Standard Grids Smart Homes - final report
August 2018

Rijksdienst voor Ondernemend Nederland

In collaboration with external partners :

eandis

ORES
OPÉRATEUR DES RÉSEAUX GAZ & ÉLECTRICITÉ

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LABORELEC

Prepared for

Alliander, Eandis, ENGIE, Ores, RVO, Technolution, TU Eindhoven

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LBE04130500 - 1.0	2 Aug 2018	New report.

Abstract

This report presents the results of the Standard Grids, Smart Homes (SGSH) project, running from 2015-2018. Apart from the Dutch partners Engie, Alliander, Technolution and TU/e, also Belgian distribution network operators Eandis and ORES participated. The objective of the project has been to develop a Home Energy Management System (HEMS) for use in households. This HEMS enables the local system to remain within specific limits of injecting or demanding from the grid. The SGSH HEMS measures the grid/consumption/injection, automatically controls some devices, takes into account flexible user requests and reports to the user the information required. If successful, this potentially can lead to great savings in investments in distribution networks.

The HEMS has been tested in the ENGIE Laborelec laboratories, followed by a one year field study (summer 2017 - summer 2018) at the homes of 16 'friendly users' in Belgium (11) and the Netherlands (5). All households had PV panels, 10 received a battery system, 5 used hybrid and full EVs and two households a heat pump. The social embedding of the HEMS has been investigated by regularly interviewing all 16 households and using surveys. Insights were also derived from HEMS prosumer workshops, digital diaries, and aggregated HEMS data. For the business model study, a workshop has been organized. Also, all participants in the project have been interviewed twice. Finally, all results have been collected and are presented in this report.

Executive summary

This report presents the results of the Standard Grids, Smart Homes (SGSH) project, running from 2015-2018. Apart from the Dutch partners Engie, Alliander, Technolution and TU/e, also Belgian distribution network operators Eandis and ORES participated.

The objective of the project has been to develop a Home Energy Management System (HEMS) for use in households. This HEMS should enable the local system to remain within specific limits of injecting or demanding from the grid. If successful, this potentially can lead to great savings in investments in distribution networks. The SGSH HEMS measures the grid/consumption/injection, automatically controls some devices, takes into account flexible user requests and reports to the user the information required. The HEMS consists of a local part and a back-office. The HEMS first has been tested in the ENGIE Laborelec laboratories. Next, a one year field study has been executed at the homes of 16 'friendly users' in Belgium (11) and the Netherlands (5). All households had PV panels installed, 10 received a battery system, 5 used hybrid and full EVs and one household owned a heat pump. One of the systems without a battery did not function properly; the data from this user have not been used for the technical analysis. Feedback to the users has been provided by a HUE lamp and a Graphical User Interface. The functioning of the HEMS system has been analysed from a social, technological and economic perspective.

The overall conclusion of the project is that the technical objectives of a HEMS as developed in this project have been met: installing the SGSH HEMS with a battery greatly reduces the impact of distributed generation and new large loads on the current distribution networks. It can be considered a feasible option to deal with the great challenges the energy system is facing now and in the future. However, there is not yet a business case for suppliers, distribution network operators or communities to implement a HEMS as has been investigated in this project. The feasibility depends on changes in the regulatory framework. Depending on political decisions, it will become clear which business model will have the best chance to succeed. Finally, HEMS need to be adapted to the local circumstances and demand profile, but also to the preferences and wishes of the households in order to be acceptable and attractive. The field research shows that there is some flexibility in energy consuming routines, but other routines are not open for negotiation.

More specifically

- From the social study:
  - With regard to the feedback, because of the direct feedback, the HUE lamp has been more meaningful for households than the GUI. Both forms of energy feedback provided almost all households with more insights into their energy consumption.
  - The social response of households to HEMS and its integration into energy-related routines seems to depend on the type of energy consuming routines: some routines are flexible (mainly related to washing and EV charging) while others are not.
  - Shifting routines depends both on negotiations among household members and the physical presence in the home;

- Tariffs and incentives, like future capacity tariffs and dynamic prices, and the price of the HEMS (including battery) shape the willingness of households to become more flexible;
- Although the 16 participating SGSH households were friendly users, there are still significant differences between households in embedding the HEMS, depending on different narratives about the meaning of the HEMS, the differences in the mix of HEMS element available in the home and different attitudes, based on prior experiences.

■ Recommendations on the basis of these results are:
- Optimize incentives with a focus on financial incentives for 'normal households';
- Simplify feedback, as an intermediate between HUE and GUI form of feedback is preferred;
- Optimize the HEMS design, especially with regard to the options for user control;
- Develop narratives why it is important to mainstream a HEMS.

■ From the technical data analysis

Based on the measurement data of 15 users and simulations at Engie-Laborelec, the following technical conclusions of the SGSH HEMS can be drawn:

- The SGSH HEMS succeeds in decreasing substantially the number of injections (69%) or demanding (76%) exceeded the Ampere limit set;
- The maximum demand and injection peaks have been reduced substantially (38, resp. 26%);
- The introduction of a battery has an effect on both the size and timing of the peak of injection and demand. If implemented on a large scale this has an important positive impact on the power profile. If simultaneousness decreases, peaks reduce and grid investments can be postponed or even prevented;
- Not all users need to have a 6 kW battery to prevent the evening peak; the users with EV and heat pump require a (larger) battery;
- The SGSH HEMS shows that the maximum load by EVs can be reduced substantially (50%); even without HEMS, smart charging reduces the impact on the grid by 30-40%;
- To reach zero exceeding on a yearly basis, the size of the batteries needs to be adapted: a battery size of 6-12 kWh (which is smaller than the Tesla Power Wall 2) is enough for users with PV systems up to 4-5 kWp. Smart charging is necessary to prevent big batteries which then are only used for peak shaving during EV charge sessions;
- The control algorithm of the SGSH HEMS increases the auto consumption of the electricity generated by the PV system, slightly, but the user profile, the size and the orientation of the PV system have a larger impact.

- Recommendations:
  - Don't use a standard battery capacity for all houses; the size of the battery should be adapted to the user profile and the installed energy system;
  - Installing optimal sized batteries at the houses with the highest demand can reduce the need for installing storage systems in all houses;
  - Smart charging should be introduced, independent of the implementation of a HEMS.

- From the business model study:
  - A HEMS creates different types of added values, for the 3 key stakeholders in this project (grid operators, prosumers and suppliers). Together with the indirect values created, this provides a promising image for the socio-economic impact of the HEMS;
  - Depending on the development of the future energy system, different models for a HEMS can be foregrounded: a commercial model with a focus on the commercial products and service delivered by companies, a public model with a major role for grid operators and the government guaranteeing public values and a community model where local prosumers and organizations focus on autonomy and self-sufficiency;
  - For each model the business case will be different. At the moment (anno 2018) there is *no business case*, the main reason being the current net metering regulation;
  - There are several societal trends (economic, regulatory, cultural, etc.) that will determine the potential of a HEMS. Assessing the impact of those trends, it seems that a business case becomes interesting per 2021-2022 for all models.

- Strategic options, based on the business model study:
  - An Anticipate & Prepare strategy: this 'passive' strategy suggests that actors developing the HEMS map emerging technological, regulatory and economic 'windows of opportunities' to introduce the HEMS at a later stage (2020-2024);
  - A Fit & Conform strategy: this more active strategy suggests that the SGSH-HEMS conforms to existing regulations and market dynamics.
  - A Stretch & Transform strategy: this very pro-active strategy aims to strategically change the market and regulatory conditions, and possibilities/limitations through lobbying and new partnerships.

OUTLINE

1. Specific information regarding TKI Urban Energy

The content of the final report and also the way of executing the project is described in thin case the information is mentioned in another part of the report, the chapter number is indicated.

1.1. Project identification

Project number	:	TKI TESG114001
Project	:	Standard Grids Smart Homes, de ideal combination (SGSH)
Subvention by	:	Rijksdienst voor Ondernemend Nederland (RVO)
Secretary	:	Technical University of Eindhoven
		(correspondence and reporting)
	:	ENGIE Laborelec (daily Project Management)
Other Participants	:	Alliander N.V.
	:	Technolution

In partnership but outside of the subvention also 2 Belgian DSO's Eandis and Ores participated in this project. This gave an extra input in the results also outside the boundary of the Netherlands and so the DSO's could also exchange information with each other.

1.2. Content and execution of the report

The content of the final report and also the way of executing the project is described throughout the report and contains summary, introduction, goals, approach, results, conclusions and recommendations.

2. Introduction

The background of this project is that low voltage electricity grids more and more have to deal with injection due to the upcoming solar and wind production. Solar energy will become standard in residential areas, either individual or collective. Because of the simultaneity of these renewable production and therefore possible errors in the grid, mitigating measures will be taken. Another evolution that will have a big influence on the future grid is the more and more electrification of the grid. This caused by the Paris climate agreement that aims on a carbon-zero house in 2050 which means no more natural gas consumption.

In the Netherlands the road to a gasless residential area will probably be reached even earlier due to the current problems in Groningen.

All this means that the grid will be more and more (over)loaded, and next to that also the growing number of electrical vehicles (EV) must be dealt with in the grid.

It is no understatement to say that the energy transition for the residential clients will take place in the low voltage grid.

For the Distributed Grid owners and the connected user it will be a huge challenge to keep the available (most of the time old) infrastructure up and running without need for extension of the capacity within the residential area.

The current approach to increase the flexibility is demand side management, for example shifting the peak of electricity. Next to that this investigation is about the possibilities of local storage, for example by installing batteries. This project goes further in the development of flexibility in the households than the current available energy management systems do. In this project the goal is not to shift the peak or using the self-consumed energy as much as possible yourself, but to stressor even use the grid as less as possible. In fact, maintaining good power quality by limiting grid loading is the main objective of the project.

For all this a development of a new Home Energy Management System (HEMS) is needed, this will be the intelligent part of the smart home system. The advantage of this approach is that huge savings can be achieved: grids do not have to be adapted or exchanged. Another contribution of a smart home system for making the grid flexible is that, if needed, the system can be used as temporary storage. The different functionalities of a HEMS can also lead to possibilities for other parties starting to develop and offer new products and services. Another way of flexibility is to let other market players use the system for their request, e.g. for balancing purposes. Next to all that, the HEMS should be acceptable and attractive for the user also.

This 3 year project is a collaboration between 3 DNO's Alliander/Eandis/Ores, Laborelec, Technical University of Eindhoven (TUE) and Technolution.

Alliander (the Netherlands), Eandis (Flanders Belgium) and Ores (Wallonia Belgium), have the knowledge about local grids and support in implementing the HEMS in their areas. Laborelec is the knowledge centre of ENGIE. Technolution is a company that develops innovative products and systems in the technical automatization. Laborelec and Technolution will cooperate in the development of the HEMS and the integration in the local system. The role of the TU of Eindhoven in this project is to focus on the social (user

behaviour and demands) and economic embedding (business models). Overall project management was done by Laborelec.

This report describes the different steps needed to develop the HEMS (chapter 3), gives insight in the social (chapter 5) and economic (chapter 7) survey done in this context and also shows how the field-test during one year was set-up and experienced (chapter 4 and 6).

3.   Home Energy Management System (HEMS)

The Home Energy Management System (HEMS) is defined as the software and hardware stack needed for the control of the household electricity consumption. Its primary objective is to respect the grid electricity injection/consumption limits by:

- measuring the grid consumption / injection (smart meter);

- automatic control of some devices (e.g. battery, white goods);

- taking into account (and respecting) flexible user requests (e.g. EV, white goods);

- reporting to the final user the appropriate information.

The grid injection/consumption limits are used as constraints on the total energy exchanges (or average power) on a 15 minute basis.

When the grid limit can be respected, one of the three following second objectives can be pursued:

- economical: minimize the total cost of the electricity bill;

- autonomy: minimize total energy taken from the grid;

- efficient: minimize total electricity losses (including grid losses & storage losses).

3.1.   General architecture

The HEMS is split in two main blocks:

- The local HEMS (small hardware in the house) responsible for:

    o   the physical connections to the devices and providing an abstraction layer for these devices;

    o   the monitoring of these devices;

    o   pushing measurements to the Back-Office (BO) and recovering long terms set points from this BO;

    o   trying to follow the BO set points while reacting to real-time measurements.

- The Back-Office (BO) located in the cloud and responsible for:

    o   the predictions (PV, baseload, EV requests);

    o   the long term optimization based on the forecasts;

    o   long term data archiving;

    o   end user reporting.

This structure is illustrated in the following figure.
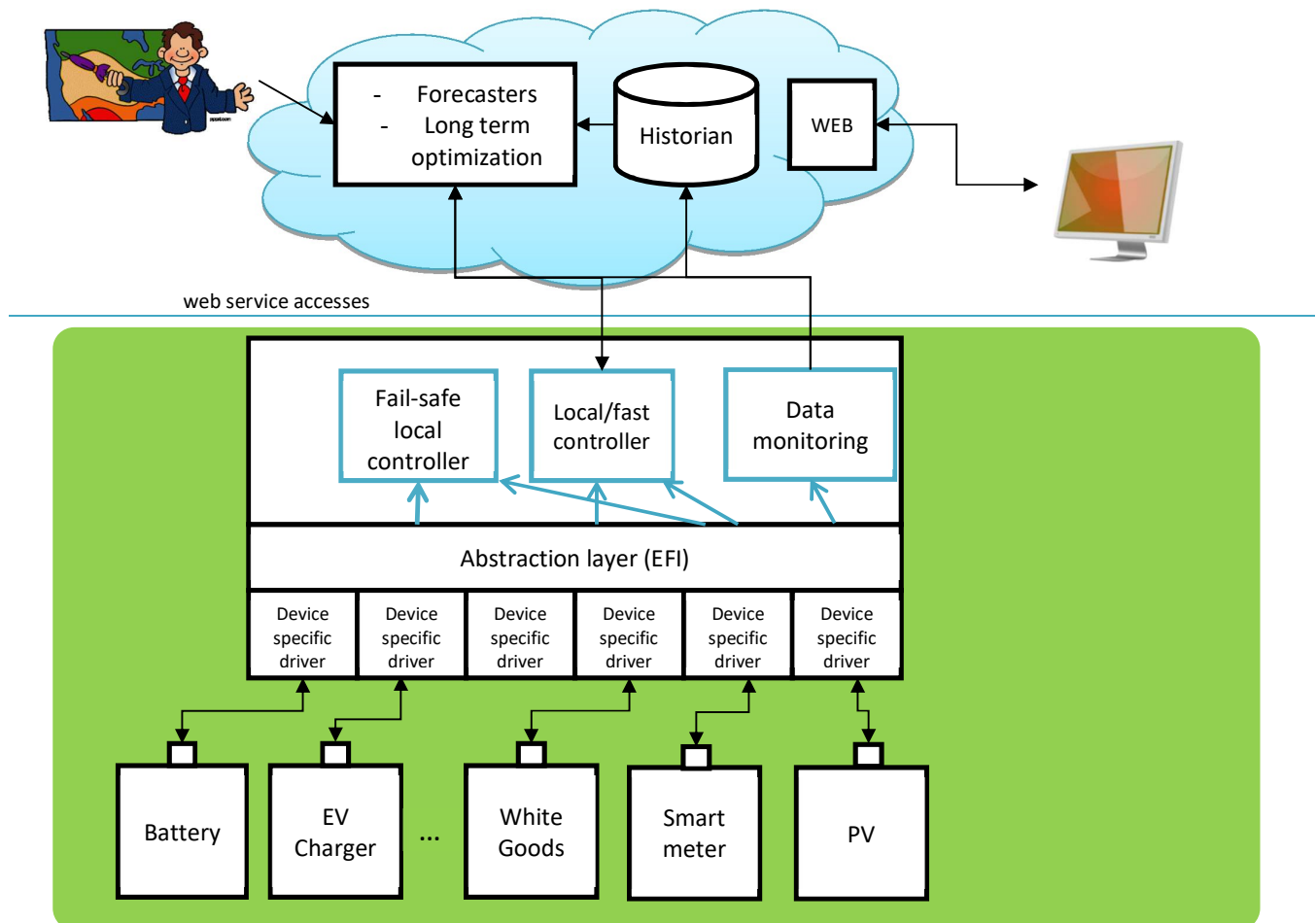
The motivations behind this decomposition in a local and cloud-based BO are multiple:

- A part of the HEMS **has** to be local:

  - for the physical connections to the devices (we are still far away from an "all devices accessible from the internet" world);

  - a failsafe controller must be present to manage the system when the internet connection is lost.

- A part of the HEMS benefits from being located in the cloud:

  - Some components (e.g. the optimization engine and time series data bases) require costly powerful machines. To reduce the total cost of the system it's better to mutualize these machines in the BO than install one such machine per home.

  - The end-user interface being in the cloud, it's accessible from everywhere and not only from the home. It allows use cases where the participants want to monitor their system when they are outside (e.g. at work).

  - It eases the management and deployment of new version of the software. As this is a research project this is especially important because this makes experimenting with algorithms etc. much easier.

3.2. Functional description

The following figure describe the functional blocks (some of them being in the local HEMS, other in the BO).
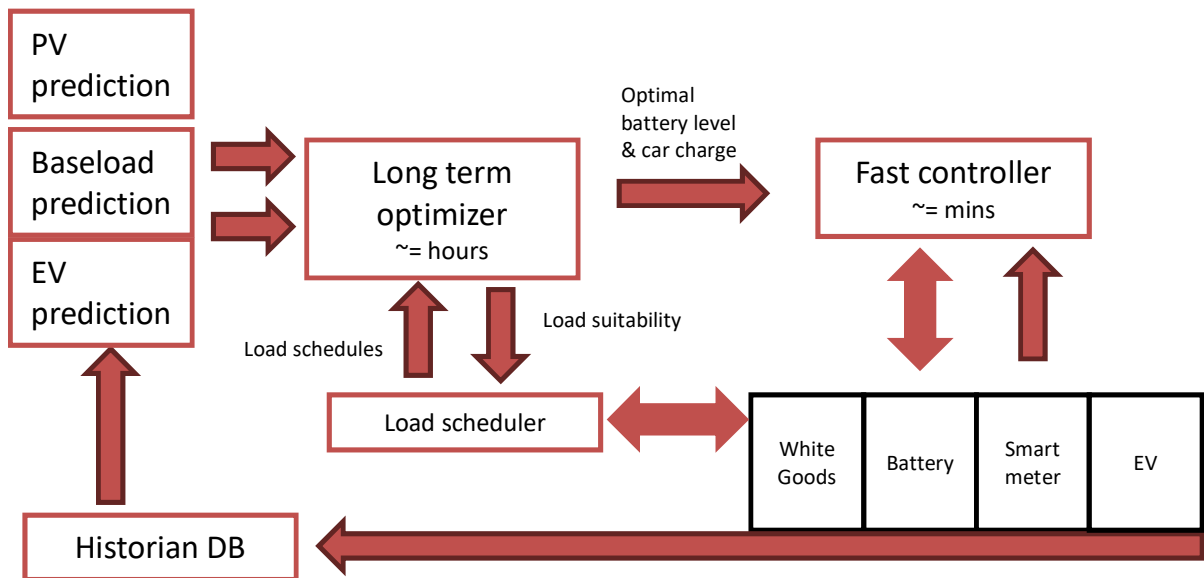
3.2.1. Predictors

It is obvious that predictions are important components for the correct control of the whole system:

- If a large PV production is expected then the battery should be **emptied** before in order to be able to absorb the PV production.

- If a large load consumption is expected then the battery should be **filled** before in order to provide the needed energy.

There are three predictors used in the HEMS. All these predictors are used to predict the values on "long" term (i.e. 12-24 hours) with a 15-minutes granularity.

PV predictor

The PV prediction is done using an external source (which uses weather forecast) combine with a statistical treatment using historical measurements. Actually two external sources are available:

- The ELIA PV forecaster (http://www.elia.be/fr/grid-data/production/Solar-power-generation-data/Graph) .

- The ICARUS forecaster (https://icarus.energy/)

Baseload predictor

This predictor is used to predict all uncontrolled loads (i.e. everything excluding EV, smart-white goods, battery behaviour and PV production). This prediction is done on the basis of calendar information (month, type of day, hour) and historical measurements.

EV predictor

Due to the large amount of energy associated to an EV charge (with respect to the base load), a specific predictor is used for the EV. Like for the baseload predictor, this prediction is done on the basis of calendar information (month, type of day, hour) and historical measurements.

3.2.2. Long term optimizer

The long term optimizer is the core component of the Back Office. This component computes the optimal control of the battery and, if any, the EV charge.

Optimizer inputs

The input used by the long term optimizer are:

- The three forecasts: baseload prediction, PV prediction and EV prediction if no real EV are currently connected

- The associated EV request If there is a connected EV (arrival time, requested energy, maximum departure time)

- The battery actual SOC

- The system description: max power injection/consumption, second objective chosen by the end user, energy prices, battery characteristics (efficiency, capacity, maximum power)…

Optimizer objectives

The first objective is to reduce the risk to violate the grid constraints. Note that it's is a difficult objective in presence of uncertainty (where we are relying on information coming from forecasters, not from a perfect oracle ☺.

- The easiest way to avoid any grid injection excess is to keep the battery as empty as possible to be able to absorb any unexpected PV production burst. But this is very risky if there is a large unexpected load.

- The easiest way to avoid any grid consumption excess is to keep the battery as full as possible to be able to absorb any unexpected load consumption. But this is very risky if there is a large unexpected PV production.

When the first objective can be met with sufficient confidence, one of the three following second objectives can be pursued:

- Economical: minimize the total cost taking into account

    o The energy prices which could depend on time and be different for the consumption/injection

    o The battery losses.

- Autonomy: minimize the total energy taken from the grid

- Efficient: minimize the total losses (both from grid & internal use)

    o The grid losses are fixed parameters which can depend on the time (higher losses during peak times)

Note that "autonomy" and "efficient" are not similar since "autonomy" is using the battery more often and therefore the internal losses are higher.

Optimizer outputs

The main outputs of the long term optimizer are:

- The optimal battery SOCs in function of time

- If an EV is connected: the optimal EV SOCs in function of time

- The "load eagerness" in function of time. The load eagerness is a value describing if an additional load would help (load eagerness > 0) or hinder (load eagerness < 0) the objective. The amplitude of this value gives additional information (if we are already expecting to violate the injection grid limit then the value will be higher than if we are "only" close to the limit).

3.2.3. The fast controller

The fast controller is located in the local HEMS and is responsible to perform the following tasks at a relatively high frequency (~= minute basis):

1. Recover the smart meter information and the optimal SOCs set points from the BO

2. Validate that following these SOCs won't lead to a grid injection/consumption violation based on the last fetched smart meter information. If a violation would appear then adapt, as few as possible, the target SOCs.

3. Send charging orders to the battery and the EV in order to reach the target SOCs.

3.2.4. Device monitoring

On a relatively high frequency (~= 10 seconds) recover all device information and send them to BO for archiving. Not only information strictly needed for the control (power, energy,..) are fetched but also all advanced information needed for troubleshooting (e.g. maximum discharging power of the battery).

This high frequency/large monitoring was needed for troubleshooting during the research phase. In an industrial version, this frequency could be much lower (1 minute or even 5 minutes basis) and fewer information types fetched.

3.2.5. Historian DB

All measurements performed by the local HEMS are stored in an historian. This information is needed for the proper training of the forecasters, end user reporting and for troubleshooting during the field tests.

The information stored in the historian is anonymized and access rights strictly controlled.

3.2.6. Load scheduler

The load scheduler is responsible for the placement of "discrete load". These discrete loads are loads which once started cannot be stopped or modulated. Typical examples are whitegoods devices.

Request received from smart whitegoods includes:

- Minimal start time

- Maximal end time

- Expected power profile

Once a request is received the load scheduler identify the best (or least worst) time to start the device. This identification is done on the basis of the load eagerness received from the BO and the expected power profile.

Once the load is scheduled, this information is sent to the BO. This will trigger a new optimization updating the optimal SOCs and associated load eagerness.

3.3. Open interfaces

There are mainly three interfaces which are fully described and can be used to connect additional components or replace some parts by other ones:

- EFI: the Energy Flexibility Interface[1] is "*a communications protocol to control multiple smart appliances*". Any EFI compatible device can be easily added and supported by the local HEMS. In addition the device description transferred by the local HEMS to the BO is based on this EFI.

- The web service exposed by the BO and called by the local HEMS to push data and recover SOCs targets is described in Appendix C.

- The web service exposed by the BO and called by the Graphical User Interface (GUI) is described in Appendix C.

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[1] *http://flexible-energy.eu/efi/*

3.4. Supported hardware

The following hardware is actually supported:

- Head meters
  - P1 compatible smart meters (DSMR v2 and DSMR v4)
  - ABB meter
- Electrical Vehicle charging station
  - Powerdale
- Battery
  - BYD Mini ES 1-phase
- PV inverter
  - SMA web box
  - Generic pulse meter
- White goods (Miele)
  - Washing machine
  - Tumble dryer
  - Dish washer
- Lamp (Philips HUE)

3.5. Technical design decisions

The motivation behind the split between local HEMS and cloud BO has been explained in Section 3.1. This section presents a few additional technical design decisions.

3.5.1. The local HEMS

- General:
  - Java is used as high level and platform independent programming language and runtime environment to speed-up development and ease testing.
  - Use open-source libraries and frameworks.
  - The application is fault tolerant, when communication to devices or the BO (temporary) breaks it should continue operation using fall-back behaviour and values.
- Fast controller
  - The smart meter readout (which is pushed by the smart meter) is used as a trigger for a new control loop, this way the system can react to the new

situation as soon as possible limiting the potential over- consumption or over- injection.

- o To prevent hysteresis the reaction time of the battery has to be taken into account. This is done by ignoring the next smart meter measurement after the one used to perform the control loop (at a 10s interval).

- Device communication:

  - o EFI is used as a device independent abstraction layer between the device drivers and the application. This makes it easier to use different type of devices. For example to the application the ABB meter and the Smart meter (P1 port) are both seen as a grid measurement device.

  - o When polling is required this is done at the lowest level, from there on the data is communicated to the rest of the application using a publisher subscribe mechanism. This gives short response times and low system load.

3.5.2. Back-Office (BO)

- The whole system is designed to be horizontally scalable with limited cost:

  - o Each houses are treated individually. Treating 100 times more houses imply "only" to add 100 times more power to the BO.

  - o Only open-source software are used by the BO. No licence cost is needed, only computing power.

  - o The whole process has been split in individual "tasks" (forecaster learning, optimization triggering, answering the HEMS calls,…) managed by a distributed task scheduler. These tasks are processed by workers. Increasing the BO power implies simply to add additional workers.

- Related to the optimization problem

  - o The problem has been formulated in order to avoid, as much as possible, the introduction of integer variable.

  - o The problem has been formulated using the "pyomo" language and is solved using an open-source solver.

- Existing standard open-source language and technologies have been re-used as much as possible: python, celery, redis, mariadb, influxdb, pyomo, CBC, swagger,…

3.6. Example of BO optimization algorithm

This section illustrates the main ideas implemented in the BO optimization algorithm on a particular extreme case. The system used in the following figures includes:

- An ideal (no loss) 3 kWh battery with a maximum charge/discharge power of 3kW

- A 5kWp PV installation

- A tumble dryer

- A 10 A (=575 Wh/15min) limit for grid injection and consumption

- Electricity prices equal for injection and consumption and independent of time

- An EV car with 30 kWh battery and 16 A charging limit.

3.6.1. Step 1: prediction

The first step is to predict the PV production (see Figure 2) and the baseload (see Figure 3). Based on these two values a net load can be predicted (see Figure 4).
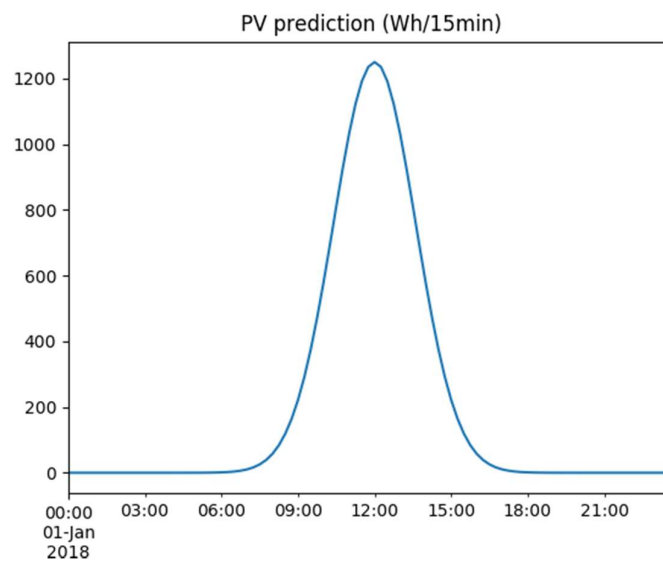
Figure 2 PV production prediction (Wh/15min)
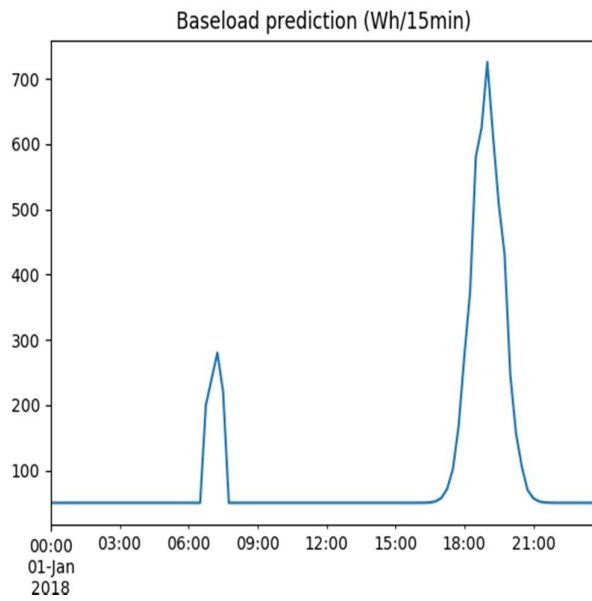
Figure 3: Baseload prediction (Wh/15min)
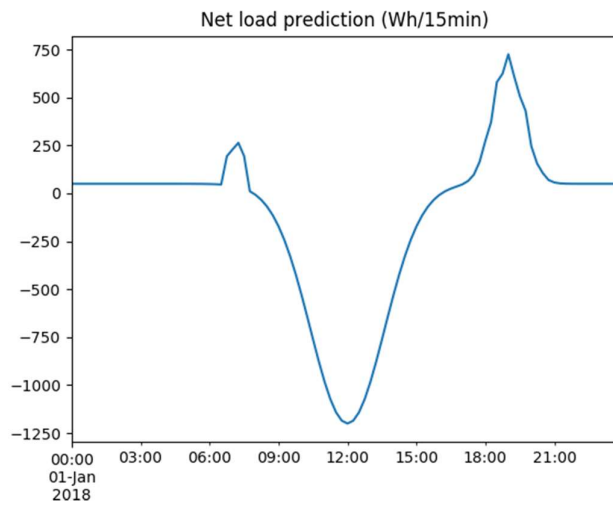
Figure 4: Net load prediction (Wh/15min)

Based on these predictions one can see that it is expected to have both a large injection excess (up to 1250 Wh/15min around 12:00) and a small consumption excess (up to 750 Wh/15min around 19:00).

3.6.2. Step 2: optimisation

Based on the net load prediction and a description of the system an "optimal" control for the battery is identify in order to achieve simultaneously multiple objectives. In this particular simplified case one wants to:

1. Respect the injection and consumption limits (575 Wh/15min).

2. Keep the battery around a 50% SOC in order to cope with the unexpected prediction error (will there be more PV production? will there be an unexpected additional load?)

The main results of the optimization are represented in Figure 5.
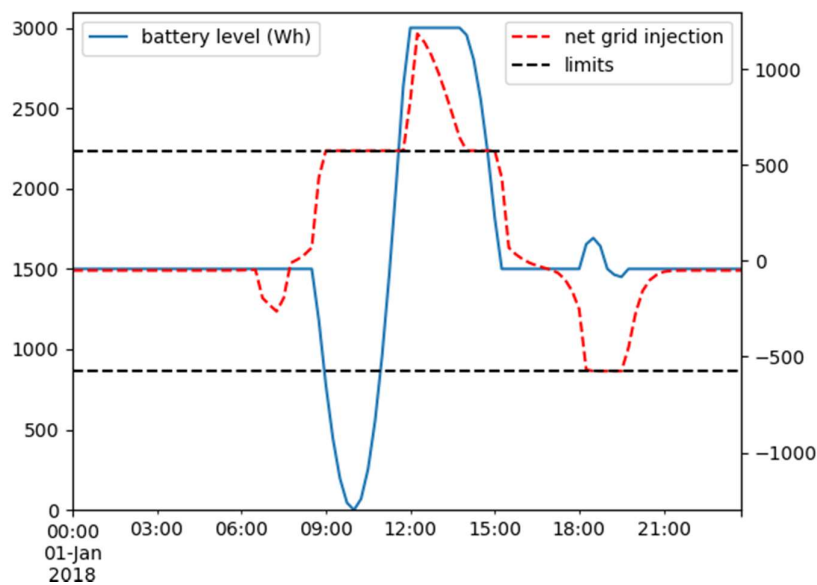
Figure 5: Optimal battery SOC (Wh) and associated net injection (Wh/15min).

One can see that:

- A little before the PV massive production, the battery is discharged in anticipation.

- At the beginning of the massive PV production, the limit is kept (the red line plateau from 9AM to 12AM) by charging the battery.

- When the battery is full (around 12AM), the limit cannot be respected anymore and a grid injection excess occurs.

- When the PV production is reduced, the battery can discharge down to its 50% SOC steady state target.

- At the evening peak, there is the reverse situation: the battery charges to be able to discharge during the consumption peak. In that case, the consumption limit is respected.

A side product of the optimisation is the "load eagerness" represented in Figure 6.
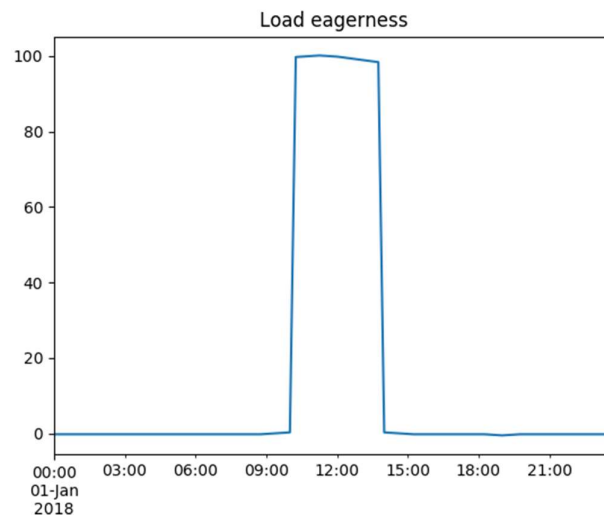
Figure 6: Load eagerness associated to the optimal battery SOC.

This load eagerness indicates where a load could help (if positive value) or hinder (if negative) the system. In this case, it is very clear that additional load would be welcome around 12AM.

3.6.3.   Step 3: scheduling of white goods

When a white good request is encoded by a user, the device send the following information to the local HEMS:

- an estimation of the associated consumption in function of time. For example a program from a Miele tumble drier could look like: [900, 900, 900, 900, 854, 550, 32] where each value is the consumption in Wh for a 15min period.

- constraints on the minimum starting time and the maximum ending time.

The local HEMS identifies the optimal starting time by maximising the product of the load eagerness (Figure 6) and the program expected consumption. In this particular case, the optimal starting time will be around 10AM.

With this new information, the BO can redo an optimization and compute again a new battery SOC target. The new results are presented in Figure 7. Even if there is still a grid injection excess it is much lower than previously (the area of the top red triangle is lower in Figure 7 than in Figure 5): the tumble dryer program has been placed at the correct time to help the system.
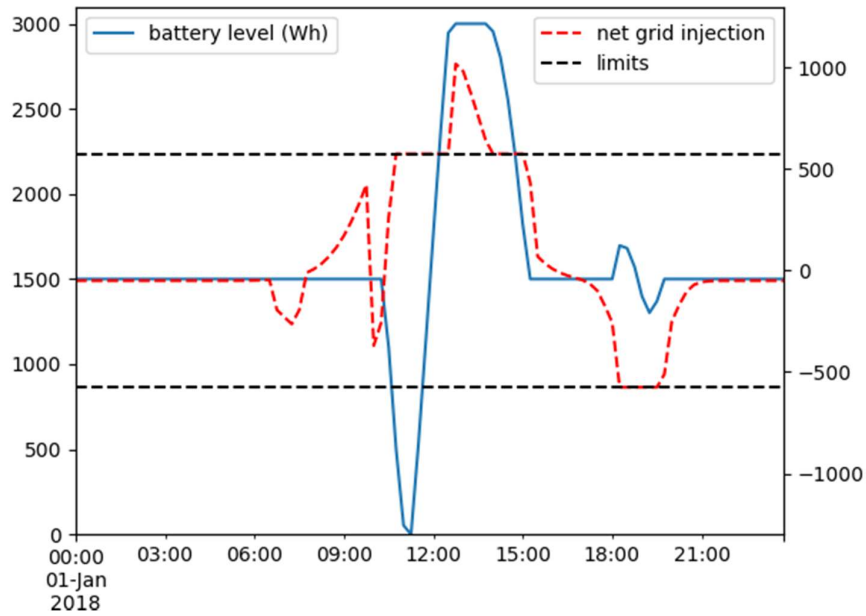
Figure 7: The optimal battery SOC (Wh) and associated net injection (Wh/15min) after taking into account the placement of the Tumble Dryer program

3.6.4. Step 4: EV incoming request

When an EV connects, the user request is transmitted to the BO. This request includes different information such as:

- requested energy

- latest departure time

- maximum charging power.

In this scenario, we assume to have receive at 10AM a difficult request to handle:

- a very large charge request of 30 kWh that must be finished that day (i.e. 12PM).

- with a basic installation (single phase, maximum 16A)

Figure 8 represents the result of the new optimization including the EV.
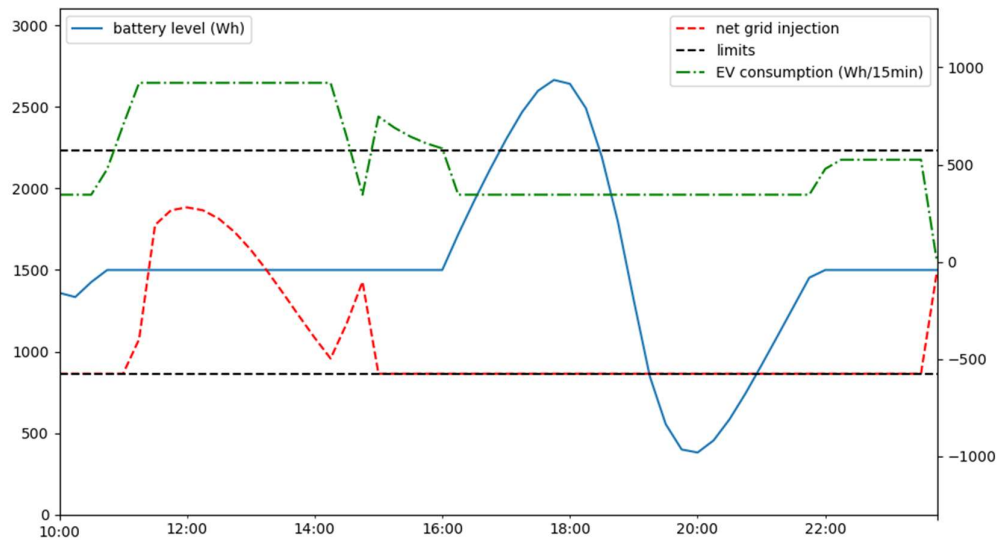
Figure 8: impact of an EV request on the optimal battery SOC and the associated net injection.

Different elements can be noticed:

- There are no more injection excess. All the PV production can be handled thanks to the EV consumption

- The EV consumption is more important at midday (when PV production is present), decrease during the evening (where there is already a natural baseload) and increases again at night.

- The battery must be charged during the afternoon to cope with the evening peak.

3.7. Graphical User Interface

A web graphical user interface (GUI) has been designed allowing all end users to follow their own consumptions and some associated KPIs. The list of available information is:

- **Net injections**: the net injections with the grid (as measured by the smart meter)

- **PV productions**: the measured PV productions

- **PV predictions**: the expected PV production in function of time for the next 24 hours

- **Baseload**: the recomputed baseload. This baseload is recomputed using the net injections, the battery powers, the white good powers, the EV charging powers (if any) and the PV productions.

- **Battery SOC**: the battery State of Charge as reported by the Battery Management System.

- **Consumption**: the house consumption (as measured by the smart meter)

- **Grid exchange excesses**: the total number of grid injection and consumption excesses. This value is computed based on the smart meter data and the imposed limits.

- **HEMS status**: basic information about the correct working of the HEMS (online, offline,…)

- **EV actual delivered energy:** if an EV is connected, this report the amount of energy already charged by the car

- **White goods next schedules:** if the user has started some white goods, this report when the HEMS system has planned to trigger the program starts

- **Consumption summary:** some summary information about the energy consumed on a given period and its origin. It includes:

  o The total consumption

  o The consumed energy coming from the grid

  o The consumed energy produced locally

- **C02 saved emission**: The CO_2 savings on a given period thanks to the whole HEMS system (incl. the battery and the control algorithms). This value is a rough estimation where assumptions are made on the CO_2 production for electricity production and grid losses.

- **Savings**: the monetary savings on a given period thanks to the whole HEMS system (incl. the battery and the control algorithms). This value is a rough estimation where assumptions are made on the energy cost, grid losses and grid injection/consumption limit violations costs.

- **Normalized load eagerness**: the load eagerness in function of time. A normalization is done such that the end user can interpret the values:

  - "1" as "increase the load as much as possible"

  - "0" as "no user intervention needed"

  - "-1" as "reduce the load as much as possible"

Appendix A shows some examples of the way the GUI was presented to the users.

4. Field-test

This chapter describes the roadmap for organizing, implementing, running and technical analyzing the field-test that was created. After installation the systems in the households ran for one year to see over the four seasons how the HEMS could deal with the programmed injection and consumption limits.

(Next to that it was interesting to see how the users experienced such a test, this is described in chapter 5: social embedding and impact)

4.1. Components

In the design of the field- test it was decided to use as less as possible the existing IT infrastructure of the user. Therefore an own local SGSH-network was set up in each house. The user only had to supply one cabled internet connection (in one case we had to use wifi because the routing of a cable was difficult to realize) and off course electricity.

If necessary, some adaptations to the existing electrical installations were made by professional companies to guarantee the safety of the installations

A full SGSH-installation consists of:

- HEMS local embedded system;

- Energy meter that measures the complete energy flow of the house, if available we used the existing P1-port of the smart meter;

- Energy pulse meter for PV production measurement and monitoring;

- Internet router for creating an own local LAN;

- Windows tablet to execute interventions from a distance if necessary;

- Philips HUE light with bridge for the connection to the HEMS;

- BYD battery system with a 3 kW bi-directional inverter and 6 kWh capacity;

- Powerdale 16A EV charging station;

- Miele white good : washing machine / tumble dryer / dish washer

- Miele gateway for the connection of the white goods to the HEMS;

- Energy meter for all connected peripherals (HEMS/router/bridge/gateway/tablet) to see what the extra consumption is of these installed devices

For all connected devices a specific driver was designed to communicate with. Depending on the device this was done with some kind of protocol for instance: ZigBee, Modbus, etc.

Pictures of the components are shown in appendix B.

4.2.   Prove of Concept (POC)

The POC is in fact the first friendly-user that was installed to test the SGSH-installation in detail and without bothering a user. The POC was installed in the Laborelec Smart Home Energy Laboratory (SHEL) in Linkebeek Belgium. This laboratory is in fact a dummy house with all the facilities and equipment available as in a real household. For almost a year the SGSH-system ran in the SHEL and a lot of fine-tuning and troubleshooting could be realized before "going live" in the houses of the friendly users. Also during the year test at the friendly users the installation in SHEL was running to test adjustments and adaptations before implementing it at the users if applicable.

4.3.   Selection friendly users

All 3 DNO's published a call for participation and after several screening and also visits at the homes a final selection was made. In total 16 users participate, hereunder an overview:

Alliander (The Netherlands)

- Number of participants: 5

- Location: all in Lochem

- Installed devices:
  - Home Energy Management System (all)
  - SGSH router (all)
  - Energy meters (all)
  - Battery (5)
  - EV loading station (2)
  - White good (dishwasher, tumble dryer, washing machine) (0,0,0)
  - HUE light (all)
  - Tablet (all)

- Extra information gathered for these users is indicated hereunder:

USER - ID		Alliander_A01	Alliander_A02	Alliander_A03	Alliander_A04	Alliander_A05
Heat supply	--	hybride air/water heatpump and wood fire	Gas	Gas	Gas	Gas
mono phase / 3 phase connection to the grid	--	3 phase	mono	mono	mono	mono
Yearly electricity consumption	kWh	1000	650	3000	2076	3400
PV	# panels	32	10	14	12	20
PV	kWp	8	2,4	3,85	3,24	5
EV	type	hybride	no	no	no	Full EV
Heat pump	yes / no	yes	no	no	no	no
Battery	yes / no	yes	yes	yes	yes	yes
Washing machine	yes / no	no	no	no	no	no
Tumble dryer	yes / no	no	no	no	no	no
Diswasher	yes / no	no	no	no	no	no

Eandis (Flanders Belgium)

- Number of participants: 9

- Location: East and West Flanders

- Installed devices:

  o Home Energy Management System (all)

  o SGSH router (all)

  o Energy meters (all)

  o Battery (3)

  o EV loading station (2)

  o White good (dishwasher, tumble dryer, washing machine) (6,6,6)

  o HUE light (all)

  o Tablet (all)

- Extra information gathered for these users is indicated hereunder:

USER - ID		Eandis_E01	Eandis_E02	Eandis_E03	Eandis_E04	Eandis_E05	Eandis_E06	Eandis_E07	Eandis_E08	Eandis_E09
Heat supply	--	Gas	Heat pump	Gas	Gas	Gas	Gas	Gas	Gas	Gas
mono phase / 3 phase connection to the grid	--	3 phase	3 phase	mono	3 phase	3 phase	mono	3 phase	mono	mono
Yearly electricity consumption	kWh		5794	3300	7000					3750
PV	kWp	6	5	3,3	6	4	4	5,5	5	3
EV	type	no	no	no	hybrid	hybride	no	no	no	no
Heat pump	yes / no	no	yes	no	no	no	no	no	no	no
Battery	yes / no	yes	yes	yes	no	no	no	no	no	no
Washing machine	yes / no	yes	yes	yes	yes	yes	yes	no	no	no
Tumble dryer	yes / no	yes	yes	yes	yes	yes	yes	no	no	no
Diswasher	yes / no	yes	yes	yes	yes	yes	yes	no	no	no

The 9 Eandis users were selected based on their consumption and size of the PV installation and put into a capacity bandwidth and 3 different categories of installation:

Bandwidth	High – full option (HEMS + WG + Battery)	Medium – control (HEMS + WG)	Low – monitoring (HEMS)
6 – 10 kVA	Eandis_E01	Eandis_E04 (+EV)	Eandis_E07
3 – 6 kVA	Eandis_E02	Eandis_E05 (+EV)	Eandis_E08
0 – 3 kVA	Eandis_E03	Eandis_E06	Eandis_E09

Ores (Wallonia Belgium)

- Number of participants: 2

- Location: Baisy-thy and Stambruges
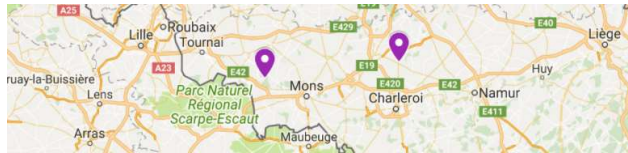
- Installed devices:

  o Home Energy Management System (all)

  o SGSH router (all)

  o Energy meters (all)

  o Battery (2)

  o EV loading station (1)

  o White good (dishwasher, tumble dryer, washing machine) (0,0,2)

  o HUE light (all)

  o Tablet (all)

- Extra information gathered for these users is indicated hereunder:

USER - ID		Ores_O01	Ores_O02
Heat supply	--	petrol	gas
mono phase / 3 phase connection to the grid	--	mono	mono
Yearly electricity consumption	kWh	4500	2000
PV	# panels	22	19
	kWp	5,72	4,3
EV	type	hybride	no
Heat pump	yes / no	no	no
Battery	yes / no	yes	yes
Washing machine	yes / no	yes	yes
Tumble dryer	yes / no	no	no
Diswasher	yes / no	no	no

4.4. Injection and consumption limits

In the HEMS-system the injection and consumption limits are the most important parameters and therefore designed to be able to be adapted if needed.

During the selection of the houses also the profile of the user was investigated and a first setting of the limits was agreed on with the DNO.

Sometimes the first setting was safely chosen to limit the impact on the users and to let them get used to the system.

Each user received a HUE Lamp that indicated if the injection or consumption limit was exceeded and / or the self-learning algorithm expects that it will exceed in the coming period).

The explanation given to the users about how to react to the HUE was:

Your HUE is indicating a red light :

If possible please **use less energy now** and try to consume this energy later.
If you help the system now you increase the possibility to stay below the **grid demand limit.**

Your HUE is indicating nothing (no colour) :

You are within the boundaries of the grid limits, **no action needed for the moment.**

Your HUE is indicating a green light :

If possible please **use more energy now** instead of consuming this energy later.
If you help the system now you increase the possibility to stay below the **grid injection limit.**

How this was experienced is explained in detail in chapter 3.

During the test some injection and/or consumption limits were adjusted if needed or because the battery was not challenged enough. In all the cases the limits were made more strict to challenge the battery more and to create more reaction from the HUE and also by the user.

In the table below an overview of the grid limit settings during the duration of the field-test is shown including the date at which a setting was changed if applicable:

User	Installation date	date	Injection	Consumption	date	Injection	Consumption	date	Injection	Consumption	date	Injection	Consumption
			Limits (A)			Limits (A)			Limits (A)			Limits (A)	
A_01	27-Mar	27-Mar	20	10									
A_02	01-May	01-May	10	10	01-Jul	6	6						
A_03	03-May	03-May	10	10									
A_04	08-May	08-May	10	10									
A_05	06-Jun	06-Jun	10	10									
O_01	04-Apr	04-Apr	15	10	02-Jun	10							
O_02	06-Apr	06-Apr	10	10									
E_01	13-Jun	13-Jun	43,48	43,48	01-Jul	13	13				10-Nov	10	10
E_02	15-Jun	15-Jun	43,48	43,48	01-Jul	13	13				10-Nov	10	10
E_03	09-Jun	09-Jun	43,48	43,48	01-Jul	13	13				10-Nov	6	6
E_04											10-Nov	13	13
E_05	08-Jun	08-Jun	43,48	43,48	01-Jul	13	13				10-Nov	10	
E_06	08-Jun	08-Jun	43,48	43,48	01-Jul	13	13				10-Nov	10	10
E_07	07-Sep	07-Sep	13	13							10-Nov	10	
E_08	12-Jun	12-Jun	43,48	43,48	01-Jul	29,09	29,09	18-Sep	13	13	10-Nov	10	
E_09	12-Jun	12-Jun	43,48	43,48	01-Jul	8,7	13				10-Nov	6	

Table 1 Ampère limits set at the pilot participants

5. Social embedding and impact

This chapter presents the results of the social study. It describes the social embedding and impact of the HEMS. It zooms in on how the HEMS - as an integrated and composite technology – has been experienced, used and integrated in energy consuming routines of participating households.

5.1. Methodological note

The social field study started with the HEMS installation in all participating homes (5 Alliander, 9 Eandis, 2 Ores), in the period (April till August 2017). During the course of one year (summer 2017 – summer 2018), there were four 'measurement rounds'. Having multiple measurement rounds was useful to analyse: (1) potential differences in impact of the HEMS in different seasons, given the seasonal variety of solar energy/sun hours; and (2) changes of experience and impact over a period of time (approximately every 3 months).

	1st measurement round	2nd measurement round	3rd measurement round	4th measurement round
Period	Summer 2017	November - December 2017	March – April 2018	May - June 2018
Description	Baseline measurement of 'normal' energy consuming routines and expectations regarding HEMS	First experience and social impact of HEMS after summer and autumn	Experience and social impact of HEMS after winter	Experience and social impact of HEMS after spring, and year evaluation

Figure 1 Overview of measuring moments social field study

All 16 households were approached for semi-structured interviews and surveys (1 Alliander household stopped participating for private reasons as of early 2018). Additionally, insights were derived from HEMS prosumer workshops, digital diaries, and aggregated HEMS data.

For the social study, energy-related routines and practices have been centre-staged. Contrary to rational theories on (consumer) behaviour change, this social practice approach focusses on routines behaviour. It highlights how the HEMS has been adopted by households; how it fits or changes their norms, routines and knowledge related to energy consumption (such as comfort, hygiene, planning routines, responding to feedback)

5.2. Household demographic profiles

All 16 homes are privately owned and located outside densely populated urban areas. In terms of the age group, the (adult) users are mostly between 35 and 66 years old, men (65%), higher educated (over 70%). Most professions of the householders are in domains such as consultancy, health care or education and/or have a technical background (a couple of them are retired). Over 40% of households notes they are knowledgeable when it comes to the topic of energy technology. About 35% considers him/herself to have neither much, nor little knowledge (30% little or no knowledge). However, degrees of knowledge and insight into their own energy consumption is a different story. Around 40% claim to have a lot of insights into their own energy consumption use, i.e. before the HEMS installation (25%

has no or little insight, 30% has not little/much insight). 35% believes (i.e. self-perception) they use little energy (below 'average'), since they use their own self-produced solar energy, or trying to be energy efficient (turning off lights in unused rooms, domestic appliances). 30% believes this is above average (highlighting the many electricity consuming appliances they have, washing machine, laptops, tablets, televisions, etc.), and 30% believes it is average. Prosumers explicitly mention that they do have some basic idea about their energy consumption levels, but they lack more precise energy insight and feedback (before the HEMS). Most households consist of two adults with one or two children (that live at home). In terms of income, most Dutch and Belgian households have an average income ranging between €2.000 and €4.500 (gross a month), with some exceptions below or above.

Most households considered the HEMS as an 'assistant', either in terms of synchronising energy supply and demand, or to become more sustainable, or autonomous. In some instances, it was 'just fun' or 'a game' to play around with this new technology. It is important to note that these 'friendly users' are not representative of the 'average households', given their interest and knowledge about the energy sector, smart technology and grid management issues (working for grid operators and energy cooperative members).

5.3. Energy feedback: GUI and HUE lamp

A key building block of the HEMS, from the perspective of prosumer, is energy feedback. This is provided to households in two ways: via the GUI and the HUE lamp. Energy feedback increases energy awareness and information for households

It seems to be the case that the GUI has been least interesting for users, especially after a couple of months into the project. The GUI was logged on only several times a month for most users. There are two main reasons for this: it often takes much time to access the GUI information, and the information itself is often 'too detailed' or 'complex' to make sense of it directly. As such, its added value is relatively low. However, some (tech-savvy) users say that the detailed information provides them with insight into recent 'peak moments'. Based on the monitoring of GUI use (clicks and duration), it seems that HEMS data profiles that interest most households are related to: energy autonomy (self-sufficiency and grid power) and environmental savings (CO_2 emissions). The least interesting one seem to be about the battery (state of charge). This is related to the more general lack in interest and knowledge about the battery for many households. Additionally, monthly GUI information is also more interesting then daily information, which is explained by the marginal changes and savings per day.

Next to these GUI, the HUE lamp was a key point of reference for most participants. For them, the lamp was actually the most interesting and interactive device of the entire HEMS network (which was also designed as such). During virtually all conversations with households, 'the lamp' was mentioned first, in one way or another. From the perspective of HEMS 'users', the lamp is a very meaningful device (for over 80% of households). The lamp is often positioned in the living room, in order to directly be aware of changing colours. As expected, the lamp often turned green during summer months (due to ample energy production) and afternoon hours. Contrastingly, the lamp turned red during winter months and during peak moments, especially in the evening. These signals were experienced as fairly simple and provided a direct form of feedback, which are significantly different from the GUI. In winter months, however, when the red lamp turned on more often, some households

became a little discouraged or upset they were not able to shift energy. A red lamp, for some, led to some apathy in this period.

However, since the beginning of 2018, it seemed many households also started to get used to the lamp, and developed a 'response routine' whenever the HUE lamp turned green or red. For instance, the first response to a red lamp often is: "what appliances are running"? Followed by: "what can be turned off, or done later or tomorrow"? Such responses illustrate that, over time, new energy management practices can emerge, revolving around self-monitoring and peak shifting.

The most direct effect of these forms of energy feedback were especially insights into energy consumption patterns and peaks. Over 90% of all households noted their HEMS has increased their insight into their own energy use.

5.4. Impact of HEMS and household flexibility

A key aspect of the social study has been to examine the extent to which households are willing to shift energy routines, in terms of either delaying or bringing forward in time. This is directly related to the overall effectives of the HEMS in the context of the SGSH project.

5.4.1. Shifting the use of appliances and energy

In accordance with previous research about domestic energy use, it became clear some practices are more flexible than others.

Type of practice	Householders willing to shift
Using washing machine, dish washer, tumble dryer (whitegoods)	Over 90%
Using EV, charging pole	70% (of EV users)
Showering (warm water)	50%
Using oven, microwave, water cooker	25%
Heating home	20%
Using infotainment	15%

Figure 2 Flexibility of different household routines

Despite differences in summer (more green of HUE lamp) and winter (more red of HUE lamp), these figures seem to be relatively stable and should be considered as averages. Importantly, not all energy consuming routines are equally important for peak shaving and grid management more broadly. Differences can be made between flexible and non-flexible) routines, and the degree to which they are related to high energy consuming appliances.

	Flexible routines	Non-flexible routines
Related to high energy consuming appliances (peak inducing)	• Using dish washer • Charging EV • Using vacuum cleaner	• Using oven and microwave • Using electric cooking • Using heat pump/e-boiler/e-heater • Using water cooker/coffee machine
Related to low energy consuming appliances	• Ironing • Using washing machine • Using dryer tumbler	• Watching TV • Use lighting • Charging smartphone, tablet, laptop

Figure 3 Differences of flexibility of household routines related to energy consuming appliances

Even though 'non-flexible routines' are often non-negotiable for shifting and very 'sticky', they are not impossible to change. When certain intensives are provided (e.g. financial or information about risk), they can indeed change over time.

Compared to the willingness of SGSH households to shift energy, unsurprisingly, there is little change regarding the non-flexible shifting practices (e.g. cooking heating, infotainment). However, with regard to the more flexible shifting practices (washing and cleaning), a decrease in flexibility of 20-50% can be observed. This suggests that there is a high flexibility of shifting energy, while reducing these same practices is much more problematic or challenging. In a way, this can be said to the minimum baseline for the households regarding 'flexibility'. Interestingly, many SGSH households do find saving or reducing energy important, given their social, environmental and economic ambitions. In practice, households also do reduce energy because of the HEMS.

These energy reducing practices, however, seem to be overshadowed by the response of most households that there is a clear demarcation between wanting to save or reduce energy (peak shaving), and practical social restriction or norms of comfort. Furthermore, most SGSH household are already quite energy conscious and are already invested in some energy saving practices. In line with the discrepancy between energy shifting and energy saving, the support for actually saving energy is also different.

Reason for saving?	Percentage of households
If it saves me money	65%
If it saves environmental impact	60%
If I can manage it practically	20%

Figure 4 Reasons for saving energy

Compared to the energy shifting results, this table indicates a reduction of 15 to 50% of the households' willingness and capacity to actually change their behaviour using the HEMS. Consequently, this means that energy shifting is more flexible and negotiable than energy saving via the HEMS. This is related to the HEMS only in part, given that most households simply have minimum criteria concerning their daily routines and energy demanding practices. Shifting them is open for discussion, actually reducing them not so much.

The possibilities for energy shifting do not only depend on 'willingness' and underlying values of households, but also issues of planning and timing.

Factors impacting energy shifting possibility	Percentage of households
If I am at home in the afternoon	88%
Planning for work	63%
Planning for private reasons	50%

Figure 5 Factors impacting energy shifting

5.4.2. Negotiating with household members

The role of social norms and households dynamics is significant in interacting with the HEMS. The flexibility of household routines, and thus the effectiveness of the HEMS, relies on micro dynamics and negotiations among household members. This concerns the roles and responsibilities assumed by husbands, wives and children, as well as relations of trust, control and authority. The HEMS, and particularly energy feedback such as the HUE lamp, in this sense, is introduced within a rich and complex social setting of family norms revolving around comfort, cooking, washing routines. In some instances there is a direct form of authority and control within household (hierarchy), which suggests that the norm advocated by the person(s) prevails (for instance via parenting, or a 'knowledgeable tech-savvy partner). To some extent it might be safe to say that in some SGSH households, energy demanding routines such as cooking, cleaning and washing are performed by women. However, men (and to some degree children) are equally important in determining whether or not a household practice is flexible.

Negotiation is significant since there is often not one clear-cut prevailing social norm of hierarchy associated with a particular energy consuming practice. Rather, flexibility is to be asked for, welcomed and socially negotiated (for instance ironing or doing laundry). Households norms and roles, in such cases, are less clear and flexibility is the outcome of negotiations among household members.

5.4.3. Physical presence in the home

Next to the degree of household routine flexibility and internal household dynamics, the HEMS effectiveness depends on the physical presence of humans in the home. This holds especially for the daytime, when there is ample sun, and immediate energy consumption is preferred. Physical presence was also mentioned as a critical factor by a number of prosumers. Importantly, this also resonates with the HEMS feedback system, especially the HUE lamp which assumes physical presence for adapting energy consumption.

Of the households, about 65% has at least one person above 13 years old in the home during the day (workday). For them, it would be more or less manageable to follow HUE feedback. Some households mentioned that the HEMS system requires extension of its feedback system (using an SMS-alert, or an app).

Furthermore, if work and private planning does not intervene, households are able to shift. Over half of the households argue that their professional and private planning/agenda is an important factor that limit their possibilities for shifting energy.

5.4.4. Tariffs and incentives

Three types of 'financial incentives' seem to be relevant in determining the effectiveness of HEMS and willing of households to shift energy consuming practices. First, the role of capacity tariffs. A lower capacity tariff (in the near future) would mean that HEMS become

more interesting, financially, and thereby, the ability of households to manage their own home energy system, including peak shifting aspects. Second, relatedly, the cost to obtain a HEMS are currently (2018) relatively high for most households. The price of batteries mainly determines the overall costs, and is expected to drop in the near future. Third, the role of dynamic peak pricing. The more flexible peak tariffs are, and the possibility for off-peak 'rewards' (or 'punishment' for transgressing low capacity grid limits), the more willing households would be to respond to such peak shifting incentives. Importantly, many households note that differences between peak and off-peak prices should be significant, otherwise little shifting is expected.

In sum, the flexibility of household practices (vis-à-vis- the HEMS) depends on four main aspects: (1) type of household practice; (2) internal household dynamics; (3) physical presence in the home; and (4) tariffs and incentives.

5.5. Social embeddness of HEMS households

Clearly, not all households and prosumers are the same. Some of them have clear sustainability ambitions, while others believe the HEMS helps them to become more energy autonomous. And even though most SGSH households do not consider themselves to be sensitive to financial incentives alone, virtually all households believe mainstream households are perhaps only interested in financial gains (non-experts, non-energy technology households). All in all, there are *different 'social profiles' or 'narratives'* related to HEMS prosumers. Such narratives are supported by other research on smart and sustainable energy use, but are mostly based on prosumer expectations and field research findings. Given that narratives and household profiles are socially embedded, they can be expected in other HEMS-friendly households as well. Five main narratives can be discerned.

	Narrative	Meaning of energy	Prosumer…	HEMS is expected to help…	Household practices are expected to be…
1	The green narrative	Energy is a matter of sustainability	…wants to use and normalise renewable energy	…maximise solar energy use (kW)	…quite flexible (except cooking and leisure)
2	The autonomy narrative	Energy is a matter of control	…wants to use self-produced energy (or of energy collective)	…minimise grid and grey energy dependency (power from grid, kW)	… quite flexible (except heating, cooking and leisure)
3	The financial narrative	Energy is a matter of money	…wants to save and/or make as much money as possible	…maximise savings and/or profit using own energy (€/cents)	… quite flexible (except heating, cooking and leisure)
4	The hi-tech narrative	Energy is a matter of automation	…wants to maximise comfort via domotics	…maximise domestic comfort and convenience	…not very flexible (maybe washing, cleaning sometimes)
5	The low-tech narrative	Energy is a matter of self-discipline	…wants to use as little technology and electricity as possible	…minimise electricity during peaks and overall (kW)	…quite flexible (except cooking and leisure)

Figure 6 Different narratives related to HEMS

In each of these narratives, the HEMS means something else and can play a different (social) role. In an individual household, one or two narratives often dominate. As HEMS play a slightly different role in each prosumer narrative, and thus, in each set of household routines. Consequently, the expected everyday impact and household routine flexibility

might differ as well. In the figure below, the main HEMS prosumer narratives are summarised including respective HEMS meanings and household routines flexibilities.

5.6. Households differences and changes over time

Not all household are the same, and not all HEMS experiences and opinions stay the same. The way the 16 participating households interact with their HEMS should be understood within a dynamic context.

5.6.1. Household differences

As deliberately planned, not all households received the same 'HEMS package', or broader home energy configuration. For instance, not all households received smart white good appliances, or a home battery. Also, there are more differences among participating households; not all households have EV's, there are differences in solar energy production (number of solar panels), using gas or electric stove, differences in household composition and background knowledge about energy technology. In what way did this change how households respond to HEMS?

Home energy profile element	Impact on HEMS household
Low capacity connection (0-3, 3-6, 6-10)	The lower capacity connection category, the more often more often a green lamp is expected for consumption, and a red lamp for injection. More flexibility is expected in 'normal households'
PV panels (all households) (2,4 – 8 kWp)	The more kWp, the more often a green lamp is expected for consumption, and a red lamp for injection. More flexibility is expected in 'normal households'
Battery (10 of 16 households)	Presence of battery is relatively insignificant for staying within grid limits. However, absence of battery, or small battery, increases chance on red lamp. More flexibility is expected in 'normal households', especially in winter
Smart white good (washing machine, dryer tumbler, dish washer) (6/8 of 16 households)	The more smart white good, the more often more often a green lamp is expected for consumption. More flexibility is expected in 'normal households'
Electric vehicles/charging pole (5 of 16 households)	Presence of EV/charging pole increases change on red lamp for consumption. More flexibility is expected in 'normal households'
Electric stove (8/10 of 16 households)	Presence of EV/charging pole increases change on red lamp for consumption. More flexibility is expected in 'normal households'

Figure 7 Differences between HEMS configurations and their impact

These differences in home energy profiles all impact the degree to which households actually are willing and able to shift energy, and contribute to overall SGSH objectives.

Household profiles are, that differ on the basis of certain parameters (dag/night users, number of PV panels, mix of high consuming appliances), a certain type of HEMS can be provided for households (differ in storage capacity, smart white good, charging pole).

5.6.2. Changes over time

Seasonal differences have been a key aspects on the field test. During the winter, less local energy production let households to respond more frequently to a red lamp. This, as mentioned above, made households experience 'their own grid limits' with regard to flexibility and comfort norms.

Over time, clearly differences emerged about households thought about the HEMS. In the beginning virtually all households were enthusiastic about the HEMS and its potential. During the first months, most households also experienced it as a meaningful and useful technology that could assist them in becoming more sustainable and energy autonomous. However, after the winter of 2017-2018, the overall attitude towards the HEMS became less optimistic. Three types of attitudes seemed to emerge after one year, which can roughly be divided into groups with similar amounts of people:

■ **HEMS optimists**: households that are univocally happy about the HEMS, its hardware and software, and consider it to be a great addition to their home. They also do not mind that it is (still) relatively expensive, as it will help them to become more energy aware, sustainable and autonomous. This group considers problems to be minor practical ones, that can be solved technically, through proper design and regulation, or market development over time. This group was largest in the beginning of the project.

■ **HEMS sceptics**: households that are ambulant about the HEMS, its hardware and software, and consider it to be some addition to their home. They consider the HEMS to be (still) relatively expensive, and might help them in the future to become more energy aware, sustainable and autonomous. This group considers problems to be significant ones, that however can be solved technically, through proper design and regulation, or market development over time. This group grew in size after the winter of 2017-2018.

■ **HEMS pessimists**: households that are univocally unhappy about the HEMS, its hardware and software, and consider it to be no addition to their home at all. They consider the HEMS to be too expensive, and will not help them to become more energy aware, sustainable and autonomous. This group considers problems to be major ones, that are hard to solve in the forthcoming years. Alternative energy saving tools and technologies are potentially more interesting than a HEMS. This group grew in size after the winter of 2017-2018.
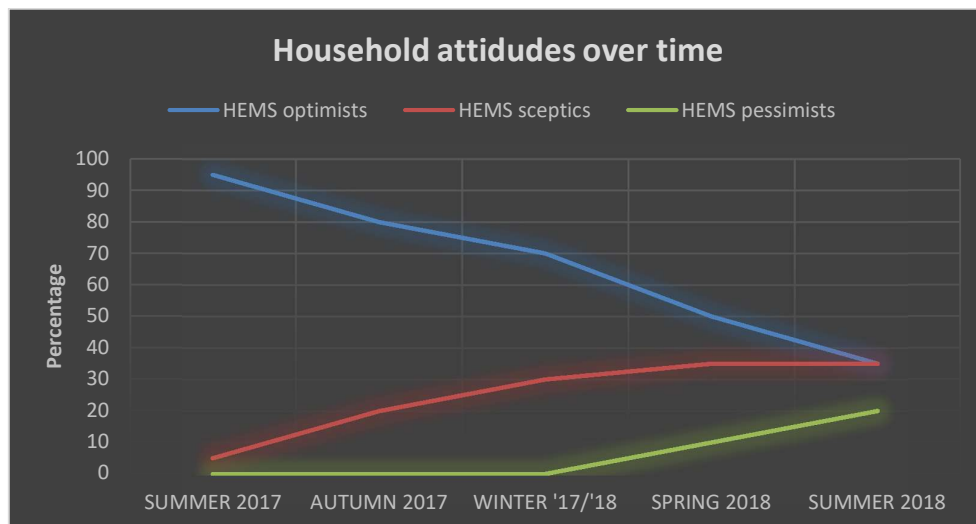

Figure 8 Household attitudes towards HEMS

5.7. User feedback and suggestions

Often, SGSH households provided interesting and creative recommendations to further develop and improve the HEMS. These pointers sometimes relate to specific incentives and small technical enhancements, but sometimes relate to public policy priorities and using cultural norms and social media. Since these ideas can actually be considered as forms of user feedback, as well as broader ideas to improve the SGSH-HEMS project, they are clustered thematically.

5.7.1. Optimising incentives

The HEMS is a technical and digital network, but it also depends on household flexibility. The ways in which prosumers can be 'seduced' or 'steered' into moving along with the low grid capacity parameters, and shift production and consumption peaks, can be realised via incentivising households. Incentives assume that users are sensitive to incentives (either financial, environmental or social). An overwhelming number of HEMS households argue that 'average households' are sensitive to financial incentives, and not so much interested in environmental gains and grid management concerns (which is not necessarily true, households might be interested in several gains). To them, households that actually find sustainability and/or autonomy interesting is a small part of the population and market share. However, certain types of incentives could actually make every households accept HEMS feedback and change into HEMS-friendly households.

SGSH households believe that HEMS is interesting for any household, only if saves them significant amounts of money. This can be organised in all kinds of ways, since the money that is saved (earning 'HEMs points') and can be turned into 'free products or services'. This way, money is indeed a key trigger for people to accept the HEMS, but the personal gains can be turned in more creative and fun 'gifts'. Next to underlining the potential for HEMS, many SGSH households are also sceptical about the business case for prosumers. Financial incentives are considered very important, especially given that HEMS are not actually designed to help mainstream households, but grid management challenges.

5.7.2. Simplifying HEMS feedback

Most SGSH households refer to the HUE lamp most of the time, when it comes to their 'experiences'. And even though they seem to like the HUE lamp, there is much room for improvement. More generally, many SGSH prosumers mentioned all kinds of additional forms of feedback that simplify HEMS feedback information, as to become more user friendly.

Even though the HEMS can be complex indeed (algorithms, grid management concerns, synchronising software, etc.), users should not be bothered with too many aspects. The HEMS will only work if users cooperate and are incentivised properly, which means feedback should be simple, personal, graphic and fun. In other words, 'behind the scenes' the HEMS back office might be highly complex, but the user interfaces should be as simple and user friendly as possible. Simple tips and tricks might also work, in addition to providing households with the space to make their own choices and considerations which energy consuming practices to postpone or bring forward. This suggests that most people do not simply use and follow a HEMS for intrinsic reasons, expect for the 'usual suspects'. Many SGSH prosumers argue that potential mass consumers are mostly triggered by financial reasons and simpler HEMS feedback. Feedback that combines HUE (as too simple) and

GUI (as too complex), is preferred by many households (an app or in-home display). For example, a simple interface with a maximum of 3 preferred graphs synchronised with the HEMS.

5.7.3. Design issues

Next to these specific ideas to further improve the SGSH-HEMS feedback system, SGSH household have mentioned a wide range of broader ideas to technically innovate and improve the HEMS more broadly. A number of households argue that the HEMS is indeed a smart and automation-driven technology, but it can become more user friendly and integrate domotics elements.

A range of possibilities is imaginable, making the HEMS both more user-friendly and more automated. This might be driven by algorithms and software that can be active, synchronising the HEMS algorithms with for instance smart lighting, air-conditioning, sun screens, and digital agenda's. Next to these ideas to further extend and improve the HEMS software, SGSH households also have some views to further develop the hardware-side of the HEMS (including Vehicle-to-Grid solutions).Control is particularly relevant, as multiple households argue that the current HEMS version still lacks possibilities for intervention, such as an list of appliances that can be switched on/off when the HUE turns green or red.

5.7.4. Regulations and cultural norms

Other recommendations relate to policy and using cultural references (e.g. via 'celebrities' or 'ambassadors'). In this context, the HEMS can be further developed, up-scaled and mainstreamed into (more) average households. A number of households explicitly mention that the role of governments is crucial in making the HEMS successful. Legal and fiscal incentives (e.g. related to net metering, environmental policy) can make it more attractive for commercial companies as well as for prosumers to invest in HEMS, or elements thereof (software, battery, etc.).

There are many ways in which governments can be more proactive and further environmental goals and local sustainable energy. Some SGSH households mention that HEMS can indeed be integrated in renovation projects and new housing plans (on a large scale). Introducing HEMS into already existing homes is more challenging. However, there are many ways governments can step up and make HEMS more attractive for current home owners and households. Next to legal and policy measures to advance the HEMS, some prosumers also mention the role of popular cultural, social norms and new media as important. First of all, SGSH households acknowledge a broader cultural awareness regarding climate change, environmentalism and energy efficiency. This is an important underlying driver for HEMS to become socially acceptable.

Next to this cultural shift in energy awareness, the HEMS itself is considered as an indispensable force to reach broader audiences, it makes the HEMS more accessible and fun for everyone. There are different ways to change this and utilise cultural and community incentives to bring HEMS more interesting to a broader population (using well-known icons or celebrities).

5.7.5. User concerns about HEMS

During the many interactions with SGSH households, some prosumers articulated underlying concerns and challenges. One of the key concerns relates to the relatively

meagre added value and business case for prosumers. As the business case for prosumers is not very convincing (see chapter *Economic Embedding and Impact*), there are questions about the potential for 'mainstream households'. Another concern that was brought forward by some households (not that many, interestingly), was related to privacy, data ownership and data security related to the HEMS. This is especially relevant given that HEMS are private technologies, in that, they are inside the home and SGSH energy data and profiles express highly personal information.

Another important future challenge related to proving access to (relatively sustainable and cheap) energy for all households. If HEMS will be a personal choice, mainly, for high-income groups, differences might emerge between households to access to relatively cheap and sustainable (self-produced) energy, and households with little access. This requires stakeholder, grid operators and regulators in particular, to safeguard public values and principles of equality in future smart energy systems.

5.8.   Conclusions

A number of general insights and conclusions can be made on the basis of the social study.

First, regarding energy feedback, the HUE lamp has been more meaningful for households than the GUI. This can be explained due to simple and direct for of feedback from the HUE lamp, compared to the GUI. Both forms of energy feedback, however, provided virtually all households with more insights into their energy consumption. Despite the enthusiasm about the lamp, some households became somewhat apathetic about the red lamp, especially during winter months, as they simply were not able to shift most energy consuming routines.

Second, the social response of households to HEMS and its integration into energy-related routines – and the overall effectiveness of the HEMS - seems to depend on a number of aspects:

- The type of energy consuming routines, as there are flexible routines (mainly related to washing and EV charging) and non-flexible routines (mainly related to cooking, heating and leisure);
- Negotiations among household members, as this shapes what routines are shifted by which household members;
- Physical presence in the home (mainly in the afternoon), as shifted energy consumption depends on physical activities;
- Tariffs and incentives, as predominantly financial incentives shape willingness of households to become more flexible. These relate to: (1) future capacity tariffs; future (market) price of HEMS, especially batteries; and (3) dynamic peak pricing.

Third, even though the 16 participating SGSH households are friendly users (high income/educated eco-oriented group), there are significant differences between household that impact the social embedding and impact:

- Social HEMS-related narratives about the meaning of energy and the HEMS for households (green, financial, autonomy, etc.);
- Different mix of HEMS elements (battery, EV, heating pump, etc.);
- Type of attitude towards the HEMS, based on prior experiences.

Fourth, different type of user feedback and suggestions can inform strategies of grid operators, designers and suppliers:

- Optimize incentives, especially focusing on financial incentives for 'normal households';
- Simplify feedback, as an intermediate form of feedback is preferred (between simplistic HUE and over-detailed GUI);
- Optimize HEMS design, especially regarding user control;
- Use regulations and popular culture in to enable mainstreaming of HEMS.

6. Technical analyses

This chapter contains results based on analysis of the measured data obtained from the field. This data is filtered to have relevant results, which represent reality enough but remove child disease errors in the first month of installation of the systems.

Also, because of the immense collection of 680 million data points, only relevant examples and summarizing tables and figures will be presented.

6.1. Forecasting performance

As explained earlier in the document, forecasting is used to improve the performance of the HEMS. By knowing PV production and load demand a few hours ahead, the HEMS can control the battery in an optimal way. Since 100% accurate forecasting is not possible, some errors on the forecasts will always be present. To cope with the forecast errors, margins on the state of charge of the battery are taken to be sure a small error will not immediately lead to grid exceedings. An exceeding is a consumption or injection of power above the demand limit or below the injection limit. This on 15 minute average base. This demand or injection limit (determined together with the grid operators) is imposed on the system control, thus peak shaving will be used to be in between both limits as best as possible.

An example of forecasting the PV production and load is shown in Figure 9 and Figure 10. As expected PV can be forecasted well on very sunny days (26 and 28 May), on cloudy days (27 and 31 May) this is more difficult (Figure 9). It was not investigated what the impact of a good or bad PV forecast is on the performance of the HEMS. It is expected to be limited since the forecast of the energy content is good on cloudy as well as on sunny days.
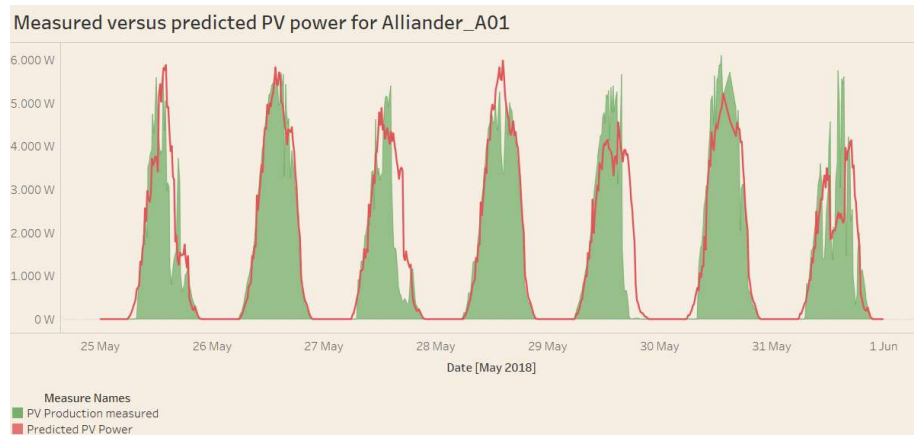
Figure 9 Example predicted versus measured PV power

Also the electrical energy used for normal activities on daily basis is quite constant and easy to forecast (except holidays), which is the most important for the HEMS optimization.

Figure 10 shows the predicted load of the grid for the same user Alliander_A01.This prediction takes into account the EV of this user. This can be seen from the red line, which is the typical uncontrolled charge curve of an EV charging with 16A. Later on in this chapter

a detailed analysis is performed to explain the behaviour of the HEMS system countering expected and unexpected exceedings.
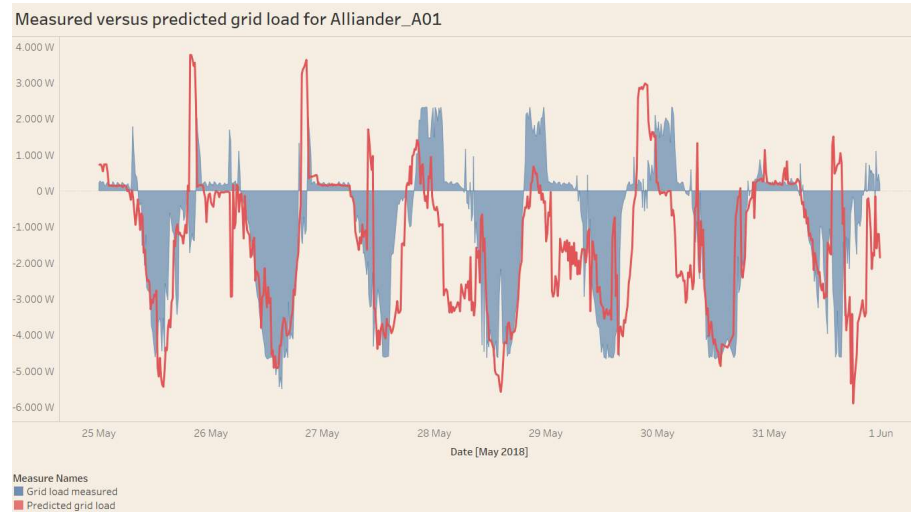
Figure 10 Example predicted versus measured grid load

Another example of prediction of the total impact on the grid is shown in Figure 11. As can be seen the prediction of demand from the grid as well as for injection into the grid is of high quality. This improves performance of the HEMS, but this is not easy to quantify.

Figure 11 Example predicted versus measured grid load

6.2. Base load user (reference profile)

To understand the effect of the HEMS on the user power profile, a reference must be available. Two references are used for the analysis:

- A measured power profile from 1 year before the pilot based on smart meter readings

- A calculated reference by removing the impact of the battery

Both are not perfect references since the circumstances and behavior are not the same. But since there is no other possibility to obtain better referen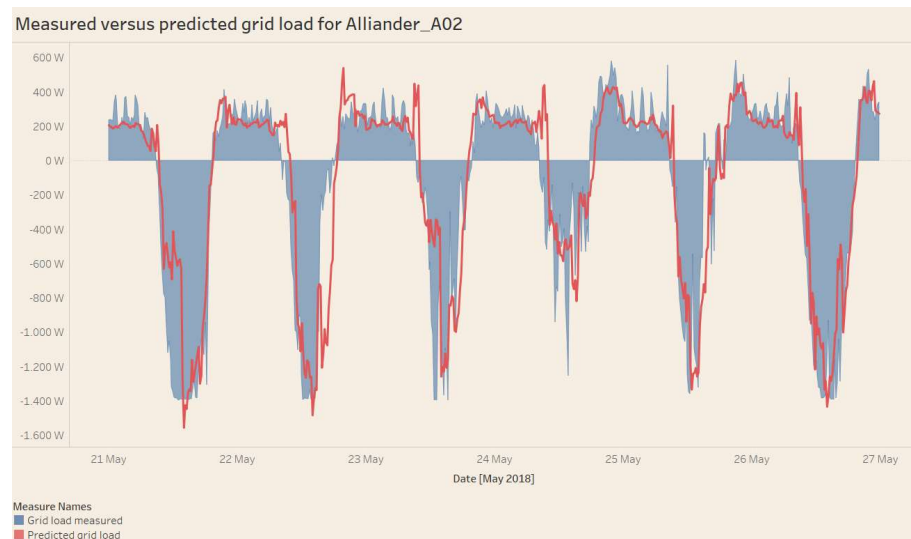ce profiles, the analysis is performed this way. It gives a good and representative view on the added value of the SGSH system for peak shaving. To give an example, Figure 12 is a reference profile of one user. The orange horizontal line is the demand limit (10 Ampere), the red horizontal line is the injection limit (10 Ampere). Since there was no HEMS installed at that time (measurement is from 2016 while HEMS systems where installed from April 2017), this profile is not influenced by a HEMS or battery. There is no limit on the power being used from the grid or injected into the grid (the limits are just shown for comparison). As can be seen both demand and injection limit are often highly exceeded. The goal of the SGSH HEMS is to minimize these exceedings per user in the pilot.
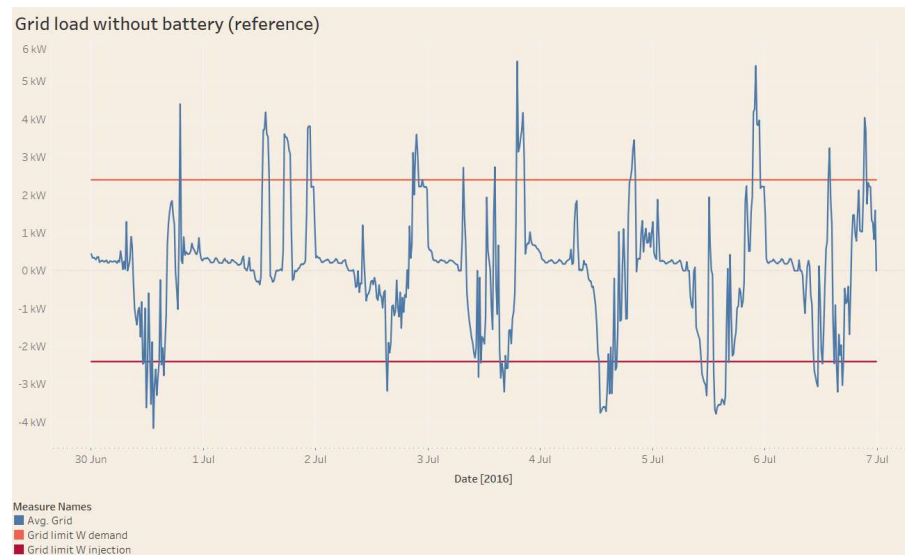
Figure 12 Calculated reference profile from the measured profile by removing battery influence

For all 10 users with a HEMS with battery, reference profiles are available. For the users with a HEMS without battery there is no reference profile available. For these users not all analysis can be performed.

6.3. New profile with SGSH-system

During the pilot 10 users with a HEMS system with a 6 kWh battery where closely monitored. A few examples are presented to show the results per user. Later a global effect on grid level will be analyzed. The example in Figure 13 shows the reduction of all demand and injection peaks in one week. This user with 8 kWp PV, a plug-in hybrid car and a heat pump was set to have limitation to grid of 10A for demand and 20A for injection. As can be seen the 6 kWh battery was able to prevent all the peaks above the demand limit or below the injection limit. To show the results on a longer period, Figure 14 and Figure 15 are made. In these picture is shown how many demand and injection exceedings occurred for this user

with the battery system installed and without. Please notice this is for a user with plug-in hybrid EV and small heat pump system. The demand limit exceedings, more than average 10A demand per 15 minutes, was reduced with 89% seen over a whole year. In February and March 2018 there were quite some demand limit exceedings when the car was charged while also the heat pump was on. For the injection limit, set on 20A for a PV system of 8 kWp, the reduction was 95%. In May 2018 reduction was only 80%, it was very sunny.
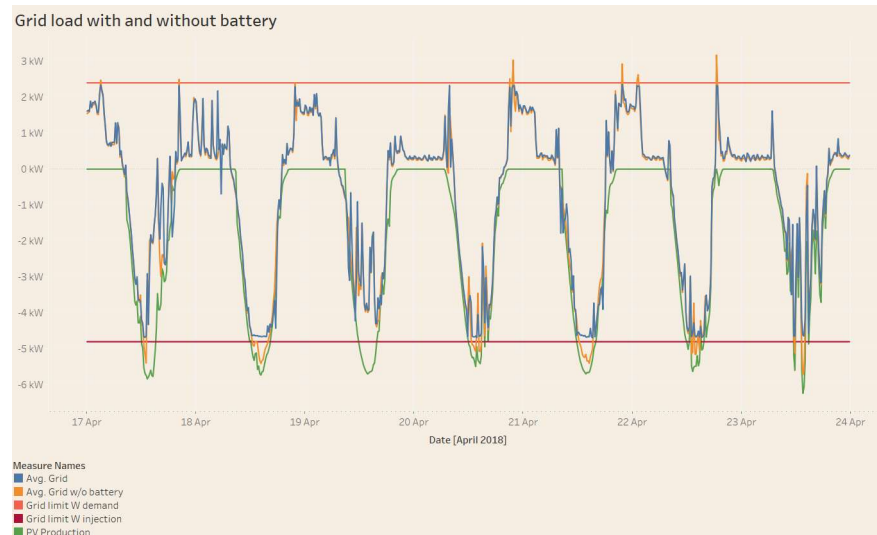

Figure 13 Power profile with and without battery
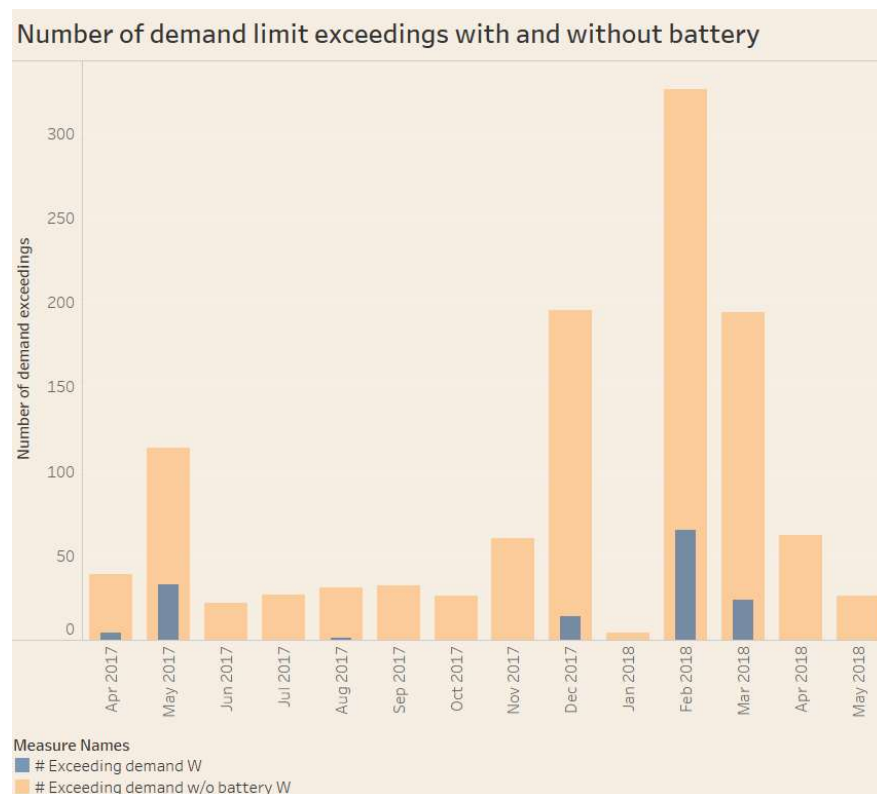
Figure 14 Comparison demand limit exceedings with and without battery for Alliander_A01

Amongst the participants several had no exceedings at all left when this HEMS with small battery was installed. For others the reduction was lower, for instance in case were the injection limit was set to 10A while the PV production was 6 kWp. This will be shown later in this chapter.
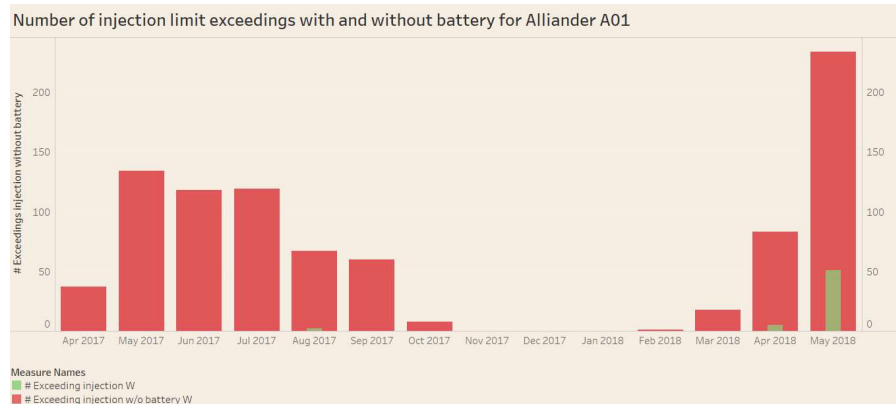
Figure 15 Comparison injection limit exceedings with and without battery Alliander_A01

An example where the battery has less impact is user Eandis_E02 with a heat pump system + airco system used for heating (Figure 16). The battery is too small to cover long periods of heat pump working (including long periods where the airco is used for extra heating), causing long periods of load above the demand limit (left part before 3 March 2018 in Figure 16).
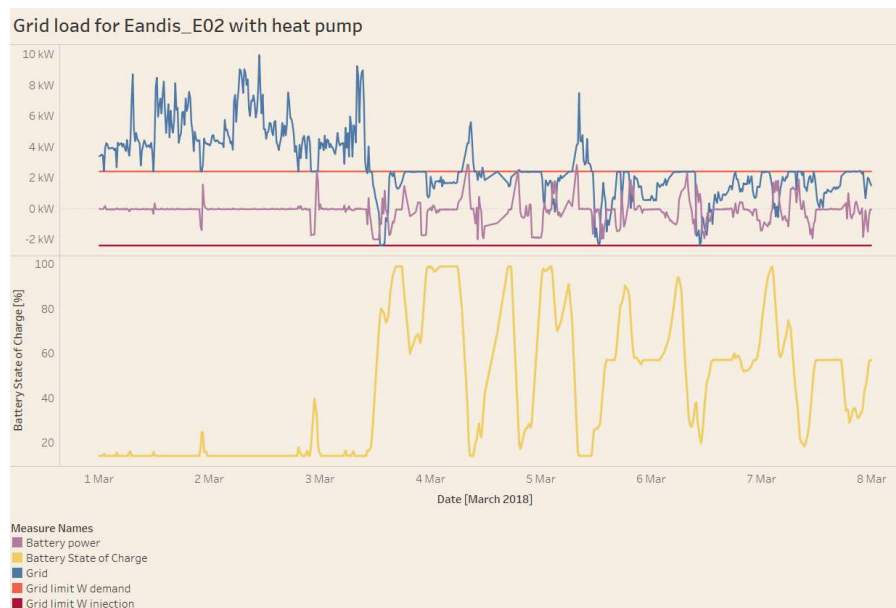
Figure 16 Heat pump causing demand exceedings @ Eandis_E02

As can be seen in Figure 16 the grid is loaded with up to 10 kW (blue line), while the battery stays at 15% SOC (yellow line). Although PV is installed at this location, in March the production is too low to cover (part of) the demand during the day let alone to recharge the battery. Figure 17 shows the total number of exceedings for this user per month with the HEMS installed. The reduction on the exceedings for this 'heavy' user are:

- 29% reduction for demand exceedings

- 74% reduction for injection exceedings

Figure 17 Eandis_E02 exceedings with HEMS installed

The last example shows the impact of the HEMS on user Ores_O01 with a plug-in hybrid car and 5 kWp PV. All exceedings, demand and injection are prevented in this example week. The charging of the car is controlled (purple line), and the grid is not abused outside the grid limits. The purple line shows the charging current is only limited when needed. When enough PV or battery power is available, the EV charge current does not need to be adapted while having no demand limit exceedings. This user is a good example where a battery helps to prevent high peaks on the grid, while the user still has his comfort for charging his EV as he or she wants and producing all PV he or she wants. To summarize this user prevented 87% of his demand exceedings and 89% of his injection exceedings, while being a 'tough' user with EV and large PV system.
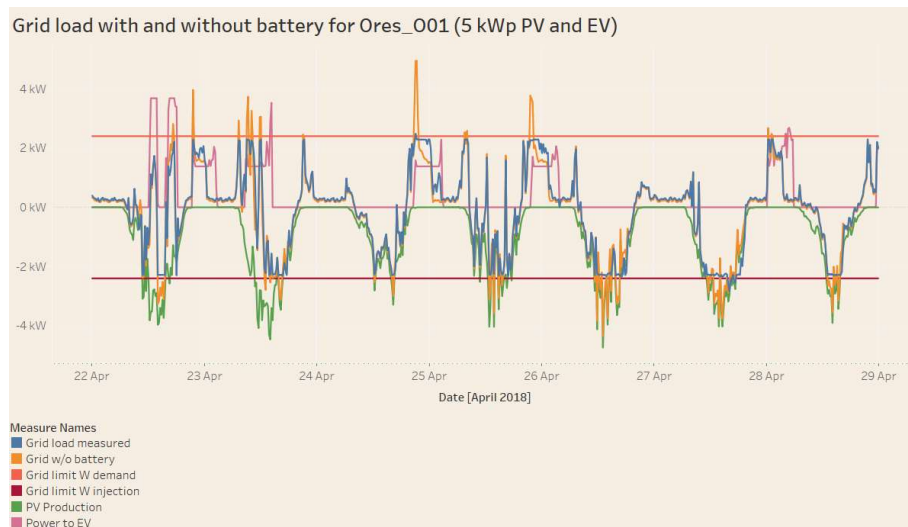
Figure 18 Ores_O01 load profile with and without HEMS

6.4. Analysis of differences between load profile with and without SGSH HEMS

In this paragraph some examples will be taken to show in detail how the HEMS with battery changes the load profile. Also the impact of the HEMS on EV charging is treated.

The first example shows the preparation of the battery state of charge (SOC) when a peak in solar production is predicted. Because the SOC is kept at about 50% to be able to charge and discharge at all times, the effective battery capacity for charging or discharging is only 50% of the total capacity of the battery. This means without prediction you would only have 3 kWh of energy storage available (instead of the 6 kWh, which is the capacity of the battery). Depending on the forecast, the HEMS decides if it's necessary to discharge the battery some hours before the actual peak of the solar production is expected. This is clearly visible in Figure 19. The yellow line, representing the SOC of the battery, drops to store the predicted excess PV production (the green part below the red injection line limit). Without this smart control of the SOC, a higher peak was caused on the grid (orange line). Now with SGSH HEMS with battery the grid loaded with the blue line, which always stays above the injection limit.
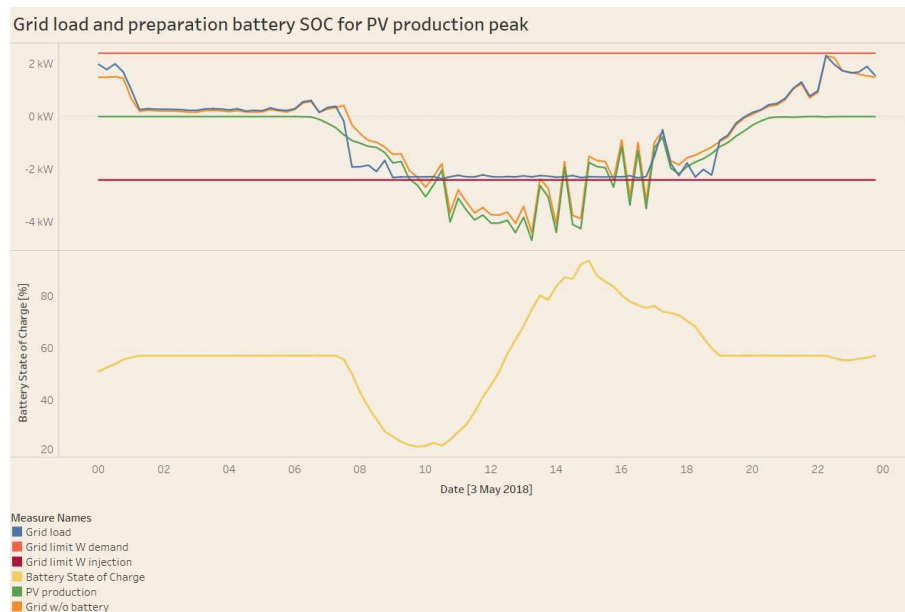
Figure 19 SOC reduction to be able to deal with the PV production peak

Similar control is applied to prevent demand excesses. For example to prevent high demand peaks during EV charging. To tackle the problem with EV charging peaks, two measures are used:

- Prepare the battery to cope with the high energy demand in the short EV charge period

- Control the charging the current of EV based on the inputs of the user and prediction of base load and PV production.

An example of this behaviour is shown in Figure 20. In this case the predicted EV charge did take place, the battery was prepared (yellow line) and a peak on the grid was prevented (orange line). The grid load (blue line) stayed below the demand limit of 10A. A reduction on the grid demand peak of 50% is achieved This smart control has as main benefit the battery can be smaller since it's optimally used by adapting the SOC based on the predicted need for charge or discharge.
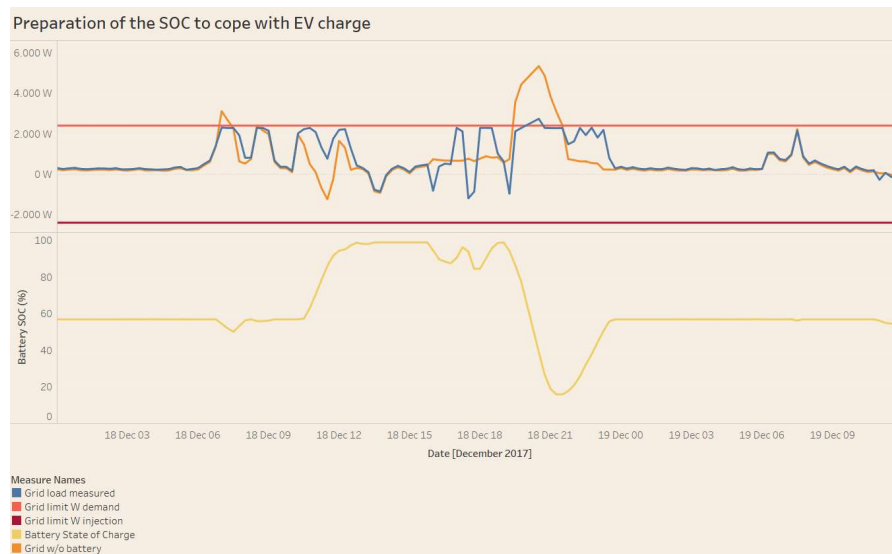
Figure 20 SOC increase to be able to deal with the EV charge

6.5. Exceedings analyzed in detail

An overview of the performance of all systems with a battery is shown in Figure 21 and Figure 22. In Figure 21 the reduction of the demand exceedings is shown. The impact of the HEMS is clearly visible. In the best case the reduction of the exceedings is 100%, for user Eandis_E02 this is only 29% due to his heat pump system + airco. This is not an average user (with startup problems with his heat pump system) and is only an example where the current setup would be not sufficient to help the grid. The measured average reduction was 69% for this new build large house with the tested setup.

Number of demand limit exceedings per user with and without battery
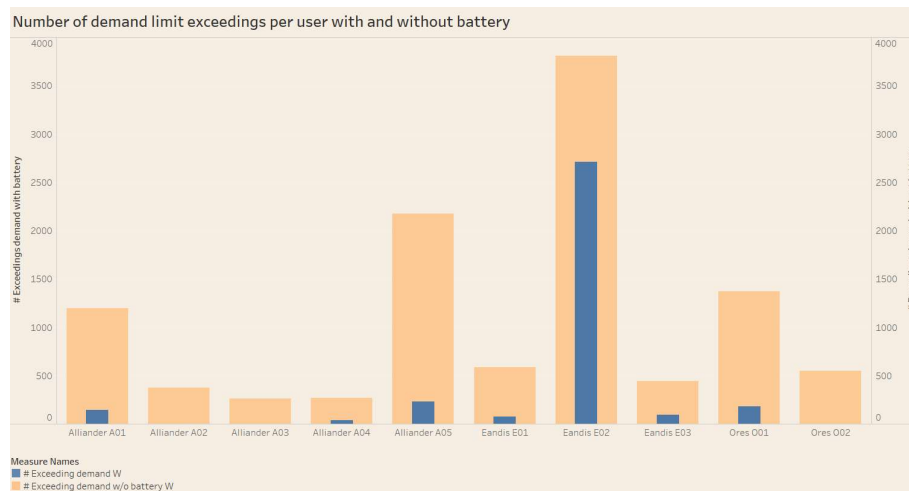
Figure 21 Comparison demand limit exceedings for the 10 users with battery system

For the injection exceedings shown in Figure 22 the following conclusions can be drawn:

- Some users have no injection exceedings left after installation of the HEMS with small battery

- Some users with large PV systems need a bigger battery to prevent all injections exceedings.

- On average 76% of the injection exceedings is prevented

Number of injection limit exceedings per user
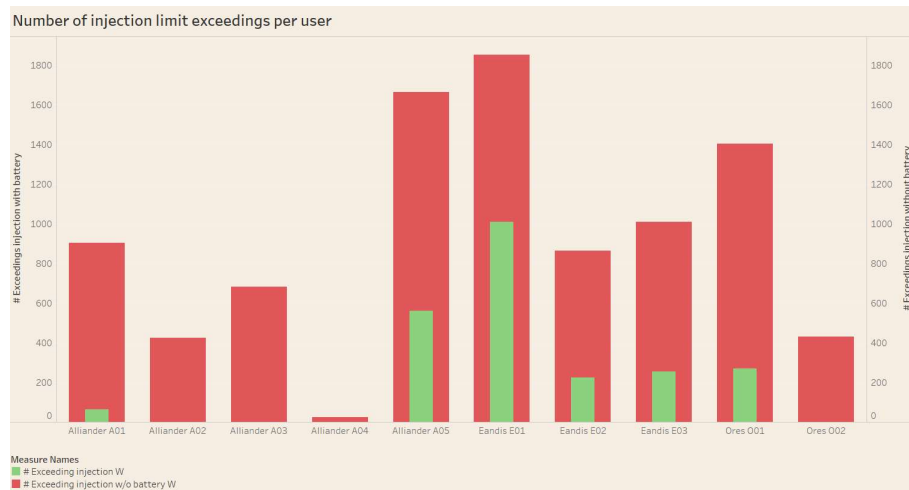
Figure 22 Comparison injection limit exceedings for the 10 users with battery system

The number of excesses is an interesting parameter for one user. When analysing the impact on the grid, it's more important to know details about the exceedings, such as:

- How much power and energy has an exceeding?

- At which time do they happen?

- Do exceedings of the different users happen at the same time?

The grid is not designed for one user and changing the profile of one user will not have a measurable effect on the total grid load. When many users change their profile, then the impact on the grid is important. This is analysed in this paragraph.

First is looked at the exceedings of a single 'heavy' user. In this case user Alliander_A05 because of his full electric EV and large PV system. We compare the profile with HEMS and battery and without any HEMS or storage.
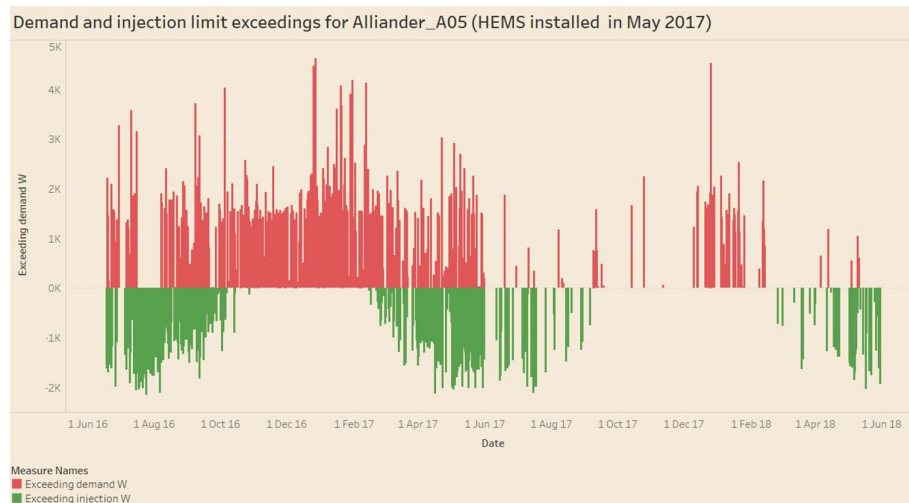
Figure 23 Exceedings for Alliander_A05 voor en na installatie van het HEMS

Figure 23 shows the number of exceedings after the installation of the HEMS in May 2017 were greatly reduced. This was explained earlier. When we zoom in, we can perform an analysis for each exceeding that is left after installation:

- Why did the exceeding happen?

- Was the time of peak shifted?

- What was the power an energy of the exceeding?

If we look for this user to the maximum hourly demand exceeding that happened with and without HEMS we get Figure 24. This shows the maximum exceeding is lowered and shifted in time. This is caused mainly by the battery system, which can prevent a demand peak only till the battery is empty. As a result the maximum peak is reduced with 40%, and occurred 3h earlier. Which is a great achievement, since the evening peak is difficult to prevent (has large impact on comfort of the user). Also this user has a full electric EV which charges every day between 8 pm till 2 am the next day. This charge cycle is not seen back in the new maximum peak profile, which is a big advantage of the HEMS protecting the grid from high loads during peak evening hours.
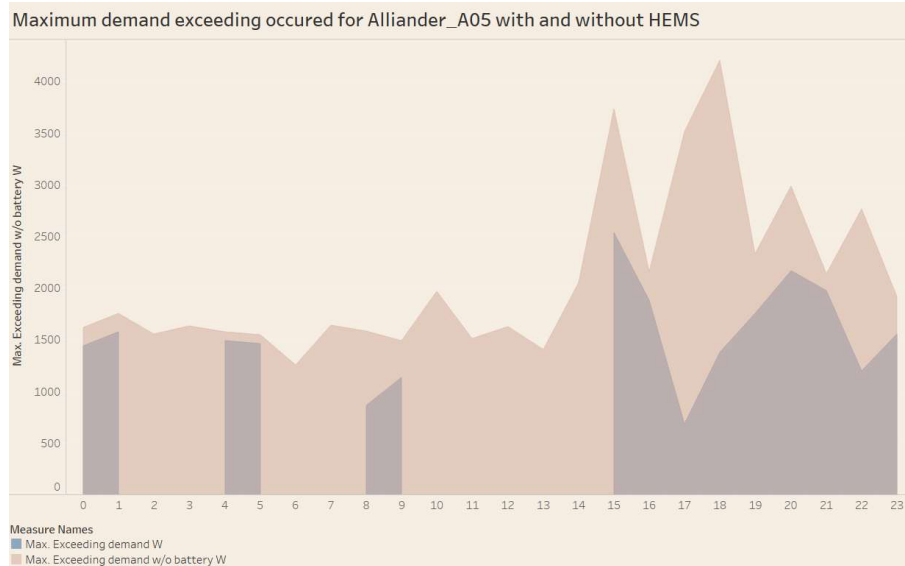
Figure 24 Maximum exceeding peaks above the demand limit of Alliander_A05

The same analysis is performed for the maximum exceeding of the injection with and without HEMS and battery installed. This is shown in Figure 25. It shows the maximum injection exceeding is lowered and shifted in time. This is caused mainly by the battery system, which can prevent an injection peak only till the battery is full. As a result the maximum demand exceeding peak is reduced with 15%, occurring at the same time. This minor achievement is due to the small battery, 10A injection limit and 5 kWp PV system. When the battery is full, all PV is injected into the grid causing the same peak as without HEMS.
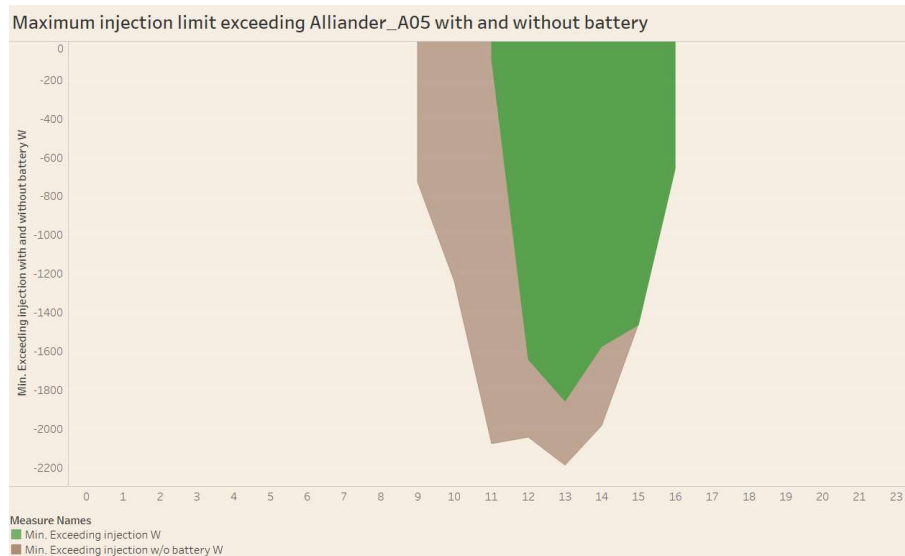
Figure 25 Maximum exceeding peaks below the injection limit of Alliander_A05

If we look at the energy in a largest exceeding peak, a calculation can be made how big the battery should be to prevent all peaks for a user. As an example is again looked at Allianders_A05, see Figure 26. Later on this exercise is done for all users with a battery.
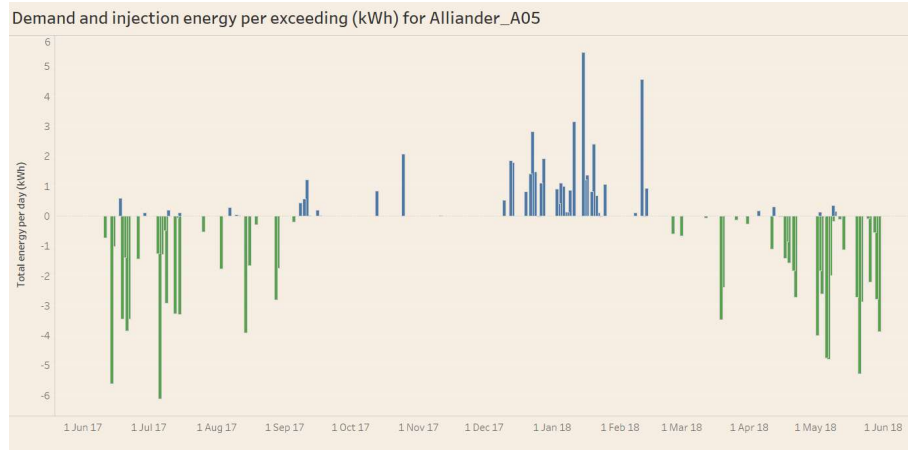
Figure 26 Energy per exceeding Alliander_A05

Figure 26 shows the largest demand exceeding had an energy of 5 kWh (total for a whole day). The largest injection exceeding is 6 kWh. So if the battery would have had a size of 12 kWh instead of 6 kWh all demand and injection excesses could have been prevented. This calculation is performed for all users and shown in Table 2.

User	PV installed	Special load	Max demand excess	Max injection excess	Needed battery size
Alliander_A01	8 kWp	HP + H-EV	6 kWh	1 kWh	12 kWh
Alliander_A02	2,4 kWp		0	0	6 kWh
Alliander_A03	3,85 kWp		0	0	6 kWh
Alliander_A04	3,24 kWp		2 kWh	0 kWh	8 kWh
Alliander_A05	5,5 kWp	Full EV	5 kWh	6 kWh	12 kWh
Eandis_E01	6 kWp		4 kWh	12 kWh	18 kWh
Eandis_E02	5 kWp	HP+airco	68 kWh	0 kWh	74 kWh
Eandis_E03	3,3 kWp		0 kWh	4 kWh	10 kWh
Eandis_E04	6 kWp	H-EV	2 kWh	5 kWh	5 kWh
Eandis_E05	4 kWp	H-EV+Tesla	21 kWh	2 kWh	21 kWh
Eandis_E07	5,5 kWp		2 kWh	9 kWh	9 kWh
Eandis_E08	5 kWp		4 kWh	2 kWh	4 kWh
Eandis_E09	3 kWp		2 kWh	3 kWh	3 kWh
Ores_O01	5,72 kWp	H-EV	5 kWh	5 kWh	11 kWh
Ores_O02	4,3 kWp		0 kWh	0 kWh	6 kWh

Table 2 Max energy content of an excess and need battery size to prevent all exceedings

From Table 2 can be concluded that for 6 users the 6 kWh is enough to prevent all exceedings in both directions. For 9 of the 15 users a 6 kWh battery is enough to prevent all injection exceedings. For 6 users a 12 kWh battery would have been enough to prevent all exceedings in both directions, from which 3 have an EV with smart charging. One user with a 6 kWp PV system needs 18 kWh of storage and the user with heat pump+airco even a 74 kWh battery is needed to prevent all exceedings. Eandis_E05 needs 21 kWh when the Tesla arrives for a charge (which is an exception but for completion mentioned here).

The final analysis on the exceedings is to look as if the users are connected to one phase in one street next to each other. To start with, how much exceedings occur at the same time with and without battery. Figure 27 shows the number of houses that have excess demand above their demand limit in a worst case week. The maximum number of simultaneous exceeding drops from 6 to 3 when installing the SGSH HEMS with battery.
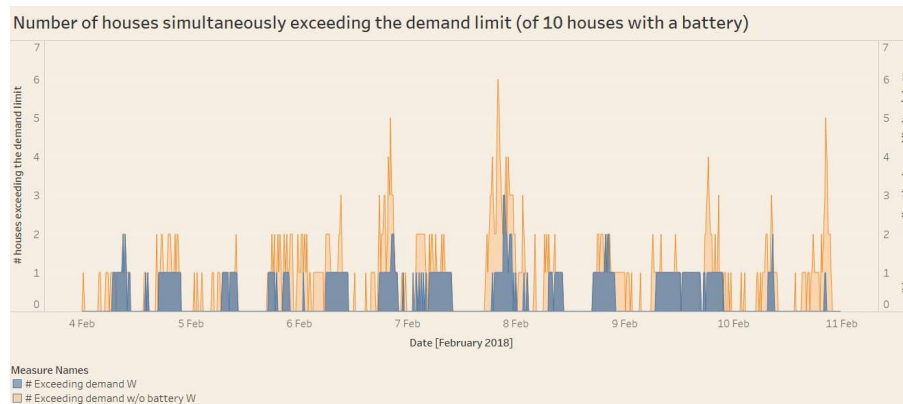
Figure 27 # of house simultaneous exceeding their demand limit

Also the total number of exceedings is lower as is explained earlier. Also there is a shift in time which corresponds with the fact batteries get empty before an exceeding can happen. A delay of about 1,5h - 2h on average is measured in the peak on the grid when installing the SGSH HEMS with battery. On the injection side also a worst case week is looked at in Figure 28. There the same is valid as for the demand side. The maximum number of users exceeding the injection limit at the same time drops from 9 to 6. Also the delay is comparable, about 1,5-2h before the maximum injection peak will happen compared with systems without the SGSH HEMS.
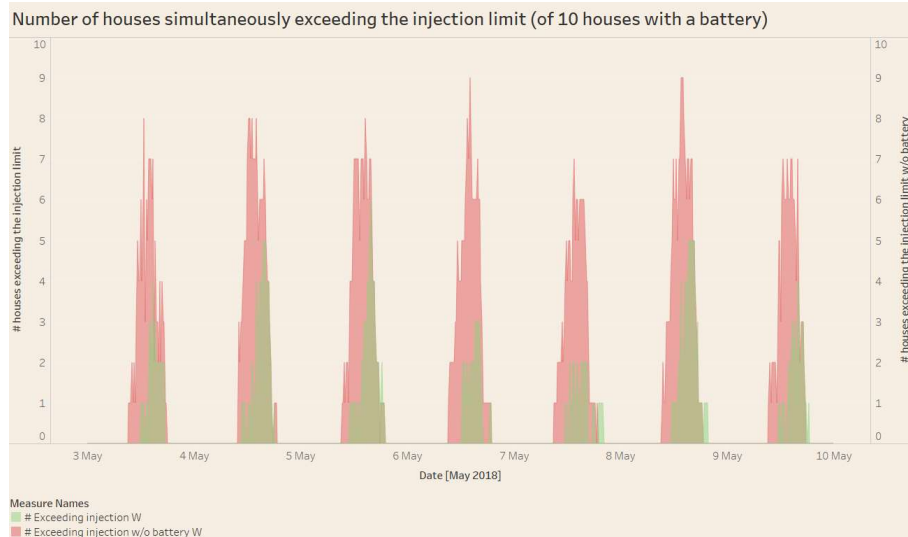
Figure 28 # of house simultaneous exceeding their injection limit

As the number of exceedings is not the most critical for the grid, the size of the peak is looked at in detail. Figure 29 shows the total simultaneous exceeding for the 10 users with a battery. From May 2017 the HEMS systems were installed. The data from June 2016 till April 2017 is the reference data without HEMS system. The maximum total exceeding of 10 houses occurred with HEMS was 6.9 kW (so 690 Watt per house average). Without HEMS this was 11.2 kW, so a reduction of 38% is achieved. Leaving Eandis_E02 with the heat pump system + airco out of the data, the maximum simultaneous exceeding drops to 5.0 kW for 9 houses (without HEMS this is still 11.2 kW). So a reduction of 55%. This includes 3 households with an EV and one house with a small heat pump. For the maximum injection peak above the injection limit, this drops from 9.1 to 6.5 kW, a reduction of 32%.
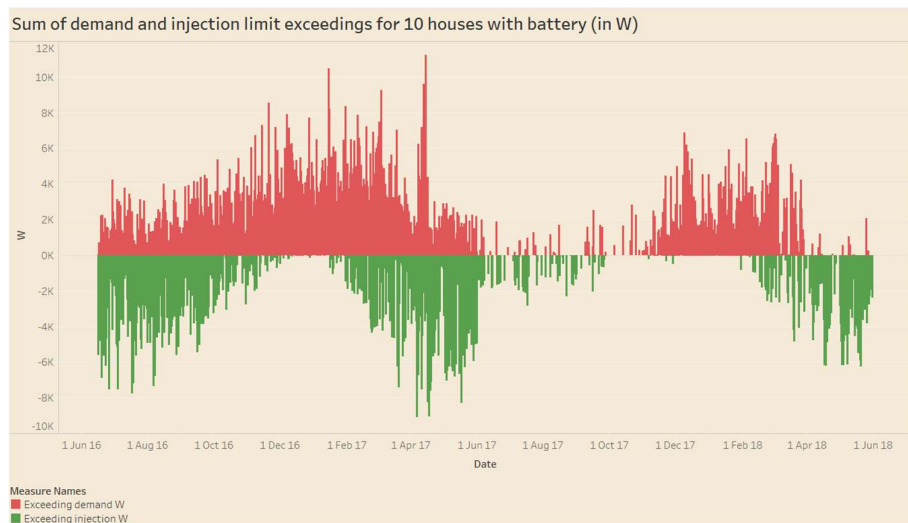
Figure 29 Sum of exceedings of 10 houses with (from June 2017) and without a battery (before June 2017)

If we look at the total pilot, 15 households of which only 10 have a battery, the following result is obtained. The maximum sum of exceedings dropped from 13 kW to 11 kW. The reason for this small drop is the connection of a Tesla for charging at Eandis_E05.

Eandis_E05 is a user without battery, and the Tesla is charged straight from the wall plug. This causes a peak of 8 kW, which is 72% of the peak of 11 kW. Without this Tesla the maximum peak dropped to 9 kW for 15 houses. For the injection the maximum peak injection is reduced from 13.5 kW to 10 kW, or 26%.
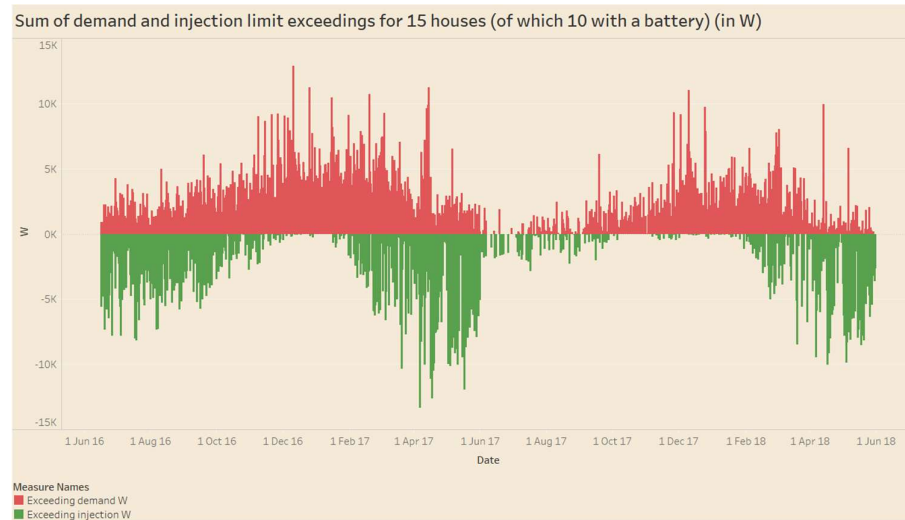
Figure 30 Sum of exceedings of 15 houses (of which 10 with a battery) (from June 2017) and without a battery (before June 2017)

6.6. Advantage SGSH for the grid

This paragraph zooms into the advantages of the SGSH HEMS on grid level.

The public grid serving households has several demand peak loading moments during the day. In the morning between 7-9 am, around noon and in the evening between 4h30 – 8 pm. For solar the main injection peak is between noon and 2 pm. Shifting part of the peak to other moments is of great value for grid operators. It reduces problems with Power Quality, postpones grid investments and also increases lifetime of grid components.

The next figures show the global peak grid load (demand and injection, based on 10 users with a battery) is indeed shifted by adding the SGSH HEMS.

Sum of injection limit exceedings, in time for 10 houses (in W)
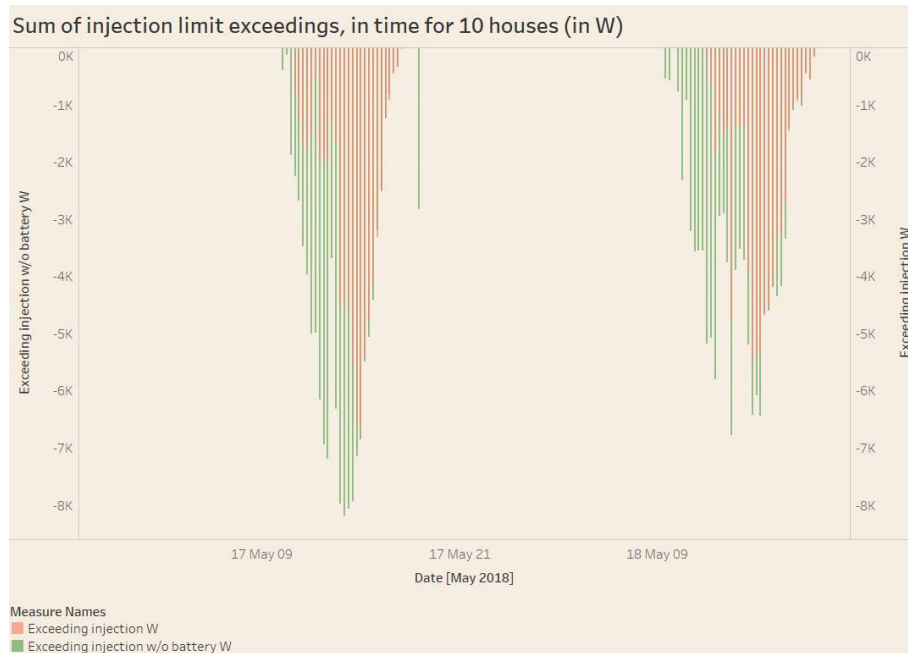
Figure 31 Comparison sum of injection exceedings with and without battery

As can be seen in the example on a very sunny day in Figure 31 the battery reduces the injection peak (-20%) but also shifts it to later moments (1h-2h later). For the demand the same analysis is performed in Figure 32. Also the demand exceeding peak is lowered (-25%) and shifted/more spread in time.

Sum of demand limit exceedings, in time for 10 houses (in W)
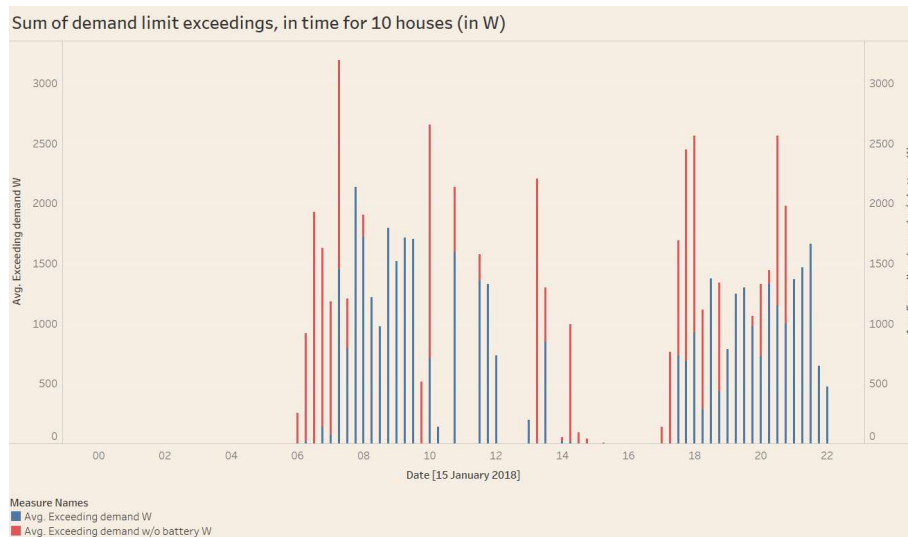
Figure 32 Comparison sum of demand exceedings with and without battery

To make the effect on the grid more visible, the analysis is broadened to the total grid load instead of the exceedings above the used limits on user level. In Figure 33 a worst case week for peak injection of PV power is shown. For clarity the summed grid limit for the 10 users is visualized too.
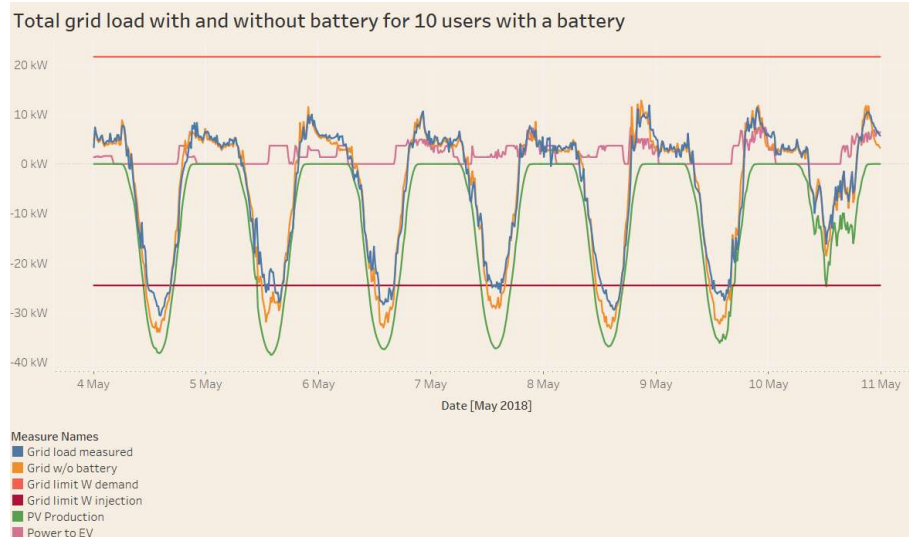
Figure 33 Total grid load of 10 users with and without a battery (worst case summer week)

The peak injection on the grid for these 10 users is reduced with **10-20%**. An important note must be made. The reduction could have been more if lower limits were imposed for the users with small PV systems and battery systems were optimized for the size of the PV system. If we only take into account the users which have a balanced energy system (Amp limit, type of user and size of the battery) the reduction is **about 30% on grid level**.

For the demand side the HEMS system has two main controls for reducing peak loads. The battery and controllable loads like the EV and white goods. Figure 34 shows the impact of 10 batteries and smart charging for 3 EV's on household level. The main peaks are reduced with 35%. **Main conclusion is that on the grid level no problems with peak loading are expected when small 6 kWh batteries are implemented in each household.** This for the case where:

- All users have a 6 kWh battery

- 3 users have an EV charging on 16A

- 2 users with a heat pump and one with also an airco

Total grid load with and without battery for 10 users with a battery

Measure Names
- Grid load measured
- Grid w/o battery
- Grid limit W demand
- Grid limit W injection
- PV Production
- Power to EV
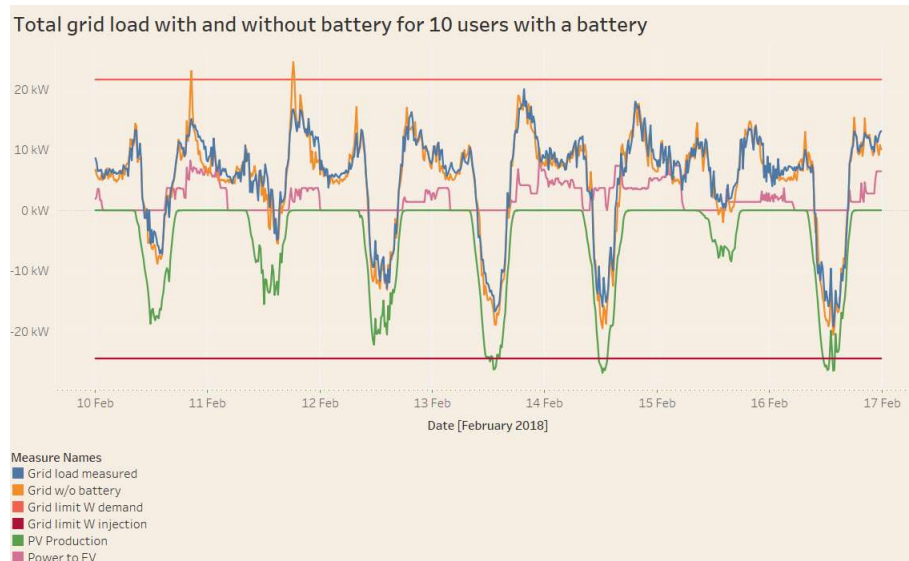
Figure 34 Total grid load of 10 users with and without a battery (worst case winter week)

If the total 15 users are considered, no batteries are needed to be within the limits for this mix of users. This has several reasons:

- Grid limit of the Belgium users is 3 kVA, which is relatively high

- Smart charging is preventing high charge current instead of the battery

- Only 1 small heat pump and one big heat pump is among the mix of users

If we look at the Dutch users only, with grid limits varying from 6A to 10A for demand, the batteries are also barely needed to be within the summed grid demand limit, this mainly due to smart charging of the EV.

If we look at the injection side the batteries are needed, both for Belgium as Dutch users to be within limits and also to prevent exceeding the summed grid injection limit.

6.7. Size battery versus limits

It was already mentioned several times, the users all got the 6 kWh battery, independent of their power profile, yearly energy consumption, type loads present and size of the PV system. Also imposed grid limits were fixed and the limit was not searched for. This leads to sub optimal use of the HEMS and battery, since it's not pushed to its limits. This paragraph analyses what the best combination is of type of user, limit and size of the battery. This analysis is based on data and experience gathered from the pilot and is not tested or simulated.

The optimal combination assumed is a balanced energy system to reach zero exceedings in normal operating conditions. Exceeding will lead to penalties, although it's not defined how this will be organized in the future. This is already true for B2B users, were the peak measured is used for billing. Drawing a higher peak directly influences the energy bill. Off course the design of the system is heavily influenced by the price of the HEMS and battery.

Therefore the following numbers are guidelines only which are based on technical aspects. The type of user is based on their measured profile and yearly consumption, where:

- Large day user: consuming mostly during the day and evening and above 3500 kWh/year

- Small day user: consuming mostly during the day and evening and below 3500 kWh/year

- Large night user: consuming mostly during the evening and above 3500 kWh/year

- Small night user: consuming mostly during the evening and below 3500 kWh/year

User	Type	PV system	Special load	Amp limit	Bat needed
Alliander_A01	Large day	8 kWp	HP + H-EV	10A/-20A	12 kWh
Alliander_A02	Small day	2,4 kWp		6A/-6A	6 kWh
Alliander_A03	Small day	3,85 kWp		6A/-6A	6 kWh
Alliander_A04	Small night	3,24 kWp		10A/-10A	8 kWh
Alliander_A05	Large day	5,5 kWp	Full EV	10A/-10A	12 kWh
Eandis_E01	Small night	6 kWp		13A/-13A	18 kWh
Eandis_E02	Large night	5 kWp	HP+airco	13A/-13A	74 kWh
Eandis_E03	Small night	3,3 kWp		13A/-13A	10 kWh
Eandis_E04	Large night	6 kWp	H-EV	13A/-13A	5 kWh
Eandis_E05	Large night	4 kWp	H-EV+Tesla	13A/-13A	21 kWh
Eandis_E07	Small night	5,5 kWp		13A/-13A	9 kWh
Eandis_E08	Large night	5 kWp		13A/-13A	4 kWh
Eandis_E09	Large night	3 kWp		13A/-13A	3 kWh
Ores_O01	Large night	5,72 kWp	H-EV	10A/-10A	11 kWh
Ores_O02	Small night	4,3 kWp		10A/-10A	6 kWh

Table 3 Overview of the type of user and battery size needed for zero exceedings

Important note for the users with EV is the need for smart charging, without smart charging battery needs to much bigger (surely for charging a full EV with 24 kWh battery inside). Most important conclusions from this analysis are:

- The size of the battery is mainly determined to prevent injection exceedings, demand exceedings can have the same maximum power but energy content is lower

- Smart charging is necessary to prevent big batteries which then are only used for peak shaving during EV charge sessions

- A battery size of 6-12 kWh is enough to prevent all exceedings with users with PV systems up to 4-5 kWp (for the representative Ampere limits tested)

- Heat pumps are not studied in detail in this pilot, but the heat pump + airco present at one user caused many demand exceedings which could only prevented with a battery of a size 10 times bigger than piloted

6.8. Separation of smart charging versus battery

The influence of smart charging in the HEMS concept is analysed to prove the necessity of such control. In SGSH smart charging is applied in the following way:

- When plugged in, the minimal charge current is 6A

- Comfort of the user comes first, depending on the needed charge (kWh) and when this charge needs to be finished charge current is adapted depending on available power

- When charge and end time give not enough flexibility, exceedings are allowed

This causes the following EV charge behavior (almost no battery influence), see Figure 35.
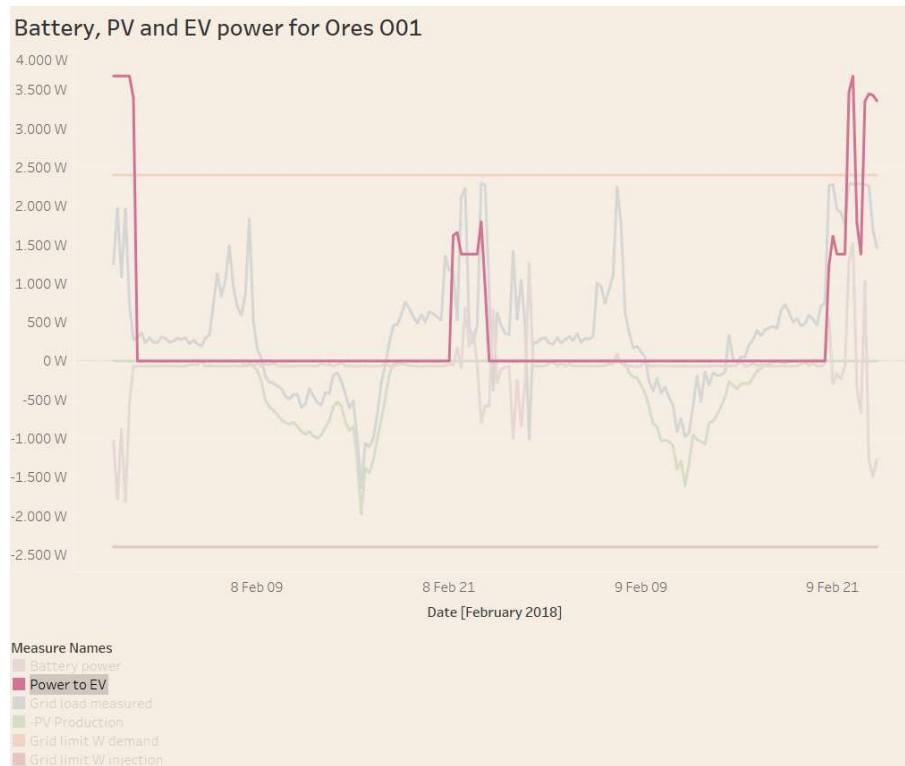
Figure 35 Example smart charging plug-hybrid EV

As can be noticed in Figure 35 the charge power (purple line) is adapted to have the grid power stay within the demand limit of 10A. A simulation is run for the five users with EV to see the effect on the grid if no smart charging is present. Comparison is done for the following scenarios:

1. Three users with EV with battery and smart charging

2. Two user with EV with smart charging without battery

3. Five users with EV with smart charging but no batteries

4. Five users with EV, no smart charging and no batteries

All users have the same EV charger (max 16A) and same SGSH HEMS control.

In the first scenario the maximum peak demand occurred was 9 kW, when all three EV users were charging at the same time. Without the battery at these users this would have been 12 kW. And without smart charging this would have been 14,1 kW. The two other users from scenario 2 used 7 kW as maximum together, when leaving smart charging out this would have been 9,4 kW.

Scenario 3 results in a maximum demand of 17 kW, including charging 4 EV at the same time. If no control of the power is used at all the power drawn would have been 24 kW, charging 4 EV with 16A in winter time during the evening.

Based on these basic calculations based on measurements of 5 different users with EV:

- With the SGSH HEMS with 6 kWh battery 3 kW is the maximum load to be expected per user in winter time (based on 16A controllable charging stations)

- When no batteries are present but EV are charged in a smart way, the maximum expected load per user is 4 kW

- If no batteries and no smart charging is used 5 to 6 kW per user with EV can be expected

The SGSH HEMS with small battery of 6 kWh and it's smart charging algorithm can reduce the impact of EV charging on the grid with about 50%. This is a major achievement since it's expected EV charging is threatening the existing grid infrastructure in the near future. **If only smart charging is applied, the expected reduction of the impact on the grid is about 30-40%.**

For the 2 users with EV and no Battery, there was a big improvement towards the reduction of grid demand exceedings because the EV was not charged together with the "home use" such as cooking/washing in the evening during the peak period.

6.9. Philips HUE light control

Every user with the HEMS in this pilot has a Philips HUE light. When it's green you should try to use more energy effectively. If it's red you should try to use less energy. An example how this behaviour of the light looks like is given in Figure 36. As you can see the light is not only green or red when there was an actual exceeding. It also is coloured when an exceeding is predicted to going to happen and can be prevented with some action from the user or battery. Off course when nobody is at home the user is unable to do something. To give an idea, for Alliander_A05 the light was 2388 times red and 2648 times green in one year time. Each time takes 5 minutes, so 198h red and 220h green. In total Alliander_A05 had 229 demand exceedings and 560 injection exceedings. And for:

- 10% of the times the light was RED a demand exceeding occurred

- 21% of the times the light was GREEN an injection exceeding occurred

In all other cases when the light was red or green, the light was only a warning. It's not possible to analyse how many exceedings are prevented by actions of the user based on the light. The only information available is that without the battery the number of demand exceedings would have been about 2174 and in the number of injection exceedings 1161.
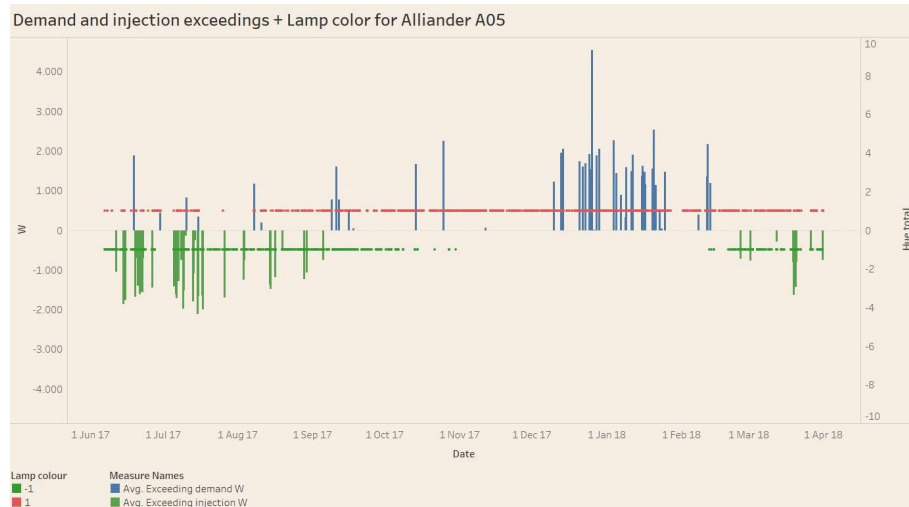
Figure 36 Philips HUE light behaviour @ Alliander_A05

In Figure 37 a detailed view for one day with the HUE light giving warnings for predicted exceedings and for exceedings happening=measured at the moment the light was on. At the evening of 18-6-2017, the red lights predicted the EV charge, which eventually indeed lead to two demand exceedings. The day after, too much sun was predicted for the size of the battery and indeed later that day injection exceedings occurred.
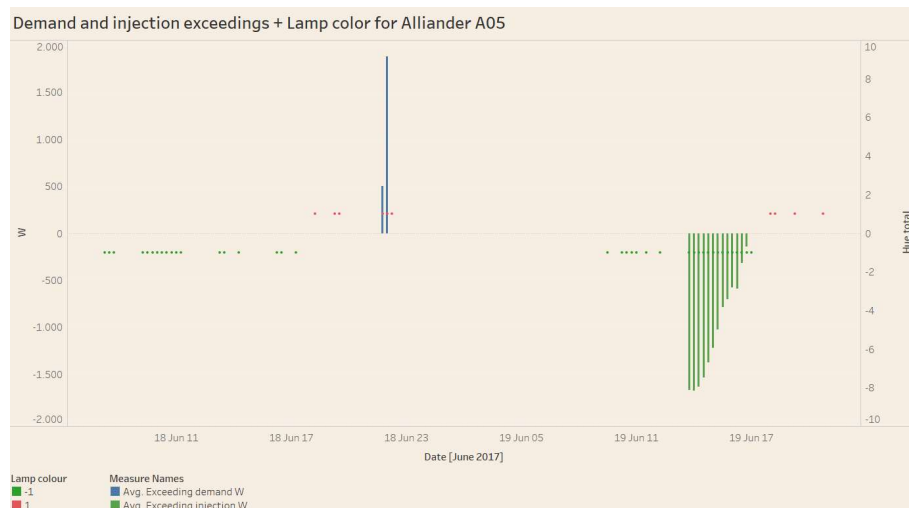
Figure 37 Detailed view of Philips HUE light control on one day for Alliander_A05

An overview of the number of all lights is shown in Table 4 and Table 5. As can be seen in Table 4 the users with battery can prevent a high percentage of the predicted exceedings. While the users without a battery in Table 5 cannot do much, if the light is green all times they exceeded the limit.

User	# GREEN = expected + measured exceeding	# RED = expected + measured exceeding	No injection exceeding measured while lamp was GREEN	No demand exceeding measured while lamp was RED
Alliander_A01	1056	2137	94%	93%
Alliander_A02	607	963	100%	100%
Alliander_A03	602	1277	100%	100%
Alliander_A04	99	1034	100%	96%
Alliander_A05	2648	2388	79%	90%
Ores_O01	2191	2033	88%	91%
Ores_O02	882	1367	100%	100%
Eandis_E01	3334	2192	70%	97%
Eandis_E02	1483	6577	85%	59%
Eandis_E03	1322	1322	81%	93%

Table 4 Measured HUE light colours and percentage of exceedings per colour for user with a battery

User	# GREEN = expected + measured exceeding	# RED = expected + measured exceeding	No injection exceeding measured while lamp was GREEN	No demand exceeding measured while lamp was RED
Eandis_E04	1156	562	0%	39%
Eandis_E05	640	1394	0%	12%
Eandis_E07	1709	461	0%	22%
Eandis_E08	711	1246	0%	0%
Eandis_E09	1551	657	0%	7%

Table 5 Measured HUE light colours and percentage of exceedings per colour for the users without a battery

6.10. SGSH users in one neighborhood

The actual pilot took place in Belgium and the Netherlands, where the users were distributed over different villages and streets. The impact of SGSH HEMS is better analyzed as if the

users are all connected to the same distribution cabinet or better to one phase of one low voltage distribution cable. A few scenarios are analyzed for Belgium and the Netherlands.

<u>Scenarios The Netherlands</u>

1. 25 users of Alliander with all PV connected to one phase without HEMS or battery (10 of them have an EV charging with max 16A, 5 of them have a small heat pump)

2. The same 25 users of Alliander with the SGSH HEMS and battery

3. 15 of these 25 with SGSH HEMS and battery and 10 of them without HEMS or battery

For existing grids the available simultaneous power is 1,5-2 kVA in the Netherlands. The maximum peak allowed for 25 users is thus 37,5-50 kVA (for injection and consumption).

Scenario 1 + 2

Figure 38 25 users of Alliander with HEMS and battery or without

*   Scenario 1: The peak demand of these 25 users of Alliander is 51 kW during the evening (average 2 kW/user). The peak injection is 91 kW between **1 and 2 pm** (3,6 kW average per user).

*   Scenario 2: The remaining peak demand of these 25 users of Alliander is 29 kW during the evening (average 1,2 kW/user). The peak injection is 69 kW between **2:30 and 3** pm (2,8 kW average per user).

- Scenario 3: The remaining peak demand of these 25 users of Alliander is 37 kW during the evening (average 1,5 kW/user). The peak injection is 75 kW between **2 and 3 pm** (3 kW average per user).

Conclusion for the Netherlands for the user mix from the pilot:

- The evening peak can be prevented with 3/5 of the users having a small battery.

- The PV injection peak cannot be prevented totally with the small battery, a peak reduction of 25% is achieved in the worst case week.

- A shift of 1-1.5h of the injection peak is achieved with the battery systems installed, which helps reducing the global injection peak

- Doubling the battery size from 6 kWh to 12 kWh would prevent all injection peaks in the Netherlands scenario and would solve all LV problems in the future

- 40% of users in the scenario is responsible for 70% of the peak, the bigger battery is only needed at these 40% of the users to greatly reduce the injection peak

- Installing the 12 kWh battery at 10 of the 25 'big' users and no batteries at the small users is enough to reduce the injection peak on average to 2 kW/user.

Scenarios Belgium

1. 15 users of Eandis + Ores with all PV connected to one phase without HEMS or battery (3 of them have an EV charging with max 16A, 3 of them have a big heat pump)

2. The same 15 users of Eandis + Ores with the SGSH HEMS and battery

3. 10 of these 15 with SGSH HEMS and battery and 5 of them without HEMS or battery

For existing grids the available simultaneous power is 3 kVA in Belgium. The maximum peak allowed for 15 users is thus 45 kVA (for injection and consumption).
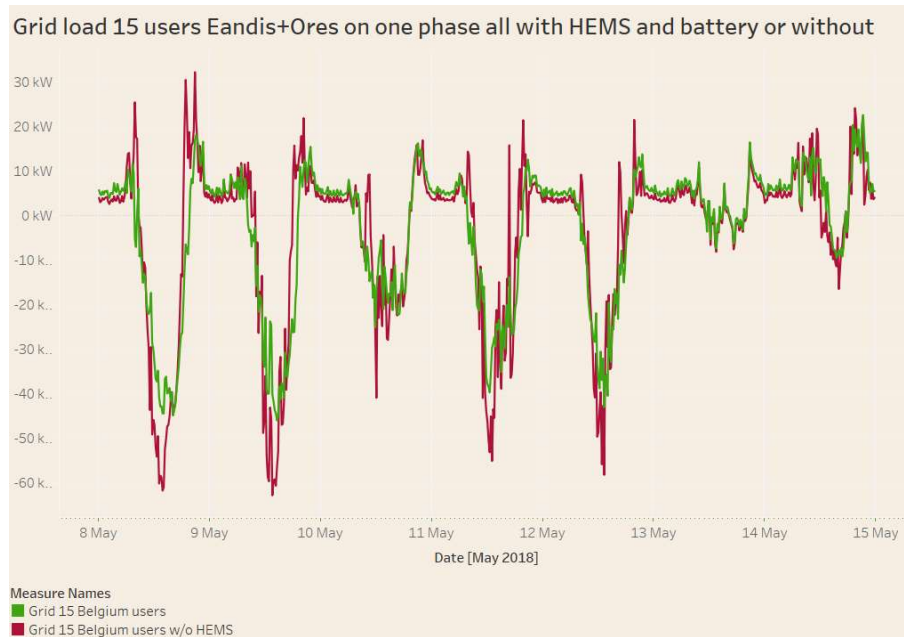
Scenario 1 + 2

Figure 39 15 users of Eandis+Ores with HEMS and battery or without

- Scenario 1: The peak demand of these 15 users of Eandis and Ores is 32 kW during the evening (average 2,1 kW/user). The peak injection is 63 kW between **1 and 2 pm** (4,2 kW average per user).

- Scenario 2: The remaining peak demand of these 15 users of Eandis and Ores is 23 kW during the evening (average 1,5 kW/user). The peak injection is 45 kW between **2 and 3** pm (3,0 kW average per user).

- Scenario 3: The remaining peak demand of these 15 users of Eandis and Ores is 32 kW during the evening (average 1,5 kW/user). The peak injection is 50 kW between **1:30 and 3 pm** (3,3 kW average per user).

Conclusion for Belgium for the user mix from the pilot:

- The evening peak is no problem for the analysed mix of users in Belgium, since 3 kVA is available per user. So no HEMS or batteries needed.

- The PV injection peak can be prevented totally with a small battery per user, a peak reduction of 30% is achieved in the worst case week.

- A shift of 1-1.5h of the injection peak is achieved with the battery systems installed, which helps reducing the global injection peak

- 40% of users in the scenario is responsible for 60% of the peak, putting a bigger battery of 12-18 kWh at these users without batteries at the others would reduce the injection peak to 3 kW average per user

6.11. Extreme case: all users on one cable with a EV

An extreme case were all users have an EV is presented below based on measured data in this pilot, this is only a first attempt to get an idea about future grid profiles with EV an batteries. In this case 5 users have a full EV of 24 kWh and 20 users have a plug-in hybrid EV of 8 kWh. Two scenarios are presented, every user with SGSH HEMS and 6 kWh battery and everyone without SGSH HEMS nor battery.
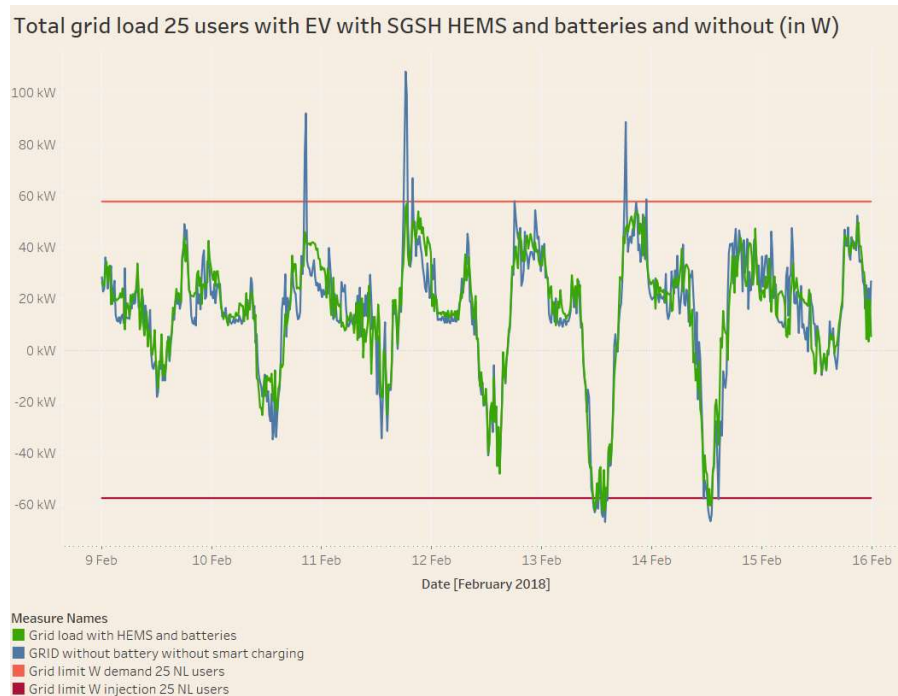
Figure 40 Grid load 25 users with EV with SGSH and small battery or without

As can be concluded from Figure 40 the reduction in the peak by installing at each house a small battery of 6 kWh and SGSH with smart charging is significant.

- The reduction in peak is from 108 kW (4,3 kW average per user) to 57 kW (2,3 kW average per user). A reduction of 48%.

- The peak is divided in time, from a 30 minute very high peak between 5 and 8 pm to a longer lower peak of about 2-3 hours between 5 and 11 pm.

- Smart charging has an important role in reduction of the EV charging peak

- Comfort of the user is not reduced since the car is at its desired charge level in time

The following Figure 41 and Figure 42 also clearly show the difference for grids with and without SGSH HEMS with battery in case of high penetration of EV.
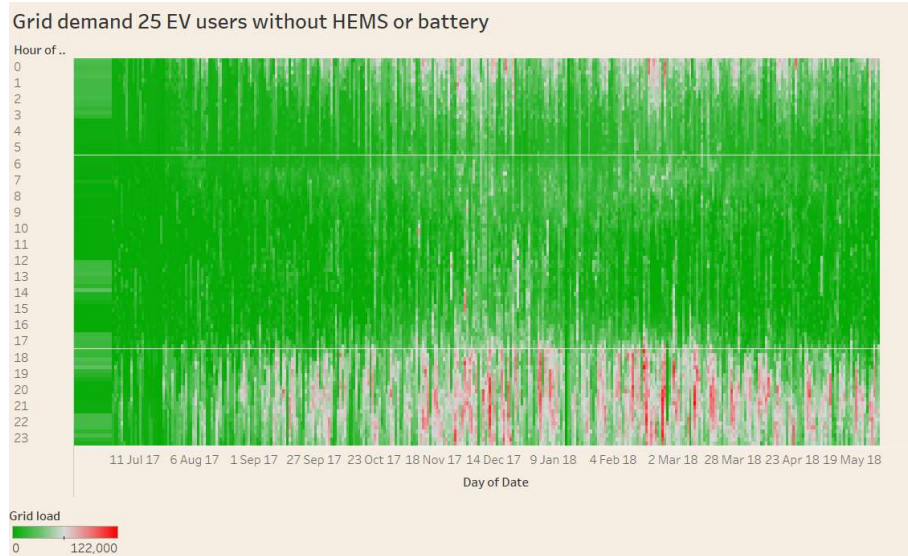
Figure 41 Hourly max load expected for 25 EV users without HEMS or battery
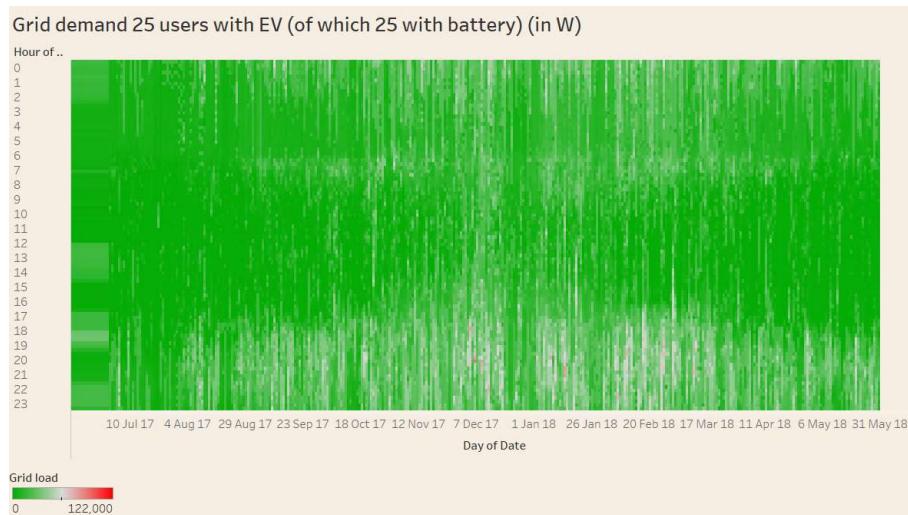
Figure 42 Hourly max load expected for 25 EV users with HEMS and 6 kWh battery

The reduction in grid load is significant and would prevent needed grid investments.

6.12. Auto consumption for all 15 users

The main goal of the SGSH HEMS is keeping the limit of an individual user between the demand and injection limit. This was analyzed in detail in the former paragraphs. It's also interesting to see what the consumption is of the own produced PV production, taking into account that some have a battery. Although the battery is not controlled for optimizing the own consumption of home produced PV, it will be a side effect in summer when solar energy is stored in the battery to prevent too much injection. **So the following auto consumption figures are for information and are not an optimized result for this parameter.**
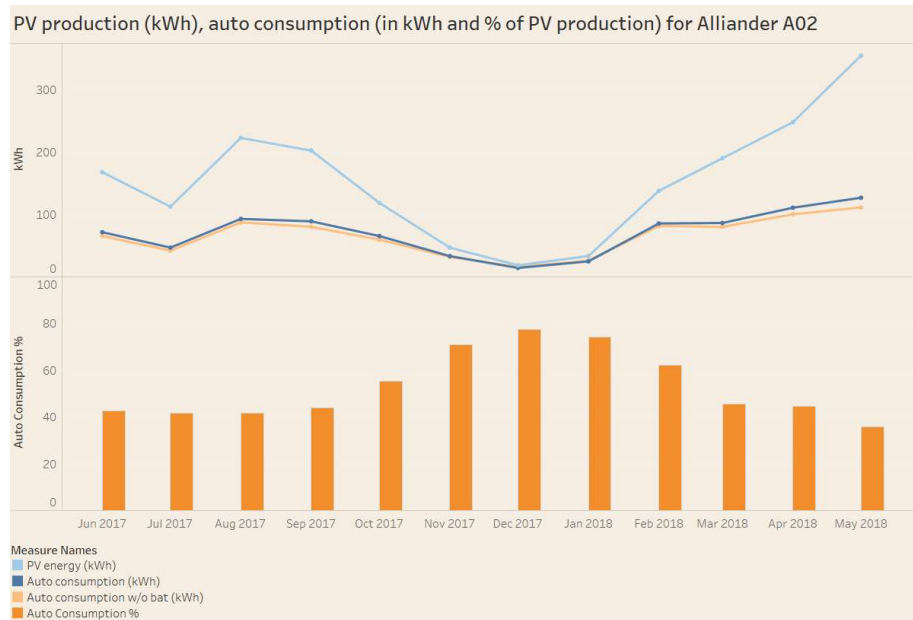
Figure 43 Auto- consumption of own PV production

Figure 43 shows the auto consumption for Alliander_A02 is between 40% and 80%, but the battery does not increase it a lot. From former research, auto consumption for users without any smart control, is known to be on average between 25-40% on yearly basis. For the users in the pilot the following figures were measured, see Table 6. From Table 6 can be concluded:

- Used control algorithm for peak shaving increase the auto consumption of PV with only a few %. As mentioned this is a side effect of the peak shaving algorithm;

- Some users without battery have a higher auto consumption of their PV than users with battery (because algorithm is not optimizing for auto consumption);

- User type and size and orientation of the PV system compared with user demand profile is more important for the auto consumption figures than the current SGSH HEMS without optimizing for auto consumption. SGSH HEMS has this functionality but was not tested in the pilot.

User	Auto consumption with HEMS and battery	Auto consumption without HEMS and battery
Alliander_A01	33%	33%
Alliander_A02	46%	42%
Alliander_A03	32%	29%
Alliander_A04	44%	40%
Alliander_A05	34%	34%
Eandis_E01	24%	21%
Eandis_E02	52%	50%
Eandis_E03	34%	31%
Eandis_E04	No battery	22%
Eandis_E05	No battery	45%
Eandis_E07	No battery	36%
Eandis_E08	No battery	43%
Eandis_E09	No battery	32%
Ores_O01	38%	35%
Ores_O02	45%	43%

Table 6 Auto PV consumption measured values all pilot users

6.13. Conclusion data analysis

Based on the collection of all the field measurement data, extensive analysis and experience the following technical conclusions can be formulated. Note: these conclusions are drawn from the representative 15 users from the pilot combined with Laborelec experience with simulations of future scenarios of low voltage grids.

Decreasing number of times of injecting or demanding more than the Ampere limit:

First objective of the SGSH HEMS is to minimize the number of exceedings per user:

- On average 69% of the demand exceedings can be prevented;

- On average 76% of the injection exceedings can be prevented;

- For some users no exceedings are left after installation of the HEMS with 6 kWh battery, for some only 29% is reduced;

- Users with a heat pump + airco system (high electric demand for heating) do hardly benefit from a battery for reduction of demand exceedings. Control of the heat pump + airco, adapted Ampere limits or an expensive big battery are needed to reduce the exceedings significantly.

Decreasing the maximum peak load for injection and demand

More important for the grid operator is the reduction in size of the grid peak in global perspective:

- The maximum demand peak on the grid is reduced with 38%, when leaving the big heat pump user out of the dataset, this is 55%;

- The maximum injection peak on the grid is reduced with 26%. This could have been more if the Ampere limits where optimized per user.

Shift in time of the peak of injection and demand

The introduction of a battery in a home has an effect on both the size and timing of the peak.

In general can be concluded that with the SGSH HEMS with 6 kWh battery:

- The maximum injection peak is, when not fully prevented to be below the injection limit, shifted 1-1,5h later in time;

- The maximum demand peak is more spread in time and below the demand limits set, mainly due to the spread of the EV charge and heat pump demand periods.

When implemented on large scale this has an important positive impact on the power profile, since next to power or current, simultaneousness is THE important parameter for grid planning. If simultaneousness decreases, peaks reduce and grid investments can be postponed or even prevented.

Global impact SGSH HEMS with 6 kWh battery on grid peaks

Although not all peaks can be prevented, they do no harm when they are all spread in time.

- The evening peak can be prevented with 40% of the users having a small battery (for a representative mix of users with EV and small heat pump systems). The users with EV and heat pump systems should off course have the batteries installed;

- 40% of users is responsible for 70% of the injection peak, a bigger battery of 12 kWh installed at these users is enough to prevent the injection peak (max 2kW/user injection) and prevent grid investments.

Global impact of EV charging of the SGSH HEMS with 6 kWh battery

- With the SGSH HEMS with 6 kWh battery 3 kW is the maximum load to be expected per user in winter time (based on 16A controllable charging stations);

- When no batteries are present but EV's are charged in a smart way with SGSH HEMS, the maximum expected load per user is 4 kW simultaneous;

- If no batteries and no smart charging is used 5 to 6 kW per user with EV can be expected as maximum peak.

The SGSH HEMS with small battery of 6 kWh and it's smart charging algorithm can reduce the impact of EV charging on the grid with about 50%. If only smart charging is applied, the expected reduction of the impact on the grid is about 30-40%.

Optimal battery size

To reach zero exceedings on yearly basis, some users need a bigger battery.

- A battery size of 6-12 kWh is enough to prevent all exceedings for users with PV systems up to 4-5 kWp (for the representative Ampere limits tested);

- The size of the battery is mainly determined to prevent injection exceedings, demand exceedings can have the same peak power but energy content is lower;

- Smart charging is necessary to prevent big batteries which then are only used for peak shaving during EV charge sessions.

Heat pumps are not studied in detail in this pilot, but the heat pump + airco system present at one user caused many demand exceedings (+/- 2000 periods of 15 minutes) which could only prevented with a battery of a size 10 times bigger than piloted.

Future scenario with 100% EV penetration

Based on the 5 EV users in the pilot, of which one with a full EV, the following experience was obtained:

- A reduction of 48% in the peak demand is obtained when every user has SGSH HEMS with a 6 kWh battery;

- Due to the simultaneous plug-in of many EV when arriving at home, a large peak is added to the evening peak. SGSH HEMS lowers this peak and spreads it to a much lower but longer peak during the whole evening or even night;

- Comfort of the user is not reduced since the car is at its desired charge level in time.

Auto consumption of PV with the SGSH HEMS with 6 kWh battery

Although optimizing auto consumption was no primary target of SGSH HEMS in the pilot, the figures and conclusions from this are interesting to share:

- Used control algorithm increases the auto consumption of PV with only a few %. As mentioned this is a side effect of the peak shaving algorithm;

- Some users without battery have a higher auto consumption of their PV than users with battery;

- User type and size and orientation of the PV system compared with user demand profile is more important for the auto consumption figures than the current SGSH HEMS algorithms tested.

7. Economic embedding and impact

This chapter presents the results of the economic study. It describes the economic embedding and (potential) impact of the HEMS. It focusses on value creation, future energy system scenarios and business case opportunities for grid operators, prosumers and suppliers.

7.1. Methodological note

This socio-economic study has been conducted in the period late 2016 – summer 2018. It started prior to the field test, and included insights from the field test as well. Data has been derived from 2 interviews rounds with all SGSH stakeholders (late 2016, and late 2017), including interview rounds with all 16 households, as well as interactive workshops.

For different parts of the study, different frameworks have been used. In order to map the value creation process and business models, Den Ouden Value Flow Model and Alexander Osterwalder's Business Model Canvas were used. For the business case opportunities and upscaling strategies, insights from socio-technical transition research were adopted.

7.2. HEMS and value creation

This simplified 'classical trinity' of users-DNO-government, has radically changed in the wake energy liberalisation and the rise of new technologies and developments such as the HEMS. The HEMS in particular seems not only to add values for the stakeholders, but also add new stakeholders. For example, users have changed into 'prosumers', and installers and suppliers of energy technologies entered the scene. Six key added values can be discerned that HEMS produce for the three key stakeholders.

	Main values	Grid operators	Households/prosumers	Suppliers
1.	Economic values (€)	Saving traditional investments ('wires & cables')	Save costs (max. 5-15 %)	New markets; New products; services, apps, gadgets; Venues for revenue/profit
2.	Knowledge values	Knowing residential energy flows/imbalance	Knowing own energy flows	New expertise; lessons for future projects
3.	Grid management values	Peak shaving/shifting, efficiency; SGSH-HEMS is 1 tool among others	Self-monitoring electricity, rescheduling household activities	
4.	Ecological values	Utilise PV's; reduce CO2 and 'grey energy'		
5.	Use values		Comfort, saving euro's/kWh/CO2, new gadget, freedom; control; social reputation; fun (gamification)	
6.	Public values	Power quality; safety; safeguard privacy	Off-the-grid, self-sufficiency, co-creating energy transition	New jobs; innovation, economic development

Figure 1 Key values created for key HEMS stakeholders

Importantly, these stakeholders and values are related and interdependent. Prior to the introduction of HEMS, a relatively simple field and value creation process existed, with grid operators, households and regulators. The figure below visualises how value creation process has become more complex by the introduction of the HEMS and new stakeholders.
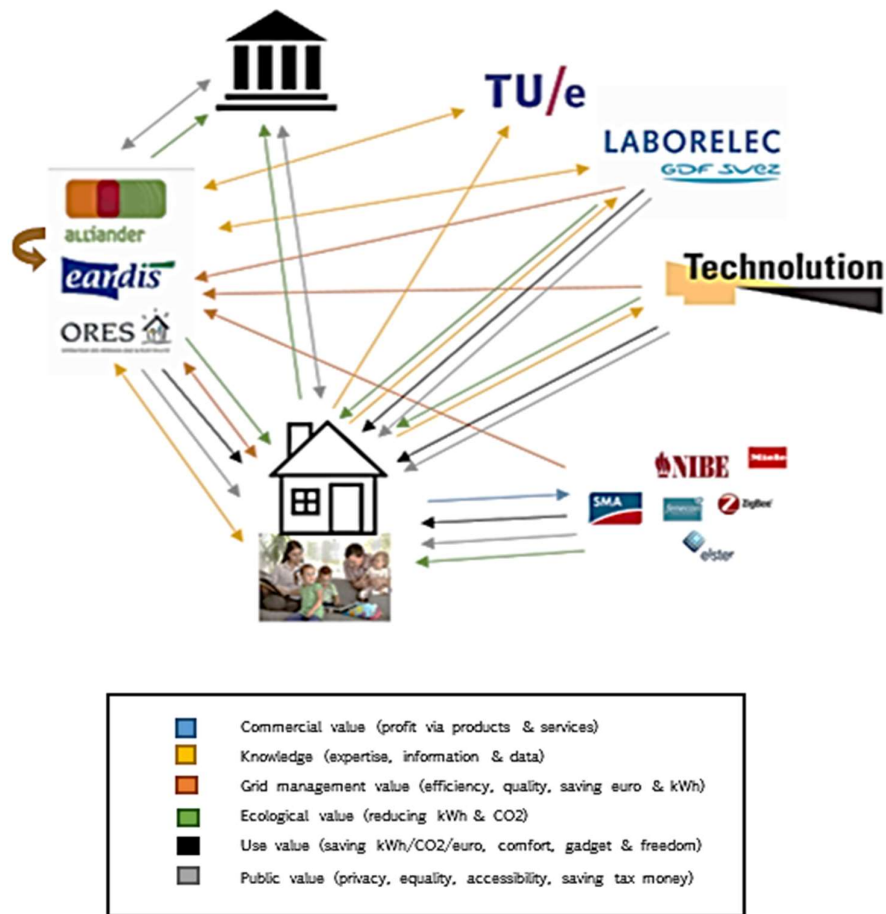
Figure 2 Value flows around via HEMS

In addition to these value flows, a number of indirect, or 'secondary' values are created by the HEMS. Again, these values mean something different for different stakeholders.

	Local storage	Modular grid management	New services	Safeguarding public good	Energy citizenship
Households, prosumers	Energy autonomy, cheap energy, strengthening local community ties	Cheaper energy, energy security/quality	New home energy-related services, products and apps	Experiencing adequate energy services (quality, secure, green, social, etc.)	Autonomy, control, renewable energy, sense of belonging
Grid operators	Balance grid locally, peak shaving, little energy is 'lost'	More grid resilience	New partners, providing users integrated services	Extending public role via physical, digital and social services	Energy conscious prosumers, peak shaving
Government, the public	Use of renewable energy, strengthening of community ties	Use of renewable energy, energy security/quality	New applications of energy data (e.g. e-health)	Having high-quality physical, digital and social energy services	Active citizen and communities
Suppliers	New hardware and software products/ services	New partners, and energy-related services, products and apps		Reliable public partner when exploring new products/services	Potential partners when exploring new products/services

Figure 3 Value creation for different HEMS stakeholders

7.3. Three energy system scenarios, three business models

Based on the different potential values that the HEMS produces, different types of 'value clusters' and business models can be developed. Each value model assumes a different societal development and prioritises different values and key players in residential energy systems. None is 'better' than the other, they signify different development paths, societal goals and are ideal type models. In all cases, the assumption is that the SGSH ambition is key, to keep the standard grid intact, while smartifying the home with a low capacity grid connection.

7.3.1. The silicon valley scenario: a commercial HEMS model

In this scenario, smart homes are driven by prosumers and commercial suppliers of energy and smart energy technologies and smart domestic appliances. This model is mainly dominated by small and large commercial stakeholders and financial incentives. HEMS related products, services and energy data are considered as commodities and can be bought and sold without much public regulations (only concerning privacy and data security). There are many market segments, given the high diversity in HEMS-related demand and supply (high-end and basic HEMS apps, batteries, software). Since commercial energy buying and selling platforms are key (with HEMS, algorithms, local and international prosumers, energy suppliers), grid operators play a less active and more accommodating role than households are used to. The main goal of this model is to utilise a low residential grid capacity and optimise prosumer value and commercial/financial revenues via the HEMS. This model defines the HEMS as a commercial technology that supports and creates economic value and activities in smart residential energy systems.

7.3.2. The cockpit scenario: a public HEMS model

In this scenario, smart homes are advocated and regulated by public policy and government agencies. The model moves away from market forces and highlights standardisation and regulation to guarantee public values such as accessibility, equality and affordability (costs are socialised). The public face of the grid operator is crucial in this model in terms of stabilising and utilising electricity peaks. Prosumers and commercial suppliers are expected

to confirm and be guided by these regulations. Grid operators would manage a range of electricity systems (wind mills, solar energy, etc.), including smart homes, residential storage capacity and HEMS. The HEMS, then, is one of the grid management tools within a larger toolbox, utilised for specific geographical areas and problematic residential grid profiles. The main goal of this model is to utilise a low residential grid capacity and optimise collective accessibility to energy services via the HEMS. This model defines the HEMS as a public technology that supports and creates public value and services.

7.3.3. The swarm scenario: a community HEMS model

In this scenario, smart homes and HEMS are employed by prosumers and local companies and organisations. Such 'swarms', or local networks aim to be self-sufficient and energy autonomous (at least, as much as possible). Prosumers are not individual commercial energy suppliers (see commercial model), but operate in broader social settings, for instance in energy-driven initiatives or cooperatives. Even though such local communities are often sceptical of big commercial (energy) companies and government regulations, they sometimes depend on cooperation from grid operators, public organisations and commercial suppliers to support their aims (via subsidies, product discounts, research, knowledge, etc.). Self-produced energy can be sold to local residents, but these collectives can also offer car sharing services or share a community garden. Such local energy initiatives are mushrooming, see e.g. in the Dutch context the website Hieropgewekt.nl. This model defines HEMS as a self-governing technology, utilising smart homes and energy sharing practices to strengthen local social and community bonds.

7.3.4. Comparing the models

The three business models are clearly designed to serve different societal objectives. Each of these three energy system scenarios, different values are foregrounded and grid stakeholders play a significantly different role. Each scenario assumes a different energy future, with different grid configurations and key players. In other words: 'if HEMS is the solution, what's the problem?'

In the commercial model, for example, there are also public and community values and stakeholders. However, they play a different role. The same holds for the other models. Therefore, the specific implications or organisational business models for each stakeholders differs per value model (commercial, public or community). In practice, obviously, different value models and roles might interplay, requiring stakeholders to be flexible and adaptive, depending on changing circumstances (new regulations, technology or market players).

	Commercial model	Public model	Community model
Main objective	Utilise a low residential grid capacity and save and/or make money via HEMS. This model prioritises values that support and/or create commercial and economic activities	Utilise a low residential grid capacity and optimise collective accessibility to energy services via the SGSH-HEMS. This model prioritises values that support and/or create public goods and services	Utilise a low residential grid capacity and optimise social and communal relations via the SGSH-HEMS. This model prioritises values that support and/or create social and cultural activities
Societal context	Rise of personalisation, flexibility and (eco)lifestyle choices	Rising awareness of energy as public issue, inclusivity, accessibility and sustainability	Rise of citizen activism, sharing economy, cooperative models and 'new localism'
Key strengths	Diversity and innovation of HEMS products and services	Standardisation and accessibility/inclusivity to HEMS products and services	Autonomy and social commitment to smart and sustainable energy systems
Key weakness	How to standardise and increase accessibility/inclusivity	How to increase flexibility and innovation	How to link communities and upscale
Co-financing structure	Mostly business investments, plus public funding	Mostly public funding, plus business investments	Combination of public funding, business investments and community funding
Revenue	Commercial gains, investing in R&D and new markets/products	Saving tax money, realising sustainability and energy policy	Sharing and local solidarity, reinvesting in community activities
Legal context	Net metering, transition tariffs charges, contracts, terms of conditions	Net metering, transmission tariffs, 'HEMS funding' programme	Net metering, transmission tariffs, cooperative (membership)
Role of prosumer	Prosumers as consumer and 'micro' energy company	Prosumer as consumer and citizen	Prosumer as part of energy collectives
Role of grid operator	Facilitator of smart energy platform	Safeguarding stable, reliable and safe grid for all	Facilitator of energy autonomy and energy selling/sharing services
Role of suppliers (hardware & software)	Commercial suppliers of new HEMS products and services (in changing markets)	Commercial suppliers of new HEMS products and services (in 'guaranteed' markets)	Commercial suppliers of new HEMS products and services (in changing markets)

Figure 4 Comparing the HEMS business models

7.4. Context dependency and flexible roles

Clearly, the HEMS creates a wide variety of societal values associated with different types of business models. It depends on the context which model, or combination of models is most useful. Similarly, a degree of flexibility is required for all stakeholders, especially in the early stages of a (market) development.

7.4.1. Context dependent models

Context is everything. For instance, the HEMS community model might operate in the context of energy cooperatives, or a city with active prosumers. Already close ties between prosumers and grid operator (e.g. LochemEnergie) might be further developed in such a way that prosumers support grid operators by utilising excess energy (shaving energy peaks), while being socially engaged. In other contexts, for instance in large urban centres with many rented/social housing blocks, a public HEMS model might work better. Given the fact that less active residents and low-income groups should also be able to benefit from HEMS products and services, might mean that urban funding programme, grid operator investments, housing organisations and commercial partners (experimentally) develop and offer a public HEMS with ample PV panels, district storage and particular smart energy software.

This way, low-capacity grid connections is realised while providing HEMS advantages for socially vulnerable groups (cheap, clean and self-manageable energy). Again, a different context, a different type of HEMS application creates a different kind of advantage. The commercial HEMS model, then, might work better in high-income cities, since it requires

ample investments from prosumers themselves. Given the personalised expectations for high-income prosumers (e.g. more domotics, in-home displays, EV's, smart appliances), high-end HEMS products and services can be offered, while, again, realising low-capacity grid connections. So, the takeaway here is that all key stakeholders involved (grid operators, prosumers and suppliers of energy and HEMS technology) would benefit from understanding HEMS business models as options within a *business model repertoire*. Different cities, residents/prosumers and legal/technical possibilities require different tailored business models. Each type of business model has its strengths that can only be utilised fully if applied in the proper context.

7.4.2. Adaptive models and roles

In accordance with the idea that the HEMS business models are quite context-dependent, the business models presented here are flexible. A group of high-income prosumers with many PV panels and multiple EV's, might benefit from utilising a 'smart energy sharing platform' (combining commercial and community model). The same holds for a public business model in which, for example, a group of 5.000 low-income residents are offered a public HEMS, but some of them extend their household electricity network by buying with extra solar panels, domotics and EV's. This would be interesting for commercial suppliers, providing add-ons via attractive lease contracts (combining public and commercial model).

HEMS business models can change along the way, depending on local circumstances. This also means that the business model canvas building blocks change accordingly. Such a 'modular' business model approach also means that actor roles can be hybrid or change over time. This is also important to note, given the dynamism in the energy sector (new technologies, regulations, market competitors).

Finally, and this should be stressed, the HEMS is not a panacea. Even though it might turn out to be a technical success with a sound business model, especially from the grid operators perspective, it requires careful consideration with regard to other (non-HEMS) projects, technologies and priorities. Therefore, the HEMS, and the HEMS business models, should be taken into account as part of a broader approach to manage residential energy systems.

7.5. HEMS business case opportunities

Based on the HEMS business models, more specific business case opportunities can be described. In order to prevent a too optimistic picture highlighting only business case 'opportunities', business case challenges are also to be taken into account.

	Main challenges	Main opportunities
Prosumer	• No business case, little savings. • High costs battery	• Using/selling stored energy (phasing out net metering (as of 2023)
Grid operator	• Legal constrains for 'local balancing' • Concerns about privacy and data security ('smart meter syndrome') • Alternative solutions (Trafo)	• Flexible/difference capacity tariff (as of 2022) • Dynamic peak pricing (more savings) • Cheaper batteries (10-30%) • Necessity for LV-cables (as of 2025/2030) • Increase electrification (EV, heat pump, E-cooking)
Supplier HEMS as product (hardware & software)	• No market or remains niche market (high investment costs, little revenue) • 'Smart meter syndrome' (few consumers)	• Large scale via contracting housing corporations (500-1k) and grid operators (+ 100k) • Standardization, compatibility regarding energy data flows, appliances, platforms • Culture of home energy control/management
Supplier HEMS as service (hardware & software/cloud)		

Figure 5 General business case challenges and opportunities

Based on the HEMS, as designed in the SGSH project, the following indicative costs and benefits can be discerned. Again, since there are different key stakeholders, they are specified per stakeholder.

	Main costs	Main benefits
Prosumer	Buying HEMS (€ 6k one-off, including battery, box, interfaces, service). plus € 0,10 per penalty, recurring costs	Lower capacity tariff, automated system, insights, comfort, autonomy, (recurring savings kWh/€, expected 5-10%)
Grid operator	Investment costs R&D, developing HEMS (€ 500k one-off)	Peak shaving and investment savings against background energy transition (€ 15 million/year, as of 2025/2030)
Supplier HEMS as product (hardware & software)	Investment costs for developing and producing HEMS (€ 500k one-off)	Revenue per unit. Simple model (€ 100/unit). Extended model (€ 5k/unit, incl. battery)
Supplier HEMS (hardware & software)	Costs for installing and maintaining HEMS as service (low recurring costs, € 10/user/year)	Revenue, per unit and contract (€ 15/unit/year)

Figure 6 Main costs and benefits HEMS (disclaimer: figures are illustrative)

These developments, or trends, all contribute to the potential of a general HEMS business case, for all actors.

7.5.1. Trends and opportunities

Even though it seems, from a technical grid management point of view, the business case for grid operators is most viable. However, since a HEMS includes many households, and suppliers as well, business cases for all actors need to be viable. Below, a rough visual indication of how 'best case' trends coincide (x-axis in years, y-axis in virtual numbers of high/low, as units widely differ per trend).

Business case oppertunity trends

Development potential (high) / (low)

2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030

- Prosumer income via net metering
- Flexibility/differences capacity tariffs
- Dynamic peak pricing
- Price batteries
- Necessity LV cables
- Culture of home energy management
- Standardisation energy-tech/data
- Large scale contracting
- Electrification (PV's, EV's, heat pumps, post-gas)
- Decentralisation of grid management

Figure 7 Business case opportunities trends

This image presents a quite bright and optimistic image. However, trends are erratic by nature and can result in a less optimistic scenario for HEMS. Depending on the degree to which all 9 trends are in favour of HEMS development (see above), a best case, a worst case and a probable (intermediate) scenario can be discerned.

Future scenarios for HEMS (based on 10 trends)
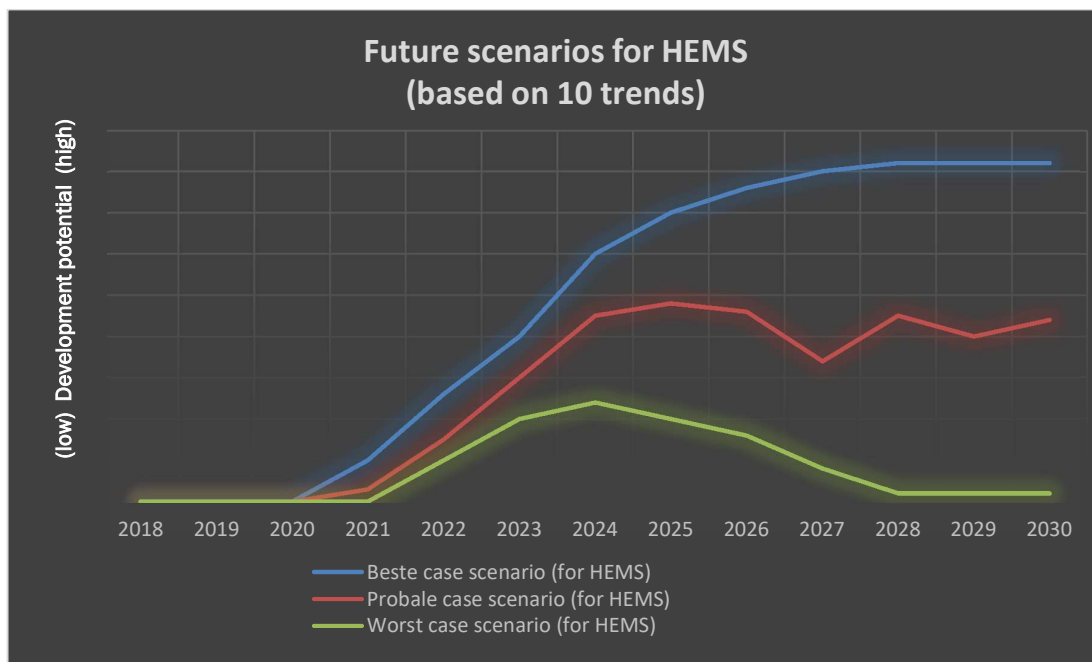
Figure 8 Future scenarios for HEMS (based on 10 trends)

Taking into account, a more probable and optimistic scenario here, again, there are different HEMS models that can be developed. A commercial HEMS model, for instance, would mean there would be less strict regulation, standardisation and possibilities for large scale contracting with grid operators. This, in turn, means that investment costs for both suppliers and prosumers will be disproportionately high. Trends and different HEMS models

More generally, a number of trends shape how likely a certain HEMS model will develop. Below, different HEMS models are visualized, based on the societal trends they depend on (scaled 0-10 per trend in spider graphs).
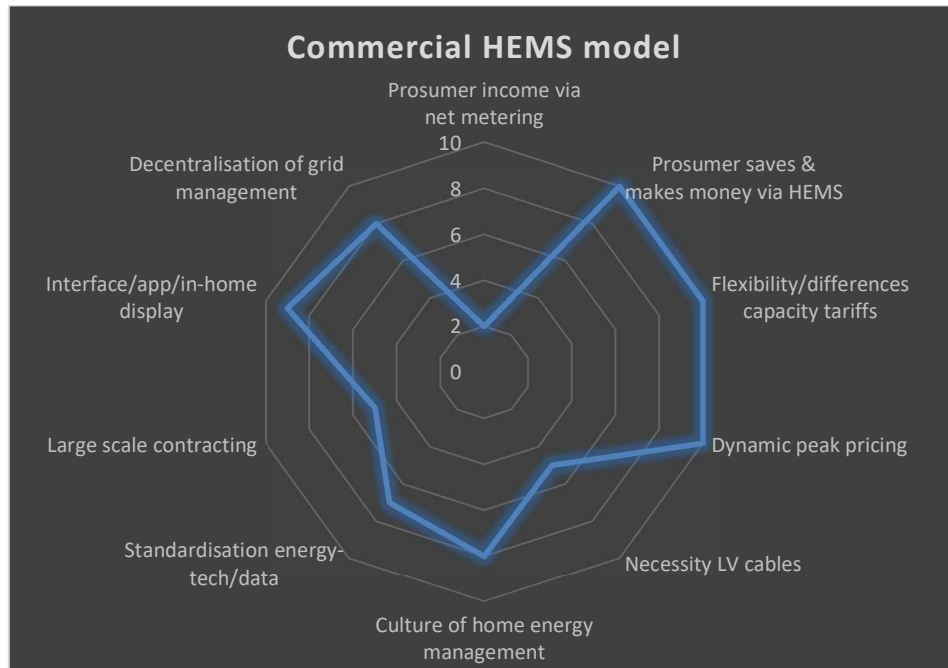
Figure 9 Commercial HEMS model

In the public model, a number of business case factors shift (see below). There is a different set of conditions that are required for a more publically-oriented HEMS to develop. Mostly, the commercial elements are less crucial, especially from the household/prosumer point of view. Furthermore, a more pro-active approach is expected from grid operators and regulators to use the potential of HEMS.
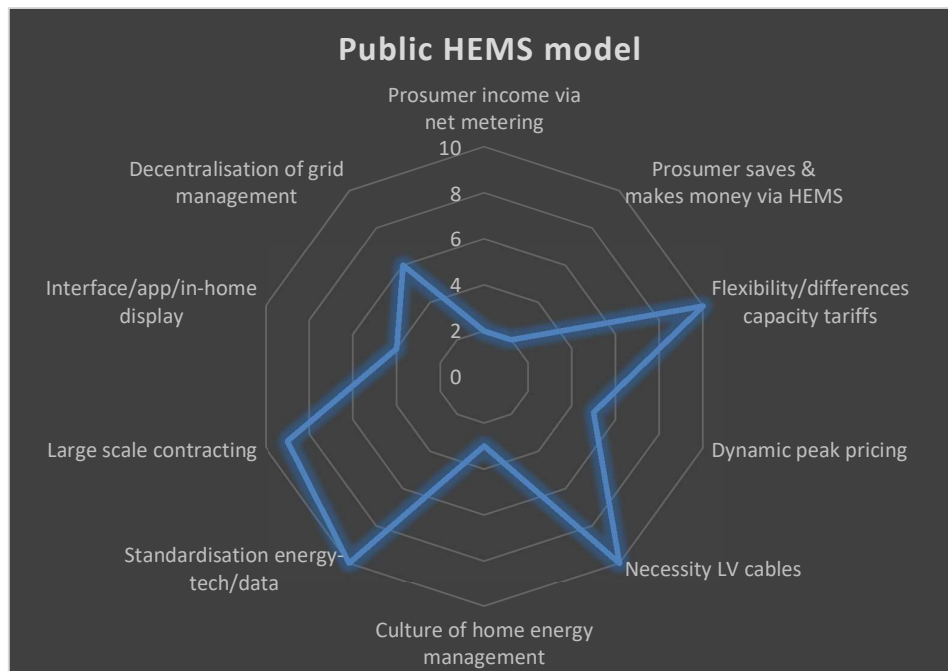
Figure 10 Public HEMS model

In a community model, the configuration of relevant business case factors, again, looks differently (see below). Here, the role of (energy) cooperatives, installers, housing corporations/associations and other intermediaries is important to create proper 'economies of scale'.
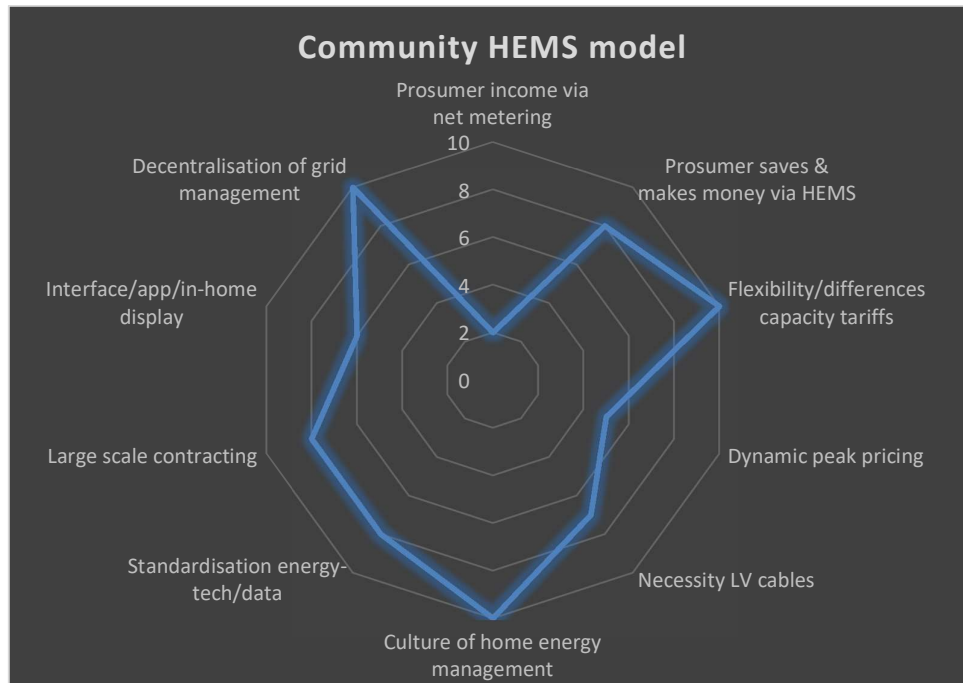
Figure 11 Community HEMS model

Of the type of business case opportunities, it seems that the commercial model is most challenging - on the short term - due to minimal savings for prosumers, high investments and standardization issues. These issues need to be addressed actively, and will also be more salient as of 2021/2022. Also, for prosumers, HEMS products and services should preferably offered as integrated 'packages' (including subscription and maintenance contract), with little effort on the side of prosumers.

A business case in the community model also seems challenging for reasons related to upscaling, large-scale contracting and upscaling. This points to a more modular, and tailored deployments of HEMS, namely in particular residential areas and streets where only a few household profiles cause grid concerns. Therefore, a business case in a public model seems to bear most potential on the short term. However, as per 2022, HEMS-related and technologies and markets might develop swift, offering additional potential to the commercial and community model.

7.6. Strategies for upscaling

On the basis of the business case opportunities, and challenges presented above, strategic actions are possible. Below, these strategies actions are briefly presented strategies. Three types of 'upscaling' strategies differ in priorities and available resources to influence societal trends regarding HEMS. The strategies can be interesting for grid operators, (commercial) suppliers, as well as partnerships (public, private, local cooperatives). These strategies are relevant for all HEMS business models: the commercial model, the public model and the community model.

7.6.1. Anticipate and prepare strategy

This relatively 'passive' strategy suggests that actors developing the HEMS preparing for 'windows of opportunity' to introduce the SGSH. These possibilities relate to specific HEMS-related trends (see above), especially regarding key trends such as net metering, flexibility of capacity tariffs, and development of battery markets. Given the relatively low priority, little resources and points of leverage in this strategy, a business case expected in the timeframe of 2023-2025.

7.6.2. Fit and conform strategy

This more active strategy suggests that the HEMS should conforms to existing regulations and market dynamics, given the availability of some resources and leverage points. This strategy argues that the development of HEMS should align with existing possibilities/restrictions of the Dutch WETVET or Belgian VREG regulatory frameworks, available technologies, and consumer expectations. Within available regulatory and market spaces, the HEMS can scale up to some degree as of the year 2022.

7.6.3. Stretch & Transform strategy

This very pro-active strategy suggests that the actors developing the HEMS create regulatory and market space and strategize to change institutional conditions. This requires more resources, time and investments than the previous strategies. However, it allows stakeholders to impact conditions that would make HEMS more tailored to meet certain goals, concerning standards, requirements, incentives structures and investments schemes. The strategy also focusses on new (local) stakeholders and partnerships that are needed in a more transformative grid development in which HEMS are play a more central role, possibly already before the year 2022.

These strategies do not exclude each other. Rather, some strategies can be tailored to only specific HEMS-related trends. This way, strategic actions and investments can be yielded efficiently.

7.7. Conclusions

A number of general conclusions can be formulated on the basis of this study.

First, HEMS create different types of values, for 3 key stakeholders (grid operators, prosumers and suppliers). Furthermore, a number of indirect added values are produced, revolving around modular grid management, new commercial services and energy

citizenship. Together, these value creation process, provides an promising image for the socio-economic impact of HEMS, for various stakeholders.

Second, as there will be not 'one final' type of HEMS, different future energy system scenarios can be expected, associated with different types of business models:

- Commercial HEMS model: in this model ,HEMS are developed and provided by small and large commercial stakeholders and financial incentives. HEMS related products, services and energy data are considered as commodities and can be bought and sold without much public regulations (only concerning privacy and data security);
- Public HEMS model: in this model, HEMS are advocated and regulated by grid operators and government agencies (similar to smart meters). This model moves away from market forces and foregrounds standardisation to guarantee public values such as accessibility, equality and affordability (costs are socialised);
- Community HEMS model: in this model, HEMS are employed by prosumers and local companies and organisations. Such 'swarms', or local networks, aim to be self-sufficient and energy autonomous (at least, as much as possible).

In each model, the HEMS has a different societal objective, and foregrounds different types of values and stakeholders. This typology maps different HEMS futures, as well as the role of grid operators, prosumers and suppliers in these different models.

Third, business cases also differ per model. A commercial business case, for example, is less convincing for prosumer given the high costs (as of 2018) and relatively little savings. A public business case, however, is more promising on the short term, as HEMS can be deployed to support only specific (high peak) household profiles in particular streets or blocks.

Fourth, the development potential of HEMS depends on 10 societal trends (economic, regulatory, cultural, etc.). Depending on the importance/weight of these trends, different development potentials of HEMS can be described (best-case, worst-case and probable case). Furthermore, in each HEMS model (commercial, public, community), a different set of trends shapes the development potential of HEMS. In all cases, it seems, a business case becomes interesting per 2021-2022.

Fifth, despite the complex environment of HEMS developments, strategic action is possible for grid operators and suppliers to render HEMS more mainstream (whether they cooperate in networks):

- Anticipate & Prepare: this more 'passive' strategy suggests that actors developing the HEMS map emerging technological, regulatory and economic 'windows of opportunities' to introduce the HEMS at a later stage (2020-2024);
- Fit & Conform: this more active strategy suggests that the SGSH-HEMS conforms to existing regulations and market dynamics (WEVET, VREG, available technologies).
- A Stretch & Transform: this very pro-active strategy aims to strategically change these market and regulatory conditions, and possibilities/limitations through lobbying and new partnerships.

8. Conclusions and recommendations

Low voltage electricity grids increasingly have to deal with injection due to the generation of electricity by solar PV and wind turbines. Another development potentially (over)loading the distribution networks are the rapidly growing numbers of electrical vehicles (EV) and electric heat pumps. As a result, the energy transition for residential clients will take place in the low voltage grid. For the Distribution Network Companies and the connected users it will be a huge challenge to keep the available infrastructure up and running without need for extension of the capacity within the residential areas. The main objective of the SGSH project has been to maintain good power quality by limiting grid loading and consumption.

In order to test the options for network operators and households to remain within specific injection and consumption limits a new Home Energy Management System (HEMS) has been developed. The HEMS measures the grid/consumption/injection, automatically controls some devices, takes into account flexible user requests and reports to the user the information required. The HEMS consists of a local part and a back-office. The HEMS first has been tested in the ENGIE Laborelec laboratories. Next, a one year field study has been executed at the homes of 16 'friendly users' in Belgium (11) and the Netherlands (5). All households had PV panels installed, 10 received a battery system, 5 used hybrid and full EVs and two households owned a heat pump. One of the systems without a battery did not function properly; these have not been used for the technical analysis. Feedback to the users has been provided by a HUE lamp and a Graphical User Interface. The functioning of the HEMS system has been analysed from a social, technological and economic perspective.

8.1. Conclusions from the social study

A number of conclusions can be made on the basis of the social study:

- With regard to the feedback, because of the direct feedback, the HUE lamp has been more meaningful for households than the GUI. Both forms of energy feedback provided almost all households with more insights into their energy consumption. However, some households hardly responded to the HUE lamp during winter months as these households were simply not able to shift energy consuming routine;.

- The social response of households to HEMS and its integration into energy-related routines seems to depend on the type of energy consuming routines: some routines are flexible (mainly related to washing and EV charging) while others are not;

- Shifting in routines depends both on negotiations among household members and the physical presence in the home;

- Tariffs and incentives shape willingness of households to become more flexible. These relate to: (1) future capacity tariffs; future (market) price of HEMS, especially batteries; and (3) dynamic peak pricing.

- Although the 16 participating SGSH households were friendly users (a high income/educated and eco-oriented group), there still are significant differences between households in embedding the HEMS, depending on different narratives about the meaning of the HEMS, the differences in the mix of HEMS element available in the home and different attitudes, based on prior experiences.

- Some recommendations on the basis of these results are:
  - Optimize incentives with a focus on financial incentives for 'normal households';
  - Simplify feedback, as an intermediate between HUE and GUI form of feedback is preferred;
  - Optimize the HEMS design, especially with regard to the options for user control;
  - Develop narratives why it is important to mainstream a HEMS.

8.2. Conclusions from the technical data analysis

Based on the collection of the field measurement data of 15 users and the tests and simulation at Laborelec, the following technical conclusions of the SGSH HEMS with a 6kWh battery can be formulated:

- The SGSH HEMS succeeds in decreasing substantially the number of injections (69%) or demanding (76%) exceeded the Ampere limit set. Users with large PV systems have a negative impact on the results, while a system with a heat pump did not benefit from the battery.
- The maximum demand and injection peaks have been reduced substantially (38, resp. 26%).
- The introduction of a battery has an effect on both the size and timing of the peak of injection and demand. If implemented on a large scale this has an important positive impact on the power profile, since next to power or current, simultaneousness is THE important parameter for grid planning. If simultaneousness decreases, peaks reduce and grid investments can be postponed or even prevented.
- Not all users need to have a 6 kW battery to prevent the evening peak; the users with EV and heat pump require a (larger) battery.
- The SGSH HEMS shows that the maximum load by EVs can be reduced substantially (50%); even without HEMS, smart charging reduces the impact on the grid by 30-40%.
- To reach zero exceeding on a yearly basis, the size of the batteries needs to be adapted: a battery size of 6-12 kWh is enough for users with PV systems up to 4-5 kWp. Smart charging is necessary to prevent big batteries which then are only used for peak shaving during EV charge sessions.
- The control algorithm of the SGSH HEMS increases the auto consumption of the electricity generated by the PV system, slightly, but the user profile, the size and the orientation of the PV system have a larger impact.

- Some recommendations
  - One should not use a standard capacity of the battery for all houses; the size of the battery should be adapted to the user profile and the installed energy system.
  - A smart distribution of batteries over a neighbourhood also can reduce the need for installing storage systems.
  - Smart charging should be introduced, independent of the implementation of a HEMS. Although not investigated in this project, the same applies probably to the on/off switching of electric heat pumps.

8.3. Conclusions from the business model study

A number of general conclusions can be drawn:

- A HEMS creates different types of added values, for the 3 key stakeholders (grid operators, prosumers and suppliers). Also, a number of indirect added values are produced. Together this provides a promising image for the socio-economic impact of the HEMS;
- Depending on the development of the future energy system, different models for a HEMS can be foregrounded: a commercial model with a focus on the commercial products and service delivered by companies, a public model with a major role for grid operators and the government guaranteeing public values and a community model where local prosumers and organizations focus on autonomy and self-sufficiency;
- For each model, the business case will be different. At the moment there is no business case available, the main reason being the current net metering regulation;
- There are several societal trends (economic, regulatory, cultural, etc.) that will determine the potential of a HEMS. Assessing the impact of those trends it seems that a business case becomes interesting per 2021-2022 for all models.

- Strategic options

Despite the complex environment of HEMS developments, strategic action is possible for grid operators and suppliers to render HEMS more mainstream (depending on priorities and available resources). They can chose between:
  - An Anticipate & Prepare strategy: this 'passive' strategy suggests that actors developing the HEMS map emerging technological, regulatory and economic 'windows of opportunities' to introduce the HEMS at a later stage (2020-2024);
  - A Fit & Conform strategy: this more active strategy suggests that the SGSH-HEMS conforms to existing regulations and market dynamics.
  - A Stretch & Transform strategy: this very pro-active strategy aims to strategically change the market and regulatory conditions, and possibilities/limitations through lobbying and new partnerships.

The overall conclusion of the project is that the technical objectives of a HEMS as developed in this project have been met: installing the SGSH HEMS with a battery greatly reduces the impact of distributed generation and new large loads on the current distribution networks. It can be considered a feasible option to deal with the great challenges the energy system is facing now and in the future. However, there is not yet a business case for suppliers, distribution network operators or communities to implement a HEMS as has been investigated in this project. The feasibility depends on changes in the regulatory framework. Depending on political decisions, it will become clear which business model will have the best chance to succeed. Finally, HEMS need to be adapted to the local circumstances and demand profile, but also to the preferences and wishes of the households in order to be acceptable and attractive. The field research shows that there is some flexibility in energy consuming routines, but other routines are not open for negotiation.

Appendix A. GUI examples

www.sgsh-pilot.nl

SGSH - P(O)RTAL

Username

Enter Username

Password

Enter Password

login

SGSH - Energy Dashboard

Power to(-) / from(+) the grid:	2.58033	kw
PV production:	1.64	kw
Battery state of charge:	57	%
Grid demand penalties:	168	#
Grid injection penalties:	15	#
Status HEMS:	ONLINE - fully operational	
Second objective:	economical	

EV charge energy: 496.0 kwh

Starting time white goods:

Daily information	Monthly information	Detailed information
Self sufficiency	Self sufficiency	Grid power
Savings	Savings	PV production
CO2 emmisions	CO2 emmisions	Battery SOC

Version: 1.0 [Help] [More Info]

How much of your total electricity use do you produce with your own PV panels?

Monthly self- sufficiency

From PV   From the Grid

The higher the percentage from PV, the more self-sufficient you are.
An average household with PV has a self- sufficiency between 25-40% on yearly basis and this can highly vary per month.
The self- sufficiency can also be much lower (10-20%) if your demand is high compared to your PV production or if demand and supply are not matched at all.
The self- sufficiency can also be much higher (60-80%) if your demand is low compared to your PV production or your demand is matched with your PV production,
e.g. by changing your demand behaviour or adding storage.

Power profile from and to the electricity grid

Power from the grid (last 7 days)

The main meter measures the flow of power to and from the electricity grid.
Here you can see your power profile from the last 7 days based on 15-minute average values.

PV production of the last 7 days & 24h PV forecast

PV Producton & Forecast

PV production   PV prediction

The PV meter measures the power produced by your PV installation.
Here you can see your power profile from the last 7 days and 24h PV forecast based on 15-minute average values.

Battery state of charge of the last 7 days

Battery state of charge (last 7 days)

The behaviour of the battery state of charge of the last 7 days in 15-minute average values.
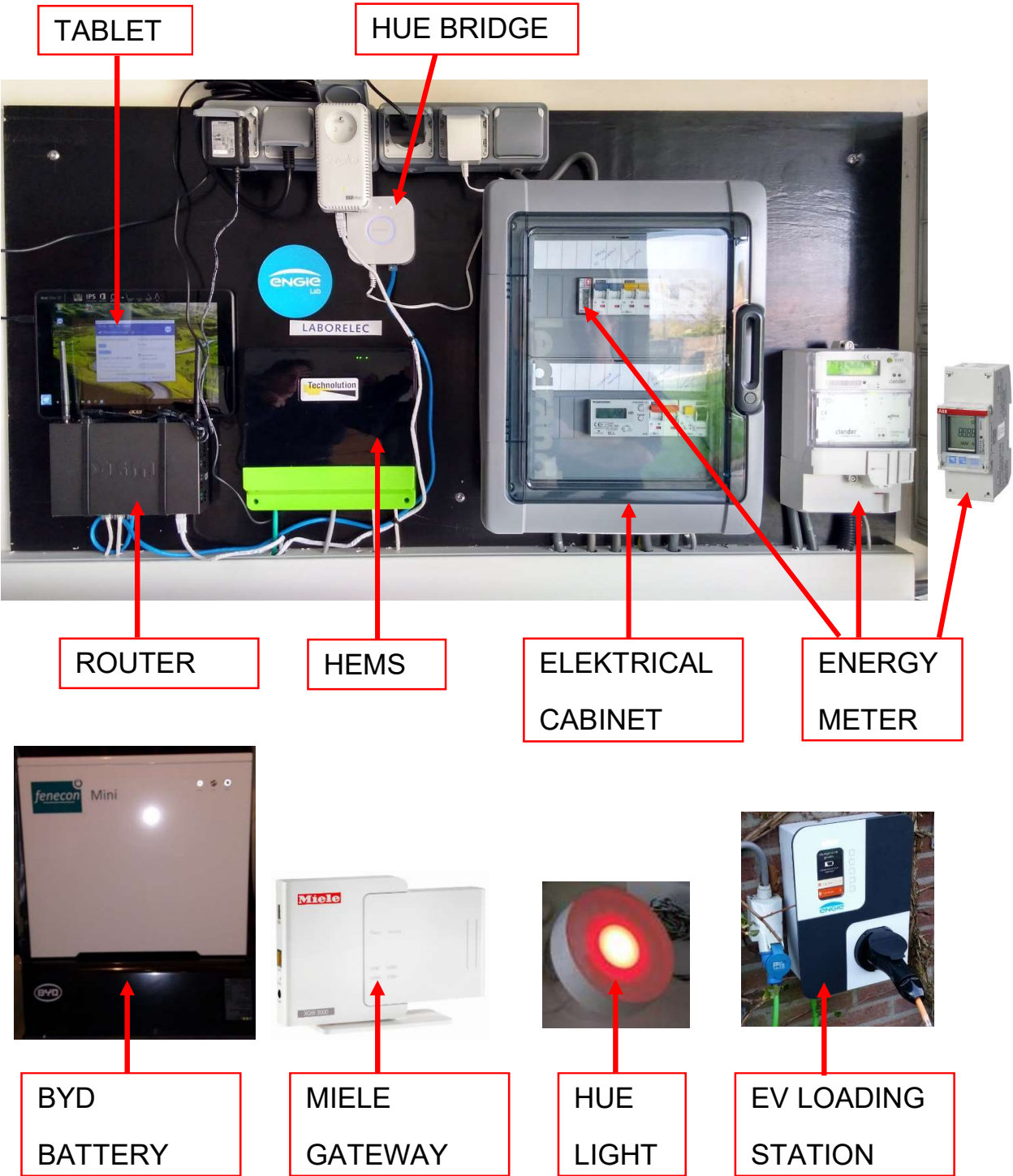
Appendix B.   HEMS installation

The next pictures show the used equipment for the complete SGSH installation:

TABLET

HUE BRIDGE

ROUTER

HEMS

ELEKTRICAL
CABINET

ENERGY
METER

BYD
BATTERY

MIELE
GATEWAY

HUE
LIGHT

EV LOADING
STATION

Appendix C. Example of BO web-interfaces

```
swagger: '2.0'

info:
  title: SGSH BO API
  description: SGSH (Standard Grid Standard Home) Back Office API to be used by the HEMS (Home
Energy Management System).
  version: "0.0.8"

basePath: /v1.0

paths:
  /historian/measurements/:
    post:
      summary: Measurements data.
      description: |
        Store measurements data measured by the HEMS.
      parameters:
        - $ref: '#/parameters/api_key_parameter'
        - $ref: '#/parameters/participant_id_parameter'
        - name: measurements
          in: body
          description: An array of measurement data.
          required: true
          schema:
            type: array
            items:
              $ref: '#/definitions/Measurement'
      tags:
        - Historian
      responses:
        200:
          description: Successful storage.

  /historian/events/:
    post:
      summary: Events data.
      description: |
        Store events data observed / generated by the HEMS.
      parameters:
        - $ref: '#/parameters/api_key_parameter'
        - $ref: '#/parameters/participant_id_parameter'
        - name: events
          in: body
          description: An array of event data.
          required: true
          schema:
            type: array
            items:
              $ref: '#/definitions/Event'
      tags:
        - Historian
      responses:
        200:
          description: Successful storage.

  /optimization/lastdata:
    get:
      summary: Most up-to-date optimization data.
      description: |
        Retrieves:
          - the **optimized state of charges (SOC)** of all controllable buffers of the house (i.e
battery, boiler, ...)
          - the **EV control setpoints** to be used if a car is connected
          - the associated **load eagerness**.
      parameters:
        - $ref: '#/parameters/api_key_parameter'
        - $ref: '#/parameters/participant_id_parameter'
      tags:
```

Appendix D. Distribution list

Electronic distribution		
Recipient		**Outlook**	**Media**
Alliander	Maarten van Blijderveen	maarten.van.blijderveen@alliander.com	PDF
Eandis	Kevin Daems	Kevin.daems@eandis.be	PDF
ENGIE LABORELEC	Ralf Bosch	Ralf.bosch@engie.com	PDF
RVO	Nicole Kerkhof - Damen	nicole.kerkhof@rvo.nl	PDF
Technolution	Wilfred Hoogerbrugge	wilfred.hoogerbrugge@technolution.nl	PDF
TUE	Geert Verbong	G.P.J.Verbong@tue.nl	PDF