Final report GreenCom Top-Up

This final report is for the GreenCom Top-UP project which supports the EU GreenCom project, funded under FP7-ICT, with hardware. The final evaluation report for GreenCom (D9.4) is to be found in the Annex-1 and is/ will be published (when accepted by our Project Officier) along with all other public documents from the project at the project web: http://www.greencom-project.eu/ 5 newsletters from the project are also available at the web.

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1.1 Project details

Project title	GreenCom Top-UP
Project identification (program abbrev. and file)	ForskEl Call 2013: 12025
Name of the programme which has funded the project	ForskEl
Project managing company/institution (name and address)	EnergiMidt Forsyning og Service A/S
Project partners	None Top-UP project for GreenCom – EU-FP7-project
CVR (central business register)	34042462

Date for submission	May 2016

1.2 Short description of project objective and results

GreenCom Top-Up supports the EU-Project GreenCom; "MyGrid; Energy Efficient and Interoperable Smart Energy Systems for Local Communities " GreenCom Top-Up supports hardware installations for the Pilotsite, which is at the Danish island Fur.
The project aims to balance the local exchange of energy at the community microgrid level, to avoid affecting the centralized grid with instability. There is a lot of potential in installing heat pumps in combination with PV-systems and the businessmodel is feasible, this combination is able to reduce the peak and create peak shaving and demand control. Furthermore PV installations in combination with batteries have also a lot of potential both in self-sufficiency and peak shaving.

GreenCom Top-Up supporterer EU-Projektet GreenCom; "MitNet; Energieffektivitet og operative intelligente energisystemer for lokalsamfundene" Top-Up støtter hardware installationer for Pilotstedet, som er på den danske ø Fur.
GreenCom vil udvikle muligheden for intelligent styring af energien, så el-apparaterne i hjemmet kan bruge el, når den er til stede i el-nettet, men også er i stand til at lagre energien lokalt til senere brug. Der er masser af potentiale ved at installere varmepumper i kombination med solceller og forretningsmodellen har muligheder. Denne kombination er i stand til at reducere kW-max og at udjævne spidslastforbrug, samt kan styres eksternt. Ydermere kan kombinationen solceller og batterier øge selvforsyningsgraden, samt udjævne spidsbelastninger.

1.3 Executive summary

The vision is to develop a technical and a socio economic foundation for introducing radical new business models, based on intelligent energy systems, which can be accepted by consumers in well-defined areas.
The GreenCom project has used a business-driven approach in an iterative technological development environment. The starting point for each pilot development is an agreed business case and associated use cases, from which pilot installations are developed and validated.
The Pilotsite is at the Danish island Fur, where 6 transformerstations/feeders have been selected for installation of heatpumps, photovoltaic systems, batteries and smartplugs/ current clamps. The concentration of equipment and generation has been chosen to illustrate the future grid.

The chosen business models are:

- Home Monitoring and Control (HMC):
  In this business model, energy consumers are motivated by two aspects: To save energy and to shift load to get cheaper energy prices. This is achieved by installing a GreenCom home automation platform which provides access to detailed, itemised energy consumption data for all their appliances. Integration of price signals with the automatic home control features allows the consumers to programme automatic shift of load to periods, when the energy is cheapest. To enhance the value proposition, bundling of services with external service providers, such as entertainment or security companies, is foreseen.
- Heat as a service (HaaS) – Load management:
  In the Heat as a service model, heat pumps are installed and aggregated with the purpose to either 1) store power that is bought when it is cheapest and delivered as heat when it is needed or 2) be used for balancing the grid. The Aggregator gets full, direct control of the pump. In return, the Consumer is contractually guaranteed a comfort level/minimum temperature in the household. The business model can be reversed and used in cooling situations.
- Intelligent Energy Storage (IES):
  Batteries are offered to individual Prosumers with PVs to use as much of their own produced solar energy as possible. A percentage of the battery is made available for grid management.

The conclusions from the project are:

Qualitative evaluation with end-users:

- Private finance is a key driver for investment but not the only one; climate and comfort concerns are also central motivators
- Flexibility depends on personal preference, economic incentive and knowing the conditions
- Services close to our immediate needs are first priority.

HMC:

- Being able to monitor devices, become aware of consumption and thereby save money is not enough for the customer to invest in a smart home solution in the long run. The introduction of (price) signals, automatic control and additional smart home services are necessary additions to benefit the flexible consumer.
- There is less interest in adding services which are not traditional 'smart home' features such as entertainment and telehealth.
- It is possibly to obtain energy savings when you install smart plugs and raise awareness in residential houses, but the general influence from other means arise even more awareness.

Haas:

- Money is not necessarily the only value for the customer in helping the grid. It could also be free kWh or cheaper electricity at night thereby accommodating the need of the grid twice.
- Control should be dynamically adjusted to fit different situations and wishes.
- The contract should state number of activations expected at different times and how long they might last.
- 'We need to know what is happening' Information sharing is crucial, both when control is performed and when the household situation changes.
- Service should be included in instances of outage.
- It is possibly to obtain load shaving and thereby lowering the cooking peak and helping the grid operator.
- The combination of Heat Pumps, PVs and demand control serves the grid quite well; in average 2,7 kW per house.

IES:

- Personal freedom of choice first, then contractual collaboration
- The most important thing is to use as much of our own 'free' solar electricity as possible
- Raise the value by offering the customer to buy back the extra battery capacity when not used by the DSO
- Sharing economy should also entail sharing the cost of batteries
- Self-sufficient level increases from 33% to 61% (from Aug to May) when installing batteries in PV houses

Every partner in the GreenCom project has made exploitations plans (confidential). But the project has produced 6 software products besides new business models for the smart grid marked. IPR rights are shared between more GreenCom partners and the software products are already being sold in the marked.

1.4 Project objectives

Overall vision:

Develop a technical and a socio economic foundation for introducing radical new business models, based on intelligent energy systems, which can be accepted by consumers in well-defined areas:

- **1st GreenCom vision – Technical (70%)**
  Develop an intelligent IT-platform, which can gather and control consumption in the Microgrid

and thereby help the DSO/Grid Operators by avoiding or reducing the peak loads on the Microgrid, without compromising the stability and the security of supply.

- **2nd GreenCom vision – Socio Economic (30%)**
  Development and validation of sustainable business models, which should engage customers in their own energy consumption and energy demand, which should increase the customers understanding and awareness for the future energy system and cover, what is valuable to the future energy consumer/prosumer, in order to increase the demand and incentive for intelligent energy solutions.

The aim of the GreenCom project is to utilise the flexibility and intelligence in the low-voltage demand and local supply side infrastructure to create in-creased regulation capacity and reserve power in the centralised power grid by extending the means to effectively and securely manage and control the demand and supply within defined boundaries. The project thus aims to balance the local exchange of energy at the community microgrid level, to avoid affecting the centralized grid with instability.

To solve such means, the GreenCom project will develop a Smart Energy Management System (SEMS), i.e. an energy management and control platform that allows energy providers (Distribution System Operators or Retailers) for the first time ever to measure and balance load in the low-voltage grid and thereby prevent or reduce critical peak situations. It will thus allow the energy distributors to move beyond focusing on Power Grid efficiency and start focusing on Energy System effectiveness; a giant step forward in European energy distribution.

The GreenCom SEMS will collect, aggregate and analyze real-time or near real-time data from appliance level consumption devices such as appliances, smart home devices, sensors and actuators and smart meters, via an independent data communication network. The data analysis will provide real-time consumption data on type of devices and location together with short term forecasts. Data can be aggregated over several sectors of the grid.

On the other hand, the GreenCom SEMS will also allow management of energy demand through intelligent control of the consumption devices and manage local energy generating and storage installations. The demand control will be based on individual consumer contracts with attractive tariffs, reward/penalty clauses and other value based elements.

A business-driven approach:
The GreenCom project has used a business-driven approach in an iterative technological development environment. The starting point for each pilot development is an agreed business case and associated use cases, from which pilot installations are developed and validated. An integral part of the GreenCom project is thus the analysis and development of realistic business models for consumers, energy distributors, service providers, and other actors. New research into defining and measuring value creation in dynamic energy constellations has been undertaken, leading to innovative business structures involving existing and new actors in collaborative, dynamic value constellations. To serve these purposes, the GreenCom project has provided a test bed for deploying selected business cases and collecting data for analysis and evaluation of the Smart Energy Systems business models and, in the end, demonstrated the best solutions in small scale pilot. Laboratory based prototype platforms has been put together and demonstrated in Cork, Ireland, while "real life" pilots has been deployed in the Island of Fur, in Denmark.

The Pilotesite:
The Pilotsite is at the Danish island Fur, where 6 transformerstations/feeders have been selected for installation of heat pumps, photovoltaic systems, batteries and smartplugs/ current clamps. The concentration of equipment and generation has been chosen to illustrate the future grid.
The final pilot status of the recruitment and installation of DERs and monitoring equipment at the Island of Fur is listed hereafter. Based on the final list of houses and installed equipment in the households, the GreenCom project has included 33 houses in total.

- 19 households are fully equipped with HMC (Home Monitoring and Control) equipment
- 11 households have heat pumps installed including:
- 7 air-to-water heat pumps fully equipped with HaaS equipment and controllable
- 1 air-to-water HP is equipped with metering equipment but not controllable
- 3 air-to-air heat pumps installed but without no metering and not controllable
- 20 PVs of which 14 are equipped with metering equipment.
- 5 Batteries have been installed and equipped with IES (Intelligent Energy Storage) monitoring equipment.

These numbers are relatively close to the original plan of 21 households planned for HMC, 15 houses with HP and 21 houses with PVs. In addition some of the budget was taken from installation of heat pumps in order to purchase and install batteries, which were not in the original plan. All of the houses have not been equipped with monitoring equipment due to the instability of the data. It was therefore prioritized to install equipment in a fewer households and focus on ensuring and maintaining the functionality in these houses.

The Business models selected for test:
Home Monitoring and Control (HMC):
In this business model, energy consumers are motivated by two aspects: To save energy and to shift load to get cheaper energy prices. This is achieved by installing a GreenCom home automation platform which provides access to detailed, itemised energy consumption data for all their appliances. Integration of price signals with the automatic home control features allows the consumers to programme automatic shift of load to periods, when the energy is cheapest. To enhance the value proposition, bundling of services with external service providers, such as entertainment or security companies, is foreseen.

Heat as a service (HaaS) – Load management:
In the Heat as a service model, heat pumps are installed and aggregated with the purpose to either 1) store power that is bought when it is cheapest and delivered as heat when it is needed or 2) be used for balancing the grid. The Aggregator gets full, direct control of the pump. In return, the Consumer is contractually guaranteed a comfort level/minimum temperature in the household. The business model can be reversed and used in cooling situations.

Intelligent Energy Storage (IES):
Batteries are offered to individual Prosumers with PVs to use as much of their own produced solar energy as possible. A percentage of the battery is made available for grid management.

1.5 Project results and dissemination of results

1.5.1 Results from qualitative evaluation with end-users

The aim of evaluation with the end-users on Fur was to get feedback on the GreenCom smart home system and business scenarios on one hand and compare and analyse consumption data on the other hand to see if any behavioral changes have occurred after installation of the GreenCom system.
User feedback was planned according to the three different installation set-ups in GreenCom:

- A smart home set-up with general appliances and business focus on: Monitor and control your energy consumption (automatically) based on external price signals (Home monitoring and control business model - HMC)
    - User interface is the GreenCom end user rich GUI
- A smart home set-up with general appliances, solar panels and heat pumps. Business focus: Enter a contract on your heat pump allowing external control in turn for guaranteed a comfort level and economic bonuses (Heat as a Service Load management business model - HaaS)
    - User interface is the GreenCom end user rich GUI
- A smart home set-up with solar panels and batteries. Business focus: Share your battery with the grid and gain a larger storage capacity for your solar production (Intelligent Energy Storage – IES)

- User interface is the Fronius solarweb

Additionally, the notion of flexibility was explored across groups in terms of: Demand control; „you allow others to control some of your household appliances and devices when needed“ and Demand response „you move your consumption when needed“.

The qualitative analysis has been supplemented by data analysis performed in all three groups, measuring the effects on energy consumption before and after the installation of GreenCom equipment, heat pumps and batteries.

We want to be flexible but it depends

All the respondents like the idea of being flexible consumers with 47 % believing they can be flexible, however, 33 % stay neutral and 20 % do not believe they can. Doubt is more prevalent in the general appliance group (HMC) which can be due to factors such as lack of incentives or flexible devices.

Some have changed their habits after installing renewable energy solutions;

"I make sure to put a wash on when the sun shines and I wait with the dish washer until the washing machine is finished "

Others are more reluctant to change behavior;

"Do you want me to cook my evening meal at a different time? No thank you. I might be flexible with some appliances but not all"

"I have not changed my habits but have reduced my energy bill 1/3 after going from oil burner to heat pump"

However, there is also an agreement that one can get used to being flexible if that is what it takes - they just need a helping hand;

"It is possible to become flexible but it takes time to adjust. We are not used to prioritizing"

"It would be easier to be flexible if we were properly informed about what the status is and what we need to do"

And that change of behavior will occur if there are economic consequences;

"The easy way for people to change habits is to regulate the energy prices"

How do we make people understand the importance of moving consumption out of the peak period?

One of the main challenges for the grid is coping with peak loads and there is a general need to make people aware of this and understanding the effects of dynamic prices and dynamic tariff on end users.

One suggestion was to initiate an awareness campaign communicating why it is sensible to move consumption away from the peak periods, spreading consumption more evenly. Another suggestion was to start showing a page with dynamic prices to push people's awareness. Whether this would make people change behaviour depends on the difference in prices but also on personal preference.

"I do not speculate in prices now and I probably won't in the future unless the prices vary a lot"

"I would definitely be interested in changing my behaviour if there were different prices at different times"

Conclusions

Private finance is a key driver for investment but not the only one; climate and comfort concerns are also central motivators

Flexibility depends on personal preference, economic incentive and knowing the conditions

Services close to our immediate needs are first priority.

1.5.2 End-user results Home monitoring and control businessmodel

1.5.2.1 The model

In this business model, energy consumers are generally motivated by two aspects: saving energy and getting cheaper energy prices by moving consumption to periods with lower prices. This is achieved by installing a GreenCom home automation platform which provides access to detailed, itemised energy consumption data about all their appliances. Integration of price signals with the automatic home control features allows the consumers to programme automatic shift of load to periods, when the energy is cheapest. To enhance the value proposition, bundling of services with external service providers, such as entertainment or security companies, is foreseen.

The goal is to evaluate the commercial aspects of the business model by identifying the business and market value in the following cases:

a) The Consumer invests in a home automation solution to save energy and money. The system

1) Shows detailed consumption data for individual devices and allows the consumer to set up automatic control schemes for different purposes and

2) Enables automatic control of devices according to price signals

b) A Service Provider delivers a home automation solution to

1) Provide enhanced customer experience through a bundling of services and

2) Obtain detailed, anonymised consumption data, aggregated to forecast demand and offer attractive tariffs

1.5.2.2 Demonstration

The model has been demonstrated by the installation of a GreenCom smart home platform and equipment in 19 households, allowing the users to access detailed energy consumption data on a number of appliances through a user interface. The other services; home automation and security services have been presented to the user in the user interface but as simulations. Information on tariffs has been presented to users as a mock-up at the workshop.

In the questionnaire and at the workshop, the model has been presented with the following selling line:

You are offered to buy a smart home solution like the one in GreenCom to help you save energy by getting detailed information about consumption and to help you control your energy usage according to dynamic electricity prices. You can programme the system to automatically turn on and off devices depending on the purpose. Additionally, you get an entertainment package with internet and TV.

The installation of the system leads to energy savings based on increased knowledge about consumption as well as a cheaper price on electricity because you can plan consumption after the price of electricity.

1.5.2.3 Evaluation

The user evaluation shows that there is no particular interest in a home monitoring and control solution without an economic incentive that goes beyond any initial savings. In the questionnaire, 4 are not willing to invest and 1 respondent places herself/himself as neutral, expecting to have the investment repaid within 3-5 years.

Similarly, the respondents are reluctant to shift consumption for the benefit of the grid alone (2 are not willing, 2 are willing and 1 is neutral), however, they are more positive if shifting entails lower energy prices (3 are willing to plan after price signals, 1 is neutral and 1 is not willing).

"I am not interested in seeing my consumption but if there was a possibility to react to prices I would be interested"

If price signals were introduced, it should be possible to programme the system to start devices automatically at a certain time or at a certain price so that one is not dependent on being present.

Svarvalg	Besvarelser	
Manually: I want to control the on and off myself	25,00%	1
Automatically: I set up the system to start and stop automatically	75,00%	3
External: I allow my energy provider to start and stop	0,00%	0
I alt		4

Table 1 - 75 % would like to programme devices to start and stop automatically

It should be noted that many Danish households still pay a flat rate for electricity no matter what time of day they use it so there is no obvious incentive to be flexible consumers. This explains the positive reception of dynamic price signals[1] as a motivator for being flexible. It should also be noted that whereas the dynamic prices in the HMC model are market prices.

"You have to remember that it is the government taxes that make up most of the price so the benefits for one's private finance is probably limited"

The battery group with only access to battery and PV information also saw an advantage in integrating with the home monitoring and control service.

"It is super if one can save the electricity to a time when the electricity price from the grid is high"

If not being able to store enough energy from PVs to cover a period of high electricity prices, HMC could be used to save energy. Also, HMC could be used to adjust how long one needs to use the battery e.g. at night and the next morning.

Bundle of services

The model is dependent on different actors sharing the same infrastructure so that the service provider can gain a sustainable service and so that the value proposition for the Consumer is more acceptable. In the model, entertainment services were used as an example and in the user interface, security services were demonstrated. The evaluation results show a greater interest in security services (60 %) than in entertainment services and broadband (0 %). Services not related to the functions of the home in the traditional sense such as telehealth were not of interest either (0 %) whereas services related to water consumption (60 %), smoke alarm (40 %) and indoor climate control (40 %) were.

Cost and savings

The model assumes that the individual consumer is able to reduce the electricity consumption by 10 % when installing the GreenCom equipment. The actual figures show that the houses in average have saved 7.8% since they have had smart plugs installed.

[1] More and more service providers offer Nord Pool power market rates. They can be based on a monthly average, on hourly smart meter readings or on a permanent time differentiated consumption pattern.

	Yearly consumption kWh			Savings in %
Home #	2013	2014	2015	%
Home 9	5.040	5.188	4.873	3,30
Home 10	6.279	6.344	5.957	5,12
Home 13	2.899	2.899	2.292	20,94
Home 14	4.067	4.043	4.105	-0,92
Home 16	1.830	1.948	2.024	-10,60
Home 17	5.711	6.528	5.710	0,02
Home 19	3.791	3.956	3.454	8,88
Sum	31.630	32.920	30.431	3,79
Home 11	3.119	3.035	2.893	7,25
Home 12	5.102	4.284	5.216	-2,25
Home 22	6.837	6.886	4.497	34,23
Total Sum	46.688	47.126	43.037	7,82

Table 2 - Annual consumption (kWh) and savings in percent

Table 22 shows the annual consumptions kWh and savings since smart plugs have been installed. The first 7 houses are connected to the same transformer station. These households have been compared to 53 neighboring houses at the same transformer station, which is the reference group. In this reference group the development in consumption has been -13,7% on average from 2013 to 2015. This means that there actually has been an increasing consumption in the test group of 6%.

53 houses at the same transformer	**2013**	**2014**	**2015**	From 2013-2015
Reference group.	kWh/year	kWh/year	kWh/year	%
Average consumption	2.890	2.628	2.496	13,7

Now this should be compared a typical Danish household uses 1.568 kWh pr. Person pr. Year.[2] This means that a typical household with two adults used 3.136 kWh and with a cost of 2,2 DKK / 0,29 EUR pr. kWh the annual cost for electricity is 6,899 DKK / 920 EUR. 7,8% savings of this is 528,12 DKK / 70,416 EUR.

These savings should be seen in relation to the total cost of the equipment of 5,977 DKK / 797 EUR. If the homeowner can keep this reduced level stabile on equivalent of 7,8% of the baseline there will be a ROI on a little more than 11 years.

If the service is solely for monitoring purposes, it becomes difficult to see how the savings can exceed the cost of equipment if the appliances are not already smart grid ready or if alternative ways of financing are not found. On top of this, the customer is expected to pay a monthly subscription for the service which will raise the cost. If the service offers more value i.e. by integration of varying price signals and automation as well as bundled services, the willingness to invest becomes more apparent.

Also, should the household enter into a demand control scheme, allowing external control of certain devices at certain times, the service would hold more value. However, this would assume that the devices can be controlled remotely.

[2] Bolius.dk - https://www.bolius.dk/saa-meget-el-vand-og-varme-bruger-en-gennemsnitsfamilie-279/

Conclusions

Being able to monitor devices, become aware of consumption and thereby save money is not enough for the customer to invest in a smart home solution in the long run. The introduction of (price) signals, automatic control and additional smart home services are necessary additions to benefit the flexible consumer.

There is less interest in adding services which are not traditional 'smart home' features such as entertainment and telehealth.

It is possibly to obtain energy savings when you install smart plugs and raise awareness in residential houses, but the general influence from other means arise even more awareness.

1.5.3 *End-user results - Heat as a Service business model*

1.5.3.1 The model

The Heat as a Service business model: Load Management deals with the control of heat pumps to offer different flexibility services to the DSO.

An Aggregator gets full and direct control of heat pumps in households which can be aggregated and offered to the DSO as a flexibility service. The Aggregator enters into contract with the DSO and the consumer who is contractually guaranteed a comfort level/minimum temperature in the household thus giving the Aggregator a degree of flexibility in the load on the grid. The consumer is being economically rewarded for allowing the Aggregator to fully control the heat pump.

The Aggregator can in principle use the load flexibility for various purposes, e.g. for buying the energy when it is cheap and storing it in the heat pumps or providing load balancing to the DSO as exemplified by this model.

The goal is to evaluate the commercial aspects of the business model by identifying the business and market value in the following cases:

a. The consumers enter into a contract on their heat pump to gain economic benefits. The system shows detailed consumption information, temperature settings and control options as well as the contractual agreement

b. The aggregated flexibility is used by an aggregator to sell load reduction to a DSO. The DSO can via a dashboard see grid status and expected loads. He can select the Micro grids for load reduction including time span, reward and fine, send request and receive the decision.

1.5.3.2 Demonstration

The model has been demonstrated to the consumers by the installation of heat pumps and a GreenCom smart home platform including equipment in 7 households. Users can access detailed energy consumption data on a number of appliances through a user interface as well as seeing information about the temperature inside and outside and the relation between heat pump consumption and temperature. Features that enable control of devices and control of temperature are shown in the user interface but as simulations. Information about the contract has been shown to users at the workshop as a mock-up.

Additionally, test contracts have been sketched for each household to establish the level flexibility and covering:

- The maximum temperature allowed in the household
- The minimum temperature allowed in the household
- The absolute minimum temperature allowed against payment
- The monthly price for offering flexibility
- The hourly price for letting the temperature go to the absolute minimum

In the questionnaire and at the workshop, the model has been presented with the following selling line:

You are offered a contract by an energy company which allows it to control your heat pump. The contract benefits you economically and you are guaranteed a certain comfort level. You can view all activity and information about temperature, energy consumption as well as the number of activations and bonuses on a webpage like the one in GreenCom.

Figure 1: Mock-up of what the heat pump contract could look like: My heat pump, Contract and bonus for February 2016, Comfort zone, Absolute minimum temperature, Number of times the minimum temperature has been achieved (show when), Comfort bonus per activation, Your flexibility bonus, See your contract documents. Last month your minimum temperature was activated 15 times and you received a comfort bonus of 243 DKK.

1.5.3.3 Evaluation

The evaluation results show that most of the customers are willing to enter into a contract on external control of their heat pump on the proposed conditions. 3 out of 5 respondents answer that they are very willing to enter into a contract. 2 position themselves as neutral. The participants are generally positive towards the DSO need of spreading the load from heat pumps more evenly to prevent peak problems and they have also experienced that turning off the heat pump has not affected comfort too much;

"At one time the power went off, and almost 30 hours passed before the temperature decreased by 8 degrees. The heat pump can be turned off for many hours before the temperature decreases considerably."

The main concern is that since nobody has experienced what it means to enter into such a contract, it is difficult to tell exactly what to think.

"We would like to see how it works first and then adjust the contract"

"We have never tried it before so we don't know how it works. I would ask for a trial period to experience what it means in real life".

Data and results

In Figure 2 on the next page data and results from one of the households at the island of Fur will be demonstrated. The data comes from the equipment installed in the GreenCom Project and shows the data during a calibration of the household.

On the Y-axis to the left, the scale is going from -10 to 30 shows both the temperate in degrees and also the HP heat curve offset, which goes from -10 to +10. Here we can follow the different temperatures measured, such as living-room temperature, kitchen temperature, outdoor temperature and also the

fixed max, min and abs. min temperature agreed on in the HP contract for this house. And finally, in the bottom it is possible to see the accumulated consumption graphs from the mains meter and HP indoor.
The X-axis in the bottom indicates time – in this case 5 days.
The Y-axis to the right, the scale is going from 0 to 120.000 indicates the energy consumption in Wh.

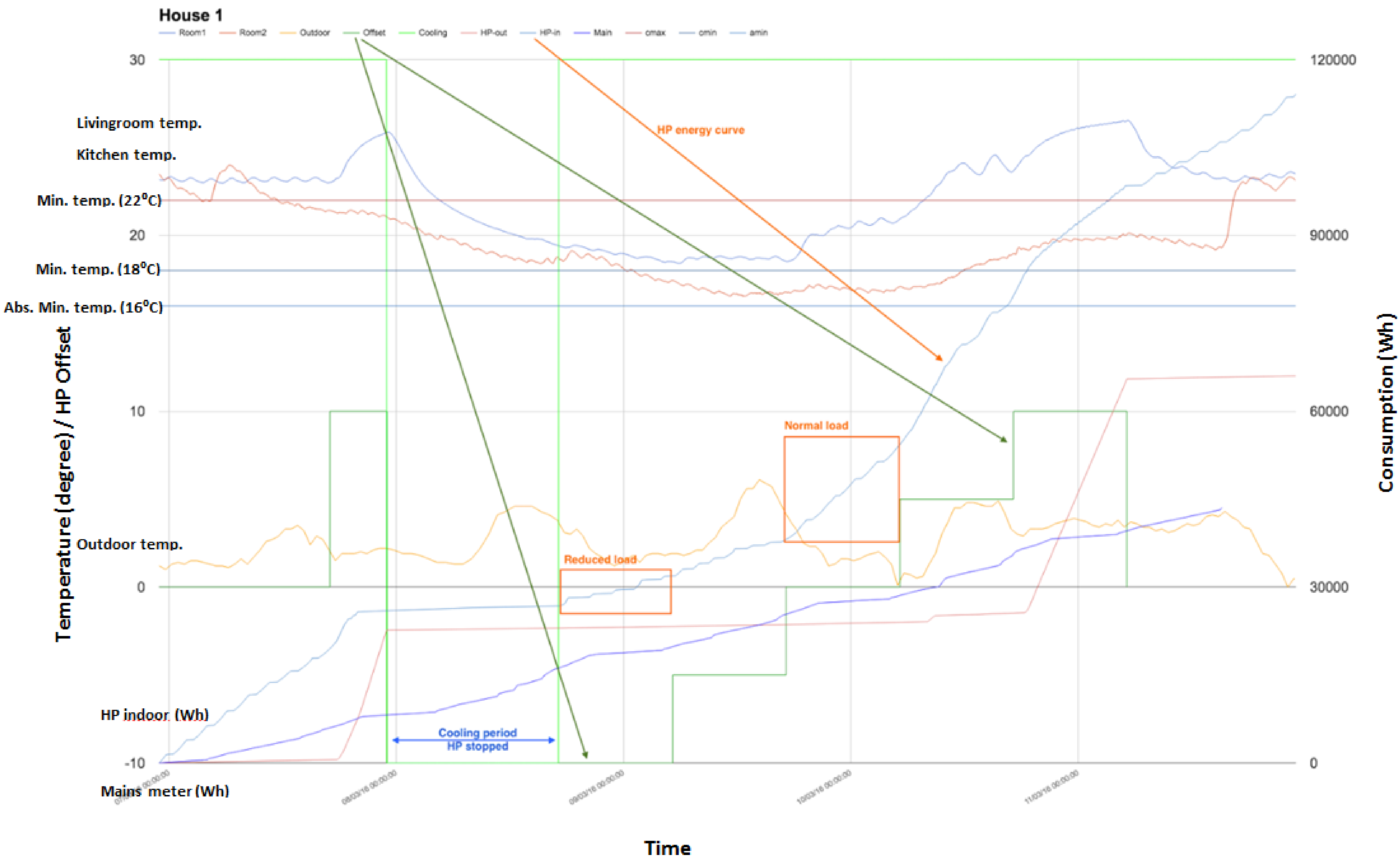

Figure 2 - Data from calibration of House 1

What is interesting with this graph is to monitor the development of all the described parameters throughout the calibration test.

The calibration test starts with a heating period of 6 hours, where the HP offset is going from the standard set point of 0 to +10. Following the temperature in the living-room, we can see that it is increasing from around 23-24 degrees to 26-27 degrees and the consumption from the HP indoor is also increasing.

After these 6 hours, the cooling period of 18 hours has started, which is written in blue. In this period the HP is running a degree minutes 0 command, which is a command used to overwrite the HP internal control, which is programmed to produce heat occasionally to maintain a certain temperature in the household according to the heat curve in the household. This means that the HP is using as little energy as possible.

In this period we can see that the temperature in the living-room is dropping below 20 degrees, while the temperature in the kitchen is dropping close to but not below the min. temperature of 18 degrees. It is also interesting to see that the HP indoor consumption in this period has almost flattened, which means that the consumption is very low.

During the next period, there will be 5 periods of 12 hours, where the HP offset is gradually increasing. Just after the cooling period the HP is set to HP offset -10, which is the lowest setting on the HP if not writing the degree minutes command. The orange box demonstrates the reduced load of the HP in this period, where the temperature in the living-room is not under the min. of 18 degrees and the temperature in the kitchen is just below and close to the absolute minimum temperature of 16 degrees.

During the next heating period the HP heat curve offset is changed from -10 to -5. In this period it can be seen from the living-room and kitchen temperature stabilizes and maintains a temperature on respectively 19 and 17 degrees.

Under the next 12 hours heating period the HP heat curve changed from -5 to 0, which is the standard HP heat curve on the heat pumps. Here we can see that the temperature in the living-room increased to around 21 degrees, while the kitchen temperature stayed at around 17 degrees. It is clear that the HP indoor is using a lot more energy in this normal mode.

The last two heating stages of 5 and 10 is not relevant, as it can be seen from the graph that the temperature is just increasing out of the household comfort zone.

So the main conclusions can be described in Table 3 below:

	Raw Data							House curves (MGR instrumentation)				
		Temperatures			Energy					Power curve		
House	Radiator settings	Outdoor	Room 1	Room 2	Main	HP outdoor	HP indoor	Heat Loss Curve	Thermostat Curve	Normal	Reduced	Comment
1	✔	✔	✔	✘	✘	✔	✔	y=3,9E-3x-0,055	Normal: HCO=0 Reduced: HCO=-10	y=-76x+1611	y=-23x+413	Nice data, eventhough room2 not usable.
2	✔	✔	✓	✓	✘	✘	✓	-ditto-	Normal: HCO=0 Reduced: HCO=-9	y=-88x+2031	y=-23x+469	Data ok. Periods with missing data (°C and W). Dismiss outdoor HP power. Narrow heat loss data band, so use House01 *Heat Loss Curve* .
3	✘	✔	✓	✓	✘	✘	✓	- ditto-	Normal: HCO=1 Reduced: HCO=-10	y=-49x+1131	y=-42x+753	Awfull data. Radiator setting unknown. Periods with missing data (°C and W). Room temperatures behave strange, use House01 *Heat Loss Curve* .
4	✔	✔	✔	✔	✘	✘	✔	y=5,2E-3x-0,068	Normal: HCO=5 Reduced: HCO=-9	y=-114x+2276	y=-68x+1356	Nice data. Narrow comfort band makes house flexibility next to non existing. We discard comfort interval in room 1 (and focus on room 2).
6	✘	✔	✓	✓	✘	✔	✔	y=0,013x-0,236	Normal: HCO=0 Reduced: HCO=-10	y=-89x+1611	y=-27x+481	OK data, however bad temperature data during cooling. Normal Power Curve extrapolated using house 1 power curve.
7	✓	✔	✔	✔	✘	✘	✘	y=3,9E-3x-0,055	Normal: HCO=0 Reduced: HCO=-10	y=-76x+1611	y=-23x+413	Only room 1 controlable. No power/energy data collected - really bad 😱 We default to using house 1 data as everything we know about house 7 is more or less similar to house 1.
21	✓	✔	✔	✔	✘	✔	✘	y=2,7E-3x-0,028	Normal: HCO=0 Reduced: HCO=-8	y=-88x+2031	y=-23x+469	Thermostats are set perfectly. The temperature data is really nice. But energy data is missing again (as for house 7) 😱 We use the power curve from house 2.

Table 3 - Data and results from household calibration in 7 heat pumps household at Fur.

Note: From Table 3 shown above one might get the impression that GreenCom do not have raw data from the mains meters. However, this is not correct. The mains consumption devices and the main consumption in the households is covered either by equipment installed on the Smart Meter or in the case with the heat pumps households which also has the PV, it has been necessary to install specific submeters for the consumption in PV houses. However, for some reason the project has discovered that these submeters are not metering the HP consumption and therefore the HP data is not included in the data from the mains meters. One explanation could be that the HP is installed on another phase in the household, which the submeters do not meter.

In order to get the expected savings for an average house as function of outdoor temperature, we simply take the average of our seven power curves, we get the following:

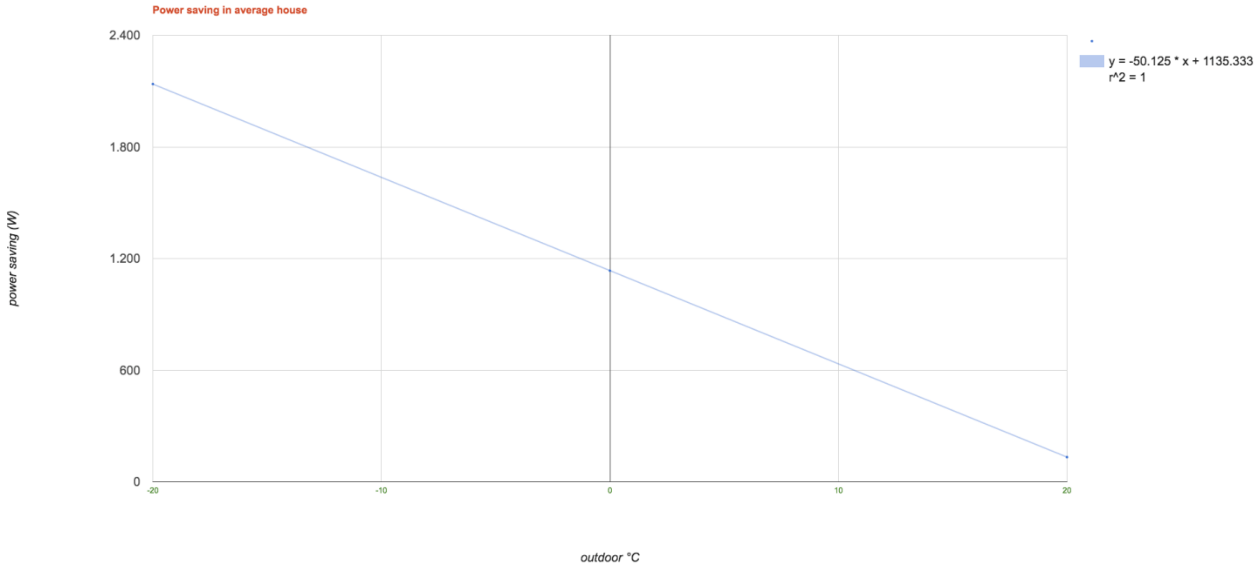

Figure 3 Power saving in average house as function of outdoor temperature

So, largely speaking, we will on a typical Danish winter day save around 1 kW per house when we run the house in reduced load yielding c_{min}. We note, that we have not been able to reduce temperature seriously below c_{min} in any house. In other words, we have never needed to go to the a_{min} temperature.

Cost and savings

When asked what they expect to gain from the contract, most of the respondents from the questionnaire expect to earn more than 1000 DKK. (133 €) yearly on the contract. 1 answers op to 700 DKK. (93 €), another 100 DKK. (33 €). The model instantiation in D2.2 (an earlier deliverable in GreenCom, to found in the web) showed a yearly award of 144 € depending on 288 hours of activations.

The actual savings for the customer is approx. 138 DKK / 18,5 EUR in the winter period with a 6% reduction in the grid tariff price and with 3 daily activations of around 1 kWh flexibility during the winter season

"It is difficult to say anything about prices apart from that there needs to be some kind of benefit or at least not cost us anymore e.g. does it cost me more to turn the heating up after having turned it down 10 degrees?"

The results from the test contracts also show that the majority (4 out of 6) imagine a yearly bonus around 1000 DKK (133 €) for being flexible. An average cost of 64 DKK/ 11 € is required by the homeowners per hour to go down to the absolute minimum. One expects 3500 DKK. (466 €) and the last 1500 DKK. (200 €).

In average the energy bill in a heat pump house is app. 21.000 DKK, this means that saving 1.000 DKK is app. 5% of your bill. This is not unreasonably, but not easy with the sensitive price scheme of today.

Money is not necessarily the only value to the customer. Some participants also express a wish for free kWh instead or cheaper prices at night.

"If the grid is benefitted then I would like a fair share of this, maybe as electricity"

Analysing the AMR data from houses which had the GreenCom system installed, heat-pumps and photovoltaic systems show that all houses have had installed heat-pumps and photo voltaic systems in the autumn 2013 and winter season 2013-2014. The consumption has developed as show in the graph:

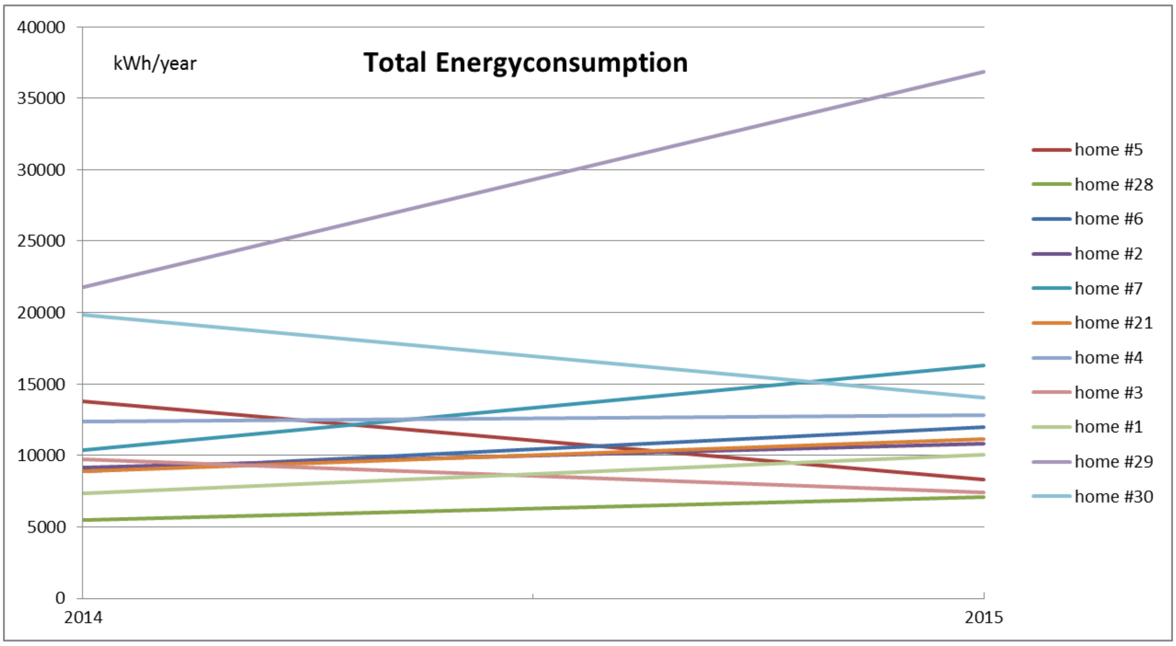

Figure 4 - Total energy consumption from households at the Island of Fur

Figure 4 shows that in households with heat pumps there has been a small increase in the total energy consumption, which was expected. However, the increase in consumption will depend on when the PVs were installed.

In household 29 there has been a massive increase in energy consumption, which is due to the fact that this household is a holiday household with swimming pool and also has an air-to-air HP installed.

One of the aims of the GreenCom project was to see if it was possible for the homeowner to utilise the grid more. For this purpose the DSO has a term called utilisation time, which is calculated as the yearly energy consumption divided by the monitored maximum effect abated in the installation. The higher the utilization time is the better the homeowners are at either by reducing the peak load or by reducing the annual energy consumption and the better the grid is being exploited as the load is spread over more time.

	Netto consumption, buy from the grid			(Energiconsumption=Electricity from the grid - sale to the grid)								
	KWh/year	KWh/year	KWh/year	Max effect	W		Utiliization time			%-change		
	2013	2014	2015	2013	2014	2015	2013	2014	2015	13-14	14-15	13-15
home #5	4.636	9.602	9.614	10.270	11.854	11.206	451	810	858	44,3	5,6	47,4
home #28	3.360	4.709	6.834	7.961	12.187	7.468	422	386	915	-9,2	57,8	53,9
home #6	5.516	8.305	11.102	8.081	8.377		683	991	1.325	31,1	25,2	48,5
home #2	7.187	7.957	8.952	11.039	7.860		651	1.012	1.139	35,7	11,1	42,8
home #7	7.771	9.450	13.582	11.474	10.253		677	922	1.325	26,5	30,4	48,9
home #21	3.144	5.688	10.383	7.112	7.955		442	715	1.305	38,2	45,2	66,1
home #4	4.878	7.468	12.149	7.109	10.702	11.026	686	698	1.102	1,7	36,7	37,7
home #3	4.363	6.192	6.006	10.276	10.626		425	583	565	27,1	-3,1	24,9
home #1	5.347	5.641	6.128	11.618	7.228		460	780	848	41,0	7,9	45,7
home #29	10.687	14.100	31.488									
home #30	15.383	15.985	12.356	12.087	14.903	12.914	1.273	1.073	957	-18,7	-12,1	-33,0
Note: Calculated with max effect from 2014												

Table 4 - Calculating the utilisation time on households at the island of Fur

From Table 4 it can be concluded that all houses except the air-to-air-Heat-pump house the “utilisation-time” has increased with 25%-66%. This means that the customer exploit the grid better. “The utilisation time” is very sensitive to peaks, especially when the electric immersion heater is turned-on during cold seasons. It should be noted that there are some missing peak data from 2015, as the meters in most houses was changed because of the PV installation and thereby affecting the data collection, which was instantiated by the DSO. The sample rate is built on 5 min values.

If we then analyse the houses, studying the total consumption, which means as if all the electricity consumed comes from the grid. The results are as follows:

	Calculated Total consumption		(Energiconsumption=Electricity from the grid +Production from PV - sale to the grid)		
	KWh/year	KWh/year	Utiliization time		%-change
	2014	2015	2014	2015	14-15
home #5	13.790	8.329	1.163	743	-36
home #28	5.494	7.076	451	948	110
home #6	8.874	11.987	1.059	1.431	35
home #2	9.131	10.811	1.162	1.376	18
home #7	10.384	16.281	1.013	1.588	57
home #21	8.900	11.117	1.119	1.398	25
home #4	12.354	12.807	1.154	1.162	1
home #3	9.760	7.412	918	698	-24
home #1	7.372	10.070	1.020	1.393	37
home #29	21.780	36.863			
home #30	19.825	14.050	1.330	1.088	-18
Note: Calculated with max effect from 2014					

Table 5 - Total consumption consumed in the house

From Table 5 it can be concluded that the utilisation time also increases in most houses. In 3 houses, home 5, home 3 and home 30 the utilisation time decreases because of decreasing energy consumption.

When comparing the two scenarios the utilisation time" decreases when photovoltaic systems have been installed, except in house #1. Analysis of the kW-peak through the project period, when heat-pumps have been installed (from 2014-2015) is shown in the table below:

	Max Power KW		Development in kW Peak 2014-2015	
Trafo	2014	2015	KW	%
home #5	11,9	11,2	-0,6	-5
home #28	12,2	7,5	-4,7	-39
home #4	10,7	11,0	0,3	3
Total kW for HaaS-houses			-5,0	-22
In average			-1,7	

Table 6 - GreenCom influence on kW peak reductions on LV-grid at Fur

From Table 6 it can be seen that the peak in one transformer has been decreased by more than 5 kW ~ 22%. This gives an average of 1,68 kW pr. Household.

Now, the typical number of households on a feeder at the island of Fur is 9, and if 80% of those households have heat pumps, the number of heat pumps in the feeder should be 7.

From the data we can see, that the combination of PVs and heat pumps leads to an average reduction in max peak from 2014 to 2015, because heat pumps has been installed during 2013 and the PVs has been installed during 2014.

This means that there should be theoretical reduction on the transformer on this feeder 1,68 kW * 7 = 11,76 kW.

Then by controlling the HP intelligently the data from the HaaS showed an additional flexibility from the HP of approx. 1 kW pr. HP. With 7 houses on the feeder this provides an additional flexibility and reduction in peak of 7 kW, bringing the total reduction on one feeder on the transformer station close to 19 kW.

Type of activity	Year 1	Year2	Year3 (2015)	Year 3
			Target	Impact
Microgrid (1 radial) measured as regulating power provider (measured in Watts)			8 KW	In total 19 KW Demand control 7 KW
Lower energy price for consumers, using new market structures (measured in average price/KWh)			Lowered 4%	Have we not been able to monitor, since there is no pricescheme
Time-shifting capabilities. Flatten cooking peak and postpone grid reinforcement costs (measured in peak reduction %)			Lowered 15%	Lowered 47%

Contract details

The participants need to know the following details about the control which must be taken into account in the contract:

- Number of absolute minimum activations expected e.g. I would like to prevent moisture damage – do I need a back-up?
- Time of day and time span – when does control occur and for how long?
- Holiday and weekend options
- Season variation e.g. low settings during summer
- Opt-out options e.g. not having 16 degrees when expecting guests
- Service e.g. we need a guarantee of service in cases of outage
- Communication whenever control or changes occur e.g. via user interface, text messaging, e-mail

Certain opt-out options should be part of the contract so that control can be dynamic;

"I would like to be able to inform when I go on holiday and the heat pump therefore needs to be switched off or run on the lowest setting".

"I will not sign a contract if I do not have the possibility of opt. out, saying; this weekend I cannot be controlled"

In average, the participants would like 24 degrees as the maximum temperature and 18 degrees as a minimum. 16 degrees is the absolute minimum. However, some participants comment that it depends on the timing;

"It is easier for us to accept a certain temperature if we are asked at the time"

Breaking the contract

The control of heat pumps for load management must be reliable for the Aggregator and DSO to use it in their planning. If control is overruled by the household, the value for the grid operator is lost and there might also be consequences for grid operation. Introducing a cost for the consumer in this case might be necessary, similar to consumers paying a price in the case of false fire or security alarms.

When asked about paying compensation, most respondents from the questionnaire are not willing to pay anything if they break the contract. Only 1 respondent accepts the terms. However, as mentioned previously, the participants accept the conditions as long as they are respected by all parties.

"I would like a stop button for special occasions like visitors but if these occasions can be part of the contract instead then this is ok for me"

"If they can't handle their side of the contract, I have a right to overrule the control".

Technical interest or not
Whether participants are willing to enter into a contract or not also depends on their technical interest. The respondents have been asked whether they agree that the technical installations 'should look after themselves' or not and the answers in this group vary with 20 % agreeing, 20 % not agreeing and 60 % being neutral. At the workshop the same pattern occurs. Some would like to know and play with the system themselves;

"I like adjusting the outdoor and indoor sensors on my heat pump for the most optimal usage

Others prefer to have as little to do with the installation as possible";

"I am ok with entering into a contract on my heat pump so my problem (of having to regulate a heat-pump) becomes the responsibility of others. Then I don't have to do anything".

Conclusions

Money is not necessarily the only value for the customer in helping the grid. It could also be free kWh or cheaper electricity at night thereby accommodating the need of the grid twice.

Control should be dynamically adjusted to fit different situations and wishes.

The contract should state number of activations expected at different times and how long they might last.

'We need to know what is happening' Information sharing is crucial, both when control is performed and when the household situation changes.

Service should be included in instances of outage.

It is possibly to obtain load shaving and thereby lowering the cooking peak and helping the grid operator.

The combination of Heat Pumps, PVs and demand control serves the grid quite well; in average 2,7 kW per house.

1.5.4 End-user results - Intelligent Energy Storage business model

1.5.4.1 The model

The business model deals with the flexibility offered from PVs and batteries. The idea is to maximise the consumers' own production from PVs by storing the production for use later and this way measure, what storing of PV production means for voltage and transformer issues in the grid.

Additionally, to increase the role of the DSO and invite a more active collaboration between consumer and grid, participants have been presented with a business model whereby a part of their battery is made available for grid operation. Focus is on a sharing economy whereby cost, access and excess capacity is shared by different actors.

Under the slogan 'Get more out of your PV', a storage service provider/aggregator offers prosumers with PVs a large battery package for storing their PV production. A percentage of the battery's capacity is made available for grid management purposes and the aggregated storage capacity from all the installed batteries is offered to the DSO as a flexibility service. The incentive for the DSO is to use the aggregated storage capacity for voltage and load management. The incentive for the Prosumer is to use as much of his own produced solar energy as possible, thereby reducing distribution and electricity costs. An additional advantage for the prosumer, or even a consumer with no PV, is the possibility to charge the battery when electricity prices are low, thus giving him even more flexibility.

The goal is to evaluate the commercial aspects of the business model by identifying the business and market value in the following cases:

1) The consumers enter into a contract on their battery. The system shows
   a. Energy balance consumption and production, profitability, storing limit as well as contractual agreements

1.5.4.2 Demonstration

The model has been demonstrated to the prosumers by the installation of batteries in 5 households which have PVs. A user interface has been made available from the battery provider where users can access information about their PV and battery and watch the performance.

Features related to the business model have been presented at the workshop as a mock-up and include storing limit and contractual agreements.

In the questionnaire and at the workshop, the model has been presented with the following selling line:

"You are planning to invest in a new battery and are interested in using even more of your PV production and to store cheap electricity from the grid. You are offered a good deal on a battery package with a larger battery and capacity if you make a percentage of the battery available so it can support the balancing of the grid. The solution gives you the possibility to see information about PV production, battery capacity and the contractual premises".

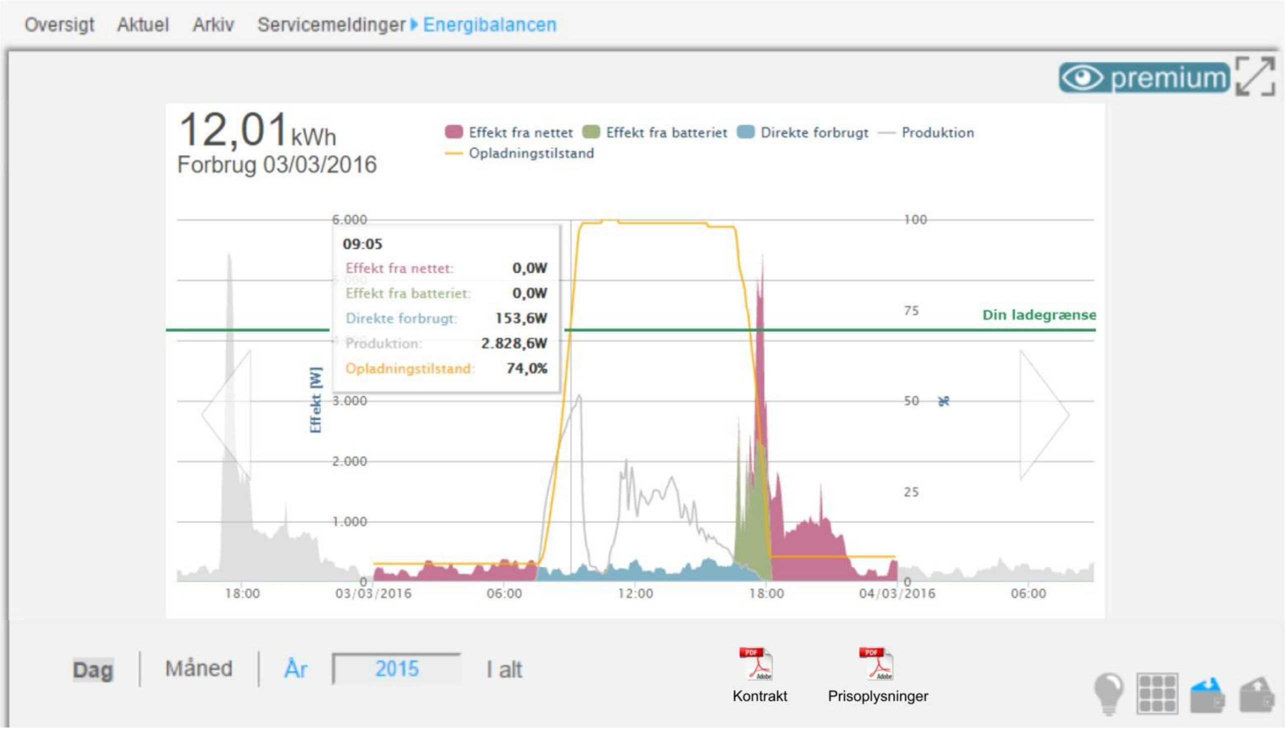

Figure 5 - Mock-up of the charging limit (green line 'ladegrænse') and contractual documents for the Intelligent Storage model. Image courtesy of Fronius.

1.5.4.3 Evaluation

The concept of a sharing economy whereby part of the battery is shared with the grid and DSO was well received with most being willing to enter into such a contract on their battery. In the questionnaire 3 are willing, 1 is not and 1 is neutral.

But there are certain limits: Contract or not, the user should be allowed to buy extra battery cells himself if desired as there is already room for four more battery cells in the existing solution. The sense of personal freedom is essential here. Additionally, control should not obstruct the very reason for investing in solar panels;

"We do not want the DSO to control the PVs if there are any balancing issues if it means that we miss out on free electricity"

Similarly, it is not as important to know where the electricity comes from as what the green energy means to the economic self-sufficiency;

"All in all, we just prefer to use our own free electricity"

1.5.4.4 Results and data analysis

In households with PVs without batteries installed the data from the PVs are collected from a submeter mounted on the electric circuit board, where the power from the PV goes into the household. These data goes into GreenCom end user rich GUI from where they can be viewed by the homeowner as in Figure 6.

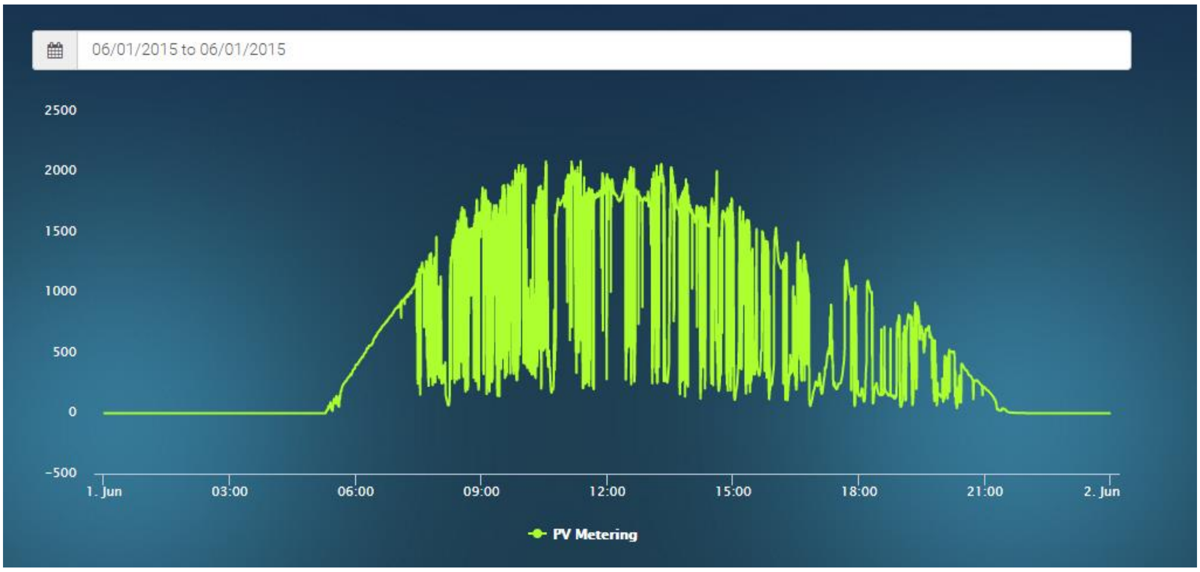

Figure 6 - Data from PV metering in Home 2 on June 1st 2015 (Summer day)

In the households with PVs and batteries the data from the PVs and batteries are collected by simply connecting the GreenCom GW to the house home router. Based on the development of a Fronius Data Adapter component in GreenCom it is possible to retrieve the same data as the one going into the Fronius Solar. The FroniusAdapter component is part of the xGateway runtime. Its initial purpose is to retrieve particular PV measurements from the Fronius inverters via the Fronius Solar API and to deploy them into the Data Warehouse.

Based on analysis of these data the following tables (Table 9) of productions have been made:

House #	From August 2015 to 11th of May 2016					
	PV production 2016 (kWh)	Energy to grid (kWh)	Energy to battery (kWh)	Energy directly consumed (kWh)	Own consumption (%)	Battery share (%)
Home 20	2.838,10	1.271,78	710,13	856,19	55,19%	25,02%
Home 24	1.740,29	430,40	633,51	676,38	75,27%	36,40%
Home 25	3.094,25	1.624,96	682,45	786,84	47,48%	22,06%
Home 26	1.573,96	472,30	505,46	596,20	69,99%	32,11%
Home 27	2.934,59	1.272,04	703,87	958,68	56,65%	23,99%
Average	2.436,24	1.014,30	647,08	774,86	60,92%	27,92%
Total	12.181,19	5.071,48	3.235,42	3.874,29	58,37%	26,56%

Table 7 - PV production and utilization in 2015-2016

When looking at the data for 2015 and 2016 it is interesting that around 300 kWh of the PV production on average have been fed into the battery from each house in 2015 and 347 kWh in 2016. Without the battery total average of 647 kWh pr. household would have been send to the grid since the batteries were installed. This should be interesting for some DSOs or aggregator as this will provide a flexibility from these 5 houses of as much a 3.235 kWh. Another interesting finding is that most of this flexibility is utilized during the peak period, as the battery is set up to discharge when the consumption exceeds the production. Typically, the battery is able to provide 2kW under maximal load and thereby covers between 30 and 75% of the peak load, depending on the daily peak load, which we can see from Table 8 below varies quite a lot from day to day and from house to house. A good example is to compare day 4 and day 5 in home 20 or day 1 and day 2 in home 25.

	house20	house24	house25	house27	Houses Mean
Day 1	2338,9	5435,3	2425,6	3505,9	3426,4
Day 2	2733,0	3423,5	6952,3	4415,2	4381,0
Day 3	2946,3	6069,4	2479,2	6123,0	4404,5
Day 4	1206,1	6775,7	2880,4	4081,5	3735,9
Day 5	5610,5	5821,3	3619,2	6797,6	5462,1
Day 6	3959,1	4113,5	4053,5	4776,0	4225,5
Day 7	2730,6	5337,8	2776,1	3442,0	3571,6
weekly mean	3074,9	5282,4	3598,0	4734,5	4172,4

Table 8 - Daily peak load consumption for Sept. 28, 2015 to Oct. 4, 2015

When looking at the percentages of the own consumption for 2015 depicted in Figure 7, the combination of PVs and batteries enables the homeowners to reach an average own consumption of the PV production to almost 64%, but home 24 is actually close to 85%. Of the own consumption the battery covers an average of approx. 29%. This means that with the battery the homeowner in this period of 2015 was able to utilize around 29% more of the PV production than without the battery. Again, these numbers heavily depends on the consumption pattern and the intelligent or flexible consumption by the homeowners, which can bring the number close to 37% in the case of home 24.

For 2016, the numbers depicted in Figure 8 shows an average own consumption of the PV production of almost 59%, but again home 26 almost reached 73%. Of the own consumption in 2016, the battery covers an average of approx. 27%, just slightly below the numbers for 2015.

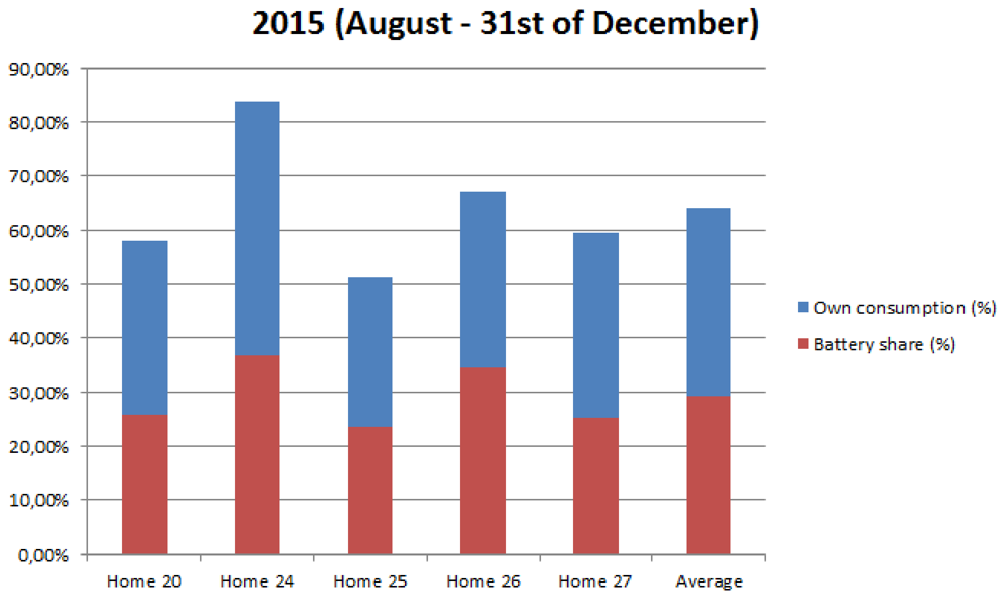

Figure 7 - Own consumption of PV production and battery share in battery houses 2015

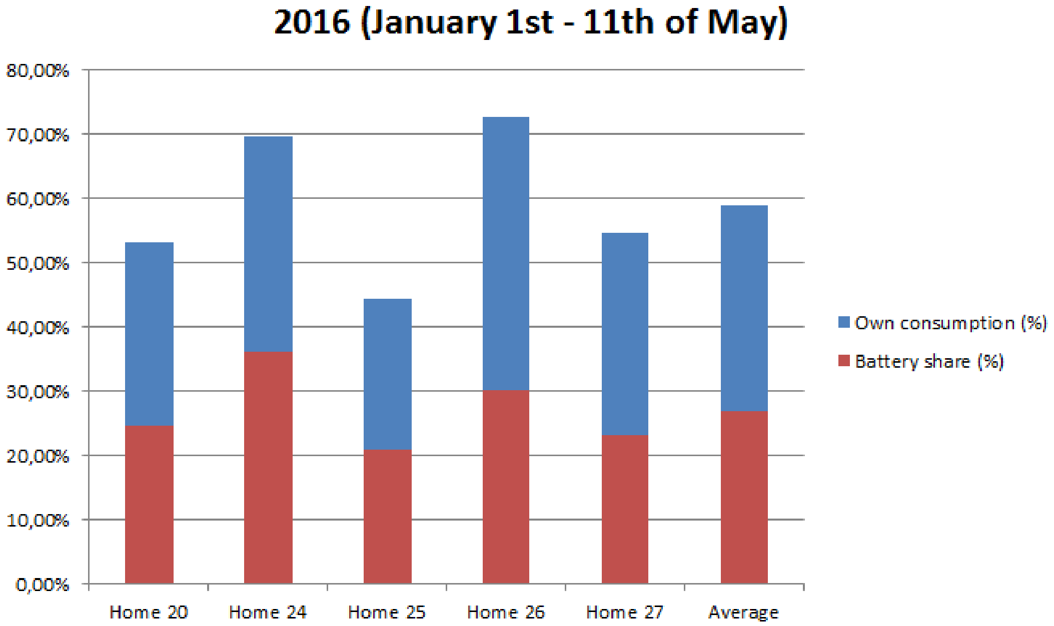

Figure 8 - Own consumption of PV production and battery share in battery houses in 2016

One of the aims with the IES business model and combination of PVs and batteries was for the homeowners to utilize more of the PV production. In order to visualise and analyse the data from the battery houses at the island of Fur the following figures have been created.

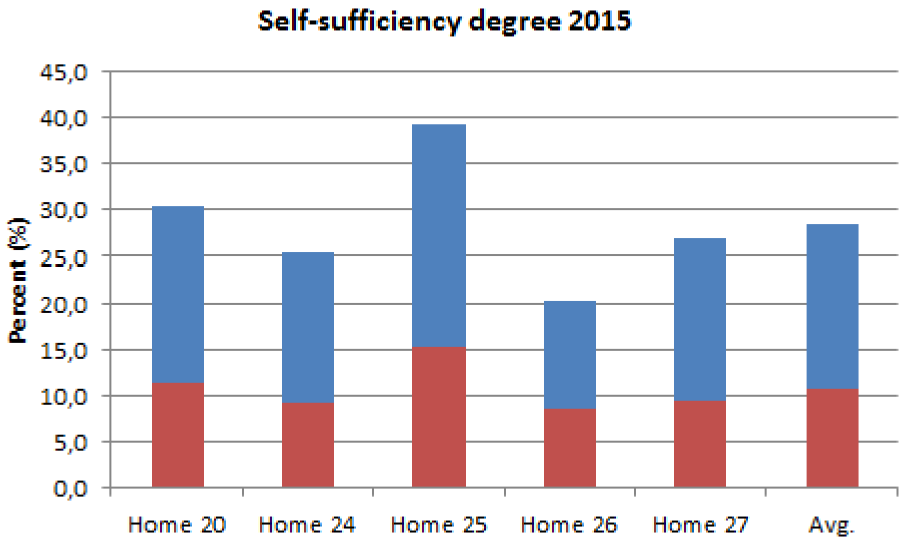

Figure 9- Self-sufficiency degree in 2015

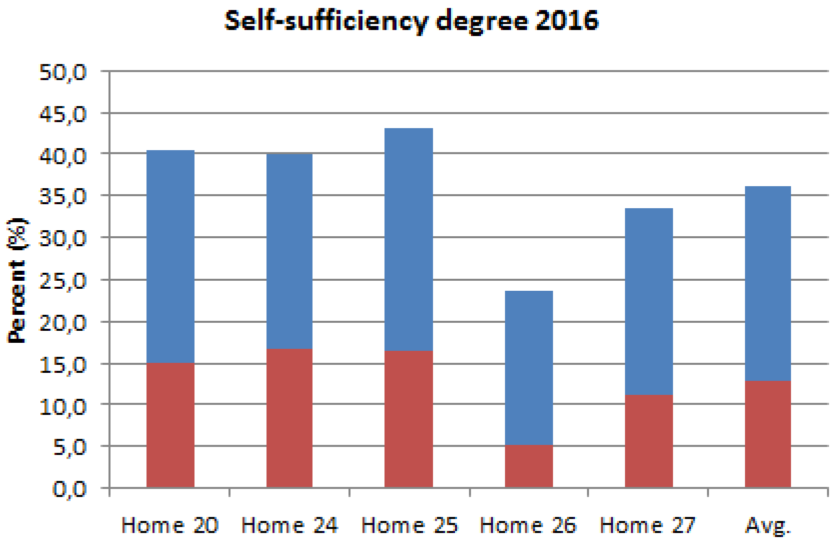

Figure 10 - Self-sufficiency degree in 2016

The self-sufficiency degree for 2015 (medio August to December 31st 2015) and for 2016 (January 1st – April 31stl have been depicted in respectively Figure 9 and Figure 10. The columns in both figures indicates the household indicates the average self-sufficiency degree for this particular household during this period out of the total electricity consumed in the household in the period.

Especially for 2015, there are quite distinct variations, even though many of the households, except from Home 26 have PV systems of similar sizes. The highest self-sufficiency degree is for home 25 with an average of around 40%, while home 26 has the lowest with just above 20%. The main difference is caused by the household consumption. The lower the consumption is the higher the self-sufficiency degree is but also intelligent consumption improves the self-sufficiency degree for instance by starting the washing machine, when there is a surplus production from the PVs and/or if the battery is fully charged. This flexible consumption enable more use of the PV production, when it is available instead of washing during the night, when there is no production from the PVs and the battery is empty.

For 2016, there are still variations among the houses but the differences are smaller than for 2015.

What is interesting in relation to the batteries is indicated in the red part of the column. The red column indicates the battery share out of the total consumption in the household. This means that in 2015, 11% of the total consumption in the household was covered by the battery. This means that the homeowners have increased their self-sufficiency degree in 2015 with 38%. In the period for 2016 battery share increased to almost 13 % of the total energy consumption for the period, which meant that the homeowners so far in 2016 have increased their self-sufficiency degree with an average of around 36 %.

In the questionnaire, the respondents estimate the degree of self-sufficiency (PV and battery) to be between 40-90 %[3]. The actual numbers show that the highest self-sufficiency rate in the months with battery (from August 2015 to February 2016) was 74 % in August and the lowest 2,6 % in December. In average the self-sufficiency rate was 29 % in 2015 of which the battery accounted for 11 %. These figures do not provide a full picture as they do not cover the sunniest months from May to July. The winner of the competition had the highest self-sufficiency rate of 40,2 % achieved during the running of the competition.

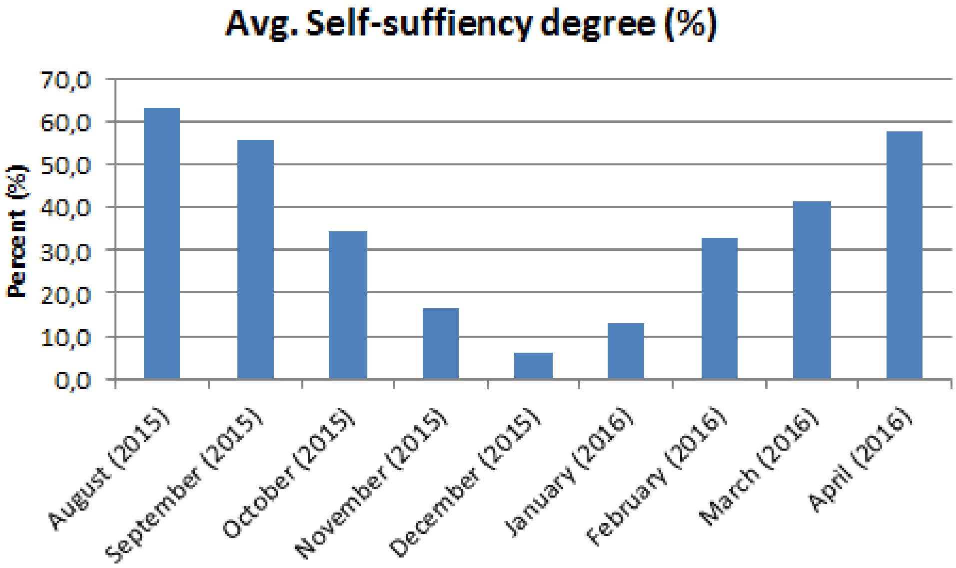

Figure 11 - Avg. self-sufficiency degree for battery households in project period

The analysis of the data has also provided the GreenCom project with the following conclusion:

- In the summer period the batteries run one cycle each day, but during the winter season the battery is only occasionally charged a few percentages, which is not even one cycle. The battery is at the moment not able to charge from the grid.
- Depending on the season and the amount of solar radiation the battery is fully charged in the period from around 12:00 CET – 17:00 CET. It should be stated that during the dark winter months in Denmark the battery is not even charged.
- The battery covers between 11-13 % of the total electricity consumption in the household but will on average increase the self-sufficiency degree with 36-38%
- Larger batteries might be interesting as there is a potential for storing more power from PVs and in order to extend the peak load reduction period. We can see that there is a lot of electricity sold to the grid in the period from when the battery is fully charged until the homeowners return and start consuming.
- Households with batteries have been able to utilize an average of around 60% of their PV production since the batteries were installed in August 2015 and medio May 2016. In the same period, the battery covers an average of approx. 28%

[3] Today, the estimation is 40 % per year for a PV without battery and up to 80 % with a battery dimensioned to the PV/house. Source: Danish Energy Agency: http://www.ens.dk and www.vivaenergi.dk

- Batteries typically reduce the peak load with 35-70 % typically for 1,5-2 hours in the peak period. If there is no significant peak, meaning that if the homeowners are not at home or for instance are using the barbeque to prepare dinner, the data show that the battery can actually provide enough power to cover the load for up to 10 hours from 19.30 to 05.30 in the morning.
- Households with batteries have an average self-sufficiency degree of more than 60% during the summer (August). This number gradually decreases to an average of 6% during the winter (December).
- Customers with batteries are highly motivated to start washing machines and tumble dryer and other high consumption devices, when sun is shining or they can see that the battery is fully charged to exploit more of the PV production. Many of the home-owners follow the batteries closely both on the Fronius solar.web GUI and on the Fronius Solar.web Live app.

Cost and savings

The final cost for HW components for Intelligent Energy Storage case includes both the equipment for collecting the data from the batteries systems and the physical components in the battery system. The final cost of the system is more than 60.000 DKK / 8.000 €.

In this price, the costs of the PVs have not been included, but would require an investment of 70.000-100.000 DKK / 9.333 – 13.333 €. However, if the PVs were purchased together with the battery solution, it would be possible to save the cost of the inverter. If the home-owner already has a PV, the old inverter needs to be replaced, as the control is built in the Fronius Hybrid Inverter.

When looking at the savings from the installation of batteries the illustration below demon-strates the savings from the battery since the batteries where installed in the households in august 2015. The first columns in the table show the energy from the battery, which has been used in the household respectively in 2015 and 2016 and the total. The next column then "translates" the energy from the battery into economic saving from the battery for the respective households in 2015, 2016 and in total and both in DKK and Euro. The battery saving has been found using a standard electricity price of 2,2 DKK/kW or 0,29 €/kWh. The data show that the households during the 9 months with the battery installed have saved around 1.000 DKK or 130 €. These data from home 20, home 25 and home 27 are extremely close, especially when considering that these data are based on approx. 9 months of data, which is a strong indication that these numbers are relatively precise despite the small num-ber of houses. However, these numbers are expected to increase even further based on the summer season.

Battery consumption and economic savings									
	Energy battery (kWh)			Savings battery (DKK/EUR)					
House #	2015	2016	Total	2015		2016		Total	
Home 20	234,36	263,94	498,3	516	69	581	77	1.096	146
Home 24	187,26	233,96	421,22	412	55	515	69	927	124
Home 25	256,96	231,03	487,99	565	75	508	68	1.074	143
Home 26	173,97	141,85	315,8	383	51	312	42	695	93
Home 27	244,22	244,8	489,02	537	72	539	72	1.076	143
Average	219	223	442	483	64	491	65	973	130
Total	1.097	1.116	2.212	2.413	322	2.454	327	4.867	649

Table 9- Battery consumption and economic savings (02-05-2016)

Having looked at the battery consumption it is also important to look at the economy for the PV production. To present this, Table 10 and Table 11 have been made to illustrate respec-tively the numbers for 2015 and 2016:

House #	2015 (August - 31st of December)							
	Economy (grid) (DKK/EUR)		Economy (battery) (DKK/EUR)		Economy (directly consumed) (DKK/EUR		Total economy (DKK/EUR)	
Home 20	307,99	41,07	693,00	92,40	866,58	115,54	2.001,04	266,81
Home 24	69,16	9,22	574,38	76,58	730,05	97,34	1.459,39	194,59
Home 25	426,50	56,87	748,22	99,76	888,23	118,43	2.219,58	295,94
Home 26	144,74	19,30	555,32	74,04	523,18	69,76	1.316,59	175,55
Home 27	317,84	42,38	726,20	96,83	981,55	130,87	2.164,79	288,64
Average	**253,25**	**33,77**	**659,42**	**87,92**	**797,92**	**106,39**	**1.710,59**	**228,08**
Total	1.266,24	168,83	3.297,12	439,62	3.989,59	531,95	9.161,40	1.221,52

Table 10 - Economy from PV production 2015

House #	2016 (January 1st - 11th of May)							
	Economy (grid) (DKK/EUR)		Economy (battery) (DKK/EUR)		Economy (directly consumed) (DKK/EUR)		Total economy (DKK/EUR)	
Home 20	455,08	60,68	869,29	115,90	1.017,04	135,61	2.517,98	335,73
Home 24	189,08	25,21	819,35	109,25	757,99	101,07	1.900,87	253,45
Home 25	548,47	73,13	753,17	100,42	842,82	112,38	2.318,01	309,07
Home 26	138,64	18,48	556,69	74,23	788,46	105,13	1.576,49	210,20
Home 27	445,39	59,38	822,32	109,64	1.127,54	150,34	2.564,27	341,90
Average	**355,33**	**47,38**	**764,16**	**101,89**	**906,77**	**120,90**	**2.026,26**	**270,17**
Total	1.776,65	236,89	3.820,81	509,44	4.533,85	604,51	10.877,63	1.450,35

Table 11 - Economy from PV production 2016

The two tables have been developed based on the data presented in Table 9. The data for PV production from the grid has been multiplied with 0,6 DKK/kWh, which is the price that the homeowners get from selling surplus production to the grid. The economic value of the PV production for the batteries and the energy directly consumed in the household is multiplied by 2,2 DKK/kWh, which is the typical standard price for a kWh in Denmark. From the two tables it can be concluded that in 2015 the homeowners had a total revenue of 1.710,59 DKK / 228,08 EUR and in 2016 the number so far is 2.026,26 DKK / 270,17 EUR. In total the homeowners have got a revenue from this combination of 3.736,85 DKK / 498,26 EUR.

The distribution of the revenue can be seen from the two figures (**Fejl! Henvisningskilde ikke fundet.** and Figure 13) below:

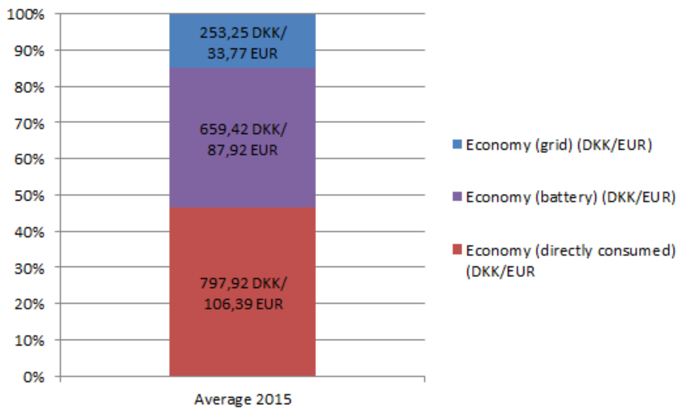

Figure 12 - Distribution of revenue from PV production from IES in 2015

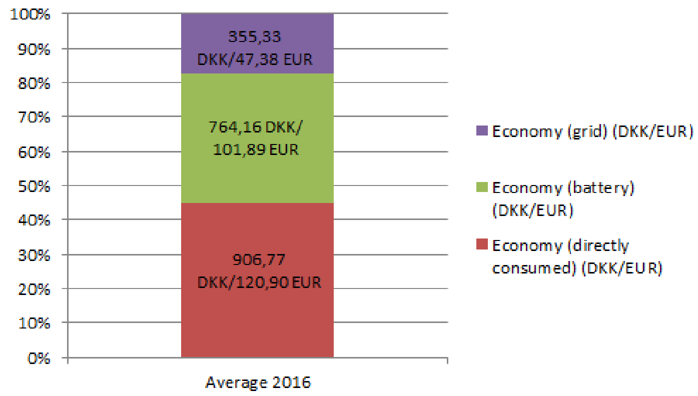

Figure 13 - Distribution of the revenue from the PV production from IES in 2016

Profitability of batteries

The main concern is how to make the investment in batteries profitable. Batteries are expensive and the business model had to take as its starting point that the customer had already decided to invest in a battery or else the case was not sustainable. Two main points were raised in the discussions; the repayment terms and the sharing of costs.

Even if the battery can last for 20 years, it is the economic and technological lifetime that matters when deciding to reinvest. The repayment period for a battery costing 60.000 DKK (8.000 €) should therefore be reduced to 5 years or less. Today it is 7-8 years. If the battery price is further reduced by subsidies, the ROI should also be further shortened. Since the installation of the batteries at the island of Fur, the costs of the batteries have dropped to around 30.000 DKK/4.000 EUR for similar type of battery.

"The DSO should investigate how far we are from a solution with a repayment period less than 5 years".

Sharing the battery means sharing the cost too. In the discussions it became clear that subsidies might be necessary for the investment of batteries to make the scenario sustainable for both customer and DSO. This was also one of the conclusions in the instantiation of the business model. Alternatively, investment should be postponed some years until the technology was more advanced yielding lower prices on batteries. For the customer it is important that the DSO does not just pay for the marginal costs by adding an extra battery cell; he has to cover some of the main investment also.

Type of activity	Year 1	Year2	Year3 (2015)	Year 3
			Target	Impact
Microgrid (1 radial) measured as regulating power provider (measured in Watts)			8 KW	In total 14 KW Peak shaving 2 KW/battery
Lower energy price for consumers, using new market structures (measured in average price/KWh)			Lowered 4%	Have we not been able to monitor, since there is no pricescheme
Time-shifting capabilities. Flatten cooking peak and postpone grid reinforcement costs (measured in peak reduction %)			Lowered 15%	Lowered 58%

Conclusions

Personal freedom of choice first, then contractual collaboration

The most important thing is to use as much of our own 'free' solar electricity as possible

Raise the value by offering the customer to buy back the extra battery capacity when not used by the DSO

Sharing economy should also entail sharing the cost of batteries

Selfsufficient level increases from 33% to 61% (from Aug to May) when installing batteries in PV houses

1.5.5 Dissemination of results

The project has published 5 newsletters about the project, see them all in the project web: http://www.greencom-project.eu/project-results/downloads/viewcategory/5-newsletters.html

In the table hereafter are the EnergiMidt dissemination activities.

Event/Other	Location	Date	Dissemination Activities
Danish National Radio Interview – DR P4	Telephone	2012-02-20	General introduction to the vision and scope of GreenCom and E-MIDTs role in the project.
Press Release - GreenCom	Energy Supply	2013-01-21	General introduction to the vision and scope of GreenCom and stating that E-MIDT have raised 4,5 mio. DKK (€600,000) from ForskEL to be able to install 21 Heat Pumps, 21 PV's and 2 Micro CHPs on the Island of Fur, in relation to the GreenCom project.
Introduction to Electric Engine-ering	Danish District Heating Merkurvej 7, DK-6000 Kolding	2013-04-16	Networking and general introduction to GreenCom and introduction to basic Elec-tric Engineering comncept on consumption, production, transmission, distribution, instal-lation and laws and legislation.
Presentation of GreenCom to Island of Fur residents	Community Center Nr. Mads-badvej 36, DK-7884 Fur	2013-04-23	Detailed introduction to the GreenCom pro-ject, presentation of the heat pump technol-ogy and the PV technology, Economic and contractual obligation for the participants.
Festival of Re-search – Smart Energy	Aarhus University S-building - 2610 Ves-tre Ring-	2013-05-03	Networking and general introduction to GreenCom and listening to the latest knowledge and research on Fuel Cells, PVs, Power Grid System Balancing, Energy Consumption in the Home and Customer

	gade 51 DK-8000 Aarhus C		Engagement, Intelligent Control and Customer Acceptance of Smart Grid Technologies, in relation to heat pumps (IMPROSUME[1]), New and improved Lithium Batteries, Smart District Heating.
Theme Day on Micro CHP	TRE-FOR Kokbjerg 30, DK-6000 Kolding	2013-05-27	Participation, networking and general introduction to the GreenCom vision and scope.
Presentation of GreenCom to the work-group in the Danish Energy Association: Market Designs	EnergiMidt A/S Tietgensvej 2-4, DK-8600, Silkeborg	2013-10-08	Networking and general introduction to GreenCom and listening to the latest knowledge and research on smart Grid in Denmark.
Danish Energy Association - “In depth with the Power Market”	Danish District Heating Merkurvej 7, DK-6000 Kolding	2013-09-04	Networking and general introduction to GreenCom and course about Electricity Prices, Measurements and Billing of imbalances, distribution of roles between commercial actors and grid companies, geographical price differences, development in electricity prices, transport and flow of electricity between countries, securing electricity prices based on financial electricity contracts, risks in relation to power trading, power trading among countries, the different power markets – including markets for system services, energi & capacity, spotmarket and the financial market.
Presentation of GreenCom for a a group of Energy Cousellors from different Danish Energy Utilities	EnergiMidt Infrastruktur A/S Normansvej 1, DK-8920 Randers NV	2013-09-12	Presentation for a networking group of Energy Counsellors from different Danish energy utilities, including an introduction to Smart Grid and an overall introduction to GreenCom.
Presentation of GreenCom at Aarhus University - Herning (AU-Herning)	Aarhus University - Herning (AU-Herning) Birk Centerpark 15, 7400 Herning	2013-10-23	3 hour presentation/lecturer at a course called “Cleantech, Innovation and Business Development” for a group of students of M.Sc. in Engineering student at Aarhus University in Herning, including an introduction to Smart Grid and an overall introduction to GreenCom, with focus on commercialization of Smart Grid and how E-MIDT, as en energy utility is working with Smart Grid and Customer Engagement.

GreenCom first newsletter	E-mail	2013-11	Distributed to all heat pump contacts in the Danish Energy Association by e-mail.
GreenCom first newsletter	LinkenIn	2013-11	Sharing the newsletter in the group: Intelli-gent Energy, Danish Energy Association, and our personal contact list
GreenCom Pressrelease	Local press	Oct 6th 2015	Press release about the solar batteries in the project
GreenCom Pressrelease	Local tele-vision Local radio	Oct 6th 2015	DR made a radio interview with Gitte and Steffen was filmed by the television, this was published I the evening news (regional) last night. http://www.dr.dk/radio/ondemand/p4vest/regionalnyt-2015-10-06-16-30/#!/ http://www.tvmidtvest.dk/nettv Also more internet news published the re-lease
European Utility Week	Vienna	4th-6th Nov. 2015	Presentation of the GreenCom project in the Hubsession. App. 30 guests attended the session. They were actively listening to the presentation and asked only a few questions about smart grid and regulations in DK.
Interview/blog by French guys – tournesol re-searching micro grids:	Aalborg	April 15th 2016	http://www.tournesol-microgrids.org/fr/2016/04/15/rencontre-a-aalborg/
3rd GreenCom Newsletter	Web	April 2016	http://www.greencom-project.eu/project-results/downloads/viewcategory/5-newsletters.html
1 or 2 more pressreleases to be published in DK in the near future about results			Waiting for final acceptance from EU – our project officer.

1.6 Utilization of project results

The results from the HMC, HaaS and IES business cases have been presented and evaluated with the local Danish DSO and with external professional stakeholders, including European TSOs, DSOs, Aggregators, Industry Associations, Retailers and Software developers.

EnergiMidt continues exploring the IES businessmodel as priority and have applied for more national and Horizon2020 projects in this context. The Haas Businessmodel is as well interesting to explore more, but heatpumps is not at the moment in EnergiMidt strategy 2020.

This represents how the results can be used in the future grid.

1.6.1 Evaluation of the Decision Support Dashboard (DSD)

The Decision Support Dashboard is part of the 'Microgrid Aggregator (MGA)' component. Its main functionality lies in allowing interaction between two of the main stakeholders in the GreenCom project: The distribution system owner (DSO) and a service provider for aggregating and shifting loads in the microgrids (called the 'Aggregator'). The aggregator would both shift loads from high energy price times of the day and aggregate loads at certain times of the day (e.g. when energy is cheap) and therefore be able to grant lower energy prices to the customers and help balancing the overall load in the microgrids.

The decision support dashboard was implemented and technically equipped to support the described and evaluated business case. To achieve this, the dashboard was implemented as a web interface that can be accessed by different logins for the different stakeholders. The dashboard is connected to several data-delivering services and databases to ensure a seamless flow of information between the stakeholders. At the same time, the Dashboard always takes care of the visibility of information, hiding from each stakeholder the parts of information that it is not allowed to see for legal data privacy restrictions. Each stakeholder gets informed about the success of the performed actions and the decisions of the other stakeholder. This guarantees awareness for ongoing decision processes.

DSO/Stakeholder evaluation

Besides checking and evaluating that the decision support fulfills all technical criteria described in the business case, it was also possible to gather some feedback from DSO towards the dashboard. This feedback comes from a number of DSOs and other interested parties in the Smart Grid domain.

A first evaluation has taken place at the CeBIT in Hannover (10.-14.03.2014), where the decision support dashboard has been presented as the GreenCom exhibit at the Fraunhofer booth. This event could confirm that the business case of load balancing for smart grids is highly relevant. It could as well be confirmed that remotely controlled heating systems will be accepted by the general public.

A workshop with representatives from several Danish DSO's was conducted by ACTUA in late 2014. Participants came from DONG Energy, EnergiMidt, HEF, OE, NordEnergi, NRGi, Nyfors, RAH, SE, and TREFOR. At this workshop, the overall concept of GreenCom was presented, as well as the decision support dashboard. The dashboard was perceived as an interesting way to have much relevant information in one place, basically as a shorthand access to the most critical network properties.

The largest evaluation of the decision support dashboard has taken place at the GreenCom presentation on the European Utility Week 2014 (04.-06.11.2014). The pitch of the GreenCom presentation was built around demand/response issues and the offering of an aggregation service. During the utility week, the dashboard could be evaluated with representatives from eight companies, whereas seven companies were also DSOs.

1.6.2 Evaluation of HaaS and IES with Danish DSO

The Danish DSO involved in this project understand and acknowledge the thoughts and idea both behind the HaaS and IES concepts, but the main problem for the Danish DSO is they do not have either capacity issues nor voltage issues present in the LV grid and are not expected to have these issues in many years ahead. The LV grids in Denmark are often over dimensioned and specifically at the Island of Fur the LV grid is often loaded only with 30-40% of the LV grids capacity.

The Danish DSO however said that the data about flexibility from HP, batteries, EVs and PVs are interesting to have, as this will help to forecast the future demands. This is also something taken into consideration as they need to dimension the grid to meet the future demands for consumption. However, they will not dimension the grid too weakly, so that they are reliant on smart grid operations and smart grid technologies to ensure grid stability and secure in supply. For them, these technologies are still too instable and unreliable the base the stability and security of supply the LV grid upon.

Therefore, the results from GreenCom are most interesting in new residential neighbourhoods, where the DSO for instance would expect to install PVs and heat pumps on a larger scale. This is to ensure that the grid is able to support these and not over dimension the grid.

In existing residential areas the grid in Denmark is in general over dimensioned, which means that it will not be necessary to use Smart Grid to balance the grid in order to avoid overload, as this almost never happen, when the grid load is typically only around 30-40% of its capacity. Therefore, in these areas the DSO will simply just lay down thicker cables, when the old one needs to be replaced.

What is interesting for the Danish DSOs in the peak load reductions and the ability to spread the load more evenly. This will lead to reduce the grid loss, especially in the 10/0,4kV substations, where the DSO has the biggest grid losses. By flattening the consumption peaks, the grid loss will be reduced at both substations and cables will be exposed to lower temperatures.

However, in the end, these costs will be paid by the homeowners as the money is collected through the grid tariff, which is the same for low-voltage-installations. Therefore, it could be a strong incentive for the homeowners if the grid tariff was changed, so that based on the utilisation time. The utilisation time u_t in grid terms describes the correlation between the annual consumption in the household and the maximum load during the year.

$$\text{Utilisation time} = u_t \frac{annual\_consumption}{\max\_annual\_peak}$$

$$\text{Example - Utilisation time} = u_t \frac{9.845kWh}{7.8kW} = 1.262h$$

The higher the utilisation time is the better the owners has been in spreading the load. We know from the GreenCom project that for instance batteries and PVs are very good at reducing the peak load and thereby increasing the utilisation time, which means that these technologies support the grid actively and in themselves are supporting the grid also with the current – non intelligent controls. For the heat pumps, the results from GreenCom can be used to compare with a HP running in normal mode. See the results in 1.5.3. a.o.

1.6.3 Evaluation with European stakeholders

This section presents the highlights of a series of interviews carried out with high level Irish and European energy actors with the aim to validate the usefulness of the features provided by the GreenCom platform and the possible market possibilities offered in the energy market for this kind of services. A total of 9 interviews were carried out, 8 of which were with Irish TSO, DSO, Aggregators, Retailers, Regulators, and industry experts during a 1½ day intense workshop in Dublin. One further interview was carried out with Portuguese DSOs.

Main conclusions

The evaluation results show that **demand response and control is of strategic importance** to all the participants. Grid stabilisation through contracts with consumers as offered by GreenCom was met with interest and GreenCom was also seen as a solution to the challenges of distributed renewable generation which raises the complexity of grid operation. Here, GreenCom offers a good tool to inform what is going on in the grid in real time, what is the actual load and what can be forecasted.

What also became apparent was the need to **always include network security** when flexibility is aggregated and sold. The aggregation and control of demand response should always take into consideration network security and the aggregator should not be allowed to control without regard for network operation. A neutral coordinator in-between could be the GreenCom service provider.

The GreenCom service is here seen as a coordination tool securing both safe network operation as well as facilitating market participation in the transition of energy, potentially providing and integrating various 'pieces of the jigsaw' in optimising the overall transmission and distribution system.
Up until now, aggregated demand response has only been concerned with industrial customers with high loads since they offer the most flexibility. One DSO points out that demand control is likely to work only for loads over 10kVA which accounts for 10 % of their customers. An aggregator is willing to build a business case for residential customers, replicating its demand response from industrial customers, assuming that he majority of private customers are, like industrial customers, **driven by financial rewards**. Risk and reward is critical for commercial customers and so it will be for residential ones.

Another obstacle is the high level of investments necessary to control household devices as indicated by the GreenCom results which is too expensive for private customers and more appropriate for larger, commercial buildings.

Like the results from the user evaluation on Fur show, customers are generally positive towards demand response, expecting a financial compensation around 100€ a year from participating in demand response programmes. However, new services must always adhere to company strategies and policies and in several of the cases, for the aggregator and retailer, **whereas the business opportunities are there, company strategies and financial conditions are not.** Several of the interviewees state that GreenCom is a solution of the future with a need for more demonstrations before a real market uptake can happen.

1.6.4 Exploitationplan.

Every partner in the GreenCom project has made exploitations plans (confidential). But the project has produced several software products besides new business models for the smart grid marked;

1. GreenCom Grid Topology Manager
   - The manager tool includes a Load History analyser and can be used by the DSO to analyse grid bottlenecks.
2. GreenCom DSO Dashboard
   - The DSO Dashboard offers real time monitoring and prediction as well as decision support to accommodate the growing need for demand control.
3. MGM Broker with Network Monitoring and Control Framework
   - The framework makes it possible to manage and control a large-scale population of ICT/Energy devices and gateways in real-time.
4. Gateway and Managers with Distributed Generation and Storage Features
   - The generalisation of DG/DS features and device at gateway level and the ability to synchronise information and control commands at microgrid level ease aggregation of DG and DS capabilities within a microgrid.
5. GreenCom Data Collection System Including End-User GUI
   - The GreenCom Data Collection System is based on a scalable data collection system that includes LinkSmart components. The system includes gateway data dispatcher, data warehouse, context awareness engine, other cloud components as well as API (Application Program Interfaces) and GUIs.
6. GreenCom Wireless Hardware and Firmware

– Various hardware platforms with supporting firmware (embedded software) have been developed to enable interfacing with loads, meters, distributed generation and storage devices to gather sensory information.

IPR rights are shared between more GreenCom partners and the software is already being sold in the marked.

1.6.5 Scientific papers

Some partners also have written Scientific Papers with results from the project:

- **Pullmann J., Mohamad Y. (2016).**
  "Linked Data Services for Internet of Things".
  Paper presented at the International Conference on Recent Advances in Computer Systems (RACS 2015). Advances in Computer Science Research, University of Hail. doi:10.2991/racs-15.2016.26
- Younesian, E.; Khaleel, H.; Delgado, M.T.; Pastrone, C.; Garello, R., **"Packet-loss modelling for multi-radio wireless sensor networks"**, Wireless and Mobile Computing, Networking and Communications (WiMob), 2014 IEEE 10th International Conference on , vol., no., pp.673,678, 8-10 Oct. 2014
- Hu, X. , Ferrera, E. , Tomasi, R. , Pastrone, C.. **"Evaluation of Short-Term Load Forecasting Techniques Applied for Smart Micro Grids "**, ICSGS 2014: International Conference on Smart Grid Systems, Istanbul, Turkey, (Nov 28-29, 2014)
- Liam Moore **"Wireless sensor networks and their role in smart grids with reference to the GreenCom project"** Darnell power forum, (sep, 2013)

1.7 Project conclusion and perspective

1.7.1 Home Monitoring and Control (HMC)

The consumption data from the HMC group was expected to show that individual consumers are able to reduce the electricity consumption by 10 % when installing the GreenCom equipment. The actual figures show that the houses in average have saved 7.8% since they have had smart plugs installed.

However, in the reference group, which is 53 of neighboring houses at the Island of Fur, the development in consumption has been -13,7% on average from 2013 to 2015. This means that they have actually has been able to reduce the consumption with an additional 6% compared to the HMC group.

When comparing these results with a typical Danish household using 1.568 kWh pr. Person pr. Year[4], this means that a typical household with two adults used 3.136 kWh and with a cost of 2,2 DKK / 0,29 EUR pr. kWh the annual cost for electricity is 6,899 DKK / 920 EUR. 7,8% savings of this is 528,12 DKK / 70,416 EUR.

These savings should be seen in relation to the total cost of the equipment of 5,977 DKK / 797 EUR. If the homeowner can keep this reduced level stabile on equivalent of 7,8% of the baseline there will be a ROI on a little more than 11 years.

Also, should the household enter into a demand control scheme, allowing external control of certain devices at certain times, the service would hold more value. However, this would assume that the devices can be controlled remotely.

1.7.2 Heat as a Service (HaaS)

One of the aims of the GreenCom project was to see if it was possible for the homeowner to utilise the grid less and save some extra consumption and for this purpose the DSO has a term called utilisation time, which is calculated as the yearly energy consumption divided by the monitored maximum effect abated in the installation. The higher the utilization time is the better the homeowners are at either by reducing the peak load or by reducing the annual energy consumption and the better the grid is being exploited as the load is spread over more time.

[4] Bolius.dk - https://www.bolius.dk/saa-meget-el-vand-og-varme-bruger-en-gennemsnitsfamilie-279/

In households with heat pumps there has been a small increase in the total energy consumption, which was expected. Here it can be concluded that all houses except the air-to-air-Heat-pump house the "utilisation-time" has increased with 25%-66%. This means that the customer exploit the grid better.

Based on analysis from the calibrations in the households it can be concluded that on a typical Danish winter day it is save around 1 kW per house when we run the house in reduced load mode.

From the data and analysis of the peak in one transformer, the results shows that the power has been decreased by more than 5 kW ~ 22%. This gives an average of 1,68 kW pr. Household. With the typical number of households on a feeder at the island of Fur being 9, and if 80% of those households have heat pumps, the number of heat pumps in the feeder should be 7. So, the combination of PVs and heat pumps leads to an average reduction in max peak from 2014 to 2015 on 1,68 kW. This means that there should be theoretical reduction on the transformer on the feeder on 1,68 kW * 7 = 11,76 kW.

Then by controlling the HP intelligently the data from the HaaS showed an additional flexibility from the HP of approx. 1 kW pr. HP. With 7 houses on the feeder this provides an additional flexibility and reduction in peak of 7 kW, bringing the total reduction on one feeder on the transformer station close to 19 kW.

1.7.3 Intelligent Energy storage (IES)

The data from the IES provides the following conclusions:

- In the summer period the batteries run one cycle each day, but during the winter season the battery is only occasionally charged a few percentages, which is not even one cycle.
- Depending on the season and the amount of solar radiation the battery is fully charged in the period from around 12:00 CET – 17:00 CET. It should be stated that during the dark winter months in Denmark the battery is not even charged.
- Larger batteries might be interesting as there is a potential for storing more power from PVs and in order to extend the peak load reduction period. We can see that there is a lot of electricity sold to the grid in the period from when the battery is fully charged until the homeowners return and start consuming.
- Households with batteries have been able to utilize an average of around 60% of their PV production since the batteries were installed in August 2015 and medio May 2016. In the same period, the battery covers an average of approx. 33%.
- Batteries typically reduce the peak load with 35-70 % typically for 1,5-2 hours in the peak period. If there is no significant peak, meaning that if the homeowners are not at home or for instance are using the barbeque to prepare dinner, the data show that the battery can actually provide enough power to cover the load for up to 10 hours from 19.30 to 05.30 in the morning.
- Households with batteries have an average self-sufficiency degree of more than 60% during the summer (August). This number gradually decreases to an average of 6% during the winter (December).
- Customers with batteries are highly motivated to start washing machines and tumble dryer and other high consumption devices, when sun is shining or they can see that the battery is fully charged to exploit more of the PV production. Many of the homeowners follow the batteries closely both on the Fronius solar.web GUI and on the Fronius Solar.web Live app.

As documented there is a lot of potential in installing heat pumps in combination with PV-systems and the business-model is feasible, this combination is able to reduce the peak and create peak shaving and demand control. Furthermore PV installations in combination with batteries have also a lot of potential both in self-sufficiency and peak shaving.

1.7.4 Danish DSO and other European stakeholders

The conclusions from the Danish DSOs and other European DSOs are quite different. The Danish DSO is not interested in the GreenCom solution at the moment, mainly because the expected challenges in the grid with low capacity and voltage is simply not present in the Danish LV grid and therefore the need for flexibility is not existing and is not expected to be in the nearest future as the LV grids in Denmark in general are over dimensioned.

European stakeholders in general are much more interested in the GreenCom solution and many of the European LV grids are not as heavily over dimensioned and strong as the Danish LV grid. Therefore, grid stabilisation through contracts with consumers as offered by Green-Com was met with interest and GreenCom was also seen as a solution to the challenges of distributed renewable generation which raises the complexity of grid operation. Many be-lieved that GreenCom offers a good tool to inform what is going on in the grid in real time, what is the actual load and what can be forecasted. The GreenCom service was also per-ceived as a coordination tool securing both safe network operations as well as facilitating market participation in the transition of energy.

Annex

D9.4. Final Evaluation Report