GENTE SYSTEM ARCHITECTURE

System architecture: Conceptional, logical and physical data models for LEC

SUMMARY

This task deliverable focuses on the system architecture and data models. It was created in the context of the objective 'Develop a cross-functional IoT-based platform to integrate different data sources and run demonstrations'.

Website genteproject.com
Contact hello@genteproject.com

Impressum

Internal Reference

Deliverable No.	D 8.1
Deliverable Name	System architecture: Conceptional, logical and physical data models for LEC
Lead Participant	REENGEN
Work Package No.	8
Task No. & Name	T 8.1 System architecture: Conceptional, logical and physical data models for LEC
Document (File)	GENTE-D8.1-Definition of system architecture and specification of functional requirements-PU-R_R0
Issue (Save) Date	15.04.2024

Document status

	Date	Person(s)	Organisation
Authors	2023-03-28	Esma Nur Çeltikçi	REENGEN
Contributors	2023-07-17	Alex D'Elia	PROSUME
Contributors	2024-04-01	Dogukan Ayci	REENGEN
Verification by	2024-04-08	Roman Lötscher	HSLU
Approval by	2024-04-09	Roman Lötscher	HSLU

Document sensitivity

☐	**Not Sensitive**	Contains only factual or background information; contains no new or additional analysis, recommendations or policy-relevant statements
☒	**Moderately Sensitive**	Contains some analysis or interpretation of results; contains no recommendations or policy-relevant statements
☐	**Sensitive**	Contains analysis or interpretation of results with policy-relevance and/or recommendations or policy-relevant statements
☐	**Highly Sensitive Confidential**	Contains significant analysis or interpretation of results with major policy-relevance or implications, contains extensive recommendations or policy-relevant statements, and/or contain policy-prescriptive statements. This sensitivity requires SB decision.

Disclaimer

About ERA-Net Smart Energy Systems

ERA-Net Smart Energy Systems (ERA-Net SES) is a transnational joint programming platform of 30 national and regional funding partners for initiating co-creation and promoting energy system innovation. The network of owners and managers of national and regional public funding programs along the innovation chain provides a sustainable and service oriented joint programming platform to finance projects in thematic areas like Smart Power Grids, Regional and Local Energy Systems, Heating and Cooling Networks, Digital Energy and Smart Services, etc.

Co-creating with partners that help to understand the needs of relevant stakeholders, we team up with intermediaries to provide an innovation ecosystem supporting consortia for research, innovation, technical development, piloting and demonstration activities. These co-operations pave the way towards implementation in real-life environments and market introduction.

Beyond that, ERA-Net SES provides a Knowledge Community, involving key demo projects and experts from all over Europe, to facilitate learning between projects and programs from the local level up to the European level.

www.eranet-smartenergysystems.eu

Abstract

‘System architecture: Conceptional, logical and physical data models for LEC’ focuses on the system architecture and data models. It was created in the context of the objective 'Develop a cross-functional IoT-based platform to integrate different data sources and run demonstrations'. In the context of the document structure; general information about the conceptual system architecture, platform services and functions within the scope of the project, system conceptual, logical and physical data modelling and detailed explanations are included.

The GENTE system relies on conceptual, logical, and physical data models to ensure efficient data management. Conceptual data models provide a high-level view of the system, allowing designers to organise and define business concepts and rules. This includes identifying platform-specific information such as data types, arrays, procedures, and triggers, which are all extracted from the conceptual data model. The goal of logical data models is to create a technical map of data structures and rules that define how the system should be implemented independently of the database management system. Logical data models help define the detailed structure of data items in the system and the relationships between them. This enhances the data elements offered by conceptual data models. The physical data model, on the other hand, describes how the system will be implemented using a specific database management system. The purpose of building the physical data model is to provide the actual implementation of the database, which involves designing tables, columns, keys, and other database objects. By using these three types of data models, the GENTE system can effectively manage and utilise data to optimise energy resources and provide efficient services to end-users.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

Abbreviation	Explanation
BLE	Bluetooth Low Energy
DER	Distributed Energy Resources
DID	Decentralised Identity
DLT	Distributed Ledger Technology
DMS	Digital Media Server
DSO	Distribution system operators
GDPR	General Data Protection Regulation
IoT	Internet of Things
LEC	Local Energy Community
LPWAN	Low Energy Wide Area Network
ML	Machine Learning
MPC	Multi-Party Computation
MQTT	Message Queuing Telemetry Transport
SCADA	Supervisory Control and Data Acquisition
TRL	Technology Readiness Level
USEF	Trading flexibility Protocol
VM	Virtual Machine
ZKP	Zero-Knowledge Proof

1. Introduction

Purpose of document

This document includes the conceptual design, concept data design and logical data models of the IoT Platform and GENTE distributed government services being developed within the scope of the GENTE Project.

Structure of document

The GENTE project includes many different services such as internet of things-based communication, electricity asset optimization, and forecasting. Section 2 explains Gente Platform Services and the functions of these services. The sophisticated system design ensures the coordinated operation of many services. Section 3 explains the conceptual data model between the services and the platform. Section 4 explains the Logical Data Model, which includes the details of the Concept Data Model. In the last part of the report, cap points are summarised in the Conclusion section.

Conceptual system architecture overview

The primary technology used in GENTE involves incorporating IoT platforms to optimise resource usage (Technology Readiness Levels 5 to 7). GENTE uses an advanced energy IoT platform to monitor and control LECs in real-time, and to communicate with grid operators' control systems, such as SCADA/DMS. This IoT platform is the foundation for integrated solutions developed by GENTE, as it collects high-quality data, utilises forecasting algorithms, optimisation and control strategies for LECs, and associated services such as peak load control for heat pumps, AC Units and buildings.

By incorporating forecasting algorithms, optimisation and control strategies, and peak load control for heat pumps and buildings, GENTE can manage energy usage more effectively, helping to reduce energy consumption during peak periods and improve overall system reliability. The use of transparent blockchain technology and smart contracts for automatic energy exchange and flexibility services ensures a secure and transparent process, which can help to build trust between energy providers and consumers.

The real-time monitoring and model-based control of LECs through the energy IoT platform allows for cost optimization, renewable energy utilisation and community federation. Additionally, the platform enables the collection and analysis of large amounts of data, which can be used to identify areas for improvement and optimisation, leading to increased efficiency and cost savings.

Bi-directional communication ensures that systems remain resilient, allowing users to manage all energy-related services through a single account platform that provides both individual and collective views. The identity system layer based on DID (Decentralised Identity standard), Zero-Knowledge Proof and Verifiable Credentials (based on private/public key) connects end-users' smart meters, the grid, and smart contracts execution to the automatic energy exchange and flexibility services that use transparent blockchain technology and contracts. The Energy Management layer connects to the DLT layer throughout a middle software, a portable virtual machine for smart-contract language execution that can process simple human-like language (Zencode) making it easy to manage data transformations related to the energy data fields and cryptographic operations related to the Blockchain layer.

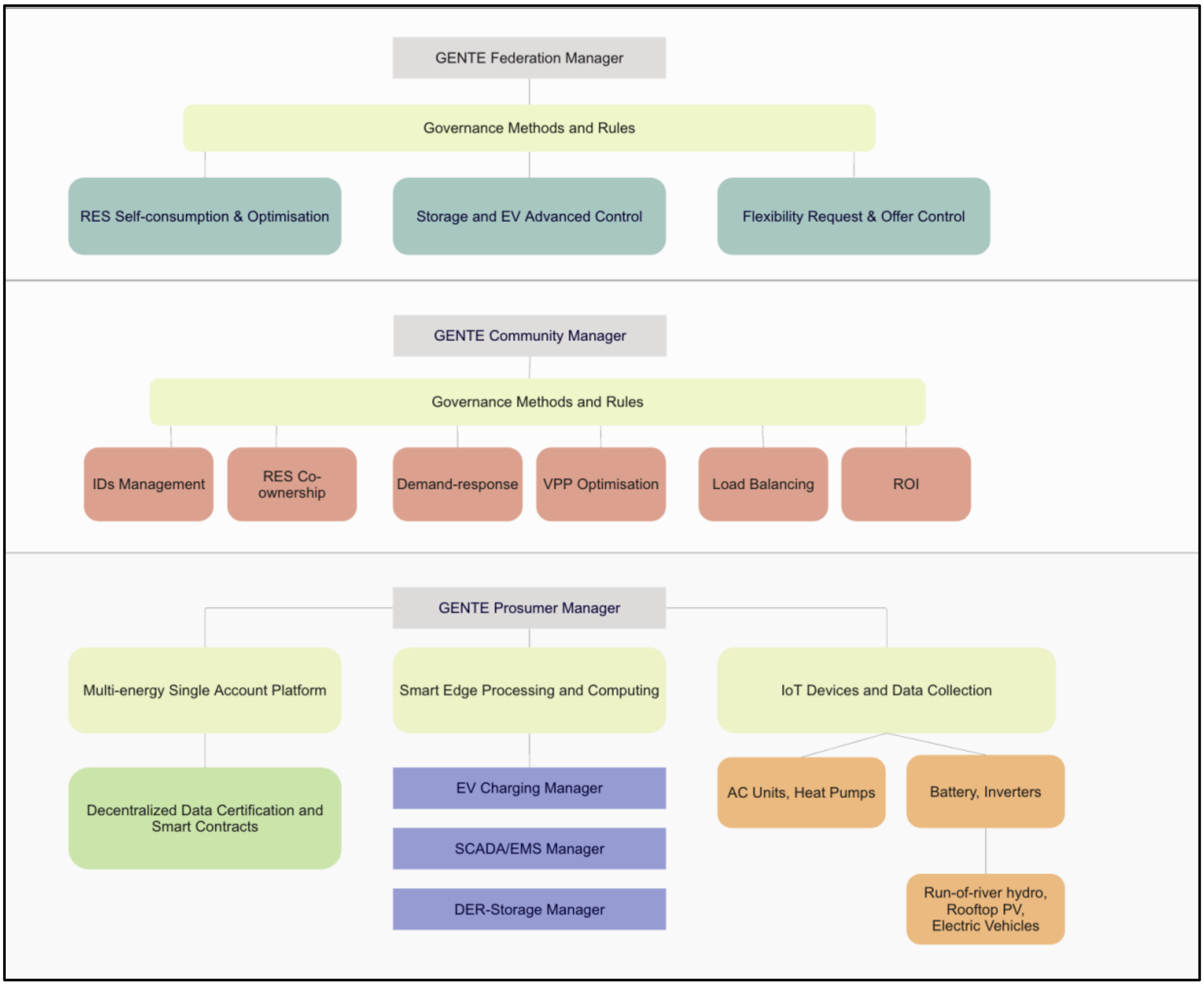


Figure 1: GENTE Conceptual System Architecture

Overall, the integration of IoT platforms in GENTE represents a significant step forward in the development of sustainable and efficient energy systems. By leveraging cutting-edge technology and innovative strategies, GENTE is poised to revolutionise the way we manage and use energy, creating a more resilient, reliable, and sustainable future for us all.

2. GENTE Platform Services and Functions

IoT platform and device communication (REENGEN)

Reengen has experience in providing IoT platform services and solutions to optimise energy management and facilitate smart city and smart grid interaction. In the context of the project, REENGEN (REE) develops a cloud-based Energy IoT Platform with Platform-as-a-Service data analytics solution for integration of distributed assets, data sources and stakeholders.

The core technology in GENTE includes IoT platform integration for optimisation of resources (TRL5 -> 7). GENTE deploys an advanced energy IoT platform for real-time monitoring and control of LECs as well as facilitating communication to grid operators' control systems (e.g., SCADA/DMS). The IoT platform will act as the backbone for developed integrated solutions, as it will gather high-quality data, incorporating forecasting algorithms, optimisation, and control strategies for LECs and associated services (e.g., peak load control by heat-pumps/buildings) by LECs. The reliable bi-directional communication will enhance systems' resilience, allowing users to manage all energy-related services, providing both an individual and collective view using a single account platform. Overall, end-users' smart meters, the grid, and smart contracts for automatic energy exchange and flexibility services through transparent blockchain technology and contracts, will be interconnected via the identity system that facilitates communications between end users and the grid.

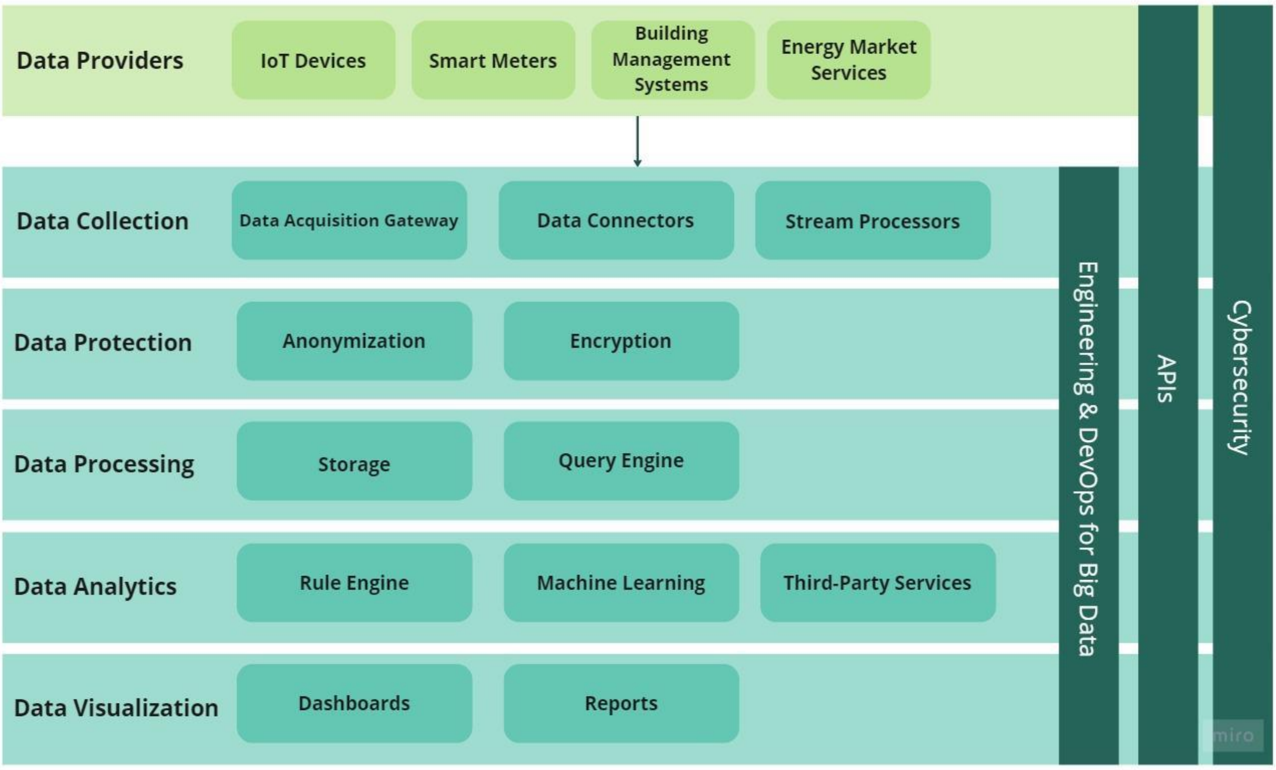


Figure 2: Architecture Layers of Reengen IoT Platform

The GENTE Energy IoT architecture enables the collection of data from various sources including IoT devices, solar inverters, smart meters, and other commercial sources. The data acquisition gateway acts as a data clearing house and customizable data connectors enable identification of data from different sources. Stream processors convert incoming data into a unified representation and user-defined rules are used to remove or mask personally identifiable data. The platform includes a comprehensive toolbox of analytic services and offers user-customizable dashboards for data visualisation. Cybersecurity threats are addressed through SSL encryption, SQL injection prevention, password hashing, and other best-practices. The platform architecture is designed to work on on-premise installations and tier-1 cloud providers and includes measures for data redundancy and increased query performance.

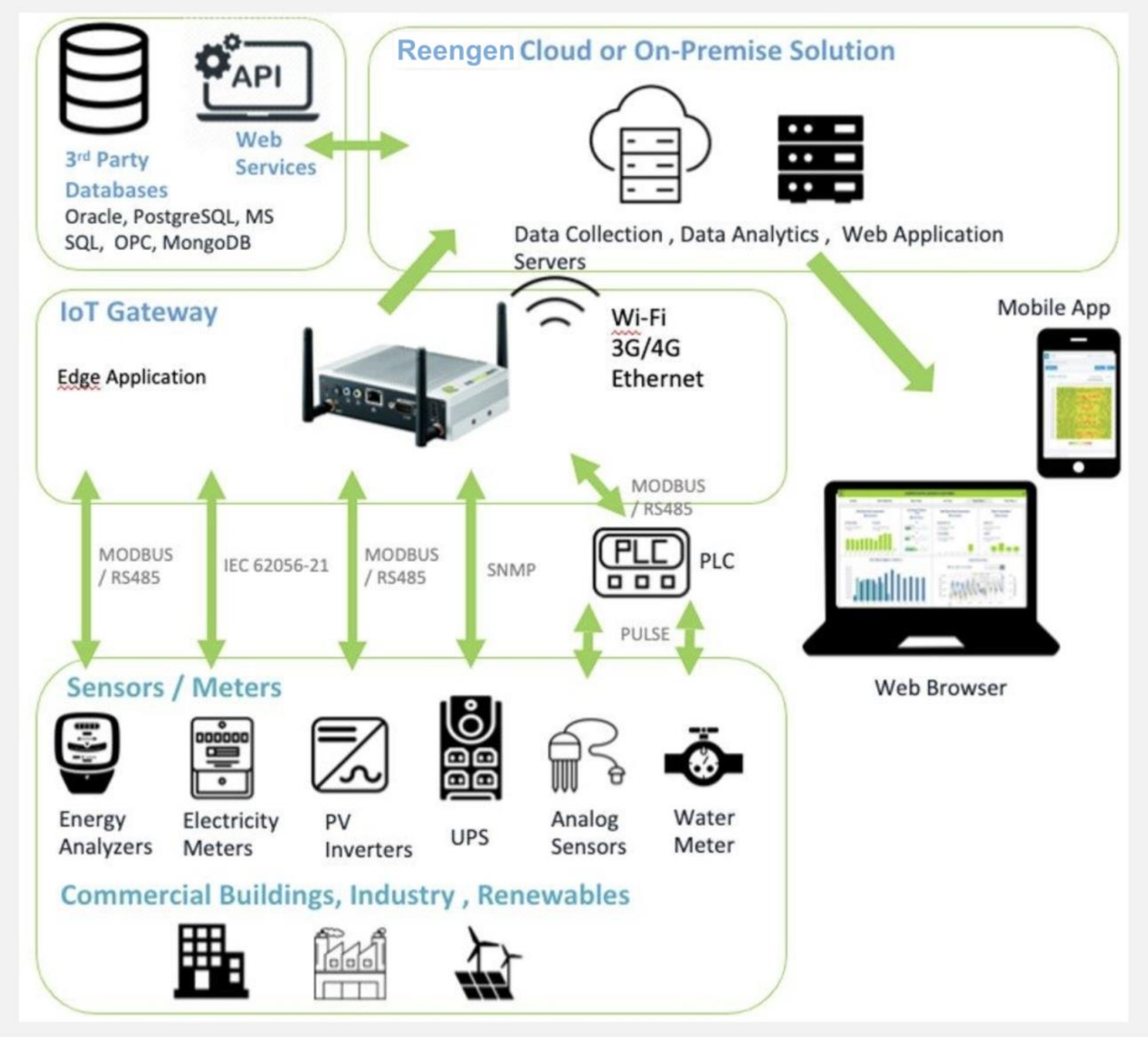


Figure 3: IoT Platform System overview

LEC optimisation / control

A LEC optimisation platform is implemented in GENTE. The optimisation platform uses data from distributed sensors within the LEC and cloud services to optimise energy consumption in the LEC, according to various objectives, defined as KPI's (c.f., GENTE Deliverable 9.1). A model-predictive control approach is used to implement the control algorithm.

The LEC optimisation algorithm is based on an IoT-aware optimisation model to aid energy communities with energy management [9]. The optimiser is based on a time horizon divided in discrete steps, during which the produced/consumed powers are assumed to be constant, considering an electrical system based on several discrete assets.

The optimisation function is designed to be modular so that it can be implemented on third party cloud servers, within the REENGEN cloud, on on-premise / local servers, or on the REENGEN IoT gateway.

Optimiser **functions** provided by the LEC optimisation / control system, broken down according to asset type, are provided below:

- **Grid**: the grid asset defines electricity import/export prices and capacities (per timestep). The optimisation model only allows export of instant production to the grid (no shifting using storage). The algorithm optimises towards an idea amount of imported/exported power;
- **Producer:** the producer asset is defined by a specific power output per timestamp, and it may have curtailment capabilities. The algorithm optimises curtailment;
- **Storage:** the storage asset is modelled by considering charging/discharging efficiency, maximal charge/discharge power, capacity, min/max state of charge (SoC), availability at different timestamps, as well as expected SoC when connected/disconnected. The algorithm optimises charging/discharging power (while managing the SoC);
- **Consumer:** the consumer is defined by maximal power, availability, desired power and allowed energy deficit. The algorithm considers the used power both as real-time and forecasting values, and optimises the delivered power through available flexibilities- mainly storage;
- **HeatNode:** As the heating system can represent a big part of end-user consumption, it is also added as an asset. The system maps the end-user needs to the electrical power required to run them, while leveraging heat storage. A HeatNode is composed of the following:
  - **HeatProducer:** defined by efficiency, maximal power, minimum running power and startup power. The algorithm optimises the startups/running time and delivered power of the heat pump;
  - **HeatStorage:** defined by min/max temperatures, a linear loss factor, volume, density, specific heat, temperature at the input, initial/final temperature and maximal flow. The algorithm optimises the temperature and flow through the thermal storage of the boiler;
  - **HeatConsumer:** defined by power consumption.

A generic workflow is provided in Figure 4. Measurements are taken from the community and stored in a database to provide a history of energy use or production. These are used in an ML-based forecaster to provide a set of forecast results, which are then used by the optimiser. The optimiser establishes set-points for the controllable energy resources in the community that are applied to the control system.

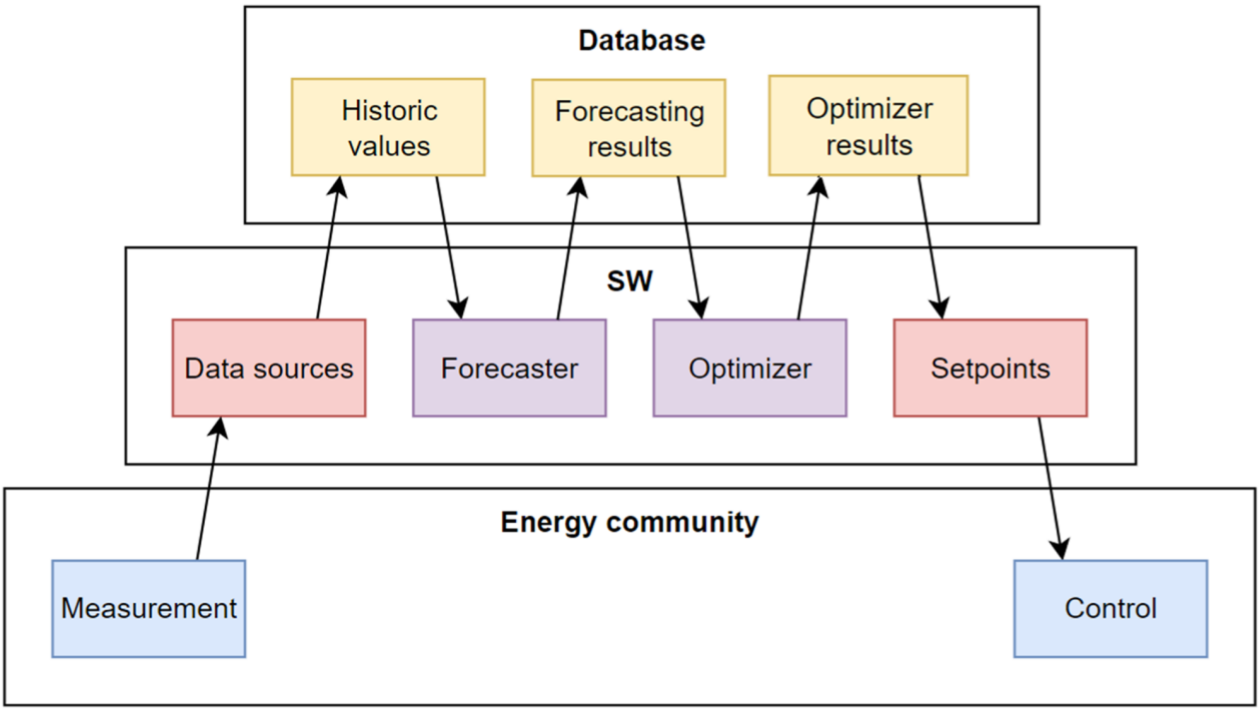


Figure 4: Generic workflow for LEC optimisation and control

The **Services** provided by the LEC optimisation / control platform are:

- Pre-processing historical and forecast data that is provided by the IoT platform so that it is suitable for use in the optimiser.
- Accepting constraints on assets imposed by smart contracts or user input.
- Post-processing of optimiser results according to predefined rules (as necessary).
- Providing results of the optimisation algorithm for storage in a cloud database (or the IoT platform) to be used by other processes, e.g., smart contracting.
- Providing set-points for assets in the LEC. Set-points are executed by the IoT gateway.
- Responding to external requests for optimisation for community federation.

Forecasting - PV, Load

Generation and demand forecasting are used in the GENTE LEC optimiser as part of the MPC approach. Forecasting is provided as a stand-alone processing block offering forecasting results to other processes, as required.

Three categories of generation forecasting are developed by HSLU within GENTE. GENTE only considers PV forecasts in the generation category. All can be run periodically (e.g. every hour), offering results in 15-minute intervals:

1. A cloud-based forecast that can be run on any partner cloud,
2. An edge-based PV forecast that can be run on the IoT gateway or on-premises solution
3. An edge-based PV forecast that can be run on the prototype SmartHelio sub-metering device.

The applications per country are summarised in the table 1 below.

Test site location	Application	Expected runtime Environment
Switzerland	PV forecasting	● On cloud ● On SmartHelio sub-metering device
Turkey, Sweden	PV forecasting	● On cloud ● On REENGEN gateway

Table 1: Applications per Country

Services required for cloud-based PV forecasting are:

- Store historical PV data on REENGEN IoT hub or on SmartHelio edge device
- Historical PV data upload to cloud database
- Compute array power
- Connect to weather service API
- Store weather forecast in cloud
- Push PV production data to edge device

Services required for edge-based PV forecasting are:

- Collect weather forecast data from cloud
- Compute power for module or PV array
- Conduct module power forecast using local ML model
- Store forecast values
- Implementation of forecasting on-device
- Re-factoring source code to ensure integration with LEC processes (reliable performance across multiple sites)

Demand forecasting will also be implemented within GENTE. Demand forecasting will run on the cloud or on the REENGEN IoT hub. Services required for cloud-based load forecasting are:

- Store historical load data on REENGEN IoT HUB
- Historical load data upload to cloud
- Compute load forecast and store forecasts results (on cloud or on REENGEN IoT Hub)

Forecasting - Heat

Heat load forecasting with focus on heat pumps (HPs) is an important aspect of the GENTE project because it provides the required input resources for building energy optimisation through BEMS to achieve "building control as a service" . Although this forecasting is a standalone service, it complements building optimisation and control strategies especially in the area of peak load control that provides required flexibility in LECs energy management.

Two categories of demand forecasting over two horizons are developed by Chalmers within GENTE. This advanced heat demand forecast can be run periodically (i.e., hourly, daily) to generate forecasts for 10 mins timestamp. The implementation detail is provided in the table 2 below:

1. A cloud-based forecast that can be run on any partner cloud or Google Cloud,
2. An edge-based PV forecast that can be run on the IoT gateway or on-premise solution.

Test site location	Application	Expected runtime Environment
Sweden (HSB Living Lab	Heat Demand Forecasting	• On reengen Gateway / Google Cloud • On IoT Gateway / on Premise

Table 2: Applications per Country-2

Requirements for cloud-based computing of Heat Load forecasting are:

- Upload and store historical Heat Load data on REENGEN IoT hub or Google Colab
- HSBLL API connection
- Store forecast values in cloud
- Push Heat Load values to edge device

Requirements for edge-based Heat Load forecasting are:

- Collect historical data from HSBLL
- Conduct Heat Load forecast using local ML model
- Store forecast values
- Implement forecasting on-premise

For the heat demand, the combination of heat pump load (i.e., output) and district heating load was forecasted. Determining the heat output of an air-to-water heat pump, factored in COP value and Electrical Power Input.

Heat functions are described as follows:

- heat Output - a function of Coefficient of Performance and Electrical Power Input measured in watts.
- Coefficient of Performance - which represents the ratio of heat output to the electrical power input. This varies depending on factors like ambient temperature, water temperature and system design. The water temperature in HSBLL is set as a constant through the heap pump set points (Vs1, Vs2). The ambient temperature data used in training the heat load forecast model is acquired from Rebase Energy.
- Electrical Power Input - this is stipulated by the manufacturer and it is used as a reference value for comparing and evaluating heat pump's performance.

Grid services (HSLU)

GENTE includes a framework for the implementation of grid services that are provided by local energy communities. The basis of the grid services approach in GENTE is the USEF framework, specifically the Flexibility Trading Protocol Specification [10]. GENTE extends the USEF framework by including the local energy community as an entity type, and by introducing a community manager as a role that manages flexibility offered by an LEC, who may in turn choose to federate multiple energy communities.

The USEF framework describes a central role for the aggregator in providing grid services to the system operator. It is expected that in the short to medium term, the main route to market for an energy community - and for the flexibility provided by the energy community - will be via an established aggregator. However, the community manager themself may also act as an aggregator, especially if the community manager is managing multiple energy communities. This is illustrated in the diagram below (Figure GS-1).

The grid services to be included in GENTE are (1) grid capacity management and (2) congestion management. Both grid capacity management and congestion management are defined in the USEF framework.

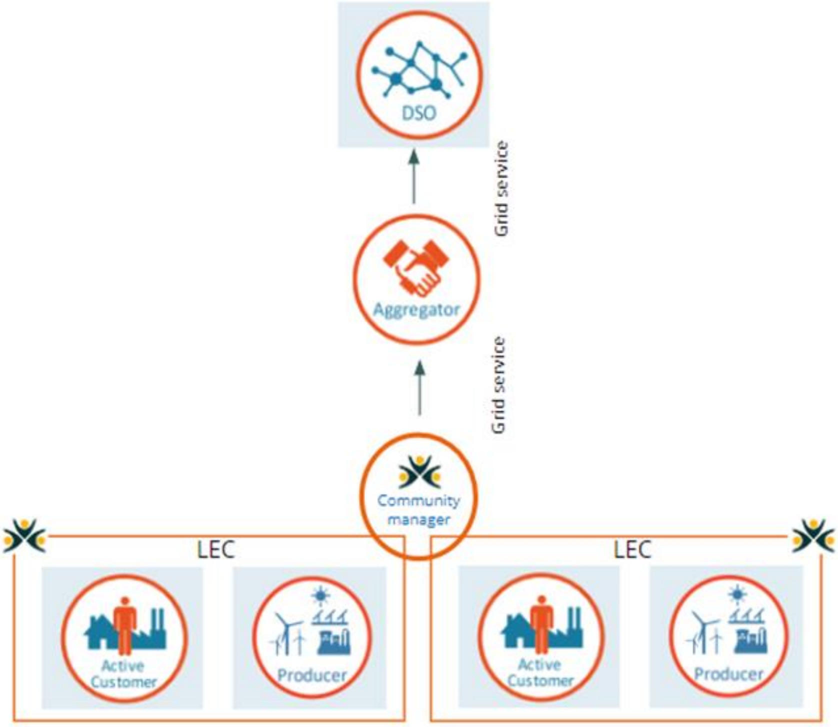


Figure GS-1: Illustration of community federation, with communities offering grid services via an aggregator

Grid capacity management refers to the use of explicit demand side flexibility to increase operational efficiency, so avoiding grid reinforcements, optimising asset operational performance, reducing grid losses, or supporting planned maintenance. The service involves procuring predictable long-term flexibility to manage known supply and demand constraints in the electricity network.

Grid capacity management as a service can be provided by a local energy community through self-consumption optimisation. It is likely to be based on long term contracts with the energy community where the community agrees to provide flexibility at regular times, for example by increasing self-consumption during the middle of the day, when PV generation is at its highest, and when the local electricity network is unable to support additional export of PV from embedded generation.

In contrast, congestion management is a shorter term, less predictable service that is used by the DSO to manage periods of system stress, for example reducing unexpected peak loads. Congestion management may complement grid capacity management, and ultimately the effect on the network may be the same, but congestion management is procured on an *ad-hoc* basis. Congestion management provides a temporary solution and may be used until reinforcement takes place, or until a grid capacity management scheme is implemented.

Various parts of the GENTE system must interact to provide the necessary grid services. In the next section, the implementation of the grid services, taking into account roles and functions of subsystems, is described in more detail.

Grid service workflow

The grid service workflow in GENTE a has five stages (Figure GS-2):

Figure GS-2 - Overall GENTE grid service workflow

In the **contract** phase, the DSO establishes long term contracts for grid services with the aggregator or energy community. Next, in the **plan** stage, an operational planning process is carried out by the DSO, based on the contracts that have been established in the contracting phase, allowing the DSO to choose how flexible resources will be managed in general to support the operation of the grid. The **validate** stage follows, during which short term resource optimisation is carried out considering actual availability of flexibility. The availability of energy resources is determined by the DSO based on exchanges with the aggregator or community manager, and optimisation may take place within the energy community to make energy resources available to the DSO based on their upcoming requests. The fourth stage is the **operating** stage, where flexible energy resources are actually dispatched. The final stage is the **settlement** phase, when validation of the flexibility action is carried out and payment is initiated. Each stage is now described in more detail.

Contract phase

A contract, defined in USEF as a FlexOption, is agreed between the system operator and the flexibility provider. In GENTE, this could be either the aggregator or the community manager. A sequence diagram showing the contract phase stages is provided in Figure GS-3. Note that nothing happens at this stage in terms of resource optimisation. The contract phase simply establishes the payment terms and availability of the flexibility.

This sequence diagram, and those in subsequent sections, includes an entity called the Common Reference Operator (CRO). The CRO is responsible for operating a common reference of the network, which contains information about connections and congestion points. It therefore acts as a trusted data platform for exchanging information on flexibility. The CRO is not directly implemented in GENTE, but is included in the sequence diagram for completeness, and can be seen as integrated within the DSO in GENTE.

A pre-qualification process takes place between the community and the DSO, and the community is contracted to provide flexibility by either the aggregator or the community manager. In GENTE, this could take place via the mobile app. The community provides information to the DSO on available flexibility, again either via an aggregator, or directly by the community manager. A firm contract to provide flexibility can then established.

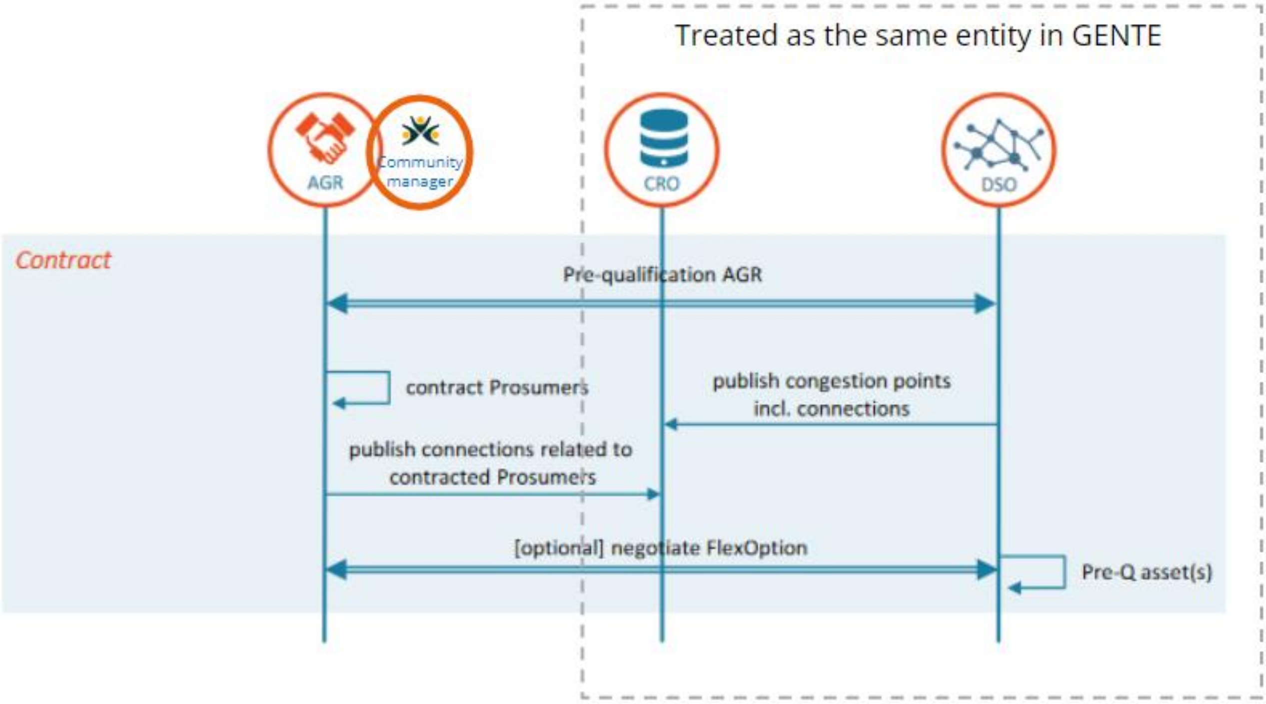


Figure GS-3: Sequence diagram showing the contract phase

The roles and actions associated with the contracting phase are described in Table 3. First, the system operator publishes the FlexOption to the aggregator or community manager's contracting platform describing their requirements for flexibility procurement. The contracting platform receives the FlexOption and calculates the available flexibility based on stored parameters, then initiates contracting with end users (e.g., via the mobile app). The availability of this flexibility is then published to the DSO. Within GENTE, this functionality is provided by Prosume. Because no actual flexibility is managed during this stage and negotiation is based on stored values of available flexibility, there is no role for the IoT platform, edge intelligence, or energy resources. However, the end user has a role to play as they accept the contract that has been proposed.

Actor	Owner (GENTE)	Actions
DSO / CRO	N/A	• Publishes FlexOption to aggregator or community manager contracting platform
Contracting platform	Prosume	• Receives FlexOption • Calculates available flexibility based on stored parameters • Initiates contracting with end-user in mobile app • Publishes flexibility to DSO/CRO
IoT platform	REENGEN	• None
Edge intelligence	HSLU	• None
Smart DER (PV)	SmartHelio	• None
End user	Prosume (via mobile app)	• Accepts contract

Table 3 - Roles and actions in Contract phase

Various components of the contract between the DSO and the energy community are provided by the USEF framework. An example is provided in Table GS-4, extracted from the USEF framework. The contract in GENTE will only consider fields relating to amount, capacity remuneration, and volume remuneration, to illustrate the functionality of such a contract.

Plan phase

The plan phase manages the day-to-day delivery of the contract which was agreed in the previous phase. The aggregator or community manager needs to get ready to supply the flexibility to the DSO by optimising their portfolio. This means that a forecast of actual resource or flexibility availability is now required. A sequence diagram showing the workflow is provided in Figure GS-4.

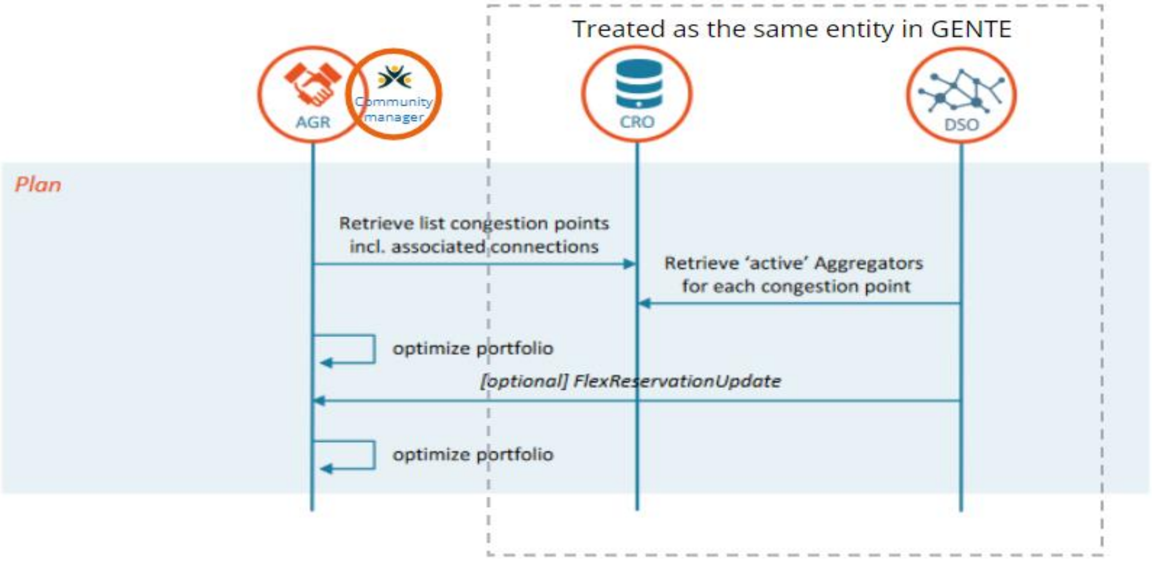
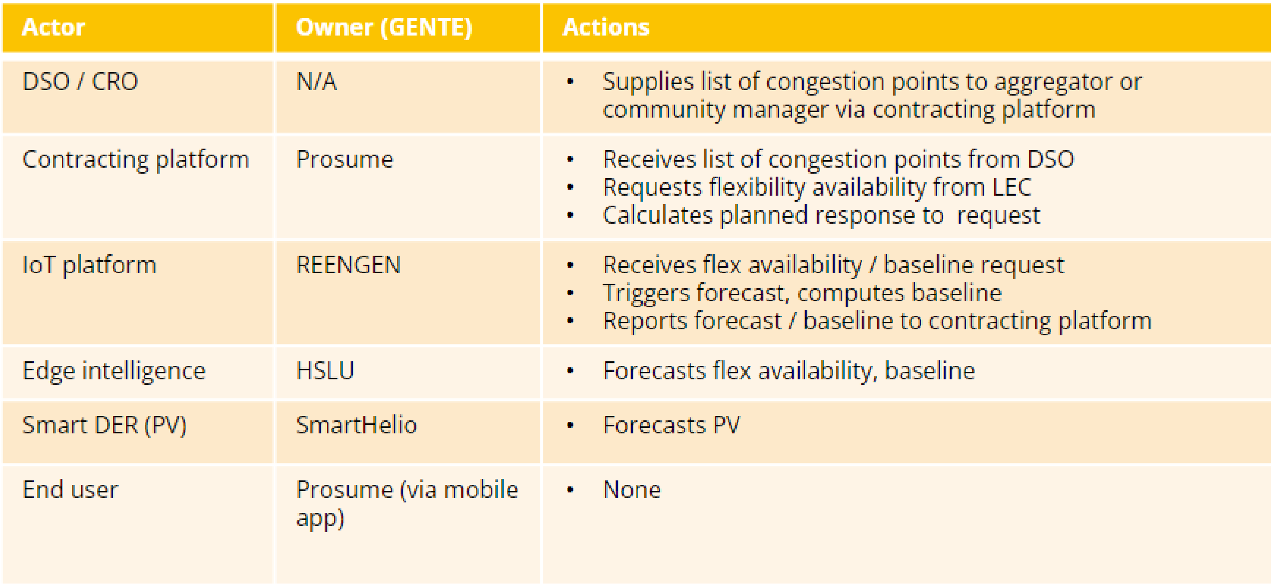


Figure GS-4: Sequence diagram showing the plan phase

The aggregator or community manager requests a list of congestion points from the CRO/DSO. Based on the response, the community optimises the local portfolio of flexible assets to ensure it is able to provide the required flexibility if requested.

The actions of different actors are described in Table 4. First, the DSO provides a list of congestion points to the aggregator or LEC contracting platform and requests flexibility availability. The contracting platform determines how it will respond to the DSO's request based on the available flexibility in the community. The IoT platform has a role to play: it receives a request from the contracting platform to calculate available flexibility, then triggers forecasting, baseline computations, and flexibility computations, which in turn are provided by the edge intelligence. Results are returned to the contracting platform. Energy resources themselves have no role to play at this stage. In GENTE, the IoT platform is provided by REENGEN, edge intelligence is developed by HSLU and Chalmers, and some embedded forecasting functionality is provided by SmartHelio.



Actor	Owner (GENTE)	Actions
DSO / CRO	N/A	• Supplies list of congestion points to aggregator or community manager via contracting platform
Contracting platform	Prosume	• Receives list of congestion points from DSO • Requests flexibility availability from LEC • Calculates planned response to request
IoT platform	REENGEN	• Receives flex availability / baseline request • Triggers forecast, computes baseline • Reports forecast / baseline to contracting platform
Edge intelligence	HSLU	• Forecasts flex availability, baseline
Smart DER (PV)	SmartHelio	• Forecasts PV
End user	Prosume (via mobile app)	• None

Table 4 - Roles and actions in Plan phase

Validate phase

The final phase before dispatch is the validate phase, during which the DSO conducts detailed planning based on all information available, including activating additional short-term contracts if necessary. The DSO collects information relating to forecast network conditions and flexibility availability, and verifies if the distribution system limits are reached, deciding how to activate flexibility. In the validate phase, a similar process is followed to the plan phase, but there may be a requirement for additional short term contracting.

A sequence diagram is provided in Figure GS-5. Forecasts are sent to the DSO; requests are in turn made to flexibility providers to provide offers. Orders for flexibility are then finalised.

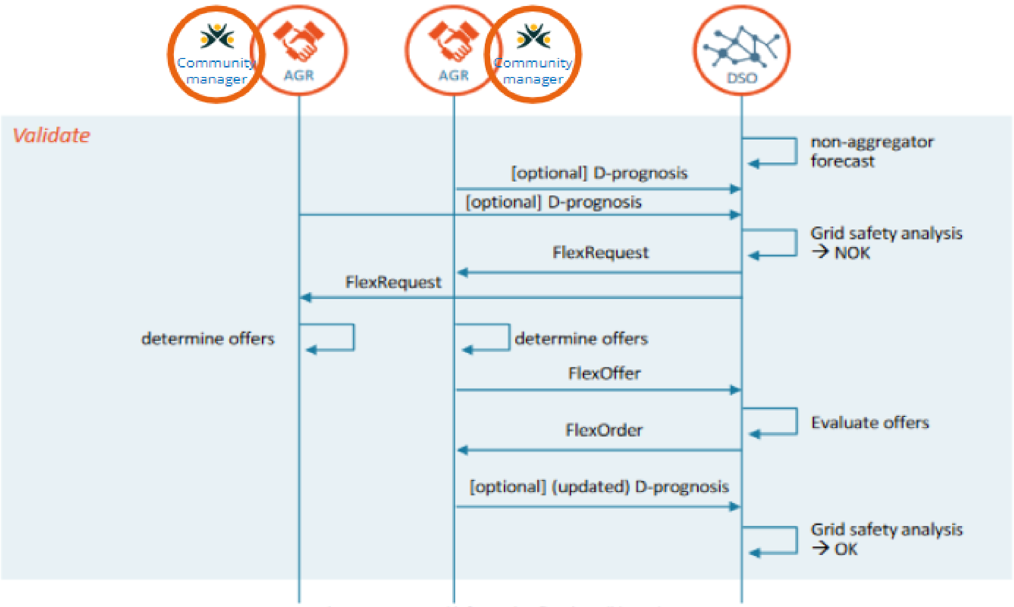


Figure GS-5: Sequence diagram showing the Validate phase

Table 5 summarises the roles of different actors in the validate phase. As before, the DSO sends a flexibility request and ultimately receives a flexibility offer from the contracting platform. The contracting platform requests flexibility availability from the LEC and if necessary initiates additional contracting with the end user in the mobile app. The contracting platform also calculates its planned response to the request from the DSO. This is very similar to the planning phase. The IoT platform, edge intelligence, and smart DER carry out the same processes as in the planning phase. The end user may have a role to play here by accepting an additional contract to provide short term flexibility.

Actor	Owner (GENTE)	Actions
DSO	N/A	• Sends FlexRequest to aggregator / community manager contracting platform, receives FlexOffer back
Contracting platform	Prosume	• Receives FlexRequest from DSO, sends FlexOffer to DSO • Requests flexibility availability from LEC • Initiates additional contracting with end-user in mobile app [optional, if required] • Calculates planned response to request
IoT platform	REENGEN	• Receives flex availability / baseline request • Triggers forecast, computes baseline • Reports forecast / baseline to contracting platform
Edge intelligence	HSLU	• Forecasts flex availability, baseline
Smart DER (PV)	SmartHelio	• Forecasts PV
End user	Prosume (via mobile app)	• Accepts contract to supply flex [optional, if required]

Table 5 - Roles and actions in Validate phase

The validate and plan phases may repeat as shown in Figure GS-6. The DSO may need to iterate the approach, calculating multiple grid states, issuing multiple requests for flexibility, receiving multiple flexibility offers, and updating their prognosis accordingly. They may need to procure both short term and long term flexibility and ultimately make a decision on the optimum grid conditions. At some point in time, the process is closed, and the DSO moves into the operating phase.

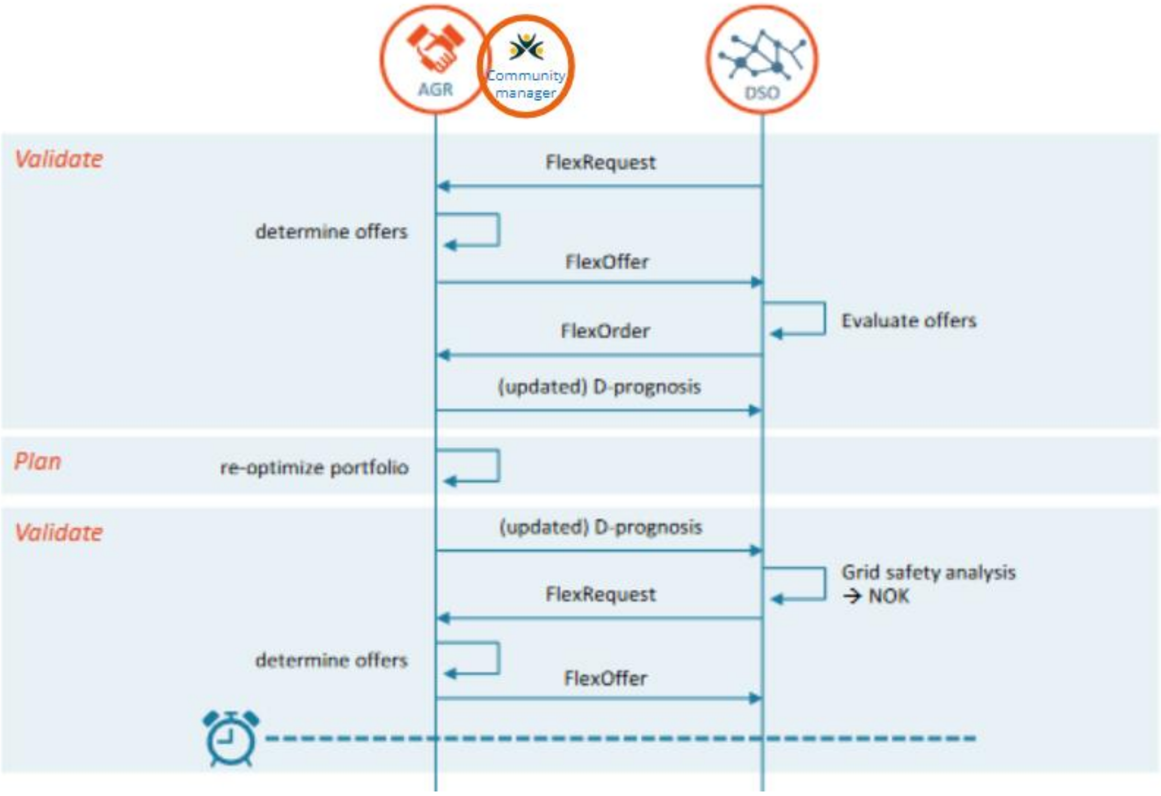


Figure GS-6: Sequence diagram showing a repeated Validate phase

Operate phase

In the operating phase, the flexibility is actually delivered to provide the required grid service. The aggregator or community manager aims to honour the pre-agreed plan, trying to deliver flexibility in line with the forecast. If reality is different to the pre-agreed plan, a new forecast is sent to the DSO, or the aggregator procures additional flexibility from elsewhere.

A sequence diagram is provided in Figure GS-7.

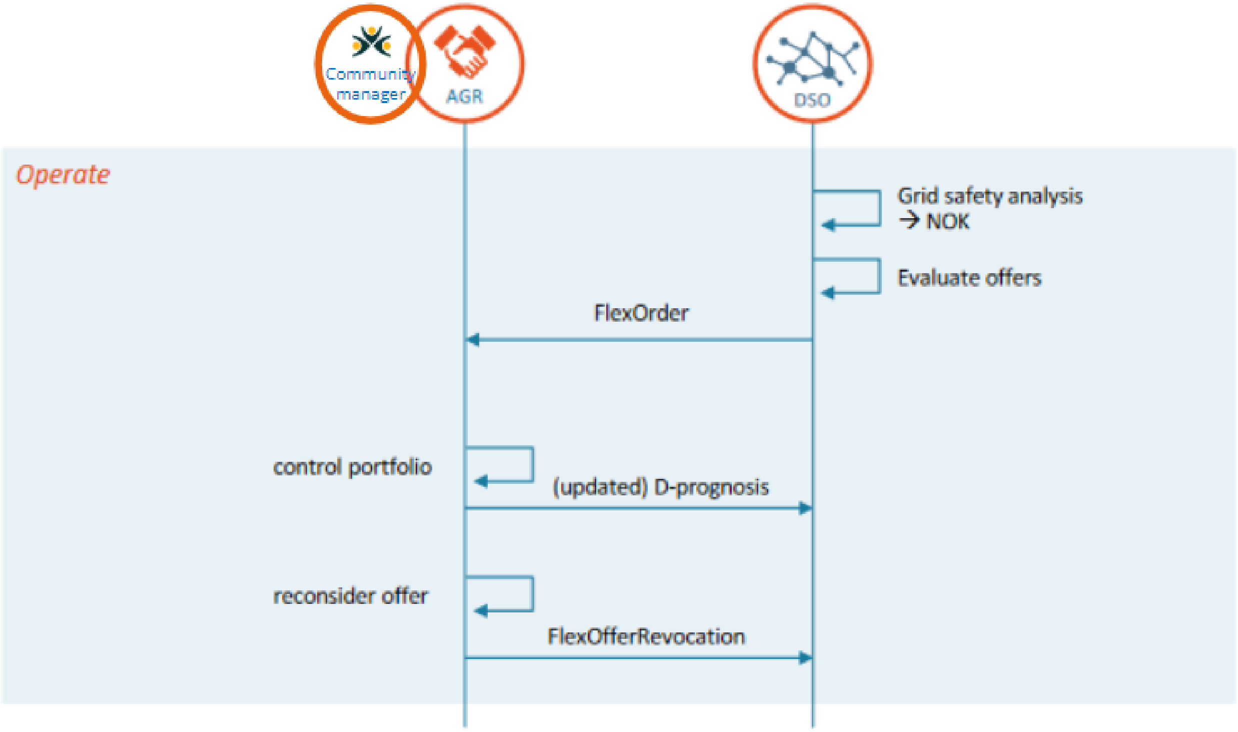
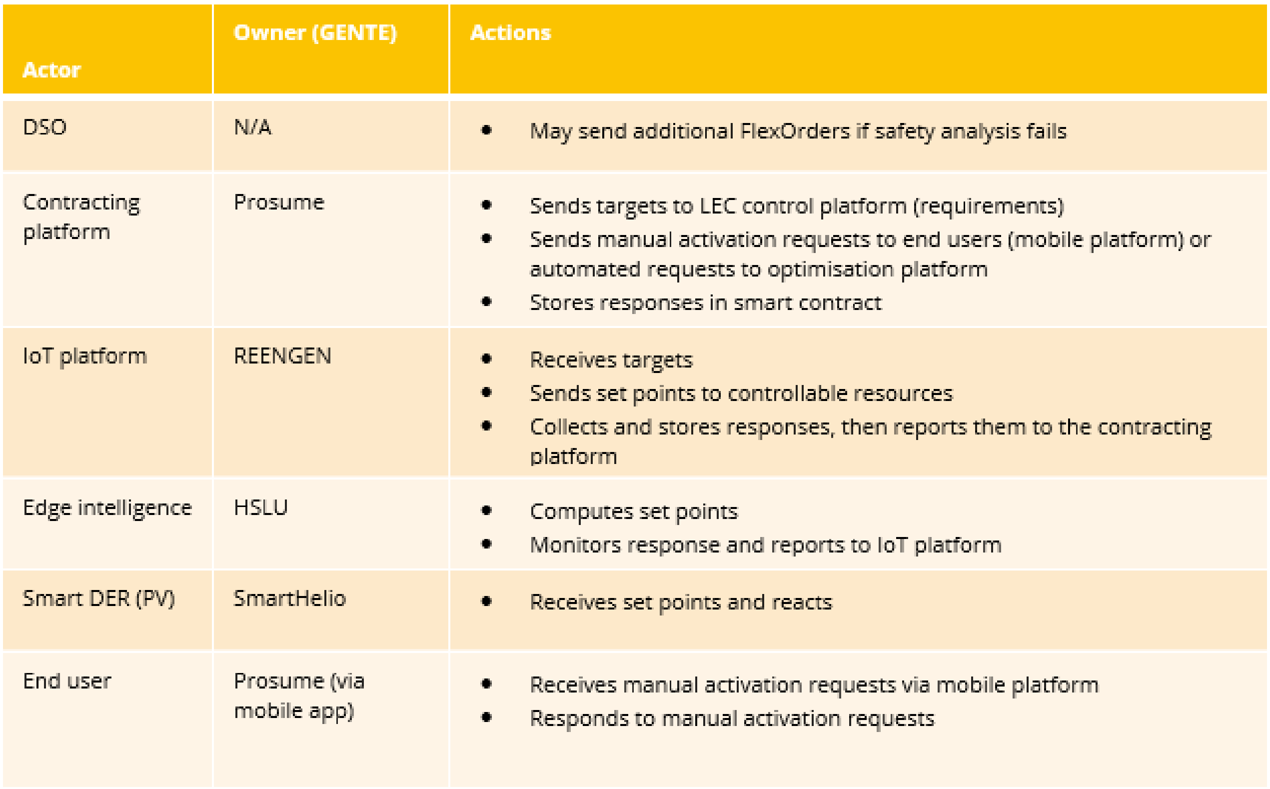


Figure GS-7: Sequence diagram showing the Operate phase

The roles are summarised in Table 6. The contracting platform is now required to dispatch the flexibility that has been reserved or requested through the contract in previous stages. It receives the dispatch request from the DSO and it sends manual activation requests to end users or automated requests to the optimisation platform.

The IOT platform receives targets from the contracting platform and sends set points to the controllable resources. The IoT platform monitors responses of energy resources and reports the results to the contracting platform based on the requests that are managed by the IOT platform. The edge intelligence computes set points for energy resources, monitors their response, and reports outcomes to the IoT platform. Energy resources receive those set points and react. In certain circumstances the end user may receive a manual activation request via the mobile platform and respond to those manual activation requests by physically interrupting or shifting loads.



Actor	Owner (GENTE)	Actions
DSO	N/A	• May send additional FlexOrders if safety analysis fails
Contracting platform	Prosume	• Sends targets to LEC control platform (requirements) • Sends manual activation requests to end users (mobile platform) or automated requests to optimisation platform • Stores responses in smart contract
IoT platform	REENGEN	• Receives targets • Sends set points to controllable resources • Collects and stores responses, then reports them to the contracting platform
Edge intelligence	HSLU	• Computes set points • Monitors response and reports to IoT platform
Smart DER (PV)	SmartHelio	• Receives set points and reacts
End user	Prosume (via mobile app)	• Receives manual activation requests via mobile platform • Responds to manual activation requests

Table 6 - Roles and actions in Operate phase

Settle phase

In the settlement phase remuneration is managed. The process is summarised in the sequence diagram shown in Figure GS-8. Remuneration is calculated by comparing actual delivered flexibility against baselines, both within the smart contracting platform and by the DSO. A settlement is then made.

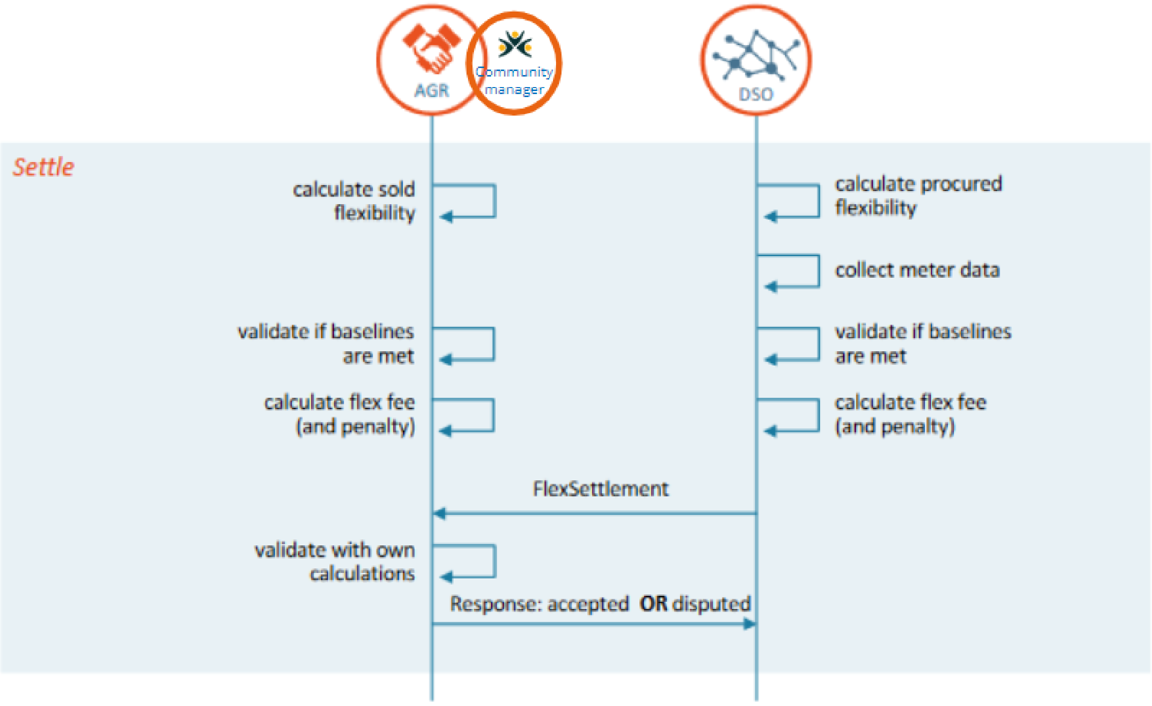


Figure GS-8: Sequence diagram showing the Settle phase

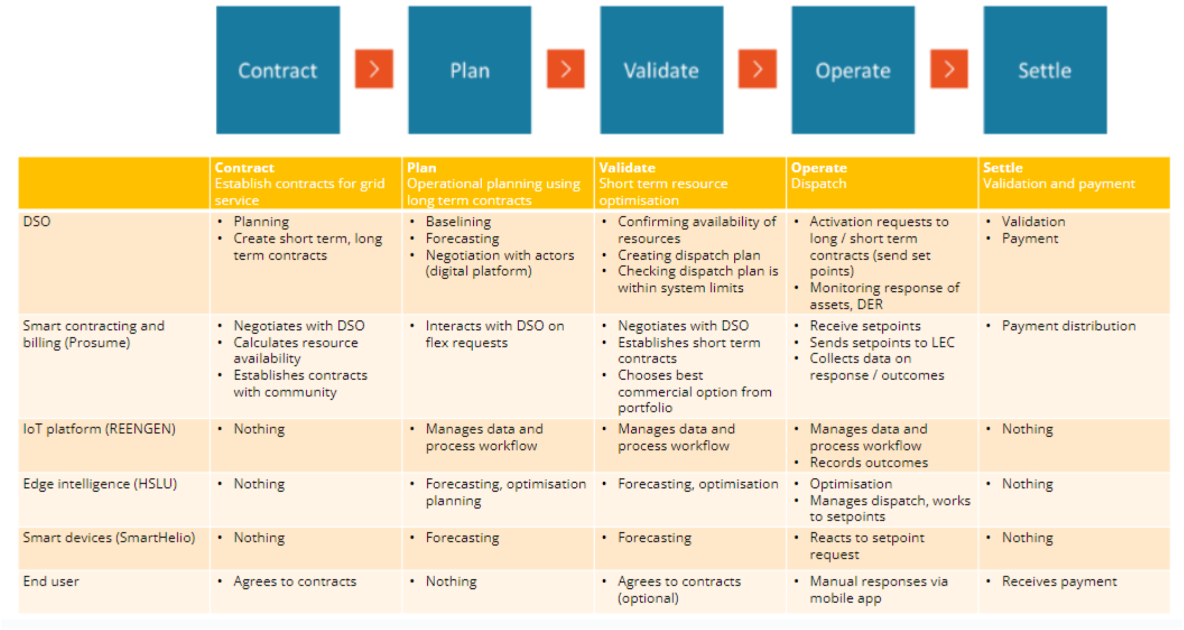
Table 7 shows the actions of actors associated with the Settle phase. The DSO awards payment to flexibility that has responded to the requests based on the contract terms agreed with the contracting platform. The contracting platform calculates the value of the response, reports any mandatory data to the DSO and ultimately distributes payments to LEC members via smart billing or tokens. In the Settle phase, there is no further action for the IoT platform, edge intelligence, or smart DER. The end user receives remuneration via smart billing or tokens.

Actor	Owner (GENTE)	Actions
DSO	N/A	• Award payment
Contracting platform	Prosume	• Calculates value of response during operate phase • Checks conditions against contract with DSO • Reports mandatory data to DSO (e.g. meter readings at LEC connection point) • Distributes payment to LEC members via smart billing / tokens
IoT platform	REENGEN	• None
Edge intelligence	HSLU	• None
Smart DER (PV)	SmartHelio	• None
End user	Prosume (via mobile app)	• Remuneration via smart billing / tokens

Table 7 - Roles and actions in Settle phase

Summary

A summary is provided in Figure GS-9. As described, there are five steps: a contract phase, a plan phase, a validate phase, an operate phase, and a settlement phase. The contract and plan phases involve determining the availability of flexibility and establishing contracts for providing it to the DSO. The validate phase involves checking that flexibility is actually available. The operating phase involves dispatching flexibility. Finally, the settlement phase involves transfer of value from the grid services buyer to the grid services provider.



	Contract Establish contracts for grid service	**Plan** Operational planning using long term contracts	**Validate** Short term resource optimisation	**Operate** Dispatch	**Settle** Validation and payment
DSO	• Planning • Create short term, long term contracts	• Baselining • Forecasting • Negotiation with actors (digital platform)	• Confirming availability of resources • Creating dispatch plan • Checking dispatch plan is within system limits	• Activation requests to long / short term contracts (send set points) • Monitoring response of assets, DER	• Validation • Payment
Smart contracting and billing (Prosume)	• Negotiates with DSO • Calculates resource availability • Establishes contracts with community	• Interacts with DSO on flex requests	• Negotiates with DSO • Establishes short term contracts • Chooses best commercial option from portfolio	• Receive setpoints • Sends setpoints to LEC • Collects data on response / outcomes	• Payment distribution
IoT platform (REENGEN)	• Nothing	• Manages data and process workflow	• Manages data and process workflow	• Manages data and process workflow • Records outcomes	• Nothing
Edge intelligence (HSLU)	• Nothing	• Forecasting, optimisation planning	• Forecasting, optimisation	• Optimisation • Manages dispatch, works to setpoints	• Nothing
Smart devices (SmartHelio)	• Nothing	• Forecasting	• Forecasting	• Reacts to setpoint request	• Nothing
End user	• Agrees to contracts	• Nothing	• Agrees to contracts (optional)	• Manual responses via mobile app	• Receives payment

Figure GS-9: Summary of actions by parties in each phase

Smart contracting

DLTs in general can provide a more transparent and trustworthy support in promoting clean energy production and sustainability plans while certifying their renewable sources. It also provides a way to incentivize affordable energy provisioning and self awareness in consumption thus promoting a steeper transition toward a more sustainable and aware society and a stronger action on impact development.

Yet, to achieve transparency and awareness of energy consumption and production, data not only has to be certified and properly executed in connection with the source of the data collected, but it also has to be automatized in a way that it still can be analysed and properly evaluated by all the stakeholders involved, respecting their privacy, without disclosing information that should not be available publicly.

In particular, the constraints of privacy/confidentiality, linked to the compulsory compliance to GDPR, are especially important to consider. While legally speaking, it is enough to evidence that a part-taker obtains an advantage from sharing her data to claim that personal data disclosure and subsequent management is subtracted from GDPR application, should not be deemed a satisfactory situation, hence we should expect application proponents to effectively take measures to provide confidential management of data. To that respect, distributed identity management should be managed carefully, as it is a necessary feature for all the other applications.

A balance may be found dividing data that should go on and off a Distributed Ledger, defining what information should be registered in the Blockchain and what not. For these reasons we have considered implementing innovative technologies like ZKP (Zero-Knowledge Proof) and MPC (Multi-Party Computation) for the GENTE Project.

The goal is to be able to provide trustworthy and scalable services that can easily be integrated into the main GENTE Platform, without giving away privacy and confidentiality while preserving the added value of strong cryptographic tools and interoperability between the services and the Blockchains. Blockchains, as we already know, are still under development and rapidly changing and adapting.

The Zenroom Stack we implement is a powerful multi platform technology that can be stripped into many microservices adapted to the specific use cases.

Within GENTE we are going to develop some Smart Contracting feature depending on the specific requests of each pilot. The first type of services we do provide are:

1. computing of rewards for users who use (or not use) energy when requested by the grid operator
2. computing of rewards for users who consume less energy or produce more energy in specific time frames, depending on the performance request as demanded by the local energy provider

Thanks to the software stack specifically implemented for GENTE, the functionalities provided by the Smart Contracts can be listed as:

1. reading data stored in multiple sources and organised in an ontology bypassing specific protocol limitations
2. compute rewards for an arbitrary number of households without depending on time constraints or limits imposed by the databases or Blockchain technology in use
3. recording data in the PROSUME Blockchain for certification purposes
4. eventually transacting tokens into other Blockchains of choice
5. strong cryptographic layer implementing various elliptic curves
6. smart contracts easy made in human understandable language (plain english)

The Smart Contracts developed depend on the specific interaction between the services provided by the GENTE Platform. Still, they can easily be adapted for future purposes as they are decoupled from the Blockchain and executed by the finite state virtual machine of Zenroom.

Mobile app

A digital wallet is a key management application, which provides a user with a graphical interface to store, manage and secure digital keys. These keys can be used to sign transactions, statements, credentials, documents or claims.

A digital identity wallet enables a user to establish relationships and interact with third parties in a trusted manner. While the wallet aspect is mainly dealing with key management, storage aspects and the graphical interface, the third party interactions are rather organised by an agent, which is a part of the wallet.

In order to build robust smart contracts & apps capable of dealing with complex & changing datapoints, the blockchain community has no option but to figure out how to interface within a blockchain to exterior data points. Apps usually ask for these data points from databases or APIs through a process called querying. Blockchains, due to their deterministic properties, need a special way to query data from the outside world & import it in a blockchain format. This is where the Zenroom VM comes into play as it enables easy interaction with exterior data through APIs and databases and even different types of Blockchain, while ensuring privacy and security throughout the strong cryptographic layer around which it is built.

The PROSUME Mobile APP will integrate the Zenroom VM to enable this type of interaction to provide a value added to the project. Right now the APP works only as an interface to the end user’s requests to envision metered energy data coming from the GENTE databases, aggregation with other parties within an Energy Community and easy interaction.

Within the timeframe of the GENTE Project the Mobile APP functionalities will be extended to integrate the Key management functions and implement the rewarding mechanism to make it a fully owned Wallet Application, capable of providing payment processing and exchange of Tokens.

During the project development phase, service analysis and tokenization contractual cases will be studied by PROSUME with the help of the 2Tokens Foundation. The goal is to analyse the use cases and shape the Token modelling so as to be compliant with rules and regulations as established within the Local Energy Community framework and testing the validation of the DLT with the GDPR guidelines.

When the GENTE Project will come to the end, the Mobile APP will be freely downloadable from Android and Apple stores and will start to integrate payment processing by integrating various layers of Tokenizing energy exchange services.

2. GENTE Services Demonstration Sites

Sweden

Though there are about 140 energy communities in Sweden, there is no dedicated legal framework for their existence. However, the operation of these communities is covered by EU energy communities' framework and Sweden Electricity Market Act. The Swedish government in the bill 2021/22:153 “Implementation of Electricity Market Directive” decided that Sweden does not require new legislation to regulate energy communities because there are no obstacles for their participation on the energy market. The Electricity Market Act (Elmarknadslagen) 2021 [17] provides the legal framework for the electricity market in the areas of:

1. Market Participation: The Act defined the terms and conditions for the participation of Citizen Energy Communities in the electricity market, outlined the requirements for CECs to become market participants, including registration procedures, eligibility criteria, and obligations.

2. Grid Connection: The act specified the rules and procedures for grid connection of CECs as well as technical requirements, grid access conditions, connection agreements, and the rights and obligations of CECs in relation to the grid operator.

3. Electricity Trading: The regulations cover the purchase and sale of electricity, bilateral contracts, pricing mechanisms, balancing responsibilities, and settlement procedures.

4. Consumer Protection: The act made provisions to safeguard consumer interests when participating in or purchasing electricity from CECs. Aspects such as transparency, information disclosure, contract terms, dispute resolution mechanisms, and consumer rights in relation to CECs were covered.

However, the aspect of monitoring and control of LECs and communication with grid operators control systems like SCADA/DMS in the GENTE pilot project makes it necessary to ensure compliance with this legislative framework especially as it concerns consumer protection. The legislation framework for IoT (Internet of Things) in Sweden primarily revolves around data protection, privacy, and cybersecurity.

1. Data Protection and Privacy [18] : The General Data Protection Regulation (GDPR) provides guidelines for the collection, storage, and processing of personal data. When implementing IoT projects, organisations must ensure compliance with GDPR requirements, including obtaining user consent for data collection and providing transparent information about data usage. The guidelines cover: lawful basis for data processing, data minimization, transparency, personal data, and data transfer security as well as data retention period.

2. Cybersecurity: Organisations must prioritise cybersecurity measures to protect IoT devices, networks, and data. Agencies like the Swedish Civil Contingencies Agency (MSB) [19] and National Cyber Security Centre (NCSA) provide guidelines [20] for secure IoT operations, emphasising the importance of risk assessments, secure communication protocols, and regular software updates to mitigate vulnerabilities. These important recommendations cut across: risk management, incident response planning, security

governance, network and system security architecture, configuration management as well as identity and access management.

3. For the pilot project at HSBLL, Chalmers, several technologies and solutions were deployed such as:
    - Physical systems: 18kWp PV system, 7.2 kWh battery, two air-to-water heat pumps (Energy Save AWH 9kW-V64), three hot water storage multifunctional tanks (MWT 500C.1), EV charger etc.
    - Cyber-physical systems: sensors, smart metres, controllers, switches, multi heat pump control system (NordFlex), Machine Learning modules, Optimisation modules etc.
    - Communication systems: Modbus, MQTT, user interface, web interface, web API, Wi-Fi etc.
4. For the pilot project at Alingsåshem, technologies and solutions stated below were deployed:
    - Physical systems: solar cells (approx. 80,000-90,000 kWh/year), heat pumps (45-90 kW, air-water), modern control system.
    - Cyber-physical systems: sensors, smart metres, and controllers.

These technologies adhered to:

- Telecommunication Standards: In Sweden, acceptable technologies for IoT deployments include wireless communication technologies like cellular networks (such as 4G, 5G, and Narrowband IoT), Wi-Fi, Bluetooth Low Energy (BLE), and LPWAN (Low-Power Wide Area Network) technologies like LoRaWAN and Sigfox.

Some of the solutions these technologies provided includes:

- Enhanced flexibility and controllability of the load and heat demand in the building. Energy management system incorporated in the pilot project successfully controlled the charging of electric vehicles and achieved flexibility in terms of the percentage of contributions of the heat pumps and the district heating in serving the heat demand at the building.
- Energy cost and peak reduction in the building. Controllers used in the project were able to delay or shift the usage of the controllable loads to off-peak or low energy price periods based on the inputs it received from the users in real-time.

Switzerland

In 2017, the Swiss government introduced legislation relating to clean energy consumption at the community level [12]. In part, the legal framework was intended to encourage a concept of ‘clean energy consumption’ [13]. To maximise this effect, a legislative framework was established that defined a legal entity called the ‘grouping for clean energy consumption’ (ZEV) . The ZEV focuses on allowing grouping of several consumers with the intention of encouraging ‘clean energy consumption’, i.e., local production and consumption of renewable energy [14].

This base legal structure was further enhanced in subsequent legislation, including:

- The ZEV being defined and regulated as a legal entity,
- It acts as a single point of consumption from the point of view of the electricity network,
- The ZEV may include multiple buildings across multiple locations, but those locations must be physically co-located. In 2019, an amendment was introduced that allowed the ZEV to span a railway line, a water course, or a road, provided the owner of the intervening infrastructure provided their permission,
- Participants within the ZEV must be final consumers of at least one of the property owners within the ZEV.
- The ZEV is responsible for its internal organisation, in particular relating to legal obligations relating to the supply of electricity to its members.

From an electrical point of view, the ZEV must generate at least 10% of its energy needs from renewable energy sources within the community, with the energy sources themselves producing at least 500 hours of energy per annum in order to be taken into account. If the consumption of the ZEV exceeds 100MWh per annum, it is able to purchase energy from the wholesale market. Typically, a community with more than 30 private residences would meet this threshold. If the total capacity installed generation exceeds 30 kVA, the generation sources must be registered in the Swiss system for guarantees of origin.

The legal framework supports the creation of communities for private residences as well as those where consumers are under rental contracts. The proprietor of the rental property is responsible for the provision of electricity in this case. Tenants have the right to refuse to participate in an RCP where it is established by the building owner. In this case, they continue with their supply contract under normal conditions with the local utility.

A variation on the ZEV is the ‘self-consumption community’. The self-consumption community has similar characteristics to the ZEV, but the local utility takes responsibility for much of the coordination and commercial operations of participants. The most important differentiating aspect between the two concepts is the ‘grouping’ of consumers into a single entity, as seen by the local electricity network, in the ZEV. In contrast, in the self consumption community, the local utility implements the framework [15].

Recent legislation has been proposed to define the concept of a virtual ZEV, allowing the connection of dispersed self consumption communities or ZEV's. The approach has not yet been fully adopted, although regulatory sandboxes could be used to implement virtualisation for the purposes of research or pilot studies.

It is in this context that the GENTE solutions are proposed. GENTE should provide a suite of tools for self consumption communities and ZEV's that support optimisation for self consumption within and across communities. Specifically, in Switzerland, the GENTE IoT platform and associated technology stack are required to:

1. Manage a diverse range of DER to support decarbonisation and self consumption objectives.
2. Support community engagement through billing and contracting tools.
3. Securely handle sensitive consumer data.
4. Support the federation of dispersed communities.

Turkey

The GENTE technology concept aims to enhance the sustainability and energy efficiency of Local Energy Communities (LECs). The IoT platform development and demo-site integration will provide an integrated and sustainable solution for the efficient management of energy resources, resulting in reduced energy costs, decreased carbon footprint, and improved overall energy performance. The deployment of this technology is aligned with the European Union's objective of achieving a sustainable, secure, and competitive energy system by 2050.

Furthermore, the REENGEN Energy IoT Platform is designed to be scalable and adaptable to different use cases, such as microgrids, virtual power plants, and smart cities. The platform will enable the integration of distributed energy resources, such as renewable energy, energy storage systems, and electric vehicles, and facilitate their optimal use in the energy system. This will result in increased energy efficiency, reduced carbon emissions, and improved grid stability and resilience.

Reengen technologies aim to optimise energy management, enhance sustainability, and improve energy efficiency. Reengen IoT platform created in the context of the objective of developing a cross-functional IoT-based platform to integrate different data sources and run demonstrations provides integrated solutions that enable the optimal use of energy resources and facilitate communication and interaction between different stakeholders in the energy system, resulting in reduced energy costs, decreased carbon footprint, and improved overall energy performance.

The Reengen IoT Platform is currently in use at many locations in Turkey. By providing end-to-end data acquisition and analytics tools for the customers and smooth onboarding processes, the Reengen IoT platform reached high demand, addressing a wide range of customers from residential to big institutions and manufacturers. Reengen IoT Platform is also utilised in Turkish pilot sites in the scope of the GENTE project. The GENTE project utilises the Reengen IoT Platform as a data and analytics layer, which provides data acquisition from multiple sites and does specific analysis for different purposes by using a wide range of data, as well as providing data and communication with other partner platforms.

3. GENTE Conceptual Data Models

Conceptual data model - Overall system

This conceptual data model is the most abstract form of data model. The purpose of creating the overall system's conceptual data model is to organise, scope and define business concepts and rules. Platform-specific information, such as data types, sequences, procedures, triggers are all omitted from the conceptual data model. It defines what the GENTE system contains, but not how it is implemented.

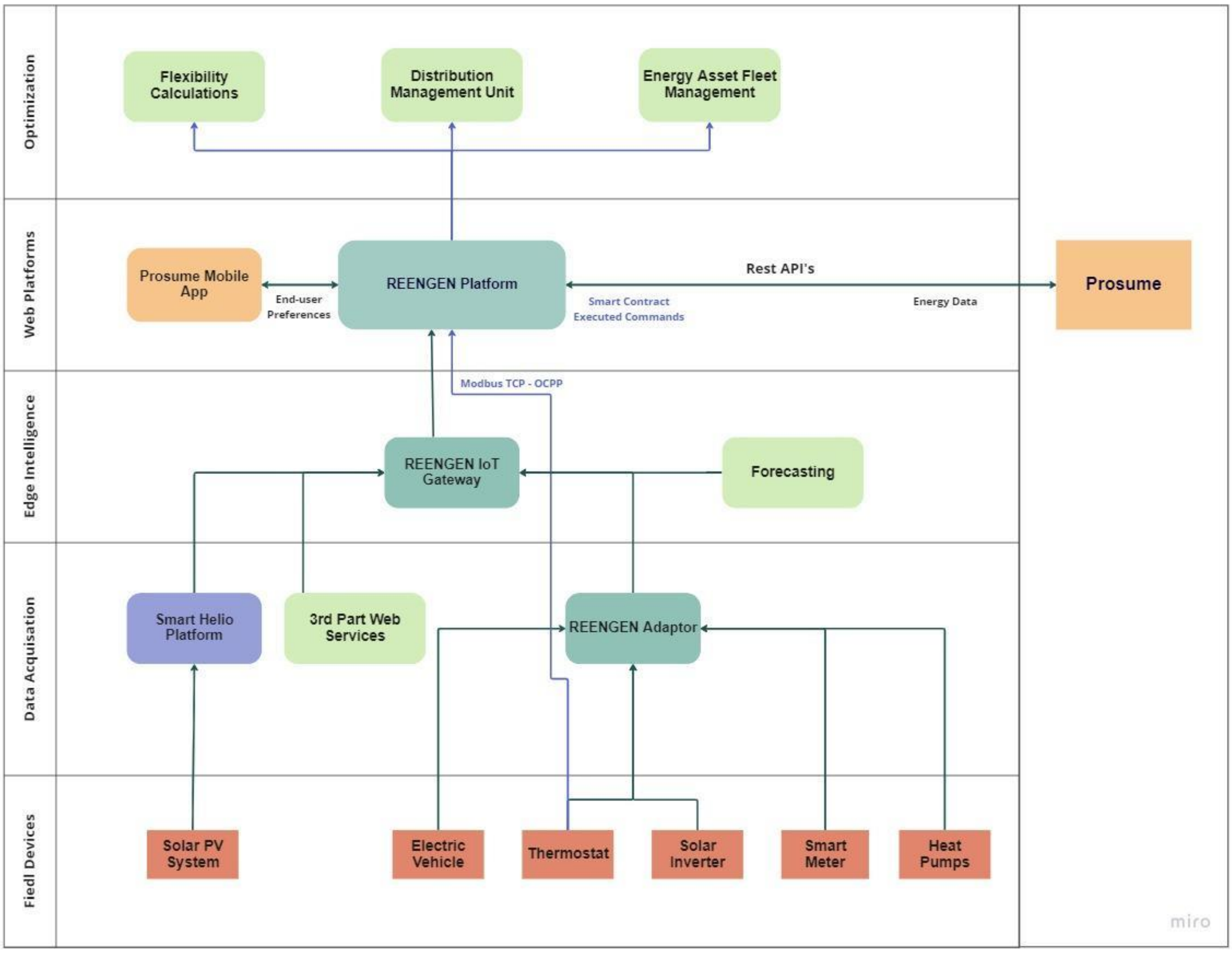


Figure 5: Conceptual Data Model-Overall System

Conceptual data model - Energy IoT Platform

The Reengen Energy IoT architecture enables the collection of data from various sources including IoT devices, solar inverters, smart meters, and other commercial sources. The data acquisition gateway acts as a data clearing house and customizable data connectors enable identification of data from different sources. Stream processors convert incoming data into a unified representation and user-defined rules are used to remove or mask personally identifiable data. The platform includes a comprehensive toolbox of analytic services and offers user-customizable dashboards for data visualisation. Cybersecurity threats are addressed through SSL encryption, SQL injection prevention, password hashing, and other best-practices. The platform architecture is designed to work on on-premise installations and tier-1 cloud providers and includes measures for data redundancy and increased query performance.

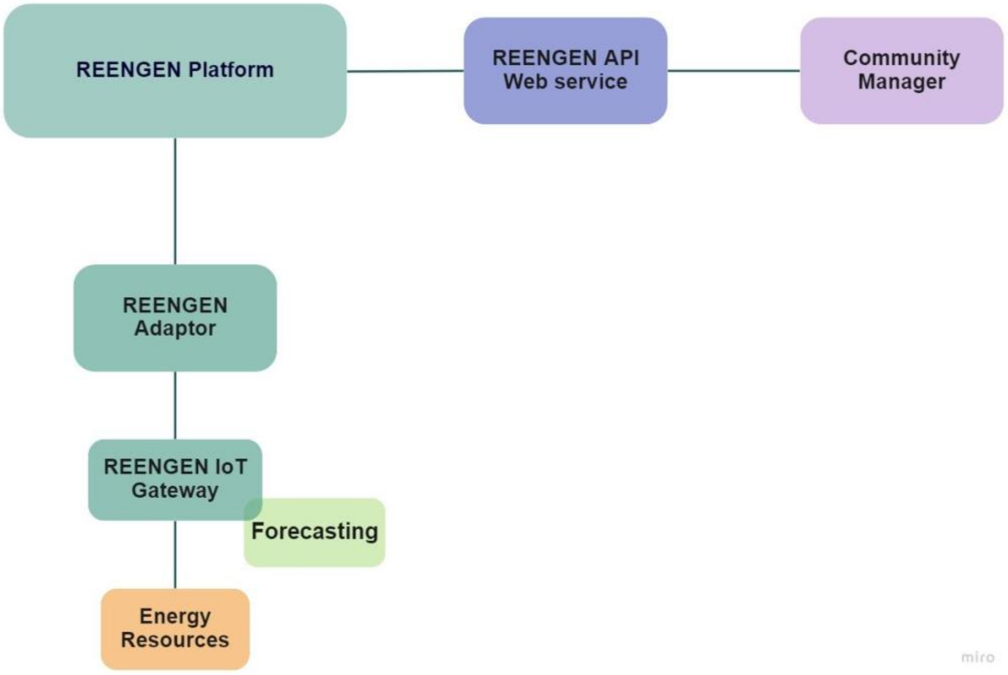


Figure 6: Conceptual Data Model-Energy IoT Platform

Conceptual data model - LEC optimisation / control

The conceptual data model for the optimisation platform is provided in Figure 7.

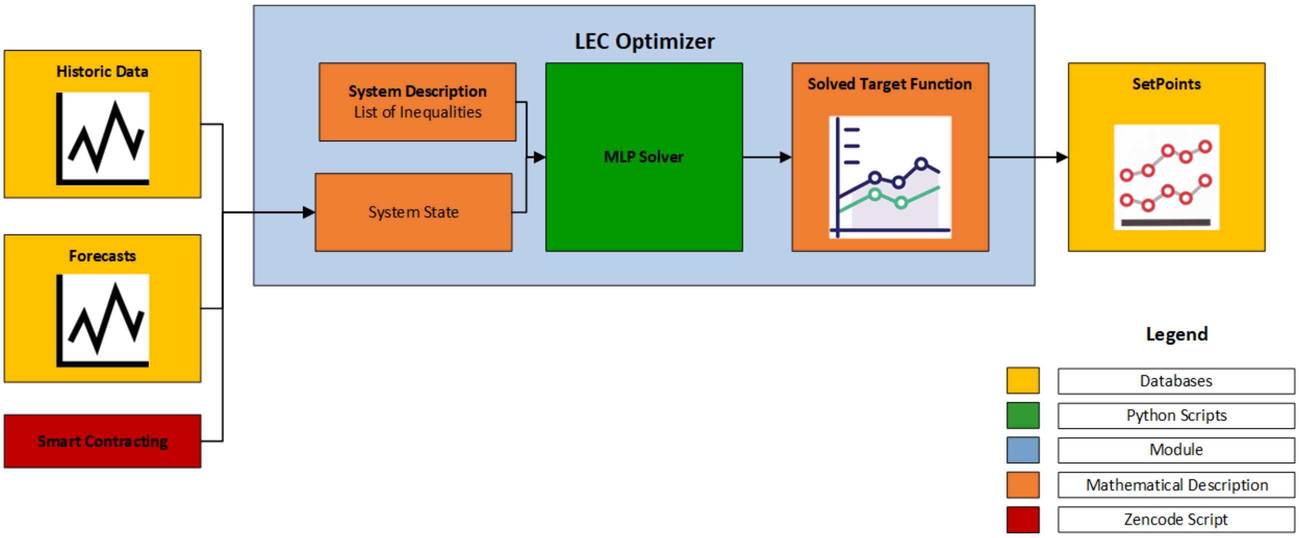


Figure 7 - Conceptual data model for LEC optimisation and smart contracting

In broad terms, the LEC optimisation/control module takes historical and forecasted consumption and generation data as inputs, and outputs setpoints for the controllable assets in the LEC, as shown in Figure 7. The historical data is related to energy consumption and generation within the LEC; this data is made available by either the REENGEN IoT Gateway or a pre-existing sensor gateway. The forecasted data predicts future energy consumption and generation patterns and depends on the historical data and other relevant factors, such as weather predictions. The historical and forecasted data is combined and processed to create a representation of the energy system state, this process is depicted by the 'System State' block in Fig. 7. Additional to the dynamic system states, the complete description of the system includes the 'System Description' represented in the block with the same name, and containing parameters such as maximum and minimum operation limits, and other constant predefined values that constitute a list of inequalities that must be satisfied. The multivariable linear programming (MLP) solver provides a solution to an optimization problem defined by the system state, encompassing both static and dynamic values. The primary objective of the MLP is to determine the values of the adjustable system settings such that a predefined optimization objective is achieved. The various optimization objectives for the multiple asset types are defined in section 2 (Platform services and functions). The obtained solutions are the target system settings for a specific time horizon, represented in the “Target Values” block. Finally, the “SetPoints” block receives the target values for the specified time horizon and uses these as set points for the controllers of the controllable assets, this way achieving the optimal operation of these and thus, the proposed goals for each asset type.

Conceptual data model - Smart contracting

As represented in the following Figure 9, the architecture is composed of the following layers:

- Field level layer: where the devices deployed at pilot sites (such as: gateways, smart meters, sensors, batteries, etc.) collect important data for energy value elaboration
- Communication middleware layer: composed of MQTT broker for exchange of messages between different system components and the Data storage which contains different data repositories, and by the Zenroom Virtual Machine that elaborates the business logics of the data collected and provides a layer of abstraction for simplified interaction
- Analytic services layer: which provides the core of analytical services by performing analysis of the data collected from devices and end users. This includes forecasting and LEC optimisation modules, as described in the previous section
- Interoperability layer: where external data sources, blockchain and user applications, can exchange the information that goes through the middleware layer and present it to the specific third-party service provider.

Taking into account the architecture shown in Figure 9, the main objective here is to enable Off-Chain Smart Contract execution while ensuring interoperability with other specific services like the optimisation of the LEC performance based forecasted consumption and production information gathering.

Users of the pilot sites could easily visualise information regarding their consumption, production and storage of energy measures in the PROSUME APP as taken from the Databases of the GENTE infrastructure without direct interaction with a Blockchain. Smart Contracts are not bound to a specific Blockchain of choice, rather they are being enclosed in the Virtual Machine of the PROSUME server dedicated to the project specific use case.

The Smart Contracts elaborated in the Zenroom Virtual Machine are decoupled from the visualisation platform of choice. In this specific case, the PROSUME APP will be provided as means to visualise data elaborated by the contracts which are being executed on a server that acts as a middle layer to simplify interoperation with the data collection and forecasting services.

The result is a micro service that performs some sort of reward mechanism following specific presets which are going to be defined based on the consumption and production habits of the pilot dwellings.

The computed rewards will take into account the optimisation produced by the LEC optimizer and the presets defined by the users and as result, communicate the information to the PROSUME Blockchain via REST API. The information provided will already be signed using a secret key whose public key is registered in the DID Document, and can be verified by 3rd parties, adding trust to the data output. The Document contains an EVM Blockchain Address, allowing the service to store data on EVM chains.

Real P2P trading based on blockchain environments is connected to a fully distributed key management for participants. Previously it was only done within decentralised exchanges on blockchain platforms. In the energy sector it is a novelty and has to be adapted to work fully automated and in line with the settings made by the participants as well as restrictions given by the energy management system.

A digital identity wallet enables a user to establish relationships and interact with third parties in a trusted manner. While the wallet aspect is mainly dealing with key management, storage aspects and the graphical interface, the third-party interactions are rather organised by agents. Agents handle third-party interactions on behalf of a user's interest.

This piece of software helps to stay in control of assets, security, privacy, purchases etc. And this is the critical part that has to be developed to establish a real P2P trading mechanism as well as compliance with GDPR and integration with the fiat payments in the banking system as provided by the PROSUME Platform. This is not in the scope of the GENTE Project, yet within the project we are demoing an architecture where such complexity and automation provided by off-chain Smart Contracts could easily be added to the actual system in place, as for the pilot sites being deployed in GENTE.

4. GENTE Logical Data Models

Data elements introduced in the Conceptual data model and whose general content is given in basic form are developed in logical data models. It defines how the system should be implemented regardless of the database management system. The purpose of creating the logical data model is to develop a technical map of rules and data structures.

Logical data models of GENTE help to define the detailed structure of the data elements in a system and the relationships between data elements. Logical data model refines the data elements introduced by the Conceptual data model. The Logical Data Model of GENTE Platform is presented in Figure 9. As can be seen in figure, there are several data sources outside of the platform. Reengen IoT Gateway is for retrieving data from different distributed energy assets such as smart meters, inverters and chargers. On the other hand GENTE Community Manager and Prosume Web 3 Platform are also communicated with the platform via API services provided. Once the data is provided, GENTE platform processes data, then organise and store this data in proper format. Each collected data is organized as a time stamp along with the linked measurement point, data type and unit value and is kept in relational databases.

Logical data model - Energy IoT Platform

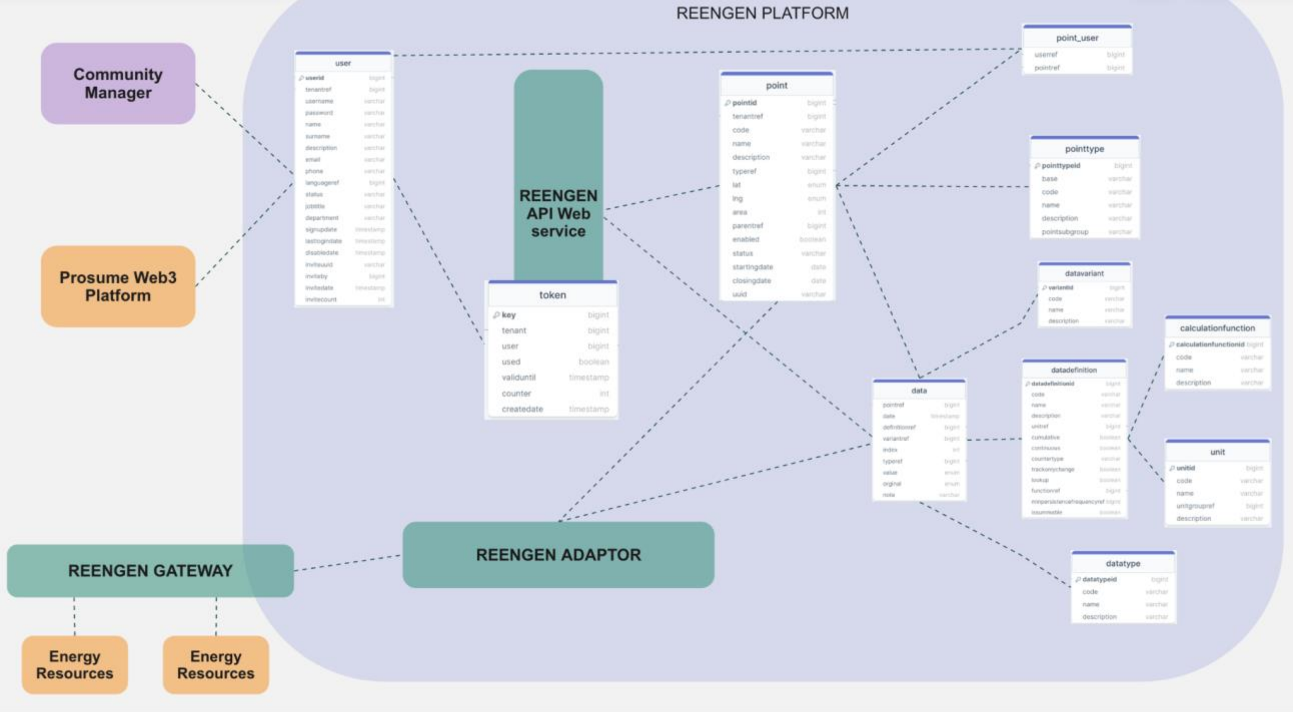


Figure 8: Logical data model – Energy IoT Platform

Reengen IoT gateway

Reengen energy IoT Gateways are used as hardware systems to collect data from a variety of sources including IoT devices such as analysers, solar inverters, and smart meters. The unique feature of the Reengen IoT gateways, which works based on a protocol-free basis, makes it substantially competent against other conventional IoT gateways. It means that any devices that work through any kind of protocol (Modbus, HTTP etc.) will be compatible with Reengen IoT gateways and transmit data to the Reengen IoT platform seamlessly. Reengen IoT Gateways are also capable of edge-computing processes, meaning that required calculations, mainly composed of basic ones, can be done at IoT gateway devices to facilitate the partial workload of the Reengen clouds.

Reengen IoT Gateway is hardware that is used to gather real-time data from a variety of sources such as analyzers, solar inverters, and smart meters. Aggregated data then is pushed to the Reengen Adaptors, where the collected data is unified depending on the specified definition and variants for each corresponding data type and pushed into the Reengen platform database servers. Stored data within the Reengen IoT Platform databases can be reached through the Reengen API service. Other project partner platforms and community managers can use the API Service through the credentials and endpoints provided by the Reengen IT team for specific data.

Data Management

In the Reengen Energy IoT architecture, data can be collected from a variety of sources including IoT devices such as sensors and analysers, solar inverters, smart meters, heat pumps, thermostats, and other commercial data sources. The data enters the system through the data acquisition gateway, which acts as a data clearinghouse.

Customizable data connectors allow the platform to identify data from different sources. In addition to standard data protocols such as Modbus TCP and SNMP, custom data schemas can also be defined to read virtually any custom tabular data format stored in files, databases, or served by APIs.

In addition to the Modbus and SNMP protocols, the following connectors can be used to transfer data from remote data sources:

SQL: Data can be read from a remote MySQL or SQL Server database by running an SQL query on one or multiple tables. This is the preferred method to read data from OPC or other compatible automation systems.

FTP Filestream: CSV files stored on remote FTP sites are transferred to the data collection server. Processed files' extensions are renamed to read.

FTP: CSV files transferred to an FTP server hosted by us are processed the same way as the FTP Filestream connector.

HTTP: A chain of steps can be defined including authorization and data validation, and the ensuing requests are sent to an HTTP endpoint, and the results are processed.

MongoDB: Data can be read from a MongoDB database by running a query on the database.

The stream processors will convert all incoming data to a unified data representation for efficient processing downstream. They will serve as the means of flowing data across the platform.

Data Adaptors

Once data is acquired, identified, and placed in data streams, all personally identifiable data can be removed or masked by user-defined rule sets. Sensitive data can be encrypted using state-of-the-art methods that are especially resistant to brute-force attacks.

Data analytics include a comprehensive toolbox of analytic services ranging from simple linear regression to advanced machine learning algorithms. The results produced by the data analytics toolbox can be easily visualised on user customizable dashboards featuring a rich variety of charts, tables, and reports.

Security Issues

Cybersecurity threats are countered by following the best-practices for SSL encryption, SQL injection, user input filtering, password hashing, rate limiting, and static analysis of the source code. Extensive server logs detailing all user actions are also kept. On the server side, server software components are kept up to date, all traffic is constantly analysed, and server logs are checked regularly against possible intrusion attempts.

A highly performance big data platform requires the careful selection of the underlying hardware and software, effective monitoring and utilisation of said resources, and robust measures against downtime and data loss. Data replication is used to provide data redundancy and is also used to increase query performance. Data sharing is used to divide data into manageable chunks spread over multiple servers. The Reengen Energy IoT platform architecture was designed to work on both on-premise installations and tier-1 cloud providers supporting virtual servers, block storage, and virtual private networking.

Logical data model - LEC Optimisation / Control

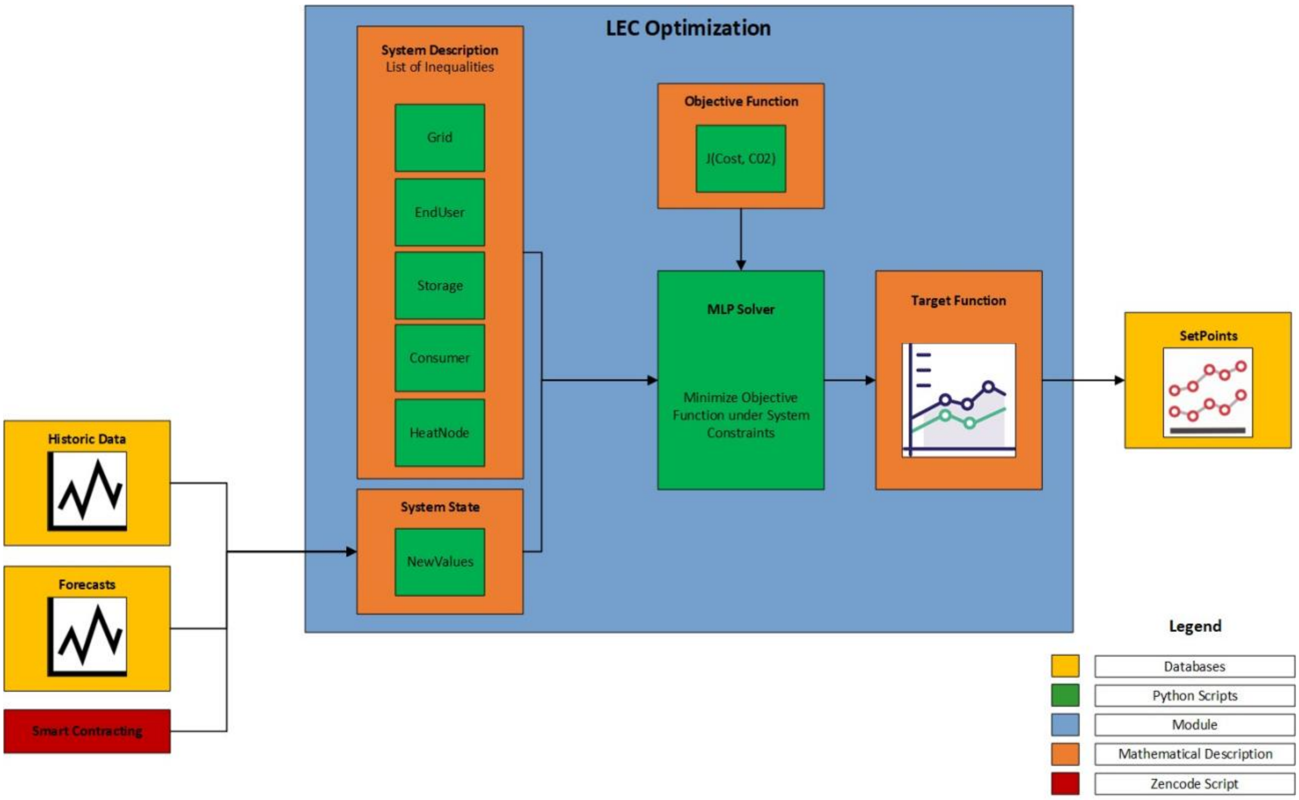


Figure 9 - Logical data model - LEC optimisation and control

The LEC Optimisation and Control module is a software solution that integrates seamlessly with other modules, including the gateway for sensor data acquisition and the integration of the constraints delivered by the smart contract module. The detailed structure of the data elements for this module is shown in Fig. 9. The LEC optimiser leverages historical, real-time and forecasted data related to energy consumption and generation within the LEC, including energy usage patterns, load profiles and generation from the various sources available, including PV systems. These inputs are combined with the flexibility-related restrictions generated by the smart contract module to update the dynamic states of the system. To wholly define the state of the system, static system parameters are also considered, these include maximum and minimum operation limits, and other constant predefined values related to the different system assets. The static system parameters also serve to impose constraints and inequalities that govern the behaviour of the LEC, which is necessary to achieve model-based control. The different constraints depend on the considered assets to impose limits, e.g. for the grid there exist limits on the amount of power pushed and pulled, and there are predefined consumption and generation prices; for storage systems there are limits on allowable SoC, charging/discharging power, and predefined times at which the SoC must have a minimum value; consumers may have predefined tariffs for power consumption and generation; and heat nodes may be defined by minimum and maximum temperatures, maximum flow values, power consumption and other physical factors. The complete state of the system, as well as other operational restrictions within the community (possibly included by the smart contracts) are the basis for the MLP solver. The MLP solver will optimize a chosen objective function while satisfying operational limits and the system parameters. The objective function can be set as e.g. minimizing costs, minimizing CO2 emissions or maximizing self-consumption (autonomy from the utility grid). The MLP solver manipulates the decision variables of the system and converges when these satisfy a predefined stopping criteria, ensuring that the outputs have reached a sufficiently small optimality gap. The MLP solver produces the optimal values for the decision variables for predefined time horizon and time step values, and this information is given in the format of a time series. The time series values are used as set points for the real-time control systems which are in charge of ensuring that the real values reach the given target values. This way, the LEC optimizer and control module is an essential analytic service, enabling LECs to optimize their energy management, reduce costs, and minimize carbon footprints, while promoting sustainability and resilience.

Logical data model - Smart contracting

The following image describes the data model being implemented for the communication between the services as elaborated in the GENTE Platform and the Zenroom Virtual Machine deployed on the PROSUME server:

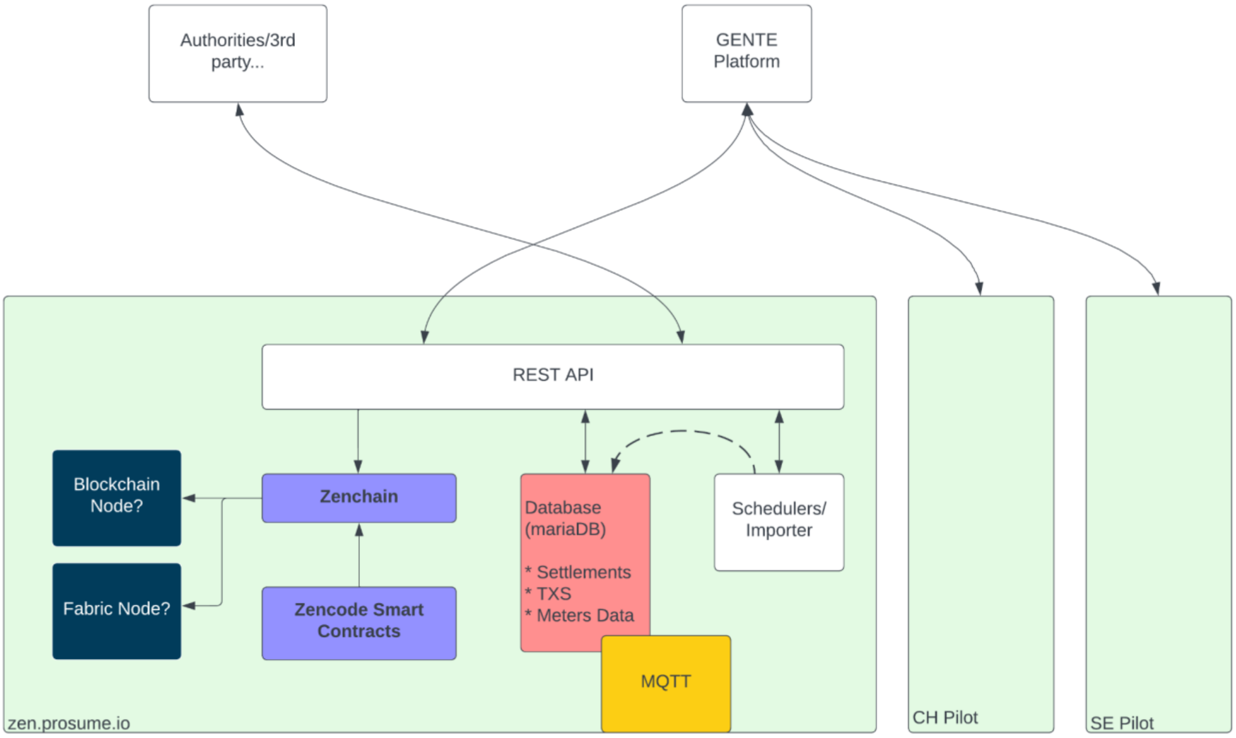


Figure 10 - Logical data model - Smart Contracting

In order to not interfere with the data collection and data harmonisation of the various services connected to GENTE Platform, the processing of data into Smart Contracts is relegated to the PROSUME server where data is being collected via REST API. The results of the Smart Contracts execution are then returned to the GENTE Platform through the same API.

The API stores the needed information regarding energy consumption, production, device identification, and any possible action that needs to be computed into the Smart Contracts, on a local DB (MySQL like) for faster processing. This information is then retrieved by the Zenroom VM that concatenates the single contracts written in Zencode language in a Zenchain. The Zenchain simplifies the Smart Contract execution by splitting each specific Business Logic in smaller contracts that can be easily modified and substituted if only a portion of the logic needs to be changed.

The final results of the Zenchain, once completely executed, are sent to a specific Ledger for certification purposes, to the GENTE Platform for retrieval of required information or to a payment Blockchain in case a token transaction is needed.

The **Zencode Smart Contracts** are concatenated in chains (so called "*Zenchain*") in order to execute **REST calls** and database operations, performed by the NodeJS based component which is also programmed in Zencode. Zenchains offer a linear flow that is easy to read and is edited and tested inside the Apiroom online IDE (https://apiroom.net).
A Zenchain can be called via a **REST API**, once all the contracts in the chain are executed successfully, the output is returned to the caller. Extending the chain to perform database operations or posting the output on 3rd party services, can be implemented and tested within minutes.

The microservice performing the reward via API is based on the "*Zenswarm*" **oracle** technology: **Zenswarm** is built on top of **Zenroom** and **Restroom-mw**, it can listen and react to an EVM emitted event, it creates its own **private keys**, **DID document** and registers a DID on the did.dyne.org service.

Data Model

The REST API accepts data formatted in JSON, once defined what type of data is being feeded to the Zenroom VM either directly or via the local Database, then the Smart Contract can easily be implemented and tested. For example, we can use as input energy consumption and production data as taken from an household metering device, the data would look like the following (see Fig. 11)

Figure 11 - Rest API Call in JSON Format

```
{

      "result": {

"eddsa_signature":
"2RyaPikmeuvpPyQpPk83EPnZmcW9dEjZWXMhTWkBM5CUoTiu5VVaRgqiTrncaWPKVxz8YuWLQ7XRe57
9yzppm1W5",

        "output": [{

            "value": "0",

            "energy_exported": "437",

            "energy_imported": "8020",

            "household_id": "CH01",

            "period_duration": "36944",

            "period_start": "1699506087",

            "reward": "80"

          }, {

            "value": "1",

            "energy_exported": "0",

            "energy_imported": "941",

            "household_id": "CH01",

            "period_duration": "6256",

            "period_start": "1699543031",

            "reward": "4 }]},
```

Logical data model - Variations for demonstration sites

Am Aawasser

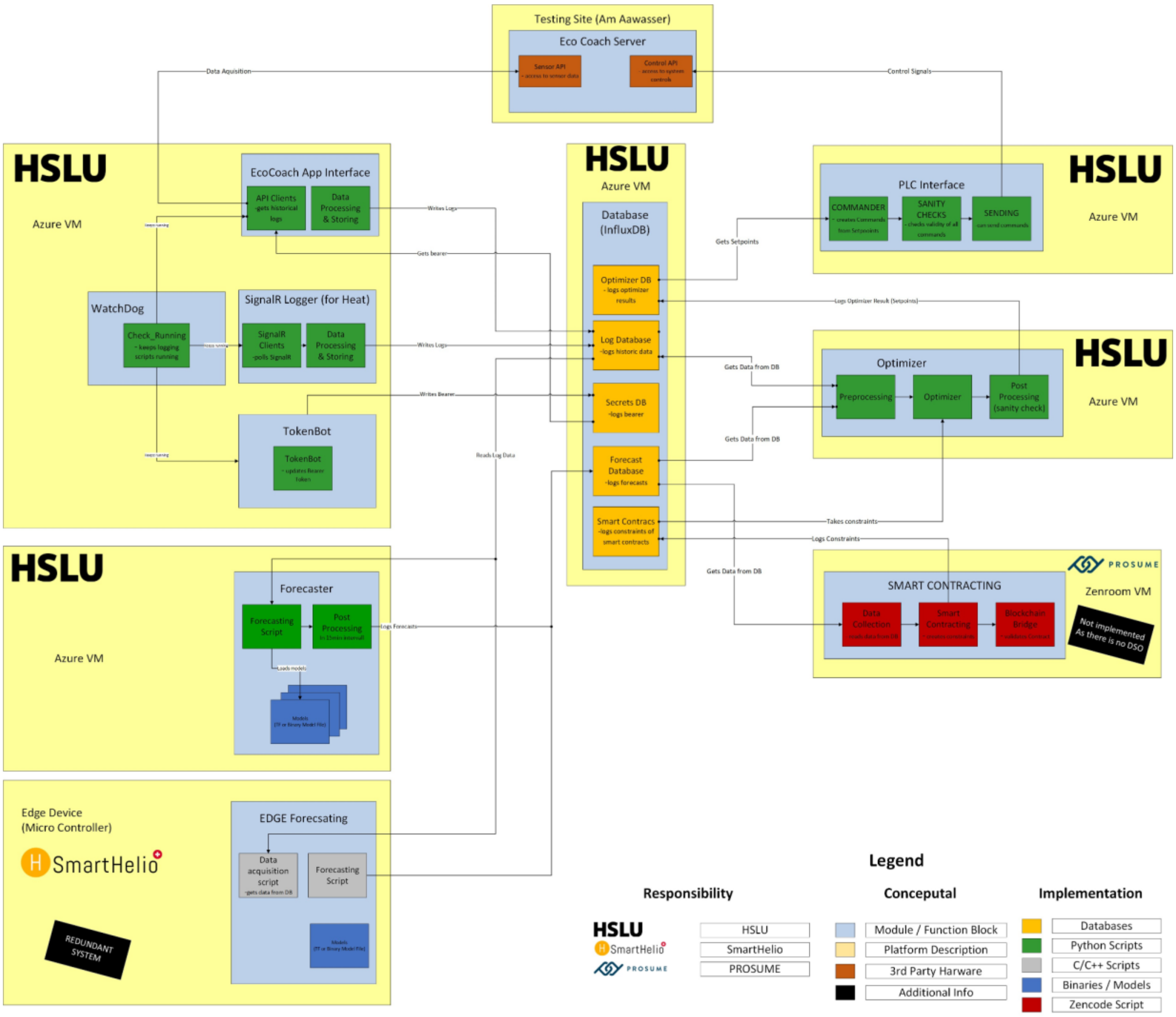
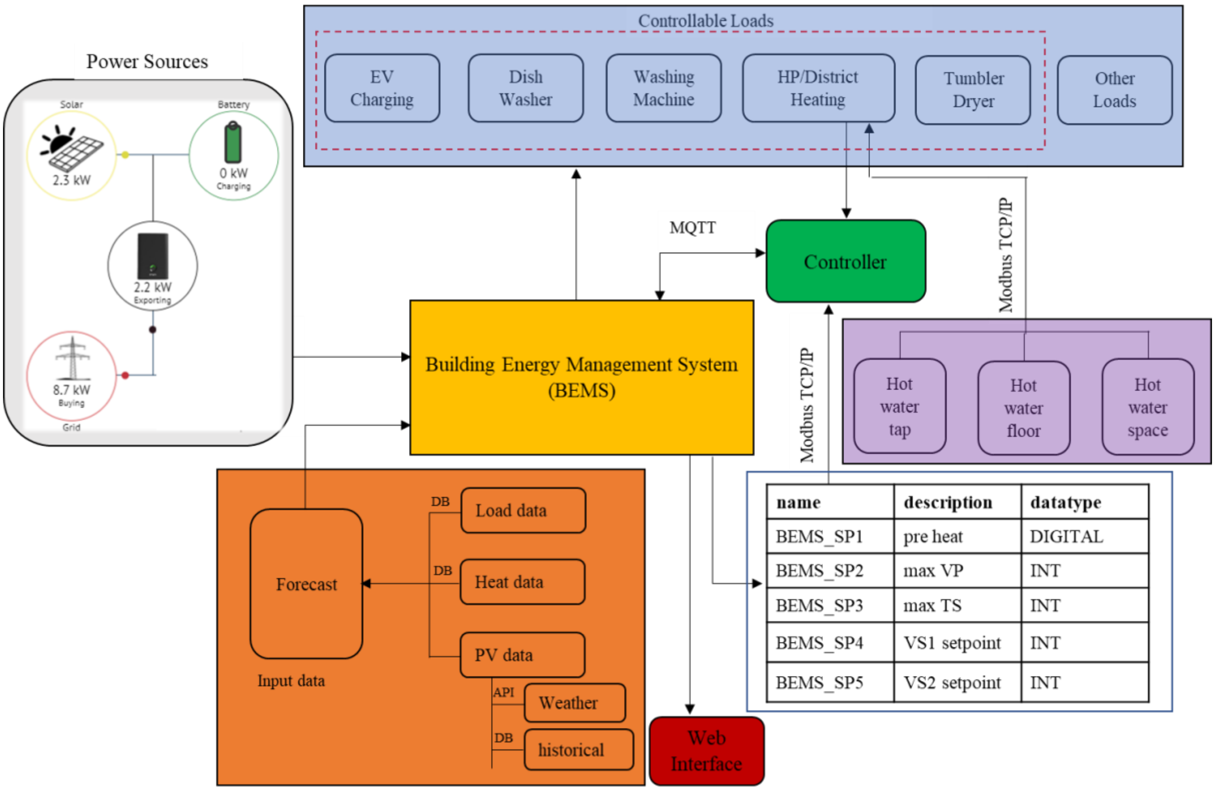


Figure 12 - Logical data model - Am Aawasser

Figure 12 describes the GENTE project variation for the Am Aawasser demo site. The main two differences are that the Reengen Gateway cannot be used as there is a pre-existing solution for data acquisition at the demonstration site; the other difference is that the smart contracting module cannot be applied, as there is no DSO at this site. In this demonstration site, the communication with the hardware, i.e. sensors and asset controllers, is achieved through the pre-existing Eco Coach Server. The Eco Coach Server includes the sensors API which sends the measured data to the Eco Coach application interface.

This interface makes the data available both to the clients API to visualize consumption and generation in real-time (not including heat), and to the Data Processing & Storing unit. The historical log database receives information from the Data Processing & Storing units of both the EcoCoach, which writes the sensor information (except for heat node data), and the SignalR logger which writes the heat node information. The forecasting and edge forecasting (developed by Smart Helio) modules get information from the historical data database and write their outputs to the Forecast database. The Optimization module receives information from the Log (with historical data) and the Forecast databases, it then aggregates and preprocesses this information, finds the MLP-optimized solution and carries out a sanity check to finally obtain the setpoint time series; these are logged in the Optimizer database. The control setpoints are sent to the PLC interface which creates the commands for the controllable assets, making sure that all are valid points before sending them to the Control API of the Eco Coach Server.

Sweden HSB living lab (HSBLL)



name	description	datatype
BEMS_SP1	pre heat	DIGITAL
BEMS_SP2	max VP	INT
BEMS_SP3	max TS	INT
BEMS_SP4	VS1 setpoint	INT
BEMS_SP5	VS2 setpoint	INT

Figure 13: HSBLL Conceptual Data Model

Logical data model - Building Energy Management System (HSBLL, Chalmers)

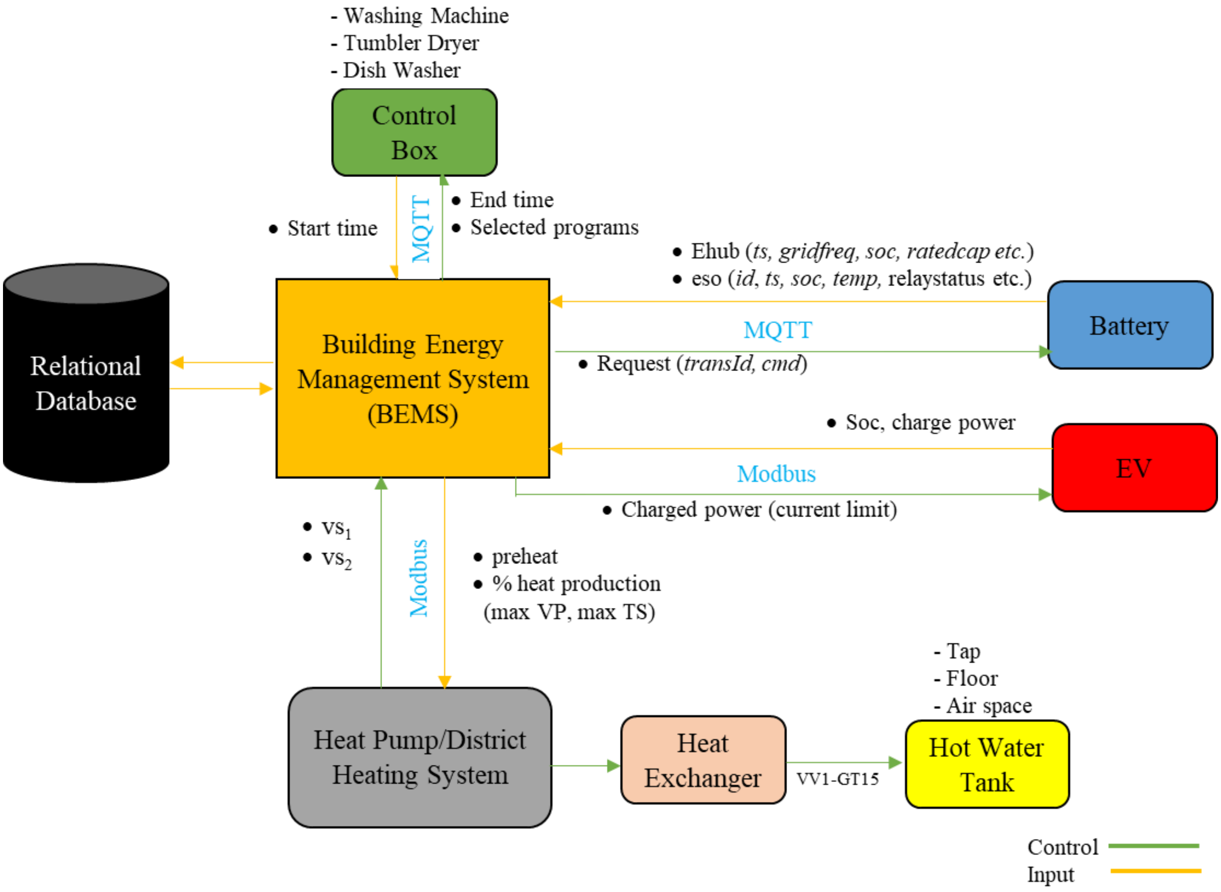


Figure 14: Logical Data Model HSB Living Lab

Figure 13 describes HSBLL residential building consisting of 29 apartments with electric vehicle charger with two 3-phase outlets, heating system that is composed of two heat pumps and three hot water storage tanks, washing machine, dish washer, tumbler dryer and other non-controllable loads, and the data communication between the components and the building energy management system (BEMS). The data communication between heat-pumps and BEMS as shown in Figure 14 is via Modbus, and optimal temp setpoints (VS1 and VS2) are the inputs, while preheat, heat production setpoints (max VP, max TS) are the outputs. Heat pumps alongside district heating and thermal energy storage provide the building's heating needs with level flexibility. During heating with a heat pump, temp is monitored and the moment the temp of the tap water (VV1-GT15) for an instance is below 50 C, the output of the heat-pump emanating from the heat exchanger goes to the hot water tank to ensure the temp is not below 50 C. Other components of HSBLL and technologies that involve data communication includes:

- **Battery:** for data communication between battery and BEMS, some input attributes like ehub, eso are being utilised and communicated through MQTT protocol. Key attributes of ehub includes ts that describes the timestamp that messages are published, gridfreq estimates grid freq., soc provides the state of charge for the system, ratecap provides the rated capacity of the battery. On the other hand, key attributes for eso are id which is a unique identifier, ts that indicates the timestamp a message is published, temp measures temp inside eso, soc that determines the state of charge and relaystatus that provides the knowledge of the relay status. The control of this controllable/deferrable load in HSBLL is done via a ferroamp portal using a control command. Control (output) – request is the control attribute, and it has 2 predefined keys: transId and cmd. Only one request is accepted at a time, and it's executed in request-response-result sequential format.
- **EV:** communication between BEMS and EV is via Modbus with soc and charge power as inputs while charged power (current limit) is the control.

In principle, the data communication between the components of HSBLL is carried out through the centralised system called BEMS. The BEMS optimization model runs in a 5mins interval to obtain the optimization plan for controllable/deferrable loads like battery storage, EV etc., using some variables such as solar power production, energy usage, and energy spot price.

- **Control box**: similar to the data communication of other devices integrated into HSBLL BEMS, the washing machine, dryer and dishwasher communicates with BEMS via MQTT using optimal start times as input and end time and the selected program as control function after optimization.

Conclusion

In conclusion, the GENTE project has made significant strides in developing a comprehensive system architecture and data models for a cross-functional IoT-based platform. The project's core technology includes IoT platform integration for the optimisation of resources. GENTE deploys an advanced energy IoT platform for real-time monitoring and control of Local Energy Communities (LECs), facilitating communication to grid operators' control systems. The IoT platform acts as the backbone for developed integrated solutions, gathering high-quality data and incorporating forecasting algorithms, optimisation, and control strategies for LECs and associated services.

The project also implements innovative technologies like Zero-Knowledge Proof (ZKP) and Multi-Party Computation (MPC) to provide trustworthy and scalable services that can easily be integrated into the main GENTE Platform. This ensures privacy and confidentiality while preserving the added value of strong cryptographic tools and interoperability between the services and the Blockchains.

Within GENTE, smart contracting features are being developed depending on the specific requests of each pilot. These smart contracts are decoupled from the Blockchain and executed by the finite state virtual machine of Zenroom, providing flexibility and adaptability for future purposes.

The GENTE project also includes the development of a mobile app, a digital wallet that is a key management application, which provides a user with a graphical interface to store, manage and secure digital keys. These keys can be used to sign transactions, statements, credentials, documents, or claims, enabling a user to establish relationships and interact with third parties in a trusted manner.

The Reengen Energy IoT architecture enables the collection of data from various sources including IoT devices, solar inverters, smart meters, and other commercial sources. The data acquisition gateway acts as a data clearing house and customizable data connectors enable identification of data from different sources. Stream processors convert incoming data into a unified representation and user-defined rules are used to remove or mask personally identifiable data. The platform includes a comprehensive toolbox of analytic services and offers user-customizable dashboards for data visualisation.

Overall, the GENTE project has shown a strong commitment to developing a comprehensive system architecture and data models for a cross-functional IoT-based platform. As the project continues, it will be essential to fill in the details of the system architecture and data models to provide a more comprehensive understanding of the project's outcomes and potential impact."

References

1. Ministry of Enterprise and Innovation. (n.d.). Implementation of the Electricity Market Directive in the area of network activities. Retrieved from https://www.regeringen.se/rattsliga-dokument/lagradsremiss/2021/12/genomforande-av-elmarknadsdirektivet-nar-det-galler-natverksamhet/

2. Swedish Data Protection Authority. (n.d.). GDPR fundamental principle. Retrieved from https://www.imy.se/en/organisations/data-protection/this-applies-accordning-to-gdpr/the-gdpr-fundamental-principles/

3. Swedish Civil Contingencies Agency. (2019). Comprehensive cyber security action plan 2019–2022. Retrieved from https://www.msb.se/siteassets/dokument/publikationer/english-publications/comprehensive-cyber-security-action-plan-2019-2022---march-2019.pdf

4. National Cyber Security Centre. (2022). Cyber security in Sweden – recommended security measures.

5. Swiss Federal Office of Energy. (2021). Leitfaden Eigenverbrauch.

6. RS 730.01 - Ordonnance du 1er novembre 2017 sur l'énergie (OEne). (n.d.). Retrieved from https://www.fedlex.admin.ch/eli/cc/2017/763/fr

7. Swiss Federal Office of Energy. (2021). Leitfaden Eigenverbrauch.

8. Swissolar. (2021). Enquête sur le déploiement des RCP en Suisse Romande.

9. Giordano, A., Mastroianni, C., & Scarcello, L. (2020). Optimization model for IoT-aware energy exchange in energy communities for residential users. Electronics, 9(6), 1003.

10. USEF. "Flexibility Trading Protocol Specification." USEF Energy, April 20, 2020. https://www.usef.energy/usef-flexibility-trading-protocol-specification/

11. USEF. (n.d.). USEF Flexibility Trading Protocol Specification. Retrieved from https://www.usef.energy/usef-flexibility-trading-protocol-specification/

12. Swiss Federal Office of Energy, ‘Leitfaden Eigenverbrauch’, Jul. 2021.

13. RS 730.01 - Ordonnance du 1er novembre 2017 sur l’énergie (OEne). https://www.fedlex.admin.ch/eli/cc/2017/763/fr (accessed Dec. 09, 2022).

14. Swiss Federal Office of Energy, ‘Leitfaden Eigenverbrauch’, (2021).

15. Swissolar, ‘Enquête sur le déploiement des RCP en Suisse Romande’, (2021).

16. Mazidi, Mohammadreza and Steen, David et. Al (2023), A novel energy management system for optimal energy and flexibility scheduling of residential buildings: a case study in HSB Living Lab, IEEE - 2023 Asia Meeting on Environment and Electrical Engineering (EEE-AM).

17. Ministry of Enterprise and Innovation (Näringsdepartementet), “Implementation of the Electricity Market Directive in the area of network activities, ttps://www.regeringen.se/rattsliga-dokument/lagradsremiss/2021/12/genomforande-av-elmarknadsdirektivet-nar-det-galler-natverksamhet/.

18. Swedish Data Protection Authority (Datainspektionen), “GDPR fundamental principle”, https://www.imy.se/en/organisations/data-protection/this-applies-accordning-to-gdpr/the-gdpr-fundamental-principles/.

19. Swedish Civil Contingencies Agency (MSB) “Comprehensive cyber security action plan 2019–2022”, ttps://www.msb.se/siteassets/dokument/publikationer/english-publications/comprehensive-cyber-security-action-plan-2019-2022---march-2019.pdf, (2022).

20. National Cyber Security Centre (NCSA), “Cyber security in Sweden – recommended security measures” (2022).

FUNDING

This project has received funding in the framework of the joint programming initiative ERA-Net Smart Energy Systems’ focus initiative Digital Transformation for the Energy Transition, with support from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 883973.