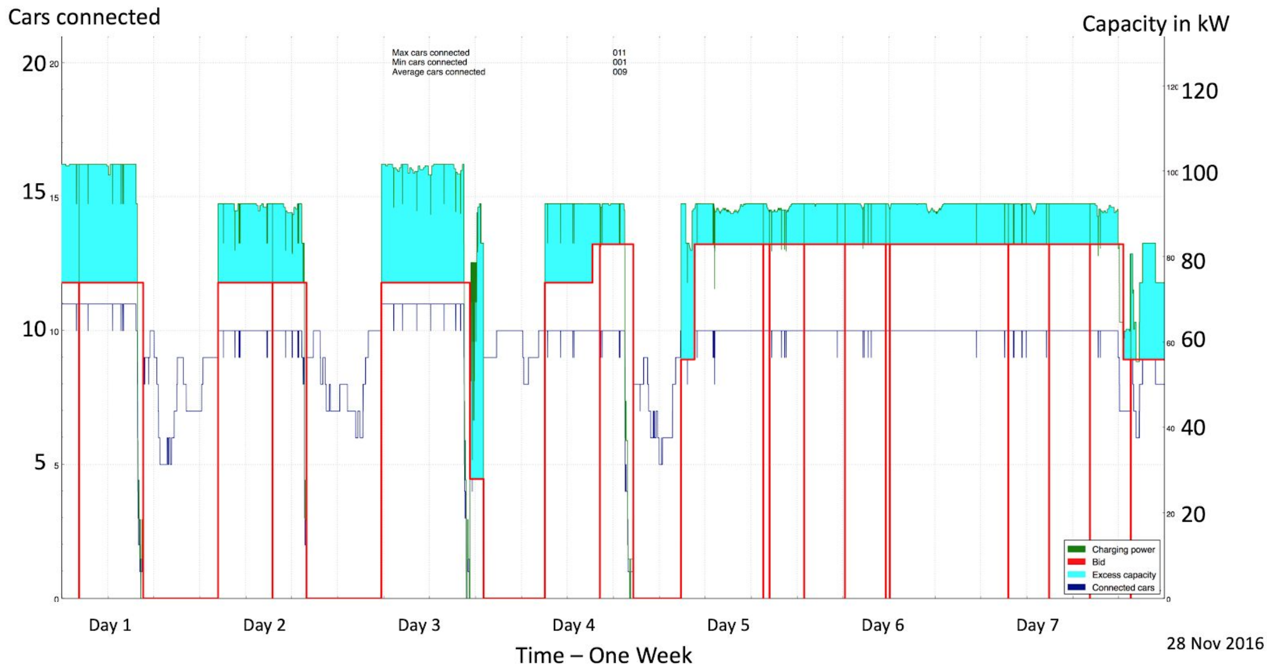


Figure 24 - Reserved capacity

Secondly, when power plants provide balancing services, they typically run below capacity, and adjust generation up and down from that level. This partial operation level is sometimes called "preferred operating point" or POP. For a storage resource, power can be either positive or negative, so theoretically the resource could sit at zero power flow in and out. In practice, two factors will shift the preferred operating point away from zero. Here we will consider power flow into the car as negative sign (e.g. -10 kW), and V2G power flow to the grid as positive. This is consistent with most TSO data systems, which treat power plants as the normal resource as positive for generation. (Note: Power plants can go negative as well, during maintenance, if service power is on the same meter as generation).

First, for the EV driving function, there will need to be some charging overall during the 24 hours. To balance this, the POP could be a small, negative value, resulting in some charging over long time periods, despite providing balancing over short time periods.

Second, TSOs differ in whether, and over what intervals, they balance up and down regulation. For example PJM[1] is required by FERC regulations to balance the energy (kWh) of up and down-regulation every 15 minutes, although the rule can also be interpreted as requiring balancing over every full hour. In either case, with this balancing of up and down requests, there is minimal need to change POP dynamically. By contrast, requests for FCR-N are not required to balance over a similar time period, and may run off balance for many hours, primarily up or primarily down, respectively depleting or filling the battery. When this happens, the aggregator needs to somehow

[1] PJM Interconnection LLC (PJM) is a regional transmission organization (RTO) in the United States. It is part of the Eastern Interconnection grid operating an electric transmission system serving all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and the District of Columbia.

recharge, or discharge in order to restore the SOC so both services can be performed again. This can be done by going off-line and just charging (or discharging), then reconnecting, and continuing to provide service. One problem with disconnecting from signal in order to charge/discharge is that the resource is not only off-line during that period and cannot provide quick response if needed, but furthermore, the resource is likely to be compensating for recent imbalance and thus providing the opposite of what the grid needs.

A better solution, is the idea of dynamic POP. The Nuvve aggregator can automatically adjust the POP to continue providing grid services, and also to compensate for any needed adjustments due to being asked to provide continuous up or continuous down service. POP adjustments are logged and can be reviewed by the TSO if there are any questions. Note that POP adjustments away from zero for a storage resource will almost always lead to a reduction in capacity, thus the aggregator is automatically motivated to keep the POP close to zero.

Another solution, which is being pursued by Energinet, is to require the service to be performed in 15 minutes intervals followed by a pause of 15 minutes to regenerate the battery.

5.3.3 User patterns

In order to reliably support grid services, it is important to be accurately aware of the user's need for transportation as well as his/her plug-in patterns. This section describes how data collected at Frederiksberg Forsyning (FF) have been analysed and describe how data analysis may allow the EV to be optimized as an asset without introducing any adverse effects on the driving patterns of the user. The section is based on the work described in a paper developed through Parker [11].

Before analysing data from Frederiksberg Forsyning the project defines a "user profile" which includes the parameters describing a user's driving requirements. The most important parameters are the energy deadline and target i.e. how much energy is needed in the battery **(kWh)** at what time **(HH:MM)**. These parameters are illustrated in Figure 25.

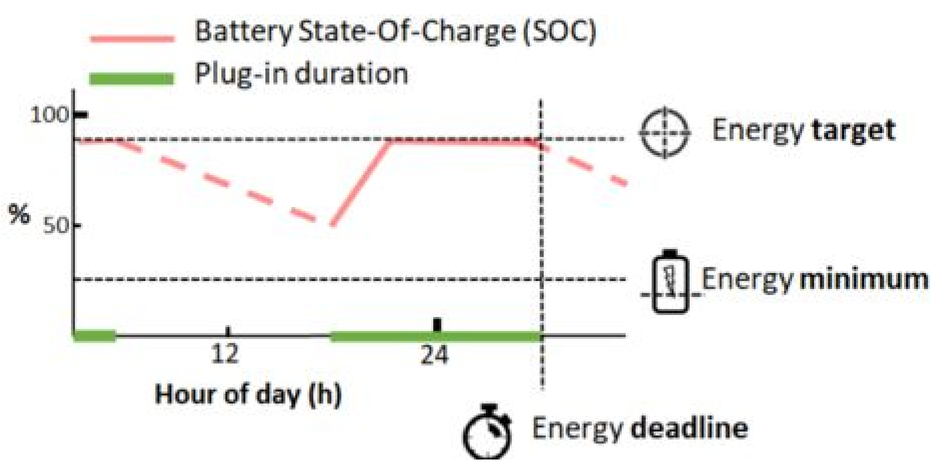


Figure 25 - Energy target and deadline

These parameters have to be fairly predictable for the periods in which the EVs are included in grid services.

Based on the above profile the study moved on to work on the data recorded at FF. Data describing plug-in behavior and energy use was recorded through the 10 Enel DC V2G chargers and saved in an online data repository. The data consist of 1-second measurements for a total of 480 days.

Next, the project carried out an exploratory analysis of the data - aimed at understanding driving needs and energy use. Each charger is used by one specific car and is numbered FF01..FF010.

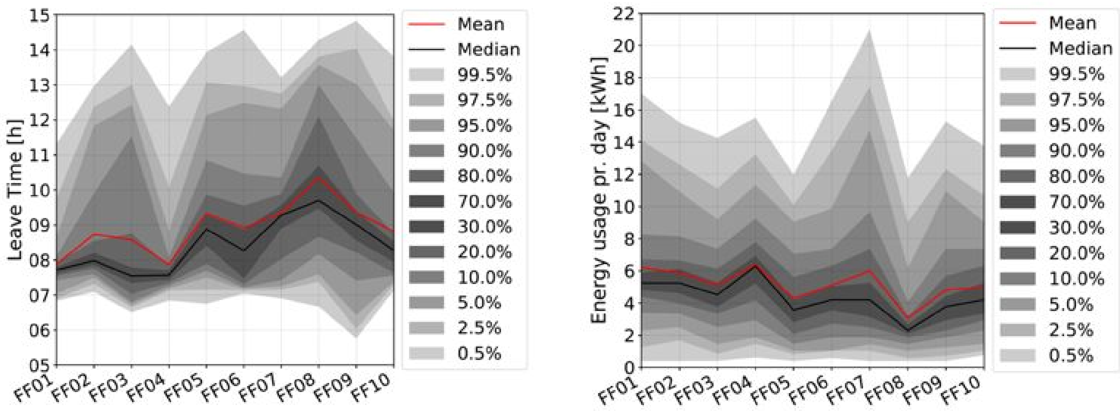


Figure 26 - Leave time (left) and energy usage (right) mean and median values and percentiles

Above, Figure 26 (left) shows the time in the morning where each vehicle depart for their first trip (leave time) as well as the typical energy use for the entire day (right). The data illustrate that the very few trips will occur before 7 AM, but with a rather large spread after that time. Also it can bee seen that the typical energy use (4-6 kWh) is rather limited compared to the capacity of the batteries (24 kWh). This indicates that the deadline for reaching the energy target may be around 7 AM or later - and that the energy target may not need to be 100% of the battery capacity.

For a more detailed analysis, data is fitted using a log-normal distribution and a Cumulative Distribution Function (CDF) is made for each user as can bee seen in Figure 27.

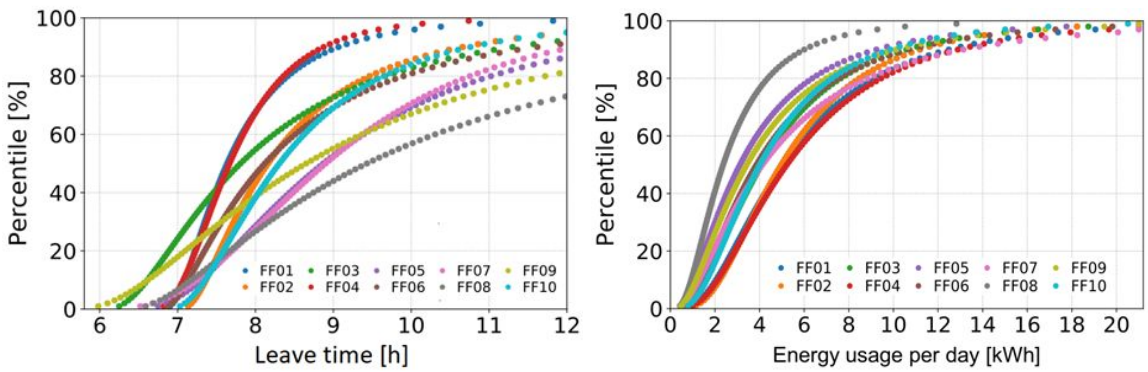


Figure 27 - Cumulative Distribution Function for the ten FF vehicles - leave time and energy usage

Each of the distributions can be used to determine a specific energy target and deadline for each user. By choosing a certain percentile for each distribution a time (hh:mm) and energy amount (kWh) is found. The choice of percentile represents the risk-willingness of the aggregator (risk of not fulfilling driving requirements based on historic values) i.e. choosing a very low percentile for leave time and a very high percentile for energy use represents a safer option - but provides less flexibility.

If considering the fleet collectively, and choosing the 1st percentile for leave time this would correspond to a common energy deadline at 06:30. The study showed that making individual deadlines - using the 1st percentile for each user - would add an average of additional 40 minutes per day for participation in FCR services. This additional time would correspond to an extra earning of 60 Euro per year/per car illustrating the benefit of individual profiles for users.

Further, if the 99th percentile was used to find an individual energy target - compared to fully charging all vehicles (energy target = 24 kWh) - this would reduce the average energy target with 10 kWh/day per car and increase profits with an additional 90 Euro per year/per car.

This study concludes that proper analysis of user behavior will allow an EV aggregator to adhere to a user's driving demands - while at the same time optimizing revenue providing FCR services.

5.4 Frederiksberg Forsyning 2 - The local grid

Frederiksberg Forsyning (FF) is located in the Frederiksberg municipality in Copenhagen, Denmark. The FF is supplied through T60170, which is a 10/0.4 kV, 1000 kVA transformer. To increase the reliability and security of supply, FF is also connected to T60160 as the backup transformer, which is a 10/0.4 kV, 1600 kVA transformer. The transformers are connected to the Lindevang main station. T60170, which is the main supplier of FF, supplies few other customers as seen from Figure 28.

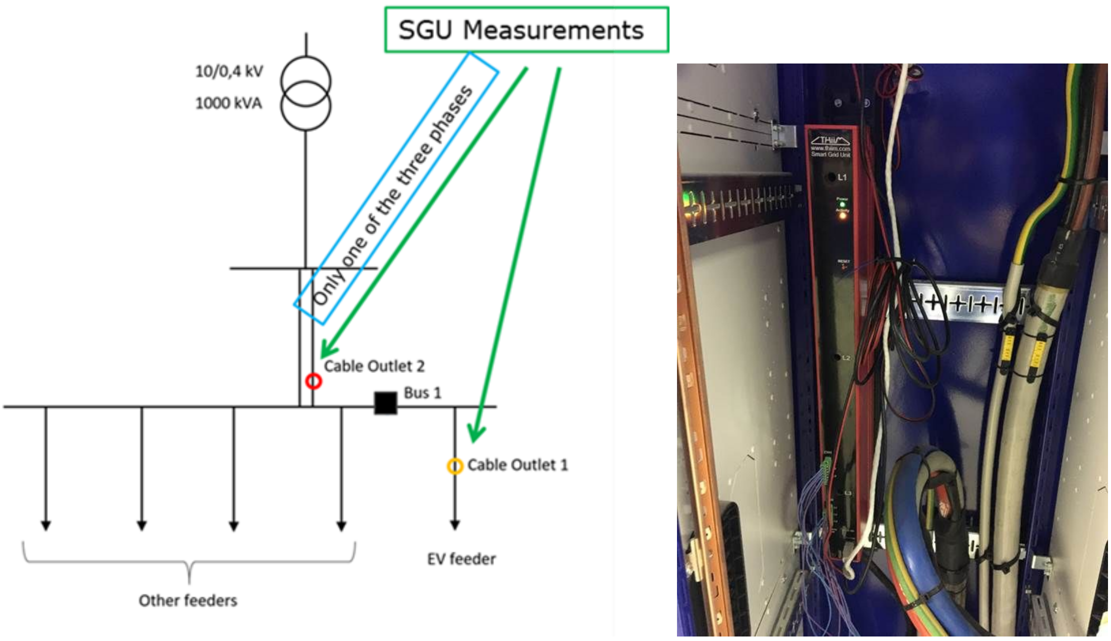
Figure 28 - T60170 is the main supplier of FF and other customers.

5.4.1 Site Network and the Smart Grid Unit installation

From T60170, there are two 400V cables, 3x240/120 CU, with the approximate length of 40 meters, that supplies FF and are connected to the electricity distribution room. Several FF units are connected to the electricity distribution room, including the EV fleet. A part of the electricity distribution room is shown in Figure 29. The total consumption of FF is measured by DONG (now Radius); however, it is decided to install a power quality analyzer at the FF site in order to monitor the grid, FF load and EV fleet more precisely.

Figure 29 - A part of the electricity distribution room at FF.

A Smart Grid Unit (SGU), provided by Thiim A/S is installed in the electricity distribution room in 2017. The measurement sensors measure the three phase voltage in the electricity distribution room, phase A current of one of the two cables feeding FF site and the three phase current of EV fleet feeder. Figure 30 shows where the measurements are performed. Based on the measured currents and voltages, other parameters such as active and reactive powers are calculated. The measured data are collected by Uptime-IT ApS and transferred to DTU. The SGU unit installed at FF is shown in Figure 30.



(a) (b)

Figure 30 - a: The selected cables equipped by the measurement sensors. b: SGU installed at FF.

5.4.2 Grid impact from frequency regulation provision

Several data are measured, and detailed measured parameters and several weeks of data measurements and analysis can be found in [12]. A few examples of measured parameters are shown here.

Impact of frequency regulation on the feeder load

In order to analyze the impact of frequency regulation by EVs on the loading of feeders, load profiles associated with one weekday and one weekend during January 2018 are depicted in Figure 31 and Figure 32, respectively. As seen, frequency regulation increased the peak load demand as well as the load fluctuations.

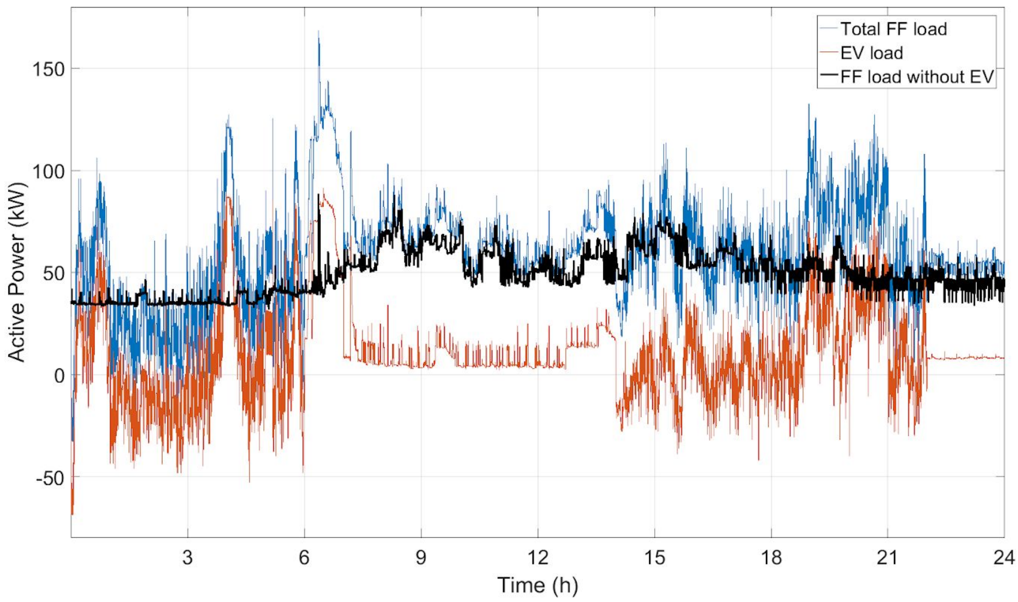


Figure 31 - active powers of EV fleet and FF site with and without EV load during a workday in January 2018.

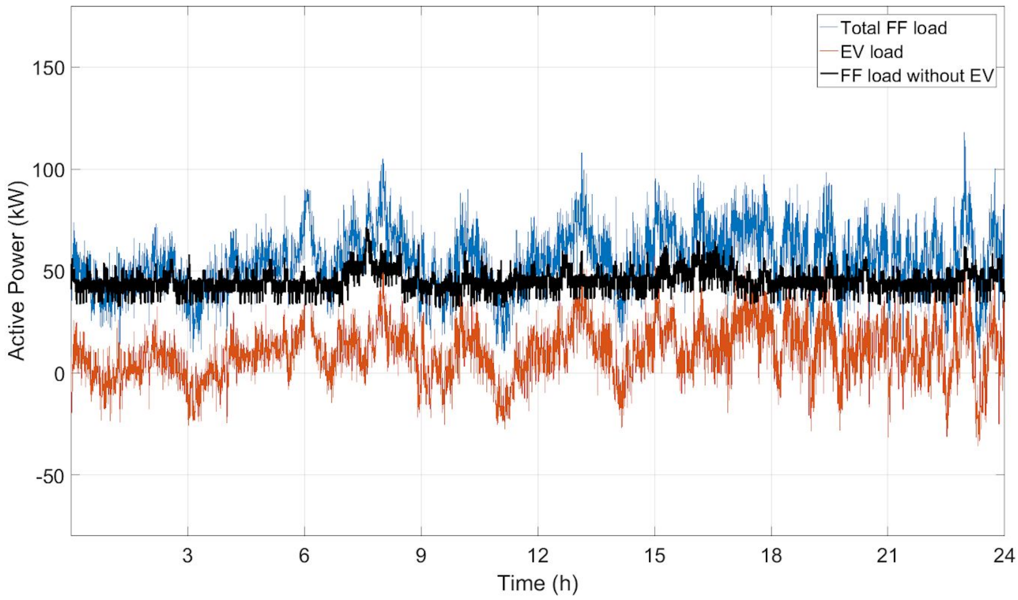


Figure 32 - active powers of EV fleet and FF site with and without EV load during a weekend in January 2018.

Impact of frequency regulation on the grid voltage

The grid to which FF is connected is strong, and the cables connecting FF to the transformer T60170 are short and strong. Therefore, it is expected that the voltage at the connection point of FF to the main grid stays in the allowed boundaries even with load variation caused by the EV fleet operation. The voltage at the connection point during a day in January 2018 is shown in Figure 33. As seen, the voltage is in the allowed boundaries.

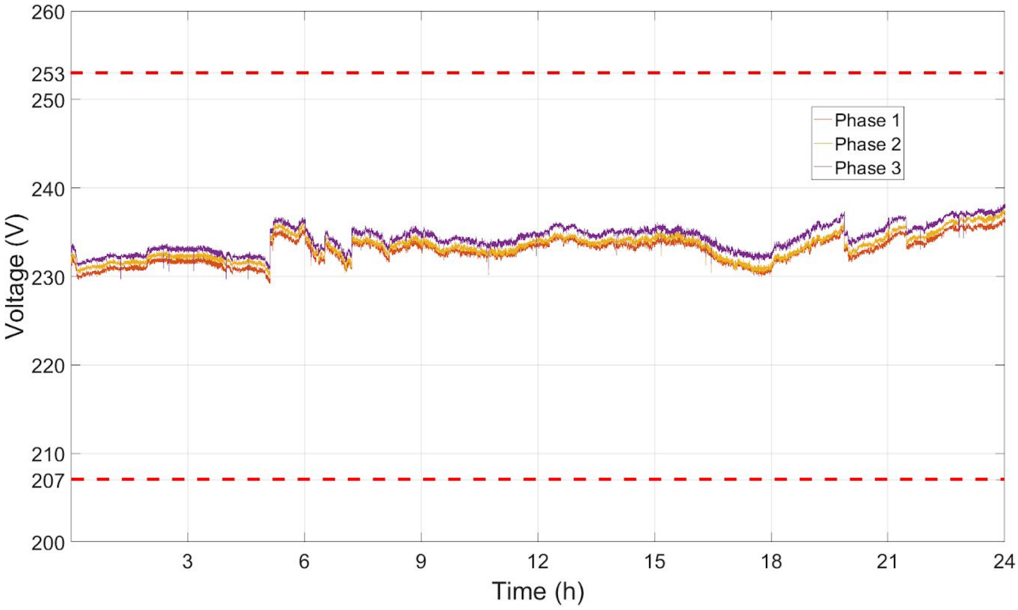


Figure 33 - voltage variations of FF site during a workday in January 2018.

It is worth mentioning that although the voltage remains in the allowed boundaries, there is a correlation between the voltage at the connection point and the active power fluctuations. The correlation during 5 hours of frequency regulation is shown in Figure 34. As can be seen, by active power variations of around ± 30 kW, a voltage variation of around 1% is expected. It clarifies that voltage fluctuation caused by EV frequency regulation should be thoroughly investigated.

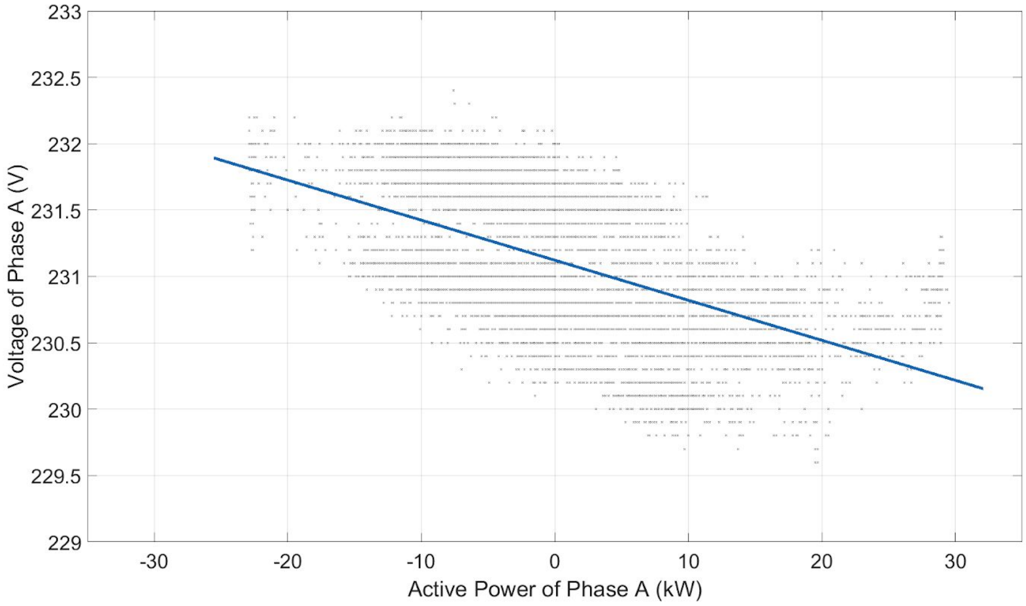


Figure 34 - correlation between EV fleet operation and voltage variations during 5 hours of operation.

5.5 Current barriers and business cases

5.5.1 Current barriers

As part of the emerging technology trial with Energinet, the barriers for introduction of VGI services in Denmark were identified and described in the report "Integration of new technology in the ancillary service markets" upon which this section is based[13].

The barriers described in this section goes beyond the regulatory domain of Energinet as the main objective was to make a comprehensive description of all major factors that may hinder the capacity offered by the technology - aggregated EVs - in becoming accessible to the market.

Barriers outside the immediate control of the partners may still be addressed indirectly - by contacting the organizations able to address such factors (example: tax authorities) - or it may inform changes on market rules to take technical considerations into account (example: metering requirements, service duration).

If distributed EV batteries are to be used as a capacity resource for the ancillary service markets some considerations have to be made to this new type of technology - a technology which differ from traditional thermal plants for which the regulations and markets were originally designed.

This will insure that the potential capacity of the technology is made available to the market as intended in the Danish Market Model 2.0 (MM 2.0) strategy.

The main characteristics for EV aggregations - similar in some aspects to fixed battery installations and other distributed resources are:

- Resources are distributed
- Can react very fast
- Can both consume and return power
- Are exhaustible (has a certain battery capacity, cannot produce energy)
- Are stochastic in nature (due to user behavior)
- Have a rebound effect, (A change in behavior now necessitate an opposite, compensating behavior at a later time)

The above characteristics represent both challenges and opportunities in using this new technology.

As part of Parker a total of seven main barriers that may hinder the use of aggregated EVs in the ancillary service markets have been identified. Four of these barriers: Long duration frequency bias, Requirements for settlement meters, Pre-qualification and Energy tariffs and Taxation have been identified as “high severity barriers” and must be addressed proactively to make the technology generally available to the market.

The barriers have been subdivided according to the categories Technical, Market, Regulatory and Economic based on their nature and are listed in Table 5 below.
Severity is set as either ‘Medium’ or ‘High’.

Barrier	Severity	Description	Possible solution
Technical			
Two-way energy loss	Medium	Energy losses in EV and EVSE when charging or discharging during service provision.	Improvement in equipment from OEMs and in aggregator power setpoints (using most efficient power range of equipment)
Long duration frequency bias	High	Battery-based storage is an exhaustible resource which cannot serve a non-balanced frequency for long durations.	Relax service duration requirement and/or allow for use of a preferred operating point or recuperation period.
Potential battery degradation	Medium/ High	Cycles following from the provision of services will, to some extent, reduce the capacity of a battery.	Technological improvements in battery chemistry. Ensure that requirements to service provision (response time, duration) doesn't go beyond what is needed.
Market			
Future market models for aggregators	Medium	No common (European/Nordic) model for how an aggregator may act in the ancillary service markets in in terms of roles and responsibilities.	Based on Danish suggestions on an aggregator market model (MM 2.0 group) attempt harmonization in first Nordic – then European scale.
Regulatory			
Requirements for settlement meters	High	Costly settlement meter requirements (technical / operational) prevents the use in distributed resources – in this case chargers installed in meters	Relaxed requirements to meters (perhaps by publishing an approved-list).
Pre-qualification	High	Pre-qualification of aggregated EVs to provide FCR can be challenging in that technical regulations are not fully defined for this type of resource and that aggregators can have dynamic and diverse portfolios of EV and chargers under their control.	It may be desirable for the pre-qualification to emphasize the performance and reliability of the aggregator instead of the individual EV-charger combinations in the portfolio. If individual assets have to be approved, perhaps a type approval, could be considered so that "known" types of EVs/Chargers can be seamlessly added without the need of repeated qualification.
Economic			
Energy tariffs and taxation	High	Heavy energy tariffs and taxation costs associated with two-way energy flow following service provision.	Apply taxes only to energy transferred for the purpose of driving. Two-way energy costs associated with service provision should be cancelled out.

Table 5 - Barrier overview

5.5.2 Business cases

The extensive tests in Nikola, Parker and FF commercial V2G operations have shown clearly that the technology works.

This section focuses on the revenue opportunities for the services.

A. Time-of-Use (TOU - Uni-directional)

Radius, which administers the distribution grid in the greater Copenhagen area has introduced differentiated TOU tariffs:

From 17;00 to 20:00 in the winter season (October to March) the tariff is 0.83 DKK/kWh (incl. VAT).
At all other times of the year the tariff is 0.3236 DKK/kWh (incl. VAT).
This gives a difference of 0.5114 DKK/kWh between peak and off-peak.

If the charge (25 kWh) is moved from peak to off-peak the savings would be:

0.5114 DKK/kWh * 25 kWh * 365/2 (winter season) = 2,333 DKK = €313/year/car

B. CO2/MEF (charging)

The optimization of charging according to MEF is described in section 5.1.3. In the absence of consumer carbon tax, the value of carbon data (for optimization and visualization purposes) has to be marketed in order to spark user interest. The Danish startup Tomorrow estimates that, especially for small distances where $ saved per drive is not large in absolute value, the marketing value of CO2 benefits can have a relatively strong impact on driver's participation in this public e-mobility scheme. Tomorrow aims at capturing a fraction of the value - added services of electric mobility, not only in Denmark, but worldwide (Tomorrow's data & forecasts are available for the more than 80 countries, including all European and most American states). From Tomorrow's customer interviews, carbon emission visualization and optimization for drivers represent a ~100 DKK opportunity per year and per driver. It would represent a 30 MDKK yearly market by 2030 in Denmark alone, and potentially much more in Europe and in the US.
Beyond mobility, the market potential for forecasts of marginal emission factors encompasses data centers and flexible electrical heating

For the following services the assumption is that the services are operated 14 hours every day of the year from 16:00 to 06:00. The power capacity used is +- 10 kW.
The data are based on availability prices from the Energinet web site. The revenue potential is estimated for uni-directional as well as bi-directional EVs.

C. FCR-N DK2 (Uni-Directional)

An uni-directional EV can support Frequency Regulation by modulating charging around a given setpoint. For a charging power of 10 kW and a setpoint of 5 kW the EV can modulate +5kW up to 10 kW (down-regulation) or regulate charging 5kW down to 0 kW (up-regulation). The EV is charged simultaneously with the support of Frequency Regulation until the battery is full and the EV has to be withdrawn from service.

The availability payments in DK2 - shown below - are highest between 00:00 and 05:00.

2017 average price

€39.94 per MW/hour.

2018 average price

€56.74 per MW/hour

Assuming a battery of 40 kWh and an average driving of 100 km per day (example car share) and consumption of 1 kWh per 4 km (incl. heating, air conditioning …) this results in a daily consumption of ~ 25 kWh.

With a charging power of 5 kW (setpoint) it will take 5 hours until the battery is full. The revenue potential for 5 hours DK2 Frequency Regulation would be:

2017

€39.94/1000 (per kW) * 5(charge power kW) * 5(hours per dag) * 365 €364/year/car

2018

€56.74/1000 (per kW) * 5(charge power kW) * 5(hours per dag) * 365 €517/year/car

If the TOU service is combined with Frequency Regulation (during night hours) this would result in revenue generation of between €677 (€364 + €313) - €830 (€517 + €313) per year/car.

D. FCR-N DK2 (bi-directional)

In order to analyze if there are variations during the year, data from 4 individual weeks were selected and it was calculated how much revenue could be earned for each week. In addition the yearly projected revenue for the full year of 2017 and the partial year of 2018 are shown.

In Table 6 it can be seen that there are great variations throughout the year from weekly €13.97 to €21.33 revenues.

The yearly revenue per car for 2017 is €1,710.72 and the 2018 revenue is €2,486.31. 2018 was a very dry year with large periods of little to no wind, which resulted in a large uptick in the availability price. The availability prices for 2017 and 2018 are shown in Figure 35 and Figure 36. The blue bars indicate FCR- N.

DK2

Period	FCR-N DK2 Price/MWh-h	Weekly Revenue/car@9.25 kW	Projected Yearly Revenue per car
Feb 06-13, 2017	€12.80	€13.97	€726.50
May 22-29, 2017	€17.91	€19.55	€1,016.54
Aug 07-14, 2017	€19.54	€21.33	€1,109.05
Nov 06-13, 2017	€13.46	€14.69	€763.96
Jan 01 - Dec 31, 2017	€27.88		€1,710.72
Jan 01 - Oct 11, 2018	€40.52		€2,486.31

Table 6 - Projected FCR-N DK2 Availability Payments per Year

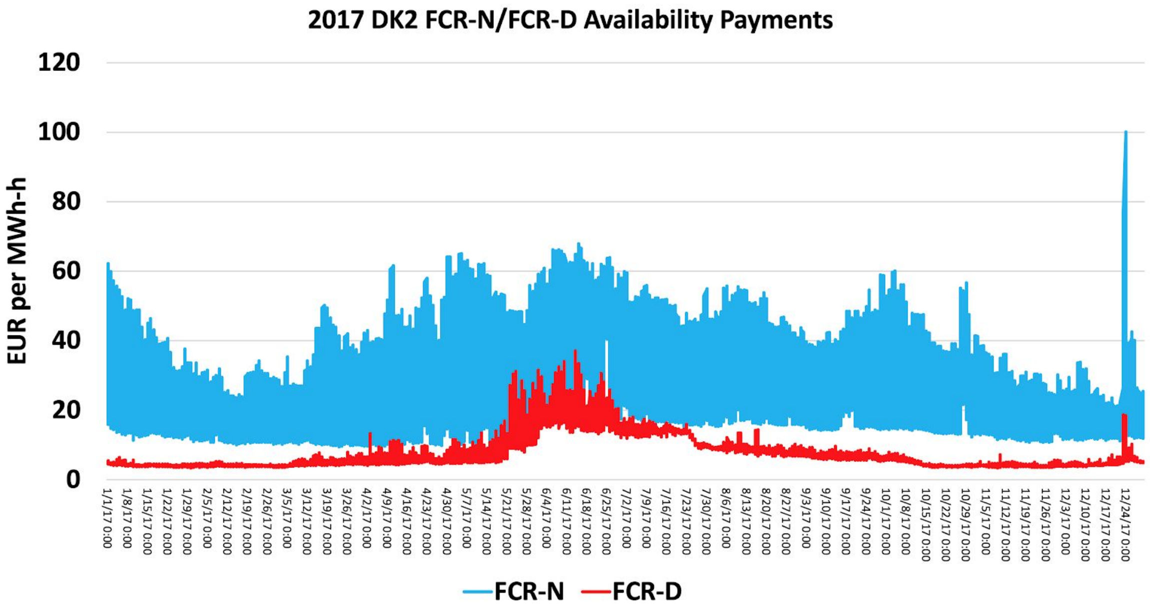


Figure 35 - FCR-N/FCR-D DK2 Availability Payments in in 2017

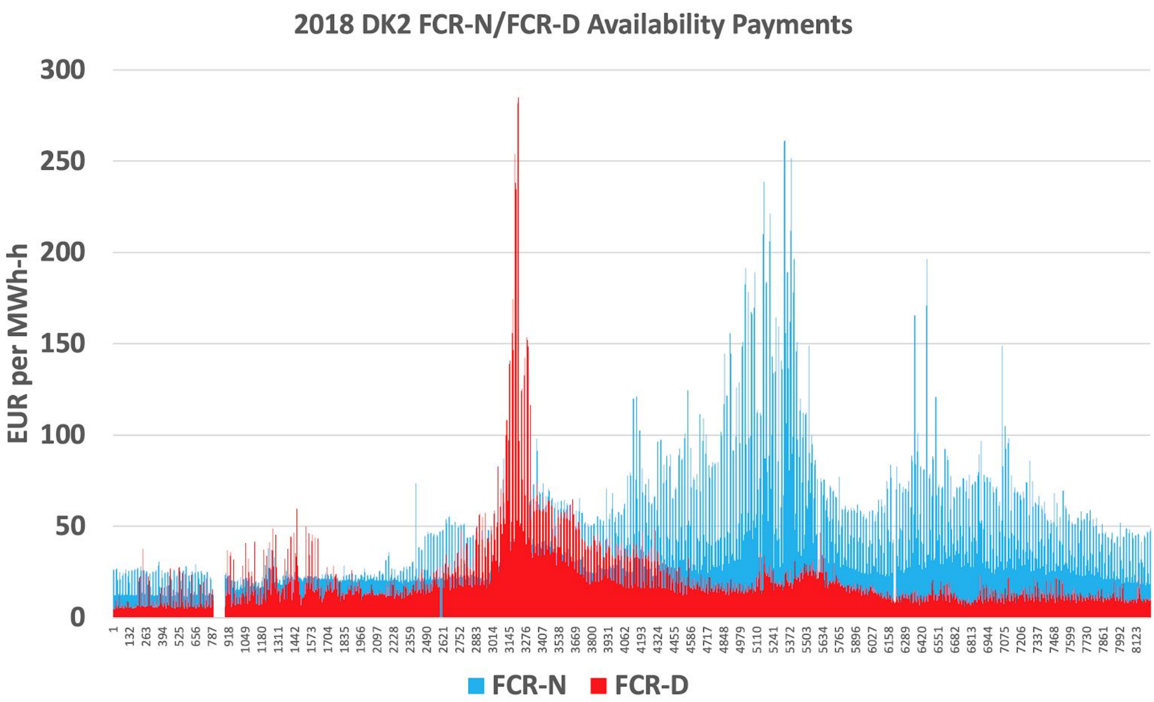


Figure 36 - FCR-N/FCR-D DK2 Availability Payments in 2018

E. FCR-D DK2 (bi-directional)

The FCR-D service availability payments were analyzed as described above.
The results are shown in Table 7 and the availability payments for 2017 and 2018 are shown in Figure 37 and Figure 38, where the blue bars represent FCR-N revenues and the red bars represent FCR-D availability payments. The revenues for FCR-D are significantly lower than for FCR-N in 2017. However, the service is less frequently activated and when activated with a much lower energy contents. The year 2018 shows a large deviation due to the extreme weather conditions and in the middle of the year the FCR-D availability payments actually greatly exceeds the FCR-N payments.

DK2			
Period	FCR-D DK2 Price/MWh-h	Weekly Revenue/car@9.25 kW	Projected Yearly Revenue per car
Feb 06-13, 2017	€4.02	€4.39	€228.17
May 22-29, 2017	€12.30	€13.43	€698.12
Aug 07-14, 2017	€8.27	€9.03	€469.39
Nov 06-13, 2017	€3.99	€4.36	€226.46
Jan 01 - Dec 31, 2017	€7.45		€457.13
Jan 01 - Oct 11, 2018	€19.56		€1,200.20

Table 7 - Projected FCR-D DK2 Availability Payments per Year

F. PFR-UP/PFR-DOWN DK1 (bi-directional)
For the synchronous area DK1 the availability payments and revenue projections are shown for 2017 and 2018 in Table 8. Figure 37 and Figure 38 show the FCR-UP and FCR-DOWN availability payments for 2017 and 2018.

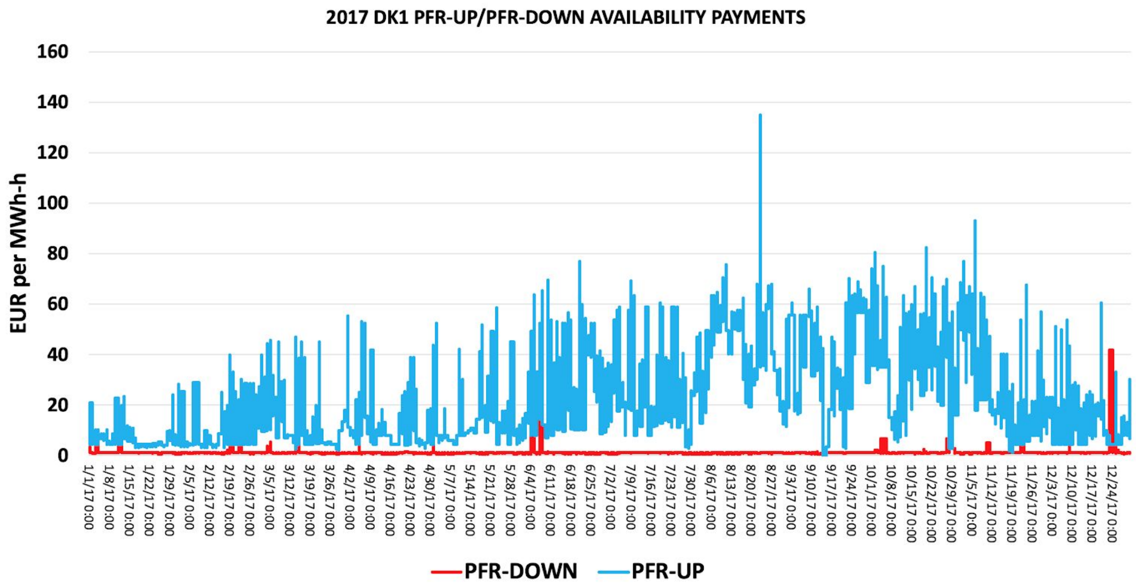


Figure 37 - PFR-UP/PFR-DOWN DK1 Availability Payments in 2017

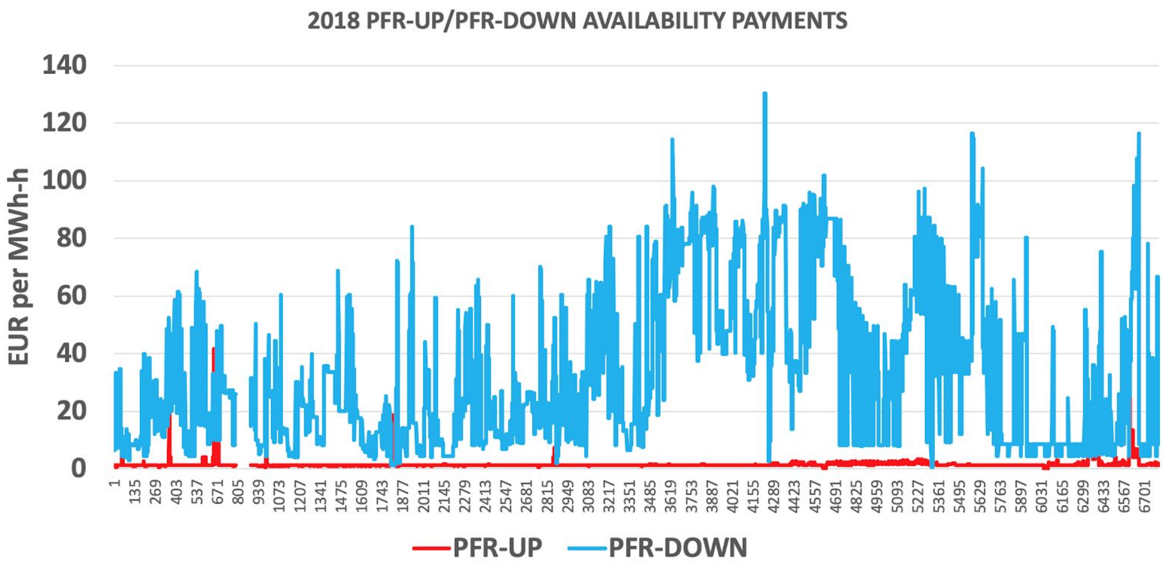


Figure 38 - FCR-UP/FCR-DOWN DK1 Availability Payments in 2018

DK1				
Period	PFR-UP DK1 Price/MWh-h	PFR-DOWN DK1 Price/MWh-h	COMBINED DK1 Price/MWh-h	Projected Yearly Revenue per car
Jan 01 - Dec 31, 2017	€23.75	€1.51	€25.26	€1,549.95
Jan 01 - Oct 11, 2018	€30.16	€1.54	€31.70	€1,945.11

Table 8 - Projected PFR-UP/PFR-DOWN DK1 Availability Payments per Year

G. aFRR DK1

This service was provided from Norway via the “Skagerrak-4” link (link between Norway and West Denmark) in 2017 on a bilateral agreement and no price data were available to Parker. As such it was not available for bidding by other parties.

6 Parker test protocol

The Parker Test Protocol will address the topic:
What will it take for an EV to be truly integrated in the energy system, and how to test that it complies to the proposed specifications?

6.1 Parker reference configuration

In the Parker project we test grid services on a V2G setup using commercial DC-chargers and commercial EVs using CHAdeMO DC-charging, but there are numerous ways of doing controlled charging with EVs: AC/DC, V1G/V2G.
12 versions of possible V2G HW control setups have been identified and tested in the lab as Proof-of-concept solutions developed by DTU and the partners in Parker.

The main take away from this extensive work is that it is the power electronics that need to be controlled. That goes for AC/DC charging and uni-/bi-directional chargers. It is not really important if the power electronics is in the EV or in the EVSE (Charger), the main question is if it can be controlled in small power steps every second.

Most of the testing in Parker has been done on commercial available equipment doing V2G DC charging using the CHAdeMO protocol, the rest of the 12 set-ups has been tested in labs.

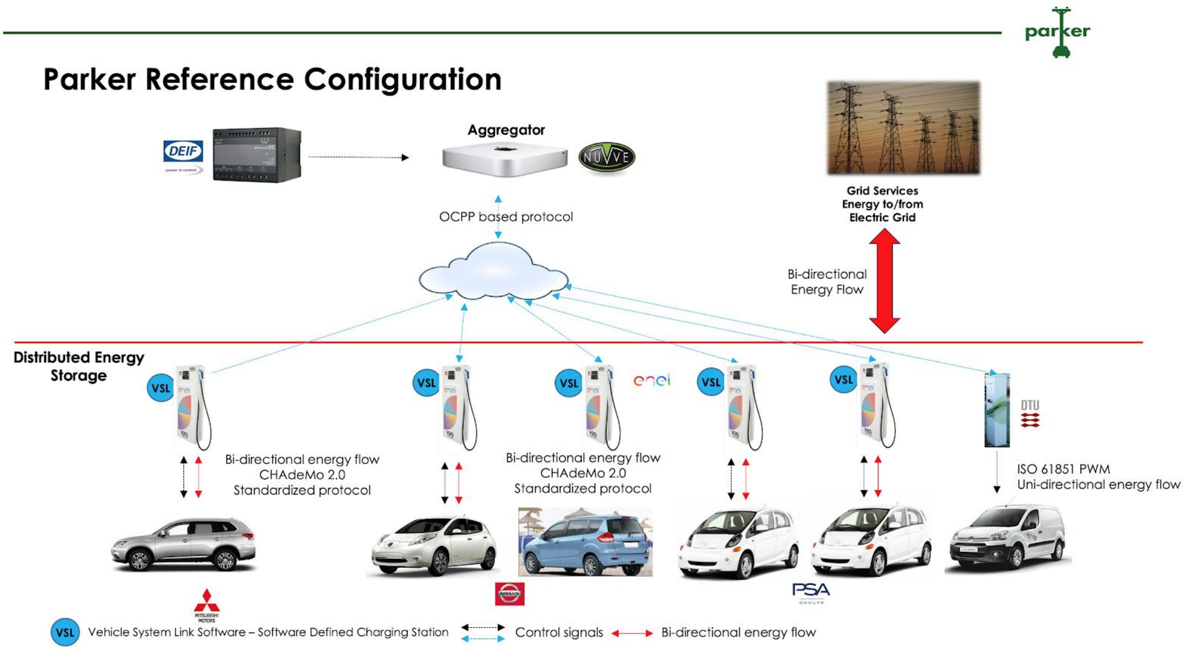


Figure 39 - Parker reference configuration

This setup is called the Parker reference configuration (Figure 39) and consist of:

1. Nissan Leaf 30kWh
2. Nissan Evalia 24 kWh
3. PSA Peugeot Ion 16 kWh
4. Mitsubishi Outlander 12 kWh

All EV's are DC-charged by the ENEL DC charger and controlled by the NUVVE aggregator.

To supplement this reference set up, additional chargers were set up in the EVlab controlled via either a local controller or a cloud based controller from Nuvve.

In all the tests, the set of EV and EVSE has been fixed during the test period in order to compensate from the lack of informational ID objects in the standards. This gives a working model, where ID and the battery size has been entered manually into the controller. The frequency is measured externally via a DEIF MTR-3 placed locally and extra AC measurement devices added in front of the two EVSE's in the lab supplemented with DC measurements on the output.

6.2 Grid keys

What will it take for an EV to be truly integrated in the energy system, and how to test that it complies with the proposed specifications?

In order to answer this question the concept of Grid keys was introduced to unlock the integration of the EV, where the EV can be considered as any other Distributed Energy Resource (DER) - in the smart Grid[14].

The introduction of Grid keys is an attempt to create a common definition of the technical capabilities needed in the physical electric vehicle infrastructure required for power and energy services.
Grid Keys are the parameters necessary for any grid connected device to perform any given grid service – existing and future. These parameters (inspired by grid codes and grid service descriptions) describe the abilities - relating to the power electronics located in EV and/or charger - needed to support grid services.

The goal of a fully integrated EV can be divided into 3 categories (Figure 40) under the Grid Key Definition:
Controllability: Controllability attributes, controlling certain electrical setpoints. The charging needs to be controllable depending on the need defined by the service it has to perform.
Observability: Observability attributes, the ability to observe relevant parameters. We need to be able to see or measure what is going on
Performance: Performance indicators, used to assess how well the equipment support controllability attributes. The control and response have to live up to some criteria defined by the service it has to perform.

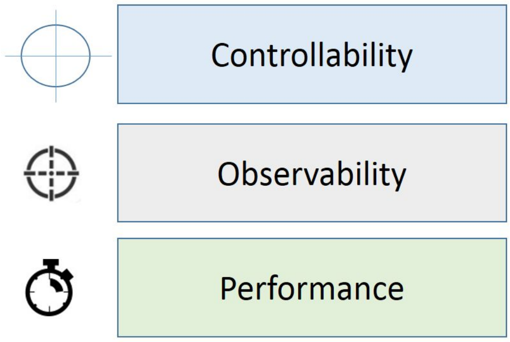


Figure 40 - Grid key categories

Grid Keys can be used for validating the capabilities of both EV, EVSE and the standards defining the communication protocols facilitating the informational objects used for control and informational exchange between the actors on the e-mobility scene [15]. This is illustrated in Figure 41.

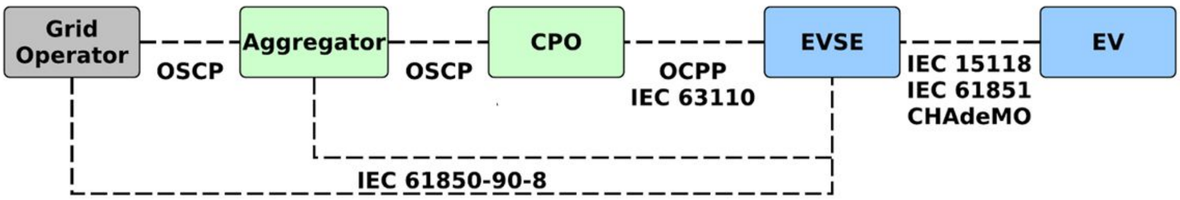


Figure 41 - The Frederiksberg Forsyning architecture

Essential missing informational objects in most interfaces are: **Power setpoint, Battery size, SOC, ID.**
These need to be in every interface/standard between the Aggregator and EV in order to secure the information flow needed to make the EV truly integrated in the grid, where it acts as a DER that the stakeholders can control based on their needs.

6.2.1 Controllability attributes

Name	**Description**	**Units**
Active power	Uni/Bi(V2G)	[W]
Reactive power	Inductive/Capacitive	[VAr]
Grid formation	Islanded operation	[Hz],[V]

Table 9 - Controllability attributes

The controllability attributes are listed in Table 9.
Active power control is an essential attribute to provide any kind of service, and is currently supported in most production EVs.

Reactive power control is useful for providing distribution grid services such as voltage quality support and congestion management.
Grid formation capability, where the electric vehicle's battery is used as a power source for a locally connected load or electrical network (V2X - V2H - V2L) has a number of interesting applications. This is currently a feature that has a marked in places, where the grid may be unstable or if there is fear of natural disasters disabling the grid. This is the case in Japan after the 2011 Tsunami that did great damage to the electrical grid, but but can be used at any location where blackouts occur, and here it is essential, that two grid forming units are not connected by accident when the grid is restored to normal operation.

6.2.2 Observability attributes

Name	**Description**	**Units**
Battery energy status	SOC and battery capacity	[Wh]
Power status	Active and Reactive Power	[W], [VAr]
Voltage and frequency	Measured at EV and EVSE	[V],[Hz]
Vehicle and connection status	ID and plug-in state	ID, Status

Table 10 - Observability attributes

The Observability attributes are listed in Table 10.
To effectively provide any kind of service it is essential that information relating to the exchange of power and energy, the resulting status of the battery and the status of any attributes controlled via a setpoint is accessible to the party providing the control. For any setpoint controlled as part of active or reactive power or for grid formation - related values should be accessible.

Observability covers all the informational objects which can be measured and the energy content in the battery (SOC) is essential for operation af grid services, together with activation time and technical factors such as ramping rates and accuracy/precision. The last item is ID, without this, it is not possible to identify the EV, and pay the user for the use of the battery or specify the EVSE location in the electrical grid.

6.2.3 Performance indicators

Name	**Description**	**Units**
Directionality and granularity	Setpoint range and step size	[W], [VAr]
Responsiveness	Latency, activation and ramp time	[s], [W/s], [VAr/s]
Accuracy and precision	Delivered vs requested response rate	[%]

Table 11 - Performance indicators

The performance indicators are listed in Table 11. To effectively provide any kind of service it is essential that the power exchange is performed in the way the service requires, this includes step size, direction, speed and accuracy. These requirements have to be clear in order for the manufacturers to comply with them.

6.2.4 Grid key test

In the Parker project, we have developed a test pattern in order to quantify a set of values to assess if a component is able to be integrated in the grid and has the fundamental capabilities needed to be a Grid Integrated Vehicle (GIV). This component can the be said to be GIV-ready or not.

The assessment points that can be evaluated based on the test pattern are listed in Table 12.

Name	**Description**	**Unit**
Bi-directionality	Support of bidirectional power flow	+/-
Set point granularity	Supported setpoint throughout the power range	[W] [VAr]
Activation time	Time between setpoint request and change in active power.	[s]
Ramping rate (Up)	Supported rate of change in power (increase)	[W/s]
Ramping rate (Down)	Supported rate of change in power (decrease)	[W/s]
Set point accuracy	Difference between required and delivered response	[W] or [%]
Set point precision	Variation of the delivered response	[W] or [%]

Table 12 - Performance assessment points

6.3 Validation of grid keys using EVs

Having defined the grid keys and established a reference configuration makes it possible to validate the grid keys parameters on the differents sets of commercial chargers and EVs. This section is based on the paper [14] .

Each EV+EVSE combination in the PARKER reference configuration will be validated using an active power test pattern shown in the Figure 42.

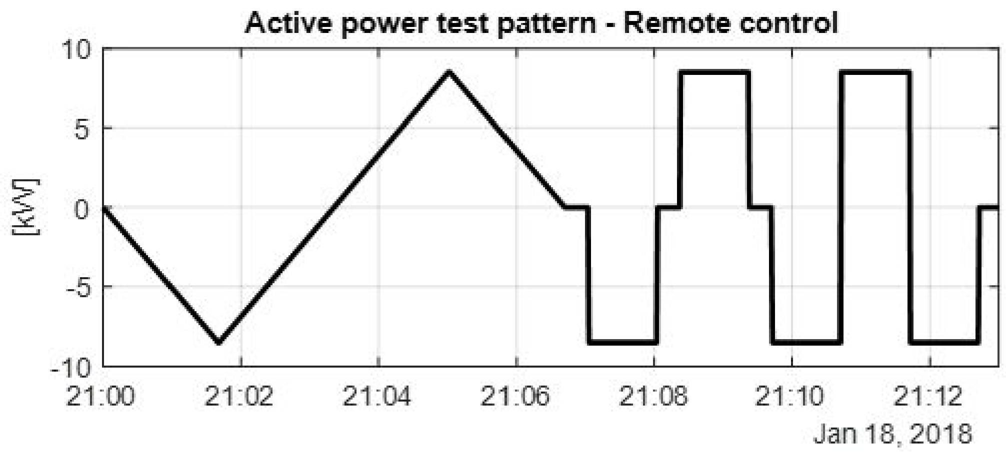


Figure 42 - Active power test pattern

Gradual power ramps are designed to test the granularity of the response to power setpoint, where full power steps are meant to test response delay, ramping rates and maximum power limits.
The first test results of this validation sequence can be seen in Figure 43 below.

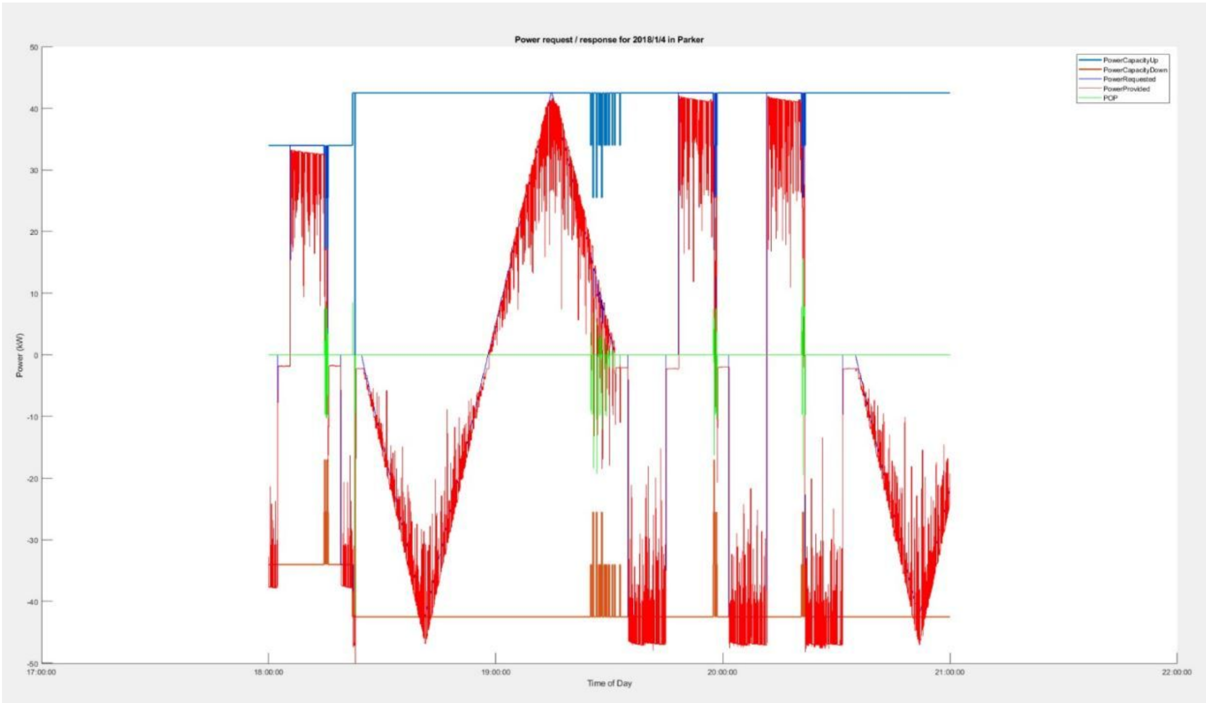


Figure 43 - Active power test pattern, first test result

The test was done using three V2G chargers in parallel.
The noise present throughout the full validation sequence is due to individual vehicle “drop outs” from the setpoint to 0. The slight power offset at 0 setpoint is due to offset of self consumption in the V2G charger.

6.3.1 Locally and remotely controlled EV’s performance tests

The first tests aim at assessing the efficiency of the V2G charger for a number of setpoints. This is done in a local fashion, i.e. the setpoints have been manually and locally set on the hardware, enabling us to derive the activation time of only the employed hardware. In order to evaluate the influence on the total activation time of additional communication latencies, the second tests were performed in a remote control fashion.

The remote control test setup includes the communication and control infrastructure utilized by an actual EV aggregator. Figure 44 as a whole shows the test configuration for the centralized control architecture, enabling us to derive the total activation time including communication latencies. In this case the EVSE receives a power setpoint remotely computed, and responds accordingly setting appropriate power flows in/out of the battery. With this design the aggregator calculates in a centralized way the appropriate V2G control signals to dispatch to its EVs, e.g. according to system frequency measurement in case of FCR. In the first local tests, the EV fleet operator platform is not utilized, whereas the setpoints are directly set on the EVSE computer embedded in the charger.

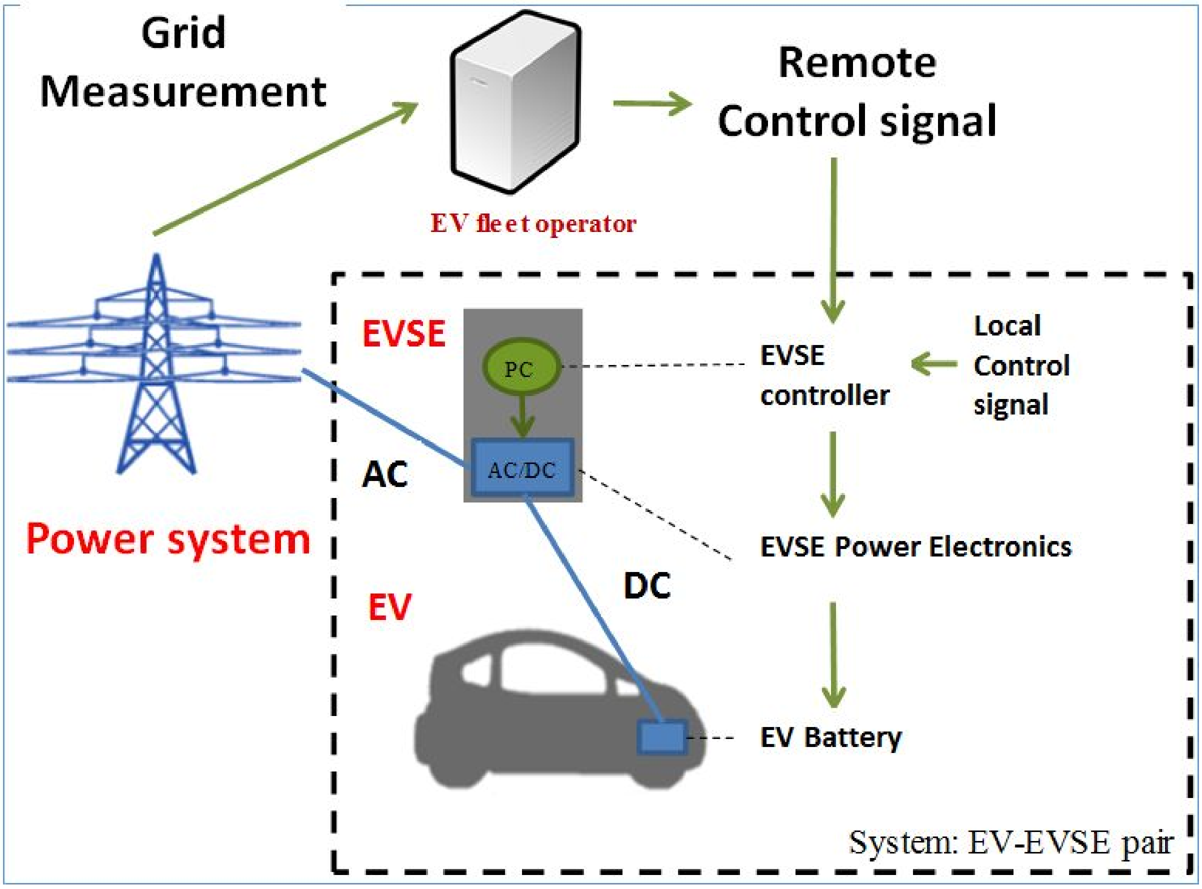


Figure 44 - Test configuration

In the proposed test activities two different active power test patterns were sent to the V2G-capable EVSE/EV. The first one is outlined in Figure 45 and represents different charging/discharging setpoints modulation from -10kW to +10kW with steps of 400 W

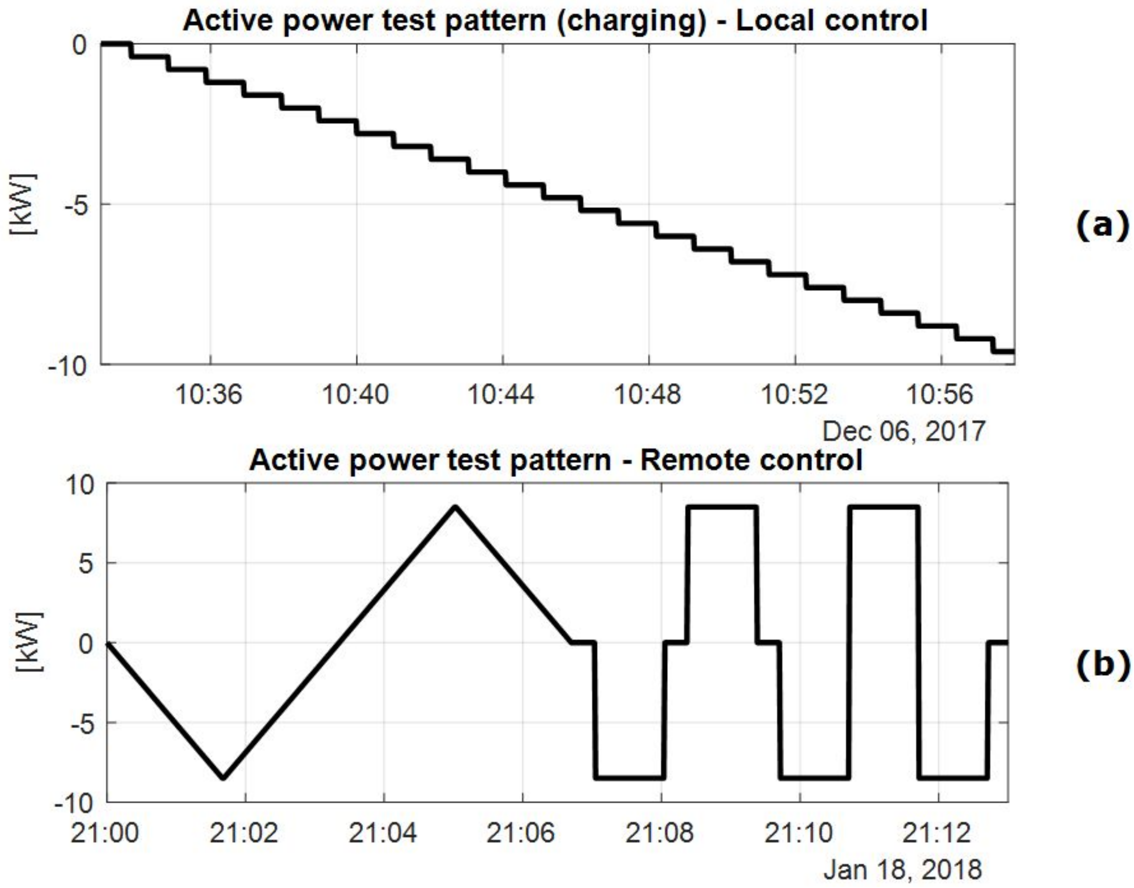


Figure 45 - Active power test patterns for local (a) and remote (b) control

Figure 45 shows the test cycle, which in practice was identically repeated 4 times, in order to have a more reliable measurement dataset for a more exhaustive and precise performance evaluation. Although the charger's size is ±10 kW, The extreme power setpoints are ±8.5 kW due to an internal limitation set on the internal charger software

This test pattern allows the operational characterization of the V2G charger in terms of efficiency mapping. For the remote control test Figure 45 (b), the pattern is designed in a way to allow an estimation of the seven flexibility service attributes which is part of the grid key concept.

Firstly, it enables us to validate the bidirectional capability and to assess total response time when controlling EVs in a remote fashion, including both communication latencies and charger and EV response time. This information is of utmost importance when assessing the capabilities on the provision of time-critical power system services from aggregated small distributed energy resources.

Secondly, the remote test pattern consists first of a continuous and then of a step-wise variation of the charging/discharging power setpoints. Such a cycle allows the measurement of the other five identified flexibility service attributes: the continuous part of the pattern allows the estimation of the step size granularity, whereas the step-wise part allows the estimation of the ramping times, the accuracy and the precision.

Figure 46 shows the charger efficiency, which in practice was done by measuring the AC input and the DC output on the DC charger. Although the charger's size is ±10 kW, The extreme power setpoints are ±8.5 kW due to an internal limitation set on the internal charger software, and it is quite clear, that there is an own consumption, which could be eliminated from the measurements.

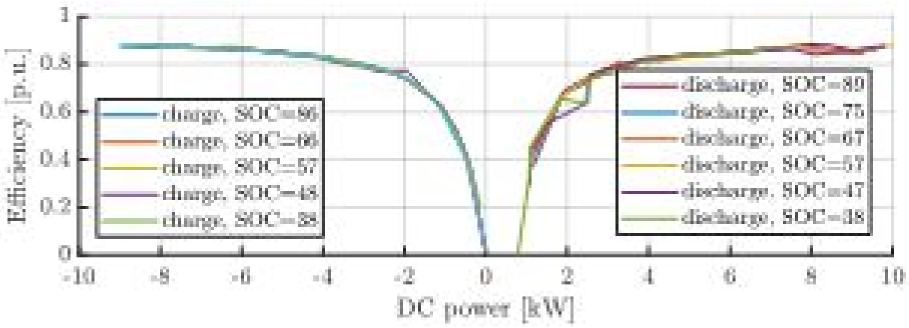


Figure 46 V2G charger efficiency map for charging/discharging DC setpoints from -10kW to +10kW with steps of 400 W.

5.3.2 Outcome of remote control tests

This Section presents the results of the performance test with the remote control setup. Note that the hardware under test and the laboratory environment conditions are the same as for the local control test.

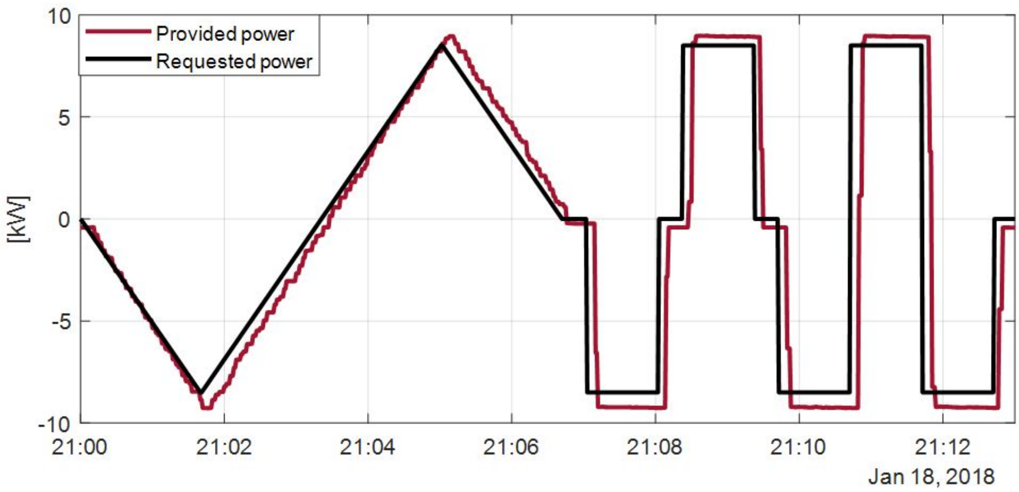


Figure 47 - 1 cycle of the performed remote performance assessment test.

Figure 47 shows the required and the provided power of one cycle of the active power test pattern. In general, a time shift can be noticed, which here represents the total activation time given the employed remote control setup. Then, one can note the non-perfect linearity in the response to the signal in the continuous portion due to the setpoint granularity imposed by protocols and the power electronics in the V2G charger. Finally, the time needed to reach the setpoint is utilized for the calculation of the ramping rates, while the measured power at the stable setpoint levels allows the calculation of accuracy and precision.

6.3.2 Calculation of setpoint linearity

The linearity in the response is studied in the continuous portion of the tested cycles, when a continuous linear setpoint is sent to the unit. The amplitude of the granular response is calculated as the difference of the measured provided power calculated at two consecutive time stamps. Hence a number of setpoint granularities are calculated, which are then analysed.

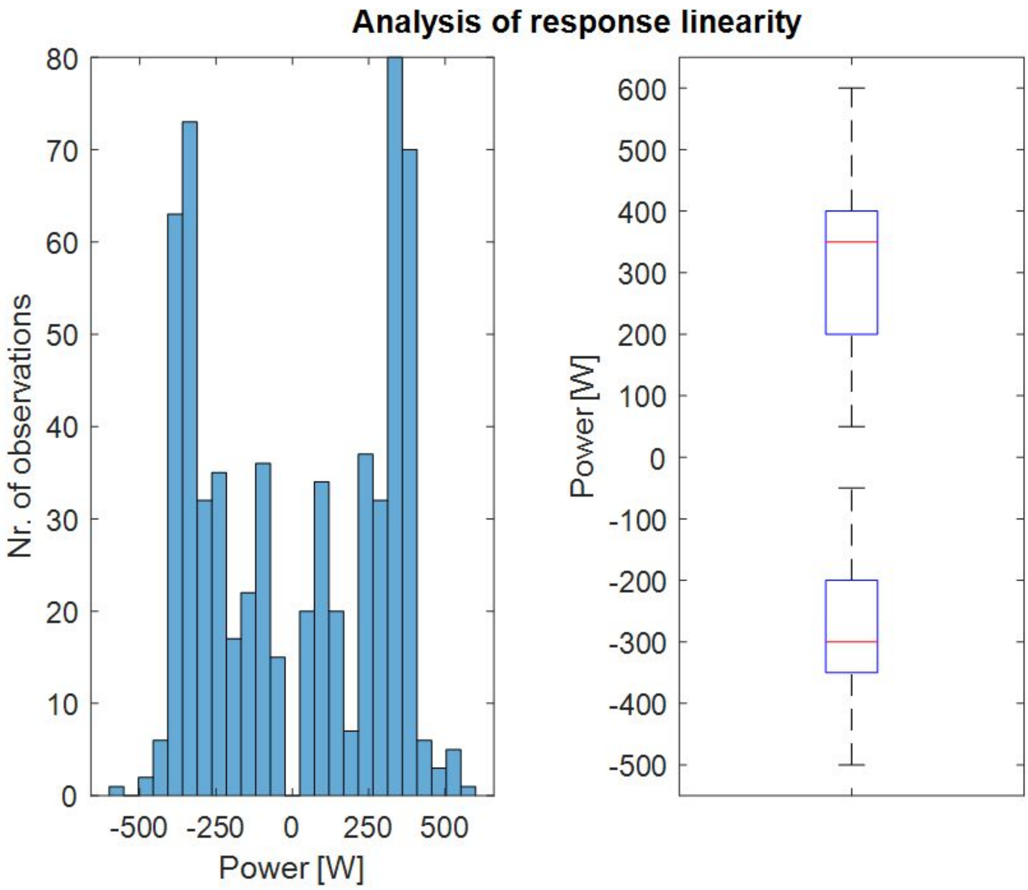


Figure 48 - Distribution of the observed granularities in terms of absolute and percentage observations. For the boxplots, the blue boxes indicate 50% of the observations, whereas the median is in red. Upper and lower quartiles (25% of the data) are located within the vertical black lines

In this response linearity analysis we have excluded two sources of probable errors: the unavoidable noise in the measurements, and the response precision when setting a given setpoint value. So, the calculation of the response linearity is done after applying a manual discreteness of 50 W on the measured data, given the average precision in the response.

Results are reported in Figure 48 The barplot shows the distribution of the observed granularities for different positive or negative sizes. First, the symmetrical distribution for charging (<0) and discharging (>0) can be noticed. Then the 2 bars with more observations (~50%) cover the range ±{300 400}W, whereas only in few cases (less than 5%) the absolute value of the granularity is > 400 W. The same results are reported in the boxplots, which show the median values -300 W and +350 W.

In general, one can conclude that in very few cases the EV responds with a discreteness larger than 400 W when controlled with a linear signal. 400 W in AC can thus be considered as the finest response granularity for the hardware under test. In this case, neglecting conversion losses, 400 W in DC means a granularity of 1 A, being the DC link voltage equal to 400 V, according to the technical CHAdeMO protocol.

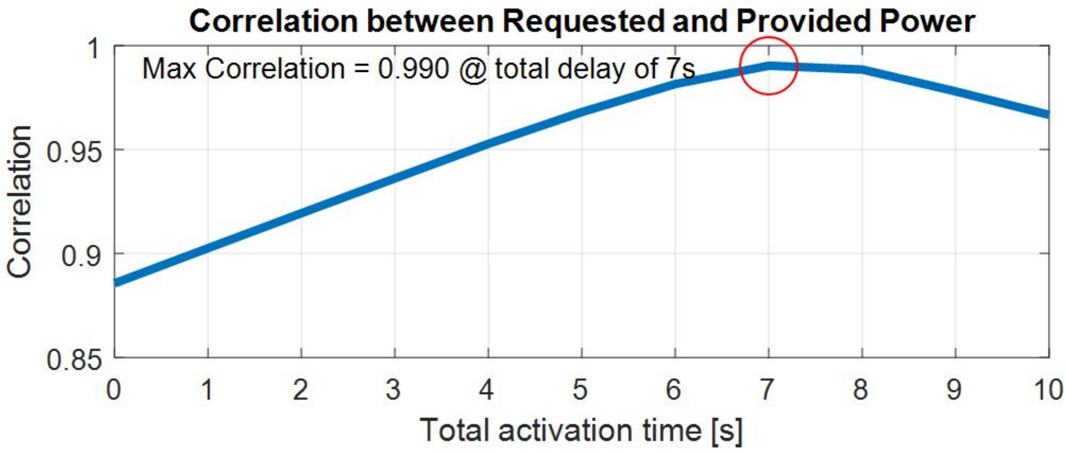


Figure 49 - The correlation between requested and provided power for remote control shows a maximum for a delay of 7 s, which can then be considered the total activation time when the tested V2G equipment is controlled via the centralized remote control setup.

6.3.3 Calculation of total activation time

The time shift shown in Figure 47 represents the total activation time given the employed remote control setup, which includes both the 4 s delay of the actual hardware response time and the additional latencies due to the centralized control architecture. Figure 49 shows the correlation of the two signals of Figure 47 when applying different time shifts to one of them. The maximum is found for a shift of 7 s, which is then considered as the total activation time when the tested V2G equipment is controlled via the centralized remote control setup.
By comparing this analysis with the similar one for local control, an assessment of the influence on the overall response time only due to a centralized control architecture can be derived. This validation can then provide a valuable information on the actual total activation time capabilities given either a local or a remote control. Such information is of utmost importance when assessing the capabilities on the provision of time-critical power system services from aggregated small distributed energy resources, when evaluating whether to implement a centralized or a decentralized control strategy.

6.3.4 Calculation of ramping up/down

The ramping up/down capabilities are studied in the step-wise portion of the tested cycles, where 4 events up and 4 events down are performed as shown in Figure 50. The charging power is changed from the zero setpoint to the minimum and maximum values, back to zero. Also the largest possible steps are analysed, i.e., when setting the maximum power starting from the minimum setpoint, and vice versa.

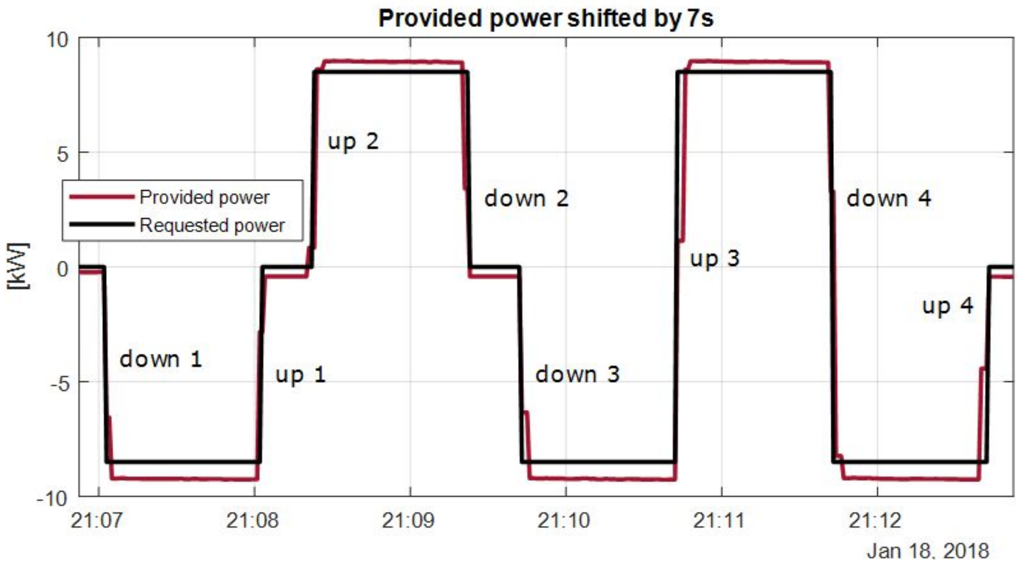


Figure 50 For each cycle of the performed performance assessment test 4 events up and 4 events down are performed to calculate the ramping rate capability. For the step-wise portion, 4 cycles have been repeated.

Table 13 reports numerical results of the calculated up/down ramping rates. The average up and down rates almost coincide, and are equal to about 3.3 kW/s when expressed in the general unit of measurement [kW/s], i.e. related to 1 s time window. Nevertheless, the minimum calculated up and down rates are 1.8 kW/s (up2-cycle4) and 2.2 kW/s (down1-cycle2,3 and down3-cycle1) respectively, which is way lower than the average. This means that the unit on average responds with 3.3 kW/s, but may respond slower.

This outcome is very important, as it can be valuable information for grid operators when performing grid regulation studies, assessing the impacts of grid regulation services provided by such units. Moreover, it can be useful also when defining requirements for grid connected V2G technologies, provided the knowledge of the technology under exam.

up 1	Cycle 1	Cycle 2	Cycle 3	Cycle 4
up 2	8.84kW in 3s	8.84kW in 4s	8.82kW in 3s	8.84kW in 4s
up 3	9.03kW in 4s	9.04kW in 4s	9.03kW in 4s	9.04kW in 5s
up 4	17.87kW in 6s	8.84kW in 1s	8.83kW in 4s	8.84kW in 3s
Ramp-up AVG	**3.35 kW/s**			
down 1	8.99kW in 3s	8.79kW in 4s	8.79kW in 4s	8.99kW in 3s
down 3	9.33kW in 3s	9.16kW in 1s	9.17kW in 1s	9.16kW in 4s
down 3	8.79kW in 4s	8.98kW in 3s	8.97kW in 4s	8.99kW in 4s
down 4	18.12kW in 6s	18.14kW in 7s	18.13kW in 7s	18.14kW in7s
Ramp-down AVG	**3.31 kW/S**			

Table 13 - Measured ramping rates up/down

6.3.5 Calculation of setpoint accuracy

The calculation of the setpoint accuracy is done during the constant setpoint levels of the step-wise portion of the tested cycles, as highlighted in Figure 51. The accuracy is calculated as the difference between the requested and the provided power over the appropriate time windows.

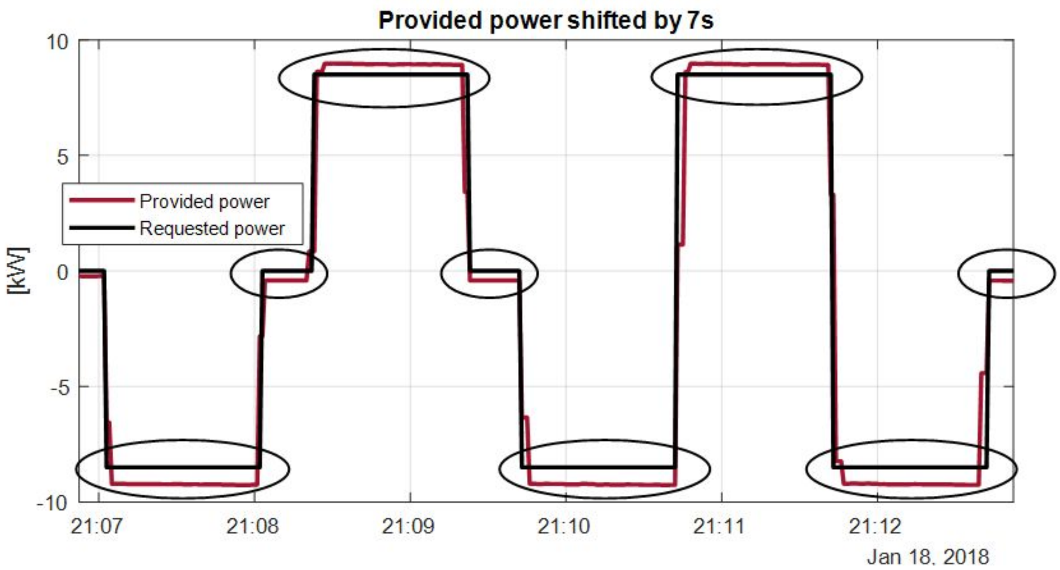


Figure 51 For both accuracy and precision the calculation is done during the constant setpoint levels of the step-wise portion of the tested cycles. This means at zero setpoint at the maximum charging (-8.5 kW) and discharging power (+8.5 kW).

It was found that for charging operations (power<0) the power drawn from the grid is larger than the requested power. The same happens in case of zero setpoint, where the power consumption is justified as the own consumption of the power electronics on standby mode. During the discharge operations, the power injected into the AC grid is higher than expected. This is probably due to a incorrect calibration of the internal EV charger power electronics, which should be tuned to avoid higher injection of power higher than the requested value, as it could compromise the safe operation.
At zero setpoint the charger draws from the grid on average 420 W, which can then be considered as the unit's stand-by loss. In case of full charging operation (requested power = 8.5 kW), the calculated accuracy is 740 W, which represents the 8.7% of the power setpoint. Such accuracy is higher than the stand-by losses, probably due to a non-optimal calibration of the unit. Finally, during the full discharging operation (requested power = -8.5 kW) an unexpected power value higher than the requested one was measured. Results show that the average power provided is higher than the requested by 440W, which is the 5.2% of the power setpoint.

6.3.6 Calculation of setpoint precision

As with the accuracy, the precision is calculated during the constant setpoint levels of the step-wise portion of the test cycles. The accuracy is calculated as the difference between the maximum and the minimum values of the provided power over the whole length of the time windows with stable extreme setpoints. This means that the precision calculated with this test cycle can be considered as the worst case for the extreme charging and discharging setpoints.

It is found that the precision is about 50 W for both the extreme charging and discharging operation. This value justifies the choice of 50 W as manual discretization factor which has been utilized in the analysis of the granularity. In case of zero-setpoint the precision was much higher, since the difference between maximum and minimum of the measured power was about 6 W.

6.3.7 Discussion and conclusions

In this section the technical capabilities of a commercial V2G CHAdeMO charger have been identified to assess the suitability of such technology for grid service provision.

Specifically, the importance of the knowledge of the efficiency for all the possible operating conditions has been highlighted, along with the seven attributes of a flexibility product to be traded in the market.

Moreover, two different test setups were utilized to investigate how the total activation time would change in case of local or remote control. This provided crucial and valuable information when assessing the capabilities on the provision of time-critical power system services from aggregated small distributed energy resources.

Table 14 shows the summary outcome of the performance tests results for each identified flexibility product attribute, with the respective performance target defined by current technical standards. In particular, the requirements have been adapted from the Danish technical standard for FCR provision [16] and the newly released Danish technical regulation for grid connected battery plants, which applies also for a number of aggregated EV chargers providing V2G services[17] . Such requirements are then considered as benchmarks when evaluating the eligibility of EVs in FCR service provision.

Going through the seven attributes, firstly it can be seen that the symmetric power reserve bid requested by tender conditions applies to a bidirectional power flow capability, which is available due to the V2G technology.

As for the setpoint linearity, generally a linearity of 1% of the rated power is requested. It is found that the finest response has a granularity of 400 W, which represents the 4% of the rated power, thus not fulfilling the requirement. However, as this is the linearity for only one single unit, when managing an EV fleet the fleet operator should then apply smart logics, e.g. based on stochastic logics aimed at reaching – as proposed in [18]– the required target on an aggregated level.

As for the activation time, the latencies due to remote control communication amount to about 3 s, while the mere hardware is characterized by an activation time of 4 s. Some DK technical regulations requires the activation of half of the full capacity within 15 s [16], which is then respected considering an instantaneous response. In reality, the response has an up-down ramping rate, which amounts to an average value of 3.3 kW/s. For the tested charger, this means that the total activation time for half of the reserve (5 kW) would be about 8.6 s, which is lower than the requested 15 s. Regulation 3.3.1 [17] requires a ramping rate capability for the aggregated fleet within the range of 10-300 kW/s, which is out of the range of capabilities of the single units. This means that, considering again the average value of 3.3 kW/s, the minimum and maximum number of EVs to be employed for matching the required 10-300 kW/s ramping range will be 3 and 91, respectively.

Finally for accuracy and precision, regulation 3.3.1 requires a response within ±5% of the setpoint and ±0.5% of the rated power. The requirement on the precision is respected, whereas for the accuracy, the limits at the two maximum charging and discharging levels are overcome. This issue may be dealt with proper calibration of the internal power electronics that should be tuned to avoid such inaccuracies. Furthermore, as the requirements refer to the overall battery plant, smart fleet management solutions could be implemented to reduce the reserve provision error via appropriate individual control of the single EVs.

To conclude, in order to make the EV flexibility product a tradable asset, relevant regulations and requirements should be respected, and standardized tests for evaluating charger's and EV's performances should be established.

In fact, a deep knowledge of the controllable hardware is needed to categorize the supplied EV flexibility product. On the one hand, insights into the charger's efficiency for different setpoints allow the calculation of the accumulated losses during a V2G session, which is crucial information for the estimation of the actual state of charge of the controlled EV.

On the other hand, the proposed investigation of the identified characteristics of the V2G unit provides valuable information for grid operators when performing grid regulation studies, assessing the impacts of FCR provided by such units with realistic models to emulate their behavior.

Furthermore, it can be useful also when defining new requirements for grid connected V2G technologies, provided an orientative knowledge of the employed technology's capabilities.

Ultimately, the proposed investigation results provide insights also for the EV fleet operators in terms of actions needed for smart fleet management aimed at respecting the grid code restrictions.

Attribute	Short description	Unit	Target for Primary Reserve	Test result
(i) Direction	Support of bidirectional power flow	+/-/±	±	± i.e. V2G capable
(ii) Set-point linearity	Supported setpoint throughout the power range	[W]	Linear at 1%	< 400 W (4%) (1 A @ 400V DC)
(iii) Starting time and maximum activation time	Time between setpoint request and change in active power	[s]	< 15 s	Local control: 4 s Remote control: 7 s
(iv) Ramp-up time	Supported rate of change in power (increase)	[kW/s]	For the aggregate: 10-300 kW/s	AVG = 3.35 kW/s Max = 8.84 kW/s min = 1.81 kW/s
(v) Ramp-down time	Supported rate of change in power (decrease)	[kW/s]	For the aggregate: 10-300 kW/s	AVG = 3.31 kW/s Max = 9.17 kW/s min = 1.98 kW/s
(vi) Accuracy	Difference between required and delivered response	[W]	±5% of setpoint & ±0.5% of rated pow.	Negative setpoint: 740W (+8.7% of setpoint) (+7.4% of rated pow.) Positive setpoint: -440W (-5.2% of setpoint) (-4.4% of rated pow.) 420 W @ zero setpoint (4.2% of rated pow.)
				≈ 50 W

(vii) Precision	Variation of the delivered response	[W]	±5% of setpoint & ±0.5% of rated pow.	(0.6% of setpoint) (0.5% of rated pow.) 6 W @ zero setpoint (0.06% of rated pow.)

Table 14 - Summary outcome of performance tests

6.4 Standards and GAP analysis

Proper communication between the actors is essential for operation and enabling the provision of grid services. Standardised communication links enable interoperability of any EV and EVSE combination to provide grid services with any aggregator. Figure 52 below shows the actors in the architecture directly relevant to grid service communication in e-mobility infrastructure, with corresponding protocols for each link.

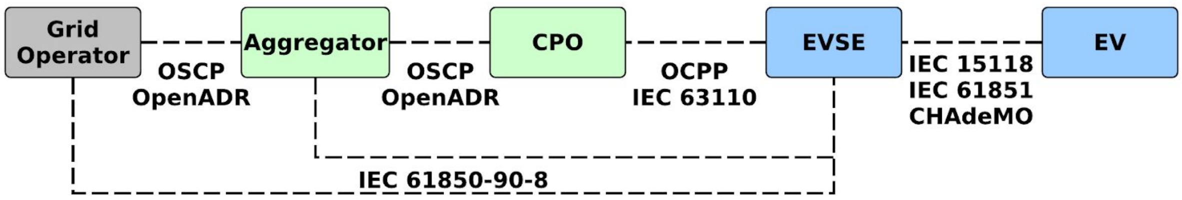


Figure 52 - The Frederiksberg Forsyning architecture

Essential missing informational objects in most interfaces are: **Power setpoint, Battery size, SOC, ID.**
These need to be in every interface/standard between the Aggregator and EV in order to secure the information flow needed to make the EV truly integrated in the grid, where it acts as a DER which the stakeholders can be controlled based on their needs.

In the Frederiksberg demo case, the architecture is relative simple, but a full reference architecture as illustrated in Figure 53, has more possible actors, but any actor can undertake one or more of these roles. This is the case if a CPO takes on the role of EMSP or Clearing House, but it could also be an energy provider, that took on the task of BRP or aggregator.

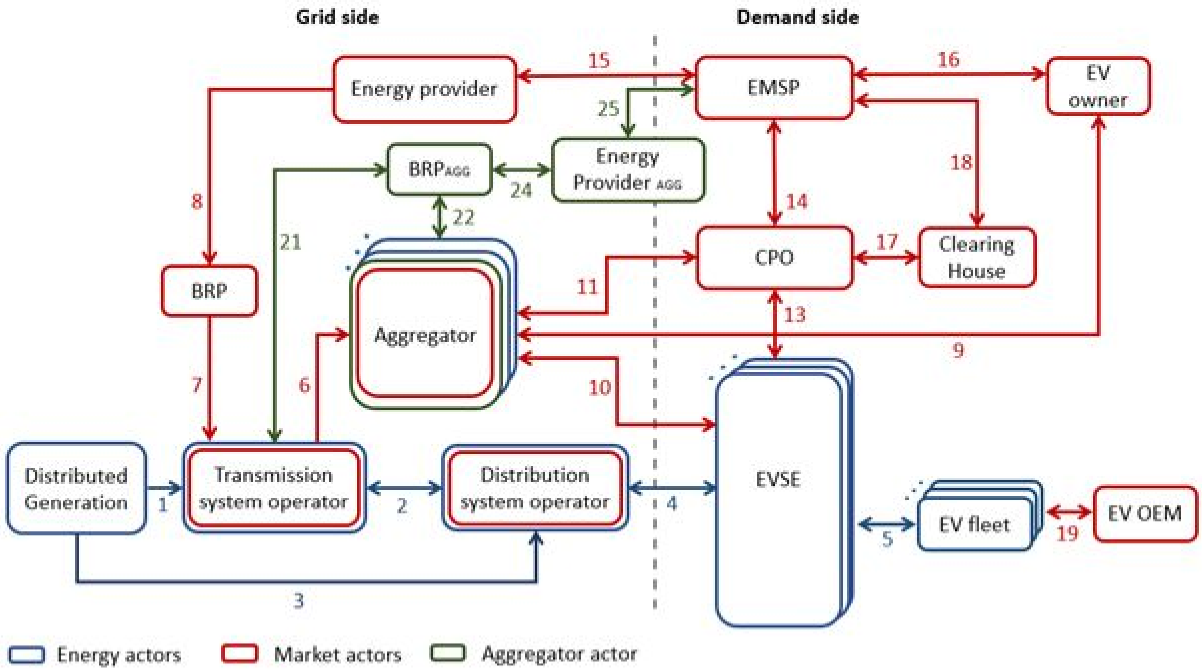


Figure 53 - The stakeholders in a reference architecture showing the stakeholders and interfaces

The Parker project uses a simpler architecture to provide grid services using the FF fleet and reference architecture. In the project, the EV aggregator also performs the role of the CPO and EMSP.

Grid operator is omitted from this diagram as the service provided by this system is primary frequency regulation. This service is solely based on reading grid frequency, thus not relying on any high level communication to the grid operator. Energy market actors are also not represented as they are interacted with manually.

Such simplification of the e-mobility architecture reduces the flexibility of connecting to different charging points through external CPOs and registering new services with other EMSPs. However, the simplification fulfills the primary purpose of the project to provide grid services, while comfortably operating the fleet.

6.4.1 Mapping of Grid Keys vs. standards

When mapping the seven Grid Keys vs. the relevant standards between actors on the e-mobility scene (Table 15) it becomes obvious, that the standards lack informational objects.

Link	EV-EVSE			EVSE-CPO		CPO-Agg		EVSE-Agg
Information object	IEC 61851	IEC 15118	CHAdeMO	OCPP 1.6	OCPP 2.0	Open ADR	OSCP	IEC 61850-90-8
Bidirectional capability	-	+	+	-	?	+	-	?
Set point granularity	1A	?	1A	?	?	?	?	?
Activation time	<3s	<60s	<1s	-	-	-	-	-
Ramping rate (Up)	N/A							
Ramping rate (Down)								
Set point accuracy								
Set point precision								
Active Power Control	+	+	+	+	+	+	+	+
Reactive Power Control	-	+	-	-	?	+	+	?
SOC	-	+	+	-	?	+	-	?
EV ID	-	+	-	-	?	-	-	?
Vehicle status	+	+	+	+	+	-	-	?
EVSE ID	NA			+	+	+	+	+
Grid ID				-	?	?	+	+

Table 15 - Mapping grid keys to the relevant standards between actors

Comments to the table:

- This analysis was carried out in the beginning of the project - not all results are updated.
- The electrical parameters such as ramping rates and setpoint accuracy are only relevant for testing purposes.
- Reactive power control is not necessary for EV-EVSE connection if a DC charger is used, since the control will take place in the EVSE.
- EVSE ID and Grid ID are not necessary for EV-EVSE communication link as this piece of information is only relevant for communication from EVSE up to the back-end actors.

6.5 Summing up

The HW technology is ready for V2G and nearly ready for VGI , but the standards are not fully mature and especially the chargers (onboard/offboard) are in an early stage and the communicational standards are lacking informational objects.

Most - if not all - standards should be able to adopt the missing informational object and thous facilitate VGI

Currently, V2G is only possible using DC charging and a fixed set of EVs and chargers using the CHAdeMO standard in its newest version but V1G can be done by all EVs that comply to IEC 61851.

For both V2G and V1G to be properly integrated in the grid the relevant standards need to be implemented and supported by both the EV, EVSE and relevant stakeholders, and all the necessary informational objects have to be supported by the standards used between them. This includes **Power setpoint, Battery size, SOC, ID.**.

The lack of informational objects in the standards are obvious when looking at the figure with the GAP analysis above. All fields in table 15 should be green or at least addressed, in order for the VGI-relevant information to be passed through to the stakeholder “behind” the interface using the standard.

7 Replicability and scalability

7.1 Replicability

The following section investigates the replicability of V2G across geographies, technologies, user groups and services. Replicability in the context of the Parker project is seen as the ability to reproduce the services, developed and tested in the project, in a commercial market within the next five years. When going into detail on market implementation the main focus will be on the FCR market, as this has been identified as the most potential market to enter within a short time horizon. The report should therefore answer the basic questions: can it be done and can it be sold?

The report will cover the key elements needed for V2G to be replicable in the future:

- Barrier analysis of selected European countries
- Segmentation of Vehicle owner types
- Standard & GAP analysis
- Value System Analysis

7.1.1 Barrier analysis of selected European countries

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, see the appendix “Barrier Analysis” and references [19]–[29][29]–[43]for more information. 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 Figure 54.

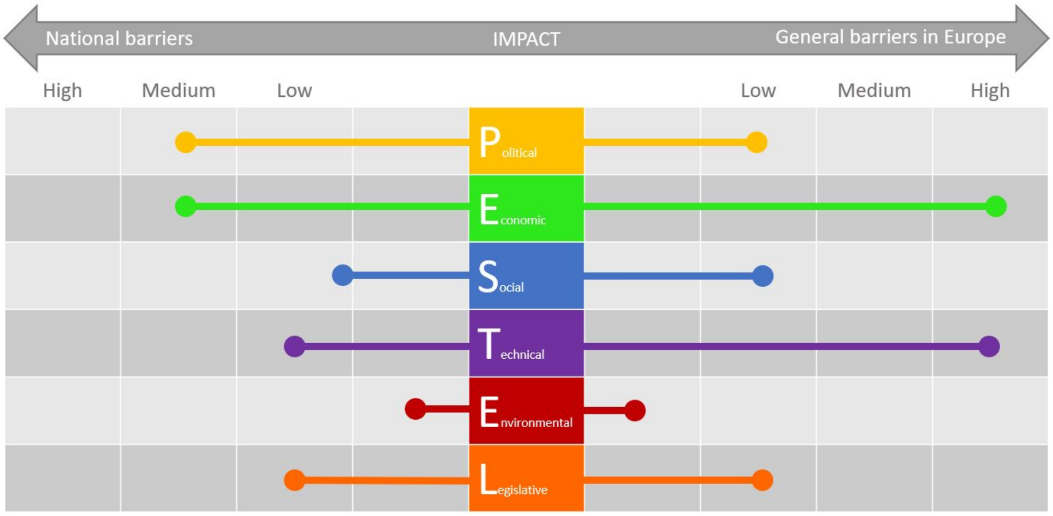


Figure 54 - PESTEL analysis - barriers in Denmark

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 Figure 55

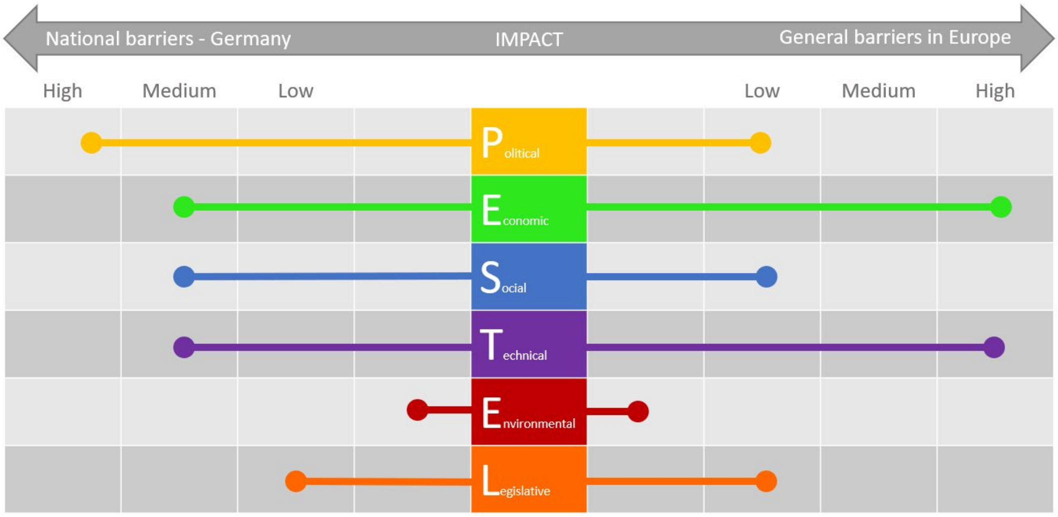


Figure 55 - PESTEL analysis - barriers in Germany

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 Figure 56.

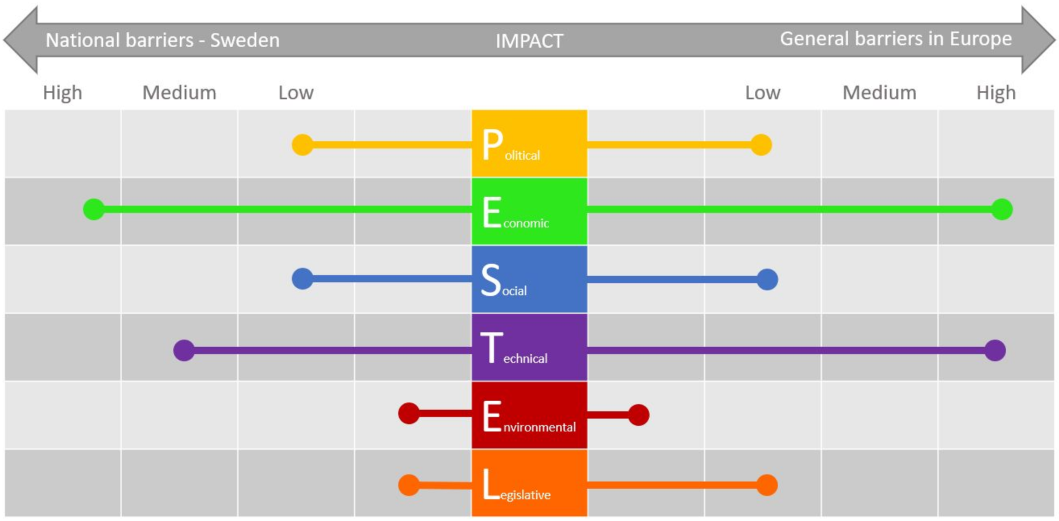


Figure 56 - PESTEL analysis - barriers in Sweden

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 Figure 57.

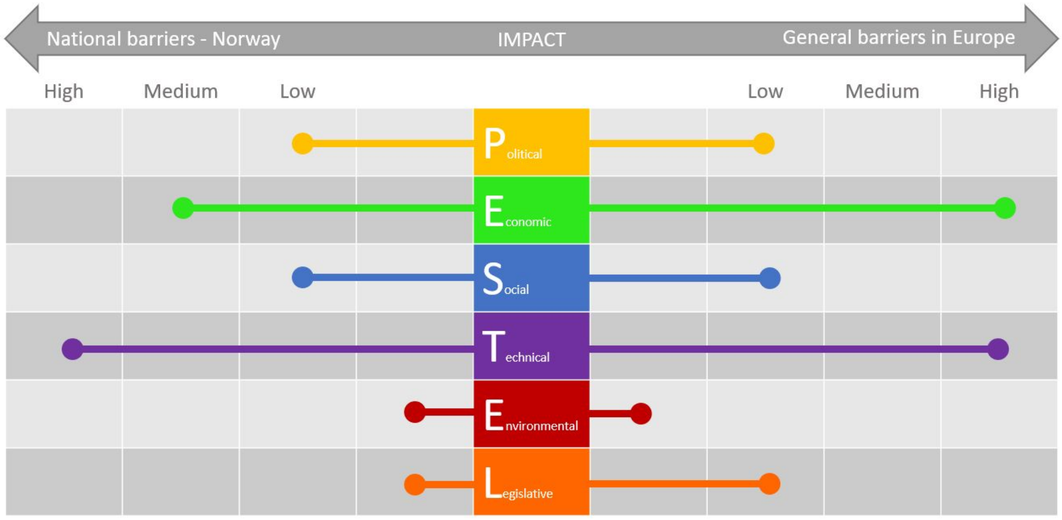


Figure 57 - PESTEL analysis - barriers in Norway

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.

7.1.2 Electric vehicle user groups

The Frederiksberg Field Pilot, described in section 5.3.1, has demonstrated the provision of FCR from a commercial fleet of vehicles parked on a private company parking lot.

The study showed that this specific fleet is available (parked and connected) for a large portion of the time and that the EV usage patterns are fairly predictable - following the companies business hours.

There are some factors, in terms of costs, charging flexibility and incentives, which inherently may be easier to manage when the EV users considered are employees at a company fleet - than it would be for other user groups.

User groups and replicability

While there are several ways to categorize EV users - two important factors are (1) where vehicles are parked, which determined when and for how long they are connected to the power system and (2) the ownership-model of the vehicle.

EV users parking options will differ according to the type of geographical location, and type of dwelling, considered.

- **Private parking**, dedicated parking spot for vehicle e.g. carport, driveway, assigned parking space.
- **Semi-public parking**, parking spots dedicated for a limited group. e.g. apartment parking garage, employee parking.
- **Public parking**, e.g. street parking, parking spots available to a large, un-restricted group.

Intuitively, rural and suburban areas will allow for a larger fraction of private parking compared to an urban environment which will rely more on public and semi-public parking.

Also the ownership models will differ and include:

- **Private cars**
- **Employee cars**
- **Shared cars**

In the case of FF we are considering **employee cars** using **private parking** (as each car has a dedicated parking place with its own charger).

While the most simple scenario may be the privately owned/private parking scenario - it is prudent to explore and understand the potential of VGI for other user groups and ownership models - especially in the light of increased urbanization and mobility-as-a-service.

In Denmark the companies DriveNow and Green Mobility provide pay-per-minute car sharing using public parking spots and charging infrastructure.

The company TADAA! provides membership based car charging to groups and communities who sign up to the platform - especially targeting housing and building association. Other car sharing groups include Let's go and GreenAbout.

Some important aspects to consider when applying VGI to other user groups:

- **Costs,** Private EV owners will be more adverse to the high upfront costs than a company owning a vehicle fleet. Such costs includes the installation of a certified DSO-grade meter (section 5.5 on barriers) as well as the DC chargers presently needed to provide V2G.

- **Charging flexibility,** One of the main motivations behind VGI is that privately owned cars are traditionally very under-utilized, remaining parked a large part of the vehicle's lifetime. This provides a lot of charging flexibility as the the vehicles stay grid-connected during long and predictable time periods. Under car sharing, however, the utility of the vehicle increases by servicing several users. As such the availability of the car, as well as the predictability of plug-in patterns, may decrease.

- **Participation willingness and incentives,** Different types of incentives may work differently on different user groups - based on user profile and ownership model there may be a difference in the degree that users are willing to allow the EV to provide grid services. In general the target should be to offer users the maximum amount of value for the least possible effort. If the users have to engage more actively by, for instance, plugging in EVs at every occasion and to explicitly describe/report the intended driving - this may be more challenging with private vehicles/parking locations - than if a company can require such behavior from its employees.

Future projects will have to understand the influence of the above aspects for different user groups.

Example - Vehicle usage at Bornholm

One parameter determining replicability is whether the driving patterns of a particular group of users allow for charging flexibility. For Frederiksberg Forsyning the flexibility was measured by investigating the usage patterns of the company fleet.

Another example is provided below where the driving on an island (Bornholm) is considered using the same metrics as above. The data used is part of the Danish National Travel Survey (http://www.cta.man.dtu.dk/english/tvu) and have been analysed as part of the ACES project (https://sites.google.com/view/aces-bornholm).

In Figure 58 the driving distance distribution of Bornholm is shown. It can be seen that typical driving distance is relatively short - requiring less time for recharging if vehicles are regularly connected to a charger.

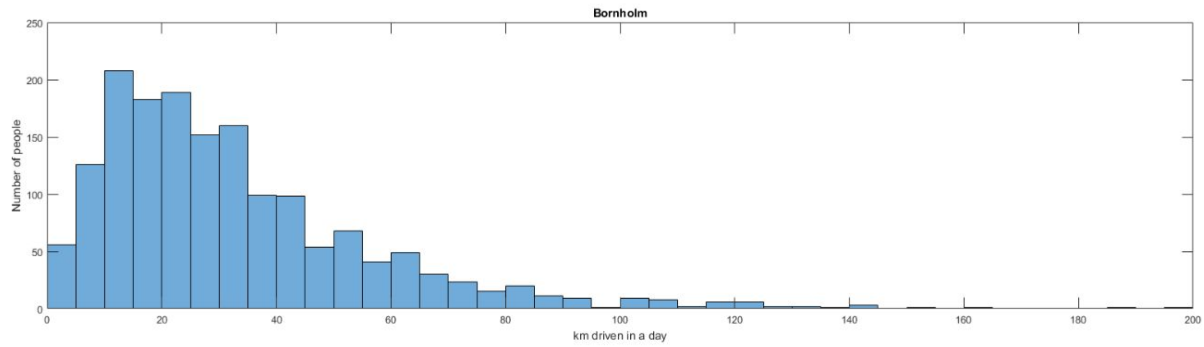


Figure 58 - Distance driven, island of Bornholm vs FF fleet, source: ACES project

In Figure 59 the workday driving activity of the island is shown - divided into arriving, leaving and driving. It can be seen that there are peaks in driving activities during morning and afternoon.

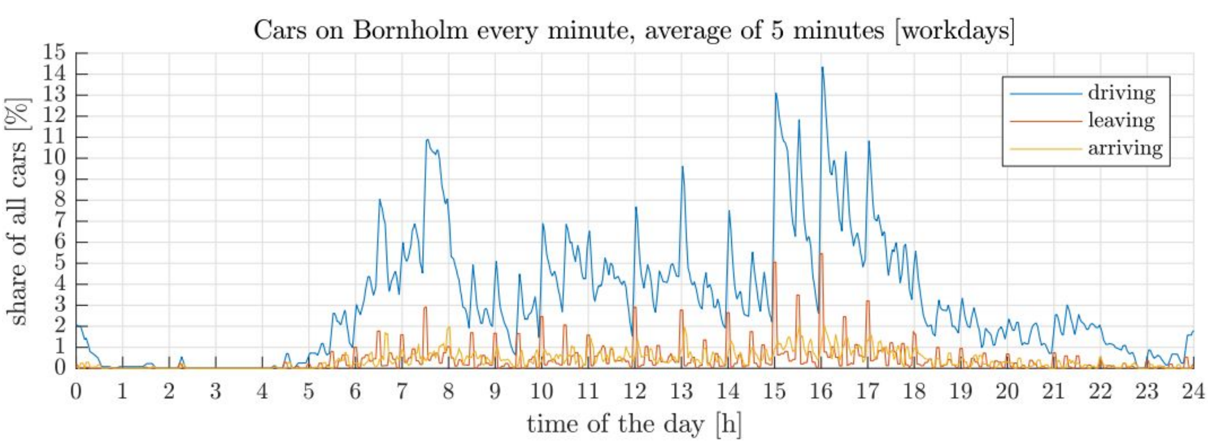


Figure 59 - Driving activity, island of Bornholm vs FF fleet, source: ACES project

The relatively small energy requirement - and concentrated usage of the cars during workday hours - is somewhat similar to what is seen at Frederiksberg and indicates that charging flexibility may also exist with this segment.

7.1.3 Value system analysis

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.
The full analysis is available in the appendix “Value System Analysis” and provides an extensive overview of the number of stakeholders and the relationships and interactions between each of these in several different market systems, based on the upcoming Danish Market Model 2.0, see section 7.2.2 for more information. Further information can also be found in the references used to create this section, [16], [41], [44]–[47].

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 Figure 60.

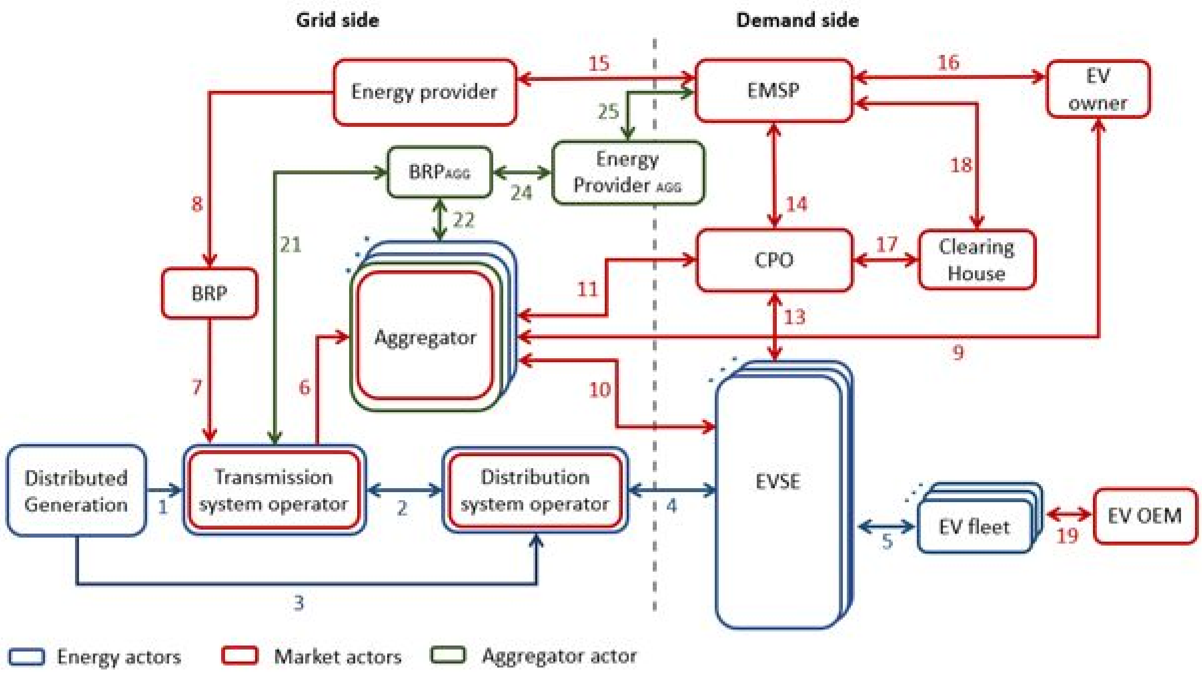


Figure 60 – Value system depiction of MM2.0 – model 3

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 direct 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 Figure 61.

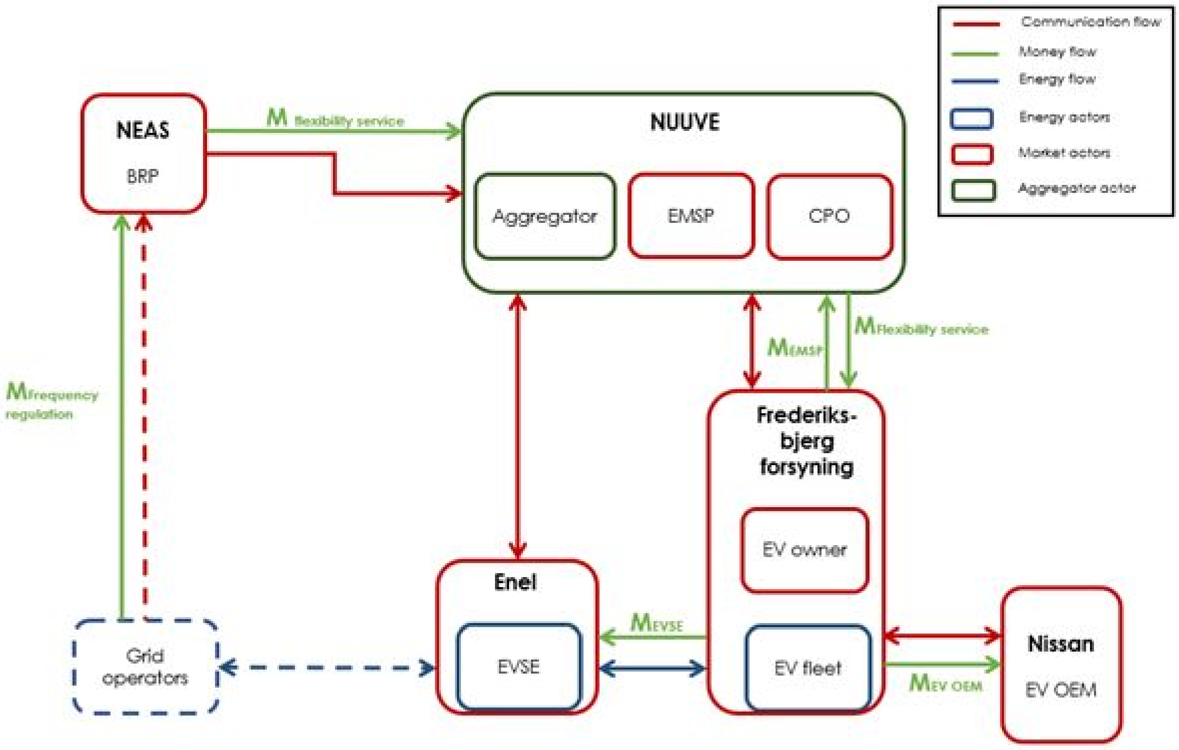


Figure 61 – Value system applied in the Parker Project

Comparing Figure 60 and Figure 61 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.

7.1.4 Evaluation of European market potential for V2G

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 (Figure 62).

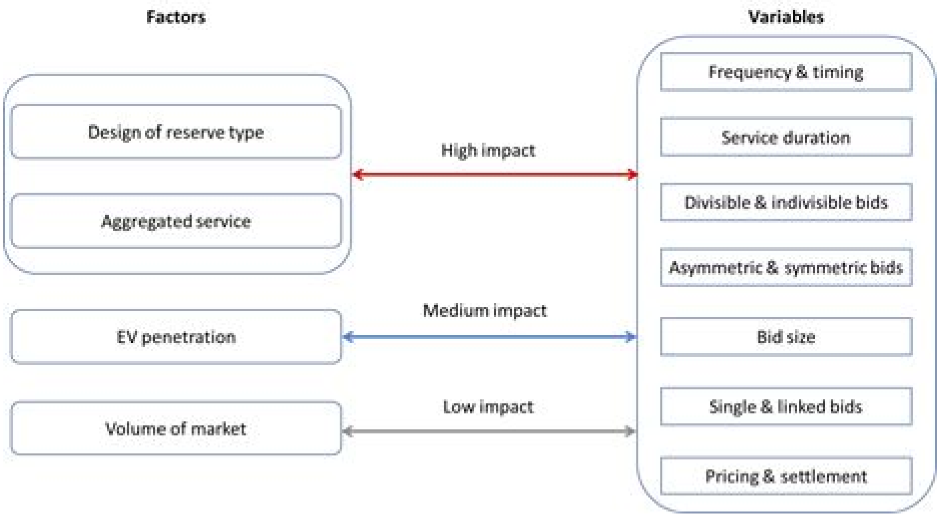


Figure 62 - Framework to assess market maturity

The survey found in the appendix "White Paper" 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.

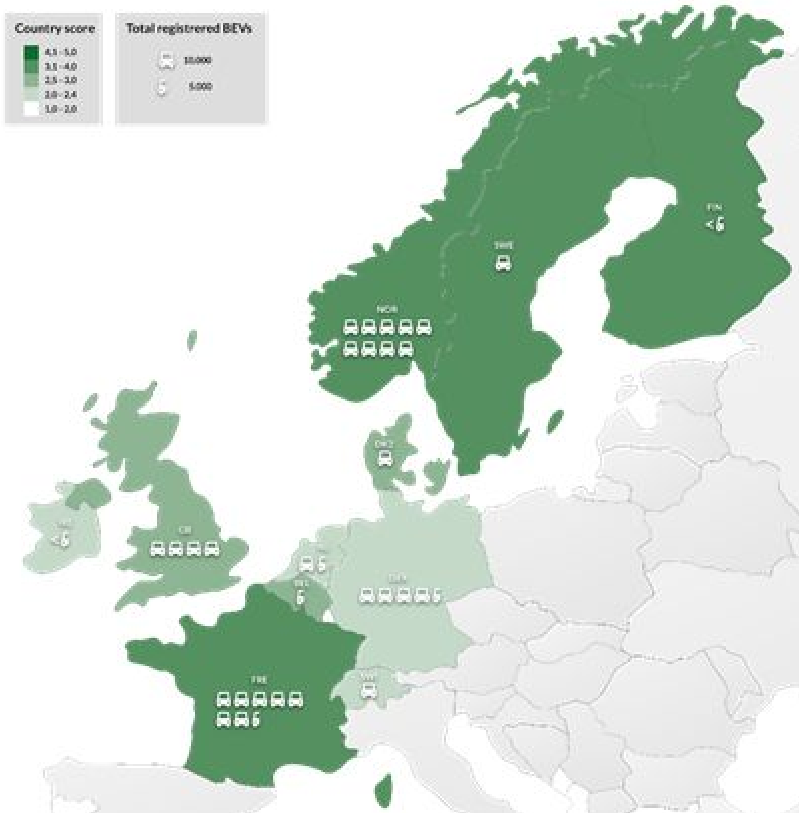


Figure 63 - Country score

7.1.5 Conclusion on Replicability

The replicability of the Parker project refers to the ability of the tested services to be reproduced in a variety of markets. The replicability is addressed from a technical and an economical point of view. The technical side of the Parker project is replicable across different European countries as seen in section 5.2.1. However, a gap analysis investigates the communication flow necessary for performing grid services. The results show that central informational standards are missing in communication flows between core actors, and this has to be addressed in order to pass information to relevant stakeholders, if a replicability of the technical aspects is going to work.

From an economical perspective, a barrier analysis showed PESTEL-related barriers in all countries. The most central issues were saturated electricity markets (Norway, Sweden), taxation issues (Denmark) and a general Internal Combustion Engine (ICE) preference (Germany). Generally, the market regulations and lack of infrastructure constitute significant barriers for the establishment of a commercial aggregator. However, an increase in the EV fleet size is likely to push a market opportunity, due to a more pressured grid and higher consumer acceptance. However, most current cars are not V2G compatible, and the same goes for chargers, hence the range of available V2G options will have to mature for the EV fleet size to matter.

A general analysis of the European countries is based on three central factors – *Design of reserve type*, *Aggregated service* and *EV penetration*. The results show a heterogeneous European market. Norway is the most mature EV market, has a well-designed reserve type and has a large EV penetration, but is mediocre in *Aggregated service*. Generally, the Nordic countries score well overall and are the most likely places to initiate V2G commercialization. France on the other hand has a low *Design of reserve type*, but high *Aggregated service* and *EV penetration*, and is a more likely market in central Europe than Germany with its strong ICE industry. Generally, throughout Europe, the market structure for aggregated services is well established, but the countries need a market *Design of the reserve type* which fits V2G better. The only current differentiator between countries is the EV penetration.

The market segmentation analysis shows that commercially managed fleets have a more stable usage pattern and are less adverse to upfront costs than private EV owners, meaning that fleet managers will be the ideal target customer for a commercial aggregator with a future possibility of expansion into private households.

A value system analysis addresses the market potential for a commercial aggregator. The main barriers stem from demand from grid operators and consumers, as well as existing market competition and regulations within grid operation. The various actors in the V2G-market will be able to engage in multiple roles at once, resulting in a strengthening of their business model through a consolidation of activities. It is critical to provide transparency regarding the question of supply security to the grid operators and driving flexibility for consumers.

In summary, there are several political, economical and competitive barriers to the establishment of a commercial aggregator operating within an FCR market. The countries are diverse in EV fleet size, and the area is complex due to variations in legislation and national market models. However, the increasingly growing EV fleet is incentivizing the need for a commercial aggregator, and the feasibility analysis shows that the Parker tests can be replicated across countries from a technical standpoint if adequate communication flows are in place. The Nordic region is deemed the most favorable market for project replication.

7.2 Scalability

The following document has the purpose to investigate the economic and technical potential and impacts on the power system and markets when applying V2G in a larger scale. Scalability in the context of the Parker project is seen as the ability to scale the services applied in the project in a commercial market in order to create a viable business – answering the basic questions: does it make economic sense?

The report will cover the key elements needed to make V2G scalable:

- Description of necessary framework for V2G services
- TSO market design for V2G
- DSO Market structures
- Potential DSO services
- Saturation analysis
- Business case evaluation

7.2.1 Description of necessary framework for V2G services

This section provides recommendations on how to promote V2G-based flexibility from EVs in Denmark.
Section 5.5 and 7.1.1 described some of the barriers currently encountered in Denmark when providing FCR with V2G-capable EVs.
Here, a number of recommendations for the support of V2G-based services are given. This means supporting Denmark's role in utilizing and commercialising the technologies and knowhow relevant to VGI.
The recommendations are primarily aimed at decision makers within the political system and public organizations tasked with supporting the development of the Danish energy sector and power system, however they can act as inspiration for other countries as well.

Transportation electrification

Denmark’s role in VGI research, development and commercialization goes hand-in-hand with the nation’s devotion and support towards the technology. A large number of EVs will allow Denmark to gain first-hand experience in developing the technologies necessary to deal with VGI. In section 7.1.4 the number of EVs is an indicator on the attractiveness of a participial country when providing V2G-based services. Having larger shares of EVs will more readily allow Denmark to host large-scale demonstrators, which in turn might attract large international organization and allow Danish companies to test and develop domestically. In addition, a certain volume of EVs are needed to enter the market and make a meaningful impact on the power system.

<u>Recommendation:</u> Denmark should have an ambitious, clear and consistent plan towards a full electrification of the Danish transportation sector.

Research and development

Denmark has a strong tradition within public support of power system research. It is important that funding toward power system research in general, and VGI research in particular, continues as to maintain Denmark's strong position in this area of R&D. Important research topics include:

- Grid impact studies
- Charging infrastructure for cities
- Battery lifetime studies
- Driving and charging patterns for EV users
- Business cases for VGI services

Also, the funding should ideally support the initialization of large demonstrators (i.e. a large number of EV users involved in field pilots) as this is the trend in e.g. UK, Netherlands, Norway, France and California.

Recommendation: National funding programs, should consider (continue) emphasising VGI research as an area of interest.

Test zones and pilots on new market designs

It is a clear target from the Danish Market Model 2.0 to utilize demand-side flexibility. Few demand-side assets can provide as much flexibility as the electric vehicle. There is, however, a need to address some barriers to fully utilize EVs potential as resources to the power system. Some of these challenges have been described for FCR services in particular section 5.5.1 and relates to:

- Regulations and tender conditions for providing services
- The design of market products matching storage-based resources
- Economic barriers when providing services behind-the-meter

Energinet has already launched a number of pilot projects which have successfully identified some solutions for using distributed energy researches and flexible demand in the market. Further, discussions are ongoing on the creation of a national test zone where new market structures, mechanisms and perhaps even energy tariffs/fees can be applied on an experimental basis.

Recommendation: Pilot projects and test zones supported by the Danish government and Energinet are very effective ways of identifying market-based and regulatory barriers for demand flexibility - but also to explore entirely new ways of using and incentivising flexibility.

International collaboration

It is important that Denmark collaborate with international groups and organizations that may aid harmonization and standardization relevant to VGI. Energinet is already engaging with other TSO's in the nordics and as part of ENTSO-E to harmonize market rules and regulations applying to aggregators of demand-side flexibility. Another example is the International Energy Agency (IEA), Hybrid and electric vehicle technology collaboration program. EUDP is currently supporting Danish participation in this program which allow Danish researchers to collaborate with other international experts as well as industry.

Recommendation: It is important that Denmark collaborate internationally, both within market and standard harmonization - as well as within research. The means that funding should be made available for such collaboration.

7.2.2 TSO market design for V2G

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; more information on this can be found in appendix "TSO market design" and in the references [16], [41], [45], [47], [55]–[57].
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 Table 16.

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.

Table 16 - 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 Figure 64. 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.

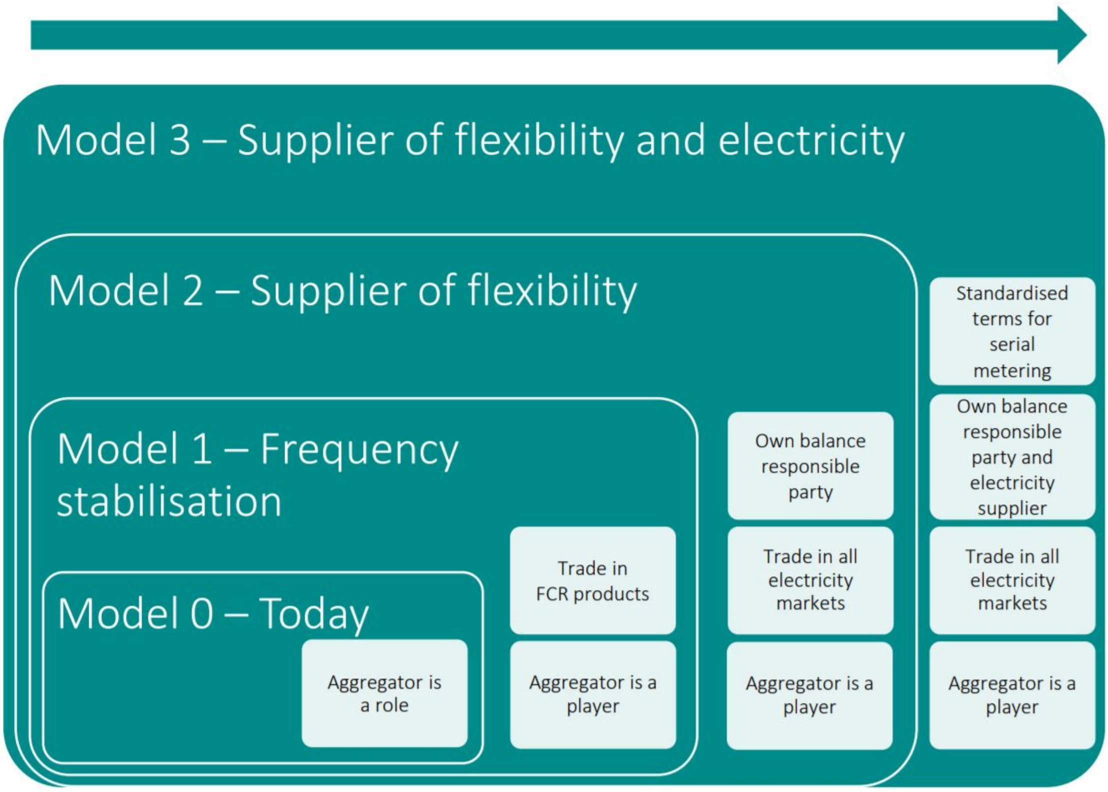


Figure 64 - Expansion philosophy of Market Model 2.0

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.

7.2.3 DSO market structures

The potential for the application of V2G services in the DSO market has often been mentioned. However, there is no existing and clearly defined market structure that enables this in any European country. Therefore, a DSO market analysis has been conducted to provide recommendations for this in order for the potential to be realized in scalable conditions. The analysis is divided up into two parts; the first part includes the choice of the market structure which is optimal for the DSO. The second part include a cost analysis of the transformer and the cables in an expanding scenario of the DSO compared to the flexibility service of an aggregator.

Market structure

Table 17 shows the four market structures chosen from 30 possible scenarios. See the Appendix "DSO market design" for the complete analysis.

Buying option	Market place	Description
Long term contract	**Call for tenders**	A market structure where the DSO sends out their requirements and the aggregator responds with tenders. The DSO makes the decision on which tender they accept and a contract is made between the DSO and the aggregator, based on months/years cooperation.
Service contracts (leasing)	**Negotiations**	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 provides the service of flexibility whenever it is needed by the DSO.
Auctions	**"Danishpool" 4 DSO**	A market structure 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 is.
Coupons	**Call for tenders**	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.

Table 17 - The four market structures

The four market structures were introduced to five experts to get their feedback on which they saw as the market structure with the most potential in the near future. The result can be seen in Table 18.

	1. Long term contract/call for tenders	2. Service contracts/ Negotiations	3. Auctions/ "Danish pool" for DSO	4. Coupons / Call for tenders
Project leader, DSO	The best solution.			
Lead Business Developer, DSO	It can happen if the Winter package is enacted – it could happen in the near future.	Best market structure – most realistic in the near future.	In the long term – some fundamental issues in the market have to be changed.	The price principle is very interesting in Radius' perspective.
Program Manager, Smart Energy, University		Could be used for time contracts.	Is not possible right now.	
Senior Researcher, University	This could be on the road for reaching #3.	The first opportunity in the near future.	A future market structure – the ultimate solution.	This could be on the way for reaching #3.
Special Advisor, Energy Agency	In the future when there are more providers. Will probably be the most obvious in the future.	Very simple as a start.	In the future when there are more providers (could be made with international aspect as well).	In the future when there are more providers.
R&D Project Manager, BRP	No clear conclusion was reached			

Table 18 - The six experts and their choice of market structure

From the interviews with the experts, the potential market structure chosen is where one DSO and one aggregator negotiate and agree on a service contract. However, it is seen as the market structure in the near future. Market structure 1 and 4 are seen as potential steps on the way to reach a market structure. The latter is seen as the ultimate solution in the future, but the market must see fundamental changes for this to happen. (See Appendix "DSO market design" for a deeper analysis).

Cost analysis

In order to figure out what a DSO is potentially willing to pay for the flexibility services, it is necessary to look at the alternatives for the DSO.
Currently, when the DSO experiences their grid reaching the max capacity in an area, the solution is often one of the following two; upgrade the transformers or install more/longer cables. However, it is not always the most cost-effective solution to strengthen the grid. As the cables and transformers are expensive to replace, the replacement has to be approved by the regulator, the consumers will bear the cost of the replacement, and the environmental footprint is not necessarily positive.
Replacing the transformers is done by replacing the existing transformer by another MV/LV transformer with a higher nominal current. When adding new cables to the grid, cables rated for higher nominal current are selected. Higher nominal current is linked to a higher cable section. In urban and semi-urban areas it is mostly underground lines that are used for the distribution grid. The replacement cost is high as it is very costly to lay down cables due to the existing road infrastructure. The price of the cables depends on:

- What area the cables must be laid within – is it in the rural area, the middle of the big cities or in the countryside,
- The length of the cable – depending on the area where the cables has to be replaced or added.
- The capacity of the cable – the capacity of the cable depends on the needs in the area of replacement.

As calculation of the price of cables depends highly on the three parameters above, it has not been possible to get a price calculation of one scenario from any supplier. Therefore, the price of the cables is not included in this calculation.
The price of transformers depends on the size of the transformer. Two examples of prices of a 10/04 kW transformers have been received from a supplier and are shown in Table 19:

Size of transformer	Price (approximate)
1,000 kVA 10/04 kW	DKK 85,000 pr. transformer
1,600 kVA 10/04 kW	DKK 120,000 pr. transformer

Table 19 - Prices for two 10/04 kW transformers, (Jensen, 2018)

The prices of the transformers are without installation price. For the further calculations a price of 100,000 DKK has been chosen as this represents an approximate average of the two prices found in Table 19. The installation price is assumed to be 40 % of the transformer price.

Cost analysis		
For the cost analysis the price of a transformer is set to be 100,000 DKK and the price of installation is assumed to be 40% of the transformer price.		
Transformer price (approx.)		100,000 DKK
Installation price	40% of 100,000 DKK	40,000 DKK

Total price		140,000 DKK
The depreciation period is set to be 10 years		
The depreciation price pr. year (140,000/10)		14,000 DKK/year
Monthly depreciation	14,000 / 12 months	1,167 DKK/month
Monthly expense for balancing is set to be 60% of the monthly payment		
Monthly expense (60% of 1,167 DKK/month)	700 DKK/month	

Table 20: Cost analysis

As seen in Table 20, the monthly depreciation will be approximately 1,167 DKK/month over a period of 10 years if the DSO chooses to change their transformer by this time.
The predictability of an investment in a new transformer is very high, as this is a known scenario for a DSO, as opposed to buying balancing services from a third party, e.g. an aggregator. Therefore, there has to be an economic advantage of buying balancing from an aggregator. If balancing with V2G has to be an advantage for the DSO instead of replacing their transformers, the monthly expense for balancing is assumed to be a maximum of 60% of the monthly depreciation value for the transformers. Under the described assumptions, the potential monthly revenue for balancing a DSO grid radial can be up to 700 DKK.

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[1] MV = Medium Voltage, LV = Low Voltage

7.2.4 Potential DSO services

Increase in the penetration of EVs, mainly motivated by environmental challenges and economic incentives, can also increase the flexibility of power systems. It is suggested that the flexibility provided by EVs can support power system operational planning, thereby avoiding new investments in power systems. Due to the manageable nature of their loads, EVs, specifically vehicle-to-grid (V2G) enabled EVs can be used to support the grid by providing several power and energy based services to Transmission System Operators (TSOs) and Distribution System Operators (DSOs). They can also be used to facilitate the integration of renewable and distributed energy sources (DERs) to distribution systems. Fig. 65 indicates some services that can be provided by EVs to different parties in power systems.

Although ancillary service provision by EVs to TSOs is a well-known concept, the concept of Distribution System Service (DSS) is a new paradigm that has been emerging in conjunction with the new roles assumed by DSOs within the smart grid context. EV-DSS appears as a set of flexible services that are provided to maintain optimized and reliable operation of local grids. As indicated in Figure 65, EV-DSS can be divided to three main categories namely active power support, reactive power support and facilitating renewable integration.These services are related to the neighborhood and building/home domains in the Parker service catalogue.

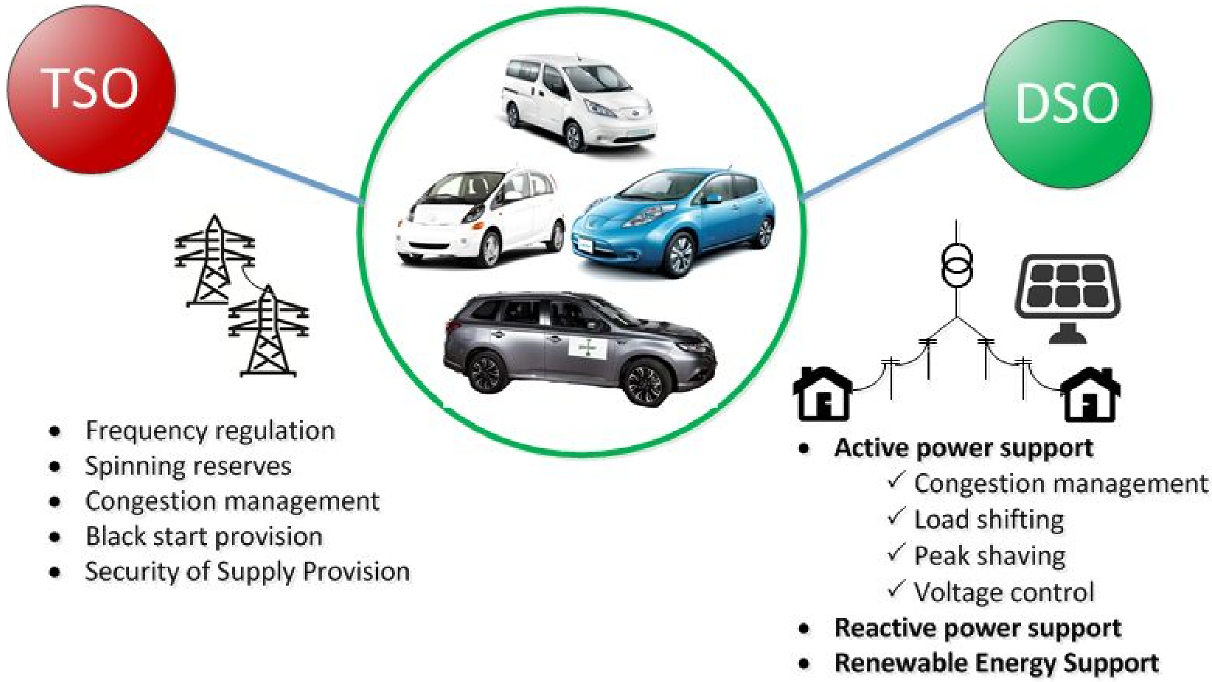

Figure 65 - services provided by EVs to power systems.

Active power support:

Load shifting, peak shaving, valley filling, and load leveling are among active power services that can be provided by EVs to DSOs. As the EV load is manageable, its consumption can be transferred to a period with less congestion in the grid or lower energy price. In addition to their manageable load consumption, V2G-enabled EVs can act as a generation unit and provide more flexibility to distribution systems. It is worth mentioning that as the resistance to reactance (R/X) ratio of conductors in Low Voltage (LV) distribution systems is relatively high, voltage in LV grids can be controlled by active power management of EVs. As a result, the EV charging/discharging can be controlled in order to increase or decrease the voltage at the EV connection point. A detailed discussion on active power services can be found in [58]

Reactive power support:

In the traditional grid operation, conventional power plants were considered the main contributors to the provision of reactive power. In the future it is expected that the entire power system is operated with DERs as conventional power plants will have a residual presence in renewable-based energy systems. This leads to a more active management by DSOs to operate the grid using the flexibility

provided by DERs, and leaves room to other resources providing such service, e.g. EVs. A proper cooperation between DSO and EV owners and/or aggregators must be supported by the right market-based incentives. These initial steps foster the potential for having a local reactive power market. Therefore, a proper tariff scheme has to be designed for this new EV service when they are also charging. The DSO will benefit from this local reactive market because it guarantees a collaborative participation of EVs to address a grid problem that traditional power plants can no longer solve. Such market perspective relies on a bottom-up perspective, by letting the EVs cooperate in the DSO operational planning, namely through the reactive provision for voltage problems.
In addition to the potential for participation in the reactive power markets, grid upgrade deferral and power losses minimization are among other services that can be provided by EVs. Increasing penetration of EVs may cause a voltage drop issue in distribution systems, and reactive power provision by EVs can eliminate or postpone distribution system upgrade. The DSO has the economic benefit of not spending its budget on new grid infrastructures, and gains more time without grid problems that it could be used on selecting the best grid upgrade plan. Overall, the DSO has a twofold benefit: *(i)* money saved with grid upgrades, and *(ii)* more time without voltage problems. Furthermore, the EVs' reactive provision can be considered as a strategy to minimize the grid power losses. It is specifically reached when reactive power provision causes low extra losses in the charger. Under this circumstance, the DSO can even use EV reactive provision when there are no voltage problems. A detailed discussion can be found in[59].

Renewable integration support

Along with EVs, RES integration into distribution systems is emerging as a means to cope with environmental issues. However, high penetration of RES may cause operational problems to the grid due to their intermittency, bringing additional challenges for DSOs. The joint operation of EVs and RES seems as a good option for DSOs to deal with these issues. The services included in this category refer to those in which EVs help to support the integration of RES into the grid, by mitigating the intermittent output power from photovoltaic (PV) systems or Wind Turbines (WTs). In addition, the EV energy consumption is encouraged during the periods of high RES power production in order to avoid overvoltage and congestion in the grid. A detailed discussion can be found in [58].

Stacked DSO and TSO services

Stackability is the possibility of combining different services, for instance frequency regulation and EV-DSS. Services in the category of active power support such as congestion management, load shifting, peak shaving and valley filling can be combined with frequency regulation because these services are mainly constrained to the time. To this aim EVs are activated during specific periods of time and according to the requirements of the distribution grid, e.g. peak hours. Then EVs can be used during the remaining time to provide other services such as frequency regulation. However, the combination of these services is limited by the kind of time-scheduling and it is applicable only if it is scheduled in advance. Combination of frequency regulation and reactive power support is also applicable, as active and reactive powers can be controlled independently in EV chargers. There is also a high possibility of a combination between frequency regulation and RES integration support. EVs can be used during specific periods of time to facilitate the integration of RES, and in the remaining time they can be used to provide other services such as frequency regulation. However, it requires advanced control systems since EVs should be ready to provide the requested service at any time. In addition, the priority of services should be defined. Figure 66 shows a typical architecture of a centralized control framework for provision of frequency regulation and reactive power support simultaneously.

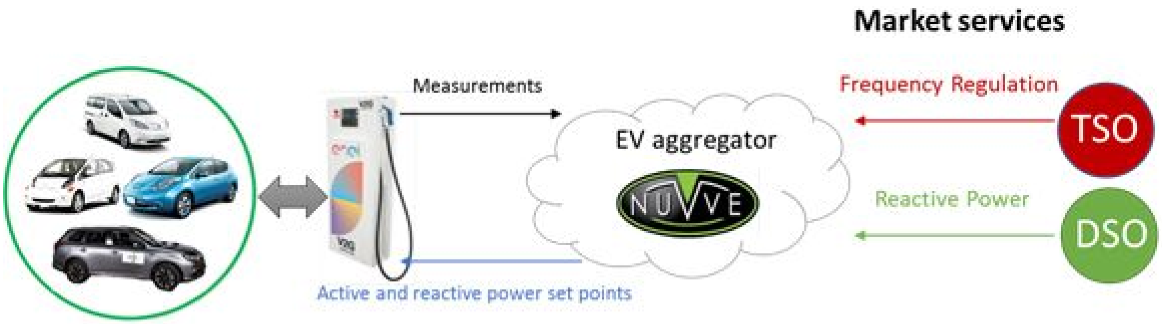

Figure 66 - an overview of stacked services provided by EVs

7.2.5 Saturation analysis of FCR in DK1

The saturation analysis serves as an example calculation on how many EVs are needed to saturate one product (FCR) in one geographical market zone (DK1) based on historical numbers. The purpose of the calculations is to showcase the amount of EVs needed in Denmark before one of the potential products have been exhausted.
As 2016 was a leap year, it resulted in 366 days in the year corresponding to 8.783 hours where the FCR have been used. Before going to the calculations, it is important to notice, that there is a difference in the down-purchase prices and the up-purchase prices. The lowest down price in 2016 where 3 DKK/MW, where the highest was 300 DKK/MW. The price span for up regulation ranged from 10 DKK/MW at the lowest and 625 DKK/MW at the highest. When comparing the average for the two through 2016, the average for up-purchased MWh were over 10 times higher at 119 compared to 11,11 for down price purchased MWh (Table 21).

	FCR **Down** price DKK per MW	FCR **Up** Price DKK per MW
Lowest	3,00	10,00
Average	**11,11**	**119**
Highest	300,00	625,00

Table 21 - Price comparison FCR down and up

To find out how many electric vehicles it would take to replace the FCR-N in DK1 in 2016, two different approaches have been calculated 1) the simple and 2) the detailed. The calculations are based on data from Energinet, where it is only possible to get data for the western part of Denmark (DK1). This is due to a collaboration between Denmark and Sweden for eastern Danmark (DK2), where some data is not public.

1) The simple calculations

The calculations are constructed by using a simple method, based on three core assumptions:

- All vehicles are connected to the "charger" all the time
- All vehicles can fulfill the need of both delivering and receiving power to cover FCR.
- Both FCR down and FCR Up perform at a 10 KW power level.

With each vehicle being able to deliver 10 KW up or down, then it takes 100 vehicles to deliver 1MW. To deliver 10 MW, the number of vehicles is 1.000.

The FCR is activated numerous times every day. The available data are constructed on a minute basis, and the peak value for a single minute is what sets the highest threshold for the needed flexibility. In order to section the day, the numbers are transferred into an hour to settle the highest and lowest number of needed EVs available during the year.

The smallest amount of down-purchased MW in an hour was 13 MW where it is 5,2 MW respectively for up-purchased MW in an hour (Table 22).

	FCR_**Down** purchased MW per hour	FCR_**Up** purchased MW per hour	Vehicles to deliver MW for **Down**-demand	Vehicles to deliver MW for **up**-demand
Lowest	13,00	5,20	13.000	5.200
Average	14,77	14,75	14.774	14.751
Highest	42,80	34,90	42.800	34.900

Table 22 - FCR purchased and number of vehicles

There is a significant difference in the distance between the lowest, average, and highest demanded MW. Therefore, it is interesting to analyze different scenarios with varying sizes of fleet's ability to cover the FCR market in 2016. This is especially interesting since it cannot be expected that a fleet will go from 0 to 50.000 in an abbreviated time period. It takes time before the desired fleet size can be obtained.

FCR Down		
Fleet amount	Hours covered (total = 8.783)	% of hours covered
Average (14.774)	6.346	72,3%
16.000	8.097	92,2%
18.000	8.282	94,3%

FCR Up		
Fleet amount	Hours covered (total = 8.783)	% of hours covered
Average (14.751)	5.878	66,9%
16.000	7.209	82,1%
18.000	7.906	90,0%

20.000	8.314	94,7%	20.000	8.010	91,2%
22.000	8.350	95,1%	22.000	8.158	92,9%
25.000	8.454	96,3%	25.000	8.650	98,5%
42.800	8.783	100%	34.900	8.783	100%

Table 23 - Fleet size for FCR down/up and hours covered

Table 23 shows the fleet size needed to fulfill the demand. There is a need for both up and down purchasing every hour, so some cars must be able to take power while others need to deliver power at the same time. In august 2016, there were several hours where the need for FCR was high, both for up and down. The highest amount that was needed for combined Down+Up MWh per hour was 73,20 which was on the 19th of August in the 4-time slots 18,19,20 and 21.

2) The detailed calculations

It is optimistic to believe that vehicles will always be available to deliver or receive the necessary demand there is for FCR. There are a lot of factors that have an influence on whether a vehicle is available or not. The most common use of a car in Denmark is work-related commuting. This gives the vehicles a high possibility of being away from the charging/receiving station during that time frame.

There are other things that affect the availability of the vehicle:

- After work people often have errands - it can be shopping, picking up kids, doing sport/fitness etc.
- During the weekend, there can be activities during the day or evenings, where people need the vehicle.
- There will often be multiple cars per household

The assumptions for these calculations are:

- Vehicles are only available when they are at home
- All cars can assist in this process, whether people live in houses or apartments.
- Most people are working 7,5 hours a day and there is some transportation time
- The vehicles all have the same pattern.

To calculate the possibility of the vehicle being at a house to charge/receive, the following percentage possibilities are used. A random probability between minimum and max is assumed based on a generic profile of an 8-16 worker. The probabilities are the same for weekdays and weekends.

To give an overview of what a random sample look like for a week, the following table is used.
This is one table out of 200 used in a Monte Carlo simulation. The percentage shows that the vehicles are mainly at home and available outside the normal working hours. This is a simple method within the complicated to make these calculations and percentages accurate and based on empirical observation, it would take a lot of time collecting data.

Based on the 200 simulations of randomly selected percentages of the possibility for vehicles to be available to replace the demand for FCR, these are the calculations for the FCR down purchased MWH per hour in DK1. Comparing the Simple calculation with the detailed, a fleet size of 14.774 EVs could in the first calculations cover 72,3 % of the needed balancing. In the detailed calculations, this number has changed to 28 %, which is a significant drop of almost 45 %.

Fleet size	14.774	30.000	60.000	90.000	120.000	150.000
Minimum	26%	59%	73%	76%	80%	85%
Average	28%	64%	75%	79%	86%	90%
Max	30%	67%	77%	82%	90%	96%

Table 24 - Fleet size for replacing FCR

It can be seen from Table 24, that commuting increases the need for a greater fleet. With a fleet of 150.000 vehicles , under the current assumptions, the vehicles can cover up to 96% of the hours for the FCR down purchased demand. As the main cause for the higher number in the detailed calculations is the lack of available cars during daytime, the needed amount of EVs to saturate the demand for FCR services during night will be far lower - expectedly closer to the number found in the simple calculations.

To rely 100 % on vehicles to replace the FCR, it takes a much larger number of vehicles than 150.000 with this method and this data. There are different ways to make the need for EVs lower. The most obvious is to have charger stations at workplaces to assist in the timeframe where vehicles are away from home. With an introduction of smart grid chargers at workplaces, shopping centers, and other public locations, the percentage of vehicles available will be much higher almost all the time.

It is not possible to find the perfect fleet size since availability of EVs is related to future behavior of people and their varying need for transportation combined with the future need of MW for balancing. This means that there are a lot of things which need to be considered when trying to find the optimal minimum fleet size:

1. The weather changes behavior and choice of transportation.
2. Behavior and needs of all individual drivers and their vehicle(s).
3. The need for flexibility balancing power in the future.
4. Electric vehicles need charge and people want it to be sufficiently charged when they need the vehicle. This increase the need for energy, which must be included in future calculations.
5. The fleet size will be rising slowly, it is not possible to replace the current FCR sources from one day to the next, as EV-uptake takes time.
6. To rely on the availability of EVs, it takes some sort of agreement with the owners of the vehicles. To solve this problem and item number 4 on this list, the electricity prices must vary, so that people not only want to charge their car in the peak hours, but during off-hours as well.

As seen from the difference in the results from the basic calculations to the detailed calculations, adding more variables and assumptions to the evaluation, significantly changes the outcome. It is assumed that the current report provides a valid conclusion on the level potentially needed to fully saturate the FCR market of being significantly beyond 150.000 EVs in the DK1 area, whereas saturation of the overnight market would be possible by a significantly lower number estimated around 42.800 EVs. A final conclusion on the exact amount of vehicles has not been identified, and adding the assumptions above to the calculations already done, would make calculations even more complex.

7.2.6 Business case evaluation

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, for more information see the appendix "Business Case" and the references [16], [60], [61]. 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 Table 25 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

Table 25 - 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 Table 25.

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.

7.2.7 Conclusion on scalability

Scalability deals with the question of technical and economic potential of a V2G system on a larger scale. There is in principle nothing that prohibits a scale up of the V2G system components, as can also be seen in section 5.2.1. However, it requires the right antecedents in the market to succeed. Technical experts support a TSO market in which the MM2.0 Model 2 moves towards a market where commercialized aggregators cooperate with BRPs in declaring the availability provided by the aggregator digitally. This is easily scalable and has interesting development opportunities. Aggregators favour the MM2.0 Model 3 in which a meter is integrated in each individual subsystem to designate the exact availability, in order to have clear legal borders in relation to own assets. The current Danish system operates under Model 0.
A market design analysis shows that V2G has the potential to play a significant role in providing grid flexibility, but there are technical challenges to be overcome - uncertainty about degradation of batteries, lack of standardization of communication and lack of consumer knowledge of the V2G-system.

In terms of a DSO market structure, there is no current market. However, experts recommend a market structure of service contracts in which the DSO and the aggregator negotiate, resulting in a monthly fee from the DSO to the aggregator in exchange for availability. This is generally seen as the most viable option in a short-term timeframe.

EVs hold the potential to support the grid in three different ways. Grid stabilization: active power support (peak shaving, valley filling and load levelling), reactive power support (can replace power plants as reactors to grid problems), and renewable integration support (solve intermittency problems – act as mobile batteries). Hence providing reliability in a system that face increasing demand, whilst relying on intermittent solutions.

In terms of the necessary fleet volume of the solution, a saturation analysis shows how many V2G-compatible EVs are needed to create complete coverage for FCR in the DK1 region. Simulations show that 150.000 EVs are needed for 97% coverage and considering that some simplifying assumptions are made in the analysis, the actual number is very likely higher. The analysis shows that there are significant variations in MW up and down demand, spanning from 13 MW/hr to 42 MW/hr and from 5,2 MW/hr to 34,9 MW/hr respectively. More detailed research into the effects of weather conditions, individual driving patterns, future need of power balancing and realistic growth in EV fleet size will have to be conducted to create more realistic assumptions, providing a better estimate, but 150.000 EVs provide a guiding minimum for a near full saturation.

The V2G solution requires that it is a beneficial option for the TSO or the DSO in terms of costs.

A DSO has various options when facing max capacity: upgrading transformers or expanding cables. Meeting demands via aggregators will have to be cheaper than the cost of depreciation of new transformers and cables. The potential monthly revenue for balancing a DSO grid radial is calculated to be up to 700 DKK.

A business case evaluation of the TSO V2G market, providing FCR-N services, shows three scenarios for profits/EV/year. The evaluation includes availability payments from the TSO as well as factors such as the cost of bi-directional charger investment, wear of the battery and loss of power in transfer. The eventual result is that the profits can span from a loss of 7.000DKK/EV/year in the worst case to a profit of 17.000DKK/EV/year in the best case, depending on actual investment costs and the size of availability payments. The business case is assumed to improve with the continued maturing of the technology.

Conclusively, there are potential revenue gains in V2G markets for both the DSO and the TSO, in their respective market models. In terms of scalability, both the DSO and the TSO markets provide the option of a scalable V2G business model with an associated revenue yield.

In summary, the V2G solution is scalable from a technical and a long-term financial standpoint and can provide nationwide grid stability. However, it requires a significantly larger EV fleet, the creation of a DSO market platform, and finally it requires battery and charger technology to mature to ensure a positive business case. All market models seen throughout Europe show potential for improvement, and there are definitive gains to be made if that potential is realized.

Under the current framework test in the Parker Project, it has been shown that there are potential profits with a small fleet of electric vehicles. No technical limitations have been found that will limit the scalability of the business model in Denmark, and the economic gains show that the first step has now been taken towards the commercialization of V2G in a market. However, for V2G to be successful on a large scale, the industrial and political actors will have to push the agenda in terms of legislation and technology availability.

8 Appendix list

All appendixes referred to in this report can be found in a separate appendix document in the following order:

1. MTR3 data sheet
2. Barrier Analysis
3. Value System Analysis
4. White Paper
5. TSO market design
6. DSO market design
7. Business Case

The appendix document can be found on the project webpage www.parker-project.com under "downloads".

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