reschool

Creation, growing and management of energy communities

Platform Architecture and Energy Data Models

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Executive Summary

This deliverable describes the architecture of the RESCHOOL energy management platform. Furthermore, it describes the RESCHOOL services that support an optimal use of the energy assets, flexibility management and trading, data management, and gamification. This deliverable also describes the RESCHOOL energy data models that serve as a common language to both consume and publish data, thus contributing to seamless interoperability and innovation.

First, this document summarises the business goals of the RESCHOOL project and presents the BRIDGE Data Exchange Reference Architecture (DERA). DERA and the business goals of the RESCHOOL projects are used to shape the architecture of the RESCHOOL energy management platform.

Second, to achieve the business goals of the project, three quality attributes are identified as important for the design of the architecture. These quality attributes are maintainability, interoperability, and security. To promote these attributes, two architectural patterns are selected to design the architecture. These patterns are the layers pattern and service-oriented architecture. The designed architecture of the RESCHOOL energy management platform is described highlighting the capabilities and services, adapters and communication protocols, and security considerations.

Third, the FIWARE smart energy data standard for interoperability is described. Using this standard, the RESCHOOL energy assets data are modelled and presented. Moreover, the input data that are required to enable the services of the RESCHOOL energy management platform are presented together with the expected output from the processing of the input data.

Finally, the means that enable the implementation and deployment of the RESCHOOL energy management platform at each RESCHOOL pilot are described. Particularly, each pilot details its targeted Business Use Cases (BUCs) and High-Level Use Cases (HLUCs), requirements, energy data gathering process, data flow and interaction with third parties, services of the energy management platform, and solution architecture.

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1 Introduction

1.1 Objectives

The objective of RESCHOOL is to catalyse the creation, growth, and management of energy communities. To do so, this project aims to develop a smart energy community platform that enhances and facilitates the collective participation (i.e., energy communities) of citizens in the energy system and the relationship with other stakeholders like Distributed System Operators (DSOs), aggregators, or other energy communities.

In this document, we provide a description of the *architecture*, *data models*, and *services* that are needed to create a smart energy platform for energy management at individual and community level and with the capacity of integrating with the grid and/or flexibility markets, stakeholders, and other energy platforms.

1.2 Contribution of partners

This document is elaborated with the collaboration of all the RESCHOOL partners under the coordination of the project coordinator. The following table, Table 1, shows the responsibilities and roles taken by the partners in the elaboration of the architecture, data models, and services of the energy management platform.

Table 1 Contribution of partners to this deliverable.

Partner	Contribution
RISE	Coordination and Elaboration of the Platform Architecture, Data Models, and Services. Elaboration of the Requirements, Services, Data Flows, and Solution Architecture of the Swedish Pilot.
UdG	Feedback on Proposed Platform Architecture and Data Models, and Services. Elaboration of the Requirements, Services, Data Flows, and Solution Architecture of the Spanish Pilot
Bamboo	Feedback on Proposed Platform Architecture and Data Models, and Services. Elaboration of the Requirements, Services, Data Flows, and Solution Architecture of the Spanish Pilot.
OpenRemote	Feedback on Proposed Platform Architecture and Data Models, and Services. Elaboration of the Requirements, Services, Data Flows, and Solution Architecture of the Dutch Pilot.
CERTH	Feedback on Proposed Platform Architecture and Data Models, and Services. Elaboration of the Requirements, Services, Data Flows, and Solution Architecture of the Greek Pilot.
ElectriCITY	Elaboration of the Requirements, Services, Data Flows, and Solution Architecture of the Swedish Pilot.
Local Life	Elaboration of the Requirements, Services, Data Flows, and Solution Architecture of the Swedish Pilot.

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2 Business Goals and Energy Management Architecture

In this section, we first summarise the business goals of the RESCHOOL project. Second, we present the experiences of the RESCHOOL technical partners in developing energy management platforms. Last, we present the BRIDGE Data Exchange Reference Architecture (DERA) that is used for the definition of the RESCHOOL energy management architecture.

2.1 Business Goals of the Project

Understanding of the business goals of this project is important to define the quality attribute requirements for the RESCHOOL energy management platform. Four business goals are identified as drivers for building a management platform that meets the objectives of this project:

- **Energy Management**: The goal is to improve the energy management within communities and address the goal of self-sufficiency, that is the maximisation of local consumption of self-generated energy at community level.
- **Community as a Flexibility Provider**: The goal is to exploit the flexibility of demand at the community level and demonstrate energy communities as relevant stakeholders in the energy value chain with capabilities to interact with local and global energy markets and stakeholders.
- **Sizing and Organisation of Energy Community**: The goal is to address organisation challenges, including the dimensioning of energy communities with an aim to convert them into organisations that are economically feasible and sustainable.
- **Social Awareness and Participation in the Value Proposition of communities**: The goal is to value and promote social awareness of energy communities and their participants as a fundamental value proposition of communities.

2.2 Experience of RESCHOOL Technical Partners

In this section, we present the experience and tools that the technical partners have previously developed to support energy management. Furthermore, we describe how these experiences and tools are used to create the RESCHOOL energy management platform.

2.2.1 The Research Institutes of Sweden (RISE)

RISE developed an open-source digital platform in collaboration with KTH Royal Institute of Technology in Sweden. The digital platform, called *Hopsworks*, is a data centre where data can be collected, streamed, securely stored, processed, and shared. Hopsworks is a platform for big data analytics and machine learning. It started as a research project between RISE and KTH and later a spin-off start-up, Logical Clocks, that continues the development and commercialization of the Hopsworks platform.

Figure 1 shows the Hopsworks platform. Hopsworks is a generic platform for data intensive analytics and AI. Hopsworks supports state-of-the-art data parallel processing on Big Data with Apache Spark/Flink and deep learning with TensorFlow/Keras, as well as distributed deep learning for TensorFlow with Horovod (Uber) and TensorFlowOnSpark (by Yahoo!). Hopsworks also provides its own libraries for parallel deep learning experiments (hyperparameter search and model-architecture search). Hopsworks implements a strong security model based on TLS with project-based multi-tenancy and dynamic roles. Hopsworks' security model employs X.509 certificates to provide encryption, authentication, and authorization to the RPC layer instead of the traditional Kerberos protocol used in other Hadoop systems.

The Hopsworks approach has the advantage of being more scalable, working across administrative domains, and compatible with Edge and IoT devices. The process of generating, signing, and shipping certificates is transparent to the user as the platform automatically handles it, along with rotation and validation for

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compromised certificates. Hopsworks can be connected to additional energy management, flexibility, and engagement platforms through integration processes.

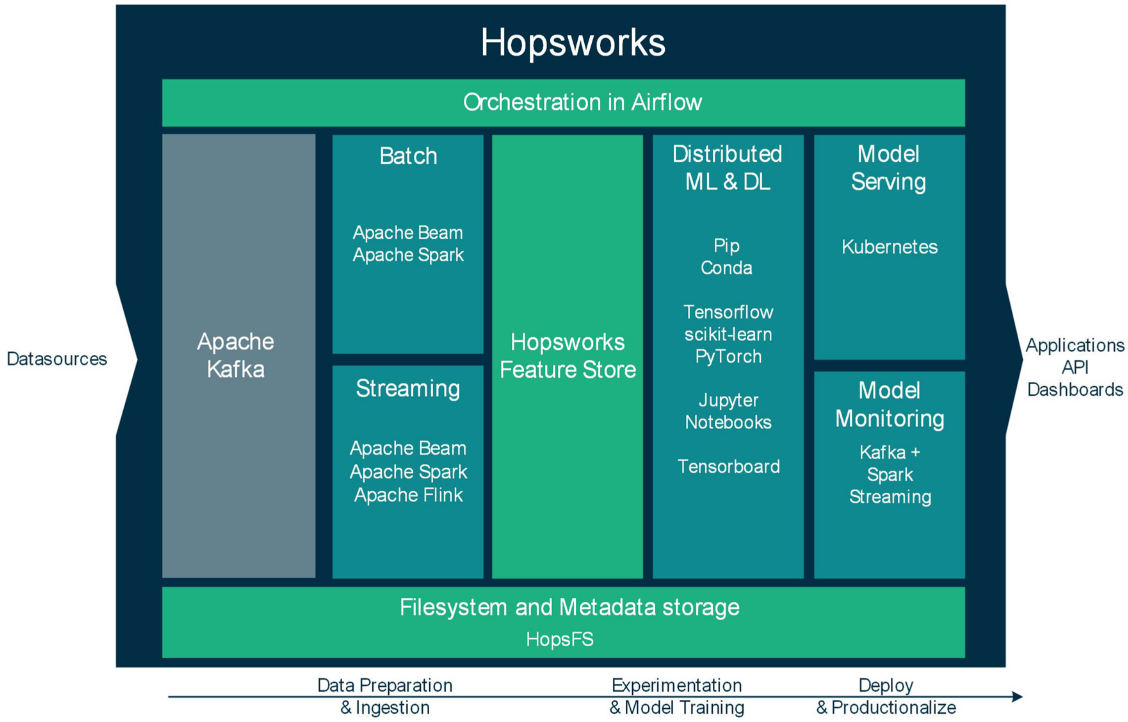

Figure 1 The Hopsworks Platform.

2.2.2 Open Remote

OpenRemote (see Figure 2) is an open source IoT platform which includes forecasting and optimisations features to apply it as an Energy Management System (EMS). It includes protocol agents and APIs to connect to different data sources, monitoring devices such as electricity meters, and devices to be controlled, e.g., batteries, chargers, or heaters. Through its rules engines, logic can be added both to automate behaviour of systems as well for alerting purposes. Thirdly, a library of web components allows users to make application specific frontend applications for both service managers, installers, or end users.

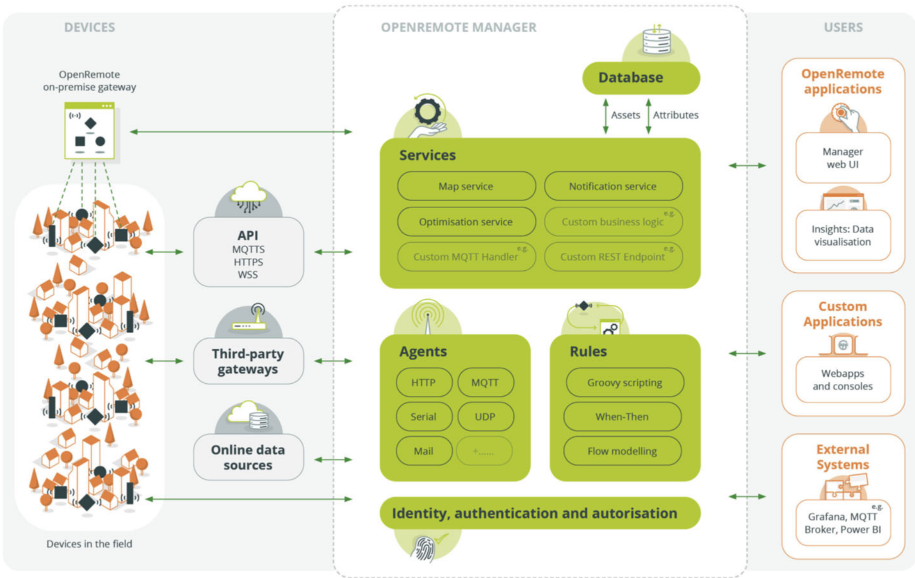

Figure 2 The OpenRemote Platform.

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The specific EMS functionality allows for scheduling power setpoints of energy consuming devices and storage devices, considering renewable energy production, energy consumption, agile tariffs from an energy provider and required charge schedules for electric vehicles. The optimisation routine targets lowest costs or lowest carbon exhaust. Within this project this functionality will be expanded to cater for optimisation of individual users or households, combined with an optimisation at group or district level.

2.2.3 Bamboo

The platform, under the name Bamboo, is based on a combination of disruptive technologies with intelligent systems (Machine Learning) for predicting the flexibility of the client portfolio and market conditions, robust mathematical modelling, and combinatorial optimisation algorithms for optimal management of the electricity demand and its analysis.

Bamboo Energy's platform is an agnostic system that allows connection to all types of flexibility asset communication systems, see Figure 3, providing the management of a wide variety of assets from different sectors and, thanks to its modular architecture, it allows existing modules to be updated and incorporate new functionalities in such a way that it is continuously updated.

Main differences of the solution proposed in respect to other demand aggregation platforms, are:

- Artificial intelligence assures the full automation of the platform.
- The platform seamlessly manages different flexibility assets at the same time, maximising flexibility valorisation.
- The platform is easily adaptable to different market requirements.
- The platform automatically realises real time flexibility trading operations.
- The algorithms are in the cloud and the software is hardware agnostic.

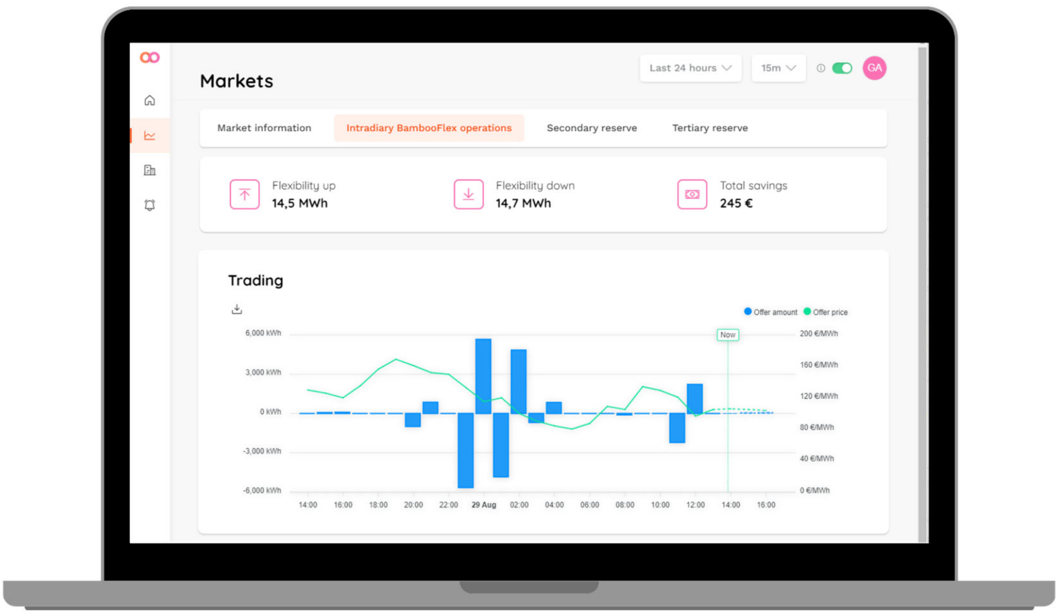

Figure 3 The Bamboo Platform.

2.2.4 LocalLife

There is a number of collaboration points within a given energy community. For instance, the energy managers within housing associations are laypeople, and they need to steer their actions towards managing their

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building's energy efficiency while trying to maximise returns on investments made into renewable energy generation and flexibility services. The success of an energy community is largely dependent on the ability of this group to build up a special type of competence that is highly specialised, and that can easily be transferred when handing over to a new layman energy manager. The other obvious stakeholder in the energy community in need of collaboration are the residents. They in part need to support the investment decisions of their energy managers, but also use the technologies and services that are provided to them, including how they charge their electric vehicles, and avoiding buying electric furnaces for the cold months and instead informing the energy managers about their need for higher thermal comfort so that a better solution can be provided for the same need.

The LocalLife platform (see Figure 4) is an energy community platform that is built based on recent research findings in the social and behavioural sciences and validated in Sweden and Portugal. It allows for energy-related and social interactions among residents and energy managers in the energy community. The platform simplifies decision-making for residents on a household, building, and community-level by e.g., informing them about an upcoming peak event and what specifically they can do to reduce their peak loads during the event. Built on recent advancements from the social and behavioural sciences, LocalLife has led to a rough decrease of 60 % power use during peak events, and a 5-10 % energy reduction in total. New interactions in the platform will enable the prioritised interactions on an individual, household, building, and community level. The goals of these interactions are to ensure:

- That the energy community has set clear goals for energy use, renewable energy production, flexibility, trading, and net energy cost per square meter.
- Energy managers can learn from each other's investments and adjustments to their buildings' energy systems, and track the performance of each other, in particular learning from the most successful, as well as lessons learned to be avoided.
- That residents are aware and support the work of their energy managers, understand their roles in the energy communities, understand their buildings' and their community's cost and environmental performance, and make better and more informed decisions in the direction of the energy communities – in effect going from behavioural changes to shaping new every-day habits for residents in energy communities.

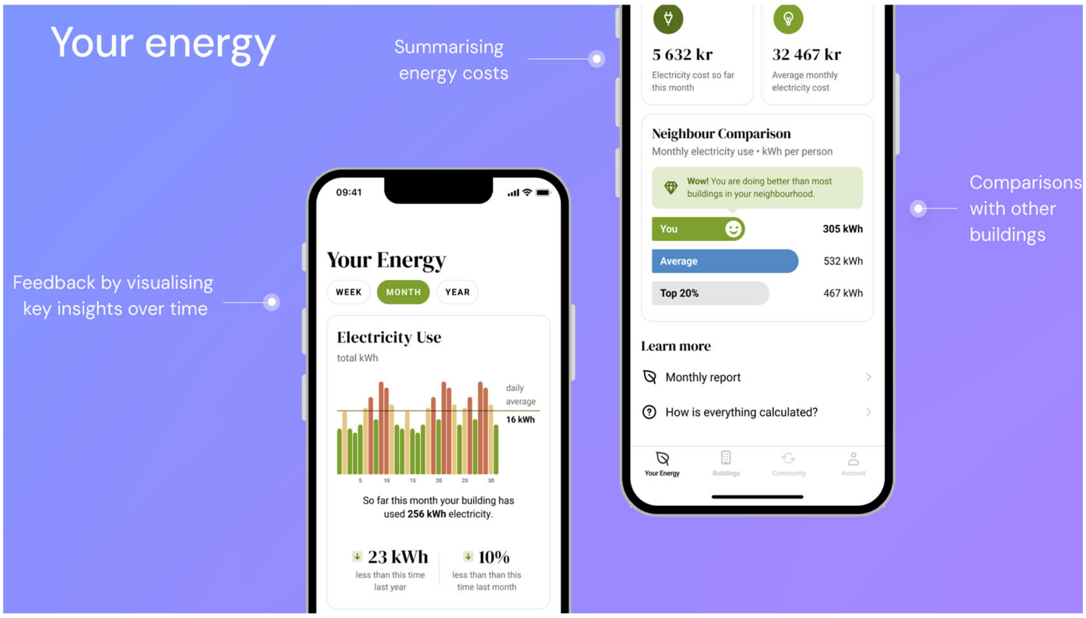

Figure 4 The LocalLife Platform.

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2.3 BRIDGE Data Exchange Reference Architecture

The European Energy Data Exchange Reference Architecture (DERA)[1] is a framework that provides a standardised structure for data exchange in the European energy sector. It's designed to facilitate interoperability and data exchange among various stakeholders in the energy industry, including utilities, grid operators, regulators, and market participants.

Figure 5 shows the layered architecture including modules and functionalities and their relationship with both the Digitalisation of Energy Systems (DESAP)[2] and the Design Principles for Data Spaces (OpenDEI)[3] building blocks. Each of the modules identifies the relevance with respect to DESAP requirements for data sharing.

The DESAP requirements are the following:

- Non-personal Data: the energy data should be anonymised.
- Security/Resilience: cybersecurity and data protections should be considered.
- User Acceptance: achieve prosumer acceptance and empowerment.
- Sovereignty: follow EU data sovereignty principles.
- Open Source: follow open-source data models and API standards and provide open-source solutions.
- Interoperability: create solutions that are interoperable.

Whereas the OpenDEI building block are the following:

- Data Interoperability: it covers data exchange APIs, data representation formats, and data provenance as well as traceability.
- Data Trust and Sovereignty: It covers identity management, trustworthiness of participants, and data access as well as usage control.
- Data Value Creation: It covers publication of data offerings, discovery of offerings based on metadata, accounting of data access or usage which are necessary to handle data as an economic asset.
- Governance: It covers business, operational, and organisational agreements among participants.

In Figure 5, the lowest layer is the component layer. This layer is abstracted as the origin of the data being handled. The data endpoints component represents the energy data sources such as data sinks, data providers, or data consumers. The component is relevant for non-personal data and security/resilience DESAP requirements.

The next layer is the communication layer. This layer is concerned with how different components of the system are communicating with each other by exchanging information and coordinating actions to achieve the goal of the system. The standard communication protocols and formats module provides a means to facilitate federation by making sure that the communication protocols and data format are openly available and standard. Examples of data formats include CSV, XML, JSON, and RDF. Communication protocols include REST, MQTT, AMQP, Web-services, HTTP/HTTPS, and SOAP. The DESAP requirements that are relevant for this component are security/resilience and open source and interoperability.

The next layer is the information layer. It provides a location for handling, managing, and storing data. It is where the data processing and persistence is occurring. The data harmonisation (Local) and Vocabulary provider (Federated) regulates the way data is presented and understood between the data sharing endpoints. These two modules are relevant for open source, interoperability DESAP requirements. The data processing module

[1] DERA: https://data.europa.eu/doi/10.2833/815043

[2] DESAP: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13141-Digitalising-the-energy-sector-EU-action-plan_en

[3] OpenDEI: https://h2020-demeter.eu/wp-content/uploads/2021/05/Position-paper-design-principles-for-data-spaces.pdf

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is concerned with data cleaning, collection, anonymization, handling, and metadata management. The data persistence module makes sure that data of the system is stored in a data storage. This module is relevant for security/resilience, sovereignty, and interoperability DESAP requirements.

Next is the function layer. This layer defines the functionalities and services that are needed to support the goals of the system. It includes credential manager (local) and identify manager (federated) modules which are concerned with user authentication, integration of data sources and users, and security and privacy. It also includes data indexer (local) and data discovery (federated) that make sure data is discoverable through the data space. The monitoring and orchestration module is responsible for ensuring that the system is performing as expected. Marketplace backend module where services are offered to users via marketplaces, App stores, or SaaS (software as a service). Digital twins and AI/ML services are related to data forecasting, system simulation, and analytics. These modules are relevant for the sovereignty, open source, interoperability, and security/resilience DESAP requirements.

The upper layer is the business layer. This layer enables different business units and systems to interoperate and exchange data in a consistent and standardised manner, supporting the flow of information across the enterprise and facilitating interoperability between different business processes. The market frontend module represents the business side of the marketplace. The local and federated use cases and business needs are concerned with energy services such as optimization of a grid or forecasting of energy sources. It also includes services that are provided by other parties. The Energy/EU regulation makes sure that data and data use is in line with EU regulations including the GDPR, eIDAS, and NIS. The actors are the expected users of the modules and functionalities provided by the system. The modules in this layer are relevant for the following DESAP requirements: security/resilience, user acceptance, and non-personal data.

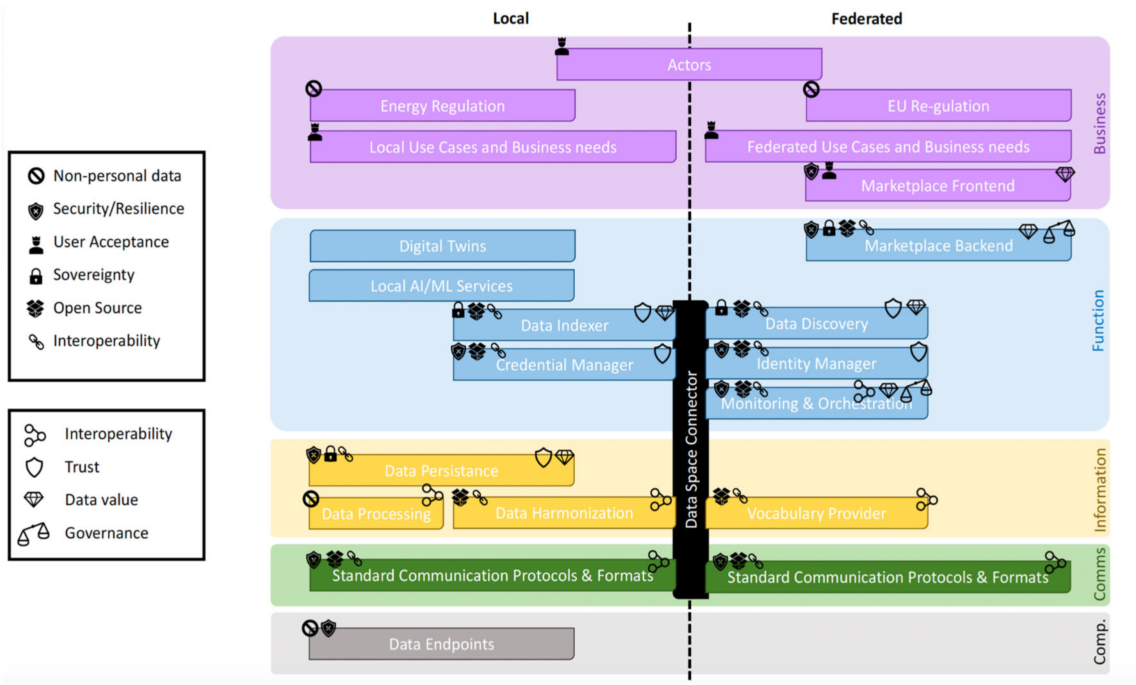

Figure 5 DERA 3.0 layered architecture and link to the DESAP and OpenDEI building blocks.

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3 RESCHOOL Energy Management Platform Architecture

The architecture is a bridge between the business goals and the final resulting energy management platform. In this section, we present the RESCHOOL architecture that is defined based on the business goals (previously summarised in this document) and use case requirements that are defined in WP1 and WP2. This architecture aims to facilitate energy management at both individual and community levels. Moreover, it supports the interaction with DSOs and energy flexibility markets. Also, it establishes channels for energy optimisation and gamification services.

First, we will describe the identified quality attributes that drive the design process of the architecture. Second, we describe the RESCHOOL architectural patterns. Third, we present the RESCHOOL energy management platform architecture, including the capabilities and services, communication protocols, and adapters. Fourth, we provide considerations on the security of the designed architecture. Last, we present a trade-offs analysis of adopting one versus several energy management platforms in the RESCHOOL project.

3.1 Quality Attributes

A quality attribute is a measurable or testable property of a system that is used to understand how well the system satisfies the needs of its stakeholders beyond the basic function of the system. The functional requirements are satisfied by designing the responsibilities of the system. In contrast, the quality attributes are satisfied by designing the structure and behaviour of the system architecture.

The ISO/IEC FCD 25010: Systems and Software Engineering: Systems and Software Product Quality Requirements and Evaluation provides a list of quality attributes. From this list, three quality attributes are considered: Interoperability, Maintainability, and Security.

3.1.1 Maintainability

According to ISO 25010, maintainability is the degree of effectiveness and efficiency with which a system can be modified by the intended users. This quality attribute is important for the RESCHOOL architecture since the energy management platforms are expected to change overtime due to new functionalities, services, technologies, protocols, or standards.

There are several tactics to control the maintainability. The goal of these tactics is to control complexity of making changes as well as reduce the time and cost of making changes. The main tactics that control maintainability are cohesion and coupling. Cohesion measures how strongly the responsibility of a module is related. Whereas, coupling measures the probability that a modification to one module will influence or propagate to other modules. To promote maintainability, cohesion should be increased, and coupling should be reduced. Increasing cohesion is achieved by redistributing responsibilities between the modules and splitting modules that have multiple responsibilities. In contrast, reducing coupling is achieved by encapsulating responsibilities, using intermediaries, creating abstract common services, and restricting dependencies.

There are patterns to support maintainability. One pattern is the layers pattern that is chosen for this project and will be discussed in the next Section (Architectural Patterns).

3.1.2 Interoperability

According to ISO 25010, interoperability is the degree to which two or more systems, products or components can exchange information and use the information that has been exchanged. This quality attribute is important for the RESCHOOL architecture since the energy management platforms are expected to exchange data and interact with third-party service providers and consumers.

There are several tactics to support interoperability. The goal of these tactics is to ensure that different software and hardware can work together seamlessly. The main tactic to support maintainability is to adhere to standards by using open standards for data formats, communication protocols, and interfaces. In this project, standards like BRIDGE and FIWARE are used to design the architecture and data models of the energy management platform. Other tactics that support interoperability include restricting communication paths (as

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it is done in service-oriented patterns), abstract common services, use a resource manager (e.g., data energy management), and create well-documented API designs.

There are patterns to support interoperability. One pattern is service-oriented architecture pattern that is chosen for this project and will be discussed in the next Section (Architectural Patterns)

3.1.3 Security

According to ISO 25010, security is the Degree to which a system protects information and data so that persons or other products or systems have the degree of data access appropriate to their types and levels of authorization. This quality attribute is important for the RESCHOOL architecture since the energy management platforms are expected to exchange data and interact with third-party service providers and consumers. Particularly, security attributes such as authenticity, privacy, integrity, and confidentiality of these data must be addressed.

Tactics that promote security and privacy include authentication, authorization, and data encryption. Authentication can be supported by means such as passwords, digital certificates, and two-factor authentications. Authorization means that an authenticated actor has the right to access, use, or modify data or services. Authorization can be supported by providing access control mechanisms. Data encryption on the other hand ensures confidentiality. Encryption can be applied to data and communication between components that exchange the data. Another tactic to support security is audit or logging since this keeps a record of the actions of users and system events.

Promoting security in this project is discussed in the Security Considerations Section.

3.2 Architectural Patterns

3.2.1 Layers Pattern

This pattern divides the system in different layers where the modules of each layer can be developed and maintained separately with little interaction between the layers. Moreover, each layer provides a cohesive set of services. Consequently, this pattern promotes decreased coupling between the layers and higher cohesion within.

Figure 6 shows an example of the layers pattern. The diagram on the left shows that the allowed relation to use is one way i.e., one layer may only use another layer that is below it and cyclical dependencies are not allowed. The diagram on the right implies relations between the layers.

This pattern promotes maintainability, portability, reusability, and testability. In contrast, layers introduce additional abstractions between the highest layer and lowest layer, which might influence the performance of the system.

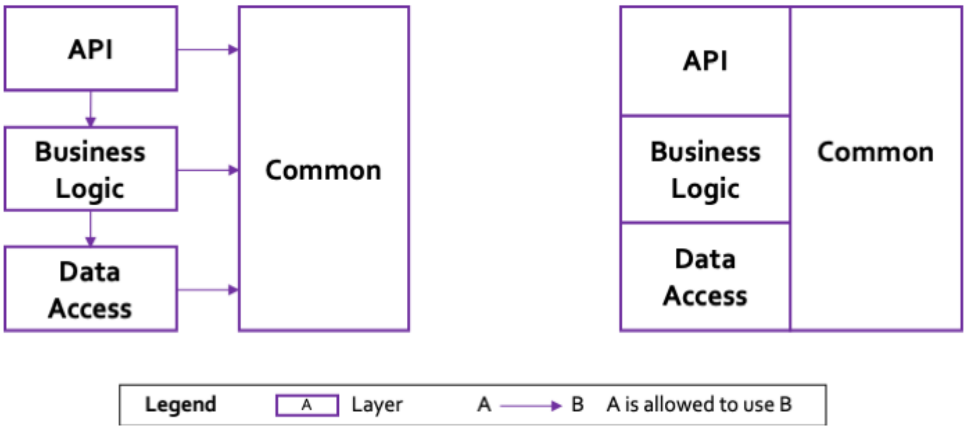

Figure 6 The layers pattern.

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3.2.2 Service-Oriented Architecture Pattern

This pattern defines a set of distributed components that provide and/or consume services. Service providers and consumers might use different implementation languages and are often deployed independently. Components have interfaces describing the services that are consumed or provided. The communication among services is typically performed by using standards and protocols such as Web Services Description Language (WSDL) and Representational State Transfer (REST) using JSON as a format over Hypertext Transfer Protocol (HTTP), and Message Queuing Telemetry Transport (MQTT) asynchronous messaging.

This pattern promotes interoperability, reusability, and scalability since services are independent and designed to be used by clients via their defined APIs. Moreover, this pattern enables teams working on different services to work independently. In contrast, qualities such as availability, performance, and reliability are inhibited by this pattern.

3.3 RESCHOOL Architecture

To promote the quality attributes that are of interest to this project (i.e., maintainability, interoperability, and security), and to be compliant with the BRIDGE Data Exchange Reference Architecture (DERA), the RESCHOOL energy management platform uses a combination of two patterns: the layers pattern and service-oriented pattern.

The RESCHOOL general architecture is presented in Figure 7. The architecture organises the elements of the system into layers. Each layer has a well-defined set of responsibilities. The architecture is presented as a hexagonal architecture style. The hexagonal architecture organises the logical view in a way that places the business logic at the centre.

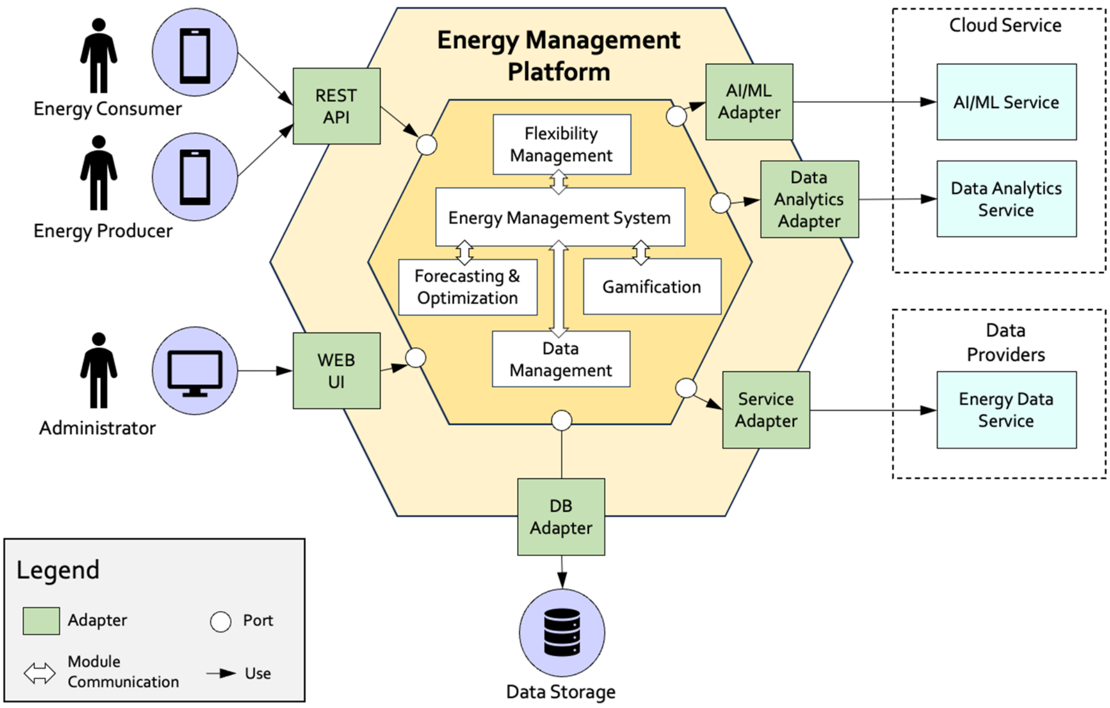

Figure 7 The RESCHOOL Energy Management Platform Architecture.

The core of the hexagonal architecture presents the business logic including all the capabilities and services that are provided by the platform. The business logic core is surrounded by different inbound and outbound adapters that handle the interaction between the business logic and the rest of the system. These adapters decouple the business logic from the presentation and data access logic, promoting maintainability and interoperability.

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Instead of the presentation layer, the platform has one or more inbound adapters that handle users' requests by invoking the business logic. These inbound adapters implement either a set of REST endpoints or a set of web pages. Another example of inbound adapters is a message broker client that subscribes to messages from the energy management platform. Furthermore, instead of a data persistence layer, the platform has one or more outbound adapters that are invoked by the business logic and invoke data storage or external systems. An example of an outbound adapter is a Data Access Object (DAO) which implements a collection of data access operations. Another example is a service adapter or proxy that invokes a remote or external service.

The business logic has ports. These ports define the operations that are used for the interaction. An inbound port is an API exposed by the business logic so it can be invoked by external systems. In contrast, an outbound port defines how the business logic invokes external services. An example of an outbound port is a DB API which defines a collection of data access operations. The adapters implement the ports for invoking the business logic or external systems, where an inbound adapter implements an inbound port, and an outbound adapter implements an outbound port.

3.3.1 Capabilities and Services

The business logic contains modules that implement the capabilities or services that are provided by the RESCHOOL energy management platform. A *capability* is a high-level concept that refers to the functionality or ability of a system to perform a specific task or sets of tasks. A *service* is a self-contained functionality that can be independently developed, deployed, and scaled, and contributes to the overall capabilities of a system. The RESCHOOL core capabilities and services are the following:

- **Capability: Energy Management System**. This capability provides access to prosumers and community data at individual and aggregated levels and facilitates the execution of specific energy services according to energy goals. This capability includes some basic energy services such as dashboard, aggregation, benchmarking, and balance. Moreover, it integrates the core RESCHOOLS services that are flexibility, forecasting and optimization, gamification, and data management services.
- **Service: Flexibility Management and Trading**. This service manages the community's energy flexibility and exposes it to external markets or aggregators for trading.
- **Service: Forecasting and Optimisation**. This service helps to forecast energy usage, optimise energy storage, maximise the consumption of locally generated energy, manage heat pumps efficiently, avoid congestion, and support peak shaving.
- **Service: Gamification**. This service uses the energy data to support decision making and interaction by establishing competitive and rewarding activities inside the energy community.
- **Service: Data Management**. This service manages all the energy data that are handled by the energy management platform. It is responsible to assure data flow from field devices and legacy systems to all the subsystems following standard protocols. It is also responsible for the curation, management, maintenance, and storage.

One energy management platform can implement all the services mentioned above. It might also implement one or a subset of these services and use the non-implemented services by calling external platforms or systems via their exposed APIs.

3.3.2 Adapters and Communication

There are inbound adapters that enable the interaction between the users of the application and the business logic. The outbound adapters handle requests from the outside by invoking the business logic. These adapters are the *REST API* and *WEB UI*. The users can be energy producers, consumers, prosumers, or administrators. The users can interact with the platform using a mobile phone or web application via a browser over HTTP-based REST communication protocol. REST uses HTTP methods such as Get, Put, Post, and Delete to manipulate system resources such as users and energy assets (battery, PV system, EV charger, etc.).

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Outbound adapters are invoked by the business logic and invoke other parts of the system or external systems. There is one outbound adapter that enables the interaction between the business logic and the data storage. This adapter is called *DB Adapter*. Data that enables the different services of the platform are stored in the data storage. Moreover, there exist different outbound adapters that enable the business logic to call external services, such as cloud services or external data providers. Examples of these adapters include *AI/ML*, *Data Analytics*, and *Energy Service adapters*. The communication protocols can be REST over HTTP, MQTT, AMQP, Apache Kafka, or other synchronous or asynchronous communication mechanisms.

3.4 Security Considerations

3.4.1 Authentication

Authentication serves as a first line of defence against unauthorised access to the energy management platform. It ensures that only legitimate users can access the platform by verifying their identity. This can be done typically by confirming the validity of the credentials. Two common approaches to achieve authentication that can be used in this project are: password-based authentication and multi-factor authentication (MFA).

Password-based authentication requires the users to provide a unique combination of characters as username and password. This approach can be vulnerable to threats like password guessing and brute force. Thus, it is important to ensure that the users use strong, complex passwords and regularly update them.

Multi-factor authentication requires the users to provide two or more distinct authentication factors (i.e., evidence) which include something the users know (e.g., a password) and something the users have (e.g., smartphone app, SMS notification, or authentication token). This approach adds an extra layer of security and makes it challenging for unauthorised people to gain access to the platform.

3.4.2 Authorization

Authorization determines what actions or resources a user, application, or service can access once their identity has been authenticated. Authorization can be supported by providing access control mechanisms. Two common approaches to achieve authorization that can be used in this project are: using REST API and OAuth2.

REST API plays a role in authorization by allowing developers to specify what resources or endpoints are accessible to different users or external applications. Indeed, through cautious design and configuration, the REST API supports the control of which users or external applications can perform creating, reading, updating, and deleting (CRUD) data.

OAuth2 is a protocol that is designed to enable secure and standardised authorization for web and mobile applications. It enables external applications or services to access specific user data or perform actions with the user's consent. This standard defines the resource owners (i.e., users), clients (i.e., external applications or services), and authorization servers. These enable the delegation of authorization without exposing user credentials.

3.4.3 Data and Communication Encryption

Encryption can be applied to data and communication between components that exchange the data. Data encryption involves the process of converting plaintext data into an unreadable format known as ciphertext by using encryption algorithms and keys. This ensures that even if intruders gain access to the data, they cannot decipher it without the appropriate decryption key. On the other hand, communication encryption secures data while it is in transit between two or more parties, making it indecipherable to anyone attempting to eavesdrop on the communication.

Various technologies enable data and communication encryption. Common encryption technologies include Advanced Encryption Standard (AES) and RSA for data encryption, and Transport Layer Security (TLS) and Secure Sockets Layer (SSL) for communication encryption. These technologies employ cryptographic algorithms to secure data. making it extremely challenging for unauthorised parties to gain access to these data.

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To implement data and communication encryption in the context of a REST API, encryption libraries and protocols, such as TLS, can be used. Moreover, when developing a REST API, it is crucial to ensure that it supports HTTPS (i.e., HTTP Secure) which is the combination of HTTP and TLS/SSL since this ensures that all data exchanged between clients and the API server is encrypted.

3.5 Trade-Off Analysis: One Vs. Several Platforms

To define the architecture and interfaces of the energy management platform, an analysis of different available energy community platforms is conducted. Several meetings with the technical partners, that are co-located to each RESCHOOL pilot, are conducted to understand the goals and functionalities of the available energy management platforms.

Based on the conducted analysis, two solutions are identified:

- **One Platform**: All pilots use one energy management platform.
    - *Pros*: Developing and maintaining a single application can be more cost-effective than creating multiple applications. Moreover, users across the pilots will have a consistent interface and user experience. Last, updates and maintenance will be implemented once, reducing the effort of the development.
    - *Cons*: Balancing the goals and requirements of each pilot can be challenging and potentially leading to compromises or complex customizations. Also, available data in one specific pilot might lead to the implementation of services or functionalities that might not work with another pilot. Furthermore, all the pilots will become dependent on one application and if one issue arises, then the pilots will be influenced simultaneously, increasing the risk of downtime and disruption.
- **Several Platforms**: Each technical partner that is connected/co-located to one specific pilot creates an energy management platform that will be used by that specific pilot. Services and information about the different platforms including experiences, knowledge, technical decisions and solutions, implemented services, market analysis, forecasting, optimization as well as gamification techniques will be shared between the partners.
    - *Pros*: Each pilot can have its own customised application with services and functionalities that align specifically with its requirements, data, and goals. Moreover, the technical partners that are co-located to each pilot can independently make changes and updates to their applications without impacting the others.
    - *Cons*: User experiences and interfaces can vary across the different applications, which may lead to a lack of uniformity. Also, services and functionalities that could be shared among the pilots may need to be developed separately for each application, resulting in duplicate or redundant work.

Considering the pros and cons that are highlighted by the trade-off analysis, it is agreed that each technical partner creates its own energy management platform based on its capabilities and design choices. Knowledge, experiences, and design decisions should be shared between all the partners. Engagement services such as optimization, forecasting, gamification, flexibility analysis must be designed and provided via APIs, so that they can be utilised by platforms created by other partners in case of need.

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4 Energy Data Models

According to ISO 25010, interoperability is the degree to which two or more systems, products or components can exchange information and use the information that has been exchanged. There are different interoperability categories described by ETSI[4]. These categories are:

- *Technical Interoperability*: It is related to software, hardware, systems, and platforms that enable machine-to-machine communication. It is mainly concerned with communication protocols and needed infrastructure for these protocols to operate.
- *Syntactic Interoperability*: It is related to data formats and structures. These data are transferred by communication protocols between systems and platforms.
- *Semantic Interoperability*: It is about the meaning of data and concerns the human interpretation of the data. It promotes a common understanding between the stakeholders of the meaning of the data that are exchanged and processed.
- *Organisational Interoperability*: This refers to the ability of organisations to effectively communicate and transfer data where these organisations might use different infrastructures and possibly operate at a distance. Achieving organisational interoperability depends on the successful achievement of technical, syntactic, and semantic interoperability.

Energy data modelling is important for syntactic, semantic, and organisational interoperability. Indeed, data models establish the syntax and semantics of key data abstractions that might be shared between collaborating systems and organisations. They also ensure that these essential data abstractions align with the data used by the interoperating systems.

In this section, the FIWARE smart energy data standard is described. Using this standard, the RESCHOOL energy assets data are modelled and presented. Last, the input data that are required to enable the services of the energy management platform are presented together with the expected output from the processing of the input data.

4.1 Smart Data Models: A FIWARE Energy Data Standard

The existence of a universally accepted de-facto standard data model is crucial in establishing a worldwide digital single market where interoperable and replicable IoT-enabled smart solutions can thrive across various domains. These models form a fundamental component of the shared technical foundation required for standards-based open innovation and procurement.

Data models assume a pivotal role in this context, defining standardised representation formats and semantics. These models serve as the common language that applications use to both consume and publish data, contributing to seamless interoperability and innovation.

Smart Data Models[5] is a collaborative initiative driven by the FIWARE Foundation, TMForum, IUDX, OASC, and numerous other contributing organisations shaping the data models. These data models are open-licensed, permitting unrestricted use, modification, and sharing of adaptations. This flexibility allows for customization and evolution according to the specific requirements of various use cases. The harmonisation of data models facilitates data portability across diverse applications, including those related to Smart Energy.

In the RESCHOOL project, the Smart Data Models are adopted to enable actual data interoperability between diverse systems based on open-licensed data models. The purpose is to advance interoperability by offering universally shared and standardised data models. The data of the energy assets of the RECSHOOL project are

[4] ETSI White Paper No. 3 - Achieving Technical Interoperability - the ETSI Approach 2008
[5] Smart Data Models: https://smartdatamodels.org/

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designed using the Smart Data Models to be utilised by a diverse group of organisations and systems, streamlining data exchange, and enhancing interoperability.

4.2 RESCHOOL Assets Data Models

The RESCHOOL data models describes the following energy assets:

- *Photovoltaic (PV) System*: this data model describes the mechanical and electrical characteristics of a photovoltaic system. Moreover, it describes the power transferred by the photovoltaic panel to an inverter device.
- *Battery*: This data model describes the physical and operational characteristics of a battery as an energy storage. It also describes the power and energy that can be charged and discharged.
- *Space Heater*: This data model describes the physical and operational characteristics of a space heater e.g., heat pump which imparts mechanical work on fluids to move them through a channel or pipeline.
- *Electric Vehicle (EV)*: This model describes the characteristics of EVs together with a description of the associated battery, power consumption, and charge as well as discharge power.
- *EV Charger*: This model describes the physical and operational characteristics of an EV charger.
- *Energy Prosumer*: This data model describes an individual or entity that both consumes and produces energy.
- *Energy Consumption*: This data model describes the amount and cost of consumed energy.
- *Energy Production*: This data model describes the amount and value of produced energy.
- *Weather Forecast*: This data model describes entities useful for dealing with weather forecasting.

The data models of these energy assets provide a list of the properties or attributes. Each attribute is described with a reference on its type and unit of measurement. In the following tables, we present the data model of each energy asset.

PV System			
Attribute	Type	Unit	Description/Example
id	String		Identifier of the energy asset
name	String		"DEVICE-PV-T2-R-012"
description	String		photovoltaic device description
location	Array of Numbers		List of coordinates: latitude and longitude
addressLocality	String		"Stockholm"
brandName	String		Brand Name of the item "EUSolar"
manufacturerName	String		"Euro Solar AB"
modelName	String		"CS6P-270P"
installationMode	Enum	Ground, Pole, Roofing, Wall, Other	Positioning of the device in relation to a ground reference system
cellType	Enum	AmorphousSilicon, CfTe, CIS, Monocrystalline, Polycrystalline, Other	Type of cells used to build the photo-voltaic unit
cellDimension	JSON Object		External dimension of a cell

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length	Number	mm	
width	Number	mm	
thickness	Number	mm	
moduleNbCells	Number		Number of 'cells' per 'module'. A module can be an assembly of 1 to n cells
moduleDimension	JSON Object		External dimension of a module.
length	Number	mm	
width	Number	mm	
thickness	Number	mm	
panelNbModules	Number		Number of 'Modules' per 'Panel'
panelDimension	JSON Object		External dimension of a Panel. A solar panel can be an assembly of 1 to n modules, which themselves are made of several cells which collect heat from the sun's rays.
length	Number	mm	
width	Number	mm	
thickness	Number	mm	
installedPower	Number	kW	Total installed power
nominalPower	Number	kW	Nominal Power of the inverter(s)
powerOutput	Number	kW	PV system power output
maxPowerOutput	Number	kW	Max Power Output
peakPower	Number	kW	Peak power for the PV
losses	Number	%	Overall PV system losses
energyTotal	Number	kWh	Energy meter value for total production
maximumSystemVoltage	Number	volt	Maximum system voltage permitted for the module
panelAzimuth	Number	degree	
panelOrientation	Enum	South, South-West, etc.	
panelTilt	Number	degree	
registerPVId	JSON Object		Identifications numbers associated to the PV
CAU	String		Self-consumption identification code: Individual: CUPS + AXXX; Collective: CUPS + 1FAXXX
CIL	String		Energy surplus identification code
selfConsumption	Boolean	True/False	Indicates the energy generated from the device is used for self-consumption. If False, all generations are exported to the grid.

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PVConnection	Enum	Grid, Indoor	Indicates if the PV is connected straight to the grid or within the interior network of an Energy Member
selfConsumptionReach	Enum	Individual, collective	Indicates if the PV is used by one or more Energy Consumers
energyMode	Enum	With-surplus & Compensation, With-surplus & without-Compensation, without-surplus	Indicates if the PV is allowed to produce more energy that the one consumed by the associated consumers.
batteryAssociated	String		Id from the battery (Hybrid Generation). If there is no value, there is no battery associated.

Battery			
Attribute	Type	Unit	Description/Example
id	String		Identifier of the energy asset
name	String		"SBM-T1-G0-027"
description	String		Battery description
supportsCharge	Boolean	Y/N	Indicates whether battery supports charge request via charge power
supportsDischarge	Boolean	Y/N	Indicates whether battery supports discharge request via discharge power
location	Array of Numbers		List of coordinates: latitude and longitude
addressLocality	String		"Stockholm"
brandName	String		Brand Name of the item "EUBatt"
manufacturerName	String		"Euro Battery AB"
modelName	String		"ESS-270B"
cycleLife	Number	cycles	Numeric value of the load/unload operation cycles for the item
statusPercent	Number	Percent %	Percentage of charge available for the battery
averageLife	Number	Years	Average life under normal battery usage conditions at reference temperatures
batteryType	Enum	alkaline, gel, lead, lead-AGM, Li-Ion, Li-Po, Li-Po4, LMP, Li-Air, Na-NiCl2(Zebra), Ni-Cd, Ni-MH, Ni-Zn, other	Type of battery used
brandName	String		Brand Name of the item

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installationMode	Enum	Ground, Pole, Roofing, Wall, Other	Positioning of the device in relation to a ground reference system
nominalVoltage	Number	Volt	Nominal battery voltage
nominalAmpere	Number	Ampere	Nominal amperage
nominalFrequency	Number	Hertz	Nominal Frequency
nominalCapacity	Number	kWh	Nominal Energy capacity
usableEnergy	Number	kWh	Usable Energy
maxOutputPower	Number	kW	Maximum Power
peakPower	Number	kW	Maximum intensity extractable over a short period
durationPeakPower	Number	seconds	Reference Time recorded for the attribute
roundTripEfficiency	Number	Percent %	Round-Trip Efficiency. Efficiency, defined as the ratio between stored energy and returned energy
chargeDischargeReactivity	Number	seconds	Charge and Discharge Reactivity which characterises the reactive behaviour of the system
chargePower	Number	kW	Charge Power
chargePowerMax	Number	kW	Maximum charging Power
chargePowerMin	Number	kW	Minimum charging Power
chargeEfficiency	Number	Percent %	Charge Efficiency
dischargePower	Number	kW	Discharge Power
dischargePowerMax	Number	kW	Maximum discharge Power
dischargePowerMin	Number	kW	Minimum discharge Power
dischargeEfficiency	Number	Percent %	Discharge Efficiency
activePower	Number	kW	Active Power: utilised or consumed
stateOfCharge	Number	Percent %	Defined as the ratio between the remaining and the current capacities
stateOfChargeMin	Number	Percent %	Minimum state of charge allowed for the battery
stateOfChargeMax	Number	Percent %	Maximum state of charge allowed for the battery
deepOfDischarge	Number	Percent %	Ratio between the capacity already discharged and the nominal capacity of the accumulator.
stateOfHealth	Number	Percent %	Ratio between the maximum amount of charge that a fully charged battery can provide under its nominal discharge regime, and its nominal capacity
temperature	Number	degree	Main temperature recorded at the time of observation compared to the nominal reference temperature of the device.
batteryLevel	Enum	0.0=battery empty, 1.0=Battery full, -1.0=Transiently not determined	Device's battery level
batteryStatus	Enum	consumingEnergy, givingEnergy, or standby	Status of the battery during the measurement (giving or not)
chargedTotal	Number	kWh	Energy meter value for total charge sessions
dischargedTotal	Number	kWh	Energy meter value for total discharge sessions

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costCharging	Number	Currency/kWh	Levelized costs of storage for charging
costDischarging	Number	Currency/kWh	Levelized costs of storage for discharging
energyLevelSchedule	JSON Object	Percent %	Indicates minimum required state of charge for each hour of the day
operationalMode	Enum	Manual, built-in, Other	
dateObservedFrom	Date	ISO8601 UTC	Observation period: Start date and time
dateObservedTo	Date	ISO8601 UTC	Observation period: End date and time
dateCreated	Date	ISO8601 UTC	Entity creation timestamp
dateModified	Date	ISO8601 UTC	Timestamp of the last modification of the entity

Space Heater			
Attribute	Type	Unit	Description/Example
id	String		Identifier of the energy asset
name	String		"DEVICE-SH-T2-R-012"
description	String		Space heater device description
location	Array of Numbers		List of coordinates: latitude and longitude
addressLocality	String		"Stockholm"
thermalResistence	Number	ºC/W	
thermalCapacity	Number	kWh/ºC	
activePower	Number	kW	Power
powerMax	Number	kW	Maximum Load Power
powerMin	Number	kW	Minimum Load Power
energyTotal	Number	kWh	Energy meter value for total consumption
manufacturerName	String		Manufacturer name
modelName	String		Model name
outputCapacity	Number	W, J/s	Total nominal heat output as listed by the manufacturer. Usually measured in Watts (W, J/s)
temperatureClassification	Enum	Low, High	Defining the temperature classification of the space heater surface temperature. low temperature - surface temperature is relatively low, usually heated by hot water or electricity. high temperature - surface temperature is relatively high, usually heated by gas or steam

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thermalEfficiency	Number		Overall Thermal Efficiency is defined as gross energy output of the heat transfer device divided by the energy input
bodyMass	Number	kg, g	Overall body mass of the heater. Usually measured in kilograms (kg) or grams (g)
thermalMassHeatCapacity	Number	W, J/s	Product of component mass and specific heat
dateCreated	Date	ISO8601 UTC	Entity creation timestamp
dateModified	Date	ISO8601 UTC	Timestamp of the last modification of the entity
temperatureSetpoint	Number	ºC	Setpoint of temperature (fixed or flexible)
MinTemperatureSetpoint	Number	ºC	Minimum Setpoint temperature
MaxTemperatureSetpoint	Number	ºC	Maximum Setpoint temperature
IncreaseTemperatureSetpoint	Number	ºC	Allowed increase setpoint temperature
DecreaseTemperatureSetpoint	Number	ºC	Allowed decrease Setpoint temperature
weightFactorCostDiscomfort	Number		Weight factor between cost and discomfort (time dependent)
rampRate	Number	kW/h	The maximum electric power gradient of the SpaceHeater (Ramp rate)
activePowerUp	Number	kW	Real-time up regulation level for SpaceHeater at time step t. For demand, up regulation is to reduce consumption.
activePowerDown	Number	kW	Real-time down regulation level for SpaceHeater at time step t. For demand, down regulation is to increase consumption.
discriminatorActivePowerUpDown	Boolean		Discriminator for up/down-regulation in real-time market per site k at time step t [0/1]. Binary variable preventing the heat pump to participate in up/down regulation at the same time.
IndoorRoomTemperature	Number (Decimal)	ºC	Indoor room temperature in kth house at time step t.
baselineTemperature	Number (Decimal)	ºC	Baseline temperature in kth house at time step t.

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EV			
Attribute	Type	Unit	Description/Example
id	String		Identifier
chargerId	String		
brandName	String		
vehicleType	Enum	bicycle, bus, car, caravan, motorcycle, motor scooter, truck	Vehicle type(s) which can be charged
socketType	Enum	Caravan_Mains_Socket, CHAdeMO, CCS/SAE, Dual_CHAdeMO, Dual_J-1772, Dual_Mennekes, J-1772, Mennekes, Other, Tesla, Type2, Type3, Wall_Euro	The type of socket
modelName	String		
manufacturingYear	String	YYYY	
supplyPhases	Number		Number of alternating current phases connected/available.
consumption	Number	kWh/km	Average energy consumption per kilometer
nominalCapacity	Number	kWh	Nominal Energy capacity
chargePower	Number	kW	Load Power
chargePowerMax	Number	kW	Maximum Load Power
chargePowerMin	Number	kW	Minimum Load Power
chargeEfficiency	Number	Percent %	Charge Efficiency
dischargePower	Number	kW	Discharge Power
dischargePowerMax	Number	kW	Maximum Load Power
dischargePowerMin	Number	kW	Minimum Load Power
dischargeEfficiency	Number	Percent %	Discharge Efficiency
chargedTotal	Number	kWh	Energymeter value for total charge sessions
dischargedTotal	Number	kWh	Energymeter value for total discharge sessions
statusPercent	Number	Percent %	Percentage of charge available for the battery
stateOfCharge	Number	Percent %	Defined as the ratio between the remaining and the current capacities
stateOfChargeMin	Number	Percent %	Minimum state of charge allowed for the battery
stateOfChargeMax	Number	Percent %	Maximum state of charge allowed for the battery
stateOfHealth	Number	Percent %	Ratio between the maximum amount of charge that a fully charged battery can provide under its nominal discharge regime, and its nominal capacity

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costCharging	Number	Currency/kWh	Levelised costs of storage for charging
costDischarging	Number	Currency/kWh	Levelised costs of storage for discharging
energyLevelSchedule	Number	Percent %	Indicates minimum required state of charge for each hour of the day
dateCreated	Date	ISO8601 UTC	Entity creation timestamp
dateModified	Date	ISO8601 UTC	Timestamp of the last modification of the entity
availabilitySchedule	Date	ISO8601 UTC	availability of the vehicle for charge or discharge (connected or not at time t (hourly))
averageHourlyDrive	Number	km/h	Average hourly driving distance of an EV
drivingEfficiency	Number	Percent %	Driving efficiency of an EV

EV Charger			
Attribute	Type	Unit	Description/Example
id	String		Identifier of the energy asset
name	String		"DEVICE-EVC-T2-R-012"
description	String		EV Charger device description
supportsCharge	Boolean	Y/N	Indicates whether charger supports charge request via chargePower
supportsDischarge	Boolean	Y/N	Indicates whether charger supports discharge request via dischargePower
location	Array of Numbers		List of coordinates: latitude and longitude
addressLocality	String		"Stockholm"
chargeType	Enum	annualPayment, flat, free, monthlyPayment, other	Type(s) of charge when using this station
socketType	Enum	Caravan_Mains_Socket, CHAdeMO, CCS/SAE, Dual_CHAdeMO, Dual_J-1772, Dual_Mennekes, J-1772, Mennekes, Other, Tesla, Type2, Type3, Wall_Euro	The type of sockets offered by this station
allowedVehicleType	Enum	bicycle, bus, car, caravan, motorcycle, motor scooter, truck	Vehicle type(s) which can be charged
socketNumber	Number		The total number of sockets offered by this charging station.
status	Enum	almostEmpty, almostFull, empty, full, outOfService, withIncidence, working'. Or any other application-specific	Status of the charging station

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amperage	Number	Ampere	The total amperage offered by the charging station.
socketAvailable	Number		The number of sockets which currently can be available. It must be lower or equal than socket number.
voltage	Number	Volt	The total voltage offered by the charging station
activePower	Number	kW	Power consumed by the entity corresponding to this observation
chargePower	Number	kW	Charge Power
chargePowerMax	Number	kW	Maximum Load Power while charging
chargePowerMin	Number	kW	Minimum Load Power while charging
chargeEfficiency	Number	Percent %	Charge Efficiency
dischargePower	Number	kW	Discharge Power
dischargePowerMax	Number	kW	Maximum Load Power while discharging
dischargePowerMin	Number	kW	Minimum Load Power while discharging
dischargeEfficiency	Number	Percent %	Discharge Efficiency
vehicleId	String		ID of connected ID required to map charger on a vehicle
observationDateTime	Date	ISO8601 UTC	Last reported time of observation
startDateTime	Date	ISO8601 UTC	Reported start time corresponding to this observation
endDateTime	Date	ISO8601 UTC	Reported end time corresponding to this observation
dateCreated	Date	ISO8601 UTC	Entity creation timestamp
dateModified	Date	ISO8601 UTC	Timestamp of the last modification of the entity
chargedTotal	Number	kWh	Energymeter value for total charge sessions
dischargedTotal	Number	kWh	Energymeter value for total discharge sessions
electricTariff	Enum	3.0TDVE, 6.1TDVE	Electric tariff for public EV and with its own grid connection. If none is selected, the EV charger is installed in the interior grid of an EC member
supplyPhases	Number		Number of alternating current phases connected/available.
maxPowerOutput	Enum		Schedule of charging power limits, Inspired by the ChargingProfile concept of OCPP

Energy Prosumer			
Attribute	Type	Unit	Description/Example
id	String		Identifier
name	String		name of the EP
description	String		A description of this item

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location	Array of Numbers		List of coordinates: latitude and longitude
addressLocality	String		"Stockholm"
timezone	String		Name of the timezone of the site, from the IANA tz database
activePower	Number	kW	Active power of the load. Load sign convention is used, i.e. positive sign means flow out from a node. For voltage dependent loads the value is at rated voltage. Starting value for a steady state solution. Default: 0.0
powerContracted	Number	kW	Active power of the load, that is a fixed quantity. Load sign convention is used, i.e. positive sign means flow out from a node. Default: 0.0
reactivePower	Number	KVAr	Reactive power of the load. Load sign convention is used, i.e. positive sign means flow out from a node. For voltage dependent loads the value is at rated voltage. Starting value for a steady state solution. Default: 0.0
reactivePowerContracted	Number	kVAr	Reactive power of the load that is a fixed quantity. Load sign convention is used, i.e. positive sign means flow out from a node. Default: 0.0
dateCreated	Date	ISO8601 UTC	Entity creation timestamp
dateModified	Date	ISO8601 UTC	Timestamp of the last modification of the entity
PVid	String		ID of connected ID required to map the associated PV
batteryid	String		ID of connected ID required to map the associated Battery
EVChargerid	String		ID of connected ID required to map the associated EV charger
spaceHeaterid	String		ID of connected ID required to map the associated Space Heater
weatherStationid	String		ID of connected ID required to map the associated Weather Station
electricTariff	String		Label of the electric tariff (category)
powerRating	Number	kW	The maximum power allowed at the site by the protections put in place. It limits the maximum power allowed to be contracted by the prosumer based on the characteristics of the electrical installation.
totalEnergyExported	Number	kWh	
totalEnergyImported	Number	kWh	
gridVoltage	Number	kV	Grid voltage

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supplyPhases	Number		Number of alternating current phases connected/available.

Energy Consumption			
Attribute	Type	Unit	Description/Example
id	String		Identifier
name	String		
description	String		
energyProsumerId	String		ID of the Energy Prosumer
energyConsumed	Array of Objects		Energy consumption and cost
supplyName	String		Company that supplies the energy
energyConsumedAmount	Number		How much energy is consumed
energyConsumedMeasurementUnit	String		kWh, MTQ, Other
totalCost	Number	costCurrency	How much is the total cost
costCurrency	String	Euro, SEK, Other	
energyPrice	JSON Object	CostCurrency/kWh	Energy price
timestampPrice	Date	ISO8601 UTC	Time at which the price is set
peak	Boolean		On peak or off-peak.
dateCreated	Date	ISO8601 UTC	Entity creation timestamp
dateModified	Date	ISO8601 UTC	Timestamp of the last modification of the entity

Energy Production			
Attribute	Type	Unit	Description/Example
id	String		Identifier
name	String		
description	String		
energyProsumerId	String		ID of the Energy Prosumer
energyProduced	Array of Objects		Energy production and value
energyProducedAmount	Number		How much energy is produced
energyProducedMeasurementUnit	String		kWh, MTQ, Other
totalValue	Number	currency	How much is the total value
currency	String	Euro, SEK, Other	

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energyPrice	JSON Object	currency/kWh	Energy price
timestampPrice	Date	ISO8601 UTC	Time at which the price is set
peak	Boolean		On peak or off-peak.
dateCreated	Date	ISO8601 UTC	Entity creation timestamp
dateModified	Date	ISO8601 UTC	Timestamp of the last modification of the entity

Weather Forecast			
Attribute	Type	Unit	Description/Example
id	String		Identifier
description	String		description of this item
addressLocality	String		"Stockholm"
dateIssued	Date	ISO8601 UTC	The date and time the forecast was issued by the meteorological bureau
dateRetrieved	Date	ISO8601 UTC	The date and time the forecast was retrieved
temperature	Number	degree	
relativeHumidity	Number	Percent %	
dayMaximum	Object		Maximum values for the reported period
dMaxtemperature	Number	degree	
relativeHumiditydMax	Number	Percent %	
dayMinimum	Object		Minimum values for the reported period
dMintemperature	Number	degree	
dMinrelativeHumidity	Number	Percent %	
precipitationProbability	Number	Percent %	
windSpeed	Number	m/s	
windDirection	Enum		
validity	Date	ISO8601 UTC	Includes the validity period for this forecast
dateCreated	Date	ISO8601 UTC	Entity creation timestamp
dateModified	Date	ISO8601 UTC	Timestamp of the last modification of the entity
Elevation	Number	m	Elevation
Irradiance	Number	W/m^2	Solar irradiance

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4.3 RESCHOOL Services Data Models

The RESCHOOL service data models describe the data that enable the services of the energy management platform. These services are optimization, flexibility management and trading, data management, and gamification services. In the following subsections, we briefly present the purpose of each service. Moreover, we detail the data that are required to enable the services (i.e., input attributes) and describe the outcome or information data that are provided by these services (i.e., output attributes).

4.3.1 Optimisation and Forecasting Services

This service helps to forecast energy usage, optimise energy storage, maximise the consumption of locally generated energy, manage heat pumps efficiently, avoid congestion, and support peak shaving. This service has two sub-services as it is shown by Figure 8. These sub-services are: forecasting services and optimisation services.

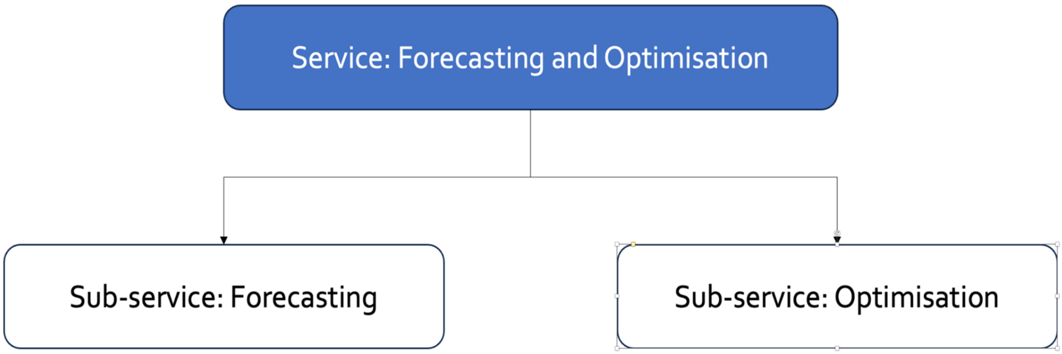

Figure 8 The Forecasting and Optimisation Services.

4.3.1.1 Sub-service: Forecasting

The objective of this sub-service is to enable the gathering of weather data and solar irradiance information. These data are forecasted for each weather station. Moreover, this sub-service supports the forecasting of the PV power production for each system based on the PV system parameterization and location. Also, it supports the forecasting of the energy demand of each household or building of the energy community.

Weather Forecasting		
Input Attribute	Output Attribute	Notes
location elevation dateIssued	irradiance temperature humidity windSpeed windDirection dateRetrieved	

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Solar PV Power Production Forecasting		
Input Attribute	Output Attribute	Notes
location panelTilt panelAzimuth panelOrientation losses peakPower installedPower Weather Forecasting output attributes	powerOutput energyTotal maxPowerOutput	

Energy Demand Forecasting		
Input Attribute	Output Attribute	Notes
Weather Forecasting output attributes activePower	activePower	

4.3.1.2 Sub-service: Optimisation

This sub-service is concerned with self-consumption maximisation where the optimal strategy regarding energy sharing, surplus management, and optimal control of the assets is computed. Moreover, it supports the optimisation of the control of the individual flexible energy assets, where an optimal strategy regarding an optimal control of the assets is computed and provided by this service.

It is worthy to note that EV optimisation is concerned with the optimisation of the vehicle, while the EV Charger optimisation is concerned with the optimisation of the charger which, in this case, can be used to charge different EV models.

EV Optimisation		
Input Attribute	Output Attribute	Notes

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stateOfChargeMin stateOfChargeMax stateOfCharge [1] dischargePowerMax dischargePowerMin dischargeEfficiency chargePowerMax chargePowerMin chargeEfficiency nominalCapacity totalPowerProduction [2] totalPowerConsumption [2] energyPrice costCharging costDischarging energyLevelSchedule availabilitySchedule socketNumber [3] socketAvailable [3] averageHourlyDrive drivingEfficiency	chargePower (control) dischargePower (control) activePower stateOfCharge	*[1] Input attribute used to indicate the initial SoC of the battery at the beginning of the trading period (t=0). Also, it can be used to impose a SoC at the end of the trading period.* *[2] This is the total (aggregated) power consumption and production of the energy community based on the: (i) topology of the energy community (i.e., how the assets are distributed and used within the community, where an asset could be of public or private usage/domain) and (ii) business model which directly influences the objective function and constraints of the optimisation model.* *[3] Based on the EV Charger data model.*

Battery Optimisation		
Input Attribute	Output Attribute	Notes
stateOfChargeMin stateOfChargeMax stateOfCharge [1] dischargePowerMax dischargePowerMin dischargeEfficiency chargePowerMax chargePowerMin chargeEfficiency nominalCapacity totalPowerProduction [2] totalPowerConsumption [2] energyPrice operationalMode costCharging costDischarging	chargePower (control) dischargePower (control) activePower stateOfCharge	*[1] Input attribute used to indicate the initial SoC of the battery at the beginning of the trading period (t=0). Also, it can be used to impose a SoC at the end of the trading period.* *[2] This is the total (aggregated) power consumption and production of the energy community based on the: (i) topology of the energy community (i.e., how the assets are distributed and used within the community, where an asset could be of public or private usage/domain) and (ii) business model which directly influences the objective function and constraints of the optimisation model.*

Space Heater Optimisation		
Input Attribute	Output Attribute	Notes

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powerMax minTemperatureSetPoint maxTemperatureSetPoint temperatureSetPoint temperature [1] weightFactorCostDiscomfort thermalResistence thermalCapacity thermalEfficiency activePower [2] rampRate totalPowerProduction [3] totalPowerConsumption [3] energyPrice	temperatureSetpoint activePower activePowerUp activePowerDown DiscriminatorActivePowerUpDown indoorRoomTemperature baselineTemperature	[1] *Weather Forecasting output attribute* [2] *Based on the Energy Prosumer data model* [3] *This is the total (aggregated) power consumption and production of the energy community based on the: (i) topology of the energy community (i.e., how the assets are distributed and used within the community, where an asset could be of public or private usage/domain) and (ii) business model which directly influences the objective function and constraints of the optimisation model.*

EV Charger Optimisation		
Input Attribute	Output Attribute	Notes
socketNumber socketAvailable chargePowerMax chargePowerMin chargeEfficiency dischargePowerMax dischargePowerMin dischargeEfficiency totalPowerProduction [1] totalPowerConsumption [1]	chargePower dischargePower activePower maxPowerOutput	[1] *This is the total (aggregated) power consumption and production of the energy community based on the: (i) topology of the energy community (i.e., how the assets are distributed and used within the community, where an asset could be of public or private usage/domain) and (ii) business model which directly influences the objective function and constraints of the optimisation model.*

Energy Consumption Optimisation		
Input Attribute	Output Attribute	Notes
Weather Forecasting output attributes timeZone [1] powerContracted [1] electricTariff [1] powerRating [1] supplyName energyConsumed dateCreated energyPrice energyProduced [2] dateCreated [2] energyPrice [2] totalPowerProduction [3] totalPowerConsumption [3]	energyConsumed (*control*) dateCreated (*control*)	[1] *Based on the Energy Prosumer data model.* [2] *Based on the Energy Production data model.* [3] *This is the total (aggregated) power consumption and production of the energy community based on the: (i) topology of the energy community (i.e., how the assets are distributed and used within the community, where an asset could be of public or private usage/domain) and (ii) business model which directly influences the objective function and constraints of the optimisation model.*

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4.3.2 Flexibility Management and Trading Services

This service manages the community's energy flexibility and exposes it to external markets or aggregators for trading. It can be observed that two sub-services arise from the definition, on one hand we have flexibility management service and, on the other one, we have trading service. In Figure 9, it can be seen how this service is defined and the target entities that the trading sub-service is oriented to.

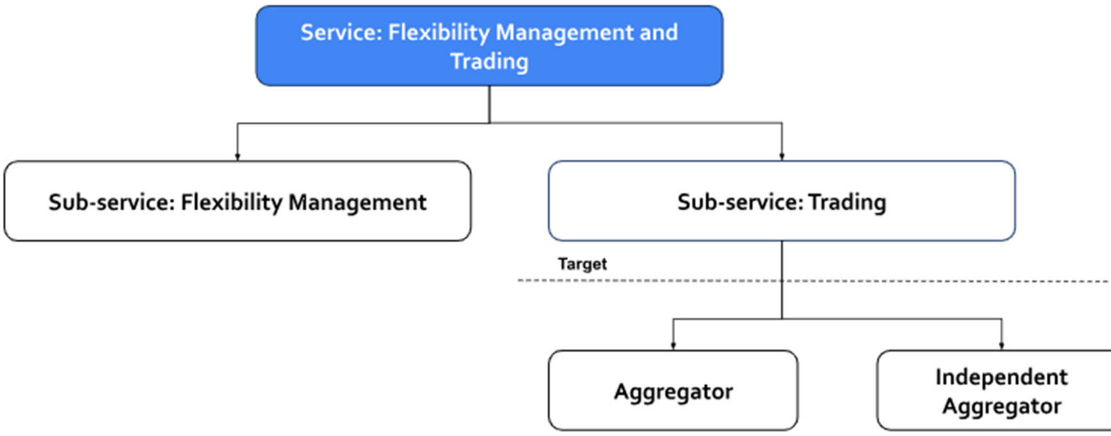

Figure 9 The flexibility management and trading services.

4.3.2.1 Sub-service: Flexibility Management

This sub-service is fundamentally about managing the interactions between forecasting and optimization services with the community's Energy Management System (EMS). It is responsible for handling the inputs and outputs for and from these services to control the community's energy assets, both optimally and efficiently based on market requirements set by the Trading sub-service. The main goal is to align the energy assets' operation with market requirements set by the trading sub-service. In practice, this means adjusting energy generation and demand response, to match the supply with the demand within the community and the external market.

This sub-service is crucial in maintaining system balance, ensuring that energy is used and stored in the most cost-effective way by reducing costs by changing consumption during periods of high prices and by providing to the system the controllability of the energy assets.

To provide accurate flexibility for each one of the assets, the following tables define the required inputs and outputs for this purpose. Flexibility and optimization services are highly linked and related, this is because the flexibility service defines some of the constraints in the optimization models. Therefore, any output attribute defined in the optimisation service won't be included in this section.

Therefore, the output attributes obtained from this service are going to be:

- *upFlexibility*. Which refers to the increase of generation (reduction of consumption) of an asset. The units used are in kW.
- *downFlexibility*. Which refers to the decrease of generation (increase of consumption) of an asset. The units used are in kW.

It is worthy to note that EV flexibility is concerned with the flexibility of the vehicle, while the EV Charger flexibility is concerned with the flexibility of the charger which, in this case, can be used to charge different EV models.

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Battery Flexibility		
Input Attribute	**Output Attribute**	**Notes**
id stateOfCharge stateOfChargeMin stateOfChargeMax activePower [1] nominalCapacity chargePowerMax chargePowerMin chargeEfficiency dischargePowerMax dischargePowerMin dischargeEfficiency chargePower [2] dischargePower [2]	upFlexibility [3] downFlexibility [3]	*[1] Battery baseline is forecasted.* *[2] These two inputs refer to the asset's engagement in previous markets.* *[3] Available flexibility up/down for a battery.*

Space Heater (Thermal Load) Flexibility		
Input Attribute	**Output Attribute**	**Notes**
id thermalResistence thermalCapacity thermalEfficiency activePower [1] indoorRoomTemperature baselineTemperature temperatureSetpoint minTemperatureSetpoint maxTemperatureSetpoint increaseTemperatureSetpoint decreaseTemperatureSetpoint powerMax Weather Forecasting [2]	upFlexibility [3] downFlexibility [3]	*[1] Space Heater baseline is forecasted.* *[2] Weather forecasting output attributes* *[3] Available flexibility up/down for a space heater.*

EV charger Flexibility		
Input Attribute	**Output Attribute**	**Notes**
id stateOfCharge stateOfChargeMin stateOfChargeMax activePower [1] nominalCapacity chargePowerMax	upFlexibility [2] downFlexibility [2]	*[1] EV charger baseline is forecasted.* *[2] Available flexibility up/down for an EV charger.*

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chargePowerMin chargeEfficiency dischargePowerMax dischargePowerMin dischargeEfficiency chargePower dischargePower energyLevelSchedule availabilitySchedule socketNumber socketAvailable		

EV Flexibility		
Input Attribute	Output Attribute	Notes
id stateOfCharge stateOfChargeMin stateOfChargeMax activePower [1] nominalCapacity chargePowerMax chargePowerMin chargeEfficiency dischargePowerMax dischargePowerMin dischargeEfficiency chargePower dischargePower energyLevelSchedule availabilitySchedule socketNumber socketAvailable averageHourlyDrive drivingEfficiency	upFlexibility [2] downFlexibility [2]	[1] *EV baseline is forecasted.* [2] *Available flexibility up/down for an EV.*

PV system Flexibility		
Input Attribute	Output Attribute	Notes
id Solar PV Power Production Forecasting [1]	upFlexibility [2,3] downFlexibility [2]	[1] *Attribute powerOutput from Solar PV Power Production Forecasting service is used as baseline.* [2] *Available flexibility up/down for a PV System.* [3] *For a PV system if operating at maximum powerOutput, upFlexibility won't be possible since increasing power output is not feasible.*

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EnergyProsumer Flexibility		
Input Attribute	Output Attribute	Notes
id PV system Flexibility [1] EV charger Flexibility [2] Space Heater Flexibility [3] Battery Flexibility [4]	upFlexibility [5] downFlexibility [5]	*[1] PV system Flexibility Output Attributes.* *[2] EV charger Flexibility Output Attributes.* *[3] Space Heater (thermal load) Flexibility Output Attributes.* *[4] Battery Flexibility Output Attributes.* *[5] Available flexibility up/down for an Energy Prosumer considering the addition of all flexibility outputs from the energy assets under its domain/control.*

EnergyCommunity Flexibility		
Input Attribute	Output Attribute	Notes
id PV system Flexibility [1] EV charger Flexibility [2] Space Heater Flexibility [3] Battery Flexibility [4] EnergyProsumer Flexibility [5]	upFlexibility [6] downFlexibility [6]	*[1] PV system Flexibility Output Attributes from communal assets.* *[2] EV charger Flexibility Output Attributes from communal assets.* *[3] Space Heater (thermal load) Flexibility Output Attributes from communal assets.* *[4] Battery Flexibility Output Attributes from communal assets.* *[5] EnergyProsumer Flexibility Output Attributes.* *[6] Available flexibility up/down for an Energy Community considering the addition of all flexibility outputs from the energy assets (communal) and EnergyProsumers under its domain.*

4.3.2.2 Sub-service: Trading

Within the trading sub-service, there are two main entities that are targeted by this sub-service: Aggregator and Independent Aggregator.

Aggregator. As an aggregator, the service is responsible for the management of bidding and direct flexibility markets interactions. The community, in this role, acts as a collective entity that combines the flexible energy capacities of its members to participate in the energy market, thus becoming its own BSP (Balance Service Provider). By pooling the community's energy assets, the aggregator can engage in trading on flexibility

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markets, offering energy based on current market prices, demands, and system needs (TSO or DSO level). The service uses forecasting and optimization data to place bids on the market effectively generating revenue for the community.

Based on the previous definition, the overall inputs and outputs required for an EC acting as an Aggregator are defined in Table 2.

Table 2 Trading sub-services targeting the aggregator.

Trading sub-service - Aggregator [1]		
Input Attribute	Output Attribute	Notes
marketId EnergyCommunity Flexibility Output Attributes biddingPriceUp biddingPriceDown	clearingUp (kW) clearingDown (kW) clearingPriceUp clearingPriceDown	*[1] Information exchanged with flexibility markets when the EC acts as an Aggregator.*

Independent Aggregator. The Independent Aggregator functionality represents the community's engagement with external independent aggregators. Here, the community uses a third-party aggregator to represent its interests in the flexibility markets. This may be done to access markets that are not directly accessible to the community or to benefit from the expertise and market presence of established aggregators. The service manages the exchange of energy and information, ensuring that the community's flexibility is accurately represented and that the transactions align with the community's operational objectives and market opportunities.

Therefore, the overall required inputs and outputs for the interactions with an independent aggregator are defined in Table 3.

Table 3 Trading sub-services targeting the independent aggregator.

Trading sub-service - Independent Aggregator [1]		
Input Attribute	Output Attribute	Notes
aggregatorId EnergyCommunity Flexibility Output Attributes	activationUp (kW) activationDown (kW) compensationPriceUp compensationPriceDown	*[1] Information exchanged with flexibility markets when the EC is using an independent aggregator.*

Here, the independent aggregators will gather all the economic value of the service provided to the system, therefore a compensation mechanism (via a contract) needs to be defined between the Energy Community and/or Energy Community Members and the Independent Agregator to share the profits generated, thus output attributes compensationPriceUp and compensationPriceDown are defined.

Finally, the independent aggregator will also have a built-in trading sub-service to interact with the balancing markets.

4.3.3 Data Management Service

This service manages all the energy data that are handled by the energy management platforms. It is responsible to assure data flow from field devices and legacy systems to all the subsystems following the standard protocols. It is also responsible for the curation, management, maintenance, and storage. For

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instance, this service is responsible for input and registration functions, correct data flow, data retrieval and summarisation, and data storage as well as visualisation.

4.3.4 Gamification Services

A notable objective of the RESCHOOL project is to effectively harness the power of gamification in the realm of energy saving and management. Digital games are often viewed as learning machines, and often recognised as interactive sources of learning. With recent developments in computer hardware, handheld hardware and general software and user centred design, serious games (games made for " a primary purpose other than pure entertainment") have emerged as a valid tool for education, medical purposes or as a tool for behavioural change. Two noteworthy aspects of serious game's strengths that are frequently overlooked is the ability to engage the users and promote soft skills. In the context of RESCHOOL's aims, engagement is a very important metric, as the topic of energy management is a very long term one, and behavioural change needs time to develop.

4.3.4.1 Importance of Engagement

Engagement in serious games related to energy management and sustainability is vital because it directly influences the extent to which players absorb and apply the game's lessons in real life. A highly engaging game captivates the user's attention, making the educational content more impactful and memorable. This heightened level of involvement facilitates deeper understanding and retention of concepts related to energy conservation and sustainable practices. More importantly, when players are fully engaged, they are more likely to translate the behaviours and strategies learned in the game into their daily lives, leading to actual changes in energy consumption and more sustainable living habits. Through immersive and interactive experiences, such games not only educate users about energy management but also empower them to make informed and responsible decisions, contributing to broader environmental benefits.

Incorporating social elements into serious games aimed at energy management and sustainability significantly enhances user engagement and learning outcomes. When players interact with others, whether through competition, collaboration, or communication, they are more likely to be engaged and motivated. This increased engagement is crucial in a context like energy management and sustainability, which can be complex and sometimes abstract for individuals to grasp.

4.3.4.2 Social Elements and Soft Skills

Social interactions in the game environment can mirror real-life social dynamics, making the learning experience more relatable and impactful. For example, players can learn about the effects of their energy consumption choices not only on their immediate environment but also in a broader social context. They can see how their actions impact others and vice versa, fostering a deeper understanding of the interconnected nature of sustainability issues.

Moreover, soft skills such as communication, teamwork, and problem-solving are essential in the real world for promoting and implementing sustainable practices. A game that encourages players to develop these skills through social interaction can have a lasting impact beyond the virtual world. Players can transfer these skills to their daily lives, becoming more effective in managing their household energy use and advocating for sustainability in their communities.

By integrating social elements, the game can also leverage the power of social influence and learning. Players can learn from each other, share strategies, and collectively evolve their understanding of energy management and sustainability. This communal learning aspect can lead to a more profound and widespread change in attitudes and behaviours regarding sustainable living.

4.3.4.3 Methodology Overview

In the realm of digital innovation for environmental sustainability, our project introduces serious games aimed at enhancing energy management and promoting sustainable practices within households. Grounded in the methodology of co-design, this initiative engages users as active participants in the game's development process, ensuring the final product resonates with their real-life experiences and needs.

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The game simulates a household environment where players make decisions impacting their energy consumption. Emphasising an iterative design cycle, the project evolves through continuous feedback loops, where each version is rigorously tested and refined based on user input.

This approach not only improves the game's effectiveness in teaching sustainable practices but also fosters a sense of ownership and responsibility among users, making them more likely to apply these practices in their daily lives. By blending the engaging nature of gaming with practical sustainability education, this project aspires to cultivate eco-conscious behaviours in a way that is both informative and enjoyable.

4.3.4.4 Contribution of Partners

The gamification service uses the energy data to support decision making and interaction by establishing competitive and rewarding activities inside the energy community.

Resourcefully

- *Current Status*: Predominantly an energy dashboard, lacking traditional gamification elements.
- *Features*: Provides forecasting services and peak shaving.
- *Future Prospects:* Introduction of badges and leader boards to add a gamification layer.
- *Unique Aspect*: Although currently not gamified, the potential addition of badges and leader boards can create a competitive and motivational environment for energy conservation.

Utrecht University

- *Comprehensive Gamification*: Integrates both forecasting services and peak shaving, along with Demand Side Management (DSM).
- *Engagement Techniques*: Features a unique storyline and narrative, offering personalization or customization options to users. A dashboard is also included.
- *Gamification Edge*: The storyline and narrative approach, combined with personalization, can significantly enhance user engagement by creating a more immersive and relatable experience.

Local Life

- *Community-Focused Approach*: Focuses on cooperative visualisation of user energy labels/usage.
- *Social Engagement*: Facilitates communication between players, fostering cooperation and advice sharing within and across communities.
- *Technological Feature*: Includes predictive forecasting, like the other two but with a stronger emphasis on community engagement and social interaction.
- *Unique Selling Point*: The social aspect of energy conservation, allowing for communal learning and support, which can be particularly effective in building sustainable habits.

Comparison of the Contributions

We compare the different aspects of gamification elements in the three RESCHOOL projects: Resourcefully, Utrecht University, and Local Life.

- *Technological Overlap*: All three incorporate predictive forecasting and energy management tools like Peak Shaving. UU Game as well as Resourcefully's prototype are web-based, whilst Local life's application is a standalone mobile application.

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- *Gamification Divergence*: Resourcefully is in the earlier stage of gamification (expressing interest in personalization/user customization), Utrecht University leverages narrative and customization, and Local Life emphasises social engagement.
- *User Engagement Strategy*: Resourcefully is more traditional with a focus on competition (badges/leader boards), Utrecht University is story-driven for a personalised experience, and Local Life is community-centric, enhancing cooperation and communication.
- *Target Audience Appeal*: Resourcefully might appeal to those motivated by competition, Utrecht University to those who enjoy a narrative-driven approach, and Local Life to users who value community engagement and social interaction.

This comparison highlights the distinct approaches each member takes to gamification, catering to a diverse range of user preferences and engagement styles within the RESCHOOL project. Figure 10 is a Venn diagram illustrating the overlap and unique aspects of gamification elements in the three PRESCHOOL project members: Resourcefully (Amsterdam Pilot), Utrecht University, and Local Life.

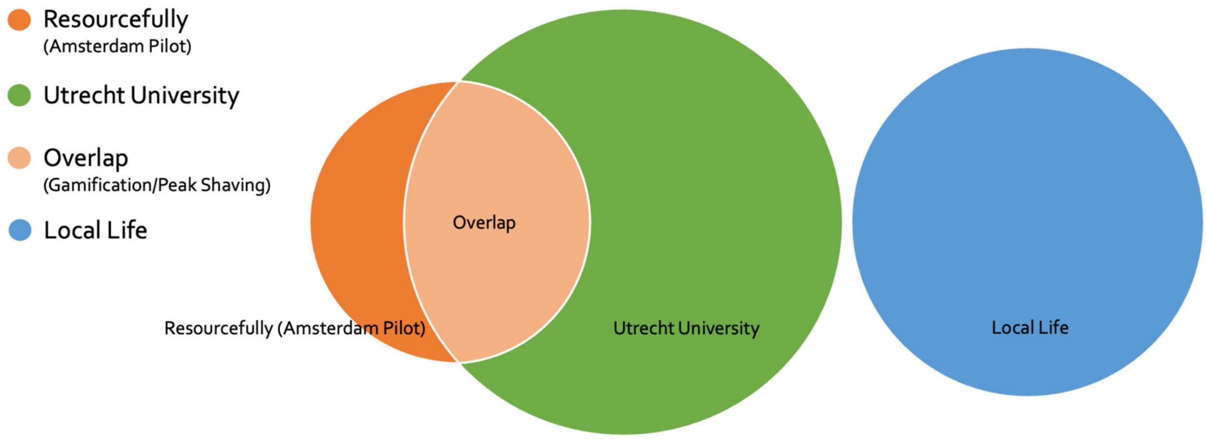

Figure 10 Overlap and unique aspects of gamification elements in the three PRESCHOOL project.

The unique elements for each project are shown in the non-overlapping sections of their respective circles. The overlapping areas indicate common elements shared between the projects. It's important to note that Resourcefully currently does not have any real gamification features, but they are considering adding badges or leader boards in the future, as indicated in the legend. This visual representation helps in understanding where the projects overlap and where there are gaps in terms of gamification features.

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5 RESCHOOL Energy Management Platforms

In this section, we describe the means that enable the implementation and deployment of the energy management platforms. Particularly, each pilot details its targeted BUCs and HLUCs, requirements, energy data gathering process, data flow and interaction with third parties, services of the energy management platform, and solution architecture.

5.1 Stockholm Pilot

The Swedish pilot centers on the Energy Community in Hammarby Sjöstad and is led by ElectriCITY Innovation. It actively involves citizens in the energy transition, promoting the generation, sharing, and storage of renewable energy. The objective is to realise environmental, economic, and social benefits through increased production and consumption of renewable energy at the community level. Additionally, the initiative seeks to optimise energy efficiency, reduce overall consumption, lower energy costs, and establish a replicable model for energy communities, both nationally and internationally. The Energy Community board consists of citizen representatives from housing associations in Hammarby Sjöstad. Currently, 9 housing associations are members of the community which corresponds to approximately 900 households. The main elements and assets available are PVs, heat pumps, EVs and batteries. Additional housing associations are interested in joining the energy community and several are considering participation in joint procurements of PVs and batteries.

Based on the primary objective that the Swedish Pilot aims to accomplish, Table 4 below shows the HLUCs and BUCs to which the pilot is subscribed, outlining the essential requirements for the solution to be implemented.

Table 4 Swedish Pilot subscription to BUCs and HLUCs.

BUC Title	BUC Objective	HLUC	HLUC Title
Energy management (intra community)	Valorisation of energy management strategies at community level	HLUC0	Energy monitoring
		HLUC1	Energy balance and self-sufficiency
		HLUC2	Optimal management of energy assets in energy communities with PV generation
		HLUC5	Energy hubs and sector coupling
Community as flexibility provider	Assess the capacity of energy communities to provide flexibility and its potential to participate in the flexibility value chain	HLUC3	Automated participation of energy communities in energy markets
		HLUC4	DSO interaction: Avoidance of congestions at secondary substations
		HLUC5	Energy hubs and sector coupling
Sizing and organisation of energy communities	Define business models to guarantee economic sustainability of the energy community and establish a	HLUC11	Adaptive communities: reacting to evolution of markets, regulations and contexts
		HLUC9	Interactive communication and collaborative participation

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	reference framework in terms of energy managed and/or participants involved.		oriented to foster joint initiatives and investments.

The following section outlines the specific requirements (along with their corresponding objectives) set for the Swedish Pilot. These specifications will form the groundwork for shaping the platform architecture.

5.1.1 Requirements

Requirements/desirable functionalities and services in the energy management platform:

1. *Access to (Sub)metering and Control Systems*:
   Access to all the (sub)metering (smart meters, PV generation, meters, etc.) and control systems (loads, BEMS, etc.) available through the Energy management system (EMS).

2. *Integration of EMS with Forecasting Tools and Historical Data Set*s:
   Integrate the EMS with forecasting tools and algorithms, providing access to historical data sets for informed decision-making and proactive energy management. Incorporate weather forecasting data from providers to enhance the accuracy of energy consumption predictions.

3. *Comprehensive Architecture:*
   Design a clear and comprehensive architecture for the energy community, with clean structure, and featuring well-defined interfaces for third parties, ensuring collaboration and data exchange.

4. *Efficient Consent Mechanisms:*
   Integrate mechanisms for obtaining consents efficiently, promoting compliance with data privacy regulations and encouraging active participation from energy community members.

5. *User-Friendly Interface for Engagement:*
   Develop a user-friendly EMP to engage and encourage ongoing participation from energy community members.
6. *Visualizations for Energy Efficiency Improvement:*
   The tool should facilitate energy efficiency improvements in members' properties with the objective of reducing primary energy levels, primarily targeting 75 kWh/m2 of heated area, but striving for lower values whenever possible. This information is derived from energy declarations, which, in turn, are based on accumulated and compiled data about energy consumption in the buildings.

7. *Monthly Primary Energy Visualizations:*
   Provide visualisations of primary energy numbers on a monthly basis to allow members to continually monitor the outcomes of their efficiency efforts rather than on an annual basis.

8. *Property Comparison Feature:*
   Enable comparisons between primary energy numbers and energy consumption among different properties to inspire and provide exemplary cases among members.

9. *Detailed Property Information Visualization:*
   Ensure detailed visualizations of basic property information, unique conditions, manually calculated data, templates, and more within the EMP for informed decision-making.

5.1.2 Data Gathering and Flow

The Energy Community in Hammarby Sjöstad aims to establish solutions in the properties to enable energy sharing and related services and utilities for the benefit of residents and other tenants, as well as the overall

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digitization of its own operations. Based on local conditions, the energy community intends, together with partners, to build an ecosystem of digital services that create entirely new opportunities for citizens and organisations operating within the city district.

Figure 11 shows the data flow. The data will be gathered from the housing associations that are members of the Energy Community. The data gathering will be performed by the company Iquest (https://iquest.se/). Detailed data, at minute and second-level granularity, will be collected in a larger database on the BRIKKS platform (https://www.brikks.online/), with one account or smaller database per housing association (Brf). This data will continuously flow from members' properties to the BRIKKS platform.

The data will be standardised and 'tagged' for identification of the specific information it pertains to. However, no further processing will take place. In BRIKKS, essentially raw data will be stored, without aggregations, summations, or compilations. This means that when data is to be retrieved from BRIKKS, the individual/organisation/service provider retrieving it must process the data for their own purposes.

LocalLife will retrieve data from BRIKKS and transfer it to the LocalLife-app. The raw data must be processed by LocalLife to generate the information to be displayed in the app. In other words, Locallife serves as a "window" for the Energy Community to visualise energy data, enabling them to view or access any information gathered in BRIKKS through the LocalLife-app.

The energy community will have access to aggregator services. Recap Power, functioning as an aggregator, aims to supply EMS capable of optimising the utilisation of flexible energy resources. This optimization will support local capacity requirements, manage "peak-shaving," enhance spot price optimization, and create income streams derived from the flexibility and ancillary services extended to local energy companies (DSOs) as well as Svenska Kraftnät's (SvK) markets.

Results of what has occurred, been achieved, earned, summaries etc, should be reported to the energy community and its members through the LocalLife-app. These outcomes should further be stored in BRIKKS, ensuring data is stored at member (property) level and Energy Community level, all gathered on the same platform.

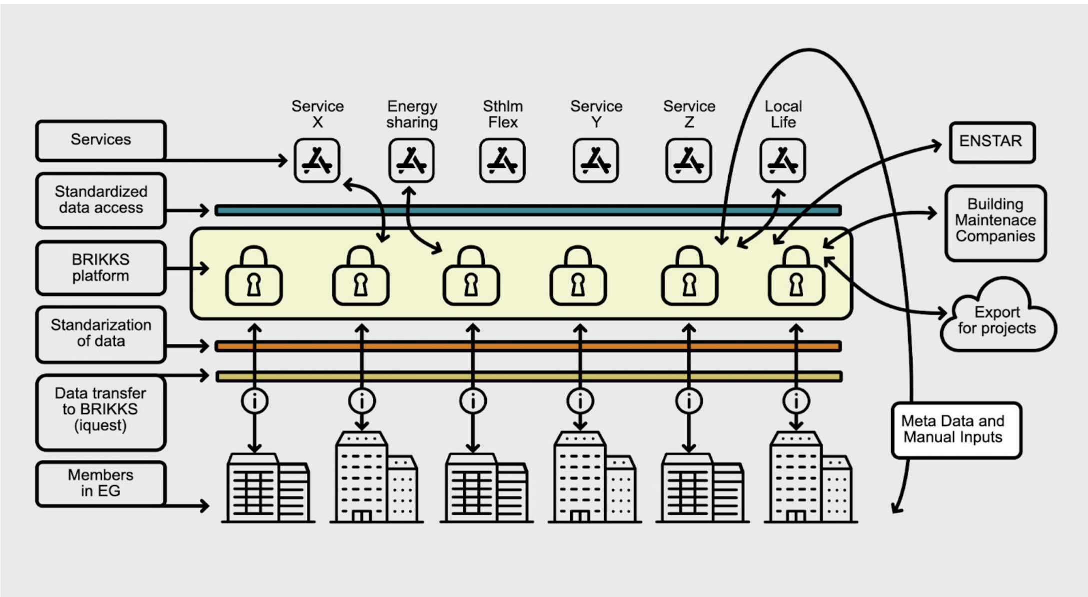

Figure 11 Visualization of the data flow – Stockholm Pilot.

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5.1.3 Services

Incorporating the requirements from above, the LocalLife application will incorporate forecasting, optimisation, flexibility management, and data management services. These services are presented in Table 5 and will be implemented by LocalLife, ElectriCITY, and RISE.

Table 5 Services required for the Swedish Pilot implementation.

Service	Objective	Description
Forecasting	Weather data and solar irradiance	The weather and solar irradiance data is forecasted for each weather station.
	PV production	The PV production is forecasted for each system. Based on the PV system parameterization and location.
	Energy Demand Forecasting	The energy demand for each household is forecasted. For the member, historical consumption data are required.
Optimization	Self-consumption maximisation	The optimal strategy regarding energy sharing, surplus management and optimal control of the assets is computed in this service for implicit flexibility purposes. Input data from the assets, community configuration and business model are required for this service.
	Energy Assets Control Optimisation	The optimal strategy regarding optimal control of the individual flexible assets of households is computed and provided by this service combined with automated personalised notifications for individual flexibility purposes.
Flexibility Management	Flexibility forecast	To optimally manage and control the community energy assets, it is required the upper and lower bound capable for each asset to modify the power (consumption or generation). Asset parametrization and real time data, generation and demand forecasts and weather forecasts are required for this service.
	Energy Markets & optimal supply strategy	The available flexibility will be exchanged to the markets. This is going to be based on the market's inputs and requirements. So, the optimal supply strategy needs to be implemented. The results obtained must comply with the market's requirements.
Data Management	Input and Registration Functions	These features will encompass the entry of basic housing association details, such as the association's name, address, heated area, number of apartments, living area, and any other pertinent information. Additionally, it will allow the input of historical monthly data, ideally spanning three years but at a minimum, covering the previous 12 months. This data will be categorised based on the components utilised in energy declaration calculations. Furthermore, the system will enable the registration of data for the previous month, a task that should be completed within the first week of each new month.

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	Data Retrieval and Summarization	The tool will feature functions for retrieving detailed data from BRIKKS and summarising it into monthly data, potentially offering daily and weekly summaries over time. This may include data such as PV production and outside temperature.
	Energy Performance Calculation	Implement a calculation function for energy performance at both the property and energy community levels. Results and summaries generated by LocalLife will be uploaded to the BRIKKS platform, ensuring that data is stored at both the member (property) level and the community level on the same platform. This algorithm will be based on measured data, and assumptions based on meta-data about the building.
	Data Visualization	Visualise data stored in BRIKKS, including primary energy figures, energy declarations, property comparisons, aggregation of properties/members, electricity consumption per consumption area, purchased and sold electricity, solar energy production, electricity stored in batteries, and more.

5.1.4 Solution Architecture

The BRIKKS platform is intended to homogenise data access to service providers, and in a future state, to facilitate energy transactions and billing between buildings. So, it is the service adapter which relates to the business model. Each service that is purchased by a building owner, will pay a fee to the service adapter (BRIKKS), that is shared with the energy community managers. This platform builds on back-end functionality from the broadband infrastructure of the 2000s that allowed various service providers to sell broadband services on the same physical broadband fibre and digital backend solution.

AI/ML services for forecasting and optimisation as well as analytics services will be implemented by RISE and integrated in the energy management platform (see Figure 12). Data and user management services will be implemented by LocalLife. Flexibility management will be collaboratively implemented by BBEN, LocalLife, RISE and ElectriCITY.

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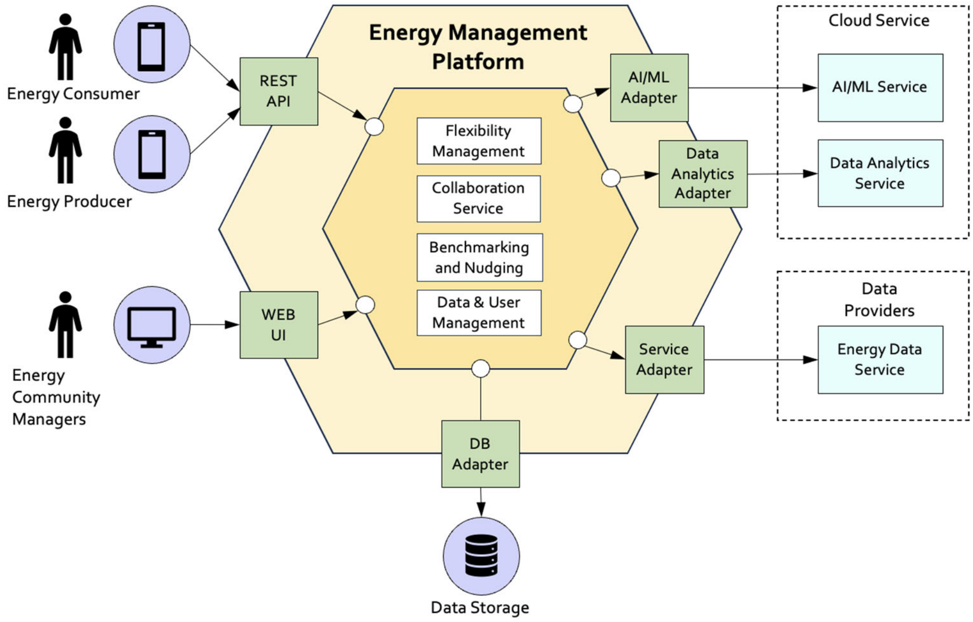

Figure 12 The RESCHOOL SE Pilot Adapted Energy Management Platform Architecture.

5.2 Amsterdam Pilot

The Amsterdam Pilot is based upon maximising collective self-consumption of the district Sporenburg, to remain within the capacity of the district transformer, avoiding congestion. It's achieved with a dual strategy of shifting energy consumption of individual households, around 500, to match periods of solar power generation, as well as limiting maximum power of high consuming shared EV charging infrastructure. As individual households are free in their choice of energy contracts, individual household net consumption still needs to safeguard the lowest energy bill for each household.

Most Dutch households currently still have contracts with only day/night tariffs, and export tariffs are legally required to be set at the same tariff as import tariffs (called 'netting arrangement'). Therefore, most households can, without too much impact, shift energy consumption. However, three trends will make individual household optimisation more important. First of all the netting arrangement will disappear, secondly more people are choosing for agile tariff contracts, and thirdly EU energy sharing legislation will allow users to share energy. This pilot will be prepared and designed to enable this more complex optimisation at individual household level in parallel to the district level optimisation.

Therefore, based on the main goals that the Amsterdam Pilot wants to achieve, the HLUCs0-4 and HLUC10, related to BUC1, BUC2 are included and detailed out in the next paragraphs (see Table 6 for an overview).

Table 6 Amsterdam Pilot subscription to BUCs and HLUCs.

BUC Title	BUC Objective	HLUC	HLUC Title
Energy management (intra community)	Valorisation of energy management strategies at community level	HLUC0	Energy monitoring
		HLUC1	Energy balance and self-sufficiency.
		HLUC2	Optimal management of energy assets in energy communities with PV generation;
Community as flexibility	Assess the capacity of energy communities	HLUC3	Automated participation of energy communities in energy

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provider	to provide flexibility and its potential to participate in the flexibility value chain		markets;
		HLUC4	DSO interaction: Avoidance of congestions at secondary substations;
		HLUC10	Benchmarking and gamification;

5.2.1 Requirements

The Amsterdam pilot addresses the following requirements, linked to the HLUCs (see figure x):

1. HLUC1: **Monitoring and forecasting power consumption at district** level and monitoring individual household actions to prevent network congestion, with the purpose of requesting individual household preventive actions and distributing financial rewards to households when meeting targets.
2. HLUC2/HLUC4: **Optimise self-consumption within the district**, to avoid congestion by shifting individual household energy consumption (EV chargers, Heatpumps, other heating devices) as well as limiting power consumption of shared charging infrastructure.
3. HLUC10: **Challenge individual households** to participate in behaviour change, shifting consumption to off-peak moments, including an incentive scheme which is linked to achieved network savings (postponed investments).

Secondly it is prepared for individual optimisation enabled by future agile import/export tariffs and energy sharing:

4. HLUC1: **Monitoring and forecasting individual** power production, power consumption, and household import/export tariffs.
5. HLUC2/HLUc3: **Optimise self-consumption and costs at household** level considering both agile import and export tariffs.
6. HLUC2/HLUc3: **Participate in energy sharing** by linking two or more users and apply self-consumption optimisation on that virtual group.

We will address and translate these 6 HLUCs requirements into the functional requirements in the following paragraphs.

5.2.1.1 Monitoring and forecasting power consumption at district level

Power production and consumption is measured at individual household level (per second) and aggregated to district level (per minute). At district level a split is made to separate consumption and production. For production (solar), the solar production is forecasted as well as the consumption. Adding these two is leading to a forecasted net power at district level.

At individual household level, a categorisation is made deriving the following: installed solar capacity, presence and brand of EV, presence, and brand of heat pump. Categorisation is done by individual user when registering as participant. Solar capacity is additionally estimated on analysis of live minute data to correct installed capacity.

5.2.1.2 Optimise self-consumption within the district

Based on forecasted net power consumption at district level and thresholds (a percentage of the transformer maximum capacity), households are given insight in their individual power consumption (seconds) as well as critical periods for the district net power consumption (minutes). They are rewarded to structurally shift consumption outside these critical periods.

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In addition, triggers are created if district power is expected to cross a critical threshold in the next hour. These are translated to individual actionable challenges with a maximum power consumption target and sent to individual households. If targets are met, an additional reward is handed out.

If monitored district power is still reaching a second higher threshold the maximum charge power of shared EV charging systems is reduced.

5.2.1.3 Challenge individual households

The personalised actionable challenges include an individual power target based on a percentage of the currently forecasted individual consumption as well as household characteristics. The power target is shared with each individual household, combined with actionable tips. When accepting a challenge and meeting the power target, challenge points are awarded to the individual user.

Individual households additionally have insights into past and future critical time windows (regarding district power consumption). Structurally shifting their net consumption outside of these time windows also is rewarded, with peak points.

On a yearly basis the total number of challenge and peak points is forecasted and monitored and includes an exchange rate. As the savings on network infrastructure is monetised, a budget is allocated and translated in this exchange rate (allocated budget divided by allocated points). The reward is handed out on a yearly basis.

5.2.1.4 Monitoring and forecasting at individual household level

Individual net power consumption is already monitored (second data) and translated to a forecasted net power. This reference is used already to define target powers for the challenges. To enable maximisation of individual self-consumption, the forecasting of production and consumption can be enabled as input for individual optimisation.

Individual agile tariffs can be monitored, including 24 hours ahead tariffs, to enable individual optimisation considering export and import tariffs.

5.2.1.5 Optimise self-consumption and costs at individual household level

An optimisation service at individual household is considering forecasted production, forecasted consumption and agile import/export tariffs. For EVs, energy schedules can be dynamically defined to safeguard minimum state of charge at specific times. Latter is required to warrant availability of EVs for its user and expected trip distance. Targeting minimum costs, the optimisation first of all filters or adjust the challenges as set by district optimisation to prevent individual energy cost increase. Secondly it creates additional triggers to users to start to postpone or start their energy consumption.

5.2.1.6 Participate in energy sharing

Once energy sharing is regulated in The Netherlands, users can share energy once they contractually agree. They need to have the same energy provider to facilitate energy sharing. Energy sharing will be regulated per 15-minute time interval. Based on matching two or more users a virtual group of users is created. In that scenario they can in couples agree to start sharing. The optimisation as described in 5.2.1.6 will be applied at group level.

5.2.2 Data Gathering and Flow

Data gathering for the Amsterdam pilot is limited to the following, as all other data are derived from it:

1. Individual net power consumption of households. Locally with a second interval and at district level with a minute interval.
2. Net power consumption at transformer level.
3. Solar power forecast.
4. Home characteristics e.g. installed solar capacity, EV charger, heat pump.

Individual net power consumption is collected via a dongle connected to the household smart meter and connected to the homeowners local WIFI, via the mobile app. Once connected the user will get insight in his net

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power consumption with one second interval, as long as the app is linked to the same WIFI. The meter data is connected to an MQTT broker, connected to the Energy Management Platform, sending data per minute. Forecast services, extend that date with forecasted values for the net power per household.

The transformers are connected via HTTP/REST API to the Energy Management Platform and sharing the total net power. Through a combination of solar power forecasts and time series forecasting on the consumption power, a forecast is created on the net power consumption for the transformer. The net power forecast is compared to the limit. Once reaching 90% of the limit, the challenges are triggered.

Weather forecast and solar power forecast services are retrieved via solar forecast cloud service.

Home characteristics are requested via user input in the mobile app. However, installed solar power, presence of chargers and heat pumps, and the actual use of the latter are retrieved from a data analytics model in the Energy Management Platform.

5.2.3 Services

Based on all the services defined in sections 3.3.1 and 4.3 as well as the requirements described in 5.2.1, the ones needed can be seen in the following Table 7.

Table 7 Services required for the Amsterdam Pilot implementation.

Service	Objective	Description
Forecasting	Weather data and solar irradiance	The weather and solar irradiance data is forecasted for each weather station. The results obtained must comply with (minimum): - 24 hours day ahead - 15 minutes resolution
	PV production	The solar power production is forecasted for each system. Based on the PV system parameterization and location. The results obtained must comply with (minimum): - 24 hours day ahead - 15 minutes resolution
	Household power consumption	The energy demand for each household is forecasted. For the member, historical consumption data are required. The results obtained must comply with (minimum): - 24 hours day ahead - 15 minutes granularity
	District net power consumption	The net energy demand or supply for the aggregated households is forecasted to predict future congestion moments. Required are the forecasts for both PV production, household consumption power and the historical district net power consumption. The results obtained must comply with (minimum): - 24 hours day ahead - 15 minutes granularity
Optimization	Household and district self-consumption maximization	The optimal strategy regarding optimal control of the individual flexible assets of households are visualised in this service combined with automated personalised notifications for individual flexibility purposes (energy bill savings and additional network awards). Input from household net power consumption is required. The results

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		obtained must comply with (minimum): - 24 hours day ahead - 1 minutes granularity
	District peak power restriction	The optimal strategy regarding optimal control of the shared flexible assets of the district are computed in this service for flexibility purposes (limit net grid power). Input from District net power consumption is required. The results obtained must comply with (minimum): - 24 hours day ahead - 15 minutes granularity
Data Management	Energy data management	All the pricing and energy data are handled by this service. This service will ensure the correct data flow.

5.2.4 Solution Architecture

The OpenRemote open-source platform is applied in the Amsterdam pilot (see Figure 13). It targets to include the required functionality as described in 5.2.1.1 - 5.2.1.6. It will include both the required asset types and services as described in 5.2.3. The OpenRemote Community EMS is extended to be the key deliverable of D3.2: a 100% open-source community EMS. Therefore, we refer to the report for task D3.2 for more details.

The key challenges which will be addressed, tested, and validated in the Amsterdam pilot relate to the different layers of optimisation (household and district), the forecasting at district level, and the gamification.

We foresee one ultimate: the amount of peak reduction we can achieve. This is depending on two other factors: the number of people who sign up (we target at least 100 out of 500 households), and the average reduction of individual peaks we can achieve.

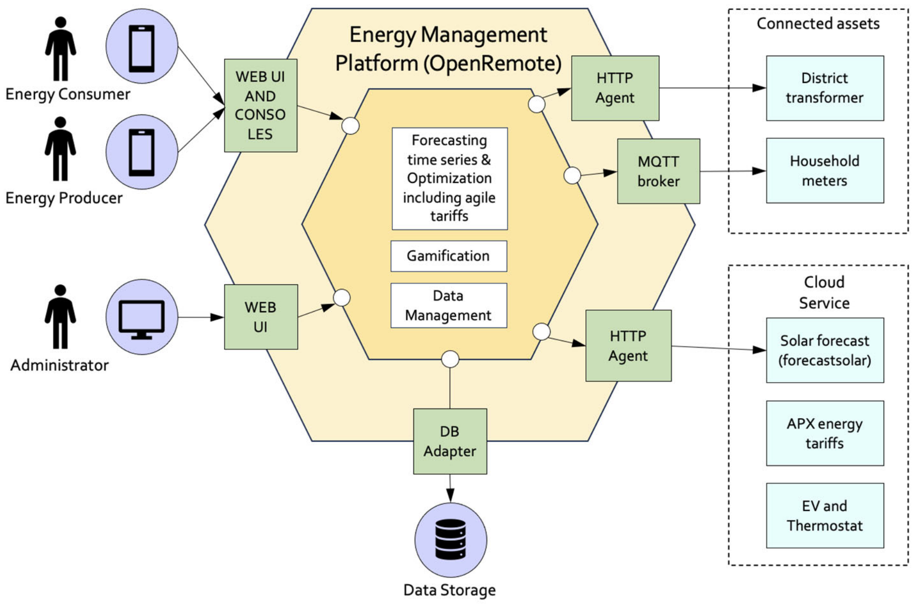

Figure 13 The RESCHOOL Amsterdam Pilot Adapted Energy Management Platform Architecture as implemented with the 100% open source OpenRemote Community EMS. All parts are included in the OpenRemote platform with the exception of the cloud services.

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5.3 Girona Pilot

Girona Pilot is based upon a scheme of collective self-consumption, but with the main objective to add additional services to the community with the goal of attracting new consumers by offering flexibility services. Those services are going to allow the members to have a more active role within the community and with the system, thus enabling the creation of new savings (maximizing self-consumption) and extra revenue streams (offering flexibility to the balancing markets and to the DSO).

This appealing approach to the end consumer, has the objective of increasing the value that an energy community can offer to its members. Thus, empowering the end consumers and making them a key element within the electric system.

The main elements and flexible assets that are going to be available for the energy communities in the Girona pilot are PV, EV chargers and Batteries, as well as consumers. Energy data will be gathered using the already existing Sentinel Solar energy platform, which is fed from Wibees (metering devices with real-time data, 1 minute granularity), Datadis (consumption data, hourly granularity) and direct connection to the APIs of the solar inverters. Then, the energy data is going to be integrated into the Bamboo Energy's platform with the objective of monitoring, forecasting and optimally managing the energy assets.

Based on the main goal that the Girona Pilot wants to achieve, the following Table 8 shows to which HLUCs and BUC the pilot is subscribed, thus defining the basic requirements for the solution to be implemented.

Table 8 Girona Pilot subscription to BUCs and HLUCs.

BUC Title	BUC Objective	HLUC	HLUC Title
Energy management (intra community)	Valorisation of energy management strategies at community level	HLUC0	Energy monitoring
		HLUC1	Energy balance and self-sufficiency
		HLUC2	Optimal management of energy assets in energy communities with PV generation
Community as flexibility provider	Assess the capacity of energy communities to provide flexibility and its potential to participate in the flexibility value chain	HLUC3	Automated participation of energy communities in energy markets
		HLUC4	DSO interaction: Avoidance of congestions at secondary substations
Sizing and organisation of energy communities	Define business models to guarantee economic sustainability of the energy community and establish a reference framework in terms of energy managed and/or participants involved.	HLUC11	Adaptive communities: reacting to evolution of markets, regulations and contexts

In the following section, the specific requirements (and objectives within them) are defined for the Girona Pilot. This will establish the basis for the platform architecture.

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5.3.1 Requirements

Considering the HLUCs subscribed, the Girona pilot has the plan to implement and accomplish the following requirements[6]:

1. Monitoring of energy consumed by assets and visualisation of consumption forecast and flexibility estimation.
2. Management of self-consumption surpluses among the members.
3. Demand side flexibility to provide balancing services to the system.
4. Demand side flexibility to manage congestion in the distribution network.

5.3.1.1 Monitoring of energy consumed by assets and visualisation of consumption forecast and flexibility estimation.

The first approach consists of accessing the metering and sub-metering devices integrated within the community. This action aims to obtain all possible energy data at individual and community level. Mainly, the integrated devices for data collection are Wibeees, PV inverters and consumer energy meters. Then, all of the information and energy data gathered is stored in Sentinel Solar platform. Finally, the energy information from the data collection devices and/or from the Sentinel Solar platform will be integrated into the Bamboo platform (see section 0 for further details). Also, if the energy prices are available and it is required, energy costs could be shown.

Based on the information gathered, machine learning algorithms are going to be implemented with the goal of forecasting the energy production of the PVs and the demand for the members of the community and all the assets. This information is going to be used for visualisation and flexibility purposes, allowing the optimization models to optimally maximise self-sufficiency and define the right scheduling of each asset.

Ultimately, it is also required the visualisation of the available flexibility for the community as a whole, but also for the member and asset. Therefore, there is going to be a visualisation section just for flexibility purposes, where the available flexibility and the flexibility activations are going to be shown (allowing the monitorization).

This requirement is set with the objective (see

Table 9) of offering a tool to the Energy Community Members (M) and the Energy Community Managers (ECM) in the Girona Pilot which allows them to access the energy consumed, produced and forecasted and to visualize the available and activated flexibility. Therefore, HLUC0 and HLUC1 are going to be considered and implemented (HLUC1 only partially and with the specific objective of accounting).

Table 9 Girona Pilot objective for the requirement: Energy monitoring and forecasting and flexibility visualisation.

Objective	HLUC associated	Justification
Monitoring energy consumed	HLUC0, HLUC1	Monitoring power/energy consumed and generated and the respective energy costs.
Monitoring energy forecasted	HLUC0	The results obtained from the forecasting service will be used for monitoring and visualisation purposes.
Flexibility visualisation	HLUC0	The results obtained from the optimization and flexibility management services will be used for monitoring and visualisation purposes.

[6] Requirement 3 set by the Girona pilot are on a testing basis, since there is not enough demand aggregated within the community to participate in balancing markets and there is no definition yet of the demand aggregator figure in Spain. Also, the only way an EC could get involved in balancing markets based on current regulation is through the utility company or if the EC itself becomes a utility company. Finally, requirement 4 is subject to the involvement of the local DSO since no legislation regarding local markets is defined in Spain.

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5.3.1.2 Management of self-consumption surpluses among the members

This requirement is based upon the current legal framework set in RD 244/2019 that enables self-consumption in Spain. This approach is set with the goal in mind of allowing the community to sell the energy surplus generated by its resources to the market and to analyse the optimal strategy regarding the energy surplus management. Therefore, HLUC1 and HLUC2 are going to be considered and implemented (see Table 10), thus allowing the community to optimally manage the usage of the shared PV to maximize self-consumption at the lower operational cost.

Currently, each one of the four communities within the Girona Pilot only have one single PV generation facility[7] for collective self-consumption under the modality surplus with compensation (modality regulated under RD 244/2019). Where the energy surplus generated by the PV is managed by each one of the community members utility company and it is compensated at the price signed in the contract between the two parts (utility and consumer). Alternatively, the energy community could sell the energy surplus generated to the market in a single operation as the owner of the facility if the self-consumption modality is changed to surplus without compensation. This new approach is going to be analysed to see if the current compensation mechanism established with-in the community can be improved.

Then, the second approach is going to analyse the energy production sharing coefficients. Where an hourly approach is going to be considered instead of the static as they are now. This may increase self-consumption within the community members, thus reducing the energy surpluses and improving self-sufficiency.

Next, it is going to be analysed the optimal strategy regarding the energy exchanges between the different community members. Where, the energy surplus by any user of the community can be assigned to another user, to an EV charger and/or sent to a battery (seeking to maximize self-sufficiency) instead of being kept by the retailer or sold to the market. This approach could enable the community to use privately owned assets for the benefit of all.

Ultimately, to integrate the previous objectives, specific optimization models are needed to be defined and implemented to optimally manage the sharing of self-consumption and the control of the assets.

Table 10 Girona Pilot objective for the requirement: management of self-consumption surpluses among the members.

Objective	HLUC associated	Justification
Improve energy surplus economic compensation due to the PV for the community.	HLUC1, HLUC2	Manage generation and energy demand to improve the operational cost of the community and optimally manage the energy surplus of the community as a whole.
Validate usage of hourly vs static energy sharing coefficients.	HLUC1, HLUC2	Optimally manage how the energy production by the PV is shared with the members to maximize self-sufficiency and reduce operational cost.
Manage energy surplus by either	HLUC1, HLUC2	Optimally manage energy surplus by using either batteries or loads to increase self-consumption and an efficient energy

[7] It is expected that during the execution of the project the already existing PV generation facilities will be expanded and/or new generation facilities could be included.

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Objective	HLUC associated	Justification
Improve energy surplus economic compensation due to the PV for the community.	HLUC1, HLUC2	Manage generation and energy demand to improve the operational cost of the community and optimally manage the energy surplus of the community as a whole.
Validate usage of hourly vs static energy sharing coefficients.	HLUC1, HLUC2	Optimally manage how the energy production by the PV is shared with the members to maximize self-sufficiency and reduce operational cost.
using community members or the battery.		management.

5.3.1.3 Demand side flexibility to provide services to the system

Demand side flexibility (DSF) is essential for providing services to the system, particularly in the context of energy communities. The focus is on estimating the potential flexibility of demand from these communities as a collective entity (see Table 11). This estimation involves analysing historical consumption data of the participants to forecast their flexibility potential and the possibility to use EV chargers and batteries for this purpose.

Key aspects include:

- *Flexibility Products for DSOs and TSOs*: The primary goal of DSF products is to optimize infrastructure investment needs, minimize asset reinforcement, enhance maintenance planning, manage unexpected network interruptions, improve supply quality, and expand network capacity for renewable generation.
- *Balance and Flexibility Services*: Operators of transmission networks use Balance Service Providers (BSPs) to maintain system security and balance generation and demand. This involves standard capacity products for the energy balancing market such as secondary and tertiary reserve.

Other aspects:

- Validating flexibility potential through real-time measurements and planned tests to adjust consumption levels.
- Simulating the provision of services in markets like tertiary or deviation markets, and analysing energy and economic benefits distribution among participants.
- Identifying regulatory, technical, and economic challenges to make DSF viable.
- Acting as a Balance Service Provider (BSP) using an EMS system (BambooEnergy platform) and market offering platforms.

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Table 11 Girona Pilot objective for the requirement: Demand side flexibility to provide services to the system.

Objective	HLUC associated	Justification
Optimize infrastructure investment and expand network capacity for renewable generation	HLUC1	DSF is vital for facilitating energy sharing at the intra-community level, optimizing infrastructure investment needs, and supporting renewable energy integration.
Balance generation and demand	HLUC3	Identifying and designing flexibility products at the community level to be offered to the balancing markets through demand response mechanisms
Validate flexibility potential and simulate market provision services	HLUC3	Validating and testing flexibility potential in real-time is crucial to adjust consumption levels and effectively participate in tertiary or deviation markets.
Develop more granular flexibility products at the DSO level	HLUC4	More granular flexibility products at the DSO level are essential for improving operational safety and avoiding congestion in distribution grids.

5.3.1.4 Demand side flexibility actions to manage congestion in the distribution network

Managing congestion in the distribution network through DSF involves leveraging assets like batteries and the collective demand flexibility of the community. Key actions include:

- Using battery implementation or demand flexibility to alleviate network congestion, especially in high-demand scenarios.
- Engaging with local distribution networks (e.g., Electra Avellana) to understand network status and address congestion issues.

Different approaches to solve congestion encompasses:

- Predictive actions based on congestion forecasts to either supply energy from batteries or reduce community demand.
- Gathering data from distribution networks to make informed decisions on managing congestion.

These strategies aim to enhance the efficiency and reliability of the distribution network by dynamically managing demand and leveraging energy storage solutions (see Table 12).

Regulatory Considerations The pilot acknowledges that the current regulatory framework in Spain and the broader European context does not fully accommodate DSF services by Distribution System Operators (DSOs). Future regulatory changes are essential to facilitate the acquisition of flexibility services as alternatives to network expansion.

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Table 12 Girona Pilot objective for the requirement: Demand side flexibility actions to manage congestion in the distribution network.

Objective	HLUC associated	Justification
Alleviate network congestion using battery implementation or demand flexibility	HLUC4	Employing batteries and demand flexibility strategies is essential to manage high-demand scenarios and maintain network stability.
Implement predictive congestion management actions	HLUC4	Predictive actions for congestion management contribute to the collaborative effort between energy communities and DSOs in improving grid operations.
Utilize technological innovations for congestion management	HLUC11	Technological advancements in congestion management are essential for energy communities to adapt to changing market and regulatory environments.

5.3.2 Data Gathering and Flow

The Energy Communities in Girona aim to harness a range of data sources for energy management and optimization within the energy community. This involves gathering data from various devices and platforms to create a comprehensive view of energy usage, generation, market conditions, and environmental factors. These devices are mostly Wibeees and the PV inverters themselves.

Data Sources and Collection

1. **Wibeee Devices:**
    - Wibeee. Sub-metering device that gathers real-time information from an asset but can also act as a smart-metering device and get information from the energy community as a whole. This device offers an easy installation and data output via API.
2. **PV Inverters:**
    - Inverters from photovoltaic installations provide data on energy generation.
3. **EV Chargers (expected to be integrated):**
    - Chargers APIs and smart metering could be installed to provide data.
4. **Batteries (expected to be integrated):**
    - Battery inverters APIs and smart metering could be installed to provide energy data.
5. **Datadis:**
    - Collects additional metering data relevant from the energy community members.
6. **Sentinel:**
    - Aggregates energy data from various sources for a comprehensive view.
7. **Market Data:**
    - Price data from REE (balancing markets) and OMIE (spot price/FTP) are collected.
    - This information is crucial for understanding market dynamics and optimizing energy strategies.
8. **Weather Data:**
    - Acquired through API (Meteoblue)

Once all this data is collected, Bamboo Energy´s platform is employed for demand optimization, flexibility management, and understanding market operations. The processed data is then visualized through a user-friendly interface, enabling the energy community to easily understand and utilize the information.

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Process

1. **Aggregation in Sentinel Platform:**
   - The data collected from Wibeee devices, PV inverters, and Datadis is first aggregated in the Sentinel platform. This aggregation compiles and consolidates data from multiple sources, providing a comprehensive dataset that reflects the energy consumption and generation.
2. **Integration with Bamboo Energy's Platform:**
   - Bamboo Energy's platform connects to Sentinel via an API. This connection facilitates the seamless transfer of the aggregated data from Sentinel to Bamboo.
   - Simultaneously, Bamboo's platform also connects to OMIE to receive spot price data and to REE for balancing market prices. This market data is essential as it provides the economic context in which the community's energy management strategies will be deployed.
3. **Flexibility Prediction by Bamboo's Algorithms:**
   - Utilizing the data from Sentinel and the market price information from OMIE and REE, the algorithms within Bamboo's platform engage in predicting the flexibility of the community's energy assets.
   - The flexibility forecast enables the anticipation of potential energy surpluses or deficits and the identification of optimal times for energy consumption or generation.
4. **Flexibility Activation and Community Asset Management:**
   - Once the flexibility forecast is computed, Bamboo's platform sends activation signals to each asset within the community.
   - These activations are designed to leverage the predicted flexibility for financial savings based on the spot price. This implicit flexibility involves adjusting energy consumption or generation in response to market signals to optimize costs. Furthermore, flexibility activations will be implemented to simulate potential economic gains in balancing markets (explicit flexibility).
5. **Outcome and Savings Realization:**
   - The result of these activations is a more efficient energy usage pattern within the community, aligned with market conditions to maximize savings, reduce emissions and helping renewable energy integration.

5.3.3 Services

Based on all the services defined in sections 3.3.1 and 4.3 as well as the requirements described in 5.3.1, the ones needed can be seen in the following Table 13.

Table 13 Services required for the Girona Pilot implementation.

Service	Objective	Description
Forecasting	Weather data and solar irradiance	The weather and solar irradiance data is forecasted for each weather station. The results obtained must comply with (minimum): - 24 hours day ahead - 15 minutes granularity
	PV production	The PV production is forecasted for each system. Based on the PV system parameterization and location. The results obtained must comply with (minimum): - 24 hours day ahead - 15 minutes granularity
	Energy Community Member and asset power demand	The energy demand for each supply point and asset is forecasted. For the member, historical data, location and weather are required. As for the asset, historical data and parameterization are also required. The results obtained must comply with (minimum): - 24 hours day ahead - 15 minutes granularity

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Optimization	Self-consumption maximization	The optimal strategy regarding energy sharing, surplus management and optimal control of the assets is computed in this service for implicit flexibility purposes (savings). Input data from the assets, community configuration, business model and technical market characteristics are required for this service. The results obtained must comply with (minimum): - 24 hours day ahead - 15 minutes granularity
	Flexibility towards balancing markets and DSO congestions	The optimal strategy for flexibility activations towards balancing and local markets is computed in this service for explicit flexibility purposes (revenue streams). Input data from the assets, community configuration, business model and technical market characteristics are required for this service. The results obtained must comply with (minimum): - 24 hours day ahead - 15 minutes granularity
Flexibility Management	Flexibility forecast	To optimally manage and control the community energy assets, it is required the upper and lower bound capable for each asset to modify the power (consumption or generation). Asset parametrization and real time data, generation and demand forecasts and weather forecasts are required for this service. The results obtained must comply with (minimum): - 24 hours day ahead - 15 minutes granularity
	Energy Markets & optimal supply strategy	The available flexibility will be exchanged to the markets. This is going to be based on the markets inputs and requirements. So, the optimal supply strategy needs to be implemented. The results obtained must comply with the markets requirements.
	Intraday operation	Real time execution of flexibility activations (implicit or explicit).
Data Management	Energy data management	All of the pricing and energy data are handled by this service. This service will ensure the correct data flow.

5.3.4 Solution Architecture

Bamboo Energy's platform (see Figure 14) is offered to the Girona pilot with the objective of implementing the requirements set in section 5.3.1. Also, it will consider the structure of the community itself (affecting assets and data gathering and flow, defined in section 5.3.2). Finally, all the services set in section 5.3.2 will be also integrated within the EMS to manage the assets based on the requirements.

Some information will be required from third parties, such as energy data (Sentinel and Wibeee, mostly), weather data and forecasts (Meteoblue) and market data (OMIE and REE). For this, services adaptes and API will be developed and implemented to gather and exchange the required information. Also, the connectivity with edge Assets based on use cases: Edge gateway, OEMs and/or SCADAs are defined. Thus, enabling the Bamboo Platform to ensure real time controlling capabilities to the asset based on API or MQTT protocols.

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Finally, Bamboo Energy's platform will not offer within the solution a Gamification services, but a Service Adapter / API can be implemented with the objective of providing the required information to this external service provider.

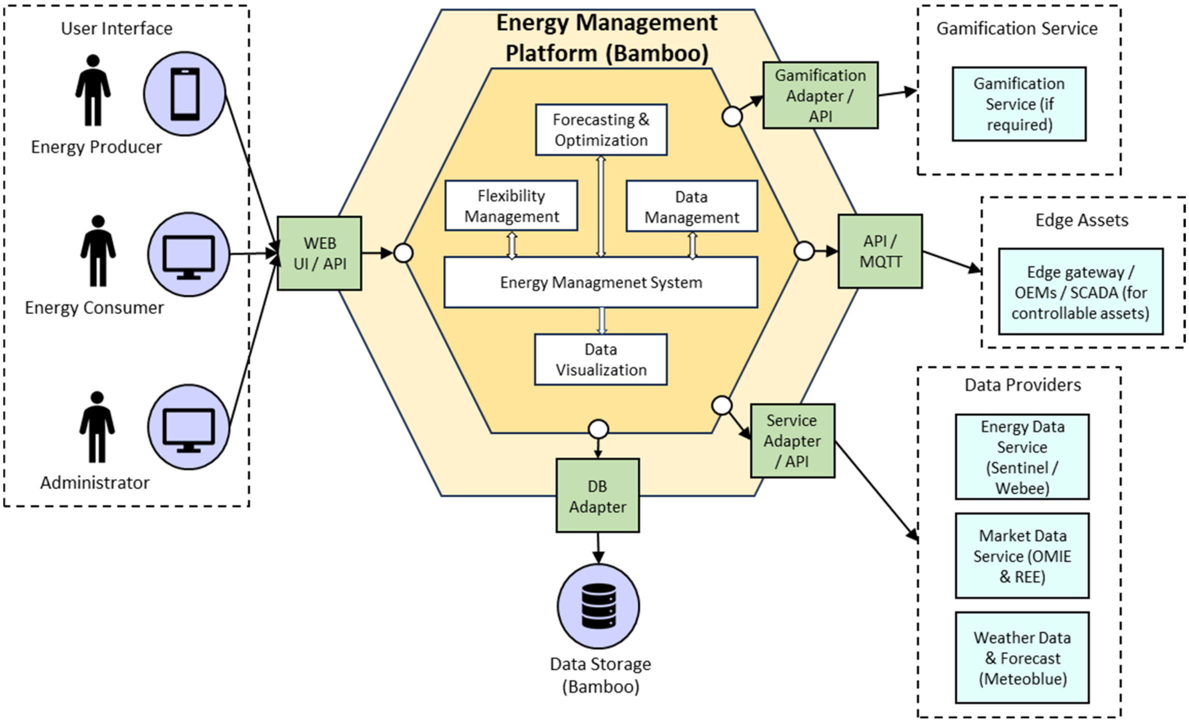

Figure 14 The RESCHOOL Girona Pilot Adapted Energy Management Platform Architecture implemented with Bamboos Energy platform for demand aggregation and flexibility.

5.4 Athens Pilot

At the core of the Athens pilot is the Collective Energy Community (CoEn). Their primary business model revolves around a 100-kW solar power plant operating under the framework of collective self-consumption facilitated through Virtual Net Metering. This solar facility is anticipated to produce 145 MWh annually, covering the energy requirements of the 45 members of the energy community. The benefits of the solar plant are extended, and a portion of the produced energy will be offered to vulnerable households, offering them access to clean and affordable energy. This is made possible by the legislation under which CoEn is established, and this business model will be one of the first applications in Greece. The produced energy for the PV plant is netted with the individual consumptions of the members at predefined time slots. CoEn's model is designed to be replicable by other energy communities and municipalities, offering a means to increase local renewable energy penetration and reduce external energy dependence, thereby contributing to regional and national energy sustainability goals.

Additionally, CoEn owns an energy storage system, a 3 kW, 10 kWh, fully controllable Li-ion battery system, which is used for educational, demonstration and research activities. As part of the EU funded project Synergies, CoEn is actively installing smart meters in its buildings to provide real-time insights into energy consumption patterns, allowing household and enterprise owners to make informed decisions to reduce energy usage, lower costs, and contribute to overall energy efficiency. To deepen the understanding of energy consumption and promote sustainable practices, CoEn will deploy a number of (around 10) advanced IoT solutions to test demand response scenarios. This set of devices are strategically focused on highly engaged community members who are actively involved in shaping the community's energy future. The pilot aims to utilize the infrastructure to unlock the potential of flexibility, offering new services and activities for the members and relevant stakeholders Table 14 presents the pilot's subscription to BUCs and HLUCs.

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Table 14 Athens Pilot subscription to BUCs and HLUCs.

BUC Title	BUC Objective	HLUC	HLUC Title
Energy management (intra community)	Valorisation of energy management strategies at community level	HLUC0	Energy monitoring
		HLUC1	Energy balance and accounting
		HLUC2	Optimal management of energy assets in energy communities with PV generation
Sizing and organisation of energy communities	Define business models to guarantee economic sustainability of the energy community and establish a reference framework in terms of energy managed and/or participants involved.	HLUC11	Adaptive communities: reacting to evolution of markets, regulations and contexts

5.4.1 Requirements

The Athens pilot addresses the following requirements, linked to the HLUCs:

1. HLUC0/ HLUC1: **Monitoring and visualization of power consumption and production at community and household level** with the purpose of having an overview of the energy flows within the community and at individual level, visualizing graphs and benefits.

2. HLUC0/HLUC1/ HLUC2: **Optimise self-consumption, activate flexibility from storage and behavioural change**, to activate flexibility from the available assets, such as the storage device, enabling the visualization of the benefits, fostering behavioural change.

3. HLUC0/HLUC1/ HLUC2: **Participate in energy sharing** to reduce the electricity costs for the energy community members, calculate the benefits from the sharing schemes and support energy poor households in the process.

Next, these requirements are described in detail.

5.4.1.1 Monitoring and visualisation of power consumption and production at community and household level

To effectively manage and optimise energy resources within the community and at individual household levels, a comprehensive monitoring and visualisation system is essential. This system will provide real-time insights into energy flows, empowering members to make informed decisions about energy management, consumption patterns, and investment in renewable energy sources.

At the heart of this system lies the real-time tracking of energy production from various sources. This includes renewable energy generation from the PV system, individual household energy consumption and energy

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storage devices. Data aggregation from these diverse sources ensures consistency and accuracy of information, forming the foundation for comprehensive energy monitoring.

Energy consumption monitoring is crucial, encompassing thorough tracking within households and across the community. Real-time feedback to residents regarding their energy consumption levels highlights areas for potential savings. Analysis of energy consumption data identifies patterns and trends, enabling residents to identify and address wasteful behaviours.

Effective energy visualisation is paramount for conveying energy usage trends, patterns, and comparisons in a clear, engaging, and understandable manner. Dynamic graphs and charts utilise data visualisation techniques to effectively communicate energy usage across different periods and locations. Personalised insights tailored to each household empower residents to understand their individual energy footprint. Community-wide comparison fosters peer-to-peer learning and motivation by allowing residents to benchmark their energy consumption patterns against those of their neighbours and the community as a whole.

5.4.1.2 Optimise self-consumption, activate flexibility from storage and behavioural change

The objective is to finely tune and maximise self-consumption, leveraging various strategies such as activating flexibility sources from storage capabilities and behavioural adjustments. By harnessing the inherent adaptability within available assets, especially within storage devices, the goal is to unlock their full potential. This, in turn, facilitates the visualisation of the advantages awaiting exploration, thereby nurturing a shift in behaviour towards more optimised and efficient usage. Ultimately, it's about tapping into the untapped potential of existing resources and encouraging a paradigm shift in how these resources are perceived and utilised, culminating in a more sustainable and effective approach.

5.4.1.3 Participate in energy sharing

The primary goal is to facilitate energy sharing among members using a virtual net metering scheme. This process involves the Distribution System Operator (DSO) managing the netting of energy consumption and generation among the involved parties, ensuring a fair exchange. Meanwhile, the responsibility of billing falls upon the retailer, streamlining the process for participants.

One crucial aspect tied to this initiative is the meticulous calculation of the benefits produced from engaging in this energy sharing scheme. This involves a comprehensive assessment of the benefits derived from actively participating in the sharing program. These calculations typically involve complex analyses that evaluate how much energy is being shared, the associated cost savings, and the environmental impact, among other factors. Additionally, simulating various energy billing scenarios becomes pivotal in understanding and forecasting the financial implications for the involved parties. These simulations involve running hypothetical scenarios to forecast how different levels of energy consumption, generation, and sharing might impact the bills of individual participants. This exercise helps in predicting potential cost savings, identifying optimal sharing strategies, and anticipating framework changes.

5.4.2 Data Gathering and Flow

Data gathering for the Athens pilot is limited to the following, as all other data are derived from it:

1. Individual power consumption of households. Near real time velocity, 1 minute temporal resolution.
2. Storage device data (State of Charge (SoC), Voltage, Power). Near real time velocity, 1 minute temporal resolution.
3. PV production data through data logger. Resolution to be defined with the procurement of the data logger.

Individual power consumption is collected via sub meters that will be installed in the members households. Once connected the user will get insight into their power consumption within a minute interval. The meter data will be connected to an MQTT broker, connected to the Energy Management Platform, sending data per minute. Forecast services, extend that date with forecasted values for the net power per household.

The storage device will be accessible through several protocols, such as MQTT, MODBUS-TCP, JSON API.

The PV production assets data will be gathered through a data logger, that is yet to be procured.

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5.4.3 Services

The services as required for the functionality as described previously are presented in Table 15.

Table 15 Services required for the Athens Pilot implementation.

Service	Objective	Description
Forecasting	Weather data and solar irradiance	The weather and solar irradiance data is forecasted for each weather station. The results obtained must comply with (minimum): - 24 hours day ahead - 15 minutes granularity
	PV production	The PV production is forecasted for each system. Based on the PV system parameterization and location. The results obtained must comply with (minimum): - 24 hours day ahead - 15 minutes granularity
	Energy Community Member consumption	The energy demand for each supply point and asset is forecasted. For the member, historical data, location and weather are required. As for the asset, historical data and parameterization are also required. The results obtained must comply with (minimum): - 24 hours day ahead - 15 minutes granularity
Optimization	Self-consumption maximization	The optimal strategy regarding energy billing, optimal time slots for consumption and optimal control of the assets is computed in this service for implicit flexibility purposes (savings). Input data from the assets, community configuration and business model are required for this service. The results obtained must comply with (minimum): - 24 hours day ahead - 15 minutes granularity
Flexibility Management	Flexibility forecast	To optimally manage and control the community energy assets, it is required the upper and lower bound capable for each asset to modify the power (consumption or generation). Asset parametrization and real time data, generation and demand forecasts and weather forecasts are required for this service. The results obtained must comply with (minimum): - 24 hours day ahead - 15 minutes granularity

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5.4.4 Solution Architecture

The OpenRemote open-source platform will be applied in the Athens pilot (see Figure 15). It will include both the required asset types and services as described in the previous sections. The OpenRemote Community EMS is extended to be the key deliverable of D3.2: a 100% open-source community EMS. Therefore, we refer to the report for task D3.2 for more details.

The key challenges which will be addressed, tested and validated in the Athens pilot relate to the monitoring and visualisation of the energy assets of the community, as well as the optimisation of self-consumption.

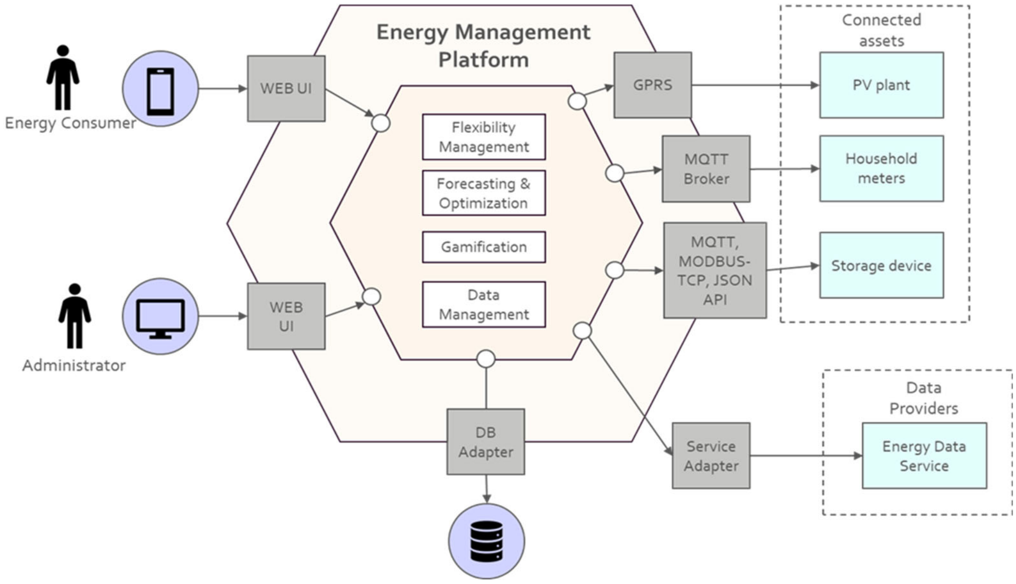

Figure 15 The RESCHOOL Athens Pilot Adapted Energy Management Platform Architecture as implemented with the 100% open source OpenRemote Community EMS.

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6 Conclusions

This document describes the architecture of the RESCHOOL energy management platform. Moreover, it details the data structures related to the RESCHOOL energy assets as well as data that enable the RESCHOOL services. The RESCHOOL architecture and data models are created based on EU standards such as BRIDGE's DERA and FIWARE' Smart Energy Data.

All the four pilots (Stockholm, Girona, Amsterdam, and Athens) describe the BUCs and HLUCs that they are subscribed to, their requirements, data flow and data acquisition process, and planned RESCHOOL energy management solutions as well as services.

The architecture and pilot specifications in this document provide an input for pilot deployment, adaptation, and validation that will be conducted in WP4 of the RESCHOOL project.

7 Acronyms and abbreviations

Table 16 Deliverable Acronyms.

Ex	Example
BUC	Business Use Case
HLUC	High Level Use Case
M	Energy Community Member
ECM	Energy Community Manager
DSF	Demand Side Flexibility
DERA	Distributed Energy Architecture
EU	European Union
WP	Work Package
DSO	Distributed System Operator

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