Project no.:	**957982**
Project full title:	**Sustainable and Integrated Energy Systems in Local Communities**
Project Acronym:	**SERENE**

Deliverable number:	**D5.1**
Deliverable title:	**Report on the proposed set of technical measures to be taken in the different neighbourhood/buildings**
Work package:	WP5 : Integrated local energy system demonstrator in Netherlands
Due date of deliverable:	M12 - 30.04.22
Actual submission date:	M12 – 29.04.2021
Start date of project:	01/05/2021
Duration:	48 months
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Contributing partners:	SAX, UT, LOQ, VAON

Dissemination level of this deliverable	**PU**
Nature of deliverable	Report

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 957682. Any results of this project reflect only this consortium’s view and the Agency is not responsible for any use that may be made of the information it contains.

Document history

Version no.	Date	Authors	Changes
0.1	20.01.22	Cihan Gercek	Contents and basic structure
0.2	04.02.22	Edmund Schaefer, Aditya Pappu, Bahman Ahmadi, Viktor Nikolayev, Gerwin Hoogsteen, Cihan Gercek	Main content Research & Innovation scope
0.3	18.03.22	Edmund Schaefer, Aditya Pappu, Bahman Ahmadi, Viktor Nikolayev, Femme Taken, Gerwin Hoogsteen, Cihan Gercek	Mid report version
0.5	21.03.22	Gerwin Hoogsteen, Cihan Gercek	Editing, additional content
0.6	28.03.22	Edmund Schaefer, Aditya Pappu, Bahman Ahmadi, Viktor Nikolayev, Gerwin Hoogsteen, Cihan Gercek	Finalised technical content
0.7	15.04.22	Cihan Gercek, Gerwin Hoogsteen	Editing, improving the content, summarising and conclusions
0.9	28.04.22	Edmund Schaefer, Aditya Pappu, Bahman Ahmadi, Viktor Nikolayev, Gerwin Hoogsteen, Cihan Gercek	Final internal version: Addressing reviewers' comments
1.0	29.04.22	Katherine Quinteros	Final version.

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1 Executive Summary

Deliverable 5.1 reports on the investigation of the set of technical measures that can be taken in the different neighbourhood/buildings for Dutch demonstrators of the SERENE project in order to reach a (nearly) soft-islanded energy system. The main focus of this report is WP5's first target: "Investigate 100% local renewable and balanced energy supply for individual buildings, neighbourhoods and the village using solar PV, storage, insulation, smart control and bio-energy sources.". The findings and insights in this report serve as a guideline for making an implementation plan, evaluating flexibility and future options for improvements of the project test-site. The report also provides the specific set of measures and their potential for the value created.

The Deliverable 5.1 (D5.1) is the first report that captures and summarises the Dutch techno-economical investigations for the first year of the SERENE project, within the work package 5 (WP5) "Integrated local energy system demonstrator in the Netherlands". This work package involves two demonstration sites, the community Aardehuizen with 24 houses and neighbourhood Vriendenerf that consists of 12 houses, both in the village of Olst. Aardehuizen is the main focus of this deliverable as they are a pioneering community in terms of sustainability. The technological innovations, methods and energy management solutions that are being developed, will be introduced and applied to Vriendenerf at a later stage. The site visits, literature, models, toolset, and historical usage data are utilized to evaluate different potential measures using various KPIs at the Aardehuizen. Flexibility, costs, problem-solving aspects of smart grids are explored in order to apply in the pilot case, considering implementations of various innovative carbon-neutral technologies for a clean energy transition. This is done by using several literature findings and optimisation models developed by the University of Twente and Saxion University of Applied Sciences. In addition, to make those results close to the practice, national-wide or EU-wide databases are used, both for situating the position of the demonstrator regarding national averages, and mapping the value creation considering national grid emissions and/or EU energy market prices.

The extensive data analysis and simulations help us to conclude that the local energy community demonstrator Aardehuizen, is performing way more sustainable than the Dutch average. Yet, they still have a significant potential to decrease their energy costs and emissions even further with feasible improvements. Various measures are investigated and discussed, with conclusions on our final selection of the set of measures as well as their potential added values. These impactful solutions highlighted in this report will be the basis of our future detailed investigations: "Final Report on the techno-economic feasibility of a smart grid and local E-car concept". With the value creation potentials mapped, SERENE dutch demonstrator is now directed towards impactful, greener, and scalable set of measures.

2 Introduction

2.1 General introduction

Local energy communities play a crucial role in residential energy transition, as being early adopters of energy innovations (ROGERS 2003; CHADWICK ET AL. 2022). A place where the energy innovations can be validated, improved, and tested for upscaling, where motivated communities provide ideas and co-design useful solutions that empower prosumers (KOIRALA ET AL. 2021). This work focuses mainly on technological aspects, yet the communities play in an important role in the residential smart grids. Due to this multidisciplinary nature of smart grids, it is important to introduce the context of the case study as well as scientific and societal* interest in implementing smart grid technologies (SMALE ET AL. 2017) (REINDERS ET AL. 2018). This chapter (2) summarises the goals of the Dutch pilot case that could be obtained via workshops and scientists-citizens interactions as well as the research scope. Further chapters will assess the technological possibilities (Chapters 3), flexibility, problem-solving and design aspects (Chapters 4), and value creation (Chapter 5). This report concludes with a discussion of observations and their implications, and provides a summary of the results and perspectives in Chapter 6.

**Societal aspects will be mentioned to only highlight interactions between work packages and implications on techno-economical facts. Please refer to SERENE WP3 and their deliverables D3.1, D3.2, D3.3 for socio-economical, societal, regulatory and governance analysis of the local energy communities.*

2.2 Dutch Smart grids and integration of renewable energy

EU Commission reports indicate that the Netherlands' climate and energy targets are to decrease its carbon emissions in 2030 by 49% percent compared to 1990, plus to increase the renewable energy integration to 35% (EU COMMISSION 2019b). Higher proportions of renewable energy and carbon-neutral technologies integration will result in a larger demand/supply mismatch. Hence smart ways of using electricity in different sectors are required to maintain balance, system stability and reliability of supply.

There have been 3549 smart grid demonstrations (including lab or innovation demonstration) across the EU, of which only 20% were implementation on sites (JRC 2019). Of the Dutch demonstrators that have been investigated up until 2019, 84 smart grid cases found in the same EU databases, only about 23 of them were documented to include user engagement, and even fewer pilots (6) documented on user control (GERCEK ET AL. 2019), (BROUWERS & VAN MIERLO 2019). the Dutch roadmap of energy transition indicates that rooftop/Building-integrated photovoltaic solar panels(PV) are enabling the land allocation to other activities such as agriculture (CALVERT & MABEE 2015). On top of that, Energy Performance of Buildings Directive (EPBD) (EU COMMISSION 2018) obliges all new buildings to be nearly zero-energy buildings (NZEB), which means more and more buildings will incorporate renewable energies, where flexibility will be inevitable to remain cost-effective within the future (dynamic) energy system and markets (GERCEK ET AL. 2020). One of the most techno-economically feasible solutions to provide grid flexibility and balance supply and demand is the implementation of smart grids and the inclusion of both end-users and their devices in this system.

Annex A summarises the different technologies that are applied and are envisioned to be implemented in WP5 pilot locations. It also lists previous residential Dutch smart grid pilots with similar information.

2.3 Scientific and societal interest for the implementation case

Integration and improvements on renewable energy, as well as energy transition, have been a subject of interest since the last two decades. Improvements in carbon neutral technologies resulted in widespread of those technologies in residential sector such as roof-top solar panels, heat pumps, home batteries, electric vehicles, etc. Yet to obtain the most efficient operation and integration, the addition of information communication technologies (ICT) to the energy grids is required to enable coordination. The combination of the two results in the Smart Grid, a subject of research of more than hundred thousand of research papers (SIANO 2014; BARBATO & CAPONE 2014; VARDAKAS ET AL. 2015; DENG ET AL. 2015; ALAM ET AL. 2016). Residential implementations have to specifically cope with unpredictable human behaviour and their interaction with the system, which makes the type of smart grid research and their application challenging. Furthermore, while improving the energy autonomy, residential smart grids need to meet a certain level of energy comfort that inhabitants were used to with fossil fuel supported energy systems. However, there is much to benefit for both end-users, in terms of economic savings, as well on the global scale due to the share of energy usage by the residential sector (EUROSTAT 2022). To decarbonize the grid, smart integrated energy grid implementations could play a major role beginning with local energy communities to wide spreading towards the residential sector, allowing flexibility and avoiding congestions.

This report investigates smart grid solutions and energy management systems that empower the local energy communities and therefore their citizens. Especially when the incentives on renewable energies, notably net metering, will be gradually step down (BELLINI 2019; LONDO ET AL. 2020), value creation, comfort provided, sustainability contributions, initial costs as well as the return of investments should stay in reasonable ranges as ensuring the community engagement for longer terms. With the rapidly rising energy prices, the volatility on the markets, and the introduction of real-time pricing schemes (VISAKH & MANICKAVASAGAM PARVATHY 2022), there is an opportunity for energy communities to benefit from local energy sources and flexibility. Smart grid solutions are the cornerstone to all these aspects and to keep the residential energy revolution spinning by empowering the community and the citizens. The aims of the citizens as well as research questions are stated below.

2.4 Sustainability goals of Aardehuizen and results of the workshop

Aardehuizen, a neighbourhood consisting of 23 ecological houses built in 2017 by and for the members of *Association Earth House East Netherlands* (Dutch, official, “Vereniging Aardehuis Oost Nederland”) . The association dates back 2006 and after working on the planning, financial and legal feasibility of the construction, they started to build these houses in 2012 by using second hand, local, and environmentally friendly construction materials. Their official mission is: “Building, working, and living in harmony with nature, in connection with each other and to inspire the world around us”. And their vision is “an ecological neighbourhood of self-sufficient earth houses in which all aspects of sustainability are in mutual relationship in balance." Renewable energy sources were also part of the targets, all houses are equipped with rooftop PV panels and solar thermal panels (AARDEHUIZEN 2022) (Figure 1).

Figure 1. Aardehuizen local energy community in Olst

The community, including two renewable energy installers by profession, knew that using the grid electricity would result in indirect fossil fuel consumption. For example, at times when the sun does not shine, the energy imported from the electricity grid originates (partly) from fossil fuel and therefore will harm nature. Their ambitions, however are to further investigate how their energy consumption can be further reduced, how the remaining energy can be sourced from local and sustainable (micro-)generators, and how the electricity from the main grid's fuel mix can become 100% sustainable as well. Thereby, the community takes its steps according to the Trias Energetica (LEEUWEN 2017). To reach these goals and ambitions, the community has joined in the research project to facilitate research, experiment with novel solutions to achieve these goals; educate, inspire and share knowledge with anyone willing to step in their footsteps.

A workshop was organised with the inhabitants of the Aardehuizen to understand the dynamics of the community, existing infrastructure and their current goals as now being a partner of the H2020 SERENE project. Reaching a (nearly) soft-islanded Aardehuizen community (HOMAN ET AL. 2019) and thereby becoming fully sustainable is the common goal as expressed by the inhabitants. The discussion round with 33 participants resulted on the following requirements:

- Long term financial feasibility: they would like to stay environmental-friendly without a significant financial burden or risk;
- Ecological over economical: they would like to do both, but if there is not a financial burden, they would like to stay as green as possible;
- Communitarian over individual: they prefer joint efforts rather than individual improvements;

- Low tech over high tech if sustainable: if a solution exists for a given function, they would prefer low tech rather than novel technologies; unless it is more sustainable;
- Ownership over full automatism: Overruling the devices offered by the project must be possible. Data ownership is also important;
- Home specific solutions over generic designs: Individual houses have different setups and different way of living, that might result in home specific design / set of designs;

Sense of effort and contribution seemed also important during the discussions, as well as dissemination of the knowledge as they are carrying an exemplary living of sustainability.

2.5 Research and Innovation scope

The aspects mentioned above are closely related to WP2 (modelling) and WP3 (social acceptance); and the multidisciplinary perspectives will be subject of those work packages. This report only focuses on techno-economical aspect and the set of measures that will improve the neighborhood in terms of energy independence and sustainability. Therefore, the main research goals of this report is:

“Investigate 100% local renewable and balanced energy supply for individual buildings, neighborhoods and the village using solar PV, storage, insulation, smart control and bio-energy sources.”

This investigation is oriented on demonstration activities, where technological innovations and integrated systems are investigated to optimally demonstrate in real-life setups in Olst. In that regard, the side research and innovation scope that will be addressed in this report are (specific to Aardehuizen as community, but also applicable for residential houses in general):

- What set of measures are suited to improve local energy communities; to minimise energy demand and maximise flexibility?
- What are the differences in hybrid heating systems used in Aardehuizen and conventional heating systems?
- What are the advantages and disadvantages of these atypical hybrid heating systems?
- What are the advantages and disadvantages of various storage solutions?
- What is the potential flexibility of the Aardehuizen community and how to improve that?
- What are the control schemes and objectives that would improve flexibility on community level?
- What is the potential value creation of the set of measures proposed on community level?
- How different flexible assets of different houses could be coordinated in a real setup?
- How different flexible assets from different manufacturers could be facilitated in one single energy platform?
- How the system integration and optimisation can be enhanced via design of the energy management and monitoring platform?
- What is the impact of energy optimisation on renewable energy integration, using different technological innovations?
- How do the technological innovations (flexible assets) perform under different objectives (optimisation priorities) ?

- What are the potentials of the value creation by the innovation of the energy management platform from various perspectives ; namely cost, energy balance and CO2 emissions?

By analysing those above, one could suggest a smart grid system that could be customized for the neighborhoods. Those questions, not only defined the technological innovation that might be considered/sized to be applied in practice, but also helps WP5 to develop a better platform for system integration. The aimed energy management platform will coordinate the technological innovations (PV, Battery, smart control …). Flexibility potentials, connectivity and controllability of those components ;tied to the new EU regulation concerning energy communities are crucial for attaining mature solutions and integrated systems (EU COMMISSION 2019a) . Besides, these are relevant for understanding spread mechanisms and facilitating energy transition.

As part of our methodology, the historical data, site-visit inspections, specific energy consumption data and household configurations are used to address the research objectives that concerns to investigate the current situation and its main characteristics (Chapter 3). Flexibility, smart control and exploring the potentials of set of measures are investigated by customized open-source simulation models (ALPG,DEMKIT) and validated (Chapter 4). Those simulations helped to specify the technical requirements further. The simulation results were the basis to map the potential value creation in combination of other external (national/EU/market) databases; to quantify the value for different partners and from various perspectives (Chapter 5). In the conclusions, the research questions listed above are address with the quantified results and validated observations.

3 Modeling and monitoring to identify a set of measures for achieving lower energy demand

3.1 Modeling tools

The goal of this research is to identify a set of measures that can be taken to achieve the goals of the Aardehuizen community as set forward in Chapter 2. Furthermore, it is important that the methods to achieve such goals can be replicated in other communities too. In order to investigate the impact of measures before actual implementation, models and simulation studies need to be carried out. Within the project, we have two important requirements:

- The used toolchain must not only carry out an energy simulation, but also perform optimisation and simulate the effect of energy management.
- Since measures will be deployed in practice, a transition path from simulation to demonstration in practice is needed.

For these reasons we have chosen to use DEMKit (HOOGSTEEN ET AL. 2019), short for “Decentralized Energy Management Toolkit”. This software tool follows a cyber-physical systems (HOOGSTEEN 2017) approach, where the physical flows of energy are simulated and the digital control algorithms for energy management are implemented (tt 2). DEMKit furthermore follows the digital-twin design paradigm, which means that each device and controller is modelled individually and can be modelled using real-world data. Therefore, this tool allows us to perform simulations using real-world data from the demonstrator site, hardware-in-the-loop validation tests, and practical deployment of the algorithm. Hereby, only one code-base is used to boost development efficiency and to perform system validation.

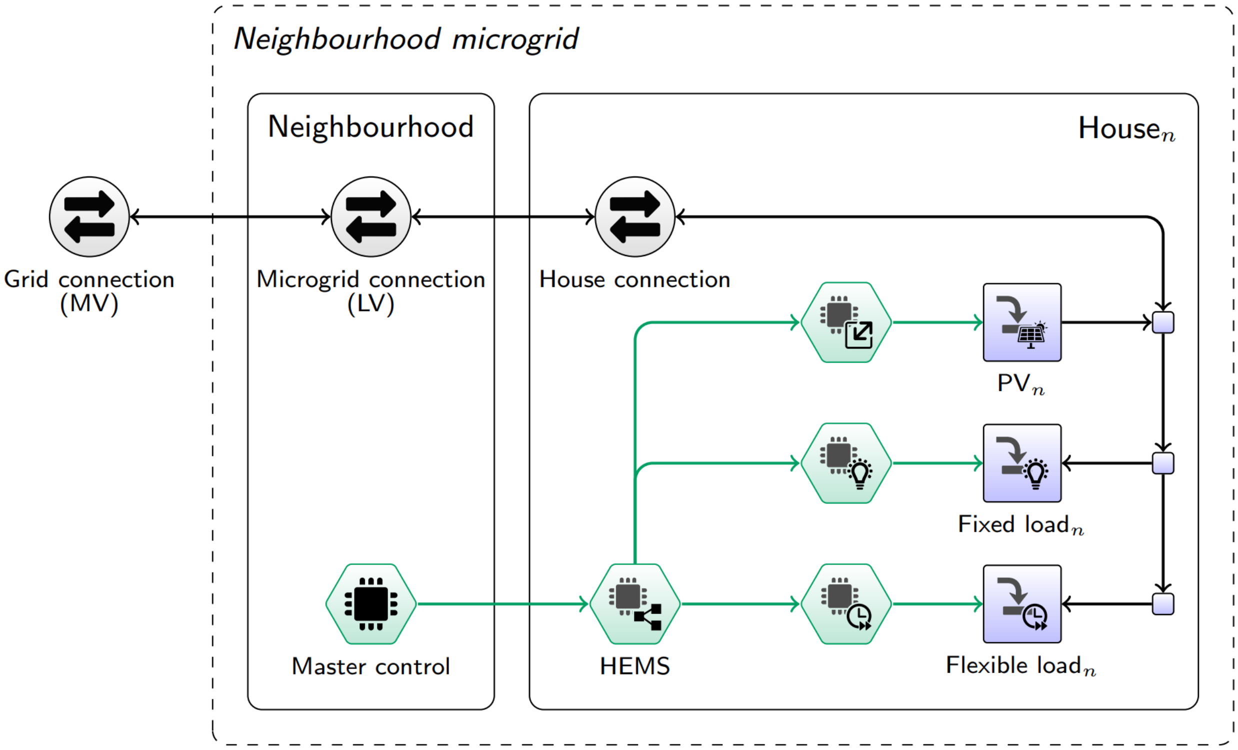

Figure 2: Generic DEMKit model for a household. Blue rectangles indicate physical device models, green hexagons indicate optimisation algorithms and controllers controlling the devices.

Next to the DEMKit modelling tool, we use the ALPG (Artificial Load Profile Generator) tool (HOOGSTEEN 2016) to generate input datasets of energy usage patterns in cases where real data is (still) missing. Furthermore, the ALPG explicitly specifies the energy flexibility, in the form of mathematical constraints, required for energy management systems to optimise the energy flows.

3.2 Residential Monitoring systems

Smart meters are widespread over EU, and they are capable of registering electricity exchange of the houses accurately and reliably (less than a minute resolution and 0.2% accuracy depending on the smart meter model) (NETBEHEERNEDERLAND 2022). Therefore, automated reading of energy (electricity and natural gas) usage is possible, and or electricity the current power drawn from or injected into the grid is a common way to monitor residential consumption behaviour without the need to install additional measurement devices. By monitoring the electricity exchange with the grid, one can identify patterns and select appropriate technologies and/or behavioural changes to improve the electricity profile. For instance, the energy fed back to the grid due to overproduction could be stored in a battery, for which the energy measurement indicates the optimal size in terms of storage capacity and the maximum power measurement determines the required power rating of the inverter.

We have designed two different monitoring systems to monitor the consumption patterns of the households and grid exchange. The first system is a low-cost system designed by Saxion University researchers, and the second system is a professional solution proposed by Loqio BV. Both systems communicate with smart meters via the P1 port as specified by the DSMR (Dutch Smart Meter Requirements) standard (NETBEHEERNEDERLAND 2022), and communicate using an encrypted connection to a secure server, to which only involved researchers have access.

3.2.1 Saxion Monitoring system

An embedded low cost monitoring system for electricity usage and PV production has been developed by Saxion. The platform is based around the Arduino microcontroller platform and is equipped with wireless internet capabilities. The whole system is encased according to local regulations concerning safety. The systems can be installed in the electrical cabinet (single phase). The system has two inputs for measurements:

- An RJ-11 socket to connect the monitoring system to the P1-port as specified by the DSMR (Dutch Smart Meter Requirements) (NETBEHEERNEDERLAND 2022) to read out the power consumption, production and the energy usage counters used for billing by energy suppliers. Various DSMR versions are supported.
- A current clamp to measure the current produced by the solar inverter.

Internally, both the P1 data stream and current measurements are used to calculate the power consumption and production separately. The monitoring system sends the data to another system for data collection using an encrypted and secured connection. The details of the overall system architecture are presented in Section 3.2.3.

To describe further the monitoring system, the hardware of the system, is shown in Figure 3 (a,b). The flowchart of the monitoring system is shown in Annex B. The recorded and a displayed data for one household is shown in Figure 4. One week is displayed to visualize the net-metered electrical exchange with grid.

(a) (b)

Figure 3. Monitoring system with its circuit (a) and circuit box (b)

Figure 4. Recorded data by the monitoring systems. Green line represent high resolution electricity net metered (consumption minus PV production) data (10 sec.) in kWh for one dwelling

3.2.2 Loqio Monitoring systems

The Loqio Home Energy Management System is based on a low cost embedded computer that collects measurements from the main smart meter and several single or three phase electricity submeters. The submeters are used to monitor the current, power, energy usage and power factor of specific loads such as a PV inverter, electrical boiler, heat pump, dish washer or washing machine. The number of submeters varies per home depending on the heating system and appliances used by the household.

The electricity submeters are installed behind the circuit breakers of the circuits that need to be monitored (Figure 5). In order to install the submeters, modifications have to be made to the wiring inside the electrical distribution board. The energy management system is housed in an enclosure that matches the brand and type of consumer unit being used in the specific home, contributing to a professional installation that complies with safety standards.

Wired communication is used for both the smart meter and submeters, enabling very short readout intervals of 1 to 10 seconds. Optionally, measurements can be collected through wireless plug-in electricity meters.

Figure 5. Loqio electricity submeters installed behind the specific circuit breakers that is aimed to be monitored

The system runs a building automation software package that allows for easy integration of all kinds of sensors and appliances and is suitable for both data acquisition, control and automation. A message queuing service is used to continuously stream measurements to a centralized data platform where the data is persisted in a time-series database. The centralized platform also allows data to be shared with other partners in the project through an API and a message queuing service. The API will be extended in collaboration with Saxion and UT to support the control of local energy resources. All communication between the local home energy management systems, the centralized platform and other SERENE partners is carried out over encrypted connections.

In addition to power and energy-related measurements, wireless room sensors will be installed to collect data about comfort levels and occupation. A private LoraWAN gateway will be installed in the neighborhood to collect measurements from wireless sensors, avoiding the need to equip every HEMS with a dedicated wireless interface.

The software services on the home energy management systems are remotely managed through a software management platform that enables automated provisioning of newly installed systems, automated deployment of software updates, and remote management in case troubleshooting is necessary. The management platform ensures stable operation and a high level of resilience to failure.

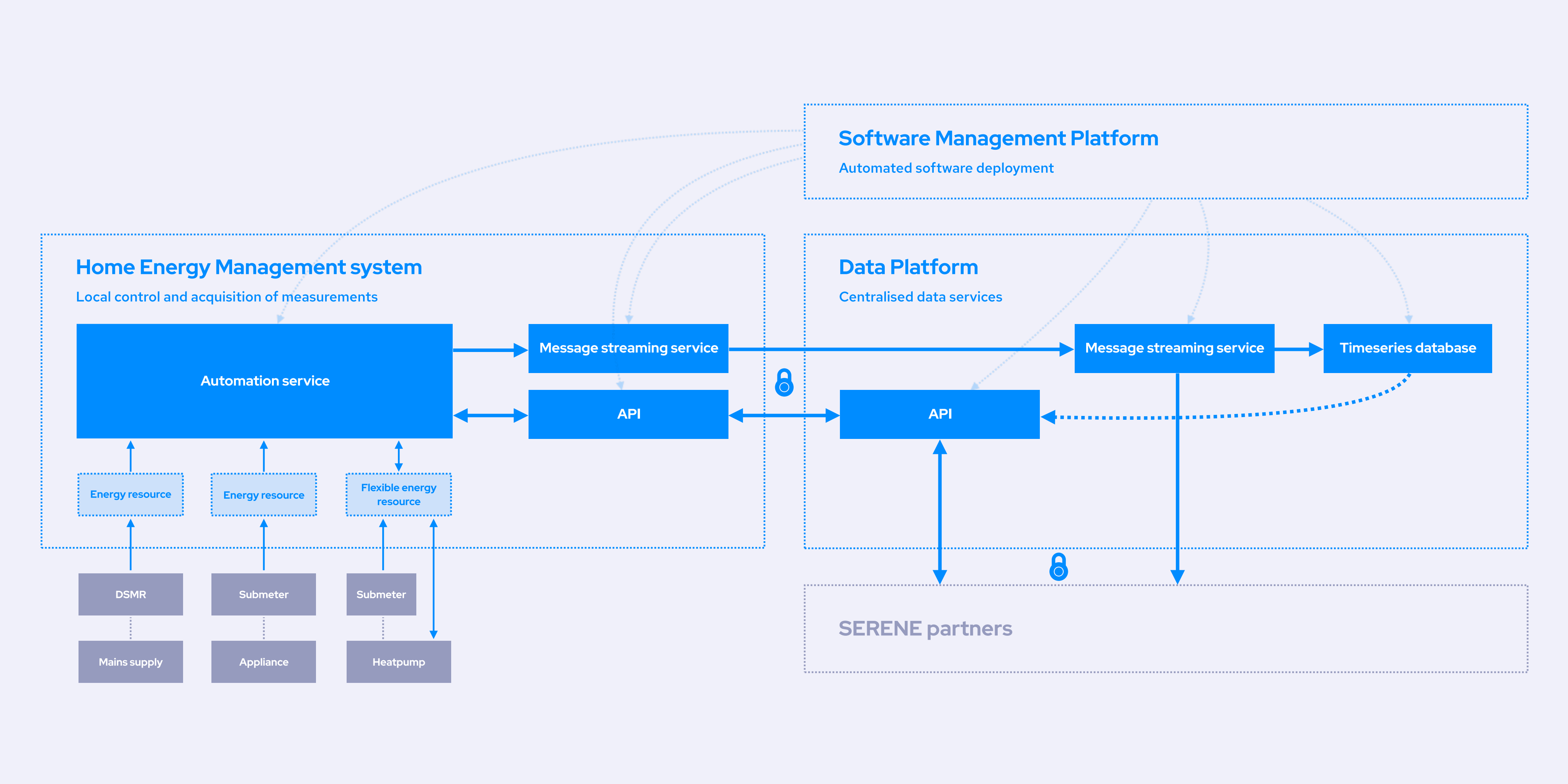

Figure 6 . Loqio Software management platform

3.2.3 System architecture

The various monitoring systems, and also controllable smart devices, are part of a software ecosystem. For the project, a system architecture is designed and set-up to collect all data using an encrypted connection and store the data in a secure way. All current existing and future IoT (Internet of Things) devices can be added into the system to retrieve data and send commands in a scalable way. For this purpose, we have set-up a broker, an intermediate piece of software, that forms the link between all IoT devices on the one hand, and all the software services that make use of the data and have to send commands to these devices on the other hand. One of such services is the DEMKit simulation tool to perform digital-twin simulations based on collected data and to provide forecasts of energy usage and production of the houses. Furthermore, all data and actions are stored in a time series database InfluxDB (INFLUXDATA 2022) and can be visualized and analysed using Grafana (GRAFANA 2022). Currently, only measurement data is collected and analysed.

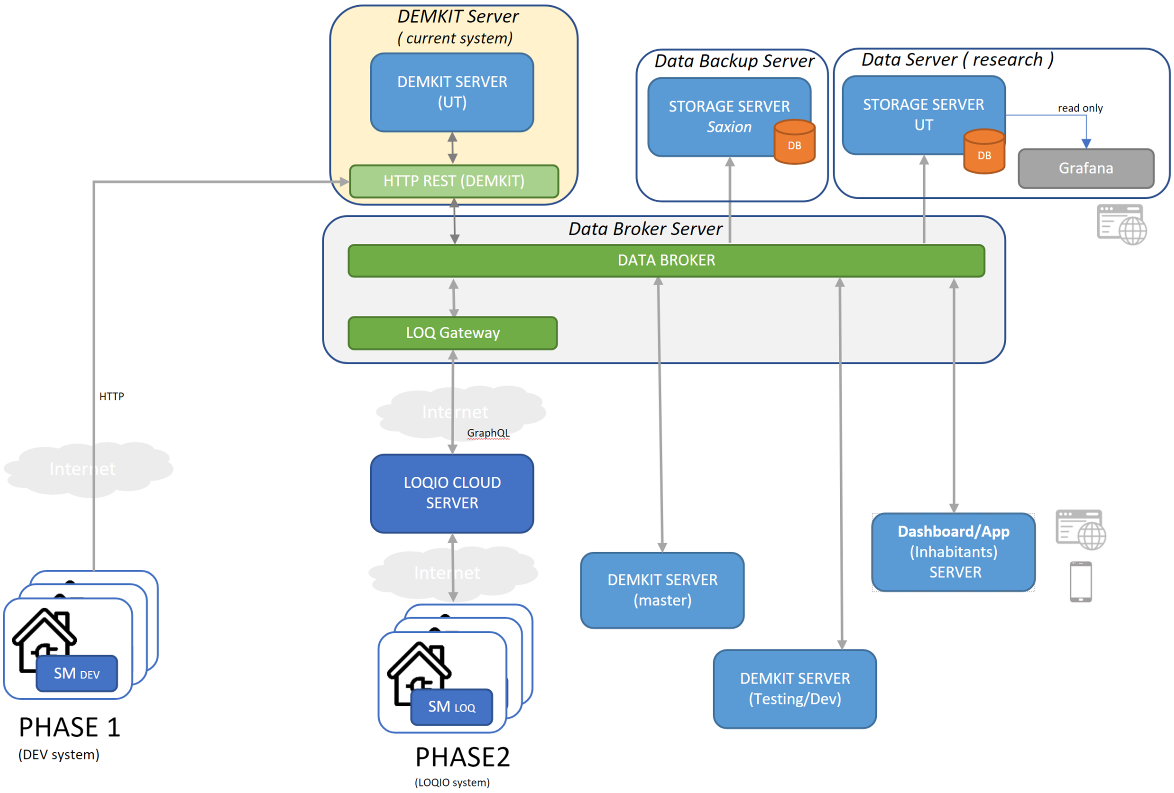

Figure 7. System architecture of the overall monitoring systems

3.3 *Yearly energy demand & supply comparisons with National averages*

Both the electricity and heat demand of dwellings are influenced by country-specific factors besides climate conditions. To show the differences between SERENE demonstrator countries and how the dutch average differs, Table 1 summarises the energy consumption of national average dwellings of the three countries according to the European authorities and databases(EUROPEAN ENVIRONMENT AGENCY 2019a).

Solar irradiation characteristics quite match, therefore one can expect approximately the same output generated from PV panels (Annex D) (ENERGYDATA SOLAR ATLAS 2021). Yet the climate conditions vary between the three countries and that will have a major impact on heating (Annex C). Energy spent per living surface is way less in the Netherlands as being mainly situated in Maritime North climate rather than Continental as it is mainly case in two other countries (EUROPEAN ENVIRONMENT AGENCY 2019b). The electricity consumption in Poland (EUROPEAN ENVIRONMENT AGENCY 2019a) is also very low compared to Denmark and Netherlands. Seeing the consumption per surface (kWh/m^2), this difference might arise from the type of average dwelling of the country (appartement/detached houses), energy efficiency and energy poverty. Both of the three countries spent less electricity than the EU average (3700 kWh) (ODYSSEE MUREE EU 2022), yet the differences between countries are clearly expressed in Table 1.

Table 1 : Energy consumption national averages per dwelling of the three countries involved in Serene, for year 2019 (database references : (STATISTA 2021) (ODYSSEE MUREE EU 2022))

Country / Variable	**Average number of people per dwelling**	**Electrical Consumption (kWh)**	**Space heating (kWh)**	**Water heating (kWh)**	**Cooking (kWh)**	**Total (kWh)**	**Total Energy spent per living surface (kWh/m²)**	**Solar Energy yearly output (kWh/kWp) ****
Netherlands	2.14	3127	10467	1977	349	15468	89.551	1000 – 1100
Denmark	2	3614	16630 *		349	19771	136.071	950 – 1050
Poland	2.56	2139	11630	2558	1279.3	16980	165.146	950 – 1070

* Both space and water heating

**These ranges are approximate averages that country solar energy yearly output belongs to, for a specific region solar power output you may refer to annex D. More information is available on (ENERGYDATA SOLAR ATLAS 2021)

The differences between those numbers' consumption patterns originate from multiple country-specific factors. Besides, the composition of the Dutch demonstrator and the motivation towards being sustainable is very different than the Dutch average. The average annual heat and electricity consumption of dwellings in the Aardehuizen community are summarized in Table 2 to give insight into how energy resilient this neighborhood is. The complete data from Aardehuizen was available from 2016, so we reformulated the Dutch averages for that period with different dwelling types and compare them.

Table 2: Dutch national averages per type of dwelling and comparison to the demonstrator average dwelling for the year 2016 (STATISTICS NETHERLANDS (CBS) 2018)

Type/Variable	Electricity consumption	Fossil / Biomass consumption	Total eq. consumption	Fossil / Biomass per m^2	Total eq. per m^2
Average Household	2910 kWh	1300 m ^{3} gas	16625	125 kWh/ m^2	150 kWh/m^2
Detached	4120 kWh	2300 m ^{3} gas	28385	134 kWh/ m^{2***}	156 kWh/m^2 ***
Semi detached	3500 kWh	1750 m ^{3} gas	21963	138 kWh/ m^{2***}	165 kWh/m^2 ***
Aardehuizen	3851 kWh*	632 m^3 gas eq.**	10518	58 kWh/ m^2	92 kWh/m^2

*Based on yearly electricity bills.

**Unregular use of biomass - mainly wood. Some data records were corrupted therefore it required interpolation of the missing data – resulting in approximate numbers.

***Indicative values based on reference houses surfaces defined in (RVO 2017) by dutch gouverment.

The number of people per house is 3.4 in Aardehuizen (vs. 2.1 dutch average), which means that Aardehuizen is consuming 20% less electricity than the Dutch average in terms of kWh spent per person. In addition, Aardehuizen is composed mainly of detached and semi-detached houses, where these types of houses on average consume significantly more electricity. Moreover, these three Dutch average figures, reflect only gas heating, as opposed to Aardehuizen where wood and electricity are used for heating. Therefore, to compare the electrical consumption accurately to detail the consumption patterns, the electrical heating data needs to be separated from other appliances' consumption. That would decrease kWh for Aardehuizen and would allow a fair consumption. Even with the current information, rather per capita, or in the category of houses that it is belonging, Aardehuizen is more sustainable than the Dutch averages in terms of electricity consumption. The electricity data recording activities will reveal more precise information about the characteristics of Aardehuizen.

For the solar electricity supply (PV), as being in an urban location free of shadows (such as other high buildings) and benefitting a good system design by experts, Aardehuizen PV production per installed power (kWh / kWp) appears to be higher (1050 kWh/kWp according to publicly available, hourly recorded data (PVOUTPUT 2022)) than national averages reported (950 kWh/kWp) in literature (EUROPEAN PHOTOVOLTAIC SOLAR ENERGY CONFERENCE AND EXHIBITION & NICOLA 2020). This is the first investigation with data recorded from the inhabitants so far. Some days or months are missing. Further investigation is needed with data recording and crosschecking. One also be aware that solar production is also subject to year-to-year weather variability (+/- 50 kWh/kWp in the Netherlands (JOINT RESEARCH CENTER OF EUROPEAN COMMISSION 2020)).

Solar electrical boilers, solar thermal panels, electrical boilers, and wood are used for heating Aardehuizen, which is quite different than a usual heating system which occurs mainly to be gas. The various source of heat makes it also difficult to reach all the data. For easing comparison, Aardehuizen values are translated into the gas, kWh, and kWh/m^2 equivalent in the table to give an overview. Although having the same surface area as the Dutch average household, Aardehuizen seems to have halved their heating energy demand, and decreased 40% below their total energy demand, compared to the dutch average household.

The data from Aardehuizen was limited and relatively old, which did not allow us to derive assertive conclusions. Yearly data gives an overview but does not provide any consumption pattern or flexibility potentials. Simulation activities were required to get a more actual, accurate synthesis of the energy demand, flexibility potentials, and set of measures that could result. The next subchapter will detail the heating system, and how it was simulated and assessed further per separate households.

3.4 Assessing heat demand & supply

During a site visit to Aardehuizen in December 2021, the heating network of 6 houses were sketched out after discussions with their respective residents. The houses at Aardehuizen have heating systems that are unconventional in nature. However, within Aardehuizen itself, most houses share a similar (base) structure.

Most houses have a woodstove and a solar collector that act as heat inputs to a buffer tank. Heat is drawn out from this buffer for various domestic requirements. Many houses follow this structure with some minor modifications to the same. Figure 8 is an example of a house that implements this general heating system structure. Some houses have hot-filled white goods such as a hot-filled dishwasher. In such a case, the heat from this central buffer would be used to pre-heat the water used in the dishwasher. This reduces the energy demand of the dishwasher itself.

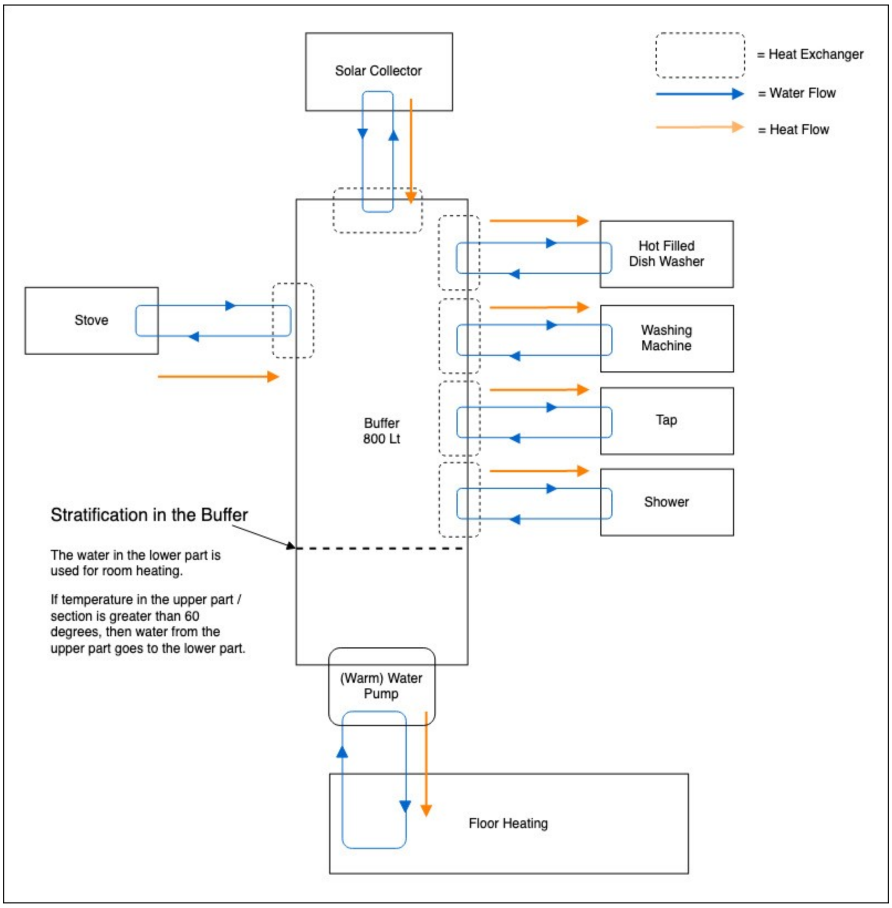

Figure 8: A house that follows the general heating system design. An interesting aspect of the heating system in this house is the stratification in the buffer.

3.5 Simulations of the current situation

A survey was done in Aardehuizen to find out the number of adults and the number of kids living in each house in Aardehuizen. The above information, combined with public information (AARDEHUIZEN 2022), personal communications, and publicly available statistics (STATISTICS NETHERLANDS (CBS) 2018) , is used as input for the ALPG configuration. This configuration results in the aforementioned load profiles in 1-minute resolution and flexibility information for each of the 24 houses, which in turn serves as input data for the DEMKit simulation model of the Aardehuizen neighbourhood. Within this model, per house information about the PV panels and inverter specifications and the electric boiler were added. The power profiles that result from simulations of a base-case, i.e. the situation as is currently, have been fine-tuned to match the collected information and obtained measurement data at Aardehuzien so far. This results in a validated base model, to which envisioned measures can be added to evaluate their contribution. This is part of the following chapters.

Figure 9 shows the total power profile at the neighbourhood/community level and Figure 9 shows the total power profile at the smart meter of House 6 for 1 week (June 1st to June 7th). Both the house and the time period of 1 week are randomly chosen. Power data with 15 mins resolution was used for both graphs.

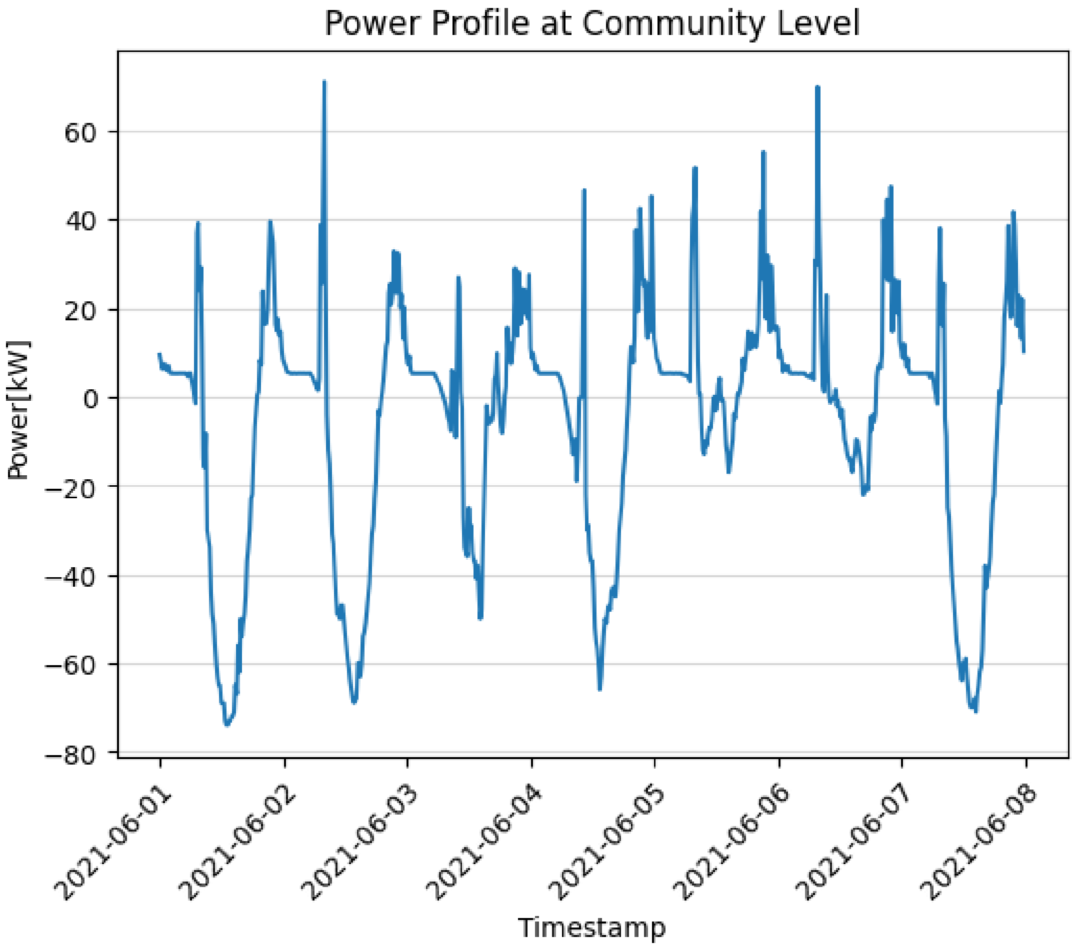

Figure 9: Power profile for 1 week at the neighbourhood community level.

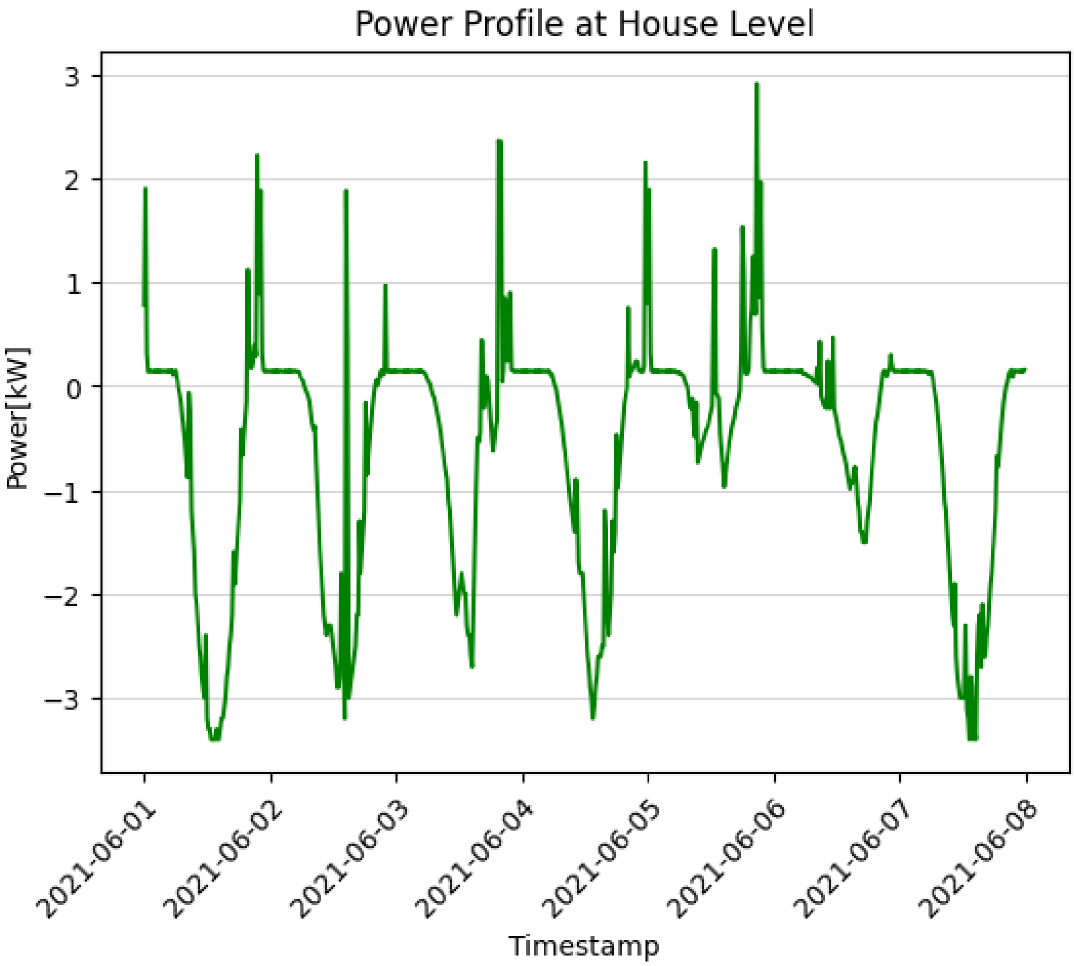

Figure 10: Power profile for 1 week at the house level.

3.6 Comparison with simulations and real data recorded

The average annual energy consumption per house of Aardehuizen based on on-site smart meter data recorded over the years 2015 to 2016 was 1403 kWh. This is the latest on-site smart meter data available. The average annual energy consumption per house of the Aardehuizen model built with ALPG's generated data for 2021 was found to be 1636 kWh. Therefore, the ALPG generated data shows a difference of 233 kWh with the on-site smart meter data.

This is a small difference and can be attributed to many reasons. For example, the ALPG assumes regular usage of the Middenhuis (middle house/central common house). However, being the central house, the Middenhuis may be used only on certain special occasions such as, for making announcements, for community-wide meetings, or for emergencies. Therefore, in actuality, the Middenhuis' actual energy consumption is likely to be much lower than that anticipated by ALPG.

Additionally, as illustrated in Section 3.4, many houses have hot-filled white goods such as a hot-filled dishwasher and/or a hot-filled washing machine. Since many houses have a solar collector and a woodstove for local heat generation, the input water required for such hot-filled white goods is heated using this locally generated heat. This eliminates the need for the hot-filled white goods to consume energy from the grid to heat the water itself, reducing its actual energy consumption. However, ALPG simulates the profile of a normal white good which is likely to be higher than that of an on-site hot-filled white good.

4 Flexibility Options and Solutions

4.1 Hybrid electrical storage solutions

This section first discusses hybrid electrical storage, including time-scales at which energy storage functions optimally. Next, a preliminary investigation is conducted for hybrid electrical storage for the Aardehuizen.

4.1.1 Hybrid Energy Storage Systems and Time-scales

Hybrid Energy Storage Systems (HESS) is defined here as systems where more than one storage technology is used. For this section, the focus is on electrical storage, meaning storage that is connected to an electrical network (in this case the Aardehuizen Low Voltage network) and is suitable for bi-directional energy exchange. Examples of storage technologies meeting this definition are Lithium-Ion batteries, supercapacitors, flywheels as well as hydrogen hubs where both electrolyzers and fuel cells are used for conversion to and from hydrogen. Heating solutions are discussed separately in Section 4.2.

Electrical storage technologies function optimally when used at specific time-scales (SABIHUDDIN ET AL. 2014). A time-scale here is defined as the period in which a time-scale must react to sufficiently meet whatever function is required of it. For each time-scale a category of functions is defined. In (SABIHUDDIN ET AL. 2014) the categories of functions, each handling electrical network behavior occurring on a certain time-scale, are given as:

- Power Quality and Regulation (< one minute)
- Bridging Power (one minute – one hour)
- Energy Management (> one hour)

Figure 11 displays an overview of different storage technologies in respect of time-scales. Energy Management is a large category, which encompasses both functions closer to day/night cycles as well as seasonal storage (>four months), which both generally require different storage solutions. For the purposes of this research, it is necessary to split Energy Management into shorter term (< one week) and longer term (> one week).

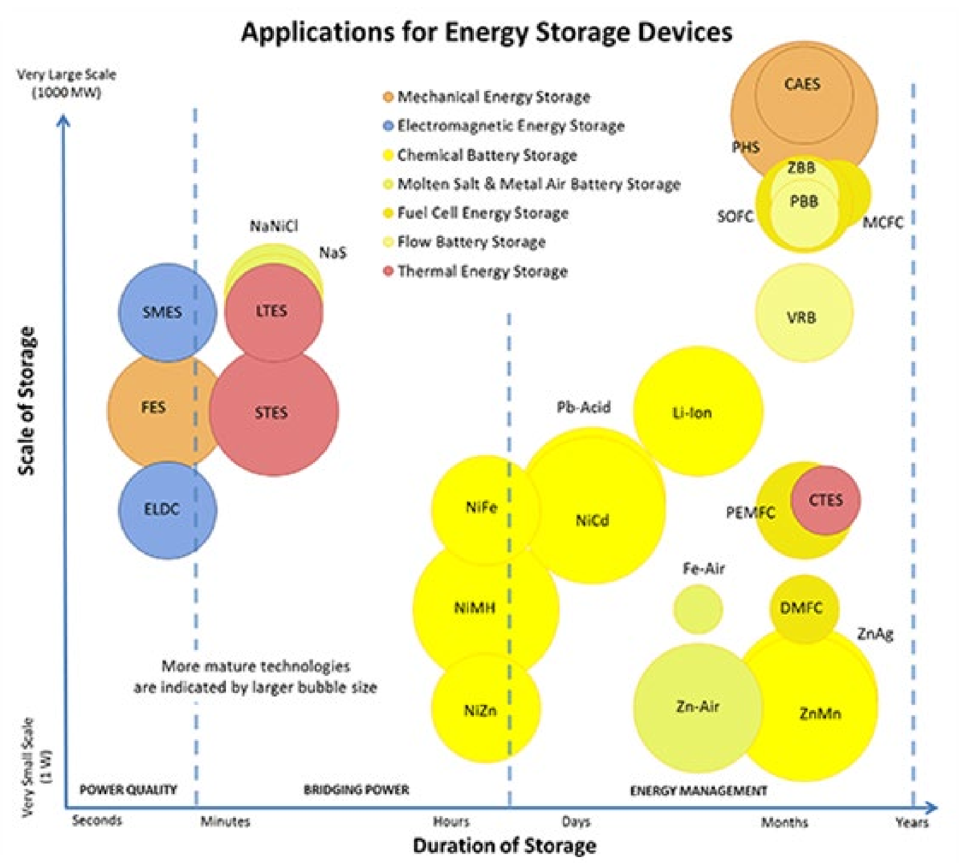

Figure 11 Storage technologies and categories of functions (Sabihuddin et al. 2014)

As storage technologies each function optimally at a certain time-scale, storage is used sub optimally in situations where functions from multiple time-scales are needed. By using HESSs, the advantages of each single storage solution are accentuated while the drawbacks are reduced. This can lead to less storage degradation (Masih-Tehrani et al. 2013). Additionally, as storage is generally costly, conventional wisdom is that HESSs are more expensive than any single storage device, but this does not have to be the case as shown in, due to storage devices being used within their optimal timescale and therefore having a longer lifecycle (Wen et al. 2017).

4.1.2 Hybrid Storage Requirements for the Aardehuizen

One of the goals of the Aardehuizen inhabitants is to reduce the dependency on the grid connection of their local microgrid. This can be achieved through a variety of local microgrid flexibility assets, one of which is by using HESSs. The connected grid can still be used to guarantee Power Quality (PQ), meaning an acceptable voltage and frequency, as well as reduce the sizing of the HESS requirements by guaranteeing energy availability. As the Aardehuizen produces more energy in a year than it consumes, energy should be kept local that is intended for use by the inhabitants, while the remaining energy can be exported to the grid.

A decision is made to investigate a HESS consisting of two storage devices, one for short-term behavior (Bridging Power and Energy Management on a day/night basis) and one for long-term behavior (seasonal storage). Two separate analyses are conducted using Load Profile Analysis Tool (LPAT), a tool developed by the Saxion in collaboration with the University of Twente (SCHAEFER, E. ET AL. 2022). LPAT is used to decompose an imbalance load profile of a power network into multiple sub-profiles, each representing a time-scale of interest. From each sub-profiles, an analysis is conducted to derive the flexibility requirements necessary for a single storage device to handle that particular sub-profile (time-scale of the original total power imbalance), and ascertain if a storage device exists that can feasibly meet said requirements. LPAT is employed as a preliminary investigation tool in order to gain insight into sizing requirements for single storages or HESSs, which can then be used for a more in-depth analysis with a modelling tool such as DEMKit. This pre-analysis gives a general indication of the requirements needed with little computational effort, reducing the design space that must be investigated in a more in-depth analysis.

The first analysis of the Aardehuizen situation focuses on short term behavior. Here, a single Aardehuizen households load profile is analysed for the period April 2019 to March 2020, with May 2020 being replaced with May 2021 due to large data gaps in the May 2020 dataset. The load profile is constructed from measured data from a household's smart meter, with a sampling frequency of one measurement every 10 seconds. Due to this relatively high resolution of data, much insight can be gained into the household's behavior on a sub-minute basis, but not enough to gain insight into second or sub-second (Power Quality) behavior. The sub-profile created using LPAT to investigate short-term storage requirements uses a cut-off frequency of 1/1800 HZ, meaning that this sub-profile contains the behavior of the time-scale 15 minutes or less. From this, the following storage flexibility requirements are derived:

- Power Range, -2.7kW to +8.7kW
- Ramp Rate Range, -0.5kW/s to +0.5kW/s
- Energy Capacity, 3.9 kWh

It is possible to also divide this particular sub-profile into multiple sub-profiles, again each representing a different storage solution, for example, if PQ related improvement is desired using supercapacitors or flywheels). This will be investigated further in the course of the project.

Figure 12 shows the load duration curve for the power to be handled by the connected grid, both in the situation where no storage is available locally (blue line) and the situation where storage is included locally (orange line). There is a large reduction in the power requirements of the connected grid. Further investigation is required to ascertain improvements to the Degree Of Autarky (DOA), for which DEMKit can be used. Additionally, the flexibility requirements as stated are for a single household and not for all houses, EVs or the solar parking lot. Further investigation will be undertaken using granular (10 seconds time interval) measurement data from the entire neighbourhood to gain a better insight into the exact short-term storage required on a neighbourhood level.

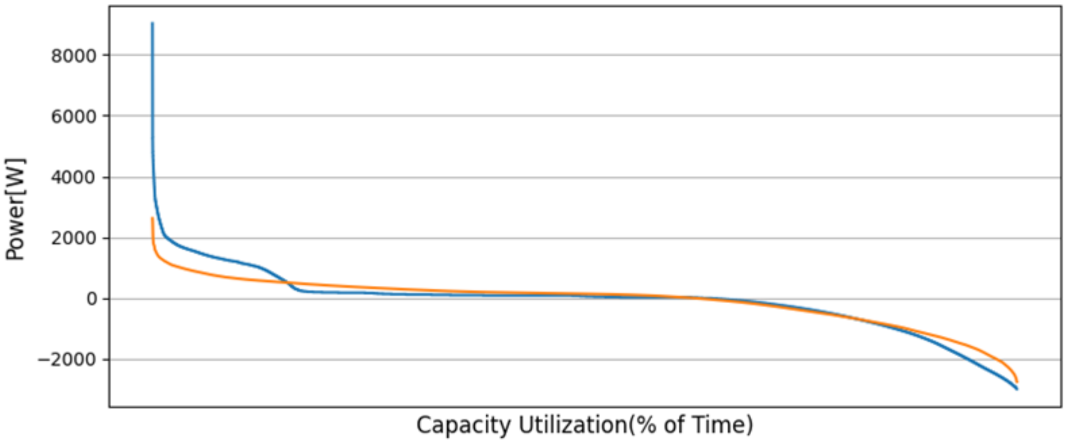

Figure 12. Load Duration Curve original situation and situation with storage

The second analysis focuses on long term behavior. As no measured data set is available currently, an artificial dataset for the entire neighbourhood was created using Artificial Load Profile Generator (ALPG), a tool developed by the University of Twente (HOOGSTEEN 2016). The data set is for one year (January to December), with time intervals of 15 minutes. This time interval resolution is not sufficient to investigate short term storage requirements as in the previous analysis, but is sufficient to investigate long term storage requirements. Again, LPAT is used to create a suitable sub-profile. A cut-off frequency of 1/1800 Hz is again used, however this time the behavior is higher than this cut-off frequency that is used to create the sub-profile. Figure 13 shows the created sub-profile, from which the following storage flexibility requirements are derived:

- Power Range, -16.8kW to +14.7kW
- Ramp Rate Range, -8.9 mW/s to +6.6 mW/s
- Energy Capacity, 49 MWh

For long-term storage the capacity requirements are large. It is not sensible to do this locally, but off site, meaning the grid connection will need to be used to handle this sub-profile. Then, a storage technology can be employed in another part of the power grid, for example a hydrogen hub. There are two notes here. First, as the Aardehuizen has an average overproduction of energy over a year, not all energy should be returned to the local grid, as it is not needed. Second, local curtailment of energy generated from PV can reduce the storage requirements, as less energy will then need to be stored. Both points will be investigated further in the project.

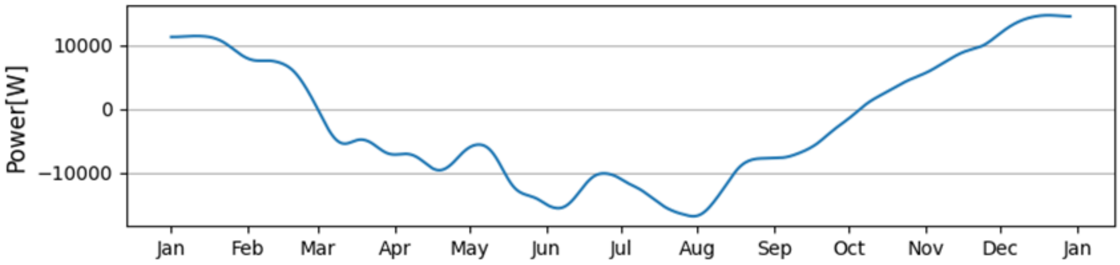

Figure 13. Long Term Storage Load Profile for one year for entire Aardehuizen neighbourhood

4.2 Hybrid heating solutions

The houses in Aardehuizen exhibit many important lessons about how architectural design and frugal techniques can result in innovative and effective hybrid heating systems. Each house has a solar collector on its roof and a woodstove in the centre of the living room or the common area. The solar collector and the woodstove heat up the water in the buffer tank. This buffer tank acts as the central heat storage unit and heat stored in this buffer tank is then used for different domestic purposes. In summer, the heat produced by the solar collector is enough to fulfil the house's needs. This locally generated heat is also used by houses that own hot-filled white goods to heat the input water flow. This reduces the energy demand of these devices.

The southern face of the houses have tall ceiling-to-floor windows intended to maximise the amount of sunlight and heat let into the house. The house itself acts as a thermal mass retaining this heat. Using such an architectural design technique to acquire and retain heat in the house reduces, and in many houses eliminates, the need for the same to be achieved using a specific device, say a heat pump. In winter, the residents burn wood pellets in the woodstoves and the generated heat combined with the house's heat retention construction material and design, is enough to keep the house warm. This reduces or eliminates the need for heat pumps or floor heating.

Each house in Aardehuizen is designed to require minimal external energy production to fulfil its needs. Automation, for example of the prediction and application of temperature preferences, could improve the energy efficiency of each house by some extent.

4.3 Electric Vehicles

Electric vehicles (EVs) are in essence also storage devices, but on wheels. Furthermore, EVs provide access to a non-fossil-fuel based transportation option for the medium to long distance. Furthermore, the Aardehuizen community recently installed a solar carport with 222 PV panels and a total installed generation capacity of 71kWp. Annually, the carport could generate as much energy as would be required to travel approximately 400,000 km (NIJENHUIS ET AL. 2021). One charger is already installed as one of the inhabitants owns an EV.

The 23 households of the Aardehuizen community strive to travel as carbon-friendly whenever possible, e.g. by public transport and bike. However, these means of transportation are not always suitable. It is envisioned that three EVs to be shared by the community would be sufficient in most cases. One of the measures to be taken is therefore to install three charging stations with a power rating of 22kW each. This power capacity ensures that the chargers together have the capacity to (nearly) fully utilize the peak capacity of the installed solar panels. Furthermore, the requirement is that these charging stations need to be locally controllable to match the PV generation in real-time. Algorithms for the DEMKit EMS to perform robust peak shaving under the uncertainty of PV production already exist (SCHOOT UITERKAMP 2021). Furthermore, these algorithms have also been tested in practice (HOEKSTRA 2018). After consulting prices and capabilities (see Annex E), some features stand-out such as smart charging and load adjusting, easiness to control, connectivity, identification (RFID), and maximum charging power. After considering all these factors, we have chosen for the Alfen Pro-Line Single 22kW charger as best value (Annex E).

4.4 White Goods

Decentralized Energy Management toolKit (DEMKit) (Hoogsteen et al. 2019) is a simulation software developed by the University of Twente. The data output by ALPG was used to perform a year-long optimisation simulation using DEMKit. Profile steering, a demand-side management algorithm developed by (Gerards & Hurink 2019) was used for the same.

Devices such as washing machines and dishwashers are 'Time Shiftable' devices. This means that the power use, and therefore the operation profile, of such devices can be shifted in time. Usually, the time window in which the device must finish its operation is defined by the end-user. For example, if the user provides flexibility by setting a later end-time interval within which the dishwasher must be finished, an algorithm can use the given flexibility to optimise the operation of the dishwasher to e.g. use locally generated sustainable energy.

Heat pumps can be considered as 'Buffer Converter' devices. These devices convert energy from electricity to heat. These devices are also coupled with a storage system. If the storage system is sometimes not explicitly present, it may be available through the piping systems. In a buffer converter device, the demand and production of energy can be decoupled using the buffer.

We consider four scenarios to study the flexibility potential in Aardehuizen. In each scenario certain devices are controlled by the optimisation algorithm in DEMKit called Profile Steering, by using their characteristics as a Time Shiftable or a Buffer Converter device. If a device is controlled by the optimisation algorithm, then it is marked green and if it is not controlled by the optimisation algorithm then it is marked red. This is illustrated in Table 3.

Table 3: The four flexibility scenarios and the devices which are controlled (or not controlled) in each scenario.

No.	**Scenario Name**	**Scenario Description**	**Washing Machine**	**Dishwasher**	**Electric Boiler**	**Heat Pump**
1	No Control	No optimisation algorithm is applied.	🟥	🟥	🟥	🟥
2	Dishwasher as Static Load	Only the dishwasher is restricted to run as a static load device.	🟩	🟥	🟩	🟩
3	Dishwasher and Washing Machine as Static Loads	Both, the dishwasher and the washing machine are restricted to run as static load devices.	🟥	🟥	🟩	🟩
4	Full Optimisation	All devices are controlled by the optimisation algorithm.	🟩	🟩	🟩	🟩

Figure 13 shows the load duration curves for an entire year at the Smart Meter for House 6 (randomly chosen) for all four scenarios. Furthermore, Figure 14 shows the load duration curves for all 4 scenarios for House 6 for the duration of 1 week (June 1st to June 7th).

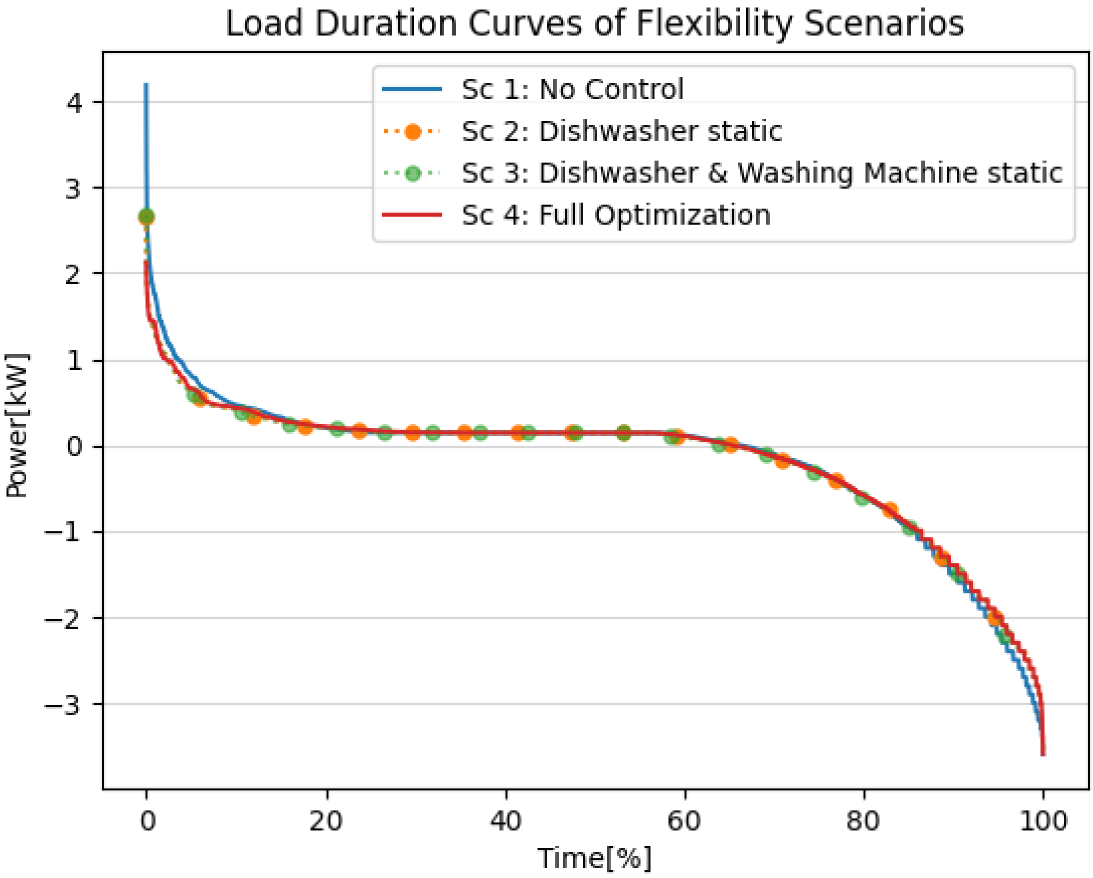

Figure 13: Load duration curves at the Smart Meter of House 6 for 1 year.

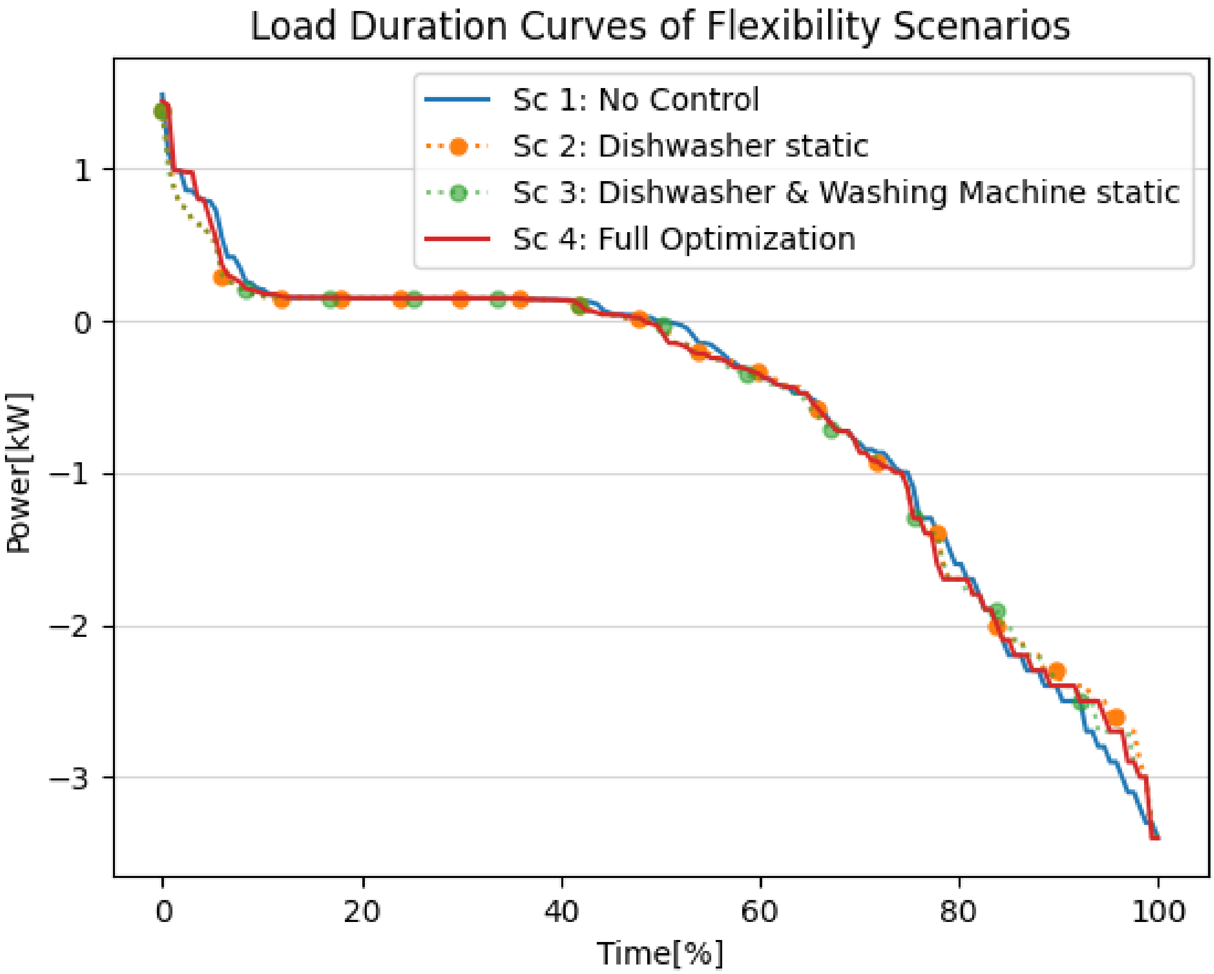

Figure 14: Load duration curves at the Smart Meter of House 6 for 1 week in June.

As can be seen from the Figure 13 and Figure 14, white goods offer marginal potential for flexibility. A similar study was conducted by Gerards and Hurink regarding the value of device flexibility (white goods, EVs and home batteries) for the overall system (GERARDS & HURINK 2017). They reported the same result regarding the low potential for white goods flexibility and stated three reasons for the same. Firstly, white goods are not used every day but often once or twice in the week. This reduces the number of instances that white goods have to impact the house profile. Secondly, as white goods become more technologically advanced, they also become more energy efficient. A smart washing machine today consumes lesser energy than one 20 years ago. Thirdly, for white goods to be able to offer their already limited flexibility potential, accurate predictions of the future are required. For example, an accurate day-ahead PV profile to know when abundant PV is available is needed. This is because the operation of white goods is uninterruptible and therefore, once started their operation cannot be stopped due to prediction errors. Gerards and Hurink conclude that batteries and EVs offer much higher potential for flexibility than white goods for the two demand side objectives of peak-shaving and self-consumption.

The Dutch smart grid pilot Your Energy Moment (YEM) studied the load shifting potential of white goods, specifically a washing machine and a tumble dryer (KLAASSEN ET AL. 2016). In this study, the users could set the desired end time and from this, the device would automatically set the start time within the operation time window. Klassen *et al.* used a dynamic price profile that incentivized load-shifting from the evening hours to the midday hours (when PV is abundant) or the night hours (when load is low). They found that, on the days when the washing machine was used, and users made use of the scheduling function, a load reduction of 34% was seen in the evening hours. They observed that a price incentive may be required to incentivize such load-shifting. This could lead to users being rewarded for load-shifting even if said load-shifting doesn't contribute to overall system flexibility. On a positive note, they noted that the use of the newly introduced scheduling function was consistent throughout the study, concluding that the users could quickly and easily adapt to the new demand response scheme.

5 Value creation of the smart grid

The proposed measures result in added flexibility to the energy system of the Aardehuizen community in particular, and the residential sector in general. Within Chapter 3 and 4, we have explored the impact of utilizing such energy flexibility in the context of the goals as expressed by the Aardehuizen community by minimising their carbon footprint through peak shaving. Where flexible assets remain and are static, the flexibility they offer can be utilized dynamically, which means that objectives may change as the energy landscape moves on in the energy transition and external factors may heavily influence the market prices. This has been seen recently in the geopolitical situation concerning Ukraine and Russia, but also the efforts on reducing our carbon footprint. This chapter therefore discusses the value of flexibility in the context of energy transition and in a broader sense. That is, the value not necessarily is measured in an economic sense (yet), but could, for example also be valued in improved sustainability or quality of life.

5.1 Levelized cost of electricity of the systems

The levelized cost of electricity (LCOE), is a measure used to assess and compare alternative methods of energy production [Corporatefinanceinstitute.com]. The LCOE is used in the preliminary assessment of an energy-producing project to evaluate if the investment is worthwhile. The formula to calculate the LCOE is: (Present Value of Total Cost Over the Lifetime)/(Present Value of All Electricity Generated Over the Lifetime). The LCOE can be calculated by first taking the net present value of the total cost of building and operating the power generating asset. This number is then divided by the total electricity generation over its lifetime. The total costs associated with the project generally will include:

- The initial cost of investment expenditures (I)
- Maintenance and operations expenditures (M)
- Fuel expenditures (if applicable) (F)

The total output of the power-generating asset will include:

- The sum of all electricity generated (E)

The last two important factors to be considered in the equation are:

- The discount rate of the project (r)
- The life of the system (n)

As equations below (Corporate Finance institute 2022):

$$\text{LCOE} = \frac{\text{NPV of Total Costs Over Lifetime}}{\text{NPV of Electrical Energy Produced Over Lifetime}} \qquad \text{(Eq. 1)}$$

$$\text{LCOE} = \frac{\sum \frac{(I_t + M_t + F_t)}{(1 + r)^t}}{\sum \frac{E_t}{(1 + r)^t}} \qquad \text{(Eq.2)}$$

The electricity system at Aardehuizen contains the following systems aspects and cost drivers:

- PV-systems. At this stage most home PV-systems have a pay-back time within a period of 7 to 8 years. In general all electric energy generated yearly by a home installation, is subtracted from the used energy. The balance (negative) is paid for by or (in case of surplus generation, positive) paid to the home owner.
- Energy grid. The tariff per kWh unit of electric energy is fixed by contract but for a positive energy balance it is a lower tariff than for a negative energy balance. This is the same as any exchange market: the tariff for buying energy is usually higher than the tariff for selling energy. At this stage there are possibilities for home owners to participate in a flexible tariff scheme, some energy companies offer this service also to home owners, although the tariffs do not vary as much as the real market prices of energy exchange markets.
- Part of the energy grid: taxes. The dutch government levies taxes on energy per kWh that is being sold to home owners: (a) energy tax, (b) raise tax for renewable energy, (c) VAT. These taxes are also included within the energy balance calculation. In case of a positive energy balance, the home owner receives a tariff per kWh for the delivered surplus energy, but also has to pay VAT.
- Local infrastructure. At Aardehuizen, the local infrastructure (from the street to the neighborhood and the houses) is owned by the regional network company Enexis. It is part of any energy contract that each home owner pays the same fixed, yearly tariff for a certain capacity connection which includes the metering service.
- Flexibility assets on the home or neighborhood level. In the Netherlands, home owners at this stage have little financial gains to be expected from flexibility exploitation, unless there is a significant positive energy balance and the costs of flexibility assets is sufficiently low.

For the flexibility options under consideration at Aardehuizen, their levelized cost will be taken into account in the following sections.

5.2 Potential economical savings

With the ongoing adoption of renewable energy sources and inherent intermittency, it is expected that the energy markets' volatility will continue to increase. Also citizens can, directly and indirectly, benefit from fluctuating energy prices through optimal usage of their flexibility. Three main options arise:

- Subscribing to a time of use (TOU) pricing scheme, where energy prices fluctuate throughout the day. Scheduling the operation of devices, aided by the energy management system, at moments of low prices can significantly lower the energy bill (VARDAKAS ET AL. 2015).
- Handing over control of (certain) devices to an aggregator, who optimises the operation of the device. The advantage is that, through the larger scale, the aggregator can act on multiple markets (simultaneously) to maximise the profit. Part of the profit is returned to the citizen. Parties already exist, such as in California leap (LEAP ENERGY 2022), but also in the Netherlands, e.g. Jedlix for smart charging electric vehicles (JEDLIX BV 2022).
- Similarly to aggregators, also the energy supplier may offer additional revenue schemes by fulfilling a double role as both supplier and aggregator (UNIVERSAL SMART ENERGY FRAMEWORK 2017).

The worth of flexibility that citizens can offer to the system is yet hard to quantify. However, various researches have indicated potential annual savings of €20 to €120 per connection when a smart grid is deployed (VAN MELLE ET AL. 2016).

5.3 Potential ecological savings

Similar to economic optimisation, the usage of flexibility may also be optimised to achieve ecological savings in the form of, e.g. reduced CO_2 emissions. This especially concerns the imports required from the main grid and is affected by the energy mix that results from operating generators. This information is already available (ELECTRICITYMAP 2022) and might also be predictable once it is known which generators are dispatched as a result of the day-ahead market clearing. As a result, a similar vector as TOU prices can be generated, and hence the cost, in this case, CO_2 emissions can be minimised using the same methods. Here, it is assumed that citizens do not yet have a significant role in the total system. However, when scaled up, the combined efforts may reduce the need for expensive backup- and/or peak power plants.

5.4 Perspective benefits for DSO

Another value that can be created using energy flexibility is by improving the operation of the main electricity grid. One goal is to perform peak-shaving as outlined in Chapter 5, which will result in reduced currents and therefore less stress on the grid. These benefits result in increased power quality, better supply voltages, less losses and an increased life expectancy of grid assets (HOOGSTEEN 2017).

Alternatively, by avoiding electricity usage at (local) peak times, it is possible to reduce the load on the grid and thereby avoid grid congestion. This can lead therefore to reduced costs, e.g. through postponing grid reinforcements, and simultaneously provide capacity for the implementation of more renewables in the local grid. Currently, more and more parts of the Dutch grid become congested, both in capacity to host most renewables and in capacity to connect more consumers (NETBEHEERNEDERLAND 2022). Therefore, local congestion markets are emerging, such as GOPACS (STICHTING GOPACS 2022) for companies, but it is also envisioned that similar markets emerge for residents, as also indicated in the USEF framework (UNIVERSAL SMART ENERGY FRAMEWORK 2017). Also, California for instance already implements local marginal prices to resolve local congestion. The aforementioned aggregators make use of these prices to reduce the energy bills of customers. Furthermore, Dutch DSOs are allowed to explore congestion management as temporary solution to avoid congestion(CONSUMER AND MARKET AUTHORITY OF THE NETHERLANDS 2016) .

5.5 Design and user friendliness

Intelligently controlled systems may also enhance the experience by automated actions and/or providing more comfort. Important here is that, to make the Smart Grid work out, a joint effort of man and machine interaction. One of the advantages of utilizing a pro-active energy management system that uses forecast, is that it can also be used to give tips and tricks upfront. For example, it can suggest a suitable start time for a dishwasher upfront, rather than providing feedback after the act. It is shown in the literature that such proactive mechanisms lead to better results and acceptance (MCCALLEY ET AL. 2011), (GEELEN 2014), (DE VRIES ET AL. 2011). The benefits of proactive engagement of citizens within the energy management ecosystem is part of research within the project.

5.6 Simulation results

Based on the DEMKit simulation model (Chapter 3), several simulations have been performed to quantify the potential of adding flexibility to all these metrics. The performance of both the ***current*** and ***future*** community setup are summarized in Table 4. Here, the current setup depicts the situation at the Aardehuizen community in 2021, whereas the future case adds the batteries and electric vehicles as indicated in Chapter 4. Furthermore, control and optimisation have been performed with the three technical objectives presented in this chapter: ***No optimisation*** (current situation), ***day-ahead cost optimisation, CO_2 emission reduction,*** *and* ***peak shaving***. The performance of each of these simulations is evaluated on the three performance indicators: ***Energy costs, CO_2 emissions, and peak shaving performance***. The latter is evaluated using the Euclidean distance of the energy imported and exported, thereby indicating the flatness (the lower the better) of the profile and the effect to reduce the stress on the grid.

For prices, the Dutch day-ahead market prices of 2021 are used (ENTSO-E 2022), without accounting for taxes and other regulations. The CO_2 emissions are calculated using 2021 data of the Netherlands provided by (ELECTRICITYMAP 2022), where negative energy (delivering back to the grid) leads to negative emissions. Optimisation is performed using DEMKit and its built-in optimisation algorithms (HOOGSTEEN ET AL. 2019). A complete year (2021) is simulated using 15 minute time intervals.

Table 4: Performance of various and solutions and optimisation goals (full year, 2021)

	Energy cost [€]	**CO_2 emission [tonnes]**	**Peak shaving**
Curent Situation			
No control	1956.63	-10.72	3,166,070
Peak Minimisation	897.00	-11.66	2,521,703
Cost Minimisation	110.00	-12.20	2,965,474
CO_2 Minimisation	551.07	-12.96	3,090,317
Future Situation			
No control	2259.63	-8.39	2,792,351
Peak Minimisation	1031.68	-9.38	2,021,945
Cost Minimisation	-1564.73	-10.69	5,128,820
CO_2 Minimisation	101.13	-13.47	5,613,594

From the results in Table 4 it is clear that, as is to be expected, directly optimising towards a certain goal leads to the best achievable results. The case without control usually leads to the worst performance across the board, except for peak shaving in the future situation. Here, greedy optimisation to global incentives (prices or CO_2) emissions. This is the result of the greatly increased flexibility, which is used to its fullest potential, leading to large power peaks due to synchronized usage of flexibility. This phenomenon is also observed in the literature (MCKENNA & KEANE 2014).

In the current situation, smart control of white goods and the electric boilers can lead to an annual cost reduction of €1846.63 in total (without taxes), which is equivalent to approximately €80 (without taxes) per household. Alternatively, an additional 2.24 tonnes of CO_2 can be reduced. Furthermore, peaks can be slightly reduced, as also shown in the load duration curve depicted in Figure 15.

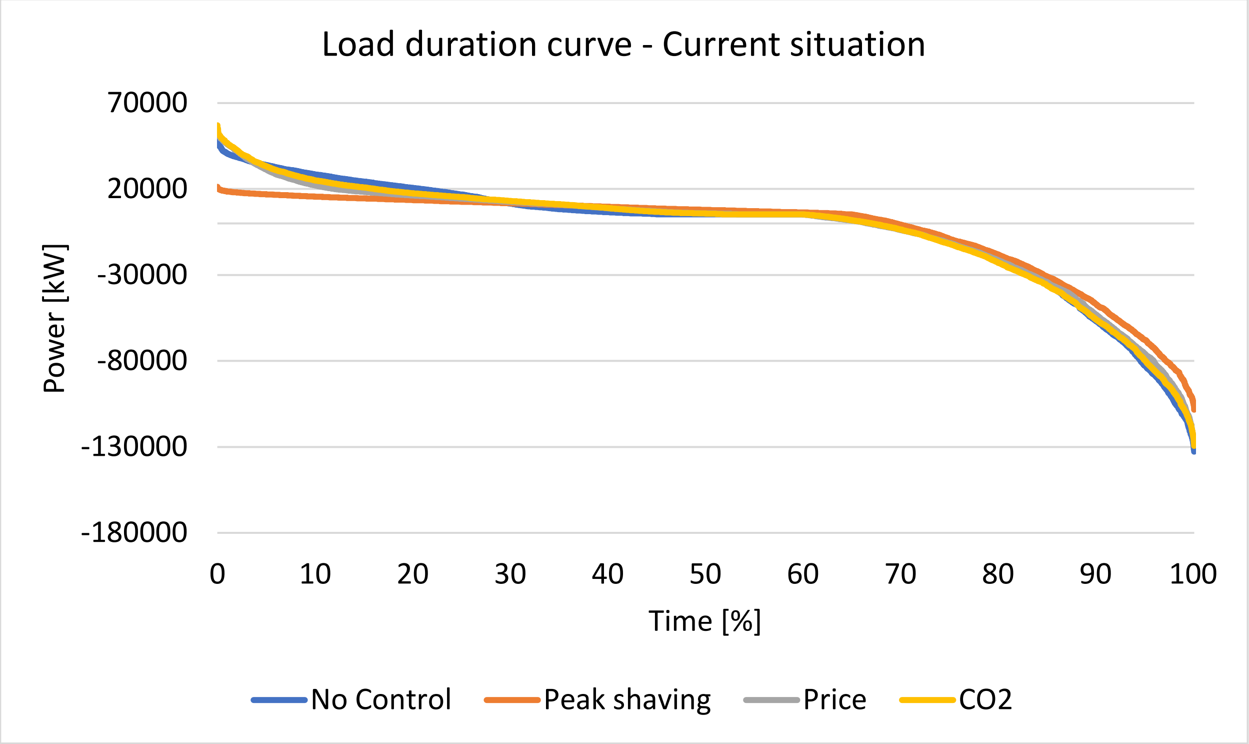

Figure 15. Load Duration Curve depending on various optimisation priorities for current situation

The future case shows that significant amounts of flexibility are added, resulting in an even flatter load duration curve (Figure 16) when peak shaving is used as an objective, especially when it concerns limiting the export to the main grid from surplus PV generation. Alternatively, an additional 5 tonnes of CO_2 can be reduced (60%). Lastly, an annual cost reduction of € 3824.36 (without taxes) can be achieved, or approximately €166 per household. The load-duration graphs however show the tremendous peaks of the synchronization effect of this optimisation towards cost minimisation or CO_2 emission minimisation. Noteworthy is the fact that foreseen upgrades do only lead to reduced CO_2 in case of direct optimisation to reduce emissions. This is due to the increased demand due to the EVs.

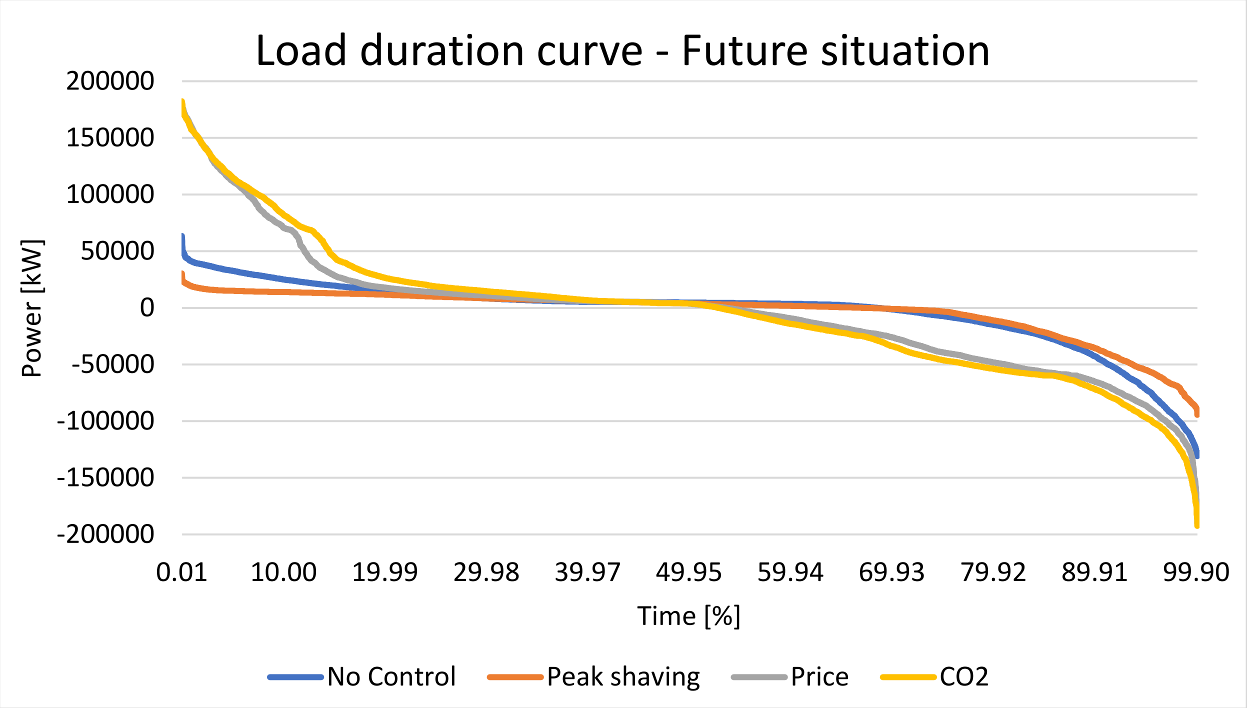

Figure 15. Load Duration Curve depending on various optimisation priorities for the future situation

The price- and emission-based optimisation leads to high peaks. Therefore, another study is executed where simultaneously the import of electricity is minimised by trying to avoid imports. The results are presented in Table 5, and shows that in this case the three optimisation objectives lead to similar results, where peak-shaving seems to perform overall the best.

Table 5: Performance of various and solutions and optimisation goals while limiting the imports.

	Energy cost [€]	**CO_2 emission [tonnes]**	**Peak shaving**
Future Situation – Limited import			
Peak Minimisation	1031.68	-9.38	2,021,945
Cost Minimisation	1024.45	-9.38	2,320,907
CO_2 Minimisation	1151.09	-9.63	2,490,951

More results are presented in the Table in Annex F, where also figures are given for imported electricity. Noteworthy is that in the current case uncontrolled, the electricity imported from the main grid results in 35.0 tonnes of CO_2 emissions, whereas the future peak shaving situation reduces this to 19.7 tonnes CO_2. Also the energy to be imported reduces from 65.7 MWh to 48.1MWh.

6 Conclusions

This document provides a feasibility study for the pilot study to achieve and "Integrated local energy system demonstrator in Netherlands" (WP5). Firstly, the document has provided an evaluation of the situation at the Aardehuizen demonstrator as it is today. The goals of the community, since their founding, as well as the community efforts, have made the demonstrator location a sustainable society from the beginning and a pinnacle of what is possible. This is also proven by the significantly lower energy usage compared to the average Dutch household.

Based on known and collected data and information, a sophisticated model using DEMKit and the ALPG is created. This model serves as both a simulation model, utilizing digital-twin concepts, as well as the basis for demonstration. For the latter, hardware is developed and installed to obtain the information required for validation. The data is stored in a scalable platform.

Through the generated profiles and simulation models, the impact of different flexibility options is assessed. Results in Chapter 4 indicate that installing short-term storage in the form of batteries can significantly reduce the imports and exports of energy within the main grid. Furthermore, significant flexibility can be added through the adoption of sharing EVs with 3 smart charging stations, and through intelligent control over the water boilers and heat buffers. Lastly, limited flexibility is found to be available with optimal use of white goods, which can be executed largely manually with the right tools and incentives. Also, it is noted that seasonal storage requires too much capacity and is deemed infeasible for now to become soft or fully islanded.

Flexibility in the given context can be used to improve the performance of microgrids in, different aspects, such as, among others, peak-shaving, cost reduction, or ecological benefits. Chapter 5 assessed the resulting potential of implementing all presented forms of flexibility (in Chapter 4), based on three performance indicators: Energy costs, CO_2 emissions, and peak shaving performance while optimising the potential for either of these three. The results indicate that the proposed setup with peak-shaving as objective results in a community and cooperative energy system. Furthermore, such a system simultaneously benefits the grid, and reduced imported emissions. The resulting annual electricity imports from the main grid are reduced from 65.7 MWh to 48.1MWh, leading to an emission import reduction from 35.0 to 19.7 tonnes of CO_2. The cost savings are moderate with €925 compared to the current situation, whereas more savings could be achieved (€3521) when optimising the future situation for cost minimisation compared to the present-day situation.

In perspective, with the value case mapped, the impactful solutions will be further investigated in detail, with the additional field data and optimisation algorithms. Value and business case will be further worked into more detail in collaboration with business case experts and societal aspects (WP3) results. The energy contracts, adequate technical solutions, and business case will be further detailed (D5.2) in order to make the right procurement steps such as sizing/technology of the commune battery. Implementation of the battery with EV chargers, and realization of the smart control will be demonstrated as part of our future work. Based on our findings, heating, community battery, and EV charging via solar production have great potential to be further tested and intelligently controlled.

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8 Annex

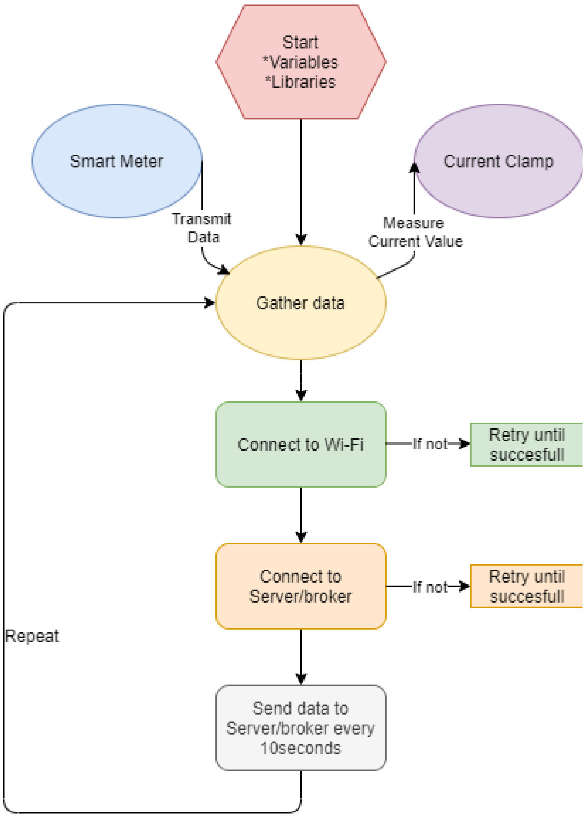
Annex A Comparaison of Dutch smart grid pilots

Annex A1. Table that list notorious Dutch smart grid pilots with end users engagement and technologies deployed

Dutch Pilot	Start-End Date	Nr. of Cases (households or Vehicles)	Technologies													
			Smart Meter	**Energy Management System**	**Energy App**	**Battery EV**	**Smart Charging**	**Smart Appliances**	**rooftop PV systems**	**Virtual Power Plant**	**Micro Combined Heat and Power**	**Demand-Response Pricing Mechanism**	**Heat Pumps**	**Battery**	**Electric Boiler**	**Fuel Cell**
Aardehuizen - Current - Olst	2012-…	22	**X**		**3**	**1**			**x**				**x**		**x**	
Aardehuizen - Future				**x**	**x**	**x**	**x**					**x**		**x**		
Vriendenerf Current- Olst	2017-…	12	**x**						**x**				**x**			
Vriendenerf Future				**x**	**x**	**x**	**x**					**x**				
Previous Dutch Pilots																
Power Matching City -Groningen	2007-2010	25 houses	**x**	**x**		**x**		**x**	**x**	**x**	**x**		**x**			

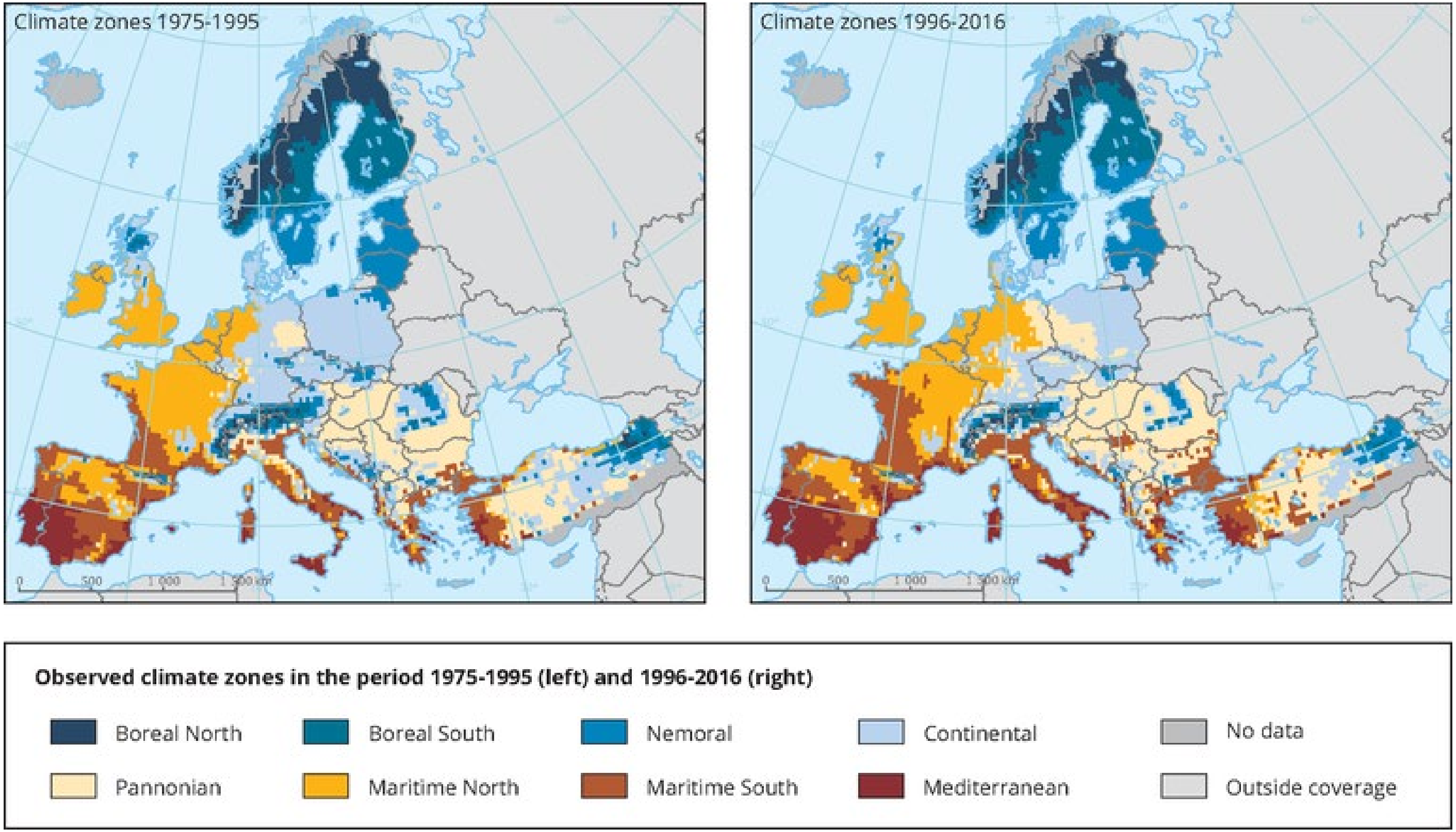
	2012-2015	40 houses	x	x		x		x	x	x	x	x	x			
Jouw Energie Moment Breda	2012-2015	382 houses	x	x	x			x	x			x	x			
	2017-present	93 houses	x	x					x			x	x	x		
Rendement voor Iedereen Amersfoort	2012-2014	100 houses	x		x	x			x							
Hoog Dalem **Gorinchem**	2014-2017	42 houses	x	x					x				x	x		
EnergieKoplopers **Heerhugowaard**	2015-2016	203 houses	x	x					x				x		X	x
	2017-present	100 houses	x						x				x	x		
Smart grid Lochem	2012-2015	250 houses	x		x	x			x				x			
Solar e-bike: Smart Living Lab UTwente Enschede					x	x				x						
Car as Power Plant: The Green Village TUDelft	2016-present	1 hydrogen car & 1 hydrogen scooter														x

Annex B. Software flowchart for the monitoring system



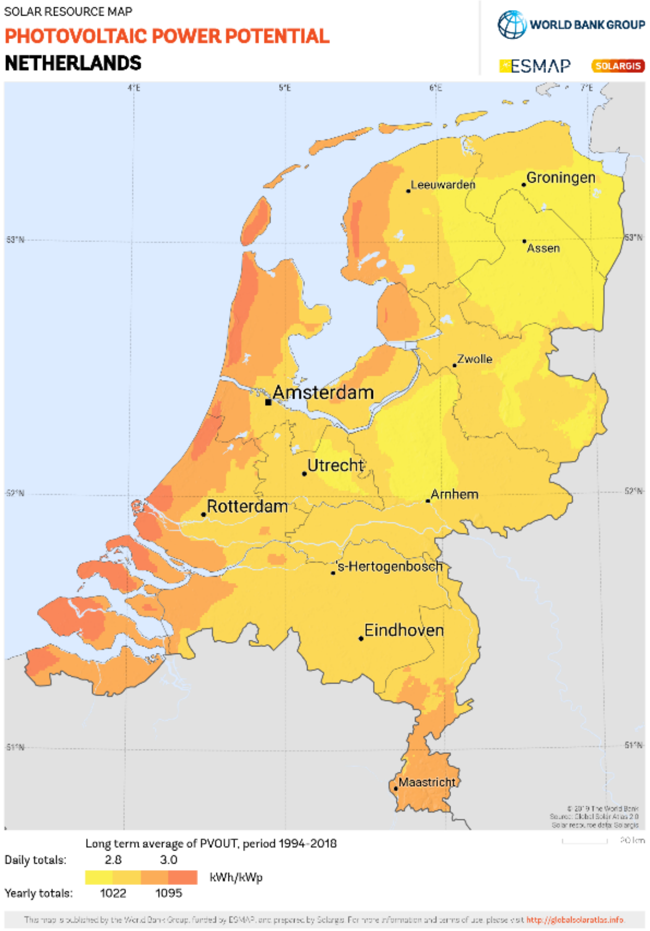
Annex B1 . Monitoring system software flow chart by authors

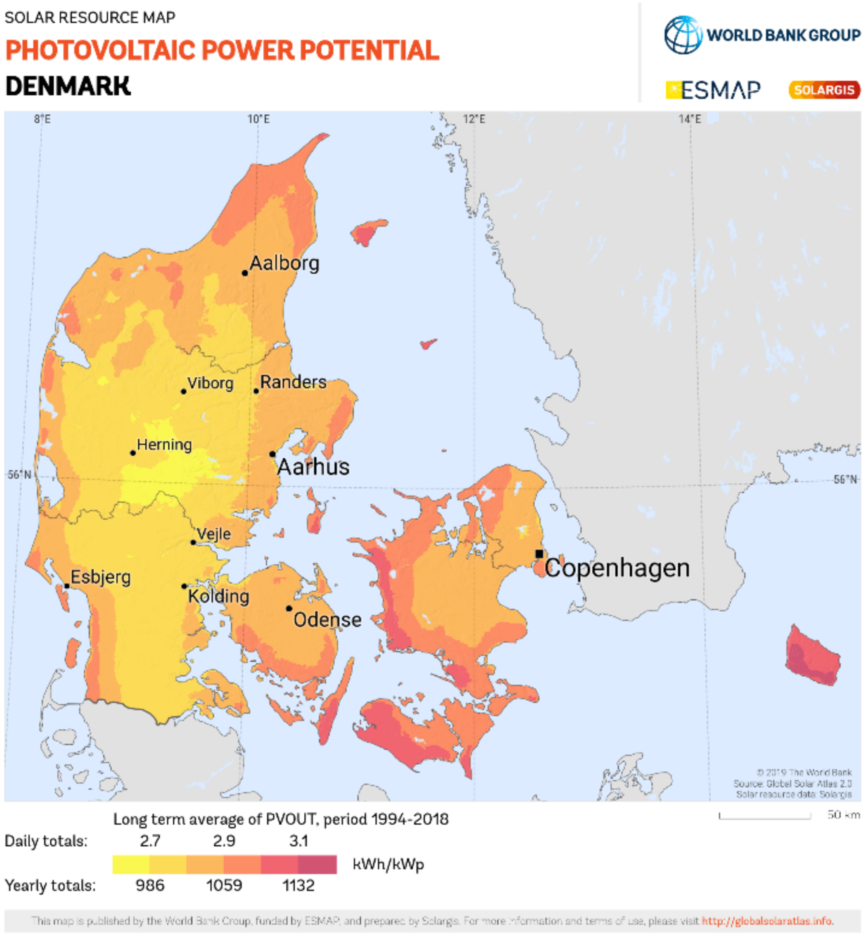
Annex C. Climate zones of the EU countries

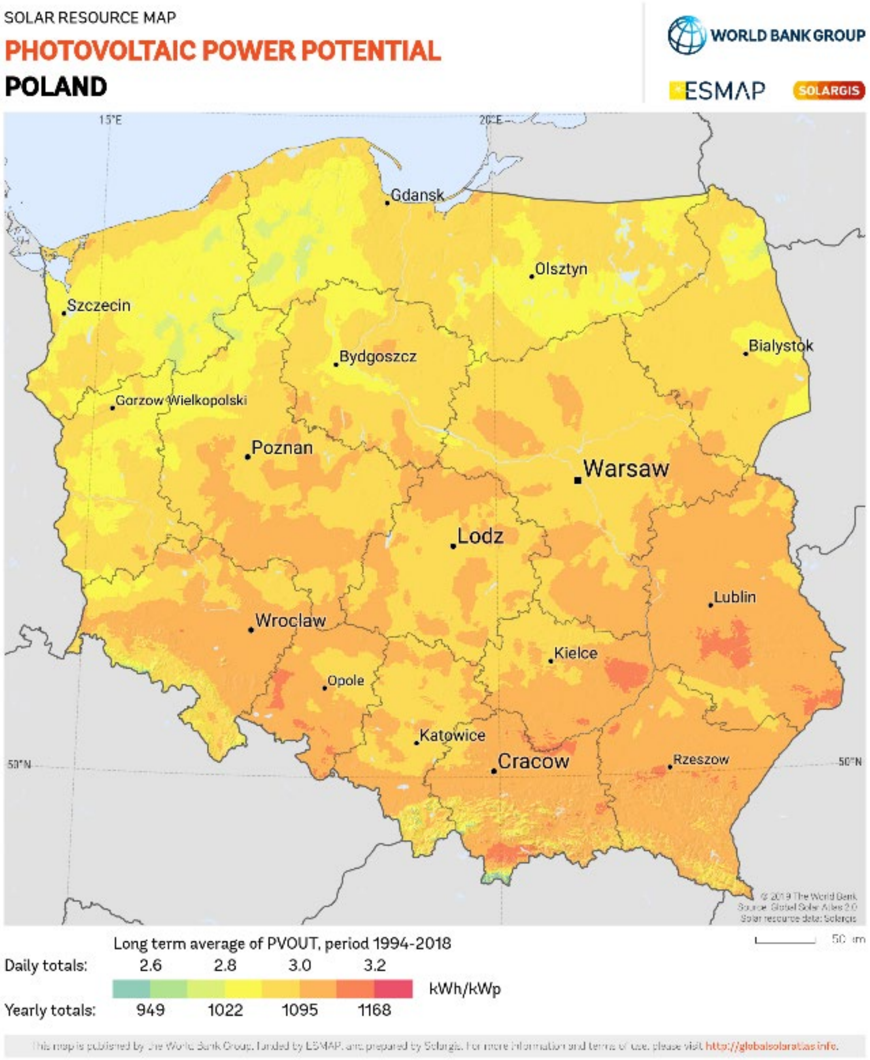


Observed climate zones in the period 1975-1995 (left) and 1996-2016 (right)

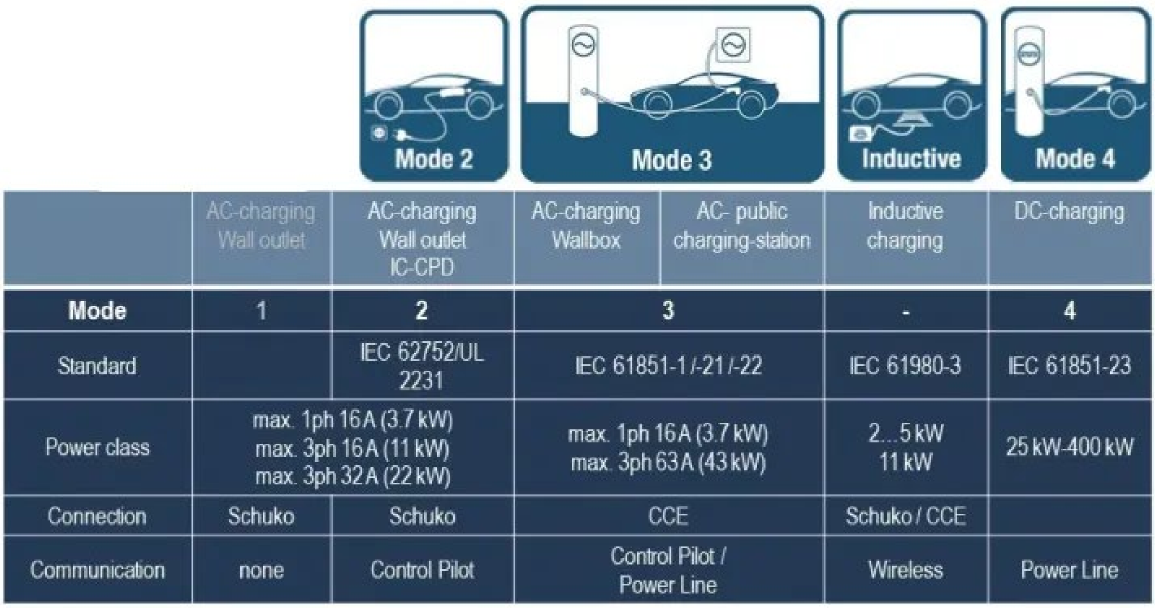
Annex D. Photovoltaic power potential of three countries






SOLAR RESOURCE MAP
PHOTOVOLTAIC POWER POTENTIAL
POLAND
WORLD BANK GROUP
ESMAP
SOLARGIS
15°E
20°E
50°N
Gdansk
Olsztyn
Szczecin
Bialystok
Bydgoszcz
Gorzow Wielkopolski
Poznan
Warsaw
Lodz
Lublin
Wroclaw
Kielce
Opole
Katowice
Cracow
Rzeszow
© 2019 The World Bank
Source: Global Solar Atlas 2.0
Solar resource data: Solargis
50 km
Long term average of PVOUT, period 1994-2018
Daily totals:
2.6
2.8
3.0
3.2
kWh/kWp
Yearly totals:
949
1022
1095
1168
This map is published by the World Bank Group, funded by ESMAP, and prepared by Solargis. For more information and terms of use, please visit http://globalsolaratlas.info.

Annex E. Different EV charger comparison and the details of the chosen solution



	AC-charging Wall outlet	AC-charging Wall outlet IC-CPD	AC-charging Wallbox	AC- public charging-station	Inductive charging	DC-charging
Mode	1	2	3		-	4
Standard		IEC 62752/UL 2231	IEC 61851-1 /-21 /-22		IEC 61980-3	IEC 61851-23
Power class	max. 1ph 16 A (3.7 kW) max. 3ph 16 A (11 kW) max. 3ph 32 A (22 kW)		max. 1ph 16 A (3.7 kW) max. 3ph 63 A (43 kW)		2...5 kW 11 kW	25 kW-400 kW
Connection	Schuko	Schuko	CCE		Schuko / CCE	
Communication	none	Control Pilot	Control Pilot / Power Line		Wireless	Power Line

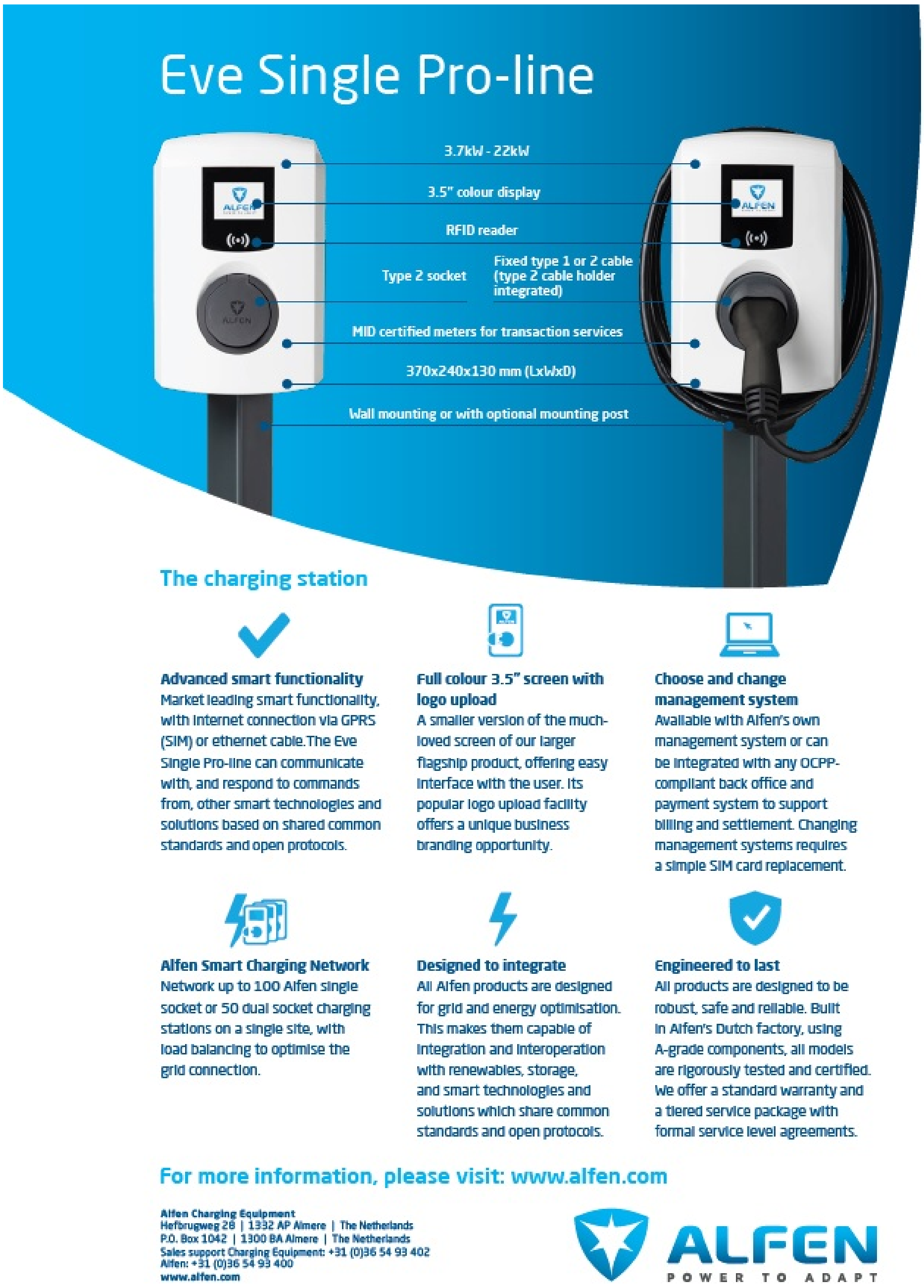
Annex E1. Modes and level of charging ; the most cost effective/practical solutions are AC-charging wall outlets, so mode 2 (Level 2) charging [https://www.eetimes.eu/high-performance-magnetic-sensors-speed-ev-charging/]

Annex E2. Table for the EV chargers (Level 2 – wall outlet- AC) supplied in the Netherlands (all functionalities listed here are necessary to ensure the maximum flexibility and smart grid control from main management system.).

Mark	**Model(s)**	**Charging power/speed**	**Smart charging**	**RFID**	**Connectivity**	**Costs per pole**
Wallbox	Copper Pulsar Plus Pulsar Plus 2 commander2	3.7- 22 kW	X*	X*	X*	800-2500 €
EVhub	Double charger	7.4 kW * 2	X	X	X	1300€
Mennekes	Amtron Compact	3.7 - 11 kW	X	X	X	650€
Mennekes	Amtron compact 2.0	11- 22 kW	X	√	√	New product - non available
Mennekes	Professional plus	22kW	√	√	√	2300€
Alfen	Single Pro-line	22kW	√	√	√	~1550€

* optional through their commercial portal– not open for customizing and open source development

Annex E3. Alfen Eve Single pro charger



Eve Single Pro-line

The charging station

Advanced smart functionality
Market leading smart functionality, with internet connection via GPRS (SIM) or ethernet cable. The Eve Single Pro-line can communicate with, and respond to commands from, other smart technologies and solutions based on shared common standards and open protocols.

Full colour 3.5" screen with logo upload
A smaller version of the much-loved screen of our larger flagship product, offering easy interface with the user. Its popular logo upload facility offers a unique business branding opportunity.

Choose and change management system
Available with Alfen's own management system or can be integrated with any OCPP-compliant back office and payment system to support billing and settlement. Changing management systems requires a simple SIM card replacement.

Alfen Smart Charging Network
Network up to 100 Alfen single socket or 50 dual socket charging stations on a single site, with load balancing to optimise the grid connection.

Designed to integrate
All Alfen products are designed for grid and energy optimisation. This makes them capable of integration and interoperation with renewables, storage, and smart technologies and solutions which share common standards and open protocols.

Engineered to last
All products are designed to be robust, safe and reliable. Built in Alfen's Dutch factory, using A-grade components, all models are rigorously tested and certified. We offer a standard warranty and a tiered service package with formal service level agreements.

For more information, please visit: www.alfen.com

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Annex F. Detailed results of the flexibility simulations for the Aardehuizen demonstrator for the current and future situation

	Peakshaving	Cost [€]	Cost Imports [€]	CO2 (tonnes)	CO2 (import (tonnes)	Import [kWh]	Export [kWh]	Max Peak [kWh]	Min Peak [kWh]
Current Situation									
No Control	3166070,309	1956,638	10459,95237	-10,7287	35,0932867	86102,96	-115882,5066	53042	-132698
Peak shaving	2521703,625	897,0038	7826,690207	-11,6592	26,7059178	65686,49	-96986,951	21367	-108352
Cost Min	2965474,22	110,0016	8696,240009	-12,1973	32,11722624	80100,58	-111349,5284	55982	-128408
CO2 min	3090317,261	551,0684	9283,093111	-12,9589	33,24031179	84629,96	-115931,9078	56993	-129441
Future Situation									
No Control	2792350,831	2259,63	9079,383118	-8,39143	29,6802207	72654,18	-96462,82767	63446	-130681
Peak shaving	2021944,669	1031,679	6108,961029	-9,37875	19,72487665	48105,15	-73507,62181	30389	-94282
Cost Min	5128820,297	-1564,73	16013,6341	-10,6925	62,25846236	156413,2	-181686,9201	179929	-190238
CO2 min	5613593,624	101,1304	19346,63354	-13,4736	70,57463848	181404,3	-206646,1168	182405	-192419
With import limitations: Current Situation									
Cost Min	2613471,4	911,6009	7950,267738	-11,598	27,33206449	67308,98	-98372,268	32690	-125448
CO2 min	2620376,727	970,8337	8005,067757	-11,6963	27,3311797	67551,43	-98604,004	31825	-120287
Future Situation									
Cost Min	2320907,206	1024,453	6275,44916	-9,38014	20,5769863	50373,54	-75568,29033	29577	-178161
CO2 min	2490951,995	1151,094	6376,165824	-9,63238	20,91764762	51363	-76480,96737	35178	-183601

Partners involved in Report D5.1

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957682. Any results of this project reflect only this consortium's view and the Agency is not responsible for any use that may be made of the information it contains.