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1 Executive Summary

The overall perspective of this deliverable D2.1 is to formulate appropriate local demand response schemes that are applicable for different demonstration sites in SERENE. In addition, the citizen-centred integrated local energy system framework for multi-energy vectors that is adapted from smart-grid architecture model (SGAM) forms a baseline to formulate the relevant use cases. The scope and objectives and their corresponding dependencies on other WP deliverables are outlined in this deliverable.

This document also discusses the system architecture of multi-energy systems, where electric power sector, heating sector and transportation sector are coupled for local community-based energy systems. The framework employs decentralized energy management system by utilizing the flexibility offered by various assets towards different market opportunities and power system services. The benefits offered involve the market coupling of multi-code requirements on frequency and voltage limits for distributed energy resources including wind, solar-PV, storage, minimizing the grid import though increasing local renewable sources share in the energy mix, supporting distribution system operator (DSO), empowering customers to actively take part in energy decisions etc. The local demand response schemes and corresponding control algorithms that are relevant to realise system services and energy flexibility are described.

Furthermore, demand-side participation schemes specific to individual demonstration sites are evaluated for availing energy flexibility to increase energy efficiency and local share of renewable energy sources. The main enablers and barriers for implementing demand response programs are discussed with respect to all demonstration sites. The current market models for prosumer-communities at the demos are examined to exploit their flexibility potentials for developing decentralized energy services. Accordingly, the main aim of this project is to fulfil the energy needs of the communities through optimally managing their local resources, while delivering social and environmental benefits.

2 Introduction

Multi-energy systems (MES) whereby multiple energy vectors including electricity, heat, cooling, fuel, transport and so on optimally interact with each other for instance at a local, district or city levels. Compared to 'classical' independent energy systems, MES features better technical, economic, and environmental performances. First part of this task deals with data analytics frameworks and models for the existing distribution networks, prosumer behaviour, local renewable resources. The latter part of the task develops a MES framework for community-based integrated local energy systems corresponding to all the three demonstrators.

2.1 Scope and Objectives

Developing framework for data analytics and cross-domain system architecture for community based integrated local energy systems is the main objective. This provides essential comprehension for optimally integrating different energy carriers (electricity, heat, transport etc.), thereby determining the suitable use cases for the three demonstration sites. This includes developing scheduling and prediction algorithms for energy production, storage, and demand, which will be used in deriving local demand response (DR) and demand side management (DSM) schemes that can generate economic incentives and encourages participation of citizens.

2.2 Partner Contribution

AAU is the task leader and is responsible in preparing the draft. Coordinating with all involved partners and collecting corresponding inputs for formulating the relevant frameworks was ensured by AAU.

- **Skanderborg municipality** provided inputs in system architecture design and use cases relevant to citizen driven integrated local energy systems.
- **Neogrid, LOQ, VAO** provided inputs on local DR and DSM schemes, formulating use cases.
- **UT and IMP** supported in establishing use cases and development of prediction algorithms, DR and DSM schemes for Dutch case and Polish case, respectively, which further can be applied to other pilots. In addition, coordinating with local pilot for data and analysis.

2.3 Relationship with Other Tasks and Deliverables

This task considers input from Tasks 3.1 1 (elements determining social transition and acceptance for demand side participation), 4.1, 5.1 and 6.1 (requirement specifications from the different demo sites for describing system framework and use cases). The output from this task will be considered as input to Tasks T2.2 to T2.7 (modelling of multi-energy system components, control schemes and electric grid integration studies), T3.1, T3.2 (socio-technical conditions and socio-economic criteria), T4.4 and T4.5, T5.1, T5.2, T6.1, T6.2 and T6.4 (system architecture for design and implementation of community-based integrated local energy systems).

3 System Architecture of Multi-Carrier Energy Systems

Figure 1 shows the smart-grid architecture model (SGAM) which is modified to include systems, assets, and functions to involve participation of citizen driven sustainable energy production and consumption facilitating local cross-sector energy systems [1]. The SGAM with five interoperability layers defines the relation between the energy flow within the domains of component layers involving integrated local energy systems as well as between the other interoperability layers, to facilitate the relationships and roles of various players for the establishment and development of smart energy system applications and solutions.

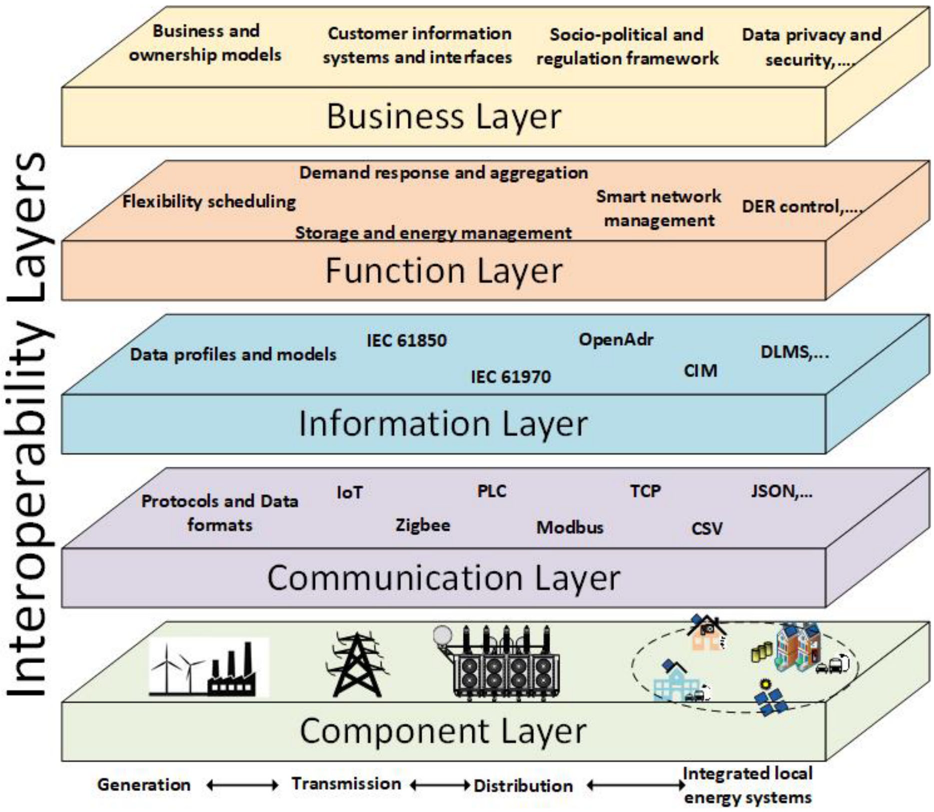

Figure 1: SGAM interoperable layers [1]

The ***component layer*** represents the physical components in electrical energy conversion that are arranged in hierarchical levels of managing power and energy systems. To ensure interoperability in such a complex system with different technologies, many actors and relationships, information and communication technologies and data exchange platforms are applied to facilitate sustainable and smart citizen-centred energy solutions. For information sharing between different interoperability layers, suitable data exchange standards and communication mediums like power line communication (PLC), LAN, IoT protocols etc. form part of the ***communication layer***. In the ***information layer***, the data handling models and procedures are based on standard communication IoT protocols for automation, demand response, and smart metering. Thus, the data exchange for various functions on grid integration and scheduling of distributed assets, energy management, control, protection, etc in smart-grid environment under a highly dynamic network of consumers and producers are facilitated. The provisions and services to maintain interactive relationships within the associated layers in the architecture model are part of the ***functional layer***. It includes functionalities like scheduling and aggregation of energy flexibility, active grid management and control, smart energy management, provisions for grid ancillary services etc. In the ***business layer***, suitable regulatory schemes, business cases, ownership models, customer and data handling environment etc. are mapped to address the interactions and dependencies between the participating smart energy systems, subsystems, and stakeholders.

3.1 System Framework for Integrated Community Energy Systems

Considering the SGAM model as a baseline, a generalised architecture concept of energy flow in an integrated local energy system under the SERENE project is represented in Figure 2. Renewable energy sources and its biproducts under appropriate technologies generate electrical and thermal energy. The interface and synergy of electrical and thermal networks with each other through different consumer and flexible loads are illustrated in the diagram. The electrical and thermal networks in EU are well developed at the distribution level but are regulated and operated individually. Through an enhanced interaction between these networks, these sectors can utilise the advantages from each other in terms of generation, distribution, and storage to establish a flexible integrated energy system. Along with the local and decentralised energy sources, the industry and commercial buildings in the locality can also participate in the generation as well as flexible consumption of thermal and electrical energy.

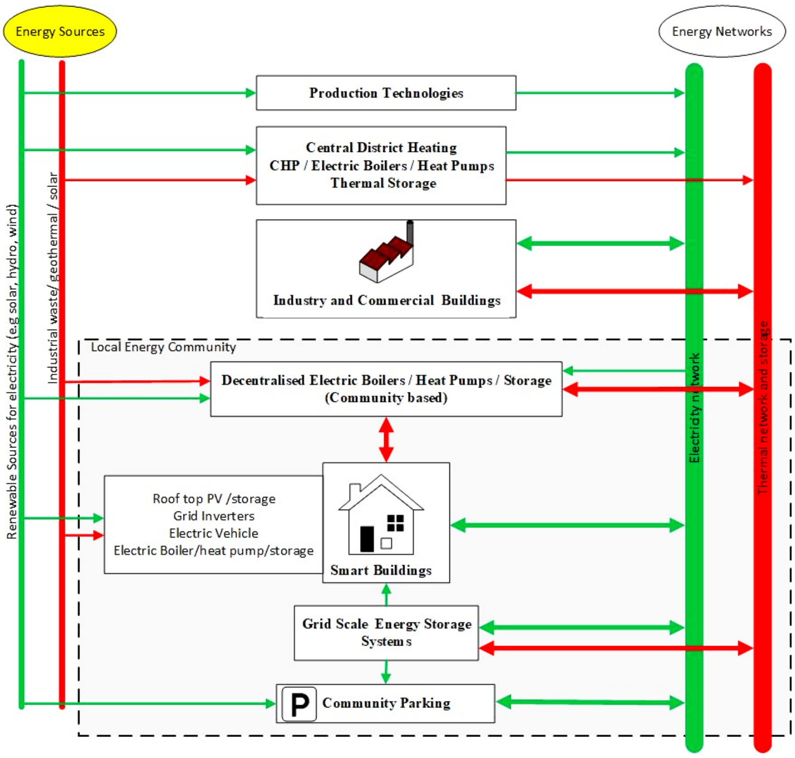

Figure 2: Architecture of energy flow in an ICES

As an example, a big supermarket uses electrical energy for refrigeration of commercial products generating thermal energy as a by-product. This thermal energy can be fed back to the heating and storage network. Smart active buildings in local energy neighbourhoods comprises of one or more of the electricity generation and flexible load units such as rooftop photovoltaic (PV), grid inverter, electric boiler (EB)/ heat pump (HP) with storage, and electric vehicle (EV).

These units can interact with electrical energy network as well as decentralised thermal units for energy exchange. A community-based decentralised thermal generation and storage systems can utilise various technologies for the generation and storage of thermal energy that can include local and booster units for district heating. EB utilise electrical energy to produce heat energy and HP can be utilised for heating or cooling systems based on their operation cycle. Through smart and flexible demand-side and storage management of these units, it can result in supplementing energy production from variable and local renewable energy units. Heat energy can be stored in different forms of storages utilising hot-water storage tanks, phase changing materials and distribution network exchangers. These systems are demonstrated in the various pilots of the SERENE project.

Community parking in local energy islands represents the common parking area for specific residential area or buildings. EVs connected to charging in the community parking not only facilitate demand-side participation for enhancing the self-consumption from renewable generation but also can support the grid. The battery energy storage units in integrated local energy systems represent dedicated grid-scale large storage system or local units that are installed for balancing energy flow or storage for future use. The energy management system module optimally schedules, regulates, and manages the cross-interactions of various energy units in an integrated energy system framework. The energy management strategy of local aggregator and the interaction with different energy players is shown in Figure 3. The general framework of integration architecture considering various flexible loads is based on two different levels. Both objectives focus on minimizing energy exchange with the grid by increasing the share of local renewable production in the energy mix.

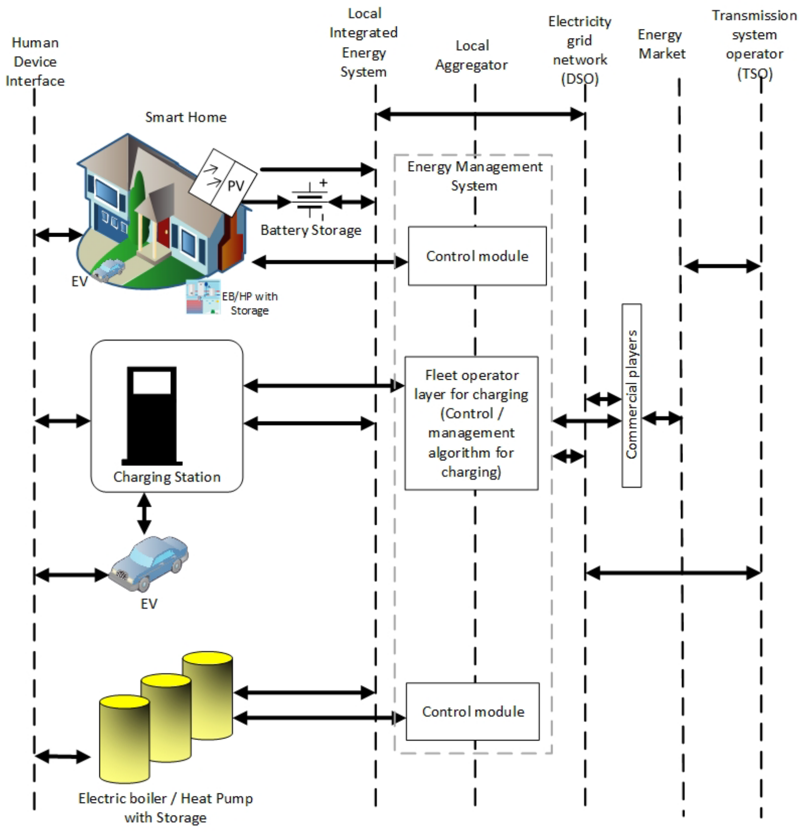

Figure 3 Integration architecture ancillary services through flexible charging and vehicle-to-grid option.

- Optimizing at household/building level: Meeting both the electrical and thermal demands, using local PV generation and demand response.
- Optimizing at community level: Meeting the electrical and thermal demands using community-based local generation, distributed energy resources and demand response.

Data management and communication infrastructure could be based on cloud-based architecture or distributed/local architecture. Human device interface can be achieved through a specific control panel or application-based interface (mobile app, browser app, etc) that can be accessed using mobile/computer. It is a dedicated interface where users can communicate with the system (e.g., smart home, EV charging station and EB or HP with storage) and make appropriate settings based on their specific needs. Each system then updates the user settings at an aggregator level, where the negotiation with the electricity producer on behalf of consumers is settled as well as the flexible operation of the system is predetermined based on the dedicated algorithm for optimal power flow.

The smart homes consist of one or more flexible systems (e.g., rooftop PV, EV, EB/HP with storage) that can communicate with a committed energy management system at the aggregator level for the establishment of flexibility in power flow. Power generated by distributed local generation such as rooftop PV can be either stored in battery storage or directly consumed at the local level by other loads. On the other hand, the locally generated power can also be handled by local grid based on the agreement between producer and the commercial players.

The EV integration is well represented for community parking as well as for individual homes. The user can interact with EV and/or charging station to define specific parameters such as flexibility in terms of charging, participation in grid ancillary services, level of charging and various other services that will come up along with the development of the project work. Then, based on the user data, the fleet operator in the aggregator layer will determine the optimal charging profile. The fleet operator layer for charging will also have a proper algorithm to estimate the charging profile based on user history from data in the cloud. EB/HP with storage here well represents either part of a smart home or a distributed unit in a specific area. These units are well suitable to utilise the locally generated power to store as heat energy or managed by energy management system at the same time. The services from flexible energy in the integrated local energy systems to the neighbouring areas and centralised infrastructure, and settlement of energy prices are realised through interactions between the local aggregators and commercial entities. The flexibility that can be harnessed from different energy units are dependent on the component characteristics and its energy system integration to provide demand-side participation. In SERENE, two of the most relevant multi-energy system components in the various demonstration sites are electric vehicles and heat pumps. The use-cases representing the flexible regulation of HPs and EVs are given below.

Use case 1: Framework for Flexible Operation of Heat Pump

Figure 4 provides an overall architecture for the smart operation and control of HP. Initially, the thermal demand is estimated based on appropriate estimation tool and weather forecast data. Thereafter, with the help of electricity price, the optimal operation schedule for the operation of HP is allocated. This process of forecasting the generation and demand and gathering the price information and creating the operation schedules is considered as a first level of control. Deviation in actual thermal demand (due to error in estimation tools, weather forecast or user need) is partly compensated by the thermal energy storage tank (based on its size) and then by the local control of HP (operated for extreme condition of storage unit such as fully charged or about to be fully discharged). The voltage at the point of coupling of HP is also monitored by local controller for HP, in order to take necessary action against supply voltage drop which forms the second level of control. Hence, this control level will manage the operation of HP with respect to state of energy of storage, HP dynamics and supply voltage. This two-level control ensures the

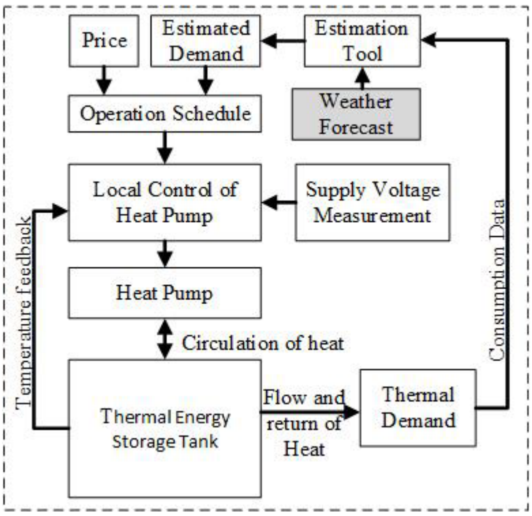

Figure 4: Architecture for smart and flexible operation of HP

reduction of forecasting errors through feedback to first level from the second level control and supports local node voltage regulation.

Use case 2: Integration of EVs in Local Energy Systems

Figure 5 shows the sequence diagram for EV integration in integrated local energy systems. This sequence diagram shows a use case for flexible EV charging involving all the relevant stakeholders in energy systems. The state of EV and relevant data on SOC (state of charge), trip details and user's preferences are collected by the local aggregator, applied from an integrated local energy systems point of view. Also, the data on forecasted local generation from distributed renewable sources and electricity prices are gathered from local aggregation level. Further, these gathered information are processed to generate charging plan for EV and generation schedule from distributed renewable sources. The short-term requirements from EV and load/generation are taken into consideration for any further adjustment. Thus, at this stage, generation of the local generator and load profile is determined. Thereafter, the grid congestion avoidance is taken into consideration for further iteration on above stages to generate optimal schedules for local flexibility within integrated community energy systems to enhance the self-consumption from renewable units. Depending on the requirements of the energy needs and economic operation of the integrated energy systems in the local community, the energy flexibility can be further utilised for balancing and ancillary services to the central and local energy systems.

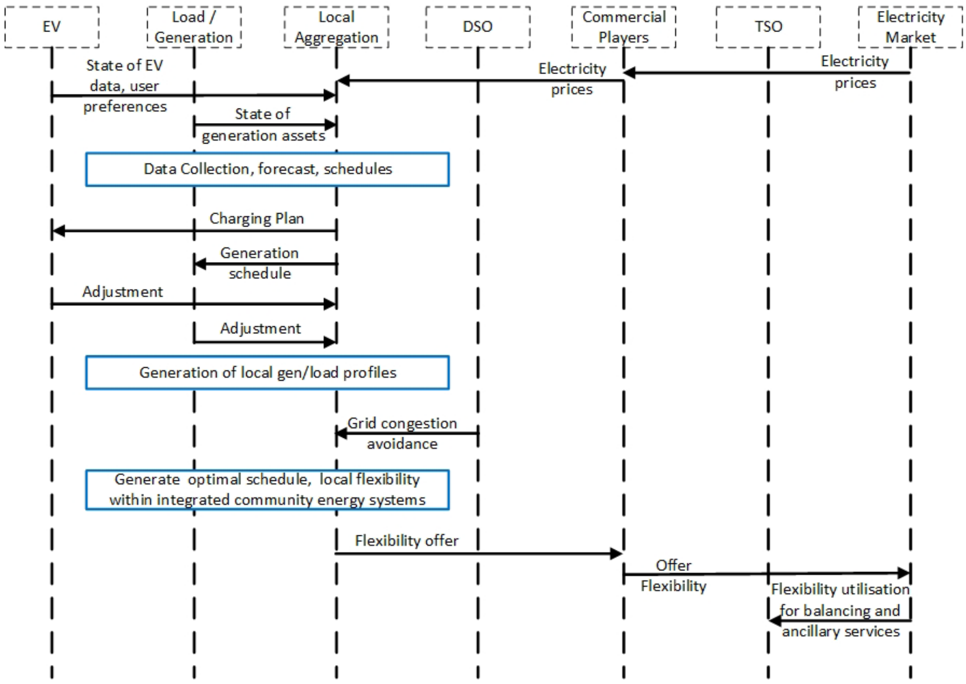

Figure 5: Use case- An example of EV integration in integrated local energy communities.

3.1.1 Integrated Local Energy System: Danish demo

The demonstration activities in Denmark involve two areas (Låsby and Hylke) in Skanderborg municipality. The goal is to carry out demonstration of replacing existing fossil fuel (natural gas and oil boilers) based heating supply to heat pumps based electric heating in residential buildings through increasing the share of local renewable energy resources (RES) and active participation of citizens, property owners, stakeholders, and utilities. Further, the electrification of transport is also considered, thereby establishing smart control of integrated community energy system to increase the self-consumption of local RES and provide grid support. The specific objective are as follows:

Developing an intelligent Community Energy Management System (CEMS) that consider the optimum operation of the various producing and consuming technologies:

- Central heat pump that supplies several buildings.
- Central thermal storage based on phase change material (PCM) or similar technology, that provide flexibility to the system.
- Central and distributed PV system, that connect behind the main meter, so the renewable energy is available for heating, hot water, and EV charging. Surplus electricity will be exported to the grid.
- DHW boosters in the households.
- Active control of heat emitters in households, to help avoid import of electricity during peak hours, by slightly frontloading the comfort temperature before expensive periods, and reducing temperatures during peak hours.
- EV charging will be optimized in accordance with user requirements of desired charge level and available renewable energy.
- Central battery storage system, that provide flexibility to EV chargers, DHW boosters and/or heat pump.
- Demonstration of EV charging using local solar-PV installations along with community-scale battery energy storage systems (BESS) by applying suitable demand response techniques.
- Demonstration of various socio-economic models for owning and operating community-based ICES at all demonstration sites.

Use case 1: Hylke

Two of the existing areas in the village of Hylke are targeted to change the heating system from oil into electricity using heat pumps. The location of demonstration area in Hylke is shown in Figure 6

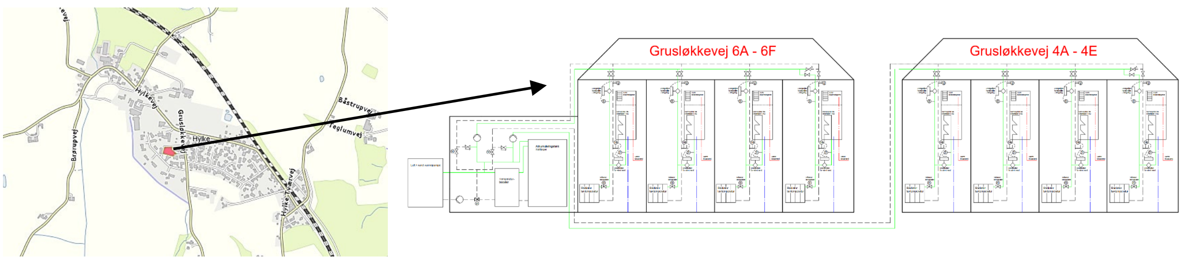

Figure 6 Demonstration area 'Grusløkkevej' (right image) in Hylke (left image)

System set-up: The heat demand for the selected locations is supplied by the central heat-pump connected to the PCM storage tank. The current installations of electric water heater are upgraded to DHW booster tanks with auxiliary electric heating. The solar-PV installations ranges from 12-48 kWp.
Control: Intelligent control of DHW based central heat pump, electric water heater by maximizing the consumption of local solar-photovoltaic production while considering the consumer preference and network limits. In addition, a cloud-based control will be designed for managing the underfloor heating in the bathroom.

Demand response: Designing appropriate demand response programs for utilizing the flexibility offered by the heating systems and other consumer appliances for minimizing the cost of operation.

Use case 2: Laasby

The new areas in the village of Laasby that are marked in Figure 7, will be designed to smart use of heat and electricity.

Figure 7 Demonstration areas in Laasby

Objective: CEMS will optimize the operation of the following components:

- Central ground source heat pump.
- Central thermal storage

- Central/ distributed PV system - (panels are installed on the roofs of the 4 buildings, but inverters are connected to the main 'sub-grid')
- Central battery storage system
- Central thermal storage
- Distributed EV chargers
- Electricity sub-meters at each household
- Heat meters in each household

Pricing: Each household will pay for the energy they consume from the community system. As all components are placed behind the main meter, the owner of the complex will pay for the import to the main meter. The CEMS will provide dashboards for both tenants and building owners to provide information on how energy consumption is planned and provides feedback when it's ideal to use high power consuming appliances. Additionally, the CEMS will provide consumption data for the building owner as a basis for the billing of energy consumption (heat and electricity).

Demand response: Shifting the electrical and heat demand using appropriate demand response programs for either energy efficiency or peak shaving applications.

3.1.2 Integrated Local Energy System: Dutch demo.

The demonstrator in the Netherlands involves two demonstration sites, the community of Aardehuizen with 24 ecologically built houses and the community of Vriendenerf that consists of 12 houses, both are part of the village of Olst. At Aardehuizen as shown in Figure 8, all of the 24 houses were constructed over a period of about 4 years, starting in late 2011 and ending in July 2015 [2]. The houses were constructed by (re-)using locally sourced, environmentally friendly materials. In Vriendenerf, the 12 houses were completed in 2017 based on Near Zero Energy Building (N-ZEB) standards [3]. The vision of both communities is to maximize self-sufficiency in energy and water usage. Keeping this in mind, these ecological communities comprising of like-minded sustainability-driven inhabitants are very good candidates for researching and deploying islanded and resilient micro-grids. The specific objectives to be implemented in Aardehuizen are:

- The demonstration of smart control of neighborhood-scale battery storage and electric boilers in synergy with solar photo-voltaic generation applying Demand Side Management (DSM) approaches at Aardehuizen.
- The design and implementation of smart control of (hybrid) heat pumps in conjunction with solar photovoltaics to increase self-consumption and enable peak-shaving in Vriendenerf.
- The implementation of local demand response schemes and increased utilization of solar PV generation for energy sharing amongst inhabitants by building and deploying an energy management system for such a (islanded) integrated local energy systems.
- The implementation of intelligent displays to both supply the inhabitants with relevant informatics and enable energy-conscious decision making. For example, a dashboard on PC/phone for monitoring and controlling energy usage and for keeping track of the origin of the energy supply (local or from the connected grid) can be made available to the residents.
- The establishment of a local EV-car sharing and charging concept as part of the neighborhood energy system.
- The design and implementation of a working administrative system for energy and knowledge sharing with neighboring communities.

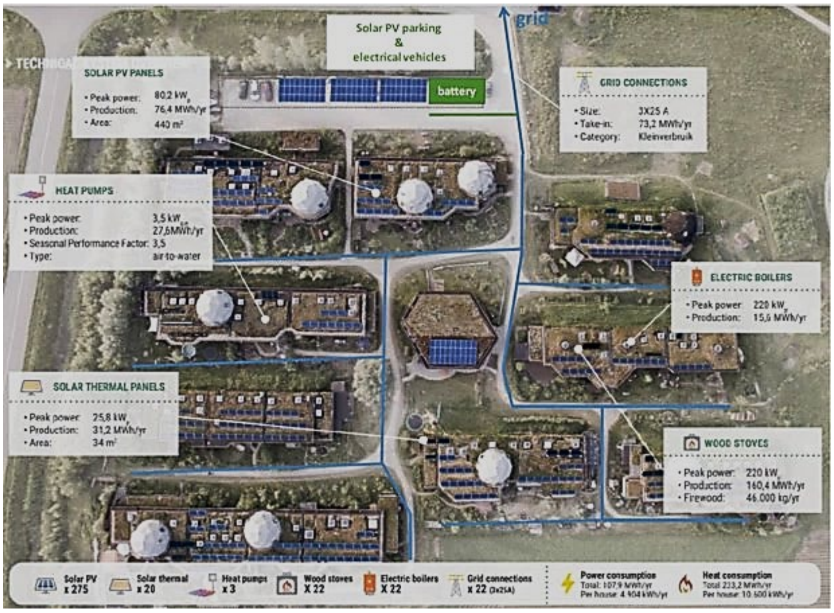

Figure 8: Aardehuizen, Olst, The Netherlands.

Use Case 1: Aardehuizen

Aardehuizen is a sustainability-focused community consisting of 23 residential houses (23 families) and 1 common house, which is shown in Figure 9. The community consists of 35 children and 40 adults and is located in the municipality of Olst-Wijhe. The residents themselves constructed the 24 houses or *earthships*, from 2011 to 2014. All houses have PV panels and a solar collector unit. The community also has a solar carport with 222 PV panels. However, this is connected on a different grid power line than the grid power line for the community. The specific objectives of this demonstrator are as follows:

- **Smart Control:** Demonstrate smart control of battery storage, (hybrid) heat pumps, electric boilers in conjunction with solar PV to increase self-consumption and minimize grid import.
- **Demand Response:** Design and implement light-weight demand side response algorithms to make use of local flexibility for peak-shaving.
- **Smart UI:** Implement intelligent UI/UX interfaces for the residents that informs them about the current energy situation (consumption, production etc) and presents them with positive actionable items to execute to improve self-consumption and/or minimize peaks.
- **Energy Sharing:** Develop and demonstrate an EV-scheduling algorithm for car sharing and charging at the solar carport. Develop an administrative system for energy sharing and knowledge sharing with the neighbouring communities of Vriendenerf and Olstergaard and with the rest of the village.

Figure 9: Aardehuizen demonstration site

Use Case 2: Vriendenerf

Vriendenerf is a community of 12 houses located beside Aardehuizen. The 12 houses are divided in 4 groups of 3 houses each, as shown in Figure 9. Each group of 3 houses is equipped with 69 PV panels. Additionally, each house has a heat pump, domestic hot water storage tank and ground thermal storage. The houses are fully insulated from the outside environment and have active air ventilation systems for preventing heat escape. The community has recently invested in electric vehicle charging stations as well. The specific objectives to be implemented in Aardehuizen are:

- **Smart control:** Develop and demonstrate a smart control system for the heat pump in tandem with the PV generation and the EV charging for minimizing grid import and reducing peaks.

Figure 10: Vriendenerf demonstration site

Use Case 3: Inter-community energy sharing.

The communities of Vriendenerf, Aardehuizen and Olstergaard are all neighbouring sustainability focused communities established with the aim of maximizing self-production and consumption of energy. Different approaches, possibly even theoretical ones, for energy sharing and for establishing a local energy market amongst these three communities could be investigated. However, the practical implementation of such energy-sharing approaches is hindered by current legislation. A draft law that permits individual energy ownership and the creation of local energy markets has been put forward for deliberation in the Dutch parliament [4]. It must be note here, that Aardehuizen has an exception from Dutch legislation. Therefore, local energy trading within Aardehuizen is permitted as part of the SERENE project.

3.1.3 Integrated Local Energy Systems: Polish demo.

The Polish demonstrator is located in the Przywidz Municipality, which is in the north of Poland as marked in Figure 11. The municipality is mainly rural, 50% of its surface is covered by forests, the population is around 6000 people. The municipality is very active regarding the implementation of new technologies, especially those leading to increasing energy efficiency and sustainable development. The municipality has already taken part in national projects and has proven to be a valuable and engaged partner. The village Przywidz is a very suitable place for the demonstrator as, in a relatively limited area, there are municipality buildings (townhall, school, sport centre) equipped with photovoltaic installations, heat pumps, EV chargers and an electricity storage unit. At a small distance, a large residential area with more than 20 photovoltaic and a few heat pump installations is located. The municipality also is home to a modern sewage treatment plant capable of participating in Demand Side Response (DSR) services as well as a number of closely connected multi-family buildings equipped with heat pumps. The local entrepreneurs are also interested in participating in local energy communities. The citizens are very open and practical people that are interested in new technologies, especially if it leads to decreasing the costs.

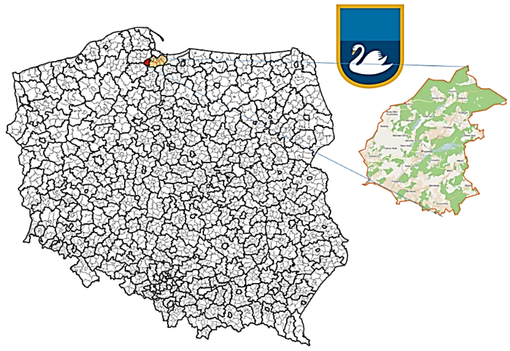

Figure 11: Location of Przywidz municipality.

The location of the selected three use cases is shown in Figure 12. The main objective of the Polish demonstrator is to implement the concept of integrated local energy systems, for which there is no legal framework in Poland. Based on this concept, the local communities, citizens, stakeholders and utilities will be involved to manage demand locally by utilizing the local RES, creating local entrepreneurship and enabling socio-economic-environmental benefits. The specific objectives are as follows:

- Installation of ICT infrastructure that is needed for collecting data of both electricity and heat profiles for estimating the flexibility of the community-based integrated local energy systems.
- Implementing the smart control of local heat pumps and battery storage to increase the self-consumption of local RES. Furthermore, the impact of this system on local grid will be analysed.
- Developing smart control strategy of ICES involving the school facility with flow battery storage, heat pump, solar-PV system, EV charging station with vehicle-to-grid (V2G) facility using an appropriate demand side management scheme.
- Demonstrating the optimal operation of sewage water treatment plant to maximise the utilization of on-site solar-PV production facility through suitable demand response techniques.
- Development of socio-economic based ownership models for enabling 'energy cluster' to encourage the participation of citizens, public and private entities with the ICES, emphasizing the integration of electricity and heating networks.

Figure 12: The location of three use cases.

Use case 1 – The district of Przywidz village

The first use case is focussed on the most populated area in the centre of Przywidz. The overall aim of this use case is to improve the operation of the PV installations in the area (by reducing the curtailment of production) by testing a mobile energy storage unit and to gather data regarding usage and peoples' behaviour to begin work towards energy communities or energy clusters in the area. The area contains buildings that are connected to a single secondary substation. There are 72 houses and 14 other buildings considered. The non-residential ones are the local clinic, a pumping station, a kindergarten and few technical buildings. The area has a number of photovoltaic installations, which are affecting the electricity quality in the area. The citizens have reported problems with their PV production during summer, but due to lack of the proper monitoring it was not clear what the exact nature of the problems is. The work in this use case includes measuring the electrical situation in the area, testing if a mobile energy storage can improve the quality of electricity (esp. if it can reduce curtailments and, in a way, increase self-consumption), and installing the measuring infrastructure in the kindergarten and at selected households. The map of the location is presented in Figure 13.

The mobile energy storage is planned to be connected to the following locations:

- Public kindergarten – PV and heat pump energy balancing will be demonstrated with the aim to minimize energy flow (maximize self-consumption) and energy cost. Demonstration of intentional islanding operation is planned.
- Pump station – since it is placed near a transformer substation, it is intended to influence power quality at the low voltage terminals. ESS integrated with substation measurements shall provide energy balancing, reactive power compensation and voltage support features.

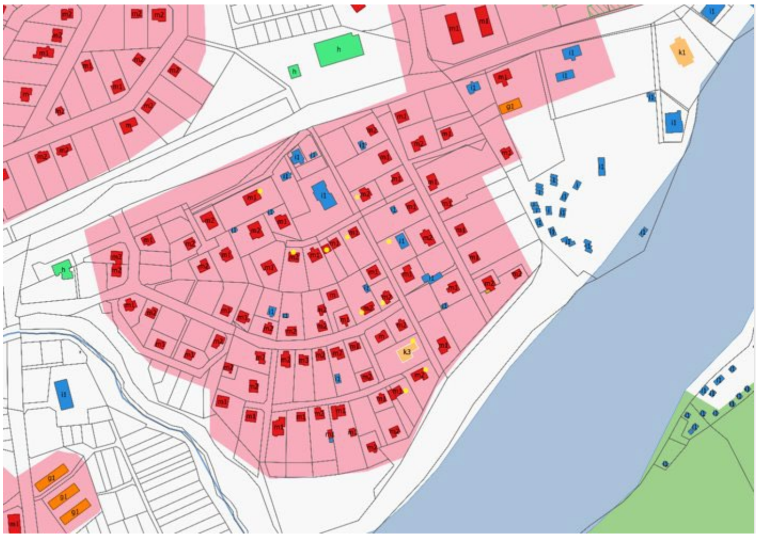

Figure 13: District of Przywidz

Use case 2 – School and sport centre

Arena Przywidz (Figure 14) and the primary school (Szkoła podstawowa im. Unii Europejskiej) are located at the heart of Przywidz, very near to the municipality building. Those two buildings are joined but still they have two separate electrical connections and two separate heating systems. The power of PV installed on the sport hall and on the school are respectively 39.99 kWp and 26.04 kWp. The aim of the use case is to implement the energy measuring system that would increase the self-consumption from the PV installation in Arena Przywidz and demonstrate the role of the energy storage unit in such a building complex.

Arena Przywidz will be equipped with the energy storage unit and the EV charging points. The energy storage will be a Vanadium Redox Flow Battery (VRFB), which is presently not very popular, even though it has several interesting advantages. The energy density is smaller than Li-Ion energy storage but has large number of cycles (20,000+) with full range of capacity (charge range is from 0 to 100% of initial capacity). The planning is to install a 20kW, 96kWh system in a container next to the building. In the final stage of the demonstration mobile energy storage will be combined with VRFB to form a hybrid energy storage system.

Also planned is the installation of one EV DC charger above 20 kW, one of V2G type and a third one which is still undefined. The chargers will not be open for public use as there are legal issues with trading or giving energy from the installations belonging to the municipality. All those devices will be connected by the Energy Management System (EMS) that will manage the energy storage and the charging of the cars. The EMS will provide energy balancing with the aim to minimize energy cost.

Presently, the heating system in school and the arena is based on LPG boilers. In the SERENE project, 3 heat pumps (23kW heating power each) will be installed in the school. No changes to the structure of the Arena heating system are planned, but a measuring system will be installed.

From 1st of March 2021, there is an electric bus line to transport citizens and school children around Przywidz. This bus has its bus terminal near Arena Przywidz, where it can charge from the EV DC charger.

Figure 14: School and sport centre

Use case 3: Sewage water treatment

This use case will research and demonstrate the possibilities of using municipality facilities in the DSR activities. The sewage treatment plant in Przywidz is a new and modern facility (opened in 2021) as shown in Figure 15, it is processing more than 95% of the sewage from Przywidz. The treatment plant uses a biological purification process, which takes a long time to react to changes of the process parameters; the optimal settings for daily operations were achieved in February-March.

The Przywidz Municipality supplied the schemas of the wastewater processing plant and the description of the process. Near the sewage treatment plant there is a PV installation of 49.95 kWp. There is no need to heat or cool down the reservoirs – the treatment process does not require it – but power is needed for operational aspects such as pumping. The buildings use electricity as a heat source.

Figure 15: Sewage treatment plant in Przywidz

4 Available Energy Datasets and Analysis

4.1 Denmark

The electricity supply capacities from renewable energy resources (wind, offshore wind and onshore wind) have been growing and the evolution from 2018 - 2030 is shown in Figure 16 [5]. The significant deployment of renewable energy is highly encouraged to phase-out fossil-fuel based generation and is driven by a combination of incentives including tax exemption for heat from biomass and electricity and so on. The use of biogas towards meeting energy demands consists of 20% already at the end of 2020 and the target is 75% by 2030 [5]. It is expected that the gas will primarily be used during peak-load periods of electricity and district heating supply and high electricity price periods. Alternatively, heat production will be based on biomass plants, heat-pumps and solar heating, while the electricity production will be preferring renewable-based generation (wind and solar-PV). The heat supply capacity from large HPs and electric boilers up till 2030 is shown in Figure 17.

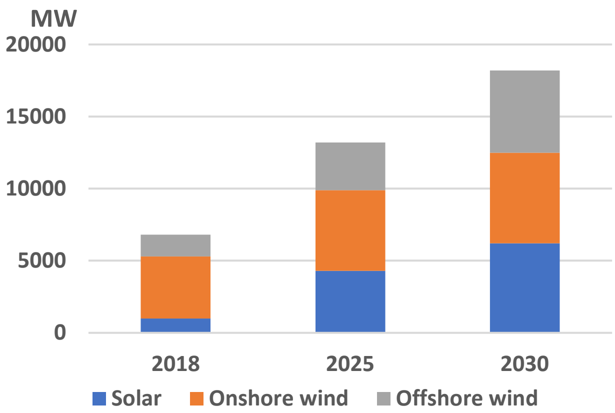

Figure 16: Electricity supply capacity from various renewable energy resources [5]

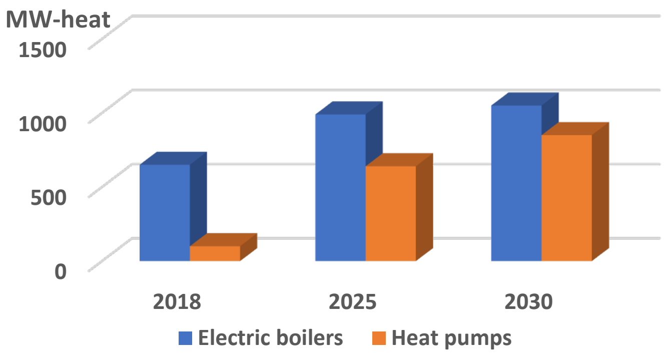

Figure 17: Heat supply capacities for large HPs and Electric boilers [5]

Energy Statistics and Trends

The demonstration activities will be conducted in two villages namely Hylke (400 inhabitants) and Låsby (2000 inhabitants) that are in the main town Skanderborg. The municipality is currently adapting the new climate policy focussing on 1) increasing the share of renewable energy in the municipality (businesses, households, etc.), 2) better demand side management, 3) cooperation with local businesses and citizens. The share of various energy types of the Skanderborg municipality is shown in Figure 18 [6].

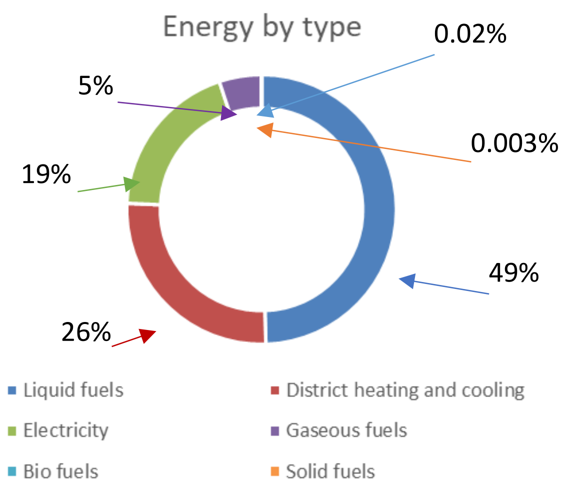

Figure 18: Percentages of various energy types: Skanderborg municipality [6]

It can be observed that the liquid fuels have the largest share in the energy mix for the municipality, district heating/cooling being the next and electricity is the third in line. Through this project, the objective is to increase the share of electricity produced by RES towards heating through heat-pumps either household installation or a central station supplying an area. In total, the electricity has the largest share (>55%) from renewable energy resources. The goal is to reach a fully renewable electricity production by 2030.

The main types of heating sources in Skanderborg municipality are as follows:

1. District heating network (68%) consisting of biomass waste and large heat pumps for most of the small towns,
2. Gas grid areas with gas boilers (15%),
3. Individual heating systems (oil, wood pellets and heat pumps)

The heating supply of Låsby village is based on gas boilers, however, further expansion of gas boilers has been stopped. Whereas, the heating supply in Hylke village is based on individual heating systems (mix of oil, wood pellets, air heat pumps and electric heating). With the demonstrator in Hylke, theaim is at not only replacing fossil fuels with electricity, but also to make the best usage of self-produced electricity from PV as nearly 50% of the selected test hosts have PV panels installed, and some are planning on adding PV. In Låsby, the selected demonstration sites are new and will be constructed within the beginning of the project. Buildings are owned by a housing company, where the heat pumps will be installed and operated as the main source of heating supply. Figure 19 and Figure 20 show the aggregated electricity consumption of three different customer categories from Jan 2022 with other heating and electric heating supplies, respectively [7]. It is to be observed that the consumption with other heating is higher than the case with electric heating facility. The objective is to move this highly unregulated energy demand towards cleaner heat supply (district heating) and heat-pumps (either central or locally in buildings), to not only reduce CO_2 emissions but also increase the share of RES in the local mix.

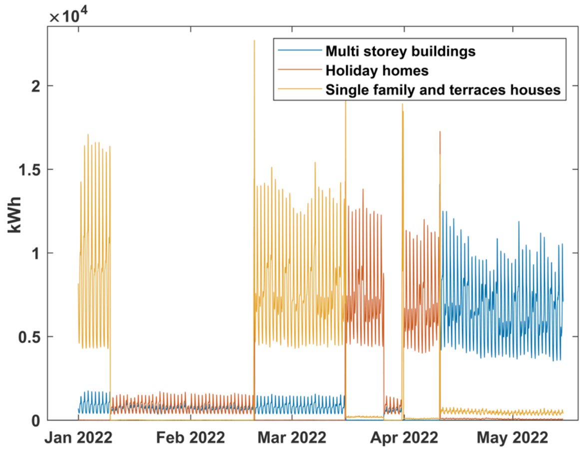

Figure 19: Consumption profiles with other heating category [7]

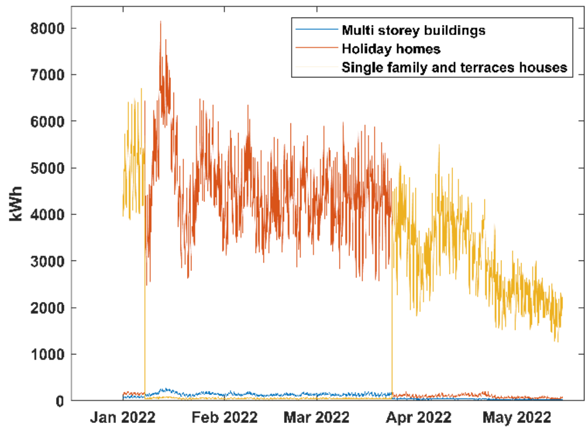

Figure 20: Consumption profiles with electric heating category [7]

4.2 The Netherlands

With the current energy transition in the Netherlands, a country-wide operation is ongoing aiming at a structural change in energy usage to reduce the emission of CO_2 in the country drastically. Most homes in the Netherlands are connected to the natural gas grid, and this gas is used for space heating, domestic hot water, and cooking. As a result, most residences in the Netherlands are currently dependent on natural gas. Simply switching to all electrical appliances is a costly and challenging process for the end-users as well as the network operators, as the national electrical grid in the Netherlands is not designed for the resulting increase in electricity usage [8].

The demonstration site in the Netherlands contains two recently built neighbourhoods: Aardehuizen and Vriendenerf. Both are situated on the southside of the village Olst, located in a rural area along the river IJssel between the cities Deventer and Zwolle. According to circular and biobased principles, the Aardehuizen neighbourhood is a unique community in which occupants built their own houses with help from volunteers worldwide (according to circular and biobased principles). Aardehuizen has solar PV systems, wood boilers using local wood supplies, decentral water sanitation, their own drinking water supply, and a working group of volunteers that help grow local crops for their food supply. This neighbourhood has an annual gross consumption of 100 MWh and an annual gross production of 130 MWh. This means that, Aardehuizen has more than the necessary capacity to be energy-neutral and the excess production of 30 MWh can be sent back to the main grid or in the future, exchanged locally with other energy communities in Olst such as Vriendenerf or Olstergaard, as described in Section 3.2.1: Use Case 3. The community received the active support of the municipality in order to successfully apply for exemptions to national building regulations, water sanitation requirements, and drinking water supply requirements. Also, the neighbourhood successfully applied to become a pilot for electricity sharing according to the Dutch experimental electricity exemption regulation. For instance, this makes it possible to trade electricity within the neighbourhood against its own defined dynamic price levels. The 24 houses were finished in 2016.

The Vriendenerf neighbourhood consists of 12 houses in which the residents (aged mostly above 50 years) formed a community project to tender the design and construction of the houses jointly. The houses are built according to Near Zero Energy Building standards, utilizing the most current standards in building insulation and installation technology: high level of wall insulation, triple glass windows, solar PV integrated roof constructions, ventilation with heat recovery, and ground source heat pumps. The community works together on a communal garden, exploitation of a community house, and has plans in the direction of EV-car sharing and an EV charging point. Members of this community also participate in the sustainable transition movement in Olst. In this movement, they regularly meet with members of the Aardehuizen neighbourhood. The houses were finished in 2017.

4.2.1 Energy Statics and Trends

On a national level, Figure 21 shows that in 2021, 10% renewable energy is achieved of the primary demand (2940 PJ/y) and this is 13% of the final demand (2280 PJ/y).

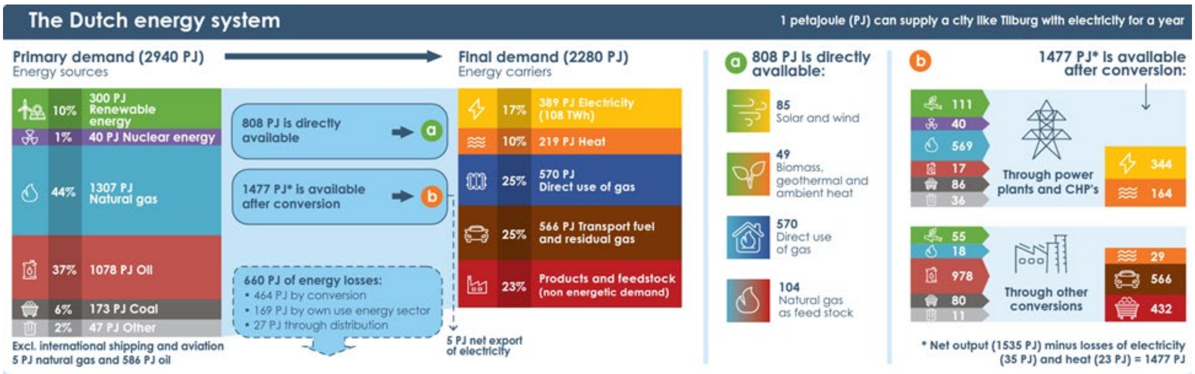

Figure 21: Energy sources of the Dutch energy system [9]

The Dutch demonstrators of Aardehuizen and Vriendenerf are located in the region of West-Overijssel in the municipality of Olst-Wijhe. In the summer of 2021, the 11 local municipalities of West-Overijssel, including that of Olst-Wijhe, the provincial board and the local water boards jointly agreed upon a long-term plan for the energy vision for the region [10]. This plan, called the RES 1.0, stipulates the energy target put forward by each of the 11 municipalities and the energy target at the regional level as well.

At the regional level, the energy target is to achieve a total sustainable electricity generation of 1.83 TWh (or 6.57 PJ), with a ratio of 60% generated by wind energy and 40% generated by solar energy. In contrast, the total energy demand of the region was approx. 42 PJ in 2020 with 10.34 PJ for electricity, as shown in Figure 22 This means that the RES 1.0 targets for 2030 aim to generate more than 60% of the present electricity demand within the region itself.

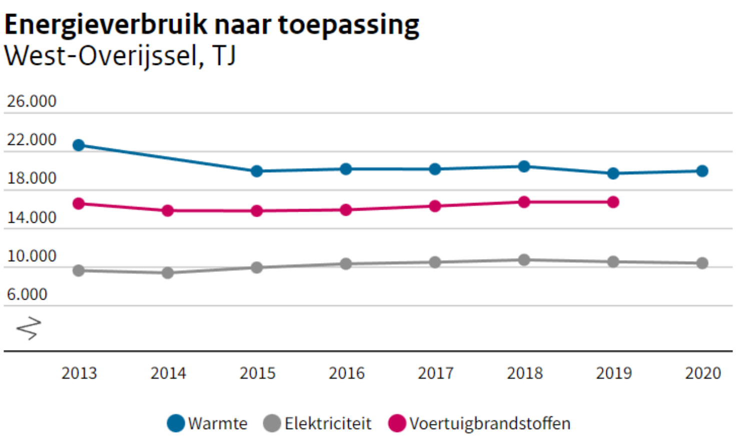

Figure 22: Final energy consumption of the region West-Overijssel: heat (warmte), electricity (elektriciteit) and fuel for vehicles (voertuigbrandstoffen) [11].

Additionally, RES 1.0 also aims to achieve at least 50% local ownership of wind energy and large-scale solar energy generation. Specifically, the municipality of Olst-Wijhe aims to achieve a total energy generation of 74 GWh by solar PV, divided as 64 GWh coming from large-scale solar fields and 10 GWh coming from roof-top installations [10].

Given the target of 50% local ownership, the municipalities in West-Overijssel aim to strengthen the regional participation of civil society organizations and energy co-operatives such as Aardehuizen and Vriendenerf in the proposed energy transition and have established an official agreement amongst the local municipalities to the same nature [12].

The rooftop PV panels are installed in the households, and in the Aardehuizen, there is a parking lot covered with PV panels. The trend for maximizing the usage of the generated power in the parking and also moving toward electrification of the devices to adding the electric cars' charging station at the parking. The other trend that started is adding the Battery storage units to the community for peak shaving purposes and maximizing the locally generated power usage. Besides, the community wants to add more heat pumps and solar collectors and use the electric cars in the V2G (vehicle to grid) mood.

Note that the energy trend in the Aardehuizen is to move towards a microgrid, and it is driven by the ideological beliefs of the members of Aardehuizen and Vriendenerf rather than by financial incentives. Nevertheless, the investments need to make sense.

4.2.2 Demand and Production Data

Demonstrator 1: Aardehuizen

The average annual heat and electricity consumption data of the 24 houses in Aardehuizen is shown in Table I. This data was derived from smart meter data available from 2016 onwards. Aardehuizen has a yearly overproduction of 30 MWh. This translates into a negative consumption of 1250 kWh per year per dwelling.

Table I: Dutch national averages per type of dwelling and comparison to the demonstrator average dwelling for the year 2016 [13].

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	-1250 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 [14] by the Dutch government.

Information regarding the number of adults living in each house was acquired on the basis of surveys done in Aardehuizen and on publicly available data [2,78]. This information was used to generate load profiles with 1-minute resolution using the Artificial Load Profile Generator (ALPG) [79]. These load profiles in turn, act as the input for DEMKit. Decentralized Energy Management Toolkit, or DEMKit, is the energy optimization software used for the Dutch demonstrators [76]. As an example of the generated profiles, Figure 23 and Figure 24 show the power profile for 1 week (June 1st to June 7th) at the community level and at the smart meter of one randomly chosen house, respectively.

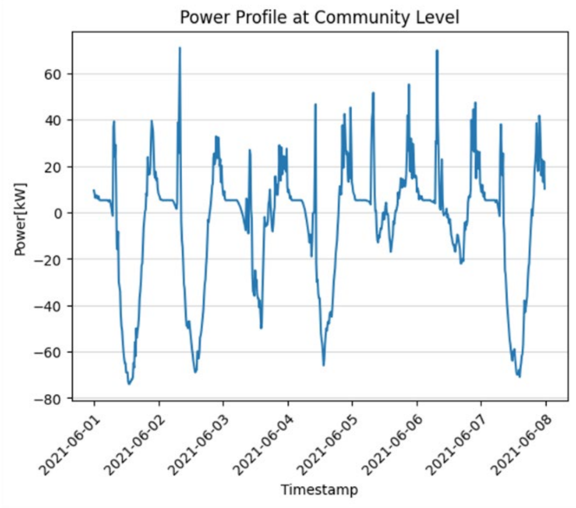

Figure 23: Power profile for 1 week at the neighbourhood community level.

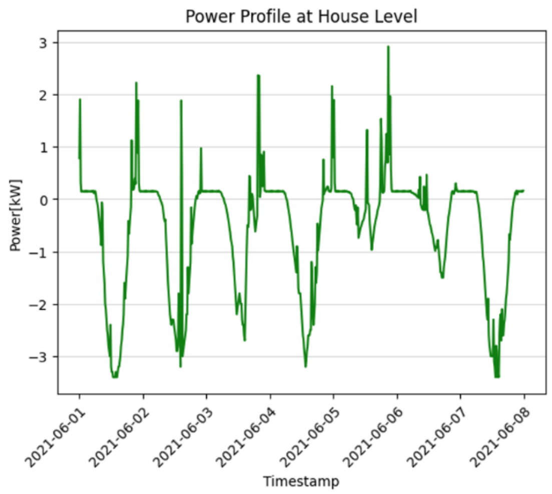

Figure 24: Power profile for 1 week at the house level.

Demonstrator 2: Vriendenerf

The houses in Vriendenerf are designed keeping the concept of ‘zero-on-the-meter’ (ZOM) in mind. This implies that the annual total energy use should come to 0 kWh. In Vriendenerf, each group of 3 houses have 69 PV panels Table II shows the solar energy generation and the energy use for an example house in Vriendenerf.

Table II. Average energy statistics for a house in Vriendenerf [15].

	Corner house (in group of 3) kWh/yr.	Middle house (in group of 3) kWh/yr.
PV Panels yield	6400	5600
Warming, cooling, ventilation and warmwater	3500	3000
Energy available for other household use	2900	2600

Historical energy data may be accessed from the residents if they choose to share it. Moreover, readings of electricity flow in 10 second intervals and with 10W accuracy could be acquired via the smart meter. Lastly, measures to read data directly from the heat pump, solar inverter and the thermostats are being developed.

4.3 Poland

Przywidz is a rural commune in the Pomerania Voivodeship, area 129 km2, population 5800 inhabitants, 50% arable land, 42% forests, agro-tourist commune, 30 km from the Tri-City agglomeration. Przywidz is a very future oriented municipality with local authorities actively fighting to get new investments that would increase sustainability of Przywidz and improve the quality of life of citizens. Funds were obtained and a tender is underway for the supply and installation of 260 PV micro installations (4-7kW each) on private houses and public buildings in the commune. In the vicinity, a private owner built a 500kW PV farm, about 150kW PV is present on the roofs of municipal buildings (in 2020). There are 14 heat pumps in 7 communal buildings for heating and domestic hot water preparation. There is no heating or gas network in the commune. Some buildings are supplied with natural gas from their own gas tanks. The vast majority of private homes use coal heating in private boiler rooms, some use gas or biomass; in about 120 homes solar collectors are installed to heat water. A biogas plant (20 kW) is being built for the private use of one of the local hotels. There are no publicly available charging stations for passenger cars in the commune. Transport organized by the commune includes the transport of children to and from school and diesel-powered buses and minibuses are used for this purpose. For communication with the Tri-City 30km away (the largest urban agglomeration in the region) and neighbouring cities, the commune's inhabitants use private cars and public transport.

In line with the medium-term and short-term energy vision and goals set up in Przywidz, the relevant attributes that are targeted through the various demonstration activities in SERENE are given below:

Medium Term

- Creation of an energy cluster enabling the creation of an internal energy market as well as cooperating and providing services for DSO.
- Disseminate public, shared and private electric transport.
- Establishment of new companies and services in the commune.
- Increased reliability of supply and quality of electricity.
- Increasing the commune's energy self-sufficiency.
- Energy monitoring of users in municipality by AMI (intelligent energy meters).
- Increasing the share of RES in the local energy system.

Short Term

- Show the benefits of the transition from coal to RES (heat pump) cooperating with PV and on the example of a public building - the school Improvement of the energy efficiency of the municipal infrastructure (hydrophore, sewage treatment plant, sports hall, school, kindergarten).
- Construction of EV charging infrastructure.
- Energy monitoring of municipal facilities by AMI (intelligent energy meters).

4.3.1 Energy Statistics and Trends

In Poland electricity production is dominated by burning fossil fuels, in 2021 72% of electricity was generated by burning coal. The production from renewable energy sources is around 17% of the total, but its contribution is constantly growing (in 2021 it grew by 4.4 GW, mostly due to photovoltaic – 3,7 GW). The government plan for the development of energy systems is presently not clear. Published in 2021, ‘Energy policy for Poland till 2040’ (Polityka energetyczna Polski do 2040 r.) is widely criticized for not having realistic assumptions and for not being coherent. Taking into account also recent disturbances in energy prices and in the supply of gas, it is very difficult to foresee the energy situation in the next 20 years.

According to Main Statistics Office (GUS) report [16], it is known what the structure of dwellings in Poland is: the average household size in general is 82,1 m^2, in the city is 51 m^2 and in the rural area 117,9 m^2.

Generally, in Poland the main heat sources are district heating and gas, but those are mainly present in the cities. According to the statistics, coal is still widely used. The percentage of the polish households that have each category as one of their heat sources are presented in Figure 25.

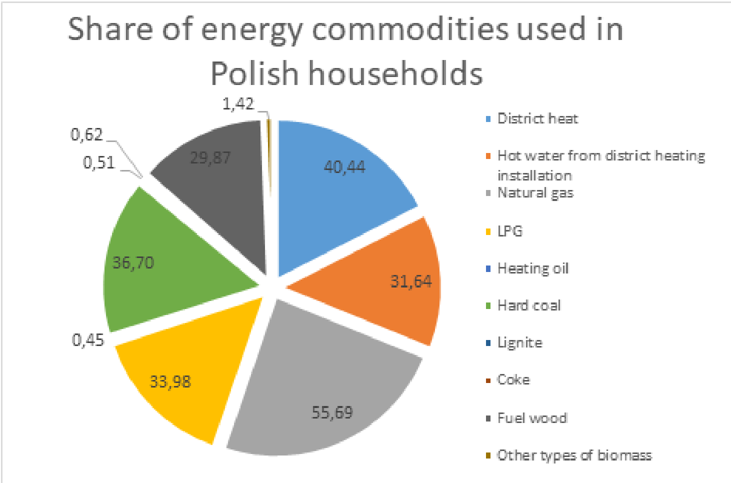

Figure 25: Shared energy commodities: Polish households [16]

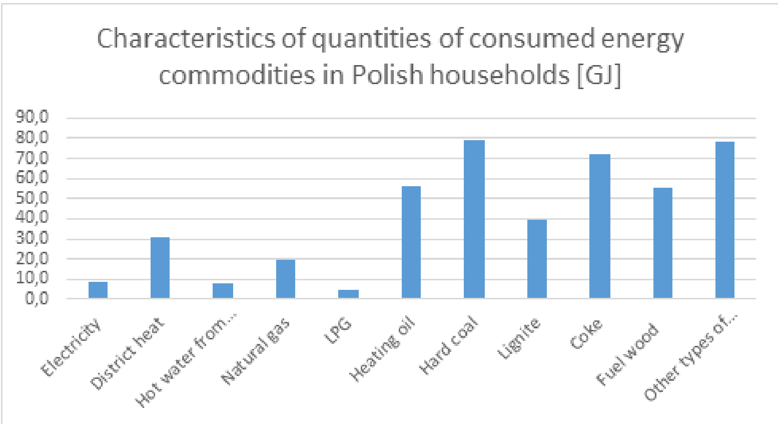

Figure 26: Characteristics of energy consumption: Polish households [16]

The amount of the energy that is used towards different categories in Polish households is shown in Figure 26. The average usage of electric energy in household during the year is 2375 kWh, with median around 2000 kWh. Furthermore, the average usage of electricity per 1 square meter of the usable house space is 32,4 kWh in the city and 25,5 kWh in the rural area.

Case I – Prosumer District

There are several dozen electricity consumers in the area covered by the Case I demonstrator. Mostly they are single-family houses, and several communal facilities such as: health centre (heated with a coal-fired boiler), kindergarten (Heat pump), hydrophore plant and several small service facilities. Heat pumps were installed only in the kindergarten building. For better network control, the local DSO (project partner - EOR) has installed AMI counters in this area. As part of the project, it was planned to install a 50kWt heat pump to replace the old coal boiler in the building of the health centre. Unfortunately, just before the start of the project the heating system was exchanged making the health centre no longer a candidate for the heat pump installation. Local DSO - EOR will develop a new MV/LV secondary substation designed according to the new standard that enable autonomous management of the LV network. The modernised secondary substation should be installed in 2023. In this use case the goal is to research the usage profiles of the citizens, such data will be obtained from the energy meters after the citizens give their consents for using such data in the SERENE project. Figure 27 and Figure 28 show the total load with respect to solar-PV generation on a least and highest sunny day for use case 1, respectively.

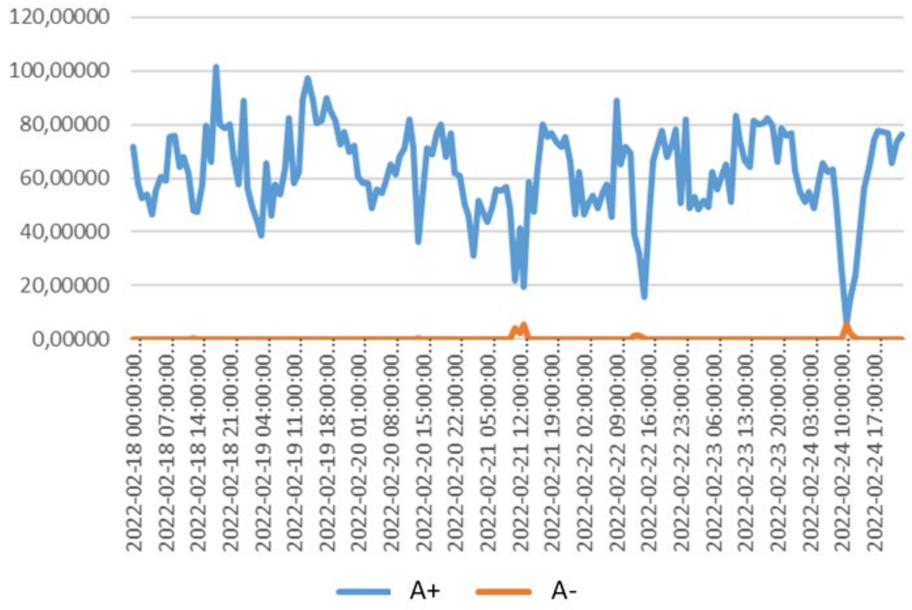

Figure 27: The graph of energy load and PV generation from secondary substation " Przywidz Osada"

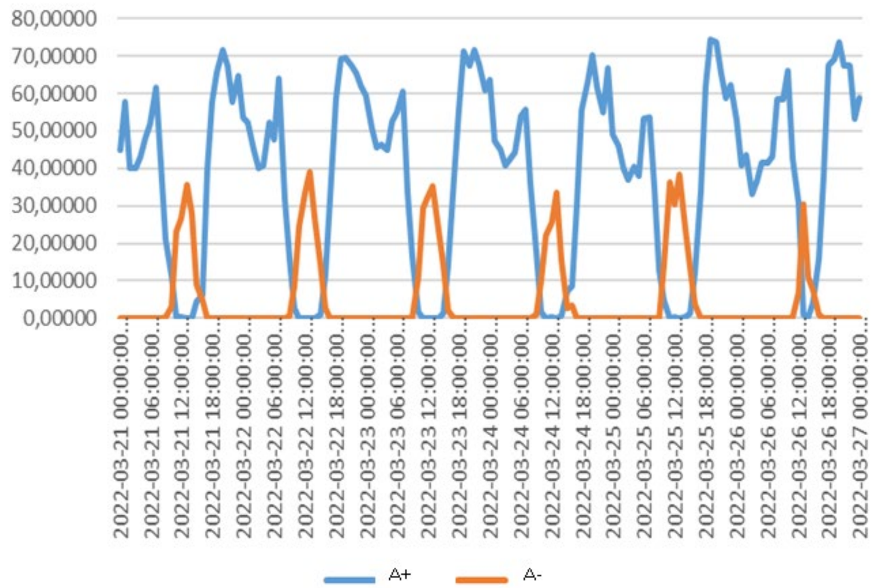

Figure 28: The graph of energy load and PV generation from secondary substation "Przywidz Osada"

Case II – Intelligent building, Sports Hall, PV, HP, transport EV, VTG, Energy storage

The sports hall building was developed in 2016 and integrated with the primary school. The sports hall has 39.99 kWp installed and the school 26.04 kWp. Currently, a HVAC system with heat pump (heating /

cooling) 100kWt works in the building. The main source of heat is 3x100kWt gas boilers powered by gas from cylinders. The system's problem is the high consumption of electricity and gas due to the lack of centralized management of building energy systems. Today, children are transported to the building by diesel buses and minibuses by an external company paid from the city's budget.

As part of the project in Case II it is planned to:

a) Install battery management system (BMS) enabling optimization of energy consumption in the facility – such BMS will also include management of the energy storage and EV chargers. The goal is to increase the level of auto consumption and also to check the profile of overproduction from PV to use it in future for the community.
b) Implement new transport of children to and from school – at the moment the municipality managed to organise the first electric bus route to take children to school (and other citizens to the Przywidz village). It is the first electric non-urban bus line in Poland. The bus is charged from the EV charging station installed with support of SERENE project (leasing from the bus company), it is a 25 kW DC charger produced by Twerd. It has two standards: CCS and Chademo – Chademo has V2G capabilities (not yet tested). In the project a purchase of 2 electric cars is planned, they will transport employees of the commune during work. It is planned to analyse the possibility of sharing vehicles between the municipality, external companies, and private individuals. Installation of 3 car chargers is planned - one is already there (with V2G capability).
c) Installation of hybrid electricity storage with the option of heat production with a capacity of 50-100 kWh. The storage should be integrated with the energy infrastructure of the sports hall and the charger of EV.
d) Installation of heat pumps in the school – 3 units (23kW heating power each).

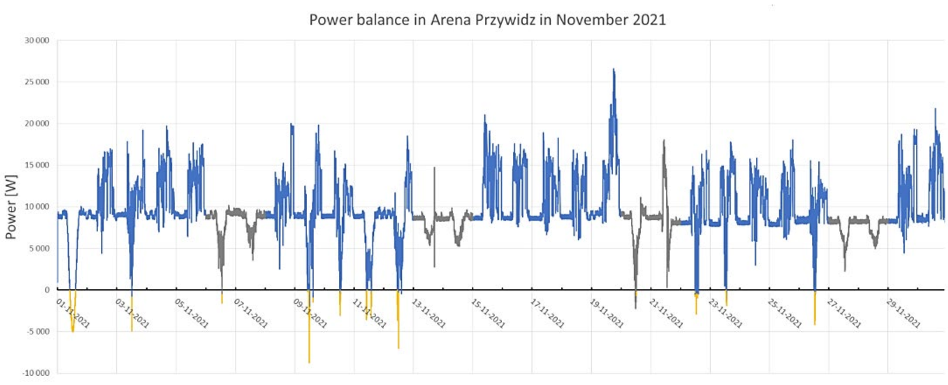

Figure 29: The power profile of Arena Przywidz that was measured by IMP in November 2021.

The energy management system is developed by the STAY-On (STAY) with support of IMP, and it will include EV chargers, Energy Storage, PV systems and Heat pumps in the school. The schema of the system is presented in Figure 30. The location of the energy storage and EV chargers is presented in Figure 31.

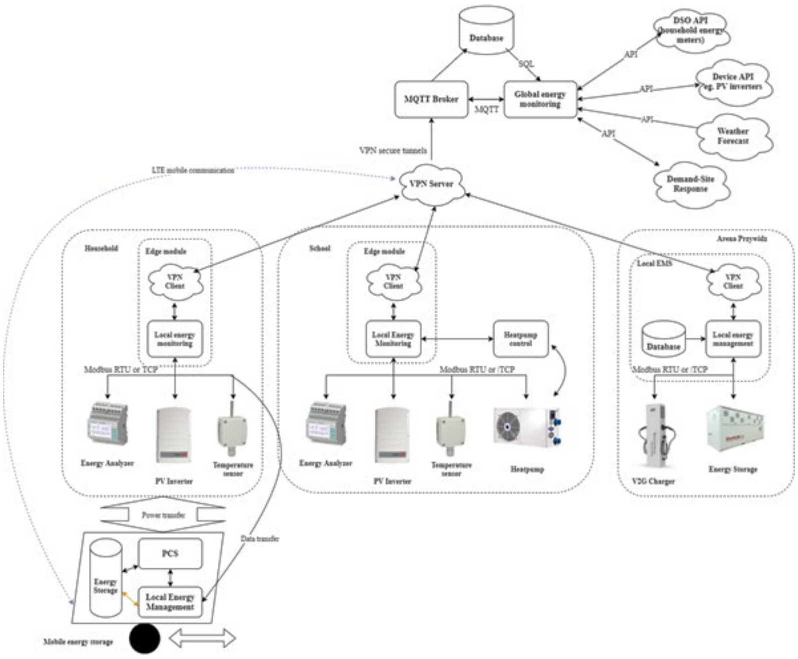

Figure 30: The concept of the measuring and management system in Use Case 2.

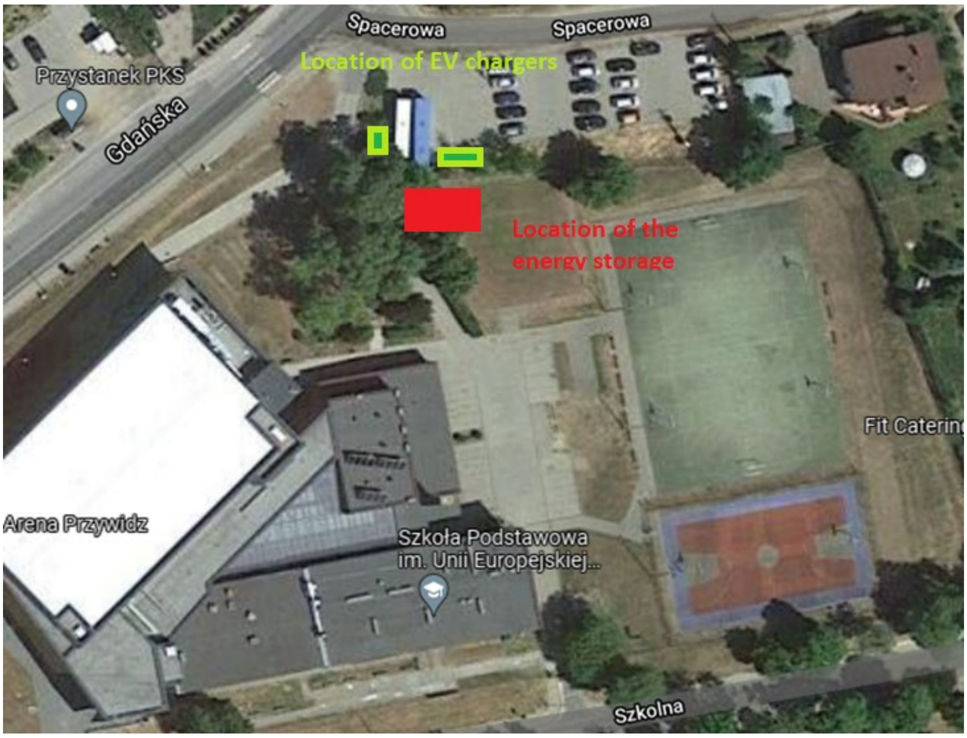

Figure 31: The planned location of the energy storage and EV chargers.

Case III - Sewage treatment plant - industrial facility

The newly built sewage treatment plant has a capacity of 535 m3 per day. The installed power is about 160 kW, equipped with micro-generation PV with a capacity of about 60kW and a diesel generator with a capacity of 100 kW. The problem today is the high cost of electricity used for wastewater treatment measured in kWh/m3 treated water. As part of the project, we plan to modify the existing SCADA to consider the energy usage of the processes. Figure 32 and Figure 33 show the relation between oxygen concentration with mixer and aerating turbine activities obtained from the SCADA system. It is also

planned to test the system for DSR services through appropriate management of internal processes (peak load shifting) and the possibility of supplying the energy to the grid (as the peak energy source).
The process of water treatment consists of the sequence of two elements: receiving the sewage to the reservoir form the pipe system or from the cars; removal of waste that cannot be purified and sand; biochemical separation of sewage in two parallel reactors; separation of purified water from the sediments, part of the sediments is guided back to the reactors. The rest of the sediment is removed, while the purified water goes to the river.
During operation in the plant, the electric energy is used mainly by pumps and aerating turbines. The purpose of optimisation is to reduce the energy usage without significant worsening of the purified sewage quality. Analysis and optimization of electricity consumption will be based on plant operation model and the data provided by SCADA.
Presently it was possible to gather data from the SCADA system and the model of the impact of a sewage aeration on the oxygen level is modelled. Model of the process will allow to define how the process can be altered to optimize the energy usage.

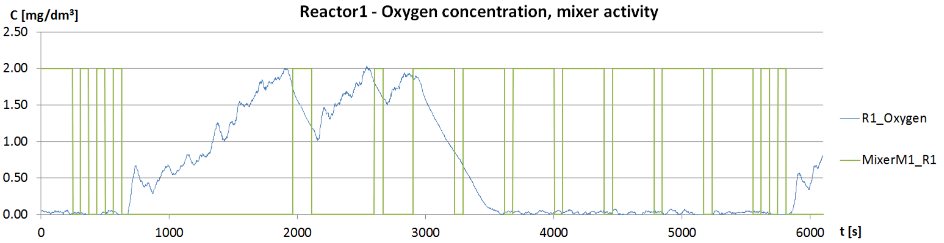

Figure 32: The example of data provided from SCADA system – the relation between oxygen concentration and mixer activity in Reactor 1.

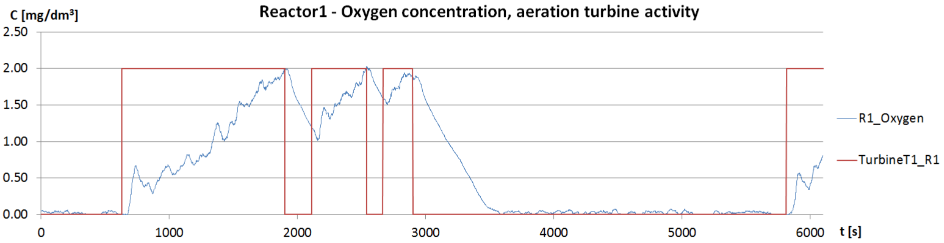

Figure 33: The example of data provided from SCADA system – the relation between oxygen concentration and aerating turbine activity in Reactor 1.

Cross-sector coupling: Electricity - wastewater treatment, electricity, DSR

5 Demand-Side Flexibility and Provisions for Grid Support

This section discusses the state of the art of the various aspects of the demand flexibility and prosumer participation for supporting the energy systems and energy utilities. In addition, the grid codes set by the system operators that need to be followed by the new distributed energy resources are also mentioned.

5.1 Prediction Algorithms to Support Local Generation and Demand Side Flexibility

The high consumption during peak hours increases the electricity prices while the low demand during abundantly available Solar-PV generation leads to costly operation. These can be addressed by devising proper prediction algorithms that can optimize the energy generation and utilization. Effectively, energy forecasting models can be categorized into three types as shown in Figure 34.

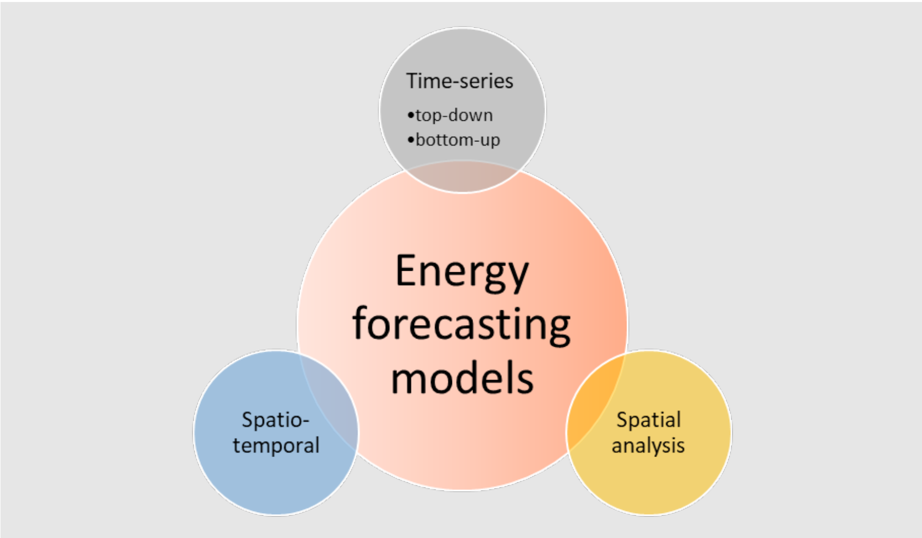

Figure 34: Types of energy forecasting models

In order to ensure a safe and reliable management of the grid, the recommended time horizons for the forecasting are very short term, short term, medium term and long term. Very short-term forecasting (up to 9 hours) is applicable in intraday, ancillary service markets and load management. Whereas short-term forecasting (up to 72 hours) includes scheduling of day-ahead demand and reserves, unit commitment etc. The medium-term and long-term forecasting methods range from months to several years that would be applicable for power system planning and operation.

5.1.1 Local RES Prediction

The emergence of decentralized renewable energy resources (RES) and their erratic behaviour increases the necessity of better prediction algorithms in order to support the grid flexibility [17]. In the literature, the methods that have been used for forecasting the RES are physical, mathematical, artificial intelligence and hybrid- based approaches. In [18], the physical forecasting method is proposed by considering temperature, pressure and terrain etc., to predict the future parameters. The main challenge in using this method is acquiring and processing the physical parameters that involve complex computations. Moreover, the intelligent based forecasting approaches are widely used as they can find the complex relation among the variables without the burden of complex math operations [19]. Based on numerical weather predictions and load forecasting, a control dispatch algorithm is proposed in [20] that lead to better utilization of battery because of improved PV forecasts. Furthermore, the authors in [21] proposed that the use of short-term irradiance and temperature forecasts can reduce the uncertainty in the PV forecast in a demand response program. However, the increase in the share of wind or solar power generation requires higher system flexibility than from the variability of the load [22]. The authors in [23] carried out a detailed review about how the smart mix of renewable energy sources in the power grid can reduce this urge for increased system flexibility.

5.1.2 Demand Flexibility Prediction

The ability of the customer to adjust their power consumption in response to the changes in the power demand and generation is termed as demand side flexibility [24]. The implementation of the DR program is dependent on the flexibility offered by the aggregated distributed energy resources. However, the complex physical behaviour of demand response (DR) and stochastic features of end-use customers poses several uncertainties [25]. A predictive control-based rolling horizon has been proposed in [26] for optimizing the deviation between actual and pre-scheduled flexibility of grid-connected EVs in a DR program. In order to deal with the uncertainties in the DR program, an accurate flexibility prediction model is necessary for aggregators while participating in grid services. The focus so far in the literature was mainly carried out on the prediction of demand directly rather on flexibility prediction. In [27], a data driven approach based on random forest regression is proposed, where short-term flexibility prediction of 15 min and one-hour intervals are determined. A recurrent neural network-based flexibility prediction model is proposed in [28] to obtain the aggregated flexibility of the domestic hot water systems (DHWS) that increased the accuracy of DR scheduling in the day-ahead and real-time. In [29], an advanced deep learning-based prediction model is proposed for finding the real-time aggregated flexibility of both EVs and DHWS multi-step ahead. It is important to mention that the aggregation of domestic and service sector customers poses wider challenges including data collection and privacy protection [30]. In order to tackle these issues, a federated learning-based technique is proposed in [31].

5.2 Estimating and Scheduling Demand Flexibility

The demand flexibility is needed for the DSO as well as other market participants including balance response parties (BRP), retailers and aggregators, who further mainly opts for either ahead (day, intraday) scheduling or direct control scheduling [32]. Further, the explicit assessment of demand flexibility is important for driving the DR program. The knowledge-based estimation of technical demand flexibility as a percentage of appliances that are used by residential, commercial, and industrial customers is carried out in [33]. The flexibility quantification of residential appliances is hard and most of the literature is based on survey data [34]. In [35], the estimation of flexibility has been carried out using real measurements from five types of appliances (EVs, washing machines, dryers, dishwashers, and hot water storage tanks). An integrated approach for finding the flexibility potential of the household laundry appliances is proposed in [36], where the considered factors that are the customer willingness to participate in DR programs, population census and activity-based demand modelling. In this work, the authors emphasized that the influence of factors such as household activities, familiarity with smart-grid technologies and inclination towards energy saving schemes is significant in estimating the demand flexibility. A bi-level joint-flexibility scheduling is carried out in [37] considering both community-level and building level optimization while satisfying the power flow constraints.

5.3 Demand-Side Management and Participation

The most common activities in demand side management (DSM) are load management, strategic conservation, power generation by consumer and installation/replacement of equipment for better energy efficiency. A DSM based on genetic harmony search algorithm is proposed in [38] to reduce the electricity expense and peak to average ration while maximizing user's comfort. In [39], the authors used machine learning strategies for modelling 30 households of different sizes, operational times along with renewable energy sources at few of them. While considering the operational constraints of home appliances that considers the user's comfort, a real-time pricing-based DSM is proposed in [40] for minimizing the home's one-day electricity cost. An experimental study has been carried out in 100 Dutch houses for reducing the evening peaks and increasing the self-consumption of domestic solar-PV systems by considering DSM of wet appliances [41]. It was found that the dish washer has the best potential in reducing the median average peak. The prosumer participation plays a key role in any DSM programs, and the authors in [42] comprehensively reviewed the diverse opportunities for aggregation to exploit the flexibility potential. Moreover, the interaction of multi carrier systems is complex and it is important to optimally schedule these devices for better coordination. An extension of profile steering algorithm is proposed in [43], where it is applied to balance a local district heating network. Another distributed optimization algorithm i.e., alternating direction of multipliers method (ADMM) that is used to optimally schedule the electric vehicle for load balancing application [44].

5.4 Aggregation of Local Energy Flexibility and Grid Support Services

The BRPs are focussing on flexibility loads as the main resource to manage the variable RES problem in the grid. The increased use of roof-top solar-PV generation leads to over-voltage issue and the charging of EV fleets during night creates under-voltage problems. A long-term planning is proposed in [45] that helps the BRPs to realize how much flexibility is required for offsetting the variability of the generation from RES. In [46], a smart load with back-to-back converter topology has been used to mitigate the voltage fluctuations caused by PVs and EVs in low voltage distribution network. The extent to which the aggregated local energy community with residential demand flexibility can increase the self-consumption of the solar-PV systems has been evaluated in [47] while considering the operational constraints from both consumer and the local distribution grid. A multi-time scale flexible optimization based on active distribution network management with participation of smart loads is proposed in [48]. The long-term scale considered the cost and try to smoothen the load fluctuations, whereas in the short-term scale stage, the smart loads are employed to expand the flexibility margin. The aggregated capacities of integrated local energy systems are predicted using long short-term memory-based data-driven approach for grid services including frequency and voltage control [49]. In [50], a cloud-based architecture is implemented through coordination among consumers for achieving reactive power support to maintain local voltage levels in limits, thereby maximizing the reliability. The aggregator trades the flexibility offered by various customers within community-based local energy systems at different energy markets. The local aggregation of assets for various grid services demands well-functioning flexible energy market to enable active participation of the end-use customers [51]. The following sub-sections discusses about the opportunities for distributed energy resources (DER) in the flexible energy markets.

5.4.1 Flexible Energy Markets and Aggregation of Demand Side Resources

A detailed review is carried out in [52] of both operational and economical aspects that should be included in the aggregator business models for both residential and service sector customers. The market integration of aggregated DER can be facilitated by coordination in a virtual power plant (VPP). A VPP acts like aggregator by aggregating the diverse set of resources to act as a single entity and can participate in the energy market providing the grid support [53]. The aggregation of loads and RES is used for energy arbitrage in whole-sale electricity market without considering voltage problems resulted from this aggregation [54]. Integration of demand response in the electricity markets is proposed in [55] for load shifting and as a replacement of control reserve. The opportunities for applying the district heating systems in the power system flexibility is reviewed in [56].

5.4.2 Local Grid Support and Ancillary Services

In the light of the decentralized structure of electrical power systems, the authors in [57] carried out a survey about the evolution of European markets and providing guidelines for the system operators and market participants to figure out effective market arrangements. Frequency regulation is one of the major ancillary services that balances supply and demand during normal grid operating conditions. In [58], the authors illustrated the potential of DSM at the time scale of seconds that can participate in the frequency regulation. Further, the residential appliances including heating ventilation and air conditioning (HVAC) systems are potential candidates for providing the ancillary services. These systems can provide regulating reserve service for a certain ramping rate [59]. In order to realize the demand response at a faster timescale, it needs high number of distributed loads that can be controlled and coordinated to create grid-scale impacts. This idea is demonstrated in [60] using building to grid integration by developing appropriate market mechanisms that encourages the customers. An industrial load coordinated with energy storage is used to provide load following ancillary service in [61] using model predictive control approach-based day-ahead scheduling.

5.4.3 Multi-Energy Carrier Integration

The transition towards a sustainable energy system asks for solutions that integrate different energy carriers into one joint system [62]. Lund et al. [63] have identified that there is a need for new models, tools and methodologies to design such systems. Surveys on applicable concepts and methods for such Multi Energy Systems (MES) are published in [64] and [65]. New load-flow simulation methods to get insight in coupled energy systems are presented by Markensteijn et al. in [66].

The foundations of MES are currently established in energy hubs, which combine multiple energy carriers, of which often a subset is imported and/or exported in a confined region. Especially the coupling different (waste) energy streams for re-use at industrial sites is emerging **[67]**. These energy hubs, often operated in privately owned grids, results in a practical size where certain markets and/or regulations do not apply, making the implementation practically and economically feasible. Research on applying the energy hub concept in a village is conducted by [68], who find that combining multiple energy carriers can reduce energy costs for the citizens. Currently, Wind-power to heat energy conversion is a commonly employed and economically feasible example of energy carrier integration for the residential sector [69].

However, for widespread integration of larger MES, further steps need to be taken. As different markets to trade energy have evolved over time separately for the different energy carriers. Therefore, timing of markets, as well as their geographic locations, may not align. This adds a barrier to the integration of ancillary services and demand response to adequately act on different carriers simultaneously. Additionally, physical coupling of multiple carriers may result in the risk of cascading effects, where one energy carrier directly affects other energy subsystems with different carriers. This is surveyed thoroughly by the authors in [70].

5.5 Grid Code Requirements for Generator and Storage Connections

The grid codes contain rules and regulations set by the grid operators that are to be followed by generators (conventional, solar, wind etc.) and electrical energy storage plants. Table III summarizes the voltage and frequency requirements for the three-demonstration sites, and this information is taken from a CIGRE working group report [71]. The electrical energy storage plants will have same limits as generators except in DK1 (where Danish demonstration sites are located) for 300 – 400 kV the underfrequency ranges are 47.5 - 48 Hz (30 min), 48-49 Hz (30 mins) and rate of change of frequency (ROCOF) tripping at ±2 Hz/s [72].

Table III: Grid code requirements for the three demonstrators [71]

Country/Grid code	Denmark/ Netherlands/Poland	
	Hz	Operation range
Frequency	47.5 – 48.5	Defined by each TSO, but not less than 30 mins
	48.5 – 49.0	Defined by each TSO, but not less than 30 mins
	49.0 – 51.0	Unlimited
	51.0 – 51.5	30 mins
Voltage	0.95 pu – 1.05 pu	

For the active participation of customers in demand side management schemes, they do not only require a physical connection to the grid, but also require monitoring and control functionalities from an energy system perspective and which can be accessed via standardised ICT interface to communicate with markets and system operators [73].

6 Local Demand Response, Demand Side Management and Control Schemes in SERENE

Demand response (DR) became a critical resource for achieving the energy efficient operation of the electricity system. There has been a growing interest in DR programs by both policy makers and market players/participants. This section gives the overview of the DR programmes that are suitable/applicable for the corresponding demonstration sites.

6.1 Energy Island Demonstrator: Denmark

Compared to other European markets, Denmark has a well-functioning electricity market due to the presence of sufficient capacity and interconnections. However, the increase in the share of renewable energy resources such as wind, solar etc., challenging the grid operators and flexibility is considered as one of the major possibilities to balance the mismatch between the production and the generation.

6.1.1 DR Status in Denmark

In Denmark, even though all electricity consumers are allowed to participate in the ancillary service markets, the regulatory environment makes it difficult for independent aggregators to develop innovative DR programs, thus limiting their participation. There are no independent aggregators yet, as the balance response parties (BRP/retailers) are responsible for the aggregation. A third-party aggregator would need a prior agreement of consumer's BRP/retailers to make a contract with the consumer [74]. However, discussions between Energinet, Green power Denmark (ienergi) regarding how an independent aggregator (without BRP) can play a role is ongoing. Main issue is to find a way for compensating the BRP's for the unbalance generated by the independent aggregator. Accordingly, The main enablers and barriers for the effective implementation of DR in Danish case are as given in the Table IV.

Table IV: Enables and barriers for DR in Danish case [74]

Main enablers	Main barriers
• Wholesale market and ancillary services market are open to DR. • Prequalification is made at the aggregated pool level.	• Payments in the wholesale market are too low due to various costs such as taxation on electricity, fees to other market players (BRP, retailer, DSO (Distribution System Operator)) • The current market definition requires that independent/third-party aggregators must bilaterally contract with the consumer's BRP and retailer.

Explicit DR in Denmark

In Explicit DR (also called incentive-based DR), the flexibility from the consumers is either traded in the electricity market or used for other purposes (ancillary services, balancing etc.). A prerequisite to enable explicit DR is to meet the minimum bid size requirements that is applicable in various markets. An aggregator can play a key role by helping consumers to not only fulfil the minimum bid sizes but also reduce the administrative cost involved in DR participation. Most importantly, the aggregator can minimize the risk for the end-users' participation in case of not delivering according to plans. If the end-user participates directly, there can be a risk of penalty, if not delivering as per the agreement. The aggregator will have the possibility to use other assets in the pool and thereby, minimizing this risk otherwise.

Implicit DR in Denmark

Implicit or price-based DR is only rewarded as savings in the electricity bill, where the consumers are exposed to time-varying electricity prices/grid tariffs. The magnitude of implicit DR in the market becomes merely a question of cost/benefit for the consumer, i.e., that the measure of volatility of the price signals are sufficient to ensure that it is profitable for the consumer to change its consumption pattern as a response to the price signals. Furthermore, to enable implicit DR, it is necessary that the consumer is metered and billed at the same resolution as the price signals.

6.1.2 Local Demand Response and Control schemes in SERENE: Denmark

The control framework for Danish case includes intelligent operation of heat pumps for increasing the self-consumption of local RES generation at both building level and community level. Figure 35 shows the control framework describing the interaction between all stakeholders including prosumers, local RES, aggregator, and electricity market.

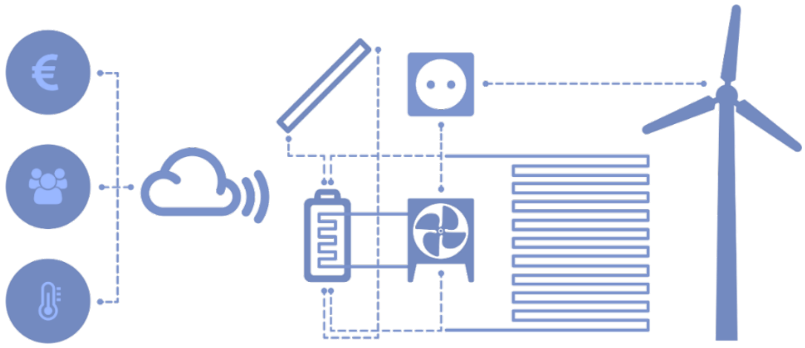

Figure 35: Control framework for Danish demonstration

The control algorithm for the demonstration site includes,

- The objective is to minimize the energy exchange with the grid through increasing the utilization of local renewables, if RES is at household level, or increasing the renewable integration in the grid, if RES is at aggregated level, by using electricity to heat networks (installations of HPs with PCM-based hot water storage tanks in this case).
- The local controller associated with HPs at consumer site provides the state of HP and energy level within storage tank to the central controller (PreHEAT Aggregator).
- The central controller gathers the information about excess production, electricity price along with consumer preferences as main constraints to determine the optimal operation of HP's.
- In addition, the electrical network constraints like voltage limits would also be considered as one of the constraints.

The HP operational constraints (delays associated with compressor output and pump ON-OFF, storage state of charge limits, etc) and consumer preferences (thermal comfort limits, EV charging preferences, etc) play a key role in finding the optimal scheduling of HPs and EVs. This control algorithm can be applied to the central HP station scenario also.

6.2 Energy Island Demonstrator: The Netherlands

In general, small and medium-sized enterprises (SMEs) (also >3x80A connections) already participate in real-time-pricing schemes through energy retailers (e.g. NieuweStroom) to e.g. temporary shut-down of coolers or even wind turbines based on day-ahead and imbalance prices. This goes way broader and is already applied for some years now. The current model, called 'salderingsregeling' (English: 'net-metering') allows a house to only be billed for the difference between their consumption and the amount they send back to the grid [80]. Thus, each house only pays for the 'actual' energy they consume. If a house produces as much energy as much it consumes, then theoretically, it can nullify the electricity part of its energy bill. However, it must be noted starting from January 1st, 2025, this net-metering model shall be phased out in stages with the intention being to stimulate self-consumption via the use of home energy storage systems.

6.2.1 DR status in the Netherlands

The main drivers for demand-side participation are imbalance management of BRPs for their own portfolios and so-called "passive balancing," which presents the advantage of simplicity, but prevents third-party aggregator to access consumers directly. The main enablers and barriers for the effective implementation of DR in Dutch case are as given in the Table V.

Table V: Enables and barriers for DR in Dutch case [74]

Main enablers	Main barriers
• DR can access majority of ancillary services. • Minimum bid sizes are adequate for DR capabilities.	• The third-party aggregators can participate in the market only through BRP and retailer.

In the Dutch market, the aggregators offer portfolio optimization services to BRPs, through trading in day-ahead, intraday, and balancing markets. BRPs can act as aggregators or hire third-party aggregators for this service. This offering is always bundled with the sale of electricity, where consumer must accept or reject the entire service, or negotiate with another retailer in order to access the DR services. However, so-called sub-metering is possible, such that a customer can have multiple energy contracts, allowing to e.g., charge electric vehicles through a different retailer with potentially a different DR scheme. The prerequisite for this is separate metering infrastructure. Furthermore, a growing number of retailers is offering time-of-use pricing schemes based on the Day-Ahead market clearing outcomes, thereby incentivizing their customers to adapt their loads to moments of low prices.

6.2.2 Control Framework

The control framework to be implemented in the Dutch demonstrator site includes:

1. Energy sharing amongst the 24 houses to maximize independence at the community level.
2. Implementing demand side management approaches such as profile steering [75] for day-ahead planning to achieve various objectives such as minimizing CO2 emissions, maximizing peak shaving, increasing self-consumption to various degrees.
3. Integrating the solar carport and EVs into the energy sharing system of the community.

DEMKit, short for Decentralized Energy Management toolkit, is used to model and implement the aforementioned objectives [75]. Firstly, DEMKit is a software tool that provides models for both the devices and the controllers for these devices as well as the software for the required optimization algorithms. Secondly, DEMKit adheres to a modular and cyber-physical system design paradigm. Each grid component can be modelled independently and thereafter the connections between these components can be described. DEMKit also adheres to the software tenant of abstraction, by providing a suite of elementary components from which new custom components may be generated. Thirdly, DEMKit has the ability to optimize multiple energy carriers in a multi-energy system thereby simulating scenarios resemblant of the current energy transition. Lastly, DEMKit is written in Python in order to allow rapid development as well as increase its accessibility for research and collaboration.

6.2.3 Local Demand Response and Control Schemes in SERENE: The Netherlands

Profile steering as a DR scheme

The Demand Response (DR) scheme of choice used for optimization in DEMKit is Profile steering [75]. Profile steering used a decentralized network architecture consisting of coordinator nodes and child nodes as shown in Figure 36. Profile steering consists of two phases, an initialization phase and an iterative phase. During the initialization phase, the coordinator node asks each of its child nodes to steer their own (local) profile towards a desired profile. Thereafter the local profiles of the child nodes are summed up by the coordinator and the deviation from the desired global profile is calculated. Successive stages (iterative phase) use these deviations as steering signals for the child nodes to generate new local profiles.

Profile steering case-study

B. Homan *et al* [8] investigated the possibilities for (near) autarkic behaviour in a micro-grid consisting of 16 houses in the Netherlands using the software tool DEMKit and profile steering as the DR scheme. They assume a scenario wherein PV panels and a CHP are the energy sources and batteries, and a heat buffer are used for energy storage. Therefore, the authors focus on simulating a Multi-Energy System (MES) inspired by the community of Aardehuizen introduce a new term, Degree of Autarky (DoA) to objectively measure their results.

$$DoA = \frac{E_{consumption} - E_{import}}{E_{consumption}} \times 100\% \qquad (1)$$

$$E_{consumption} = Total\ amount\ of\ energy\ consumed\ from\ local\ sources$$

$$E_{import} = Total\ amount\ of\ energy\ imported\ from\ the\ grid$$

The authors show that with a year-long simulation they are able to achieve a DoA of 98.4% in an optimization scenario with realistic battery model. A DoA of 98.4% means that the community may import energy from the grid for at most 1 week in the entire year. G. Hoogsteen *et al* [78] study the application of a DSM approach such as profile steering in the same MES as presented above (but now including heat pumps) using distributed optimization. The DEMKit model used is shown in Figure 36. It must be noted that the objective of [77] was to study the performance of the modified PS algorithm for MES systems. Therefore, the authors did not consider predictions, making the results of [8] and [77] incomparable. The authors of [77] show that optimizing an MES consisting of a heat pump, a buffer and a CHP, using their proposed modified profile steering algorithm, leads to a 51% reduction in the energy exported from the MES.

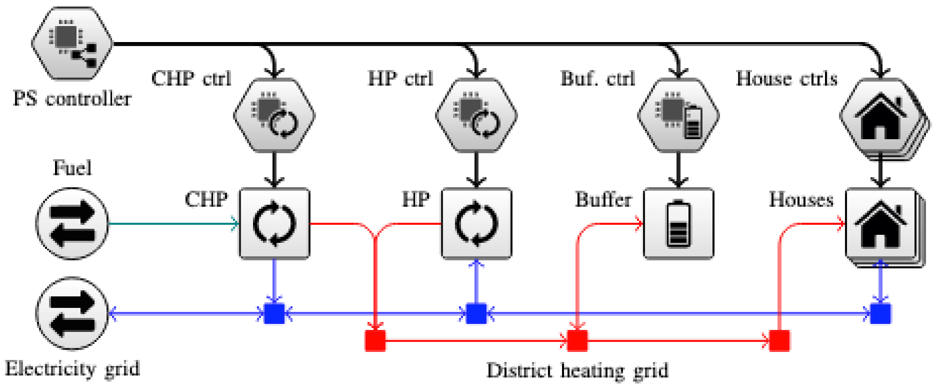

Figure 36: DEMKit model of the MES of [76] with the devices and the controllers.

6.3 Energy Island Demonstrator: Poland

Coal is the predominant source of energy in Poland, but the public opinion is aware that it has to change soon. The production from RES is constantly growing and the cost of energy from conventional power plants is increasing, so grid operators are forced to take action to increase the flexibility of resources that can improve the security of the supply. Poland is now witnessing the biggest legislation changes in energy laws and regulations – since 2021 a number of changes and updates were introduced: further digitalization of the energy usage data, introducing advanced metering infrastructure (AMI), central system for metering data, regulations regarding energy storages, regulations regarding EV and EV charging. All of those aim to adjust Polish regulations to the guidelines defined by EU.

One of the changes has proven very impactful on the RES market – since 2016 the owner of PV system could take back from the grid part of the energy it has sent to the grid (80% for ≤10kW installation and 70% for ≤50kW installation). By the end of Jan 2022 number of PV prosumers have reached 880 thousand with over 6,5GW installed power. Since 1st of July 2022 the distribution grid will be buying produced energy for a fixed tariff (net-billing). This change caused a huge increase in installation of the PV installations till march and completely halted the installation after then due to the lack of knowledge about the prices.

6.3.1 DR Status in Poland

In 2014, the balancing market was officially opened for DR. Under emergency conditions of the grid, the Polish transmission system operator (TSO) is legally allowed to curtail medium to large commercial and industrial customers, which would be given priority than commercial Emergency DR programs (EDRP). In EDRP, the aggregation service providers/BRP has a bilateral contract with the TSO but not with energy providers. The DSR services really started in 2017 and contracted powers were growing from 313 MW in 2017 to 790 in 2020. In January 2021, the rules for contracting power within DSR has changed – it was connected to introduction of power market in January 2021. Since then, it is not TSO making DSR contracts but companies that won the tender. For the period from 1st of April 2021 till 31st of March 2022 there were companies that were allowed to contract DSR services with companies and clients: CMC Poland Sp. z o.o., Enel X Polska Sp. z o.o., Enspirion Sp. z o.o., Lerta S.A., Polenergia Obrót S.A. oraz Tauron Sprzedaż Sp. z o.o. [https://www.pse.pl/uslugi-dsr/programy-dsr-w-latach-2017-2021] One of this companies – Enspirion Sp. z o.o. is active in Przywidz area and is interested in results of SERENE project. Up to now the minimal reduction abilities that are considered in the DSR are 250 kW.

The main enablers and barriers for the effective implementation of DR in Polish case are as given in the Table VI.

Table VI: Enables and barriers for DR in Polish case [74]

Main enablers	Main barriers
• Access to balancing market. • Emergency DR programs.	• Ancillary service market is not open for DR and not transparently contracted. • No legal role for independent aggregator.

6.3.2 Local Demand Response and Control Schemes in SERENE: Poland

Due to the scale of the polish demonstrator, DSR services are researched in context of Use Case 3 i.e., the sewage treatment plant. This facility has a PV installation, diesel generator and enough flexibility in consumption to significantly reduce the usage, but it is not clear if the duration and amount of reduction is sufficient to contract the power reduction with the DSR service contractors.

The control of usage and production will be implemented in all the use cases of Polish demonstrators, but in different scale:

Case 1 – Prosumer district

Prosumers' ability to participate in DR schemes will be analysed within the project considering future trends and the possibility to aggregate citizens in some forms of energy clusters and energy communities. The project does not consider creating a single system for control of the energy usage but creating the system to gather data to fully understand the needs and preferences of citizens. A coordinated voltage control using mobile storage system is to be employed for Case 1.

Case 2 – Sports hall

The sports hall area smart energy system will be integrated within the common EMS. Presence of energy storage system and V2G charger will enable higher flexibility of the electrical energy profile. This case will cover a very specific case – the function of the building allows for planning and forecasting of the usage (classes and sport activities are scheduled, as well as special events), but there is very limited possibility to shift the usage. Considering the size of the storage, the management system will focus on increasing auto consumption of the facility and ensure to not to use beyond the contracted power.

Case 3 – Sewage Treatment Plant

It is intended to include sewage treatment plant into DR scheme or at least verify the possibilities to do so and define the conditions under which such service is possible. The main function of the sewage treatment plant is to purify sewage to be biologically safe and not polluting. After initial research, it is visible that the biological processes of water purification are very slowly changing and have certain tolerance to changes. That might show the potential for reducing the usage for some time, also that gives the potential to increase the self-consumption of local RES generation using the waste-water treatment plant.

7 Summary and Conclusions

A generalised system architecture is formulated for harnessing the energy flexibility that takes into account the interaction between various local energy vectors like electric vehicles, heat pumps, and battery storages to establish a renewable energy based flexible integrated energy system for all the individual demonstrators in SERENE. The energy statistics corresponding to all demos provides the knowledge of energy mix from both supply and demand that is used to determine the opportunities to increase the local renewable energy production by channelizing to heating/cooling and transportation. Further, the predictive analysis of production and consumption data reveals interesting patterns that can better represent the flexibility for demand-side management services. In addition, relevant flexibility aggregation methods, aggregator business models and flexibility market frameworks are essential for local integrated energy systems to provide grid support services.

For implementing local demand response techniques corresponding to all demonstration sites addressing community energy systems, the control frameworks based on USEF models are adapted. The framework also highlights the participation of local citizens, local authorities, and stakeholders for establishing community-based transition of the heating supply from fossil fuel (natural gas and oil) to electric heating for individual residences and centralised heating network for selected local communities. In addition, the integration of electric vehicles to the local community energy systems for all demos and implementing vehicle-to-grid technology in the polish demonstrator are also emphasized.

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