**Project no.:** **101022587**

**Project full title:** **Sustainable energy system for achieving novel carbon neutral energy communities**

**Project Acronym:** **SUSTENANCE**

| | |
|---|---|
| Deliverable number: | **D2.1** |
| Deliverable title: | System framework and demand response schemes for different demonstrators |
| Work package: | WP2 |
| Due date of deliverable: | M12 |
| Actual submission date: | 30/06/2022 |
| Start date of project: | 01/07/2021 |
| Duration: | 42 months |
| Reviewer(s): | Johann Hurink (UT), Asha Rani (NITS) |
| Author/editor: | Pavani Ponnaganti (AAU), Jayakrishnan R Pillai (AAU) |
| Contributing partners: | Aalborg University (AAU), Universiteit Twente (UT), Instytut Maszyn Przeplywowych IM Roberta SZEwalskiego Polskiej Akademii Nauk (IMP), Wlasnosciowa Spoldzielnia Mieszkaniowa Im Adama Mickiewicza (WSM) , Indian Institute of Technology Bombay, (IITB) |

| | |
|---|---|
| Dissemination level of this deliverable | **PU** |
| Nature of deliverable | R |

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101022587, and the Department of Science and Technology (DST), Government of India under the SUSTENANCE project. Any results of this project reflect only this consortium's view and the funding agencies and the European Commission are not responsible for any use that may be made of the information it contains.

## Document history

| Version no. | Date | Authors | Changes |
|---|---|---|---|
| 0.1 | 07.03.2022 | Pavani Ponnaganti, Jayakrishnan Pillai | Preliminary structure |
| 1.0 | 19.04.2022 | Pavani Ponnaganti | First version of the text added to the various sections |
| 1.5 | 15.05.2022 | Pavani Ponnaganti | Additional contents and mid-report version |
| 2.0 | 30.05.2022 | Pavani Ponnaganti, Jayakrishnan Pillai | Editing, improving contents |
| 3.0 | 22.06.2022 | Pavani Ponnaganti, Jayakrishnan Pillai | Addressing reviewer’s comments, final internal version |

## Contributors


| Partner no. | Partner short name | Name of the Contributor | E-mail |
|---|---|---|---|
| 1 | AAU | Pavani Ponnaganti<br>Jayakrishnan Pillai<br>Birgitte Bak-Jensen | pap@energy.aau.dk<br>jrp@energy.aau.dk<br>bbj@energy.aau.dk |
| 7 | UT | Aditya Pappu<br>Gerwin Hoogsteen<br>Frans Coenen | a.pappu@utwente.nl<br>g.hoogsteen@utwente.nl<br>f.h.j.m.coenen@utwente.nl |
| 9 | IMP | Patryk Chaja | patryk.chaja@imp.gda.pl |
| 13 | WSM | Małgorzata Śmiałek-Telega<br>Adrian Lis | smmickiewiczasopot@gmail.com<br>cybadrian@gmail.com |
| 14 | IITB | Zakir Rather | zakir.rather@iitb.ac.in |

## Table of Contents

1 Executive Summary ..... 4
2 Introduction ..... 5
2.1 Scope and Objectives ..... 5
2.2 Partner contribution ..... 5
2.3 Relationship with other tasks and deliverables ..... 5
3 Multi-energy system framework ..... 6
3.1 Cross-energy sector framework for integrated local energy systems ..... 6
3.1.1 Integrated local energy systems: demo case in Denmark ..... 8
3.1.2 Integrated local energy systems: demo. cases in India ..... 10
3.1.3 Integrated local energy systems: demo cases in the Netherlands ..... 14
3.1.4 Integrated local energy systems: demo case in Poland. ..... 18
4 Datasets available ..... 21
4.1 Denmark ..... 21
4.1.1 Energy information, demand and production data ..... 22
4.2 India ..... 23
4.2.1 Energy information, Demand and Production data ..... 24
4.3 The Netherlands ..... 25
4.3.1 Energy information, Demand and Production data ..... 25
4.4 Poland ..... 27
4.4.1 Energy information, Demand and Production data ..... 28
5 Demand side management schemes ..... 34
5.1 Denmark ..... 34
5.1.1 DSM requirements and status in Denmark ..... 34
5.1.2 Local Demand Response and Demand side management in SUSTENANCE: Denmark ..... 35
5.2 India ..... 36
5.2.1 DSM requirements and status in India ..... 36
5.2.2 Local Demand Response and Demand side management in SUSTENANCE: India ..... 38
5.3 The Netherlands ..... 39
5.3.1 DSM requirements and DR status in the Netherlands ..... 39
5.3.2 Local Demand Response and Demand side management in SUSTENANCE: The Netherlands ..... 40
5.4 Poland ..... 42
5.4.1 DSM requirements and DR status in Poland ..... 42
5.4.2 Local Demand Response and Demand side management in SUSTENANCE: Poland ..... 42
6 Summary and Conclusions ..... 45
7 Bibliography ..... 46

# 1 Executive Summary

This deliverable D2.1 is an open access document providing the overall perspective of the technical specifications, requirements, and system architecture to establish integrated local energy systems at the various demo sites in the SUSTENANCE project. This document describes the architectural frameworks for multi-energy systems, which will be used to relate appropriate use cases and local demand response techniques applicable to corresponding demonstration sites with citizen-centred integrated local energy systems. The introduction of partner contributions is outlined in the document followed by system frameworks that can be applied in all four demonstration sites.

The system architecture is formulated based on the smart grid architecture model (SGAM) with various interoperability layers that considers the interrelation between various components and functions in energy systems. This is further adapted to involve different requirements, dependencies, and roles for realising and managing cross-energy sector coupling for establishing integrated local energy systems in SUSTENANCE. Based on the interfacing requirements and solutions from the integrated local energy system framework, the use cases for the various demo sites in Denmark, India, Netherlands, and Poland are analysed to determine specific technical objectives. Hereby the geographical locations corresponding to the different demo sites are the base to determine the potential for energy flexibility, the requirements for multi-energy systems in local communities and the available local production and consumption profiles.

The demand-side response strategies that are suitable for the different demo sites for utilising energy flexibility for enhanced energy efficiency and increased self-consumption from renewable energy are evaluated. An analysis of the specific requirements, and the status of demand-side participation schemes prevailing in Denmark, India, Netherlands, and Poland shows that the concept is still evolving. The level of adoption depends on the existing policies and the available electricity markets in individual countries. There still are gaps in suitable regulations and their acceptance to realise demand-side response. This leads to various challenges in techno-economic and institutional aspects, in the level of interaction and the definition of clear roles of various energy stakeholders. Finally, the most suitable demand side management schemes that are applicable for activating local flexibility in integrated local energy systems for different use cases in the various demo. sites are identified in this deliverable.

# 2 Introduction

Sector coupling has the potential to provide an increased flexibility through the inclusion of heat and mobility energy demands and will have significant impact on the effective management of the generation from renewable energy resources or green fuels. This report presents a framework for multi-carrier energy systems and corresponding demand response schemes for citizen driven integrated local energy system in the different demo sites in the SUSTENANCE project. This framework forms the basis for unlocking energy flexibility from various energy vectors to develop local demand response schemes and thereby enabling active end user participation.

## *2.1 Scope and Objectives*

The aim of this deliverable is to define a framework for multi-energy systems and to develop appropriate local demand response schemes for all the demonstration sites. The objective is to establish requirements and options to exploit energy flexibility from heat pumps, electric vehicles, smart buildings, electric boilers, and water pumping etc., using the derived integrated energy system framework for the citizen driven local energy systems.

## *2.2 Partner contribution*

AAU is leading this task and IITB is the lead beneficiary for WP2. The workflow and partner contributions are coordinated by AAU and ensure that appropriate frameworks and models are set-up which form the base for the upcoming tasks within WP2. The other partners contribute in the following way.

- The different demo sides give insight, knowledge and a description of the use cases and their supply and demand data (cooperation with WP4, WP 5, WP 6 & WP 7)
- Technology provider Neogrid supports in defining and selecting suitable local demand response schemes for Danish demo cases.
- University of Twente and University of Applied Science Saxion support in defining and presenting potential local demand response schemes for the Dutch case.
- Polish partner IMP supports in defining and giving suggestion for potential local DR schemes for the Polish case.
- IITB is responsible for defining potential local demand response schemes for Indian case.

## *2.3 Relationship with other tasks and deliverables*

This deliverable uses input from Tasks T3.1 (factors influencing social acceptance and system change for demand side management), T4.1, T5.1 - T5.5, T6.1 (specifications and requirements of various demo activities to formulate system architecture and suitable use case) and the outcome of this deliverable will provide inputs to Tasks T2.2 to T2.8 (models, control schemes and grid integration analysis), T3.1 (socio-economic framework), T4.4, T5.1 to T5.5, T6.2 to T6.4, T7.5 to T7.7 (generic frameworks for system design and implementation of integrated community energy systems).

# 3 Multi-energy system framework

A multi-energy system (MES) framework enables the interaction of the various energy vectors including heating, cooling, fuels, transport with each other at various levels of the system (local community level, district level etc.) unlike the classical energy systems where these sectors operate independently [1]. This interaction gives a great opportunity to improve technical, technological, economic, and environmental performances for the coherent operation of MES. A MES can be of different categories: spatial (buildings, communities cities etc.), multi-service (combined heat and power), multi-fuel (electricity to heat), time resolution, and energy network [2]. Possible configurations, impacts and prospects of multi-energy systems are detailed in CIGRE joint working group report [3] that illustrates cost effective operation through unlocking flexibility. Furthermore, a detailed review of existing methods and approaches for modelling MES has been carried out in [4], where the authors stated relevant challenges especially for modelling urban districts including poor data quality and conflicts of interest among various stake holders due to lack of transparency.

## 3.1 Cross-energy sector framework for integrated local energy systems

Citizen driven integrated local energy systems promote not only sustainable energy production and consumption but also citizen's participation. The European Commission strongly supports the establishment of community-based renewable energy systems, recognizing their value in stimulating increased competition, limiting dependency on imperative electricity suppliers, avoiding costly distribution network reinforcements, and revitalizing local economies. The smart grid architecture model (SGAM) [5] contains different layers to include integrated local community energy systems (see Figure 1 for an overall energy system overview). As the figure shows, SGAM contains five interoperability layers representing business objectives and policies, supporting functions, information exchange and models, communication protocols, and components. This figure presents not only the relation between objects within the layer but also the inter-relation between objects within different layers.

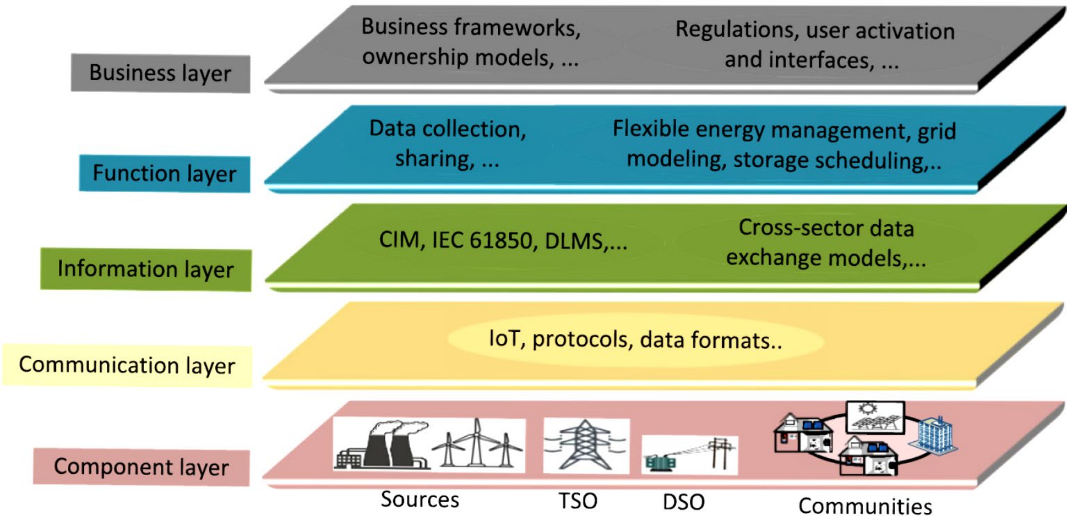


**Figure 1: SGAM interoperability layers [5]**

***Business layer***: This layer maps regulatory and market structures and policies, business models, business portfolios (products & services) of the energy stakeholders and energy clusters that are involved.

***Function layer***: This layer describes the integrated functions, requirements and services including their relationship and interactions with other layers.

***Information layer***: This layer provides a illustrates the information that is being used and exchanged between functions, services, and components.

***Communication layer***: This layer mainly describes the data formats, protocols, and mechanisms for the interoperable exchange of information between components related to the basic use case (description of system before implementing planned objectives), function or service and related information objects or data models.

***Component layer***: This layer refers to the physical distribution of all components of integrated energy systems in the data exchange platforms and the energy management solutions.

A developed example for a cross-energy sector architecture for a possible integrated local energy system for the SUSTENANCE project is shown in Figure 2. The figure gives the interaction of various consumers/components included in homes, buildings, water pumping system, on-site solar-PV and community EV charging stations, which are connected to a data information and communication layer through corresponding local energy management system.

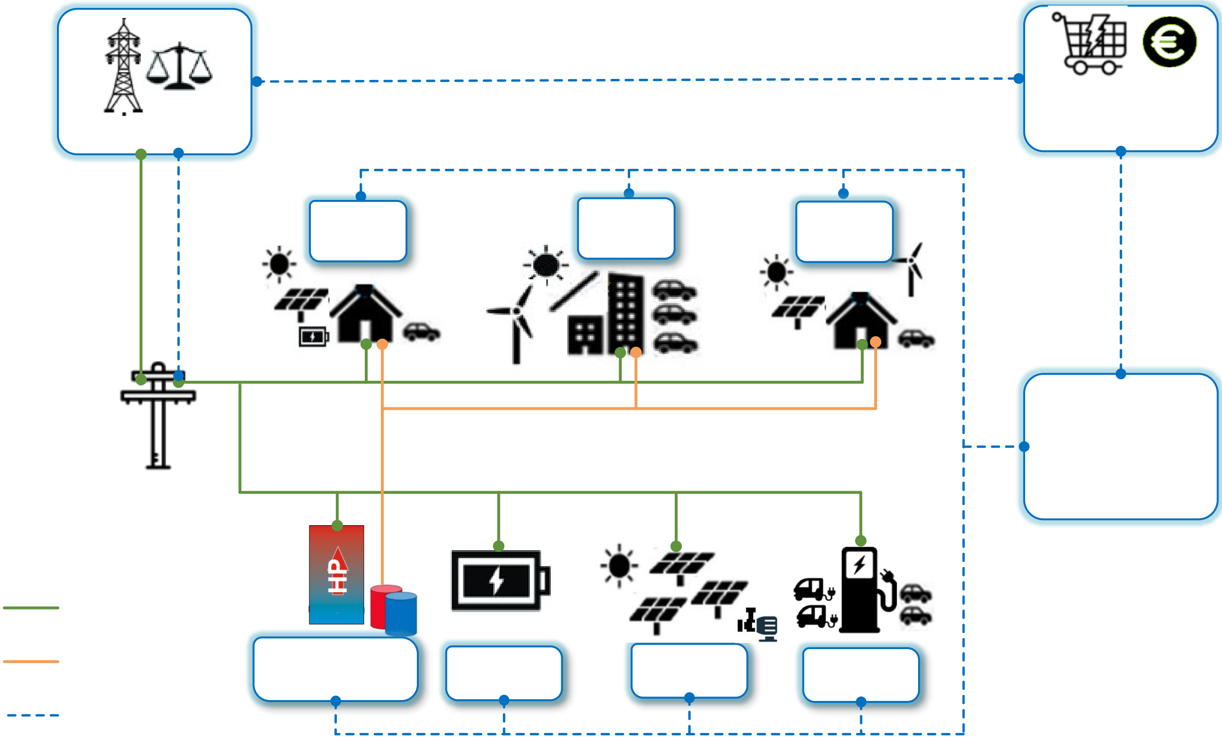

**Figure 2: Cross-energy sector architecture for integrated local energy systems**

The community-scale energy management systems communicate and exchange data with aggregators, who perform functions including flexibility management, grid services etc., thereby using proper business models to participate in the market. This framework is relevant for the demonstration sites that are part of this SUSTENANCE project, where the local energy initiatives may participate with both power and heat demands in electricity markets to reduce their electricity cost or provide grid services through e.g., an aggregator. Local energy initiatives can have different types of ownership models including partnerships, cooperatives or entities owned by local authorities, or can be a formalized citizen centred energy systems according to the EU-regulative on local energy communities (EU Directive on common rules for the internal electricity market 2019/944). This local energy ownership empowers the local communities to deploy and increase the use of RES, e-mobility, electric heating systems and smart utilisation of water resources, thereby supporting citizens to reduce their energy cost and be part of energy efficient solutions.

### 3.1.1 Integrated local energy systems: demo case in Denmark

The demonstrator in Denmark is formed by the villages Voerladegård and Dørup in Skanderborg municipality. The demonstration includes 20 private houses in Voerladegård and Dørup and the surrounding area, which must / will replace their oil or gas boiler with a heat pump with salt storage and smart control. The houses are primarily private owned houses and should preferably also have solar cells and/or charging stations. The demonstration site including markings of households is shown in Figure 3 and the planned activities include the active participation of local citizens, the municipality, and energy stake holders (Neogrid and AURA), thereby smartening the energy networks through ICT technologies and smart control of heat sources. The specific objectives of the Danish demonstrator are as follows:

- Developing an intelligent control of salt hydrate phase change material (PCM) storage-based heat pumps (HP) in synergy with on-site solar-PV production in residential households.
- Demonstration of community based solar PV-based EV charging station with battery storage by applying suitable local demand response scheme.
- Impact analysis of integrated community energy systems on local distribution grid for smartening their operation and increasing the economic benefits of both citizens and stakeholders.
- Develop and demonstrate a novel business and community-based ownership model for operating a smart micro- grid based solar PV-HP-EV energy systems where energy can be shared between households in the community within a regulatory test zone.


**Figure 3: Voerladegaard: Danish demonstrator**

#### 3.1.1.1 Use case 1 Danish demonstrator

The definition of use case as stated in Bridge document is “A list of actions or event steps typically defining the interactions between an actor (assets, customers, stake holders, BRP, DSO etc.) and a complete system to achieve a goal” [5]. The key stakeholders in this demonstrator are consumers (installed with HPs, PCM based thermal storage tanks, solar-PVs and EVs), aggregator (Neogrid), and the DSO (AURA). The use case as shown in Figure 4 deals with the integration of heat pumps, salt heat storage, solar cells, electric cars, etc., with smart control to increase the self-consumption of local renewable energy resources while respecting the electricity grid limits (voltage limits, feeder capacity limits).

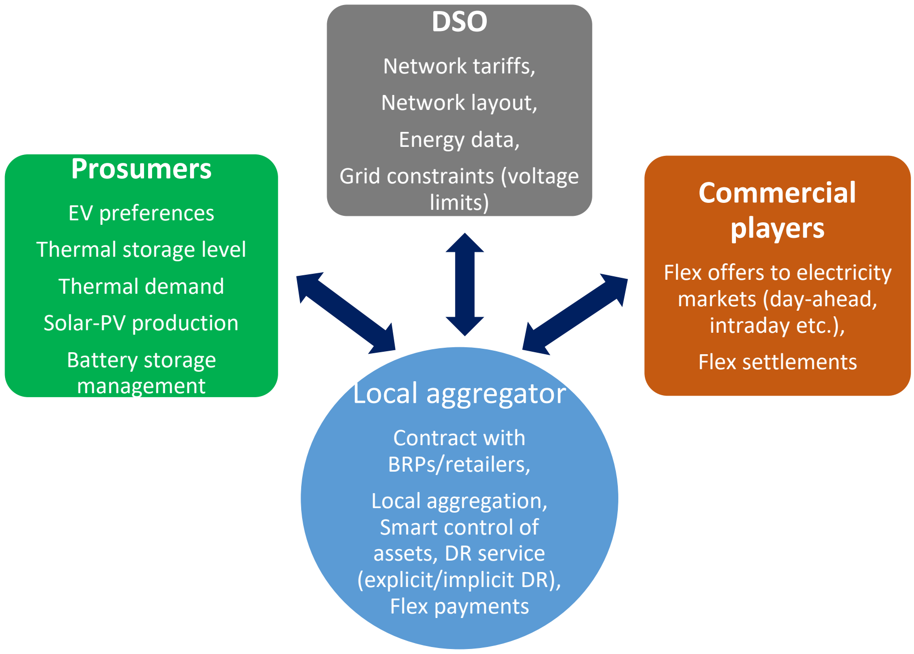


**Figure 4: Use case for Danish demonstrator illustrating functions and interaction of integrated local energy system players**

The local aggregator or local energy company establishes contacts with commercial players like retailers and BRPs to enable third party access control over prosumer flexible assets. By this the individual prosumers can provide information of their assets including consumption, production, and flexibility preferences to the aggregator. The DSO is also part of such contracts and monitors the impact of the DR on the local grid and provides necessary tariff and grid information to the aggregator. Based on collected load and network data, the local aggregator determines proper schedules of the assets for minimizing the electricity cost and maximizing the self-consumption of local solar-PV production.

### 3.1.2 Integrated local energy systems: demo. cases in India

The Indian demonstration activities in the SUSTENANCE project involve 3 demonstration sites, which includes i) a remote village of Barubeda, Ranchi in the state of Jharkhand, ii) Borakhai village, Silchar in the state of Assam and iii) a smart building system at the campus of IIT Bombay, Mumbai, Maharashtra. Hereby **Barubeda Village, Jharkhand** is focusing on off grid local energy systems, **Borakhai Village, Assam** has a weak and unreliable grid connection, and **IIT Bombay campus, Mumbai** has a grid connected, integrated smart building system. The main objectives of the Indian demonstration sites are as follows:

- Development and demonstration of the use of solar PV powered water pumping schemes to eliminate manual fetching of water by the residents and possibly improving the agriculture productivity using domestic water supply.
- Development and demonstration of community based solar PV powered electric-rickshaws and implementation of a campus-based EV charging infrastructure for the users.

- Demonstration of a biomass/biogas-based cooking system for a local school kitchen and household cooking in the villages. This is aimed for eliminating the use of firewood and generating positive health impact to the community and reduce the air pollution.
- Development and demonstration of a community cooling, heating, and drying system for increasing the productivity and shelf life of agricultural products (vegetables, milk etc.) and for storing medicines (including lifesaving medicines) at community/local pharmacy level.
- Demonstration of a solar PV fed bio vegetable and plant waste processing unit for converting plant and vegetable residues to manure.
- Development and demonstration of smart energy management systems for multicarrier energy systems (power sources like solar PV, wind turbine, biogas, biomass etc.) and flexibility from energy storages and deferrable loads, for reliable energy supply in two rural households and in the research institute campus building
- Development and demonstration of local balancing and distributed control for energy sharing between households, household clusters and in the overall integrated community energy system. Hereby, also the feasibility for interconnecting the micro-energy clusters with the neighboring village is analyzed.
- Demonstration of a smart electricity system for buildings.
- Demonstration of grid support services including ancillary services, demand response and grid flexibility from the local integrated energy system at the campus.
- Establishing energy community cooperative and ownership models for efficient and harmonized operation of local multi-vector energy islands.

**Figure 5: Barubeda Village, which aims at becoming a carbon neutral "islanded" energy community [Source: IIT Bombay]**

In Barubeda Village with around 57 houses, the core income source of the people is from agriculture. There is only a limited access to water in general, and clean water in particular. The inhabitants (primarily women) have to fetch water manually for its use in the community, as there is no water pumping system, primarily due to lack of electricity. Firewood is primarily used for cooking, and kerosene-based lamps for lighting. The village does not have access to any public transportation services, and the inhabitants generally walk over around 3 kms to reach the nearest road. For several months in a year, the men migrate to nearby cities for work. The village is in a dire need for energy supply and therefore the inhabitants are keen to have a local sustainable energy system established.

**Figure 7: BORAKHAI VILLAGE, which aims at delivering smart clusters based on local energy systems powered by renewables [Source: IIT Bombay]**

Borakhai Village is in a relatively comfortable situation as compared to Barubeda site, since it is partially electrified, however with limited hours of electricity access each day. For some houses, this means that it can only have a connected load of less than 200 W, limited to only few hours a day. For others there is a maximum power of 0.5 kW, however the residents are getting electricity only during 1/3$^{rd}$ of the time in a day. The inhabitants do not have access to clean and reliable domestic water supply. Moreover, while some families have LPG connection, firewood is primarily used for cooking purpose andkerosene -based lamps are used for lighting. The residents have a very limited access to unreliable transport system. In total 40 houses are part of this site.


**Figure 6: Solar powered building in IIT Bombay Campus in Mumbai (left) and a campus map with planned EV-chargers localization (right) [Source: IIT Bombay]**

In the two rural sites (Barubeda and Borakhai), the overall goal is thus to develop a community-based integrated renewable energy system (RES) enabling smart energy solutions for supplying reliable, low-carbon and efficient energy to meet the basic daily needs of those rural populations. Around 57 households in the Barubeda village, and 40 households of Borakhai village are involved in implementing the local energy system. The demonstrator at IIT Bombay campus is significantly different from the other two sites as the campus is having 24x7 power supply from the main grid as well as rooftop solar PV system of around 1 MW installed capacity. For IIT Bombay site, with more than 10,000 in campus population, the aim is to set up a smart energy system consisting of a smart electric building coupled with EV charging infrastructure. The smart electrical building will be equipped with state-of-the-art technology including a solid state transformer, a multi-port converter system and with demand response features.

#### 3.1.2.1 Use case-1 for Indian demonstrator: Sustainable islanded local energy system at Barubeda

A local renewable energy based islanded energy system is aimed to be developed at this site. The local energy system will provide various utilities to the village community, which includes electricity, a domestic water supply system, a e-rickshaw based transportation system, biogas and biomass-based cooking, and a multiutility based heating, cooling and drying facility. The generation sources include solar PV systems, wind and biogas-based generation, along with battery energy storage system. A local energy management system will be developed to integrate all the planned energy vectors, as shown in the Figure 8.

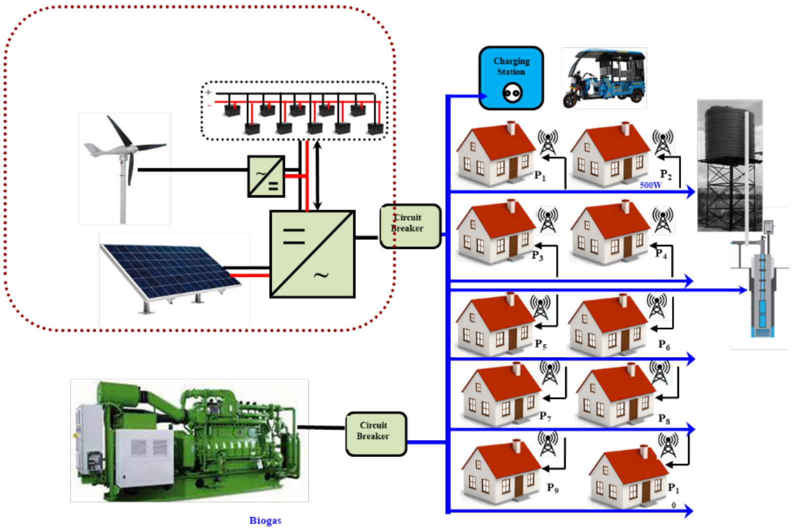


**Figure 8: Energy system planned for Barubeda site**

#### 3.1.2.2 Use case-2 for Indian demonstrator: Weak grid connected Energy system at Borakhai

In Borakhai, a multi-energy cluster based on local renewable energy will be developed. This demonstration site comprises of around 40 houses located at two separates, however, close by locations. The local energy system will provide various utilities to the village community, which include electricity, domestic water, e-rickshaw based transportation system, and a biowaste to manure conversion facility. The generation sources include a hybrid solar PV-wind system, a solar PV system and wind generation and are coupled to a battery energy storage system. A local energy management system will be developed to optimally integrate all the planned energy vectors, as shown in the Figure 9.

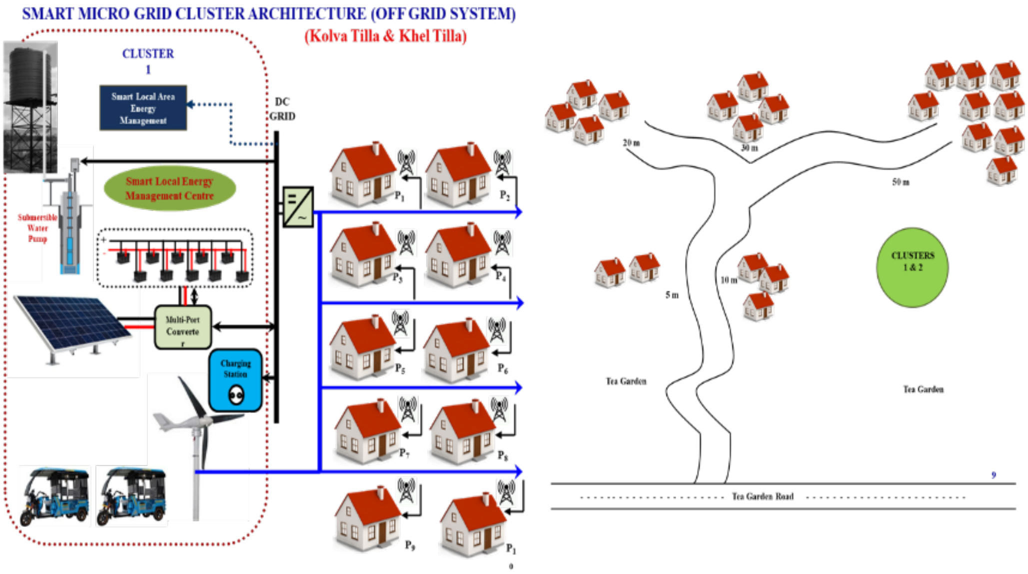


**Figure 9: Energy system planned for Borakhai site**

#### 3.1.2.3 Use case-3 for Indian demonstrator: Smart energy system at IIT Bombay campus

In this demonstration site, the main focus is to develop smart electric vehicle charging system, smart electrical building system, and to demonstrate vehicle to grid services. A local energy management system will be developed to optimally integrate all the planned energy vectors. The charging infrastructure includes charging points for the 2-wheeler and the 4-wheeler segments. Moreover, the smart electrical building will be used to demonstrate a vertical building microgrid system with demand side management, as shown in the Figure 10.

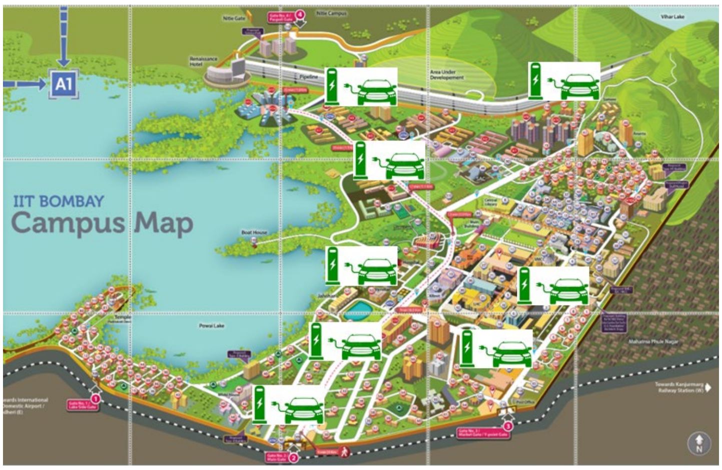


**Figure 10: EV charging infrastructure in IIT Bombay campus**

### 3.1.3 Integrated local energy systems: demo cases in the Netherlands

The Dutch demonstrator consists of two project sites: Vriendenerf community in Olst and the SlimPark car charging community at the University of Twente. Furthermore, potential integration of Vriendenerf with the broader energy community of Olst is investigated, e.g., by a collaboration with the Aardehuizen community, the new Olstergaard community and the rest of the village.

#### 3.1.3.1 Use Case 1 for the Netherlands demonstrator – Vriendenerf

Vriendenerf is a community of sustainability focused residents of age 50+ consisting of 12 houses and a community house built in 2016-2017 after a preparation period of 4 years [6]. It is located in the municipality of Olst-Wijhe, on the southern edge of the village of Olst as shown in Figure 11.


**Figure 11: Location of the first site in the Netherlands, Vriendenerf.**

The 12 houses are divided into groups of 3 as shown in Figure 12. All houses were constructed keeping ZEB (Zero Energy Building) or 'zero-on-the-meter' (ZOM) criterion in mind. To reach this criterion, each row of 3 houses is equipped with 69 PV panels and designed in such a way that also solar irradiation can be used for space heating using a façade. In addition, each house is equipped with a heat pump, domestic hot water storage tank, and ground thermal storage. Each room has its own thermostat, allowing for careful adjusted heating. The fully insulated houses are furthermore equipped with active air ventilation systems including heat recovery to ensure that most heat is kept within the building to minimize the heating demand. Lastly, the community recently installed electric vehicle charging stations to take the next step in reducing their carbon footprint.

**Figure 12: 4 groups of 3 houses/group and the Deelhuis (community house).**

The specific objectives of the demonstrator include:

- Develop and demonstrate a smart grid Energy Management System (EMS) to employ flexibility options (batteries, electric vehicles, heat pumps, electric boilers) within a local integrated community setup to utilize a high level of self- consumption based on generated solar PV.
- Enable the system to be able to operate - at least for some time period – in soft-islanded mode.
- Develop various energy modii options to account for scenarios such as high congestion or grid failure and study the EMS operation and behavior under these various energy modii.
- Develop and demonstrate an Internet of Things (IoT) data platform to support the planning within the system and the economic and reliable operation of the (islanded) local energy system.
- Develop and demonstrate smart grid ready interfaces for asset utilization and control to support DSM, peak shaving, offering flexibility options to larger networks and increasing the degree of autarky.
- Develop organizational models, a dashboard, and Multi Criteria Analysis tools for energy communities for collective energy exchange and effective management of the local integrated energy systems.

The overarching goal here is to demonstrate the exchange of energy and flexibility between the prosumers in the Vriendenerf community, with the goal to be as much self-sustainable as possible at every time instant. The community asks for a new method of energy sharing that is based on cooperation instead of competition as seen in classic market-based systems. Yet, a fair price for offering energy and/or flexibility needs to be guaranteed. Furthermore, the seniority of inhabitants requires that the implemented solutions are simple and intuitive. Furthermore, the energy management system and dashboards have to take care of collecting preferences and help the inhabitants, while controlling devices autonomously.

Within this context, the Vriendenerf community can be seen as a “holon”, a cooperative of equal stakeholders that jointly organize their energy system. Together with neighbouring communities, a holarchy can be created. Interaction with other stakeholders, being the municipality, DSO and energy suppliers, is envisioned. For this, the Universal Smart Energy Framework (USEF) provides a blueprint (Figure 13). However, with the current laws being non-permissive when it comes to energy sharing, and the new Dutch Energy law not in force yet, the exact relations and interaction still has to be investigated. See also Subsection 3.1.3.3.

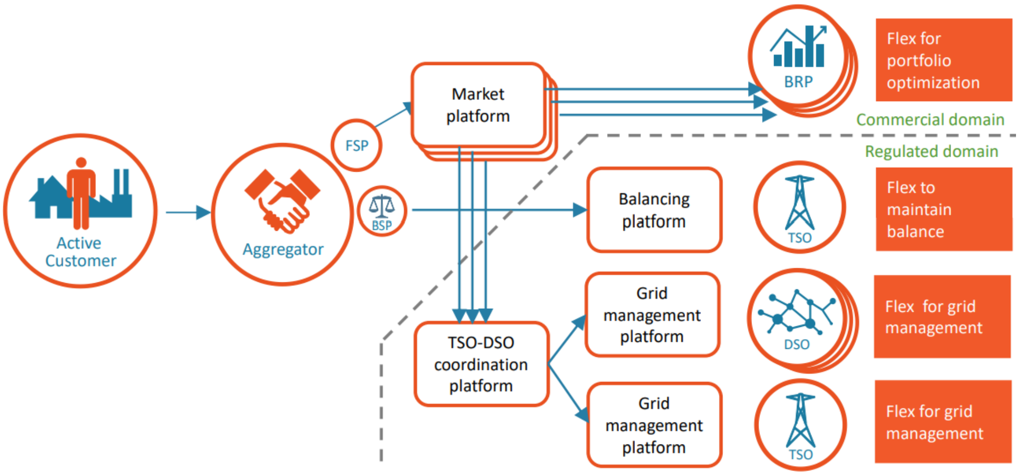


**Figure 13: Overview of the entities and their interactions in the USEF Framework [14].**

#### 3.1.3.2 Use Case 2 for the Netherlands demonstrator – SlimPark

SlimPark is a living lab for electric vehicle charging at the University of Twente (UT) campus consisting of nine 3-phase 22kWp (32A per phase) Mennekes Amtron Pro chargers and a 27 kWp solar panel rooftop (see Figure 14 for a view of the EV charging station). Furthermore, a 30kWh/20kW battery storage system is installed. All these components are connected to a 3-phase grid connection with a 125 A per phase limit, which is significantly lower than the installed capacity of EV charging stations. For this reason, the smart charging parking lot is equipped with sensors and novel energy management systems are tested in this test facility to ensure reliable and clean supply of electricity for the EVs to be fuelled in a sustainable way. The hardware specifications are show in Table I.

**Table I: Specifications of UT demonstrator site**

| Hardware | Capacity | No. |
|---|---|---|
| EV Chargers AC | 22 kW | 9 |
| PV Panels | 360 Wp | 69 |
| PV Inverter | 25 kW | 1 |
| Energy Storage | 30 kWh / 20kW | 1 |

**Figure 14: The EV charging station at the UT campus.**

The specific objectives of the demonstrator include:

- Develop and demonstrate an EMS system for EV scheduling with priority towards a high level of self-consumption from PV panels and batteries.
- Design and implement energy modii options for the charging station to account for scenarios such as a large number of EVs charging in parallel or a scenario under a cyberattack.
- Develop and demonstrate intelligent EV scheduling interfaces for asset utilization and control to support demand side management and flexibility services.
- Investigate new organizational models (e.g., the users could form an own local energy community with a special purpose), develop a dashboard and Multi Criteria Analysis tools for effective energy management of the local integrated energy systems.

The main use-case here is to study new methods of direct interaction with the energy system. Since EV charging already leads to direct interaction (i.e., plugging in the electric vehicle), it is expected that this physical interaction can be exploited to make users more aware of the energy system. Through innovative apps and new business models, we intend to nudge EV users to charge more consciously and sustainably by asking their preferences, while depicting the energy balance of the overall system. The energy optimization algorithms should provide direct feedback, such that a transparent energy transaction can take place. Furthermore, in this test location, investigating the direct energy interaction with the local grid and other university buildings is possible, as the University of Twente acts as the local DSO for the electricity grid on campus.

### 3.1.4 Integrated local energy systems: demo case in Poland.

The demo activities in Poland involve 5 residential and one commercial building in Sopot housing estate. The aim is to establish a sustainable integrated local energy system through solar PV based multi-energy systems that are integrated with heat pumps, and to test e-vehicles and the use of battery storage systems. By applying smart control, monitoring and energy management, the core focus of the activities is to increase the share of electricity from solar PV, as well as on an optimized operation of the local energy systems and the underlying electricity grids.

The specific objectives for the demonstrator include:

- Demonstration and test of integrated electricity-to-heat system with solar PV/PVT and heat pumps for heating domestic hot water and supporting the heating system of the building.
- Demonstration of the integration of EV chargers and electricity storage into the local energy system in the community.
- Demonstration of smart utility meters (electricity, water) and Advanced Metering Infrastructure (AMI) systems to support demand-side response and the operation of the local community energy systems
- Demonstration of AMI and LV automation/switchgear systems to enhance the level of observability, quality of supply and monitoring of the low voltage distribution grid in cooperation with the developed active citizen driven integrated energy systems.
- Development of business and ownership model for cooperation between individuals, community and local DSO for sharing renewable energy installations.
- Development of a technical and architectural concept of local energy island for the housing community as well as possible business model and financial structure of such investment.

#### 3.1.4.1 Use case 1 for Polish demonstrator: community based integrated energy system model

A micro grid based integrated local energy system is developed in the Polish demo site within the housing cooperative of Sopot as shown in Figure 15. The energy system within the microgrid involves the following installations to achieve the specific project objectives in SUSTENANCE:

- Monitoring units of local energy system,
- Integrated system of heat pump and PV installation in tall multiapartment building,
- EV charging stations and EV testing, and V2G technology,
- Energy storage implementation and its integration with local distribution grid.

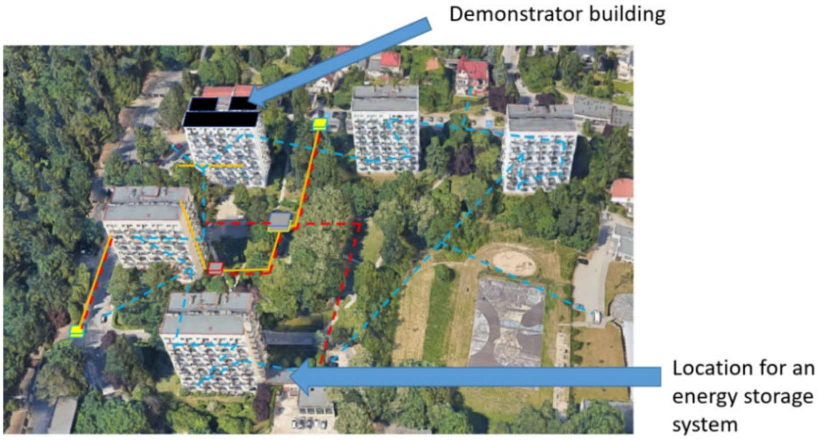


**Figure 15: The planned shape of the energy system in a housing cooperative in Sopot**

There are several options in Poland to form and establish a suitable framework for establishing and operating such local community based micro grid systems for such multi-apartment building blocks. Community-based integrated energy systems are a relatively new phenomenon in Poland and are developing slowly. The rate of development is far from the expectations (and probably the possibilities) of potential prosumers, primarily due to the nature of the policy of the central government - which has not yet created a sufficiently comfortable formal and legal framework for the formation of communities of this kind. According to the requirements of the main legal documents regulating and creating conditions for the operation of entities in the field of renewable energy sources - the Law on Renewable Energy Sources of 15 February 2015 (amended in January 2022) and the Energy Law of 10 April 1997 (amended in February 2022) - prosumers can be established in Poland in one of the following forms:

**- Renewable energy prosumer**
**- Virtual prosumer of renewable energy**
**- Collective prosumer of renewable energy**
**- Energy clusters**
**- Energy cooperatives.**

The intended “energy greening” of the mentioned multi-apartment building in Sopot cannot yet aspire to the scale of an energy cluster (and cluster in general) - but it may become a model case for other housing communities in Sopot.

The concept of an energy cooperative is also not applicable to pos the case of the housing community of Mickiewicza Street in Sopot. The first reason for this is the restriction of energy cooperatives to rural and urban-rural areas and the minimum limit for covering the own needs of the energy cooperative and its members (not less than 70%). An additional but different issue are the aspects of the Cooperative Law of September 1982, on the basis of which the concept of energy cooperatives was built, but which are not compatible with modern times (e.g., the issue of transferability of rights of participation in the cooperative).

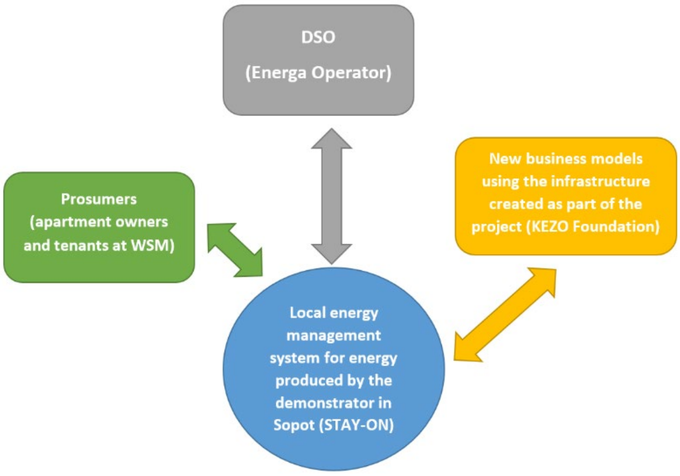


**Figure 16: Use case for Polish demonstrator ill**ustrating functions and interaction between players

From the point of view of the Mickiewicza street community, the usefulness of the following of the other categories mentioned earlier also seems doubtful: the virtual prosumer of renewable energy (possible only from July 2024 and not suitable for the specifics of the case in question) and the prosumer of renewable energy (a variant not suitable for the specifics of this particular case). Therefore, the Polish team's attention is focused on the so-called collective prosumer of renewable energy and - to some extent - on the prosumer representative (a specific intermediary between prosumers and the energy market). Based on the specificity of the category of "collective prosumer of renewable energy" this variant is considered to be best suited for the conditions of a multi-apartment building located in urban areas, and for this reason it is likely to be developed within the framework of the work of the Polish demonstrator.

# 4 Datasets available

## 4.1 Denmark

The energy goals set by Danish parliament for a completely fossil-fuel free energy poses both technical and regulatory challenges. The sector coupling by means of electric vehicles, electrification of heat, storage facilities etc., can effectively support the renewable energy integration. One of viable solutions requires the formation of citizen driven integrated local energy systems involving a number of actors (renewable energy producers, flexible prosumers, aggregators, suppliers, DSO, TSO etc.), which needs proper energy regulations and cross—sectoral frameworks as described in Section 3. In Figure 17, Figure 18 and Figure 19, the monthly production and consumption profiles along with import/export for Denmark are shown (see also [11]). It is evident from the Figure 17 that the wind energy share (>40%) is larger than that of the other sources in Denmark, and that supplies the load demand.

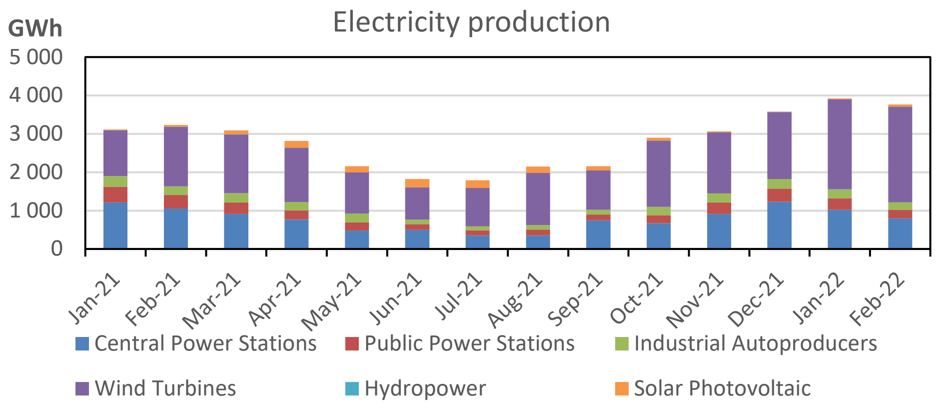


**Figure 17: Electricity production: Denmark** [11]

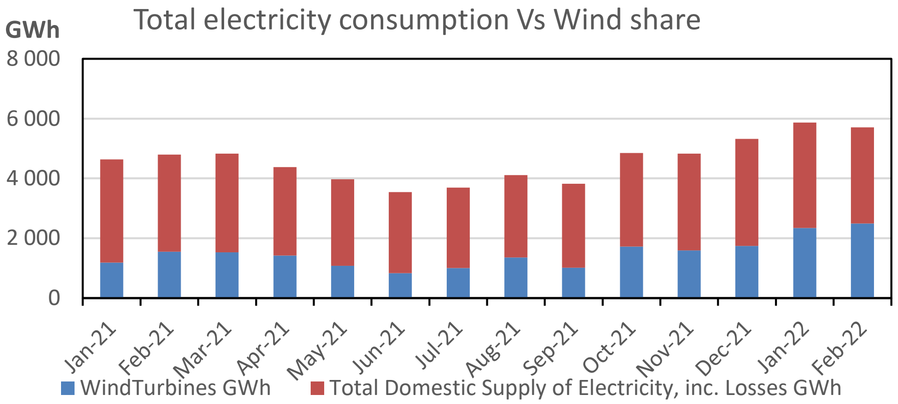


**Figure 18: Total electricity consumption: Denmark** [11].

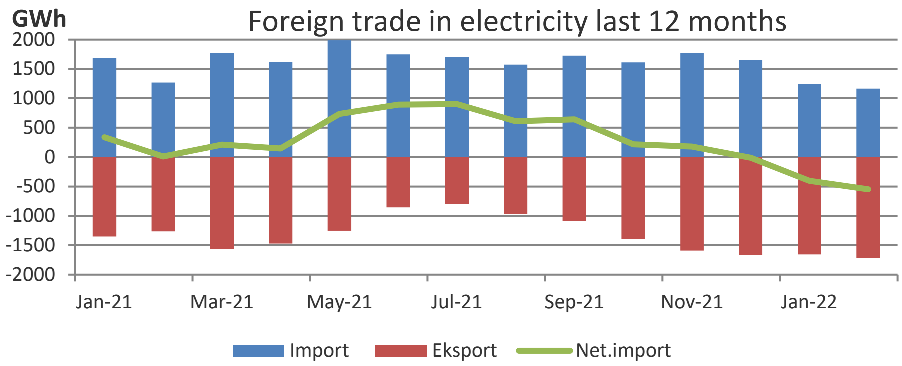


**Figure 19: Total import/export: Denmark** [11].

### 4.1.1 Energy information, demand and production data

This section describes the energy statistics for Skanderborg municipality. The data is obtained from the Energinet webpage [11], where grid operators collect readings from measurement points for all connected electricity consumers in Skanderborg municipality, Denmark. The readings are sent to the Energinet's data hub. Figure 20 shows the number of measurements points within a municipality and for each DE35 Industry Code (private homes, buildings, offices, agriculture, industries, public enterprises etc.).

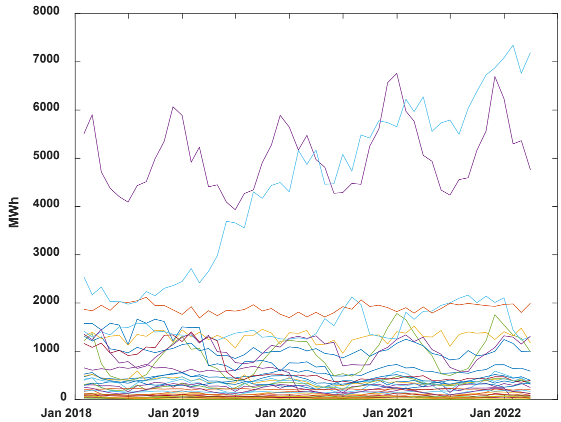


**Figure 20: Skandeborg municipality monthly consumption for various industry codes [11].**

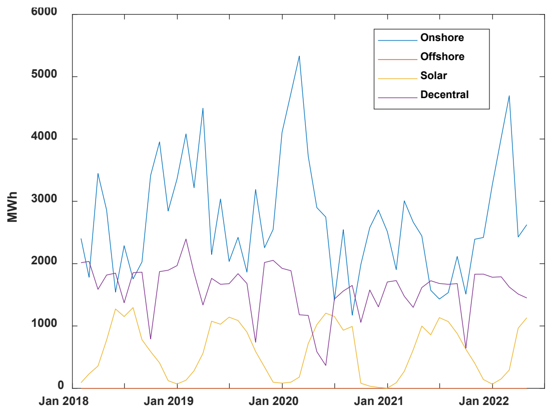


**Figure 21: Monthly production profiles of Skanderborg municipality [11].**

The total electricity consumption and production capacity of Skanderborg municipality are shown in Figure 20, Figure 21. It can be observed from Figure 21, that the onshore wind energy has the maximum share in the production mix compared to other sources (offshore, solar and decentral plants), where the decentral power plants are the power plants that are located at other locations than the already existing production facility locations. The light blue rising curve and the violet curve in Figure 20 show the consumption (>2000 MWh) corresponds to 'Anonymized and / or unknown' and 'Single Family Homes and similar, without electric heating' consumer types, respectively. These two consumer types have the largest share of electricity consumption compared to all others consumer types. There are ample amounts of local renewable energy units and energy plans in Skanderborg are focussed on to shift to demand units like heat pumps (replacing gas and wood boilers) and EVs. So, there is greater potential to incorporate flexibility solutions through community-based integrated local energy systems with integrated energy systems that includes these large demand consumer types to support enhanced integration of RES and thereby not only reducing peak consumptions but also increasing RES share though local DR schemes as described in Section 5. Furthermore, the selected Danish demonstration site has 20 houses, where the power consumption from all houses will be collected as soon as consent forms has been signed. Further, also that grid parameters for the local electricity grid will be available for grid impact calculations.

## *4.2* India

Within COP 21, as part of its Nationally Determined Contributions (NDCs), India had committed itself to achieve that 40% of its installed capacity for electricity production will be from non-fossil energy sources by 2030.

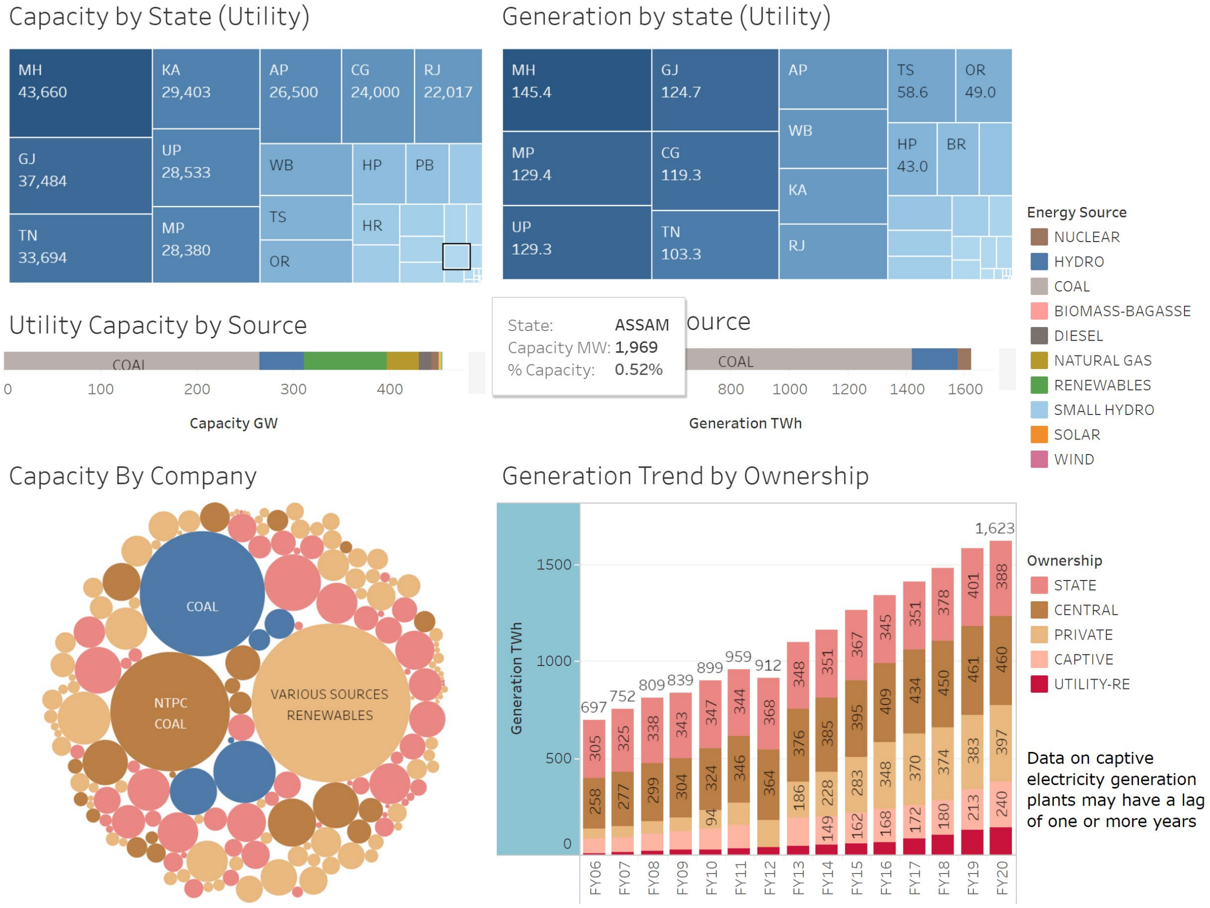


**Figure 22: Electricity sector of India (source: NITI Aayog)**

India has announced its commitment of achieving 500 GW of installed generation capacity from non-fossil fuel sources by the year 2030, and net zero carbon emission by 2070 at the recently concluded COP26. The corresponding energy statistics are shown in Figure 22. However, to achieve net zero emission, a multidimensional effort aiming at sector coupled energy system is very important to be able to accommodate a high share of RE and cater different energy demands in an optimized and reliable manner. **In this context, remote villages with limited or no access to the main grid offer a good opportunity to contribute towards the net zero emission target.**

### 4.2.1 Energy information, Demand and Production data

A dataset consisting of historical data for Barubeda site together with available information on Air Temperature (°C), Due Point Temperature (°C), Global Horizontal Irradiance (GHI) (W $m^{-2}$), Relative Humidity (%), Surface Pressure (mm), Wind Direction, Wind speed at 10m height (m $s^{-1}$), Cloud Opacity (%), Perceptible Water Thickness (cm) and Zenith (°) is ready for utilization in the SUSTENANCE project. An hourly granularity dataset for fifteen years from 2007 to 2021 with 131496 data points in total is made available from the entity. Using this data average temperatures for each hour of a year have been created. Solar and wind energy analysis have been carried out for Barubeda, Jharkhand based on this dataset and are shown in Figure 23. The figure gives daily average GHI, daily average Wind Velocity, daily average AC Output Power for Solar, daily total Units of energy generation for Solar and Wind Power Plants, and weekly total Units of energy generation for Solar and Wind Power Plants.

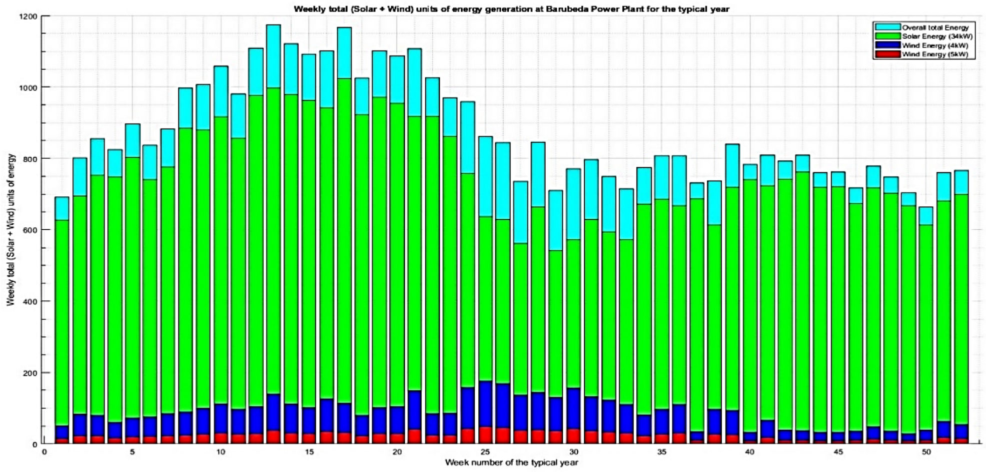


**Figure 23: Weekly total (Solar + Wind) units of energy generation at Barubeda site**

Considering the geographical location and climatic conditions in this area with an average irradiation of 750 w/$m^2$, there is a tremendous scope for harnessing solar power. It can be observed from Figure 24 that the annual average solar irradiation of Silchar (Borakhai siste) is around 4.45 kWh /$m^2$ /day Also, it is observed that the average wing velocity of a year is around 1.6 to 1.9 km/h in Silchar which provides an opportunity for installing a small wind power plant as well. Thus, the scope is on integrating energy systems like Solar PV, storage, and wind for providing electricity access, water pumping and also on the conversion of plant waste to manure etc. for the sustainable growth of the rural community.

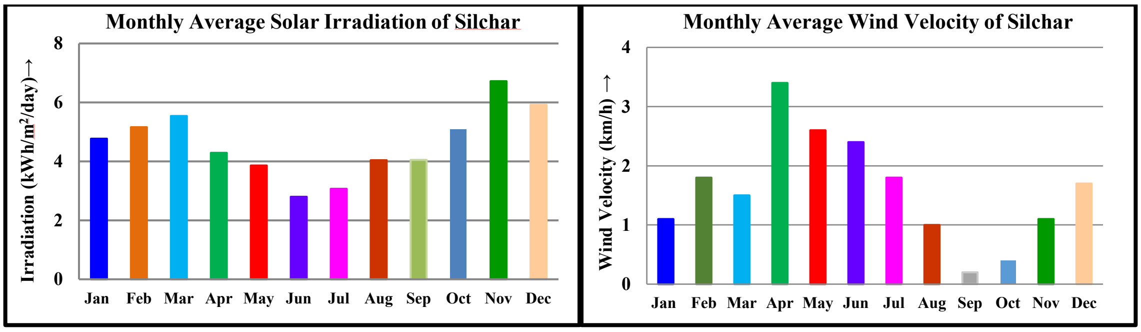


**Figure 24: Monthly average solar irradiation and (b) windy velocity of Silchar**

The test site at IIT Bombay campus is having 24x7 electricity supply from the main grid. The campus also has 1 MW rooftop PV installed capacity spread across various academic and administrative buildings in the campus. Besides, there are a few waste to energy systems developed in the campus.

The EMS planned at the demo sites will enable the local energy system to participate in energy management through demand side management and demand response. For example, at Borakhai site, the household loads will be divided in critical and noncritical loads connected through separate smart switches. The switches will be cloud-connected and allow the application of demand response.

## 4.3 The Netherlands

### 4.3.1 Energy information, Demand and Production data

**Vriendenerf data**

In the Netherlands, the houses in Vriendenerf are designed keeping the concept of 'zero-on-the-meter' (ZOM) in mind. This means that the annual total energy use reading on the kWh meter should be 0. Each group of 3 houses have 69 PV panels. Table II shows the PV panels energy yield and energy used for heating, cooling, ventilation and hot water per year.

**Table II Average energy statistics for a house in Vriendenerf [5].**

| | 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 |

Detailed real-time energy generation and consumption profiles for a single house shall be acquired by reading out usage data from metering infrastructure. One being the smart meter, which provides insight in the electricity flows in 10 second intervals and 10 W accuracy when locally reading its P1 port as per

Dutch Smart Meter Requirements (DSMR). Furthermore, options for acquiring data directly from the solar inverters, heat pumps and thermostats are investigated. Additional Internet of Things sensors may be applied.

**Insulation of Vriendenerf houses**

Figure 25 shows the heat resistance values of various sections of the houses. The houses have an insulation layer of 20-25 cm thickness, and the windows have high-quality HR++ glass. This results in high heat resistance values from 5 to 6 $m^2$.K/W.

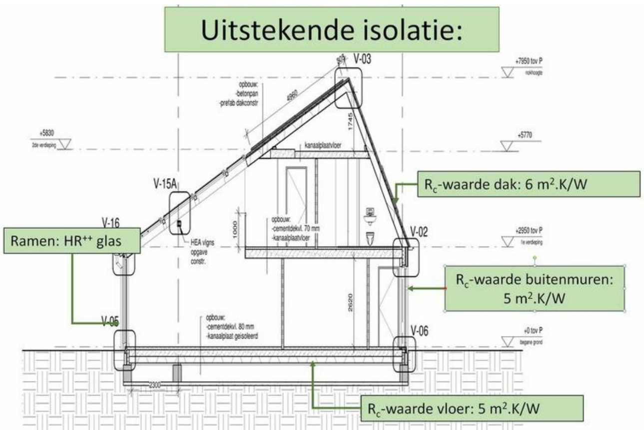


**Figure 25: Heat resistance values of an example house in Vriendenerf.**

**Slim Park data**

Figure 26 shows the PV production and the total power consumption from the SlimPark charging station over 9 months. Figure 27 shows the charging profiles of the EVs connected to (a maximum of) 9 charging points at the station. The installed PV capacity of 27kWp is expected to result in a yield of approximately 25MWh of energy annually. With an average energy usage of 1kWh per 6km, this results in 150.000 sustainable kilometres to be driven if the produced solar energy can be directly used to charge the electric vehicles.

In this test site, all components are equipped with metering infrastructure that can be fed into the energy management system using standardized protocols, such as Modbus and OCPP. As a result, energy flows of the charging stations, PV inverter, battery, and the complete setup can be monitored. Furthermore, all assets can be controlled within the local communication network. Additional information will be exchanged through the Internet. These include the charging preferences of the involved users through an App, and information about the consumption of other buildings and the local grid state with the University of Twente Campus Facility Management, which acts as the local DSO. Since this site is relatively new, and also due to COVID, no (representative) historical data is available.


**Figure 26**: **Production and consumption from May 16th 2022 to May 22nd 2022 (1 week).**

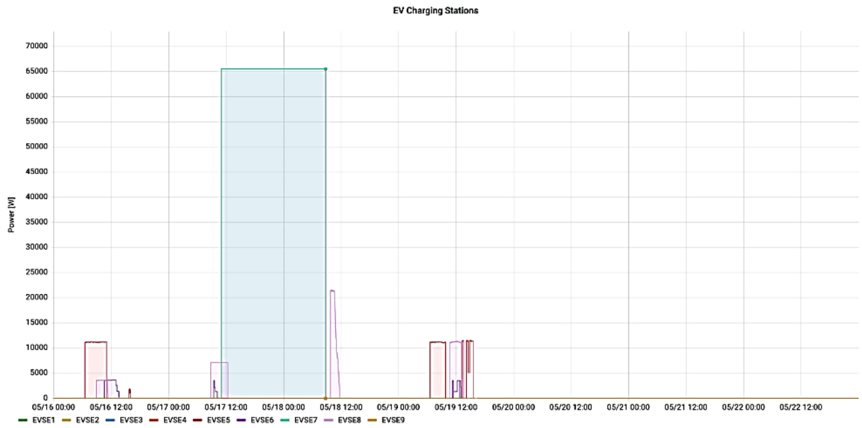


**Figure 27**: **Charging profile of EVs connected to the SlimPark from May 16th 2022 to May 22nd 2022 (1 week).**

## 4.4 Poland

As the demonstration site, Własnościowa Spółdzielnia Mieszkaniowa (WSM) im. Adama Mickiewicza in Sopot, Poland was chosen. The Estate started in the years 1969 – 72, when the first blocks of flats were built on a hill next to the Nature Reserve at the outskirts of Sopot. Nowadays it consists of 5 eleven-storey residential buildings that are of MBY-110 type and represent a tower-block technology. There is another one located at Grottgera Street and two smaller blocks-of-flats at Abrahama Street that are not equipped with elevators. Apart from the ones designated for living, the Estate is also in a possession of a set of technical properties that are either rented out, used for storage, garaging or office area for the Estate Management and can be utilized for the project. The buildings are predominantly grouped around Mickiewicza street with a few located at other locations. All buildings owed by the WSM are:

A. Building 55 at Mickiewicza street,
B. Building 57 at Mickiewicza street

C. Building 59 at Mickiewicza street,
D. Building 61 at Mickiewicza street,
E. Building 63 at Mickiewicza street,
F. Building 43 at Żeromskiego street,
G. Building 28 A at Abrahama street,
H. Building 28 B at Abrahamastreet,
I. Building 6/8 at Grottgera street.

**Figure 28: Main grouping of WSM buildings A-H**

The main group A-H of the estate properties is shown in Figure 28and the Administration and Power station are marked. The demonstrator is located in building C close to power supply station and the scale of the map is 1:1000. Note. that only the building located at Grottgera street that is further away, is missing in Figure 28.

### 4.4.1 Energy information, Demand and Production data

Electrical energy usage of the six similar buildings that are labelled A – F in Figure 29 for the years 2018-2021 is shown in Figure 30 for the staircases and in Figure 31 for the electricity usage of the elevators that are in each building. The type of building for the analysis was chosen based on the type (all being 11-storey accommodation-type ones) and their proximity. From the stacked area plot of the staircase energy consumption in Figure 30, the alteration of seasons can be clearly seen as the light on the staircases is operated manually. There are also 2 buildings of significantly more pronounced electricity consumption, which are Żeromskiego 43 and Mickiewicza 63. For both, the energy consumption is almost double the value for the other four buildings. In all cases, dips in the energy usage over the Christmas Holiday season can be seen. The reason is that many apartments in Sopot are rented by students that leave for holiday season. Similar behaviour can be also observed for the energy usage of the elevators in the six buildings of interest. Here, the energy consumption is rather evenly distributed over the buildings. Additionally, since the start of the pandemic period, the reduction in the use of elevators is marked by the drop in the energy usage around March 2020. The annual electricity consumption for each of the reporting years of the demonstrator is shown in Table III, where it can be seen that the electricity usage is stable over the period of analysis.

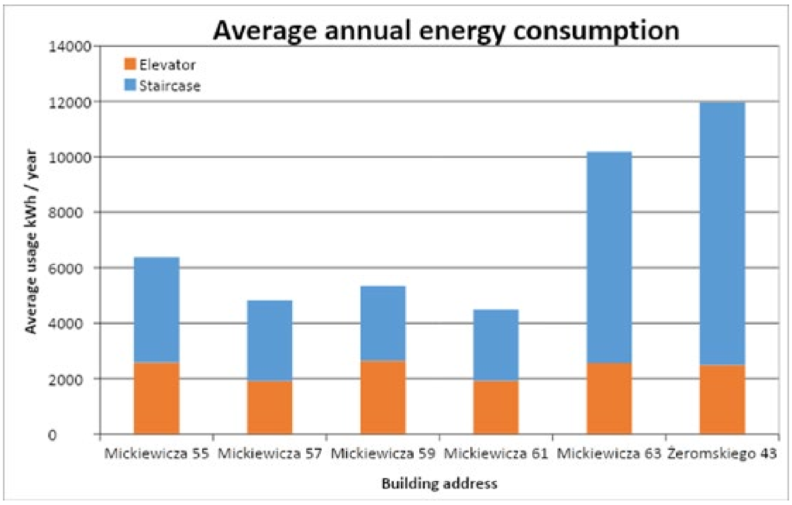


**Figure 29**: **Average annual energy consumption for all buildings that were analysed over the period 2018-2021.**

**Table III:** The annual electrical energy consumption in each of reporting years of the demonstrator in the common areas of the building (staircase and the elevator).

| Year | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|
| **Ave use / kWh** | 5347 | 5359 | 5228 | 5440 |

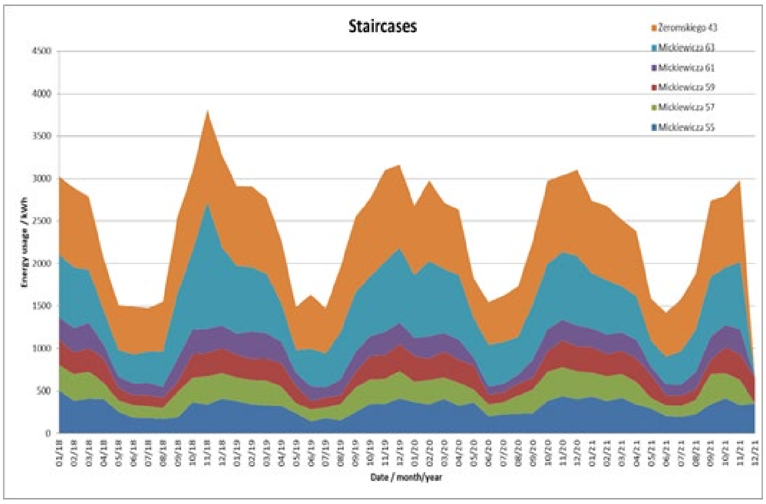


**Figure 30: Stacked area plot of energy usage in the buildings A-F of WSM in years 2018-2021 at the staircases; Mickiewicza 59 is the demonstrator**

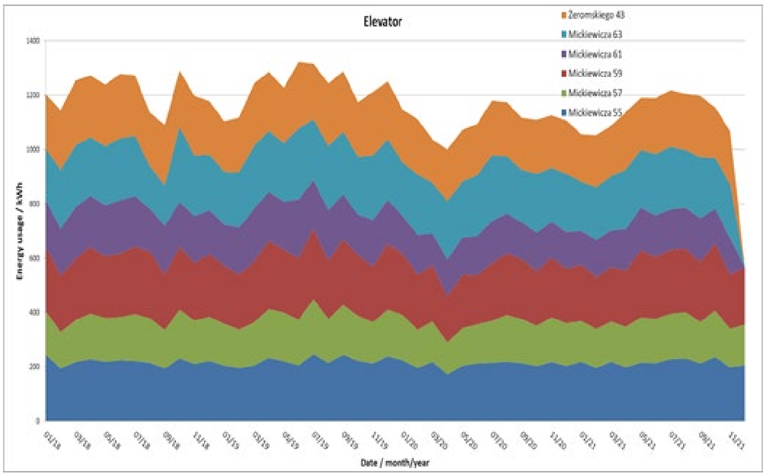


**Figure 31: Stacked area plot of energy usage in the buildings A-F of WSM in years 2018-2021 by the elevators; Mickiewicza 59 is the demonstrator**

For comparison, the administration building was also analysed for the energy usage over the same reporting period 2018-2021 and the corresponding data is shown in Figure 32 . Since 2021 a noticeable decrease in the energy consumption is observed (by about 20 %). Also, the electricity consumption of the hydrophore building, that is an important part of the infrastructure of WSM, was analysed (see the plot in Figure 33) . The average annual consumption for this building equals 9695 kWh.

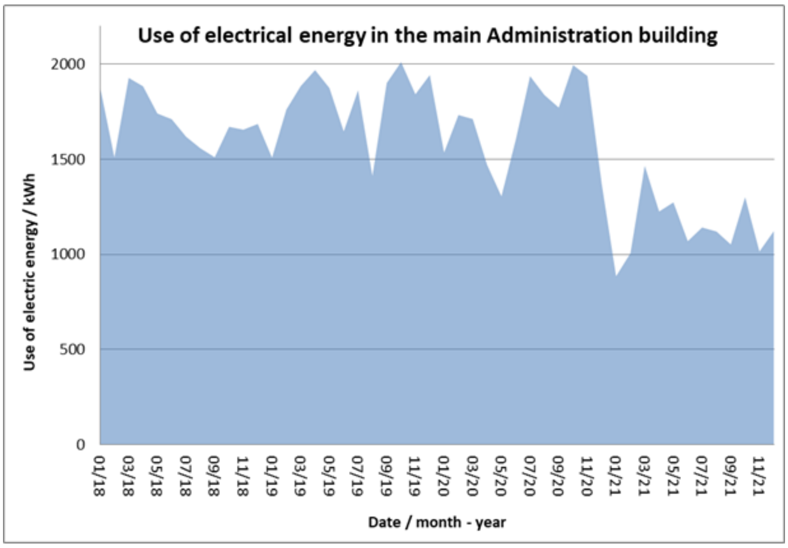


**Figure 32: Use of electrical energy in the Administration building, Mickiewicza 54/56, over the years 2018-2021.**

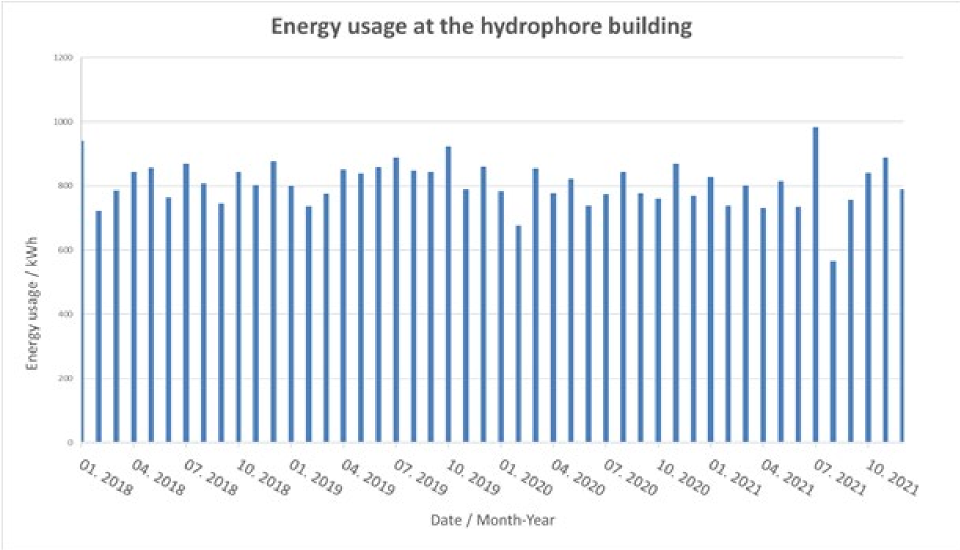


**Figure 33: Usage of electric energy in the hydrophore building for the years 2018-2021.**

In Figure 34, the electricity consumption in buildings located at Abrahama 28 A and 28B for the period of 2018-2021 is shown. As in the previous case, alternating weather seasons are clearly visible, although they are more pronounced for building 28B. It was also possible to plot data for the numerous garages that belong to WSM. The buildings that serve garaging purposes are grouped and placed in various parts of the estate. There are six meters that count the electric usage, and they are labelled after the placement of the garaging complexes.. The staked area plots for years 2018-2021are shown in Figure 35. Like in other cases, the alternating seasons are clearly marked.

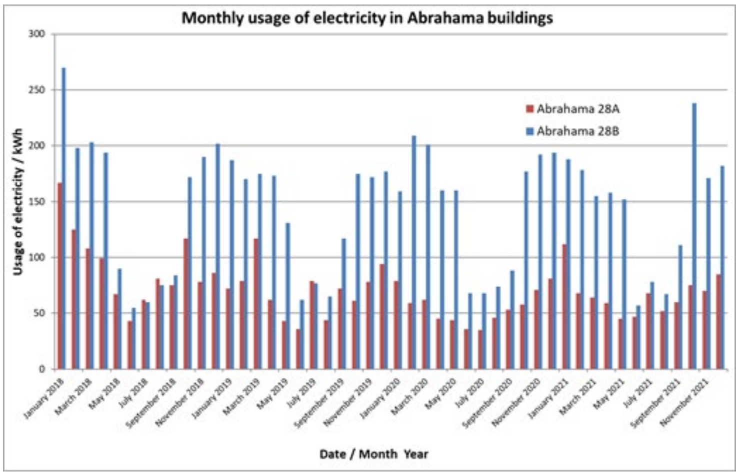


**Figure 34: Electrical energy consumption in buildings Abrahama 28A and 28B in the reporting period 2018-2021.**

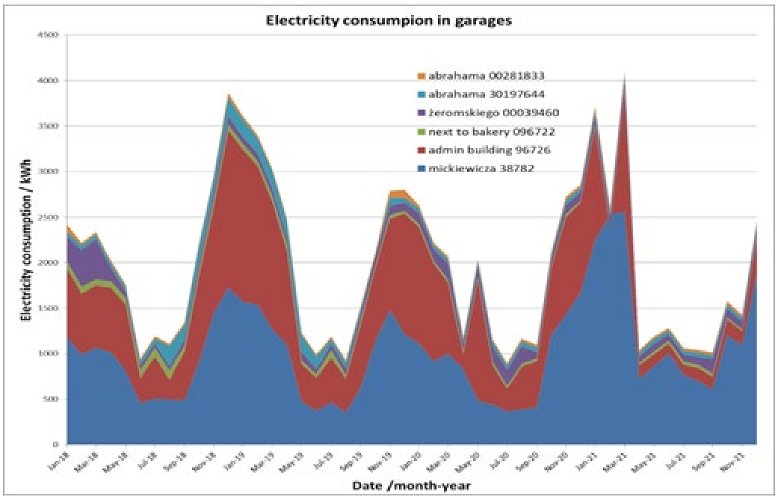


**Figure 35: Stacked area plot of electricity consumption at all the garages for years 2018 – 2021; numbers in the legend are meter ID numbers.**

Based on the given data average monthly energy consumption were derived from the given data. The demonstrator building (Mickiewicza 59) alone consumes on average 445,3 kWh/month. The hydrophore station that supplies water to the majority of the buildings owed by the Estate consumes 807,92 kWh/month, the administration building (Mickiewicz 54/56) consumes 1579,6 kWh/month and all the garages owed by the Estate, need 1981,18 kWh/month. Table IV presents the average monthly consumption of electricity in the living buildings of the Estate, resulting in 2629,68 kWh/month required to enlighten the staircases and 1175,64 kWh/month required to power up the elevator. The total energy consumption in those buildings yields 3805,32 kWh/month. Hence, the total average monthly energy consumption in all the buildings owed by the Estate adds up to 8174.02 kWh/month.

**Table IV: Average monthly consumption of electricity in buildings of the Estate**

| Building | Staircase / kWh/month | Elevator kWh/month | Total / kWh/month |
|---|---|---|---|
| **Mickiewicza 55** | 315,85 | 215,44 | 531.29 |
| **Mickiewicza 57** | 243,58 | 159,02 | 402.6 |
| **Mickiewicza 59** | 225,21 | 220,96 | 446.17 |
| **Mickiewicza 61** | 214,96 | 159,88 | 374.84 |
| **Mickiewicza 63** | 635,02 | 213,21 | 848.23 |
| **Żeromskiego 43** | 778,85 | 207,13 | 985.98 |
| **Abrahama 28A** | 71,23 | - | 71,23 |
| **Abrahama 28B** | 144,98 | - | 144,98 |
| **Total:** | **2629.68** | **1175.64** | **3805.32** |

Based on the data given in Table IV and in order to verify the assumptions concerning the size of the PV installations for the demonstrator in Poland, simulations in PVsyst have been performed. Two variants were considered:

1) A PV system of 24.4 kWp supplying a heat pump working for hot water demand
2) A PV system of 24.4 kWp supplying a heat pump working for hot water demand with a Li-ion battery pack of 21.4 kWh of useable capacity (80% of deep of discharge).

The PV system consists of 56 400-Watt modules connected to 17-kW inverter. Modules are divided into 4 strings of 14 units each. The system is placed on the roof of a multi-family building. All modules are mounted in horizontal orientation at angle of 15° and face to south (see Figure 36).

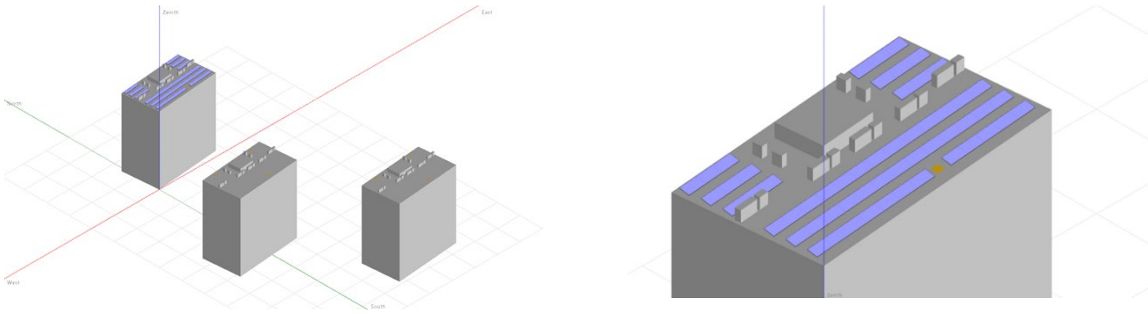

**Figure 36: Deployment of PV modules on the roof of the demonstrator.**

The PV system supplies only the heat pump. Excessive energy is injected into the grid and/or the battery (2nd variant). The daily heat pump load is assumed to be constant over a year. The load changes from 0 to 42.58 kW with average 14.68 kW. The chart in Figure 37 shows the results on a values hourly base.

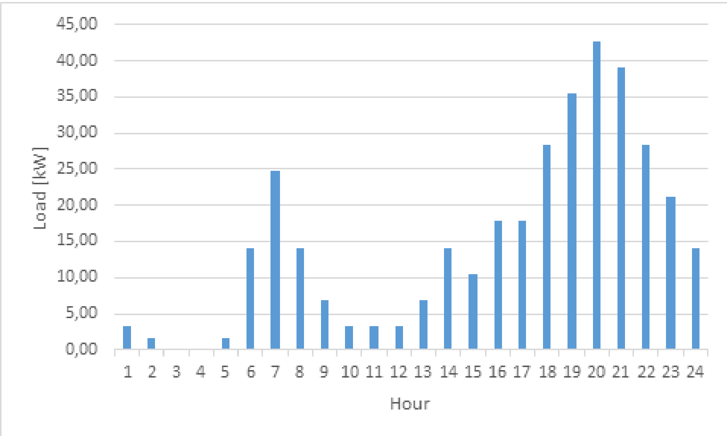


**Figure 37: Profile of energy demand for DHW production**

The load was estimated assuming a fixed COP of 3.5. In addition, the following assumptions were made for the analysis:

- Meteo data source: Meteonorm 8.0;
- Solar radiation model: Perez-Ineichen;
- PV module model: single-diode;
- Albedo: 0.2;
- Soiling losses: 3% for January and December and 1% for other months;

- Thermal loss coefficient: 29 W/(m2·K);
- LID (Light Induced Degradation) loss: 2.5%;
- Spectral correction: default for monocrystalline technology.

The simulation outcome demonstrates that most of the electricity is directly used by the heat pump. In case of Variant 1 the PV system generates annually 21.49 MWh from which 15.19 MWh is consumed by the heat pump and the rest is injected into the grid. To fully cover the user-demand an extra 113.29 MWh needs to be consumed from the grid. In Variant 2 the battery helps to reduce the grid demand to 109.63 MWh and to reduce the amount of energy injected into the grid to 2.07 MWh. This results in 18.84 MWh directly consumed. Generally, the generation of PV system is significantly lower than the user's needs. However, due to the limited roof area there is no possibility to increase the PV system capacity. From the other hand, the given setting leads to a high self-consumption and adding a battery does not significantly affect the energy flow. Therefore, in the project we will look for other possibilities of using the energy storage, e.g., by supporting the charging of EVs using night tariffs.

# 5 Demand side management schemes

Demand side management (DSM)or demand-side response has become an important concept for achieving an energy efficient operation of the electricity system. Hereby DSM includes activities that target the modification of the demand profiles of consumers, in time or in shape, to make it better match the supply. There has been a growing interest in demand response programs by both policy makers and market players/participants. This section gives the overview of the DR programmes that are suitable/applicable for the given demonstration sites and other measures to influence the matching of supply and demand.

## 5.1 Denmark

### 5.1.1 DSM requirements and status in Denmark

In Denmark, the introduction of demand side response in the power sector is intended to play a key role for incorporating renewable energy resources including wind and solar. The flexibility from households seems to be extremely limited compared to the large-scale heat pumps and boilers that are part of industrial demand. In addition, economic incentives for market participation by the households to respond to load following services are not highly encouraging [12]. The surcharges including energy duty, taxes, network charges come out to be approximately 80% of the total household tariff due to which the impact of hourly price fluctuations are significantly weakened at the household retail level. Accordingly, the long-term adjustments of household demand patterns from different appliances (those vary during a day or across seasons) will more likely lead to significant price impacts. The disaggregation of total hourly household load profile into the actual load patterns (household appliances, heat pumps, EVs etc) is carried out by the aggregator [13]. Aggregators are new market participants who represent a group of producers or consumers and effectively acts as an energy manager between utilities and consumers. The DR status in DK is as follows.

- The retailers are responsible for DR and the independent parties like aggregators are not allowed to have direct contracts with consumers.
- Electricity retailers can act as an aggregator, or they can outsource this service to third parties. The third-party company has to register itself as a balance response party or be in a contractual relationship with one.
- Aggregator needs permission from electricity supplier to pool the customer loads from a given supplier: this setting limits in practice the size of pools.
- Prequalification by transmission system operator is required to become a market player in the balancing market.

### 5.1.2 Local Demand Response and Demand side management in SUSTENANCE: Denmark

Active consumers are subjected to variable electricity and/or grid tariffs (fx. Time of Use (TOU) tariffs) who have smart meters installed at their houses/buildings. This encourages them to shift their flexible consumption to periods of low-electricity prices, which is known as implicit DR. In explicit DR, the active consumers have a contract with BRPs or aggregators to respond to mobilize their load flexibility. This type of DR is dispatchable and can be tailored to meet exact market needs (timing and sizing). The virtual representation of the demonstration site is shown in Figure 38.

**Figure 38: Virtual micro-grid: Danish demonstration**

The objective of the Danish demonstrator is to develop smart control of heat assets and EVs while maximising the self-consumption of on-site solar-PV production. The constraints are towards grid voltage limits, thermal and battery storage limits, and consumer preferences (room temperature limits, EV charge preferences, etc.). Maintaining voltage limits is one of the grid services and a local DR scheme that can be employed will be explicit DR i.e., direct load control. The aggregator collects the consumer preferences including size of shift, time of shift, behavioural pattern of the load etc. The USEF model of explicit DR schemes is shown in Figure 39 and the local optimization of flexible assets is performed by an energy service company (ESCo) or a third-party service provider i.e., Neogrid for this demonstration site. The electric grid layout of Voerladegård is as shown in Figure 40 (Voerladegård is the region where the residents involved in the demo. activities are located where DSM schemes are applied in integrated local energy systems).

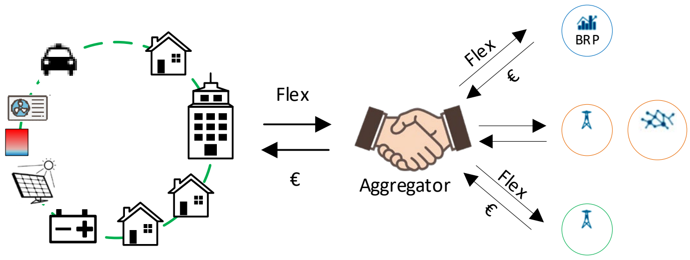


**Figure 39: USEF model explicit DR [14]**

**Figure 40: Electric grid layout of Voerladegård**

## 5.2 India

### 5.2.1 DSM requirements and status in India

In India, electricity is a topic where both central and state governments have specific interests. This makes the technical and investment related decisions more challenging. Consequently, the power industry also faces many challenges for the effective implementation of Demand Side Management (DSM). Most of the distribution companies/utilities are state-government owned entities and there is generally a political interest for low energy tariffs especially for agriculture, small-scale industries, and residential users, particularly in rural areas. Moreover, the uncertainty in the demand, fuel costs, load shedding schedules etc., makes it difficult for utilities to verify the savings from DSM programs [15]. However, the Bureau of Energy Efficiency (BEE), a statutory body under Ministry of Power, developed several policies in order to support DSM and energy efficiency programmes targeting different sectors such as industries, buildings etc [16]. The DSM activities initiated by Bureau of Energy Efficiency (BEE) are as shown in Figure 41.

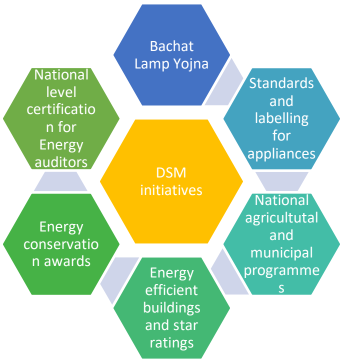


**Figure 41: DSM initiatives by the Indian government [17]**

Buildings account for nearly 35% of total energy consumption in India and its contribution continues to grow at 8 % annually. As the demand for power grows, the utilities need effective mechanisms to meet the challenges of growing demand for power. Demand response can provide a viable solution by transforming building and household loads into dispatchable resources for various load balancing mechanisms. Building Energy Management Systems (BEMS) are used by commercial facilities for monitoring, automating, and controlling building systems such as HVAC and lighting so as to enhance building energy efficiency and improve comfort conditions for its occupants. In order to implement the control objectives of BEMS a Building Area network (BAN) is configured which basically is a local area network (LAN) that covers an entire building. It may be a collection of smaller local area networks. Each floor is configured as a single LAN leading to combination of floor LANs to set up the BAN. A data communication protocol enables the different nodes in BANs to communicate with the BEMS. BACnet (Building Automation and Control Network) is the ASHRAE, ANSI and ISO standard for building communication protocol and is the preferred choice among commercial building automation systems. BACnet allows the BEMS to communicate with utilities and is an effective option for deploying DR strategies at commercial facilities. In India, more than 18 states have notified demand side management (DSM) regulations, and at least 8 states have implemented various DSM schemes. The state regulatory commissions have also issued special tariffs for DSM schemes. Moreover, several states have time of day (ToD) tariff in place for industrial and commercial consumers, which is assisting the distribution utilities in demand side management to some extent. The DSM schemes for buildings are applicable for the households.

However, there is a need for more effective and adequate regulations, required for achieving demand side management, particularly demand side response. The Bachat Lamp Yojna is a scheme promoting energy efficient lighting, where the lighting load (domestic, commercial and street) contribution in peak loads make it attractive for a utility to offer incentives to consumers in purchasing compact fluorescent lamps. This helps the utility to reduce the costly peak-load power procurement. The standard labelling program [17] enforces the minimum efficiency standards on appliances, thereby making consumer aware of the energy saving potential from the marketed household equipment. The remaining schemes on agricultural, municipal, and building level are developed to promote energy efficiency through DSM activities. The three main actors that facilitate DSM in each state are the State Electricity Regulatory Commission (SERC), the Distribution Companies (DISCOMS) and the State Designated Agencies (SDA). SERCs are responsible not only for determining the electricity tariff but also regulate state level power purchase. These regulators widely use Time of Day (ToD) tariff as a key DSM tool for shifting the peak load. DISCOMS play a crucial role as an interface between consumers and regulators. The SDAs are statutory bodies set up by the State Governments to implement Energy Conservation act 2001 and DSM at the state level [18]. When the wholesale electricity prices are high, or system reliability is jeopardized then the consumers are encouraged to respond by altering their consumption profile. Currently, there are automatic and manual DR programmes that are in operation. In manual programmes, the system operator sends a manual signal to customer through telephone to reduce the load.

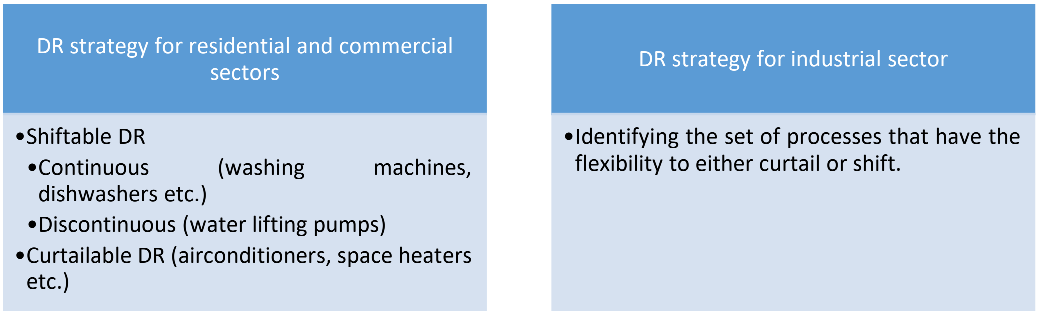


**Figure 42: DR strategy for various customers [18]**

Whereas in the automatic programme, the operator/aggregator has an automated connectivity to the customer end-use control systems. In most of the cases, the system operator calls the aggregator for any load curtailment decision and the aggregator further communicates with the customer. The DR strategies adopted for various customer is shown in Figure 42.

### 5.2.2 Local Demand Response and Demand side management in SUSTENANCE: India

In Barubeda site, which is an islanded energy system without connection to the main grid, demand management system and demand response will be carried out for optimal operation of the energy system. The demand response sources will include household load, water pump load, and e-rickshaw charging load through direct load control.

In Borakhai site, for the grid connected system residential load connected at 220/415 V are not allowed to participate in DSM/DR with the main grid. However, it will be possible to perform demand side management/demand response locally considering the local generation system and local load for achieving the optimal operation of the local energy system. The demand response sources will include household load, water pump load, and e-rickshaw charging load.

At IIT Bombay site, the smart house with demand response provisions will be used to demonstrate residential load-based demand response. The house will have local manageable loads including lighting, fan, water heating, and air conditioning. Moreover, demand response from EVs including vehicle to grid response is also planned to be demonstrated.

## 5.3 The Netherlands

### 5.3.1 DSM requirements and DR status in the Netherlands

Due to the increasing share of production from renewable energy resources and emerging electrification of various sectors in the Dutch power systems, there will also be an increased requirement of flexibility to maintain system balance and overcome congestion problems [19]. The latter is dominated by local mismatch in demand and supply and therefore local flexibility mechanisms are emerging. Flexibility service providers include conventional generation plants, energy storages, and demand side response entities. Integrating DR faces the following challenges:

- Technical (readiness of information and communication technology).
- Institutional (complex electricity system that depends on infrastructure and political barriers).
- Economical (willingness to participate in flexibility programmes that are profitable).

However, DR schemes can be enabled by cost-efficient technologies with necessary regulatory acceptance. The DR can be facilitated by various options in several markets including work for system adequacy in forward markets, service provider for ancillary services, and energy resource in day-ahead and intra day-ahead markets. Implicit (price-based) DR incorporated in Balance Responsible Party (BRP) portfolio has been in the market for several years now. In the Netherlands, the BRP is the major stakeholder for balancing and final resource allocation within its portfolio [20]. Within BRP portfolio, several actors including supplier/retailers, large consumers, and aggregators participate actively.
In addition, the energy users who both consume and produce electricity (known as prosumers) can also participate in the DR schemes. The structured contract between BRP and DR service provider (e.g., an aggregator) enables the optimized DR execution. Within the residential sector, the roll-out of smart meters has enabled time-of-use pricing schemes, for which new energy retailers have emerged recently providing such energy products and contracts. Furthermore, automated DR through smart charging of electric vehicles [21] is available for consumers. However, peer-to-peer trading between customers and/or energy communities is not yet allowed, due to delayed implementation of the new Energy law [22]. The network operators, which are TenneT (Transmission system operator (TSO)) and local distribution system operators (DSOs) are working in cooperation with policy makers and regulation authorities to design and operate the power grid in several markets. Table V gives the segments and time frames of several electricity markets starting from several days to the physical delivery.

**Table V: Segments and timeframes of Dutch electricity market [23].**

| Timeframe | Days-ahead | Day-ahead | Intraday | Realtime (RT) |
|---|---|---|---|---|
| | Forward and future markets | Day-ahead market | Intraday market | |
| | | Participants balance their own portfolio | | |
| | | | | Participants support system balance |
| | | | | TSO Balancing |

The market participants in demand side response are categorized into residential, commercial, and industrial the corresponding regulations are given in following Table VI.

**Table VI: Regulations for the participation of various customers [23].**

| Participant | Connection size | Peak capacity | Technologies | DSR potential | DSR participation |
|---|---|---|---|---|---|
| **Industrial** | > 3x80 ampere | >0.1 MW | Industrial processes | Shifting the load for specified processes | Depending upon the volume size, participation can be direct or through aggregators. |
| | | | Power to heat | Generating and storing heat when electricity prices are low | |
| | | | Power to hydrogen | Electrolysis can be used to store electricity as hydrogen | |
| **Commercial** | > 3x80 ampere | >0.1 MW | Power to heat | Generating and storing heat when electricity prices are low | |
| | | | Electric vehicles | Increasing RES penetration (daytime) | |
| | | | Power to cold | Storing cold energywhen electricity prices are low. | |
| **Residential** | ≤ 3x80 ampere | ≤0.1 MW | Power to heat | Generating and storing heat when electricity prices are low | Can only be through aggregators due to low volume of electricity |
| | | | Electric vehicles | Increasing RES penetration (nighttime) | |
| | | | Smart appliances | Smart control of appliances like washing machines, dryers etc. | |

### 5.3.2 Local Demand Response and Demand side management in SUSTENANCE: The Netherlands

In the Netherlands, demand side management will play a major role to continue the energy transition as the current grid infrastructure is already heavily congested [24]. Especially in the residential sector, the move towards electric mobility and electric space heating results in a significant change in the energy mix towards electrification. The existing grid cannot cope with this increase and lack of personnel to reinforce the underground infrastructure makes demand side management the only viable solution to keep up with these developments. The strain on especially the local medium and low voltage grids lead to localized congestion problems and therefore localized solutions are required. Currently, DSOs are investigating new tariff schemes for residential users (e.g., a bandwidth scheme) and also local congestion markets are expected to emerge soon. As a result, aggregators will not only need to play on the national energy markets, but also within the local domain. Taking into account the liberalized energy market, where customers may choose their own energy supplier (and likewise an aggregator), a complex framework emerges.

However, the localized nature provides an opportunity to solve aforementioned issues in a communal manner. Therefore, we explore cooperative demand side managements methods for energy and flexibility sharing. Opposed to a competitive ecosystem, we bring together stakeholders in an equal playing field. The upcoming energy law, based on EU Directive 2019/944, provides the legal framework for this. Furthermore, the new law aligns various features from USEF regarding roles and responsibilities. The USEF is a framework developed by a consortium of seven organizations in the smart energy industry.

USEF aims to make energy and flexibility a tradeable commodity by delivering the market structures and rules required for the design of an internal energy market. USEF presents 4 operating regimes. The green and yellow regimes represent optimal flexibility usage where no to little intervention in the free market is required to ensure system balance. However, the orange regime is set as a fallback regime in case the free market does not lead to a desirable operation of the grid. In that case, the DSO is able to intervene directly to avoid power supply disruptions or grid overloading as shown in Figure 43.

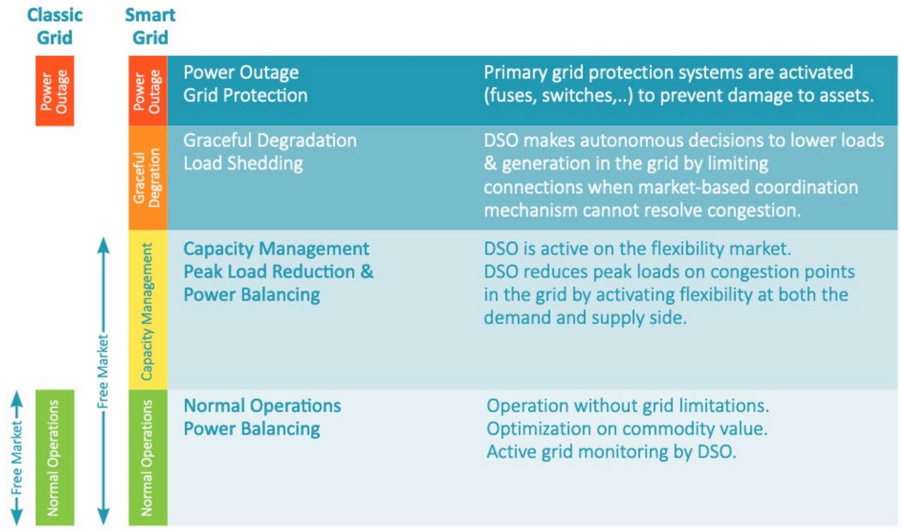


**Figure 43: The four regimes of the USEF framework.**

Combined with the new Energy law, an energy community, together with their retailer(s), will be able to share energy locally in a cooperative manner. This way, communities can voluntarily and jointly optimize their own energy profile based on their own intrinsic motivations, which are not necessarily pure monetary benefits. External incentives and constraints, such as congestion points, ensure that the needs of the physical infrastructure and national system balance are incorporated in demand side management approaches. Such coordination takes place in the green and yellow phase.

Next to the normal operation, implementations for the orange phase of USEF will be explored in SUSTENANCE. Due to the electrification, it is expected that periods of heavy local congestion will not be uncommon. Furthermore, increased share of renewable energy sources will lead to more volatility and potential grid stability issues. A robust and fair implementation of the orange phase is therefore of utmost importance to ensure a reliable operation of the power grid as a whole. To this end, *energy modii* are investigated in SUSTENANCE to gracefully reduce the quality of service (QoS) to end-users, while these modii reflect the urgency of problems in the grid, but also the temporal forecast of such modii. Based on this, energy management systems can make autonomous decisions (e.g., load shedding) to best deal with the given situation to maintain the perceived comfort of users as much as possible. Currently, more discussions in the Netherlands on if and how DSOs should be able to influence the market are ongoing. Yet, a legal and practical implementation, as well as standardization does not exist.

One example is the GridShield project [25], which aims to avoid overloading due to electric vehicle charging from the DSO perspective. The aim here is to standardize new protocols that implement the orange phase of USEF.

## 5.4 Poland

### 5.4.1 DSM requirements and DR status in Poland

Substantial dependence on fossil fuel-based generation and political influence on energy enterprises are major problems in Poland [26]. Several factors including severe environmental problems, poor reliability of supply, peak hour consumption etc., collectively directed the Polish energy policy towards integrating renewable energy resources and better energy management. In [27], a detailed review about the impact of norms and financial incentives on the energy management of Polish households has been carried out, where the main identified barriers are stemming from consumers, producers, and current regulatory frameworks. The probable solutions include increasing the consumer awareness of energy costs and developing favourable regulations for the widespread DR-adoption.

Any entity can participate in demand side response (DSR) if they are verified by their energy operator. The potential entities thatcan enlist themselves in DSR schemes are large industries, shipyards, offices, shopping centres, industries and agricultural facilities etc. These consumers can provide the DSR services to power grid in the following schemes.

- Scheme-1: 1 MW of reduction capacity or more.
- Scheme-2: 10 MW of reduction capacity or more.
- The consumer of smaller consumption level can participate through an aggregator i.e., a company that represents a group of consumers through bilateral contracts with grid operators.

The idea behind creating these schemes is to enable greater flexibility in defining the DSR parameters including reduction capacity, block length and time to commence the reduction. There are five main Distribution System Operators (DSOs) in Poland and Energa is one of them.

### 5.4.2 Local Demand Response and Demand side management in SUSTENANCE: Poland

The topology of Polish demonstrator in SUSTENANCE includes 3 main sites: In the block building, domestic hot water heat pumps and rooftop PV are planned. Furthermore, an EV charger with V2G capabilities may be located near the WSM office building. Lastly, energy storage may be installed in one of the technical buildings. The estate as a whole is supplied from one substation. The planned topology of both the electrical and IT system is shown in the Figure 44.

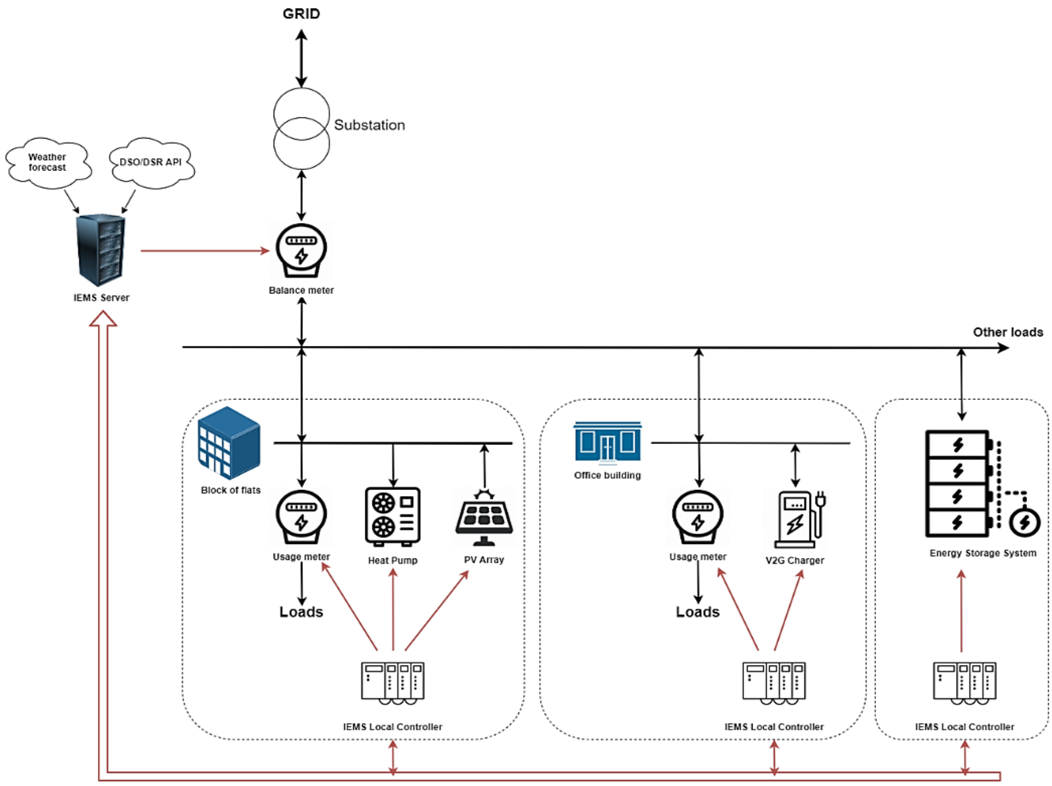


**Figure 44: Planned topology of electrical and IT system**

The EMS developed in this project will be designed in a tree structure. The whole system consists of 3 subsystems (microgrids), each responsible for managing one of these subsystems. Each microgrid has an own local controller and it can work separately as an independent system. Controllers can communicate with sub devices by protocols, like Modbus RTU/TCP, IEC61850, OCPP, etc. Next, the global EMS server is at the root of the overall EMS network. This device communicates with all local controllers, gets data from external services (DSO data, weather forecasts), stores data and performs local demand side response actions taking whole estate into account. Possibilities of EMS can be extended during the project.

The EMS system is designed to perform several use cases (scenarios):

- **Peak shaving**: ESS will be able to store energy produced by PV and discharge during peak demands. The aim is to perform energy flow forecasting to provide optimal charging and discharging scheduling and to reduce time of deep discharge and full charge of the ESS. The algorithm therefore takes battery degradation into account.
- **Peak shifting**: The heat pump working schedule can be fitted into forecasted PV peak production to maximize self-consumption in the microgrid.
- **Minimization of energy costs:** Through this feature the EMS can store energy during the energy price valleys to minimize energy consumption when energy is expensive.
- **Taking part in global DSM**: Thanks to the EMS, the whole system can be part of DSO Demand-Site Management and deliver services such as energy demand reduction.

- **Island mode**: The system is will be a self-sustainable microgrid "ready" to enable off-grid mode functionality in case of additional energy storage installation in the microgrid. An existing ESS planned to be installed during the project has limited power and capacity to make this mode applicable in practice. Major limitation is related to the size of community and loads out of the controlled grid. However, the capabilities of the EMS are expected to be able to reduce energy usage (especially the demand stemming from heat pumps and EV charger(s)). Moreover, thanks to V2G possibilities, EVs could also take part in energy balancing. Therefore, the control algorithms and operation of the EMS can be validated for future upscaling of islanded capabilities.

# 6 Summary and Conclusions

The multi-energy system framework that is applicable to all the four demonstration sites in SUSTENANCE is formulated. Based on the available data, the present energy production and consumption scenarios of all the demonstration sites are described. The corresponding use cases and appropriate DR techniques are derived keeping local differences in mind. This deliverable will be used as a baseline for the various tasks in WP2 and demo. WPs (WP4, WP5 and WP6), and also for linking the technical aspects with socio-economic frameworks in WP3.

As part of the formulation of cross-sector energy framework, the dynamic interrelations among different smart grid layers have been described using the SGAM model. The interoperability within the framework prioritizes the application of available data and communication modes to facilitate common understanding and effective interactions across stakeholders and systems. Such a platform for interoperability secures the technical and economic benefits from grid modernization towards smart grid and smart energy domains, as well as stakeholder interests with the evolving electricity system. It is also a principal enabler of appropriate control schemes for managing active participation of distributed resources, enabling cross-sector coupling, while empowering customers. To support the expansion of future grid operations, the customer and community-based integrated local energy systems depends on effective interoperability to achieve their objectives and acquire attractive financial perspectives such as return on investment.

Direct load control-based local DR programs are suggested according to the needs of all the four demonstration sites in SUSTENANCE. These programs can provide various grid services such as distribution system congestion management, demand side management, ancillary services provisions etc. The flexible assets include among others battery storage, thermal storage, electric mobility, under an integrated cross-sector energy framework that is controlled by the local aggregator towards increasing the self-consumption of local RES production and better economic and energy efficiency. Citizen driven integrated local energy systems are the result of the transition from a centralized energy system into a more decentralized and a democratized energy system. However, the socio-technical regimes (e.g., normative, formal, and regulative rules) have complex structures and mechanisms that possess a high degree of rigidness to change. Therefore, a multi-level perspective should be used for the analysis of socio-technical transition for sustainability. The current regulations and market mechanisms corresponding to all demonstration sites can pose challenges and appropriate technical solutions need to be developed taking this into account. Essential for success is therefore to start by establishing better coordination between citizen centred smart energy systems and electricity markets.

# 7 Bibliography


[1] Mancarella P (2014) MES (multi-energy systems): An overview of concepts and evaluation models. Energy 65:1–17.

[2] Kriechbaum, L., Scheiber, G. & Kienberger, T. Grid-based multi-energy systems—modelling, assessment, open-source modelling frameworks and challenges. Energy Sustain Soc 8, 35, 2018.

[3] Multi-energy system interactions in distribution grid, CIGRE JWG C6/C1.33 report, 2020.

[4] Christian Klemm, Peter Vennemann, “Modeling and optimization of multi-energy systems in mixed-use districts: A review of existing methods and approaches,” Renewable and Sustainable Energy Reviews, Volume 135, 2021, 110206.

[5] Bridge-European energy data exchange reference architecture 2.0, Data management working group, European commission, Feb 2022.

[6] Vriendenerf website: https://www.vriendenerf.nl/

[7] Directive (EU) 2019/944 of the european parliament and of the council of 5 june 2019 on common rules for the internal market for electricity and amending directive 2012/27/EU,” Official Journal of the European Union, 2019.

[8] Net-Metering in the Netherlands: https://www.zonnefabriek.nl/en/solar-panels/net-metering-in-the-netherlands/.

[9] New policy to phase-out net-metering: https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/kamerstukken/2022/05/20/zonnebrief/zonnebrief.pdf .

[10] Proposal for subsidies on household batteries: https://nltimes.nl/2022/02/19/coalition-parties-want-subsidies-household-solar-power-battery-storage.

[11] Energinet, https://www.energidataservice.dk/organizations/tso-electricity#.

[12] Andersen FM, Larsen HV, Kitzing L, Morthorst PE. (2014) Who gains from hourly time-of-use retail prices on electricity? An analysis of consumption profiles for categories of Danish electricity customers, WIRE's Energy and Environment, 3, issue 6, p. 582-593.

[13] National report 2020 for Denmark, Danish Utility regulator, Aug 2020.

[14] Hans de Heer, Marten van der Laan, Aurora Sáez Armenteros, “*USEF: The framework explained*”.

[15] S. Ahn and D. Graczyk, “Understanding energy challenges in India: policies, players and issues,” International Energy Agency (2012).

[16] Forum of Regulators (FOR), Model demand side management regulations, May 2010.

[17] A. Sinha, S. Neogi, R. N. Lahiri, S. Chowdhury, S. P. Chowdhury and N. Chakraborty, “Role of Demand Side Management for power distribution utility in India,” 2011 IEEE Power and Energy Society General Meeting, Detroit, MI, USA, 2011, pp. 1-8.

[18] Aditya Chunekar, Mrudula Kelkar, Shantanu Dixit, “Demand Side Management in India: An Overview of State Level Initiatives,” Prayas energy group, 2014.

[19] Dirk Kuiken, Hed F Mas, “Integrating demand response management in EU electricity distribution system operation: A Dutch example,” *Energy policy*, vol 139, pp. 150-160, 2019.

[20] CE Delft. (2016). Markt en Flexibiliteit.

[21] https://www.jedlix.com/nl/ and Home - Equigy.

[22] Wetsvoorstel Energiewet (UHT) | Publicatie | Rijksoverheid.nl.

[23] TenneT report, Unlocking industrial demand response, Jul 2021.

[24] Capaciteitskaart elektriciteitsnet (netbeheernederland.nl).

[25] SmoothEMS met Gridshield • Projecten • ElaadNL

[26] Pablo-Romero, M.D.P.; Pozo-Barajas, R.; Yñiguez, R. “Global changes in residential energy consumption,” Energy Policy 2017, 101, 342–352.

[27] Gołębiowska, B.; Bartczak, A.; Czajkowski, M., “Energy Demand Management and Social Norms,” Energies 2020, 13, 3779.