"By balancing electricity systems in real-time, we could enable smarter energy use and stimulate the transition towards a stable electricity grid in a low carbon future"

TKI REPORT PENINTA

Asset aggregation for real-time grid balancing

29-03-2018

sympower

engie

Project Information

Project Number	TESI116002
Project titel	Aggregation platform for real-time grid balancing Peninta
First Applicant	ENGIE Services Nederland NV
Second Applicant	SYMPOWER B.V.
Project period	from 01-09-2016 to 31-12-2017
Data of report	March 2018

Reading Guide

Different employees of both Engie and Sympower contributed to this report. The majority of the content of each chapter is written by the leading company in that chapter as described in the introduction, but all output could be seen as collaboration results.

Both Engie and Sympower had difficulties with the confidential content of this report. When finalizing this report, it is decided that two versions are needed, one public and one confidential. To ease this structure, all confidential information is moved to the appendices, so the content of the chapters could be made public.

During the final phase of this project, great focus was put on the effective outcomes of the pilot and how real data could be used to draw our conclusions. It is clear that the ambitions of the project changed during the pilot phase due to circumstances, this should be clear in the flow of the report.

Gratitude

We wish to express our gratitude to all the Sympower and Engie colleagues who contributed to the realization of this report.

Subsidy

This project was carried out with a subsidy from the Ministry of Economic Affairs, National regulations EZ-subsidies, TopSector Energie carried out by RVO (Rijksdienst voor Ondernemend Nederland)

Executive summary

Since electricity is a time-bound product, flexibility in the electricity system is required in real time to balance the difference between demand and supply. This requires the Transmission System Operators to maintain a "reserve" of electricity supply that can balance changes in demand. Currently, flexibility is mainly provided by fossil fuel plants, which incurs in significant costs (e.g. efficiency loss and increased wear and tear) in addition to the environmental costs of increasing emissions.[1] As an alternative solution, ENGIE and Sympower propose the use of an aggregated pool of energy storage assets to quickly respond to grid frequency fluctuations by providing demand side flexibility. Using the available flexibility in the energy system to balance the grid from a demand side perspective helps us to change the status quo and prepare our energy and electricity grid the transition towards increase of sustainable energy and a stable low carbon future.

Sympower and ENGIE researched the benefits of combining (second-life) batteries with household appliances for grid balancing. A pilot project is being executed to collect empirical data to provide new knowledge and insights into the development of demand response in the energy sector. With this objective in mind, a joint research effort was enabled by the participation of the pilot project in the TKI program 2016. Sympower and ENGIE applied together for funding under the TKI scheme to develop the research project System feasibility studies. To fulfill its responsibilities within this joint research project, Sympower and ENGIE worked closely together to collaborate on proper coordination of research efforts and avoid duplication of work.

Within this pilot, we found that the profitability of storage was low for the imbalance market and the batteries where implemented to react on the primary reserve. The FCR Platform is used to steer the battery storage units remotely based on frequency measurements. The batteries are set on 50% charge so flexibility is available for both upward and downward frequency regulation. The batteries used are large compared to residential units, but give a good indication of the opportunities with smaller units. If active in the FCR market, a fast reaction time if a disturbance in the grid occurs is extremely important.

This report is divided into 6 different working packages, as explained in the introduction. Partly, the real world data from the pilot project is used to answer the research questions of the working packages. The areas that could not be answered with the data from the pilot is answered by desk research and discussion with internal experts of both companies. The unique collaboration between a scale up aggregator and a large utility company showed how different one could tackle the same issues, and this reflected into interesting commercial value.

Nowadays, the Dutch regulatory framework and the economic value of small size flexibility is not ready for large scale implementation of DR in the residential sector. This report shows that the available latent flexibility in one specific household is to small to cause an financial incentive for the end-user. Only where large pools of similar assets are combined and connected efficiently, a business opportunity arises for an aggregator. The analysis shows that electric boilers and heat pumps for domestic heating and water use are the best assets to use for residential DR in the short term with payback periods for installation between 5 and 15 years is it worth to look into this assets as short term investment.

In the longer term, it is complex to make an analyses of the market environment and current market perspective and business models do not display a realistic overview of future opportunities. However, the dialogue between commercial parties, research institutes, universities and the government unfolds trends we see in the current market and indicate directions for the future. If the trend of connecting devices to the internet reaches the domestic electric appliances, the cost of connecting residential assets to the available DR platforms will decrease drastically. It is recommended that collaboration with manufacturer of electric devices is stimulated to increase the transparency available data and communication software.

Another trend worth mentioning is the growing potential of electric vehicles. The technology of vehicle two grid charging is not going to take off on the short-term, but smart changing to solve local congestion problems and bid into ancillary markets with residential connected electric vehicles is expected to change from pilots

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[1] Paterakis, N.G., O. Erdinç, and J.P.S. Catalão, *An overview of Demand Response: Key-elements and international experience*. Renewable and Sustainable Energy Reviews, 2017. 69: p. 871-891.

to practice in the upcoming years. This gives interesting opportunities to an aggregated pool of flexibility, to sell the flexibility not only in different ancillary service markets, and trading markets, but also in new arising local congestion markets directed by the DSO's.

The impact of stabilizing the grid with DR compared with conventional techniques is analyzed from an environmental prospective and gives an indication of quantifying the savings in carbon dioxide emissions. This shows that by using demand response for peak load reduction, on average 13 tonnes CO_2/MWh can be saved annually in The Netherlands. By using demand response for ancillary services, on average 56 tonnes CO_2/MW can be saved per year. One should realise, that it is not a reliably indication, since the calculations are based on a research in a different country and markets with different assets. To give a better insight the climate benefit a study should be conducted within one of the operating fossil fired power plants bidding in the ancillary service markets.

Abbreviations

DR	Demand Response
FCR	Frequency Containment Reserve
PS	Power Setpoint
PD	Power Delivered
EM	Energy Management
Hz	Hertz (Frequency of the grid)
SOC	State Of Charge
SOH	State Of Health
mFRR	Reserve-vermogen
aFRR	Regel-vermogen

Table of content

Introduction

Flexibility in the electricity system is required in real time, from second to second. This requires the Transmission System Operators to maintain a “reserve” of electricity supply that can balance changes in demand. Currently, flexibility is mainly provided by fossil fuel plants, which incurs in significant costs (e.g. efficiency loss and increased wear and tear) in addition to the environmental costs of increasing emissions[2]. As an alternative solution, ENGIE and Sympower propose the use of an aggregated pool of energy storage assets to quickly respond to grid frequency fluctuations by providing demand side flexibility.

Sympower and ENGIE have a hypothesis regarding the benefits of combining (second-life) batteries with household appliances for grid balancing. However, it needs to be validated with real-world data. Hence, a pilot project is being executed to collect empirical data. Besides the validation of this hypothesis, the outcomes of the pilot project could also provide new knowledge and insights into the development of demand response in the energy sector. With this objective in mind, a joint research effort was enabled by the participation of the pilot project in the TKI program 2016. The table below presents the working packages that compose the joint research project.

Working packages and goals of the project

WP	Description	Party	Result	Start	Finish	Hours
1	Study the minimum and optimum functional requirements of storage combined with a secondary aggregation platform (Sympower’s consumer asset aggregation platform), and large (heat) pumps – the optimum combination of symmetrical & asymmetrical assets	ENGIE primarily, partly Sympower	The minimum and optimum functional requirements of storage combined with a secondary aggregation platform (Sympower’s consumer asset aggregation platform) – a combination of (a)symmetrical assets	1-8-16	31-12-17	550
2	Study which (a)symmetrical assets could be added to the pool	Sympower	A breakdown of asset types and the required characteristics to be of value in such a pool of assets	1-8-16	31-12-17	410
3	Study the data/results of the aggregated pool of assets	ENGIE	A report on the effectiveness of the different assets being used in the pool for FCR purposes	1-1-17	31-12-17	350
4	What is the climate benefit of using a household appliance for reserve?	Sympower	Report / journal paper on climate benefits	01-06-17	31-12-17	350
5	What is the system benefit and local cost of turning on / off appliances for reserve?	ENGIE	Report on cost / benefit	01-01-17	31-12-17	550
6	Which household appliances have suitable returns on investment?	Sympower	Report on suitability of various household appliances	01-01-17	31-12-17	300

[2] Paterakis, N.G., O. Erdinç, and J.P.S. Catalão, *An overview of Demand Response: Key-elements and international experience*. Renewable and Sustainable Energy Reviews, 2017. 69: p. 871-891.

Goals of the project
The short-term goal of the research project is to successfully validate the technical characteristics of an aggregated pool of energy storage assets for demand side grid flexibility. ENGIE and Sympower want to show that a pool of batteries, flexible assets such as thermal energy storage and household appliances are a good resource for real-time grid balancing. The project aims to validate both business- and technology related aspects of the solution.

Research Methodology

The research strategy consists of a combination of desk research and quantitative modelling with real world collected data. The desk research will allow data collection for model development. In addition, a literature review of the environmental, technical and economic aspects of demand response will provide insights into problem understanding. The quantitative modelling approach is twofold. First, statistical modelling will support the analysis of the grid frequency. Second, a model will be developed to estimate the environmental and economic impacts of demand response. This estimation will be based on the adaptability of the different appliances in the pool. Due to anticipated limitations in data availability, expert interviews may be considered necessary to support the development of the model. Finally, Table 2 presents the data requirements for the research.

Table 2. Data sources

Data required	Sources
European grid frequency data	Previous work by Sympower
List of appliances suitable for demand response	Previous work by Sympower
Charging and discharging capacity of appliances (Wh)	Secondary research
Power capacity of appliances (W)	Secondary research
Baseline consumption (Wh in time T)	Secondary research & Pilot
Real power reduction due to demand flexibility	Pilot project data
Market prices for flexibility (€/MW)	Electricity market information
Carbon intensity of the grid per country (Main: The NL)	Secondary research
Average household electricity consumption	Secondary research & Pilot project data
User behavior of suitable appliances	Literature review & Pilot project data
Methods for CO2 reductions calculations	Literature review
Methods for power reduction calculations	Literature review
Methods for financial estimations calculations	Literature review
Methods for assessing user behavior	Literature review

Reporting

To complete the project a final report will be submitted within three month after finishing the project to Rijksdienst voor Ondernemend Nederland (RVO) as requested in there official documentation.[3]

[3] RVO; subsidie regelingen; Format Eindrapport; December 2016

Work package 1

Introduction

This work package describes the minimum and optimum functional FCR (Frequency Containment Reserve) requirements of storage combined with a secondary aggregation platform (Sympower's consumer asset aggregation platform) – the optimum combination of symmetrical & asymmetrical assets.

FCR Requirements TenneT

Primary Reserve (FCR)

The purpose of primary reserve is to limit and stabilize frequency disruptions in the entire (internationally) synchronously connected high-voltage grid, irrespective of the cause and location of the imbalance that has caused the frequency disruption. Without adequate intervention, frequency disruptions due to imbalance between electrical demand and supply, may lead to automatic load shedding, damage to the system and connected loads and could even cause a black-out in the worst case scenario.

Requirements TenneT

In order to offer primary reserve in The Netherlands, a technical unit must be prequalified in accordance with the prequalification requirements. Part of the prequalification is a test of whether the technical unit is in a position to supply primary reserve in accordance with the specifications[4]. The most important (basic) requirements are:

- Minimum Bid size — 1 MW (upward and downward)
- Accuracy of the frequency measurement — 10 mHz or better
- Insensitivity range of the frequency control — Max 10 mHz FCR
- Full Activation Time — 30 s for the complete bid
- Full Activation Frequency Deviation. — +200 mHz / - 200 mHz
- Real-time operating measurement of power — In a resolution of 4-10 seconds

For a technical unit to prequalify for the supply of primary reserve, it must be tested on technical requirements. The prequalification tests must take place under normal operational settings of the technical unit. The prequalification test protocol is included in Appendix A1. The tests to be performed test the power to be prequalified; the droop is set such that the expected power changes are realized.

Explanation Droop

The droop is related to the volume that is to be prequalified. The droop is defined as follows:

$$\frac{\Delta P}{P_{nom}} = \frac{100}{x} \frac{|\Delta f|}{f_{nom}}$$

Where:

Δf = frequency change in Hz
f_{nom} = nominal frequency (= 50 Hz)
ΔP = difference in power in MW
P_{nom} = nominal power in MW
x = droop in %

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[4] TenneT; Productspecificatie FCR; February 2017

The full primary reserve must be activated if the (quasi-stationary) frequency deviation is 200 mHz. This forms the basis, together with P_{nom} and the offered bid size, for calculating the droop for the technical unit concerned.

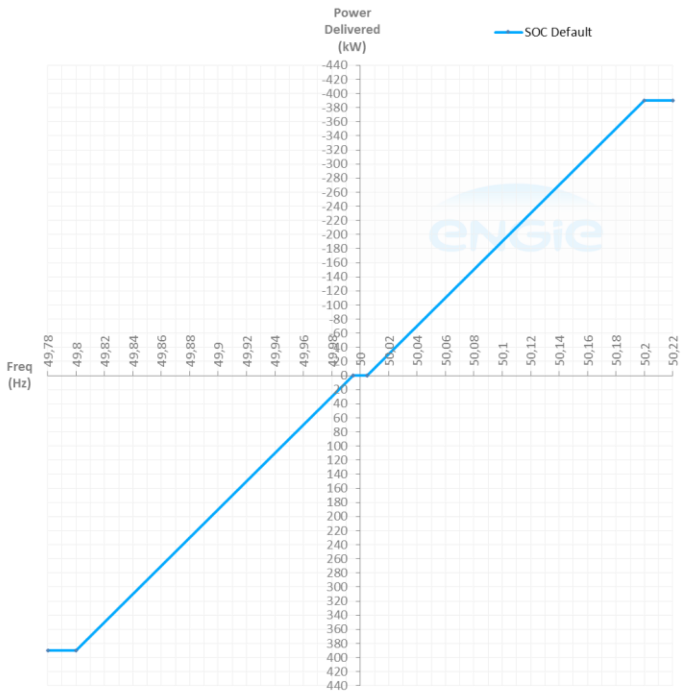

Figure 1: The result of the droop is theoretical a value on the blue line based on a 400 kW nomination

The pool

Related to the requirements, a technical unit or pool must supply primary reserve for as long as the deviation in frequency persists. Related to the TKI study we saw the pool as a configuration like the picture below.

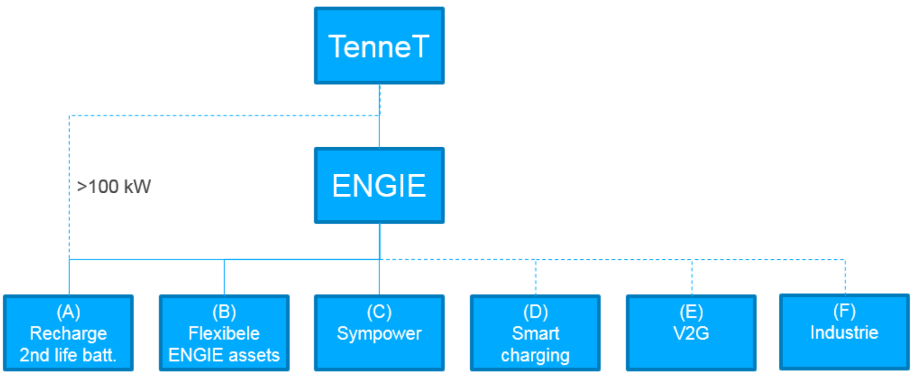

Figure 2: Original plan presented to TenneT (100 – 300 kW)

During the concept phase of the pilot we expect that the realization of a pool with different assets and different characteristics is relatively easy to realize. And as an escape in the process we expect that an 100 kW 2nd life battery storage would be achievable before the first of January 2017.

The following implementation phase gives a lot of challenges with the result that the first asset was an already realized storage unit, build for the imbalance market. The profitability of storage for the imbalance market was difficult to realize, this gives opportunities for the FCR market. That is the reason that today's pool has grown faster than expected but contains only storage units that are active in FCR delivery. The figure below shows the actual pool together with two complementary asymmetrical assets (E & F). Both asymmetrical assets will be ready for testing during the end of the pilot (1th January 2018).

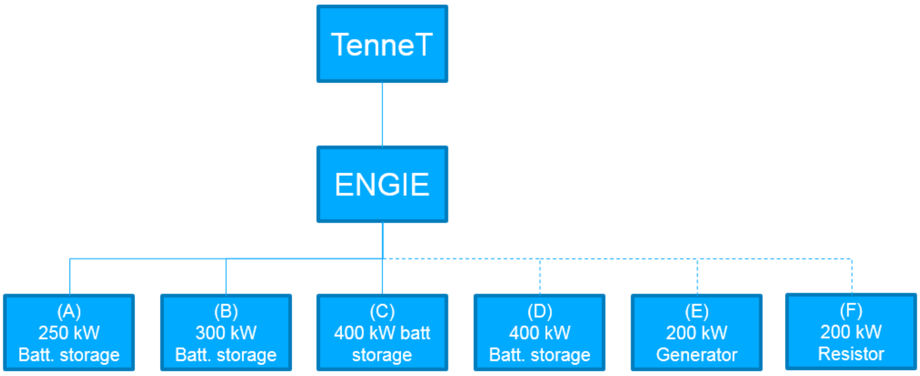

Figure 3: Realized 11 months after the start (1,3 MW)

FCR platform

The pool as described in the previous paragraph is connected via an ICT platform with interfaces to monitor and to analyze individual FCR assets. The next two sub paragraphs describes the platform split in two parts: The ICT platform (cloud solution) and the interface to the different assets or aggregators.

Cloud solution

The basis for the FCR platform is a cloud solution with steering algorithms for the different assets. The TenneT requirements described in the previous paragraph are translated into rules for this algorithms.

The cloud solution communicates with the decentralized “ENGIE boxes” or the aggregator platforms. The decentralized assets and aggregator use their own (local) frequency meter for operating their assets. Appendix A2 describes an example of decentralized asset steering from the cloud. In this example it’s an energy storage unit in an local configuration of production and consumption assets. Some of the assets have flexibility for optimizing the local situation.

Asset Interface

The interface for the pool members / assets are described in appendix A2. Where also an example of the Sympower interface can be found. The figure below shows a screenshot of the pool monitor interface. This figure shows the interface results for an individual asset or an group of assets aggregated by an aggregator like Sympower.

Figure 4: Impression real time monitor with the real time Power Setpoint, Power Delivered and optional the SOC

Frequency analysis

This paragraph explains the study results related to the historical grid frequency. The final results after the analyses are split up, in four logical sub analyses. This four sub analyses are: daily, weekly, yearly and season based. For the asset response and pool optimization it is important to understand if there are recurring profiles.

<u>Daily results</u>

The results of the daily frequency (as visualized in Appendix A3) show that the average frequency deviation between the daily profiles (Sympower and ENGIE results) are more or less the same. With a frequency that is generally kept close to the 50mHz target.

<u>Weekly results</u>

The results of the Sympower[5] study and the (not visualized) ENGIE study show that there are no significant differences between the two types of day (week- and weekend day). However, it is observed that during the week there is a tendency towards higher extreme values of frequency. Appendix A3 shows the difference between week- and weekend days.

<u>Seasonal results</u>

The seasonal analysis is split in a result for each season. Based on the available data, we didn't see a significant seasonal effect. It can be expected that there are no significant differences in the frequency between the different seasons.

<u>Yearly results</u>

The yearly frequency analysis is based on the frequency data for the years 2012 and 2016. For both years we found the same profile during the day. Both years show more or less the same deviation between quarter measurements during the day. In which we see the biggest peaks during the hour crossings.

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[5] Sympower; Insights gained from analyzing the European Frequency, María José Galeano Galván April 26th, 2017

Primary response analysis

Based on the frequency analysis (previous paragraph) it is important to understand the response of the assets based on the frequency deviations. This paragraph describes the response of the assets, related to:

- Percentage of response
- Number of responses for different scenario's
- Duration of response

Expected response

Based on the frequency results (previous paragraph) appendix A4 show the response of the pool as a whole.

- What we measured is that in most cases 17.5% of DR activation covers the required primary reserve 95% of the time.[6] This implies that the vast majority of time the activation of a small percentage of the DR pool could cover the primary reserve.
- Throughout the year, the average percentage of DR activation is 6.71% with a standard deviation of 6.40%. When only disturbances are taken into account (excluding the 0% events), the average percentage of DR activation is 8.35% with a standard deviation of 6.11%.
- The hourly based (Sympower) result are more or less in line with the (ENGIE) 15 minutes results for the year 2012 and 2016 comparison[7].

Secondary asset activation

Based on the frequency results (previous paragraph) appendix A4 show also the response of secondary (asymmetrical) assets. Examples of secondary asymmetrical assets are: boilers, heat pumps, resistors etc.

Secondary assets could be added to the pool in combination with battery storage systems. The battery storage system accounts for most of the power requests (triggered by the frequency) and manages to control the frequency deviation for the first 100mHz. For deviations bigger than 100mHz the secondary assets are activated complimentary to the battery storage system.

In the analysis we defined seven scenario's for the years 2012 and 2016. The seven scenarios are based on frequency deviation lager than 100, 110, 115, 120, 130, 140 and 150 mHz.

The three figure in appendix A4 show for each scenario the:

- Number of activations per year (2012 and 2016)
- Number of activations per month (2016)
- The average duration of the activation per year (2012, 2016)

The conclusion based on the study results is that the best range (in mHz) for activation of the secondary asset is between 110 and 120 mHz. The number of activations are relatively low and the capacity share (kW) relatively high.

[6] Sympower; Insights gained from analyzing the European Frequency, María José Galeano Galván April 26th, 2017

[7] ENGIE; Secondary asset response.xlsx; July 2017

Work package 2

Introduction and Method

Validation of a residential aggregation business model starts with researching the potential of the residential assets. Within working package 2, a technical analysis is done for the assets. Before economic value could be found in working package 6, the technical boundaries should be known, as well as the value of the different asymmetrical assets added to the pool. The value of a specific asset is strongly dependent of the characteristics of the assets in combination with the right market and the prices in that specific market for the flexibility. For example, the batteries used in this pilot could be profitable in the FCR market while DR with large scale heat pumps is likely to fit better to the FRR markets. Since the output data of the pilot consists data from batteries, working package 1 and 3 are focusing on the FCR market and the possible revenues in that market. In work package 2 and 6 DR in the FCR market is used as described in work package 1, unless past experience within Engie or Sympower indicates clearly the assets fits to better within another market.

The important potential characteristics and indicators for significant flexibility of different residential assets will be developed. Those indicators are used to score the different the household applications. After this quantitative analysis, the assets with a low score are dropped and for the assets with a high score the economic potential will be studied. Because we have real world data from the load profile of the batteries, we were able to analyze the batteries thoroughly.

Within a decision making process, one is always looking for the best decision. Unfortunately a perfect decision could only exist when only one criteria is tested[8]. In most decision making processes, multiple criteria or indicators should be reconsidered before taking a decision. Within WP2, the different important criteria will be researched to score the possible assets, to create a strong support for the decision making in business perspective. To validate the methodology, a short form of the scientific method Multi-Criteria Decision Analysis (MCDA) is used, like done in decision making research within the sustainable energy sector[6][9][10]

Firstly, the precondition characteristics of the assets are tested. If the preconditions are not sufficient, the asset does not qualify and the asset will be dropped. Secondly, a combination of internal knowledge within Engie and Sympower and external knowledge trough desk research will provide information to score the remaining assets on the developed characteristics.

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[8] Loken, E (2007) Use of multicriteria decision analysis methods for energy planning problems. *Renewable and Sustainable Energy Reviews*, *11*(7), 1584–1595. http://doi.org/10.1016/j.rser.2005.11.005

[9] Mundaca, L., & Neij, L. (2009). A multi-criteria evaluation framework for tradable white certificate schemes. *Energy Policy*, *37*(11), 4557–4573. http://doi.org/10.1016/j.enpol.2009.06.011

[10] Wang, , J.-J., Jing, Y.-Y., Zhang, C.-F., & Zhao, J.-H. (2009). Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renewable and Sustainable Energy Reviews*, *13*(9), 2263–2278. http://doi.org/10.1016/j.rser.2009.06.021

Results literature review and desk research WP2

Characteristics of the assets

In this subchapter the different important characteristics are defined, which could be used as indicators within the analysis. After literature review and internal discussion with experts the following characteristics were found:

1. Power: what is the demand of the asset and what is the peak power that could be used for DR?
2. Technical complexity
    a. Controlling the appliance: how could the software connect to the hardware?
    b. Switching on/off without harm: could there be harm done to the asset by DR?
3. Availability:
    a. Daily / Seasonal: Are devices always available or only at certain times?
4. Market penetration & growth potential: Fit for FCR Market
5. Influence on comfort of end-user

Firstly, the precondition characteristics are defined as follows:

Precondition characteristic: Comfort

When moving new technology into customers direct living environment, the impact on their day to day experience is extremely important. Bad experience, will directly result into negative publicity, bad reputation and a lot of difficulties in the scale-up phase of the new technology. To avoid this situation, one things should be very clear to all stakeholders, the customer comfort experience could never decrease noticeable. For example, a customer quantity of warm water decreases due to DR with an electric boiler is unacceptable. For this reason, we exclude assets with negative impact on the comfort. For example, washing machines, tumble dryers and dishwashers are excluded from this research, because their usage is directly controlled by the customer and the customer experience will drastically decrease if those machines are externally controlled, besides that we found that the economic value not significant enough is to change customers behavior.

The Residential Assets Matrix

Different residential customers are suitable for Direct Load Control and price-based DR programs.[11] The first funneling step is to eliminate the assets which could not meet the preconditions. The initial assets analyzed in this stage and the elimination of uncontrollable flexibility could be found in appendix B1. The remaining assets are scored from 1 to 5 on the characteristics as shown in the asset matrix below. A score of 1 out of 5 indicates the asset is not suitable due to this specific characteristics. For every asset an short explanation in mentioned below.

Asset Matrix	Electric Boiler	Heat Pump	refrigerators & Freezers	Batteries	AC	EV
Power	2	3	1	4	2	5
Complexity	4	2	3	4	1	2
Availability	2	2	4	4	3	3
Market	3	2	4	5	2	4
Total	11	9	12	17	8	14

[11] Paterakis, N.G., O. Erdinç, and J.P.S. Catalão, An overview of Demand Response: *Key-elements and international experience*. Renewable and Sustainable Energy Reviews, 2017. **69**: p. 871-891

Electric boilers

Electric boilers are sometimes used instead of gas boilers in the residential sector in The Netherlands. They are reasonable easy devices to control from a technical perspective and intensive usage will not harm the devices. The availability of electric boilers is theoretically predictable and significant enough to make them a usable asset, but due to a lack of real-time data of electric boilers in households, this is not proven. To utilize a latent flexibility asset like an electric boiler, the business case is stronger if the flexibility could be used without extra installation of hardware. In futuristic scenario's, where smart electric boilers could be controlled due to connectivity and software in the device makes this flexibility accessible. This is being researched in a pilot project in The Netherlands by an electric boiler producer and commercial parties.[12]

Heat pumps

Residential heat pumps use electricity and low temperatures from the environment to heat high temperature (floor)heating systems with two closed cycles. This system decreases the residential carbon footprint due to electrification of the build environment and a decrease in gas usage for heating, compared to common Dutch heating systems.

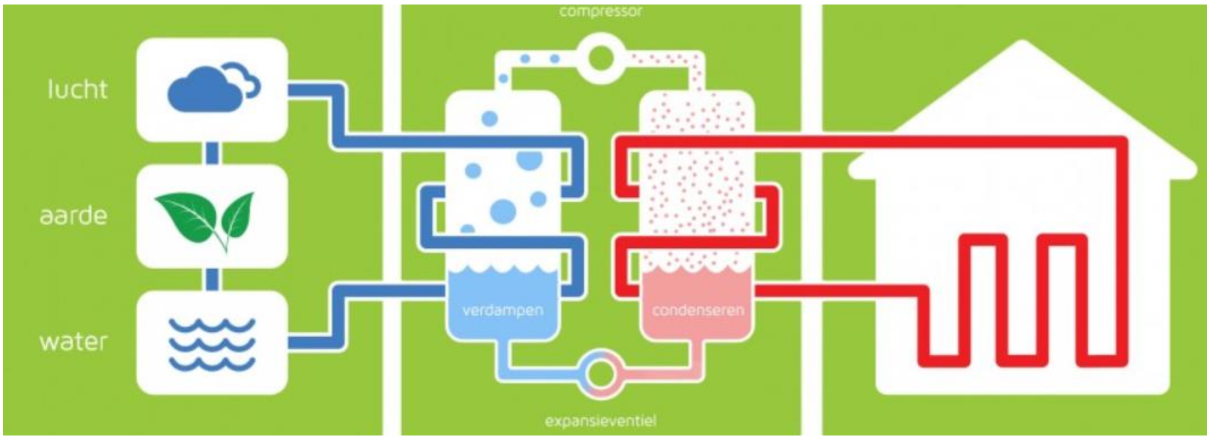

Figure 5 schemtic representation of a heat pump

The past 20 year, the heat pump became a mature product and is evaluated as most efficient and comfortable way of heating[13]. The hybrid air-water heat pump is most used in residential sector due to easy installation and low investment costs[14], within this system a backup gas boiler is normally used.
Within other projects, Sympower found that steering small residential (or larger industrial) heat pumps without buffers and connected energy management systems is highly complex. Turning the heat pumps off directly can cause technical problems in the system regarding the first closed cycle. The heat pumps availability is also unpredictable and influencing the sensors to guarantee availability in certain moments is in violation with the boundary condition, it will have a significant impact on the comfort of the end user.

The load profile of the heat pumps is depending strongly on the season of the year and the outside temperature. If more energy is needed in the house in winter, the on/off ratio will go up and more flexibility will be available for load shifting or load interruption. From data within other projects, we found that a heat pump with a buffer system is available up to 35% of the time, so with correct forecasting over 30% of the capacity could be bid into the balancing markets.

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[12] Energeia, 31-08-2017
[13] Chua, K. J., Chou, S. K., & Yang, W. M. (2010). Advances in heat pump systems: A review. *Applied Energy*, *87*(12), 3611–3624. http://doi.org/10.1016/j.apenergy.2010.06.014

[14] Staffell, I., Brett, D., Brandon, N., & Hawkes, A. (2012). A review of domestic heat pumps. *Energy & Environmental Science*, *5*(11), 9291-9306.

Refrigerators & Freezers

In a future scenario, where all devices are connected within the internet of things, we can foresee a possibility where freezers could be used for DR, since there data and energy management is easy reachable. However, the electric demand of freezers is not large enough to add significant to the pool and the investments in installation and data collection is too high. Initial calculation about power and potential revenue concludes that freezers are not suitable assets for DR from a economical point of view.

Batteries

Since batteries are used in the pilot, there technical details, characteristics, strengths and weaknesses are discussed in the rest of the report.

Air-conditioning

An air-conditioning system is mentioned in different research papers about domestic DR, but the penetration of this technology is very small in The Netherlands. The power of air conditioning systems varies around 5kW, which is significantly bigger compared to the refrigerators. During market research in the past, we found that connecting the current air conditioners is very complex, since the systems differ a lot from each other.

Electric Vehicles

EV's have a very large flexibility if compared to other residential assets. Since the batterie size is expected to grow over the next years and widely adoption of EV's could be expected, this asset could have large impact on the DR markets. Steering the charging cycles of EV's with smart charging or bidirectional charging is very complex these days, and research in collaboration of car manufacturers and charge point operators is highly recommended. Both Engie and Sympower expect a serious impact if EV's could be used commercially as DR assets. The scenario's, specifications and impact of this assets is substantial and the outcome of such research does not fit in the scope of this project.

Result and theoretic conclusions

From the asset matrix, we can see that both Freezers and AC score a 1 out of 5 and are in this stage not interesting assets to research for residential DR. EV's are extremely interesting due to their immense capacity, but fall out of the scope of this report. Both heat pumps and electric boilers are potential interesting controllable assets. Heat Pumps are compared to electric boilers overall lower scored by our experts, but more thrust is noticed. Within working package 6 the potential of those assets will be evaluated.

Work package 3

Introduction

This work package describes the (data) results of the individual assets / sites and the total result of the pool. We use the terms "asset" and "site" to describe the storage unit results. In which "asset" refers to battery storage unit and "site" to a location where a battery storage unit is located. The first paragraph "Context" describes the FCR platform, the processes facilitated by the platform and the developed tools used for the data analysis. The second paragraph "Study results" describes the (data) results on asset and pool level.

Context

FCR platform

The FCR platform is the platform used for controlling the individual battery storage units. In the current situation, it's a remote steering platform, based on the input of a central frequency meter. The platform facilitates the processes, which are described in more detail, In the next sub-paragraph. The first picture in appendix C1 shows, a visualization of the FCR platform. The platform facilitates the interaction between ENGIE, the customers an TenneT.

Processes

The main process for the FCR market access, is split up in eight sub-processes, from "Contract management" to "Billing & Back office". Each process has their own function and process owner. Appendix C1 shows the most relevant process (Monitoring & Dash boarding) for this study. The monitoring and dash boarding process describes the relation between the FCR platform and the temporary prototype tools used for data analysis. The most important tools for monitoring the different sites as well as the entire pool are the "Site analyzer" and the "Pool analyzer". Both tools are described in the next two sub-paragraphs.

Site analyzer

The site analyzer is an Excel tool used for the detail analysis of each individual battery storage container. Each asset has his own characteristics and is also dependent of the local situation.

Figure 6: On of the battery storage containers in the pool used for the TenneT FCR pilot

The most important characteristics of the storage are:

- Maximum power (kW)
- Maximum amount of Energy storage (kWh)
- Minimum inverter power for the smallest step in power (kW)
- The over dimensioning power for Energy Management

The most important parameters for the local situation:

- Grid capacity

- Energy load profile of the customer
- Energy production profile of the customer
- Peak consumption
- Availability of flexibility for additional peak shaving, etc.

The site analyzer is an Excel tool that creates visualizations based on the day data of the Power Setpoint (PS) and Power Delivered (PD) values. Appendix C2 gives an impression of the developed tool and the different visualization options.

All visualizations are based on capacity values (kW) for every second of the day. Every day has 86.400 seconds / values for each parameter (for example PS, PD, and frequency). The next paragraph shows the study results of this tool.

Pool analyzer

The pool analyzer is an Excel tool used for the detail analysis of the storage container pool. The most important function is to analyze the follow-up of the nominated power to TenneT.

The nominated power of the pool is theoretically the sum of the individual assets. However, in practice it is not. By using this tool, we gain insights in the performance of the combined pool and the challenges e still have to solve.

Challenges

- Measurement deviation (Frequency and power)
- Deviation related to Energy Management periods
- Deviation in time stamps and network communication delays

The pool analyzer tool make visualizations based on the daily asset data results. Appendix C2 gives an impression of the developed data tool and the available visualizations.

All visualizations are based on capacity values (kW) for every second of the day. Every day has 86.400 values for each site for each parameter (for example PS, PD, and frequency). The next paragraph describes the study results of these tools.

Study results

This paragraph describes the study results on asset- and pool level. Most of the results can be found in appendix C3 and C4.

Asset study

The most important results on asset level are the daily data covering the Power Setpoint (SP) and Power Delivered (PD). The figure below shows the battery performance for a single day. The assets are analyzed day by day. Sub-paragraph "Results 2017" shows different examples off days with deviations / issues.

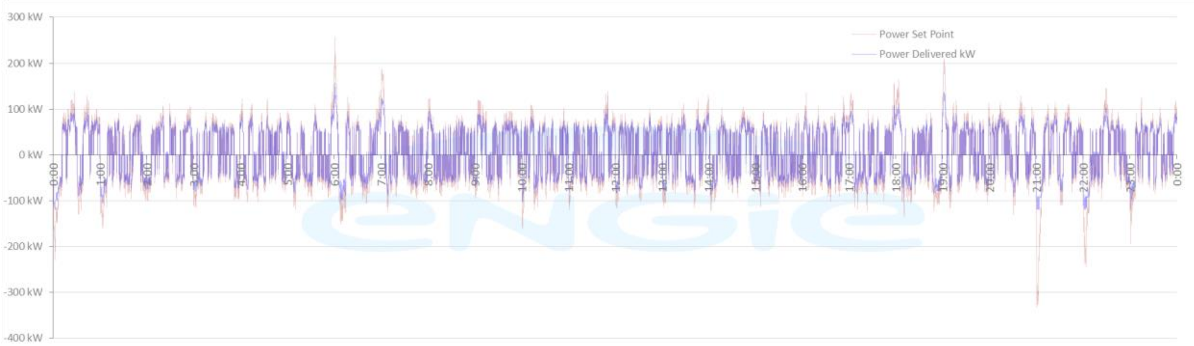

Figure 7: Battery storage performance for one day based 64.400 different Power Setpoint and Power Delivered values

State Of Charge management

For the symmetrical FCR nomination the storage should operate around a State Of Charge (SOC) of 50%. In the first weeks of operation the SOC occasionally reached the 0% an 100%. By adding the additional implemented Energy Management (EM) function it was possible to solves this problem.

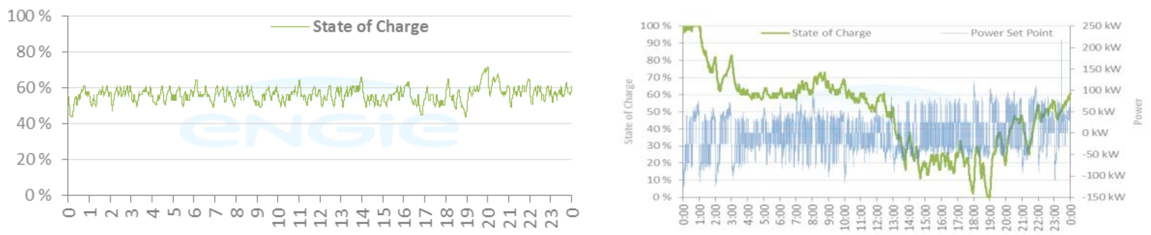

Figure 8; Battery storage State Of Charge with active energy Management 40/60% SOC (left) without EM (right)

Histogram results

In Work package 1, an analysis of the frequency deviation during a longer period of time is conducted. On asset level it could be relevant to understand the frequency deviation during the day. The figure below shows the results on daily basis. Most of the time the deviation is below the ±40 mHz.

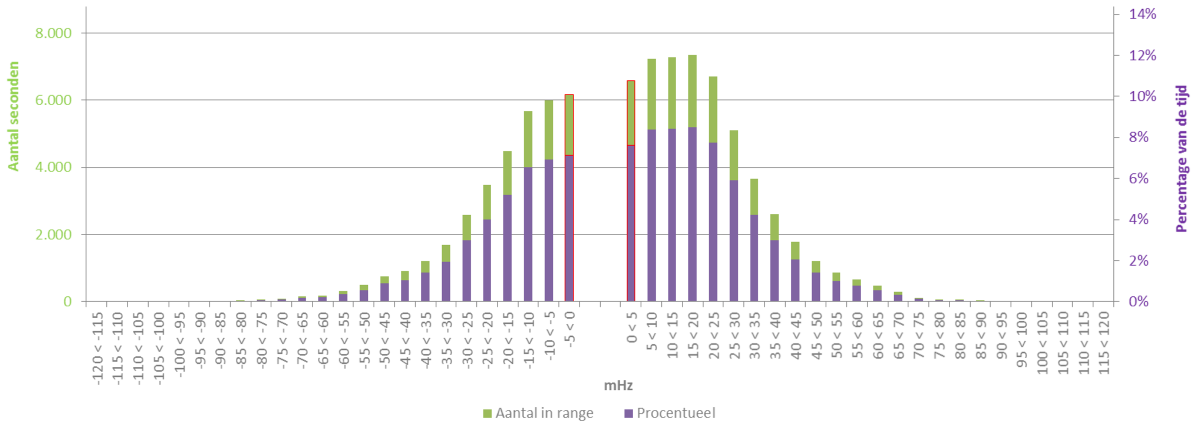

Figure 9: histogram of the frequency deviation on daily base

<u>Scatter plot results</u>

The scatterplot (figure 10) reflects the accuracy of the Power Delivered values related to the requirements of TenneT. The lines represents the Power Delivered values related to the frequency deviation. The dark blue dots visualizes the power delivered value for each second of the day. The figure (figure 10) below shows a good working system on the left and a site with power delivery issues (power to grid) on the right.

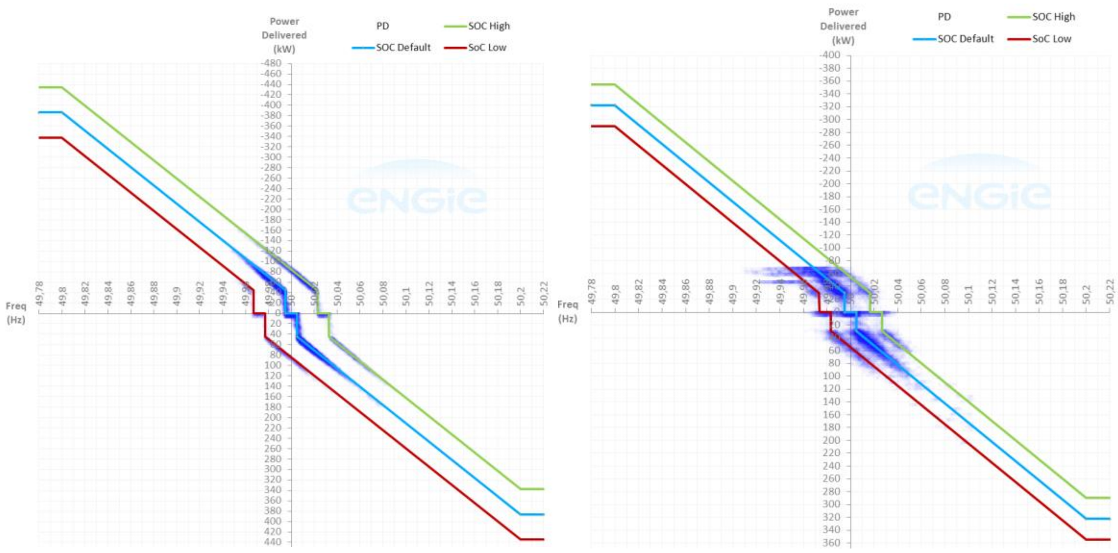

Figure 10: Scatterplot example, left good performance, right bad performance "battery to grid reduction"

Pool study

The most relevant results on pool level are the daily outputs of the Power Setpoint (SP) and the Power Delivered (PD). The figure below shows the total (pool) power output for one day.

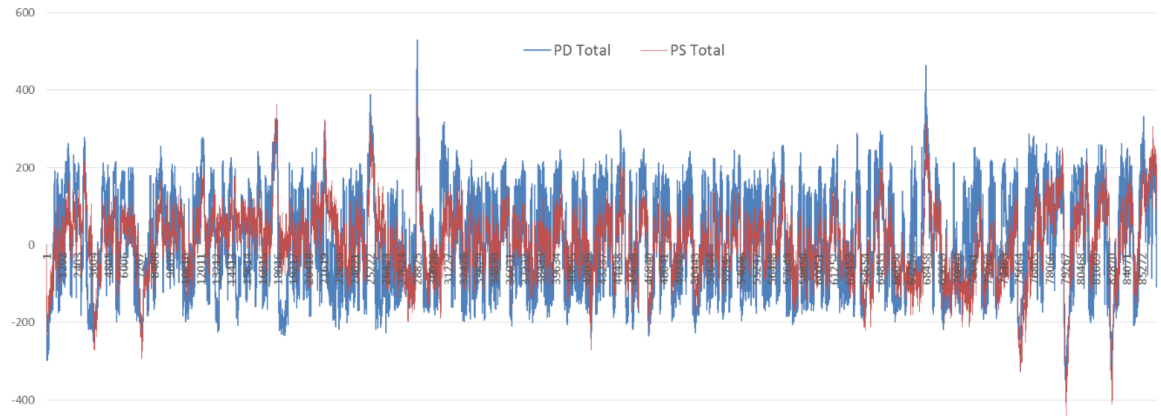

Figure 11: Visualization Power Setpoint & Power Delivered during one day

In the daily results we see a significant deviation in the Power Setpoint and Power Delivery. The most important reasons are

- Power meter deviation
- Frequency meter deviation
- Different delays in the communications to the different sites
- Energy management deviation of the individual sites

For a better visualization of the performance there should be an Energy Management (EM) correction for the energy management power for every asset, for every second of the day. In case of logging the Energy management periods the new Power Delivered can be calculated with de follow formula:

$$PD_{pool} = (PD_{assetA} + EM_{offsetA}) + (PD_{assetB} + EM_{offsetB}) + (PD_{assetC} + EM_{offsetC})$$

Even if all battery storage units perform the same (FCR) storage function, the results of the SOC of the different battery assets are not the same. In time they act more or less in parallel, the SOC is significant different on the sites. The figure below shows the differences in SOC during the day.

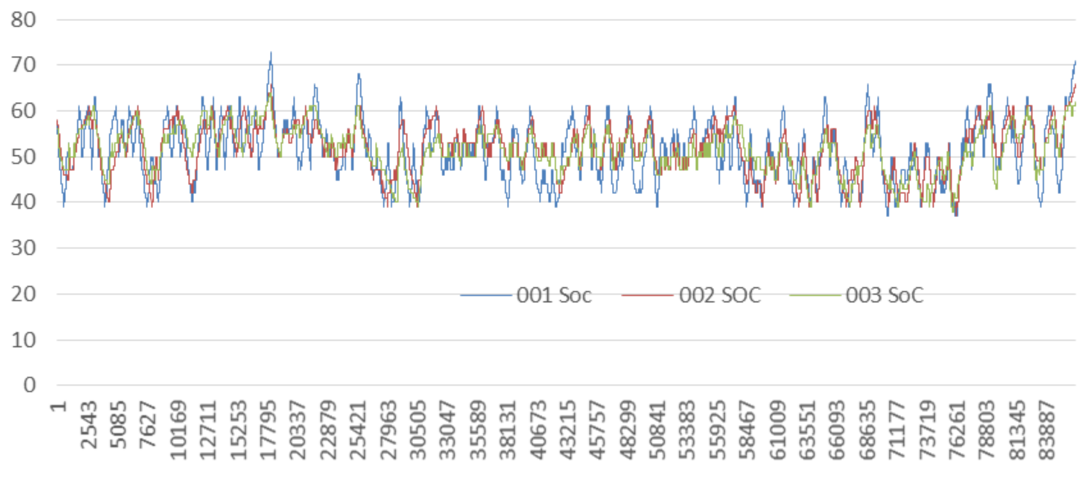

Figure 12: State Of Charge (during the day) of the different storage units

Auto detection & Correction

In the analysis so far, we regularly see an significant deviation on pool level between the PS and the PD. An auto detection & correction function is needed for compensating the mismatches of the pool.

Appendix C3 shows the results of two different approaches for auto detection. The first is based on a percentage mismatch of the Power Setpoint. The second is based on fixed power mismatched in kilowatt (kW). For example an pool of 1MW is allowed to have a mismatch of 50 kW before the value is marked as a "mismatch".

The graphs on the right of Appendix C3 show the mismatch in kW on asset level and the sum on pool level. The graphs on the left show at what time interval (in nr of seconds) mismatch takes place. Related to the TenneT requirement the best approach is the first approach (percentage mismatch of the Power Setpoint). The approach based on a fixed kW mismatch. The reason for this is that the mismatch based on percentage gives a lot of mismatches in situations with an significant low Power Setpoint value.

Results 2017

During the TenneT FCR pilot we see a lot of issues that cause issues on pool level. Many of these issues are logged in Appendix C4. However, the list of graphs that are added in appendix C4 is not comprehensive. It is merely an attempt to provide a good overview of the different types of issues we encountered between, January to October 2017.

Work package 4

Introduction

Within this work package, we discuss a very difficult but extremely important impact of this pilot and the reason behind why we do what we do: the positive impact on the climate. By conducting a literature study, some calculations are made to come up with a method to quantify this impact, but as discussed later, there are a lot of pitfalls and indirect implications or assumptions in doing so.

The most obvious positive benefit for the climate is of course direct decrease of carbon dioxide emission by substitution of polluting fossil fuel plants with storage and demand response solutions and this is the main focus of this work package. However, one should realize that there are other very important features of DR, like overall strength of the grid and system, which stimulate the energy transition strongly which has a big influence on the climate indirectly in the long term while it could not be measured directly.

Context: Estimations of CO_2 reductions from Demand Response

The environmental benefits of demand response have been related to three aspects: (i) facilitating the integration of renewables into the energy system, (ii) promoting energy efficiency and (iii) diminishing the reliance on fossil fuels[15]. Hence, demand response has the potential to decrease the carbon footprint of the system by replacing less efficient fossil fuel plants in providing energy services. For this comparison, data of carbon emissions and load the load profile of the existing balancing infrastructure is needed, which is not available for this research. Nevertheless, initial rough estimations can be deduced from a report prepared by Navigant on CO_2 reductions from demand response in three markets in the US[16].

Carbon reductions from demand response in the US by Navigant

The report by Navigant addresses direct and indirect emissions reduction from demand response. Direct emissions are reduced by replacing inefficient fossil fuel plants in providing energy services, such as providing peaking capacity on high load days. Indirect emissions are reduced by demand response's influence on long term decisions regarding the energy mix, such as its impact on the economics of fossil fuel plants that may accelerate their retirement. Navigant estimated direct emissions by using a quantitative model for two cases: peak load reduction and ancillary services provision. Indirect emissions were estimated by using a qualitative review for two cases: supporting renewables penetration and accelerating changes in the system fuel mix. The three markets modelled were the PJM Interconnection (serves 14 states in the North East), the Midcontinent Independent System Operator (serves 15 states in the Midwest and the South), and the Electric Reliability Council of Texas -ERCOT (serves 75% of Texas).

The report concluded that demand response could reduce CO_2 emissions from the power sector by more than **1%** for each direct and indirect emissions. For context, 2% of 2012 in the US power sector is equivalent to **39 million tonnes**, which is higher than the total CO_2 emissions due to mobile sources in The Netherlands in 2015 (34.65 million tonnes[17]).

Implications for demand response in The Netherlands

The methodology used by Navigant is quite comprehensive as they included several scenarios in their emissions estimations. Based on their results, a rough estimation of direct emissions reduction for The Netherlands can be deduced. As a first step, the Dutch energy market was compared with the three markets analyzed in the

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[15] Paterakis, N.G., O. Erdinç, and J.P.S. Catalão, *An overview of Demand Response: Key-elements and international experience*. Renewable and Sustainable Energy Reviews, 2017. **69**: p. 871-891

[16] Navigant; *Carbon Dioxide Reductions from Demand Response: Impacts in Three Markets. Prepared for: Advanced Energy Management Alliance*. 2014: Washington, DC.

[17] CBS; Emissions of greenhouse gases according to IPCC guide-lines. 2017 March 9

US based on the fuels used in the energy mix (See Table 3). It was observed that the ERCOT market is the most similar to the Dutch one as natural gas is the main fuel used on both markets. In addition, there are similarities in the proportions of fossil fuels and renewables used. Hence, the results of direct emissions estimations of the ERCOT market were used as a base to make estimations for the Dutch market.

p	Coal (%)	Natural gas (%)	Nuclear (%)	Wind (%)	Hydro (%)	Biomass (%)	Other (%)
NL[4]	16	66	2	8	0	1	7
ERCOT[5]	28.1	48.3	11.3	11.7	0.2	0	0.3
MISO[6]	52.3	25.4	13.5	6.1	0	0	2.7
PJM [7]	29.5	23.9	38.6	3.5	2.8	0	1.6

Table 3: Energy mix of the three markets in the US and The Netherlands

The results of the Navigant report were presented as the percentage of annual reductions of CO_2 emissions from the power sector that can be achieved by demand response under different scenarios. For this analysis, the results of the ERCOT market were transformed from percentages to their equivalent numbers in tonnes of CO_2 reduced per MW of demand response dispatched. For the case of peak load reduction, as reductions depend on the total time that demand response is provided in the year, the estimation was done per hour of service provided. Based on this analysis, it can be concluded that:

- By using demand response for peak load reduction, on average 13 tonnes CO_2/MWh can be saved annually in The Netherlands.
- By using demand response for ancillary services, on average 56 tonnes CO_2/MW can be saved annually in The Netherlands.

Conclusions and discussion

In conclusion, these initial estimations highlight the great potential benefits of demand response for the environment and gives an indication of quantifying the savings in carbon dioxide emissions. One should realise, that it is not a reliably indication, since the calculations are based on a research in a different country and markets with different assets. To give a better insight the climate benefit of using household appliances for demand response, a study should be conducted within one of the operating fossil fired power plants bidding in the ancillary service markets. Despite the fact that Engie is bidding in those markets with power plants, was it unfortunately impossible to use data from that experience, since the data is too sensitive and the insights in the current business case of the plants extremely confidential. As showed in appendix D1, internal research by Engie showed that entering the FCR market with DR could save up to 15kTonnes of $C0_2$ per MW compared to conventional FCR methods.

Work package 5

Introduction

This work package describes the costs and benefits of the assets who are connected in the TenneT FCR pool. The first paragraph “Context” describes the cost and benefits in the current energy market. The second paragraph “Practical results” describes in more detail the situation of the first and most important asset in the pool during 2017.

Context

In this paragraph the context is split in two different business case topics. The sub paragraph cost and the sub paragraph benefits.

Costs

Most of the costs are based on the energy bill of participating customers. This bill can be split up in three parts: Supply cost, Transport costs and system balancing costs. The costs of supply will be paid by the customer to the supplier for the supply of every kilowatt-hour, the cost of energy transport will be paid to the local grid operator (DSO) and the cost for system balancing will be paid to TenneT (the Dutch Transmission System Operator TSO).

The most important costs relevant for FCR balancing

- Supply costs for roundtrip efficiency
- Transport costs
  - kW contracted (yearly peak)
  - kW monthly peak
- Energy Tax
- Costs for the pool aggregation services

The Roundtrip efficiency are the energy losses related to the battery efficiency and the inverter efficiency. These losses are between 5 and 20%. Transport costs are based on the yearly and monthly capacity, requested by the customer for the electricity grid. In the Netherlands, every grid owner is able to define their own tariffs[18] for requested services.

Energy tax is the fee that every energy consumer is obliged to pay for every kWh they used from the grid. The fee for each customer depends on the total energy consumption per year. Every year the Dutch government changes the taxes and therefore the tariff fluctuates year to year.

[18] Source; ACM, Enexis grid tariffs 2017

Jaar	0 t/m 10.000 kWh	10.001 t/m 50.000 kWh	50.001 t/m 10 miljoen kWh	meer dan 10 miljoen kWh particulier	meer dan 10 miljoen kWh zakelijk
2011	€ 0,1121	€ 0,0408	€ 0,0109	€ 0,0010	€ 0,0005
2012	€ 0,1140	€ 0,0415	€ 0,0111	€ 0,0010	€ 0,0005
2013	€ 0,1165	€ 0,0424	€ 0,0113	€ 0,0010	€ 0,0005
2014*	€ 0,1185	€ 0,0431	€ 0,0115	€ 0,0010	€ 0,0005
2015*	€ 0,1196	€ 0,0469	€ 0,0125	€ 0,0010	€ 0,0005
2016*	€ 0,1007	€ 0,04996	€ 0,01331	€ 0,00107	€ 0,00053
2017*	€ 0,1013	€ 0,04901	€ 0,01305	€ 0,00107	€ 0,00053

Figure 13: Energy tax NL[19]

The picture above show the Dutch energy tariffs for the period of 2011 till 2017. During the execution of this research, most of the battery storage owners payed € 0,01305 per kWh. On MWh scale that is equal to € 13,05 per MWh.

Benefits

For the FCR pool the customer revenues are based on the weekly TenneT FCR auction prices. The weekly market price show a downward trend for the last years. For the business case this represents a difficult and uncertain parameter since there are no guaranties what the price will be in the (near) future. As it is already hard to predict what the auction prices for the coming weeks will be.

The picture below, shows the prices from January 2015 till July 2017. There are two different price lines in the graph (figure 14). Namely the minimum price and the maximum price paid by TenneT for á MW of FCR capacity during the period of January 2015 till July 2017.

The green blocks visualize the market size of the West European FCR market. Which has grown from 680 MW in 2015 to 1.400 MW in 2017.

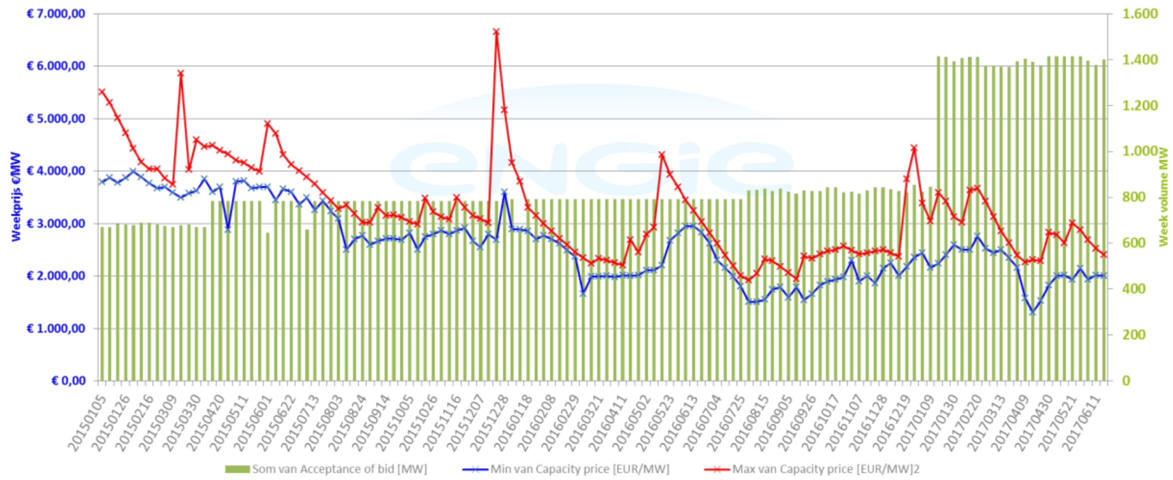

Figure 14: Market price development for the TenneT FCR market Results 01/2015 till 06/2017[20]

[19] Source; Belastingdienst; Tariffs energy tax;
[20] Source; regelleistung.net

Laws and regulations issues

The current costs in the pool depend to a large extent on current governmental laws and regulations. The actual laws and regulations however, do not take into account the availability of storage in the system / grid. As a result, there are undesirable costs when applying storage in the FCR pool. Nevertheless storage is the most important asset in an FCR aggregation pool.

The most important undesirable side-effects with FCR delivery are:

- Double energy taxes;
- Asymmetry in energy tax (B2B); price difference in consuming and feed back into the grid.
- Netting for the B2C market; consuming tariff is equal to feed in price
- Transport cost; transport costs for storage that delivers grid services like FCR delivery

In the Netherlands, Energy Storage NL tries to influence the government, for better regulations and limit the negative and counterproductive regulations against energy storage[21].

Results in practice

In this paragraph the result are split in the three different parts of the business case. Namely the sub paragraphs cost, benefits and results. The results are based on the situation as provided in figure 15.

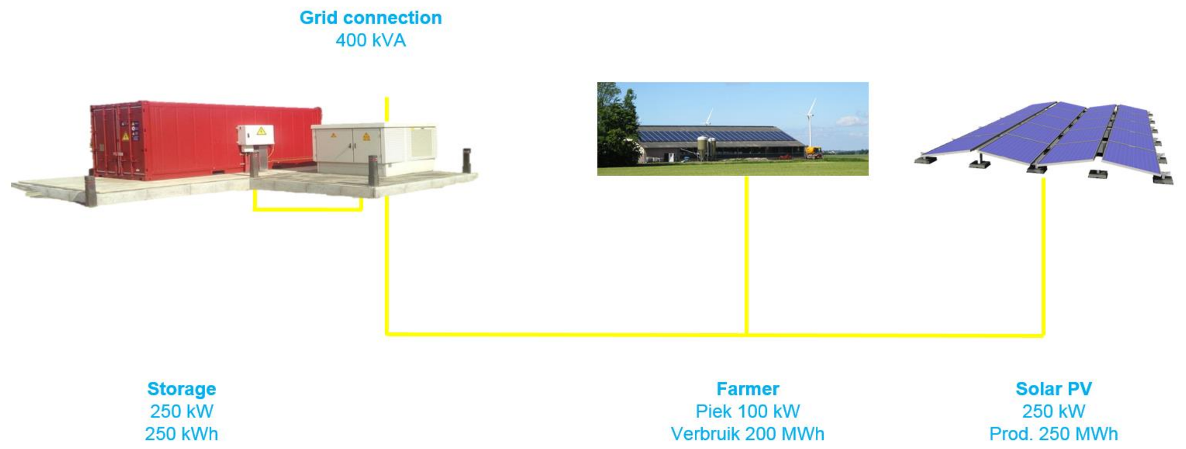

Figure 15: Situation cost benefit analysis

Costs

In this part we describe the OPEX cost, based on the defined costs subjects in the previous paragraph "Context" and the situation in the figure above.

Roundtrip efficiency

The roundtrip losses are the difference in energy import and export of the battery storage. In practice the roundtrip losses are around the 20%. This results in a loss between €800 and €900 per year.

[21] EnergyStorageNL; Nationaal actieplan energieopslag; October 2016

Costs - Roundtrip efficiency	FCR market
Roundtrip losses (%)	20%
dayly cycli	2
Total storage in	146.000 kWh
Roundtrip losses (kWh)	29.200 kWh
Energy price 33 €/MWh (roundtrip losses)	30 €/MWh
Totaal	-€ 876

Figure 16: Roundtrip losses paid to the Energy supplier

Transport costs

The total transport costs consist of three important operational costs. The Yearly and monthly peak and the kWh normal tariff for each kWh consumed from the grid[22].

Costs - Transport (extra)	FCR market
kW contr. € 14,31	100
kW month € 1,43	50
kWh normal € 0,00833	87.600 kWh
Totaal	-€ 3.019

Figure 17: Transport cost regional net owner

Energy Tax

The energy tax for this situation based on the € 0,01305 per kWh in the previous paragraph "Context" results in a total cost between the € 1.100 and € 1.200 per year for the 200 kW FCR nomination.

Costs - Energy taks	FCR market
	13 €/MWh
60% isn't solar energy	60%
Energy consumption	87.600 kWh
Totaal	-€ 1.139

Figure 18: Energy tax cost pay to the government

Benefits

The benefits for 2017 are based on the average market prices of 2017. These prices are around € 2.500 MW/wk. Yearly based its € 130.000 per MW. For the case calculated in this work package it's € 26.000 for the 200 kW storage unit, based on a nomination period 52 weeks.

Results

The total results of the costs and the benefits in a 1 MW pool of assets are around € 100.000 and € 110.000 (excl. service fee for market access). This is based on the results the 200 kW FCR analysis of appendix E1. Appendix E1 shows also the FCR results for the period week 20 till 29 of 2017.

[22] Source; ACM, Enexis grid tariffs 2017

Work package 6

Introduction

This working package is approached from different sides. Firstly, the experience of both Sympower and Engie in the flexibility market can give insight in possible revenues in different markets. Comparing the real world value created within other markets besides the residential sector, an estimation could be made what financial rewards could be expected per kW capacity. Secondly, the information from the other WP's will be used to sketch a possible scenario of an aggregated flexibility pool in the near future. The role of the different assets could be calculated one by one and compared with the total value of the pool. To understand the real value of each residential asset, complex modeling is needed to gain insights. In those models, different information is brought together to understand the process. Forecasts of average domestic electricity consumption per assets should be combined with the historical data about revenue possibilities for flexibility together with forecasting of number of occurrences. An example of such an complex model to calculate the economic benefits of domestic DR is showed in figure 19.

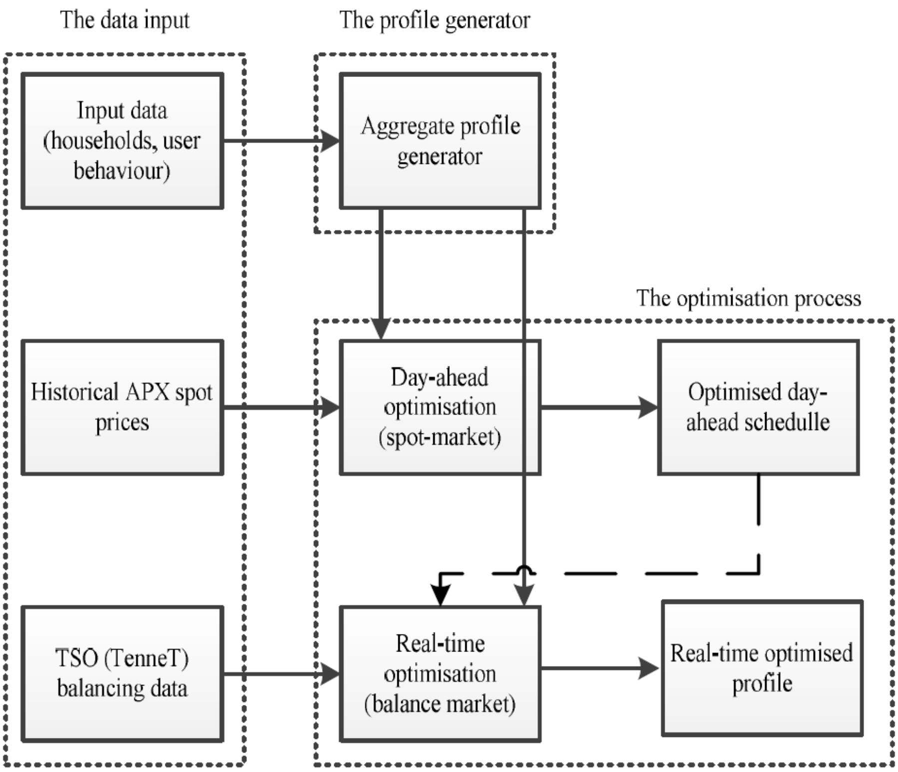

Figure 19 Example of model to calculate economic potential of assets[23]

[23] Abdisalaam, A (2012, May). Assessing the economic benefits of flexible residential load participation in the Dutch day-ahead auction and balancing market. In *European Energy Market (EEM), 2012 9th International Conference on the* (pp. 1-8). IEEE.

The capital investment needed to realise communication infrastructure within energy management systems in the residential sector are significant and could be seen as a major barrier for development of DR.[24] Nevertheless, research shows that if the existing flexibility in the residential sector is combined with historical data of the Dutch markets, the business case for aggregators has great economic potential if executed on large scale.[25] Within this report the flexibility is calculated on rough estimations of past experience and pilots and combined with prospects of future markets expectations. Due to this, the outcome of the economic potential is not trustworthy to design business models, but gives insight in which direction research could be further developed. Academic research on business models for aggregating demand side flexibility is lacking results due to lack of information about costs and benefit analysis of the Dutch residential flexibility resources.[26]

Content: Return on Investment Model & Payback period

In appendix F2 the financial model to score and compare the different assets in the pool could be found. Two major outcomes are the payback period and the Net Present Value.

$$PP = \frac{I - S}{O_y - M_y}$$

PP = Payback period [years]
I = initial investment [€]
S = subsidies [€]
O_y *= Annual revenue or savings [€ · year^{-1}]*
M_y *= Maintenance costs [€ · yearr^{-1}]*

$$\text{NPV} = \sum_{t=1}^{T} \frac{O_y - M_y}{(1+i)^t} - I = 0$$

$$\sum_{t=1}^{T} \frac{O_y - M_y}{(1+r)^t} = I$$

t = time [years]
r = interest rate [%]
I = initial investment [€]
O_y *= yearly revenue [€ · year^{-1}]*
M_y *= maintenance cost [€ · yearr^{-1}]*

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[24] . I. Lampropoloulos: Energy management of distributed resources in power systems operations" Ph.D. Dissertation TU Eindhoven 2014. P75

[25] Abdisalaam, A (2012, May). Assessing the economic benefits of flexible residential load participation in the Dutch day-ahead auction and balancing market. In *European Energy Market (EEM), 2012 9th International Conference on the* (pp. 1-8). IEEE.
[26] Van Hout, M. 'Quantifying flexibility markets' ECN (2014)

Costs & benefits per assets

The benefits of every assets depends strongly on the ancillary service market the flexibility is sold in and the business logic selling the flexibility in trading markets. Due to technical characteristics, different assets are applicable in different markets. In appendix F1 a clear overview of annual potential revenue estimations could be found. In Work package 2, the characteristics and the potential markets are already described. To simplify, for each asset the best market fit is chosen and combination of selling flexibility in different markets in time is neglected, with this strategy, per asset, the value of the pool if combined with different assets is not clear yet. For some assets, there could be a distinction between current technology and 'smart' technology. In the business case, 'smart' technology is referred to as an new product with the same characteristics, but inherent data collection and communication with a database. The 'smart' asset will be able to switch on/off or shift load without installation and connection of extra hardware, this will reduce the initial investment tremendously. Three different scenarios are developed to calculate the cost of the DR asset. The first method is to take the total cost of the product inclusive installation cost. In the second scenario's it is assumed the product is already in use and only the installation of the connection to smart software is taken into account. In the last scenario's the costs are near to zero, since we assume a 'smart' device with inherent hardware and software with the required functionalities for DR.

The yearly revenue used in the model (O_y) is calculated by multiplying the available yearly flexibility with the expected revenue found in appendix F1. The maintenance costs (M_y) are neglected in this model.

Electric boilers

A new electric boiler for residential use is ± €350,- and to connect it to an aggregator software platform an simple hardware installation could be done. Similar connections with other customer groups showed this will be low cost for the installation itself. No maintenance costs are expected with a simple connection like that. If new updated smart electric boilers will enter the market, only €20,- cost will be made to connect the asset to the platform.

Heat pumps

To heat your home and warm water with an air heat pump the capacity varies from 3kw to 12kW. Such a system cost between €6.500,- and €14.000,- but in The Netherlands there are subsidies available to reduce the investment costs for home owners up to €2.500,-[27] As mentioned in working package 2, 30% of the available 8kW could be sold as flexibility load shifting or load interruption without influencing the comfort of the end user. This payback period of the heat pump will, depending on which market the flexibility is sold in, be 34 to 154 years.

The case gets more interesting if we assume the initial investment of the heat pumps system is already done and the technology is already in place. If investment cost of the system is neglected and only the installation and hardware for the DR communication is needed (€200,-) the model in appendix F2 shows the payback period (if sold in mFRRda-down market) is only 3 years or even less than one year if the smart heat pump is controllable already!

Batteries

Batteries are quite different from the other assets for two reasons. Firstly, there is no latent flexibility in a battery, which add up the investment cost of the batteries itself to every scenario and makes the initial investment high. Secondly, since the batteries energy is used only for flexibility, the precondition characteristic comfort is not an issue. The full capacity of the battery could be used to bid in the flexibility market, which increases the annual benefit. The data from the pilot is used to estimate annual cost and benefits for a 1 MW

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[27] MilieuCentraal website

system. In appendix F2 could be seen the payback period for the battery pack used for primary reserves is in the order of 12 years.

Air-conditioning

An air-conditioning system from 5kW cost around €1.000,-. Many difficult question arise when estimating the flexibility of the air-conditioner systems and no experience in the past could give guidance. The flexibility is expected to differ significantly due to seasonal different and the load profiles during the year show this pattern. Only during summer the air-conditioning systems will be used intensively. Due to the lack of data from residential air-conditioning systems in The Netherlands, the estimation is set on 10%. Together with the relative small power of the asset, the realistic payback period is shown in Appendix F2 to be between 33 and 178 year.

Discussion & conclusion working package 6

The value of DR depends strongly on how we expect the markets to change over time. During this project we realised again the incredible amount of parameters influence this development. The energy systems is going to change during the next 10 years, but how fast is very difficult to predict. For example, we believe there will be a new value for DR solving local congestion for DSO's. Pilots are done to test the technology on local grids, but how the reward for optimizing the local grid is going to be divided and what new business models will arise is unclear. Besides different future business models, the expected technology growth and more and more internet connected devices, gives a glimpse of how a more sustainable energy system could operate.

The short term prospective is less exciting. Change in the regulatory framework and market bidding is slowly and the implementation takes a long time.

The calculation made in this working package are done with expected future prices based on historic prices from different ancillary service markets as shown in appendix F1. The uncertainty of the markets is one of the biggest bottlenecks for large scale investment. The historic data of the different flexibility markets show strong fluctuations and no one can guarantee income based on historic data. The real value of the pool is extremely hard to find. Not all assets fit to every market, some assets are unsuitable for markets due to technical boundaries, like emergency stops or slow cool down periods. Even with a payback period of only 12 years with large batteries in the current market, investors will be hesitant to trust the future value of the primary reserve market.

Conclusions, discussion & recommendations

During the conducted pilot, the initial proposal changed due to the circumstances. Unfortunately, coupling residential assets like heat pumps and electric boilers from the Sympower platform together with FCR bidding of the Batteries owned by Engie was not realistic. Without this software coupling system, the added value of the pool was not shown by the pilot. Still real world data from the pilot with batteries showed that building a pool creates significant value. The value of available flexibility increases if the aggregated pool is large enough to utilize different assets and if the pool is able to switch between different markets. During the frequency analysis, we found that with 17.5% of the capacity available in the pool, 95% of the time the primary reserve is saturated.

In working package 3 is showed how the batteries react on the frequency during the operations and its deviation. A large amount of data from the batteries was collected and used for analysis. Some days, the batteries react perfectly to the circumstances and the energy from the batteries is used to restore the frequency short term. More interesting is the data that shows limitations or problems. As described in working package 3, deviation of power meters or frequency meters could cause problems. Another problem was delays in communication and the communication must be optimal if bidding in the short term markets like FCR.

There is a big gap between the large industrial flexibility and the small scale domestic flexibility available for DR with residential assets. The owner of large industrial assets with a significant amount of flexibility could direct improve his business model by making use of the latent flexibility. For residential households, the amount of flex per household is so little that economic benefit is hardly a stimulation.

Working package 2 showed us that refrigerators, freezers and air-conditioning systems are unsuitable for domestic DR operations. Heat pumps and electric boilers show significant potential and we encourage more research and pilot projects with this technologies.

Involved stakeholder preferable have correct numbers available about the influence on the environment of specific technology. The problem we have come across in working package 4 will probably not disappear, but more research from different stakeholders will improve the insights in the environmental gain of DR.

From the model in this report we can conclude that on the short term the assets which fit the FCR market are most valuable. It is important to notice here that this is not due to high rewards in the market, but very low installation costs, since appliances are already assumed to be controllable. The cost to build the business logic and software in those future appliances could differ a lot depending on the software available in the devices.

From working package 4, the only real conclusion we can draw is that estimation of reduction of carbon emission due to DR aggregation is a very complex problem. There are a lot of pitfall and indirect implications or assumptions we have made and to make a more accurate calculation, data and business strategy insights from current situation is necessary. This is also the reason that little is written about this in literature, the data and information from the fossil fuel power plants interacting in FCR and other ancillary service markets is very well protected.

Possibilities for spin-offs and follow up

Different commercial value is obtained by this feasibility study. The results of the batteries used for FCR showed how this type of batteries will react on the frequency and that the software and hardware connection was good enough to operate the system. Knowledge is collected about the potential of the different residential asset, from a technology and economical perspective and this will guide future business development and projects.

After the rap up of this project, both Engie and Sympower gained a lot of insight about the residential DR sector, but also insight in each other's operations. Both parties will stay in close touch regarding growing a pool of commercial/industrial of residential assets to learn from the experience and stimulate the market entry.

In the longer term, it is complex to make an analyses of the market environment and current market perspective and business models do not display a realistic overview of future opportunities. However, the dialogue between commercial parties, research institutes, universities and the government unfolds trends we see in the current market and indicate directions for the future. If the trend of connecting devices to the internet reaches the domestic electric appliances, the cost of connecting residential assets to the available DR platforms will decrease drastically. It is recommended that collaboration with manufacturer of electric devices is stimulated to increase the transparency available data and communication software.

The potential of electric vehicles is enormous in the DR market. Since this topic did not fit into this specific feasibility study, a new research project is recommended. The technology of vehicle two grid charging is not going to take off on the short-term, but smart changing to solve local congestion problems and bid into ancillary markets with residential connected electric vehicles is expected to change from pilots to practice in the upcoming years. This gives interesting opportunities to an aggregated pool of flexibility, to sell the flexibility not only in different ancillary service markets, and trading markets, but also in new arising local congestion markets directed by the DSO's.

Implementation of the project

Encountered problems

During the implementation of the project, no serious problems occurred. The partners Sympower and Engie have made a clear split-up of tasks to carry out research within the knowledge and competencies of the partners and have shared this knowledge at regularly recurring meetings.

The biggest problem that has occurred is the coupling of residential assets like heat pumps and electric boilers in the FCR bidding pool. This problem has led to a minor change of the project plan and was communicated to all parties in the mid-term progress report.

Changes in relation to the project plan

During the conducted pilot, the initial proposal changed due to the circumstances. Coupling residential assets like heat pumps and electric boilers from the Sympower platform together with FCR bidding of the Batteries owned by Engie was not realistic. Without this software coupling system, the added value of the pool was not shown by the pilot. Still real world data from the pilot with batteries showed that building a pool creates significant value. The value of available flexibility increases if the aggregated pool is large enough to utilize different assets and if the pool is able to switch between different markets.

Difference between the budget and actual costs

The difference between the budget and the actual costs is minimal. In the delivered hours there is a deviation of approximately 100 hours that have been made extra.

Knowledge dissemination

Engie and Sympower will use the results of this report for further knowledge sharing. the public report will be widely shared, possibly as a download via its website. An NDA has been closed for the confidential part.

The consortium partners have also actively contributed to market development and to the scientific debate, in the form of active participation in seminars and conferences. For example, presentations were given on the results and experience of FCR Delivery with decentralized assets.

Pr project and further PR opportunities

After acceptance by RVO of this report, partners will follow up on their previously published press release. The further PR possibilities are currently being considered. For example, the results are considered to be processed in a whitepaper or short leaflet.

The project has provided good PR[28] [29] to partners and has ensured that other parties have shown interest in the development of Peninta (unlocking decentralized flexibility for real time grid balancing).

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[28] Persbericht Energeia; start-up-sympower-zoekt-naar-meerwaarde-van-flex-op-twee-fronten
[29] Persbericht TenneT; TenneT bereidt elektriciteitssysteem voor op toename duurzame energie;