Final report

1.1 Project details

Project title	Parker
Project identification (program abbrev. and file)	2016-1-12410
Name of the programme which has funded the project	ForskEl / EUDP
Project managing company/institution (name and address)	DTU Electrical Engineering Department of Electrical Engineering Ørsteds Plads Building 348 2800 Kgs. Lyngby Denmark
Project partners	DTU, Nuvve, Nissan, Insero, Enel X, Groupe PSA, Mitsubishi Corporation, Mitsubishi Motors Corporation, Frederiksberg Forsyning
CVR (central business register)	DK 30 06 09 46
Date for submission	April 30th 2019

1.2 Short description of project objective and results

English:
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).

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 and as part of a fieldtest at Frederiksberg.

The projects successfully demonstrated the vehicles ability to provide grid services using V2G and directly contributed to the commercialization of the technology with EVs participating in the ancillary service market in Greater Copenhagen and Bornholm.

Dansk:
Parker projektet var et Dansk demonstrationsprojekt med fokus på netintegration af elbiler – på engelsk: Vehicle-Grid Integration (VGI). Projekets overordnede mål var at teste og demonstrere moderne elbilers evne til at levere avancerede ydelser til elnettet ved brug af Vehicle-To-Grid (V2G) teknologi.

Projektet havde adgang til en række elbilsmodeller og V2G ladestandere leveret af projektets industrielle partnere. Disse blev brugt i en række tests og demonstrationer både i DTUs PowerLabDK faciliteter såvel som i et feltstudie på Frederiksberg.

Projektet har bevist at teknologien (elbiler og ladestandere) er klar til at levere V2G-baserede ydelser og har været med til at skubbe på kommercialiseringen af denne teknologi i Danmark som i øjeblikket leveres både i Storkøbenhavn og på Bornholm.

1.3 Executive summary

The Parker project investigated three main topics: **Grid Applications**, **Test Protocol** and **Scalability and Replicability**.

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.

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. 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 Frederiksberg Forsyning, the project analyzed 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.

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 full project report, and links to the project publications, can be found on the projects webpage : www.parker-project.com

1.4 Project objectives

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).

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.

- **Grid applications**, Explore and demonstrate new EV services using state-of-the-art vehicles and chargers.
- **Grid readiness**, Create a common definition of technical capabilities needed to support services
- **Scalability and replicability**, Understand scalability in terms of system and market impacts and replicability across users and regions.

The project was organized in three phases which focused on the experimental validation which should be carried out in the lab and the field.
The **Pre-pilot phase** was used to prepare the experimental setup and technology and ensure that all systems were installed and ready.
The **Pilot phase** represented the actual execution of the demonstration work and finally the **Analysis phase** focusing on the data and lessons learned through the pilot.

The project was originally scheduled as a 2 year project – but was extended with 6 months (See Figure 1 below)

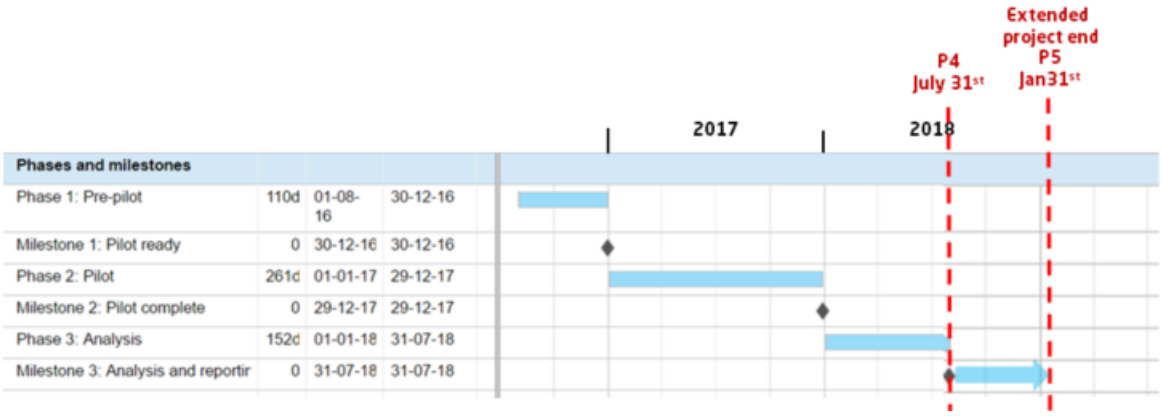


Figure 1 - Parker phases

The six month **was needed due to:**

- Extended scope and partner participation compared to original application
- Delays in experimental work (for a large part technical difficulties)

The delay caused by additional (self-funding) partners joining the project after the project had been granted was unexpected – but is belivied to have had an overall positive effect on the project. The new partners were: PSA ID, Mitsubishi Corp, Mitsubishi Motors and Enel.

The original project application described the projects use of new/state-of-the-art technology as a project risk with high impact but low likelihood. This assessment was perhaps naive – especially since the inclusion of additional partners meant an increase in the technology used (more cars to be tested).

Besides from this six month extension - the project proceeded as planned and was able to meet its objectives.

1.5 Project results and dissemination of results

1.5.1 Grid applications

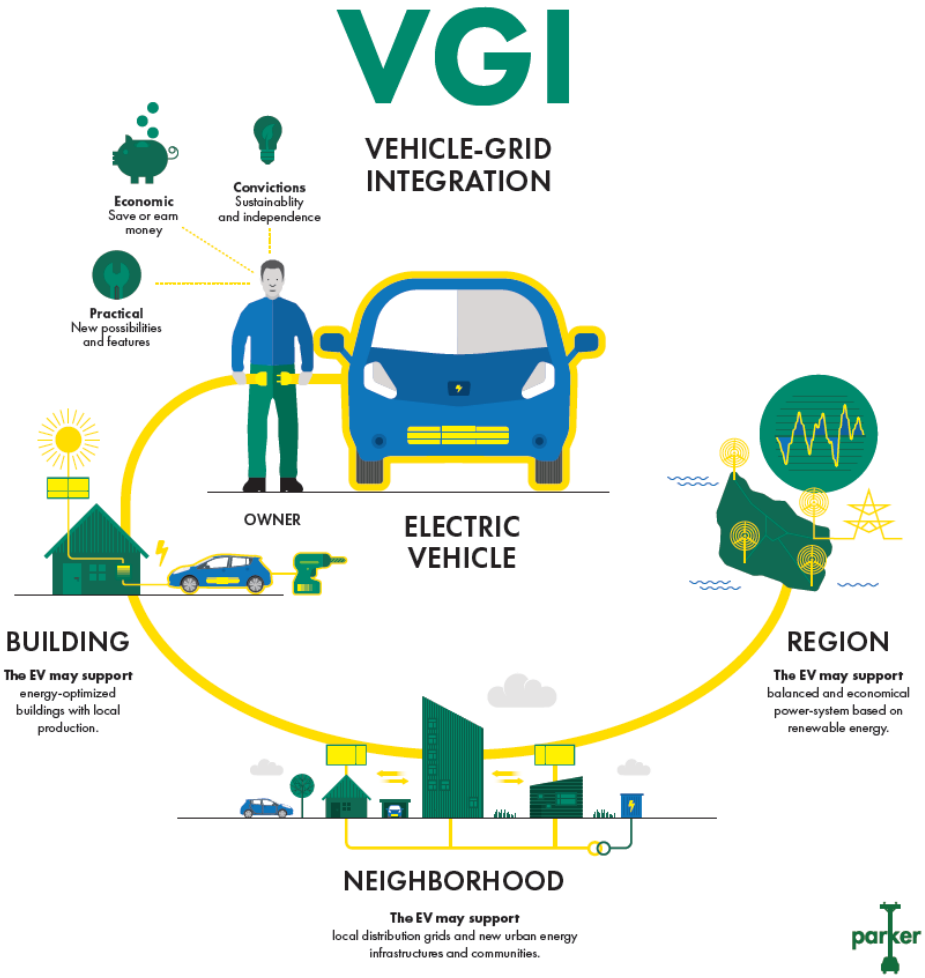


Figure 2 - VGI overview

The project has investigated the grid applications that contemporary electric vehicles (EVs) can provide to power systems (See Figure 2).

To this end the project systematically listed potential power and energy services in a so-called 'service catalog' (See appendix 1). 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.

1.5.2 Grid readiness

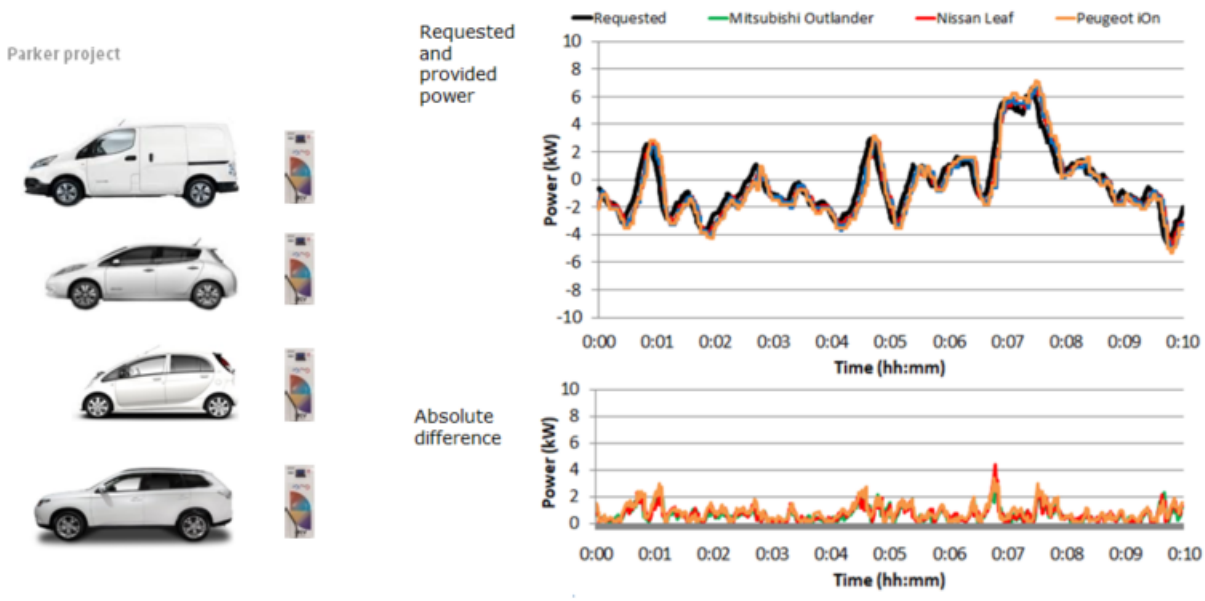


Figure 3 - Testing performance across EV brands

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 (See Figure 3). 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).

1.5.3 scalability and replicability

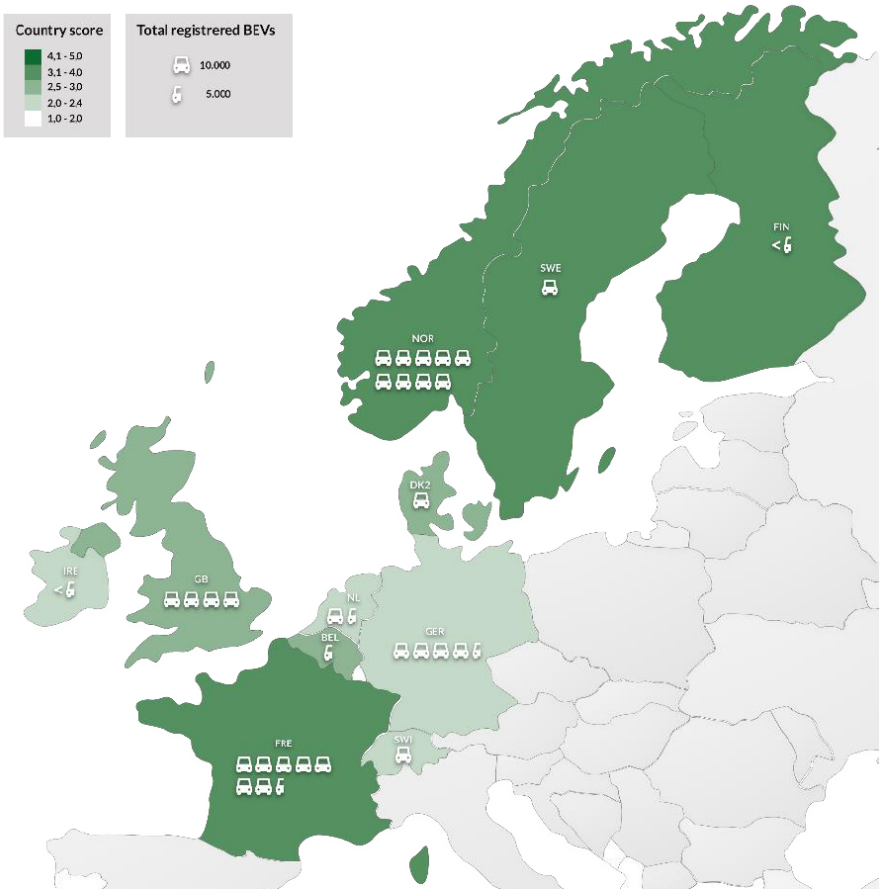


Figure 4 - Evaluation of business potential within Frequency Containment reserves

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 (See Figure 4). 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).

1.5.4 Dissemination

All the projects results were disseminated through different channels:

- **Website:**
  27 news stories, 6,227 visitors, **13,530 pageviews**
- **Twitter:**
  105 tweets, 144 followers, **74,707 impressions**
- **LinkedIn:**
  66 posts, 151 followers, **63,252 impressions**
- **Video:**
  16 videos on YouTube, **2,691 views**, 4.2 hours of viewing time
- **Press:**
  2 press releases, **110 press mentions**

The scientific dissemination was achieved through a total of **16 academic publications** (including 10 Journal papers)

The project also contributed to a **technical report to Energinet** as part of the pilot project (Integration of new technology in the ancillary service market).

Finally a large two-day summit was arranged – both serving as a major dissemination activity for the Parker project and to attract international expert and encourage continued collaboration within the field. The event was attended by more than 100 participants (See Figure 5).

Figure 5 - VGI Summit - Parker end-seminar

1.6 Utilization of project results

1.6.1 Utilization in policy, research and education

The V2G technology has been studied for many years and by many institutions – the novelty of Parker was the ability to test V2G with the car industry and applying it commercially.

The learnings of Parker allow for scaling up the use of the technology in Denmark and to have it replicated in other countries.

The commercial operation of V2G vehicles at Frederiksberg Forsyning became part of a collaboration between Parker and Energinet in the pilot "Integration of new technology in the ancillary service markets". The project helped identify the main economical, regulatory and technical barriers for using the Frederiksberg Forsyning vehicles for providing Frequency Containment Reserves.

This effort was part of Market Model 2.0 strategy by helping inform the design of products, codes and regulation to utilize flexibility at consumer level from new technologies.

Parker results are also used in a number of new research projects.

In Denmark both the projects BOSS and the ongoing ACES project use results and experience from Parker.

Outside of Denmark a number of new projects lead by project partners, builds on the Parker results and continues the efforts. These include the GridMotion project in France headed by PSA ID, and the Invent project in the US lead by NUVVE.

While the project has feed information to a large number of international groups and projects – especially the Innovate UK initiative which will head approximately 20 projects on V2G have been using project results.

The 2018 report 'V2G – A Global Roadtrip' by Everoze and EVConsult investigated a total of 50 V2G projects globally. As shown in Figure 6 Parker made the top ten of most interesting projects within the field

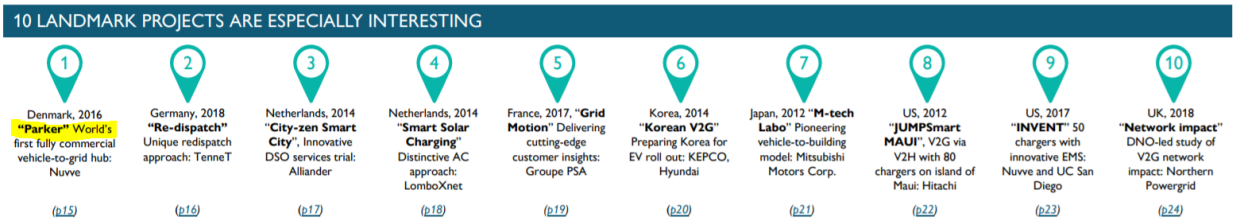


Figure 6 - "V2G - A Global Roadtrip", 2018. 10 Landmark projjects

As such Parker has made an impact on future projects which will help ensure continuity within the field.

Finally the project results were used as part of education. Eleven student projects (five special courses, two Bachelor courses and four master thesis projects) became part of the project – aiding the education of engineers within the field of Vehicle-Grid Integration.

1.6.2 Commercial utilization by partners

The description of utilization below differentiates between EUDP-funded partners (NUVVE and Insero) and self-funded partners (Nissan, Enel, PSA, Mitsubishi). For the latter category, an informal description of projects benefits have been requested.

Nissan Motor Co. Ltd:
Following would be the main outcome which we earned from project which were very fruitful.

- Project supported us to deepen the basic understanding of Nordic market and business model available for EVs.
- Result of testing were helpful to use as reference for verification of similar kind of demonstration worldwide.
- Project workshop were always helpful for networking in VGI community.
- Project results were supportive to capture the economic value with realistic assumption based on actual fleet vehicle.

For the directly supported partners, INSERO and NUVVE, the following describe the commercial utilization.

INSERO has, due to a major change in strategy withdrawn from electromobility why the description of project utilization and related impacts on employment, growth and turnover is no longer applicable.

NUVVE on the other hand has used the project directly to grow their business both in Denmark and abroad. NUVVE beskriver at de forventer at projektet inden for 3-5 år vil have bidraget med:

- 10 ekstra medarbejdere.
- En øget omsætning på 10-15 mio. kr.
- En Øget eksport på 8-10 mio. kr.

Desuden har projektet NUVVE med at markedsføre V2G teknologien og understøttet en kommerciel operation med ca 50 elbiler i København og på Bornholm.

The project has also worked together with a small Dansk start-up, Tomorrow, with which the partners have been collaborating on building a user interface for smart charging and a novel MEF signal building on Tomorrows energy and market data – giving an estimate of marginal emission from energy consumption. Parker has helped the company develop and test these new products.

1.7 Project conclusion and perspective

The general conclusions of the project are as follows:

- ✓ 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.
- ✓ A field-test in Copenhagen has proven that it is possible to commercialize this technology though the provision of FCR.
- ✓ 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 decision makers 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.

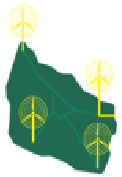
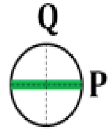
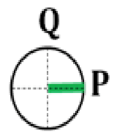
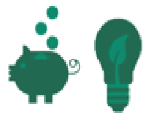
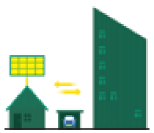
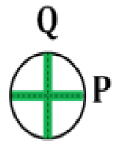
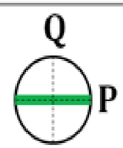
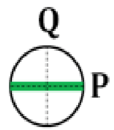
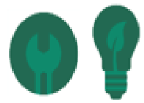
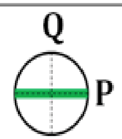
Test zones and pilots on new market designs, Pilot projects and test zones supported by the Danish government and TSO, Energinet, may prove an effective way of identifying market-based and regulatory barriers for demand flexibility - but also to explore entirely new ways of using and incentivising flexibility.

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.

Interesting topics to continue pursuing:

- ✓ Develop new services incl DSS (Distribution System services)
- ✓ Describe battery usage patterns from different V2G services
- ✓ Promote grid keys to support universal V2G and VGI support in all EVSEs and EVs
- ✓ Continue focus on user involvement, patterns and incentives
- ✓ Scaling up using large demonstrator with private end users

Appendix 1 – Service catalog

Domain	Categories	Service examples	Short description	EV and EVSE: Technical requirements		USER: Incentives	
Region (Transmission) 	Power balancing	Synthetic inertia	Mimic inertia of rotating machines.		-Fast activation -Controllable ramping rate - Bidirectional (V2G)		Availability payment
		Frequency containment	Keep the frequency within a required interval.				
	Energy balancing	Wholesale energy	Responsiveness to varying energy prices.		(no special performance requirements)		Savings on energy costs / Renewable-based charging
		Regulation	Balancing energy schedules/portfolios.				
		Marginal emission	Defer charging based on CO2 cost of marginal consumption.				
Neighborhood (Distribution) 	Grid contingencies	Loading issues	Mitigate overloading of transformers and cables in LV network. May also include phase load balancing.		- 4Q / Reactive power capabilities		Savings on connection costs /compensation from utility
		Voltage issues	Mitigate overvoltage and voltage drops in distribution systems.				
	Energy autonomy	Bilateral trading	Local peer-to-peer trading of energy.		- Bidirectional (V2B)		Savings/Independence/ renewable support
		Self consumption maximization	Ensure the highest possible utility of locally produced energy.				
Building (behind the meter) 	Islanded operation	Back-up power	Sustain a small power system temporarily disconnected from the grid.		- Bidirectional (V2B) -Islanding capability		Security of supply /Independence
		Fully off-grid	Sustain a small power system permanently disconnected form the grid.				
	Mobile load serving	Vehicle–to-tool	Provide a mobile power-source for equipment during in-field use.		- Bidirectional (V2L)		Access to mobile power source
		Vehicle–to-Vehicle	Provide energy directly from one vehicle to another.				

Appendix 2 – Project publications

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