GENTE

D9.3

ASSESSMENT OF DEMONSTRATION, IDENTIFICATION AND LESSONS LEARNED/BEST PRACTICES FOR REPLICATION

SUMMARY

This report provides a detailed description of the demonstration assessment in the GENTE pilot sites, and presents the lessons learned and best practices for replication in other energy communities.

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Abstract

The ERA-NetRE GENTE project focused on the development of a distributed governance toolkit for local energy communities (LECs). This toolkit integrates advanced digital technologies such as the Internet of Things (IoT), distributed ledger technology (DLT), edge processing, and artificial intelligence (AI) to enable autonomous energy resource management both within and across LECs, and to provide flexibility to energy networks. The project aimed to validate the developed solutions for the governance of LECs first at the laboratory level, and then in real, full-scale environments, to increase the technology readiness level (TRL) of these solutions. To achieve this, the GENTE project elements were tested in several pilots with diverse characteristics, offering a good representation of LECs. In total, GENTE had demonstrators at different scales in Sweden and Switzerland, showcasing solutions for new types of technologies and services in varying technical, environmental, and market contexts. This report provides a detailed description of the demonstration assessment in the GENTE pilots, and presents the lessons learned and best practices that have been identified for potential replication in other energy communities.

The GENTE project addressed key use cases, each targeting a distinct but interconnected area of energy management. These use cases include: grid flexibility provision, including self-consumption optimization and peak load management; CO_2 emissions reduction to promote sustainable practices; energy efficiency improvement, which aims to reduce energy costs and increase community autarky; and co-design process to engage users from the design phase and incorporate their needs in the technology solutions definition. The validation of the GENTE solution followed a three-layer approach that included functional performance tests, forecasting verification, and test case validation in real settings.

The project's approach included an assessment framework that evaluated the pilots using a range of Key Performance Indicators (KPIs) across energy, environmental, social, economic, and Information and Communication Technology (ICT) domains. This comprehensive assessment framework allowed for a thorough evaluation of the project's impact and the effectiveness of its solutions.

Key lessons were learned regarding data management, technical developments, and social aspects of energy communities. The project highlighted the need for clear data descriptors and the usefulness of tools like JSON-LD, RDF/OWL, and Data Spaces for embedding contextual information within datasets. It was found that simple linear scaling models for PV power forecasting performed as well as more complex AI models, suggesting that complex models and dedicated edge devices might not always be necessary for predicting solar power output. In addition, detailed modelling was found to be essential for precise simulations, particularly when analysing thermal dynamics within buildings. For the development of BEMS, co-optimization of energy consumption and flexibility provision is crucial, with flexibility offered as a reduction from a baseline power profile. The importance of early and continuous community engagement, the identification of local "energy pioneers", genuine stakeholder participation, and flexible planning were highlighted as key for the successful application of a co-design process for new energy communities. By synthesizing these learnings, the project aimed to provide valuable recommendations for future initiatives and the broader adoption of the developed solutions.

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List of Abbreviations

AA - Am Aawasser, Switzerland

AI - Artificial Intelligence

AHU - Air Handling Unit

BEMS - Building Energy Management System

BES - Battery Energy Storage

COP - Coefficient of Performance

DB - Database

DER - Distributed Energy Resources

DLT - Distributed Ledger Technology

DT - Digital Twin

DSO - Distribution System Operator

EC - Energy Community

EMS - Energy Management System

GRU - Gated Recurrent Unit

HP - Heat Pump

HSBLL - HSB Living Lab, Sweden

ICT - Information and Communication Technology

IoT - Internet of Things

JSON-LD - JavaScript Object Notation for Linked Data

KPI - Key Performance Indicator

LEC - Local Energy Community

LSTM - Long Short-Term Memory

PV - Photovoltaic

RDF/OWL - Resource Description Framework and Web Ontology Language

ROM - Reduced-Order Model

TRL - Technology Readiness Level

Introduction

The ERA-Net GENTE project aims to develop a distributed governance toolkit for local energy communities (LECs). This toolkit includes advanced digital technologies such as the internet of things (IoT), distributed ledger technology (DLT), edge processing and artificial intelligence (AI) for autonomous energy resource management within and across LECs and for flexibility provisions to energy networks.

The solutions developed within GENTE for the governance of LECs were validated first at the lab level, and then at real full-scale environments in order to increase technology readiness level (TRL) levels of solutions. GENTE project was tested in several pilots with diverse characteristics. This variety of pilots, from living labs to real environments, provides a good representation of LECs. GENTE has two demonstrators at different scales in Sweden and Switzerland, which can demonstrate solutions for new types of technologies and services in different technical, environmental and market contexts.

This document provides a comprehensive overview of the project's pilot implementations, summarizing the key findings and insights gained throughout their execution. Each pilot is briefly described, highlighting its scope and objectives, followed by an analysis of the main test results and calculated Key Performance Indicators (KPIs). Additionally, a validation overview is presented to assess the effectiveness and impact of the pilots in achieving their intended goals.

Following the evaluation of pilot outcomes, the document delves into the best practices and lessons learned throughout the project. These insights are categorized into three main aspects: (i) the deployment and operation of each pilot, considering challenges and successful strategies; (ii) technical developments, including innovations, optimizations, and integration efforts; and (iii) social aspects and the co-creation process, reflecting on stakeholder engagement, user feedback, and community involvement. By synthesizing these learnings, the document aims to provide valuable recommendations for future initiatives and the broader adoption of the developed solutions.

As a result, a guide with the best practices to integrate the GENTE toolkit and the services developed within the project is obtained.

Assessment framework overview

Deliverable 9.1 (D9.1) from the GENTE project gives a detailed overview of the validation methodology that was defined and the KPIs used for the assessment.

The GENTE project addresses five key use cases through its advanced toolkit, each targeting a distinct but interconnected area of energy management. These use cases are:

- Grid flexibility provision (UC1), including self-consumption optimization and peak load management;
- CO_2 emissions reduction (UC2) to promote sustainable practices;
- Energy efficiency improvement (UC3), which aims to reduce energy costs and increase community autarky;
- Community federation (UC4) to exploit the potential of aggregating several energy communities and manage them as a whole; and
- Co-design process (UC5) to engage users from the design phase and incorporate their needs in the technology solutions definition.

For the validation of the GENTE solution, a three-layer approach to test the technical and user-centered developments was defined in D9.1. The three layers included:

- **Functional Performance Tests**: These verify that the GENTE components are correctly installed and integrated, ensuring that all hardware and software systems work together.
- **Forecasting Verification**: The accuracy of forecasting algorithms for parameters like energy production, consumption, and weather conditions is evaluated to assess their reliability.
- **Test Case Validation**: The objectives of GENTE are tested in real settings by running test cases in each pilot. For example, tests include managing energy resources for self-consumption, reducing CO_2 emissions, and optimizing grid services.

A detailed explanation of these tests for each of the pilots can be found in the D9.1 report. That deliverable included the description for the Turkish pilots, which were no longer available with the withdrawal of the Turkish partners from the project. The main tests in which the validation focused were performed on the Swiss and Swedish pilots.

D9.1 also includes a list with all the energy, environmental, social, economic and ICT KPIs defined for the GENTE assessment, including a description and the calculation methodology for each of them.

Validation at Swiss pilots

Am Aawasser pilot overview

The Am Aawasser pilot site is located in Switzerland and includes a community of 23 apartments and a commercial space of 600 m^2. The site aims to achieve **a high level of autarky** through local electricity production from **run-of-river hydro** (85 kWp, producing around 120-300 MWh/year with a potential for 380 MWh/year) and **rooftop PV** (124 kWp, producing around 80-110 MWh/year). It also utilizes controllable energy resources such as a heat pump, local energy storage (260 kWh battery and 10.5 m^3 thermal storage), and controllable building services. The community's total electric usage is around 200 MWh/year. The site uses an existing optimization platform for real-time sensor measurements.

Due to a partner's departure, the project shifted to a **simulation-based approach for energy optimization**. The simulation uses real data readings from the site as input. The simulation includes a **Logger** for data collection, a **Forecaster** for predicting power consumption and production, and an **Optimizer** to manage energy flexibilities. The Optimizer can be tailored to different objectives: **CO_2 reduction, increased community autarky**, and **peak load management**. The project provides a toolkit of self-developed python libraries and scripts to support the creation of smarter local energy communities.

Validation tests at Am Awasser

Several tests were conducted in the Am Aawasser pilot site in Switzerland, which can be categorized into functional performance tests, forecasting verification and test case validation.

- **Functional performance tests**: This included a **Data Collection Test**. This test verified that all necessary data, including meteorological, load, and generation data, could be gathered and stored in a central database (InfluxDB). The test involved running a logging script for 30 days, during which both continuous and periodic data entries were successfully recorded, confirming the proper functioning of the data acquisition system.
- **Forecasting verification**: This test evaluated the accuracy of the production and consumption forecasts. The developed forecasting algorithm was compared to a benchmark algorithm, which assumed that the production and load for the upcoming day would be identical to those of the previous day. The load model achieved a **mean absolute loss of 5.201 kW**, outperforming the benchmark's 9.39 kW. The PV model also performed better than the benchmark, with an **absolute loss of 3.562 kW** compared to the benchmark's 8.193 kW. The relative energy loss for the load and PV models was also significantly lower than the benchmark.
- **Test case validation**: This involved adjusting the Optimizer's loss function to focus on different objectives depending on the test case. These tests were conducted within a simulation environment due to the departure of a project partner, which prevented the use of the originally planned IoT platform. The test cases were:

- **Test case 1 – CO_2 emissions reduction**: The loss function of the Optimizer was adjusted to minimize CO_2 emissions. Each energy source was assigned a CO_2 equivalence, allowing the system to factor in carbon emissions during the optimization process. The site achieved a **24% reduction in overall CO_2 emissions** in this scenario.
- **Test case 2 – Increase in community autarky**: The loss function was adjusted to reduce energy imports, maximizing self-consumption and increasing the site's autarky. The autarky of the community **increased from 61.91% to 74.81%** during this test.
- **Test case 3 – Peak load management**: The loss function was adjusted to minimize the maximum load on the grid by using all available energy flexibilities. This was done to distribute the load more evenly throughout the day, reducing peak demand and improving grid stability. The optimizer was able to reduce **power peaks by approximately 20%** and significantly reduce energy exports.

More detailed results for each validation test and test cases can be seen in the Deliverable 9.2 (D9.2) report. More detailed information about KPIs can be found in the D9.1 report.

KPIs achieved at Am Aawasser

The KPIs defined in D9.1 for each test case were calculated with the test results and shown in the D9.2 report together with a detailed discussion. Here, the most significant KPIs are included. More detailed results for each test case can be seen in the D9.2 report.

Test case 1: CO_2 emissions reduction

The objective of test case 1 was to reduce the CO_2 emissions by considering the on-site renewable production. The total CO_2 consumption in the baseline and optimized scenarios are shown in Table 1. The baseline scenario used the emissions factor for Spain's electricity grid as Spanish partners are part of the GENTE consortium and Spain's grid emissions factor is in the mid-range of European countries (see the D9.2 report for further details).

Table 1 - Environmental KPIs for test case 1 in Am Aawasser.

KPI	Name	Baseline scenario	Optimized scenario
KPI_ENV_1	CO_2 emissions during operation	16.1 tons	12.2 tons
KPI_ENV_2	Reduction of CO_2 emissions	-	24% (3.9 tons)

The **LEC optimization tool** developed in GENTE for the Am Aawasser site has the potential to **reduce 24% of CO_2 emissions** compared to a baseline controller. The target range for this KPI was 0–30% in CO_2 emissions reduction; this KPI has been met.

Test case 2: Increase in community autarky

The second test case focuses on increasing community autarky by minimizing the electricity consumption from the grid and maximizing the self-consumption within the community. The relevant KPIs are shown in Table 2.

Table 2 - Energy KPIs for test case 2 in Am Aawasser.

KPI	Name	Baseline scenario	Optimized scenario
KPI_EN_2	Final energy consumption in the LEC	200 MWh/year	
KPI_EN_4	On-site renewable energy consumption in the LEC	123.82 MWh/year	149.62 MWh/year
KPI_EN_5	LEC self-consumption quota	61.91%	74.81%
KPI_EN_7	Grid electricity usage reduction	-	33.87% (25.8 MWh/year)

Using the LEC optimization tool showed a **reduction on the grid usage of 33.87%** in Am Aawasser and an **increase of 12.9% in the LEC self-consumption quota**.

Test case 3: Peak load management

The third test case in Am Aawasser is related to the reduction of peak load from the grid. The key calculations are presented in Table 3.

Table 3 - Energy KPIs for test case 3 in Am Aawasser.

KPI	Name	Optimized scenario
KPI_EN_7	Grid electricity usage reduction: *grid power import reduction*	19.78%
KPI_EN_7	Grid electricity usage reduction: *grid power export reduction*	131.12%

These results reveal that the new optimizer is expected **to reduce power peaks** (grid-supplied power) **by approximately 20%**. Particularly striking is the **131% reduction in energy exports**, largely attributed to significantly improved forecasting for both PV generation and load.

Validation overview for Am Awasser pilot

Functional performance tests confirmed successful data collection and accurate forecasting, with the models outperforming benchmark algorithms. The results of the three test cases showed: a 24%

reduction in overall CO_2 emissions, an increase in autarky from 61.91% to 74.81%, a reduction of 25.8 MWh/year in grid imports, an increase of 25.8 MWh per year in energy consumed directly by the LEC, a 19.78% reduction in power peaks from the grid, and a 131.12% reduction in energy exports. These results demonstrate the **effectiveness of the GENTE project's solutions in optimizing energy use within an LEC**.

Validation at Swedish pilots

HSB Living Lab pilot overview

The HSB Living Lab (HSBLL) is a **smart residential modular building with 29 apartments located on the Chalmers Campus** in Sweden, serving as a testbed for sustainable living solutions. It incorporates a variety of energy assets, including **PV panels on the facade and roof** (18 kWp), **air-to-water heat pumps**, **hot water storage tanks, EV charging**, and a **district heating connection.** HSBLL has an annual building consumption of around 83.5 MWh/year. The site also has a 7.2 kWh **battery** which can be charged by both solar panels and the grid. Additionally, HSBLL is equipped with around **2,000 sensors** that gather building data to examine the impact of resident behavior on energy consumption. HSBLL is designed for the application of innovation in human-centered systems and testing the performance of various functionalities in an intelligent grid context.

Due to a partner's departure, the originally planned IoT platform integration of all pilot sites could not continue. Energy optimizations at the HSBLL site were conducted near real-time from an on-premise system with provision of additional potentiality for cloud computing. The help of API technology made it possible to obtain real data readings from the testing site to ensure accurate input for the optimization algorithm. The implementations included a **Data Log** for data collection and storage; a **Forecaster** for predicting day-ahead PV generation and electricity & heat loads on an hourly basis; and an **Optimizer** to optimize energy production, usage, and flexibilities.

Validation tests at HSB Living Lab

Several tests were conducted in the HSBLL pilot site in Sweden, which can be categorized into functional performance tests, forecasting verification and test case validation.

- **Functional performance tests**: The functional performance tests at HSBLL focused on verifying the communication, execution of control commands, and data collection of new hardware developed or enhanced during the GENTE project. The tests involved commissioning and integrating the new hardware, as well as ensuring the proper functioning of communication between different systems.
    - **IoT Building Energy Management System (BEMS) including heat pumps**: Testing the integration of new hardware.
    - **Hybrid system control for the heat pump and district heating dispatch**: Testing the functioning of shared signals and controller communication between systems on-site, and also with the Chalmers cloud/BEMS.
    - **Sub-metering device**: Evaluating the performance of the sub-metering device developed by SmartHelio. This device measures the current, voltage, and temperature of selected PV modules and uploads data to the cloud for analysis.

- **Forecasting verification**: The forecasting algorithms were validated by comparing their results against a baseline method, actual data, or human expert predictions. The accuracy of these forecasts was evaluated using the Forecasting KPI *KPI_FO_1: Forecasting error*. The real measurements were compared to the forecasted values from the algorithms. The forecasting verification focused on the accuracy of algorithms for:
    - **PV production forecasting**: Using solar radiation, humidity, and time factors.
    - **Consumers' load curves forecasting**: Using time factors and electric consumption data.
    - **Building/Heat forecasting**: Using time factors, outdoor temperature, and heat consumption data.
- **Test case validation**: Three specific test cases were applied to HSBLL, aiming at validating different aspects of energy management. The test cases were:
    - **Test case 1 – CO_2 emissions reduction**: This test case aimed to evaluate the reduction of CO_2 emissions through optimizing dispatch between the heat pumps and district heating network. The optimization algorithms were run, and the optimal dispatch that minimized CO_2 emissions was calculated based on a real CO_2 emissions factor for the electricity grid. The performance was compared to a baseline generated using historical data. A digital twin (DT) of HSBLL developed as part of GENTE (Deliverable 5.3 (D5.3)) was also used to perform virtual testing.
    - **Test case 2 – Reduction in energy cost**: This test case validated the reduction of energy costs through the BEMS, extended in GENTE to integrate heat pumps. The building optimizer received spot market prices and network tariffs as inputs, and calculated the optimal setpoints to avoid peaks and reduce energy costs. The performance was evaluated against a baseline calculated using historical data. The DT of HSBLL was used to simulate a conventional scenario and a scenario with GENTE optimization.
    - **Test case 3 – Autarky increase**: This test case aimed to validate the autarky increase (self-consumption increase) at HSBLL by optimally managing the energy assets. The building optimizer calculated the optimal actuation to increase self-consumption, monitoring both electricity and heat import to evaluate the autarky level. The performance was compared against a baseline generated using historical data. The DT was used to simulate conventional and GENTE-optimized scenarios.

More detailed results for each validation test and test cases can be seen in the Deliverable 9.2 (D9.2) report. More detailed information about KPIs can be found in the D9.1 report.

KPIs achieved at HSB Living Lab

The KPIs defined in D9.1 for each test case were calculated with the test results and shown in the D9.2 report together with a detailed discussion. Here, the most significant KPIs are included. More detailed results for each test case can be seen in the D9.2 report.

Test case 1: CO_2 emissions reduction

The objective of test case 1 was to reduce CO_2 emissions of HSBLL by considering the on-site renewable production. The total CO_2 consumption in the baseline and optimized scenarios are shown in Table 4.

Table 4 - Environmental KPIs for test case 1 in HSB Living Lab.

KPI	Name	Baseline scenario	Optimized scenario
KPI_ENV_1	CO_2 emissions during operation	409.36 kg CO_2/kWh	383.46 kg CO_2/kWh
KPI_ENV_2	Reduction of CO_2 emissions	-	25.90 kg CO_2 reduced

The optimization tool developed in GENTE for HSBLL has the potential to **reduce CO_2 emissions by 6.3%** compared to a baseline scenario. The target range for this KPI was 0–30% in CO_2 emissions reduction; this KPI has been met. The impact of CO_2 reduction using this tool would be even more significant in countries where the emission factor for grid electricity is higher than in Sweden (which has one of the lowest grid emission factors in Europe).

Test case 2: Reduction in energy cost

The objective of test case 2 was to maximize the utilization of power from on-site PV generation to cover electrical demand and reduce imports from the grid. The energy costs for the baseline and optimized scenarios are shown in Table 5.

Table 5 - Cost KPI for test case 2 in HSB Living Lab.

KPI	Name	Baseline scenario	Optimized scenario
KPI_EC_1	Energy cost savings	€134.78 / week	€112.22 / week
	Reduction of energy costs	-	€22.56 / week @ SEK_to_EUR = 0.092

The building optimization tool developed in GENTE for HSBLL has the potential to **reduce energy costs by 16.7%** compared to a baseline controller. Additionally, it was observed that the optimization tool **flattened the electric load**, reducing peaks and dips. This means that the problem of peak demand can be addressed using the flexibility provided by both heating sources (heat pumps and district heating) and thermal and battery storage.

Test case 3: Increase in community autarky

The third test case focused on increasing community autarky by minimizing grid consumption and maximizing self-consumption within the community. The relevant KPIs are shown in Table 6. Actual demonstration of increasing autarky was not feasible because the total PV installation (and consequently its production) was always lower than the building's electricity demand during PV generation periods. As a result, all locally produced PV energy is fully self-consumed, achieving 100%

autarky, which cannot be further improved. Simulation studies were performed to show the potential for autarky improvement with scaled-up PV production capacity and the developed optimization tool.

Table 6 - Energy KPIs for test case 3 in HSB Living Lab.

KPI	Name	Baseline scenario	Optimized scenario
KPI_EN_2	Final energy consumption in the LEC	2793.65 kWh/week	2325.71 kWh/week
KPI_EN_4	On-site renewable energy consumption in the LEC		
	Summer	66.88 kWh/week	174.09 kWh/week
	Winter	2.12 kWh/week	44.26 kWh/week
	Spring	75.26 kWh/week	146.3 kWh/week
	Fall	8.61 kWh/week	80.57 kWh/week
KPI_EN_ 5	LEC self-consumption quota	100%	100%
	Autarky	5.47%	19.14%

These results show that, using the optimization tool developed in GENTE, autarky can be increased significantly in HSBLL across different seasons, especially winter, if PV production is improved. Autarky **increased from 5.47% with the baseline controller to 19.14% after optimization** based on the simulated result. The simulations showed a change in load profile when PV production exceeded demand, with surplus energy utilized for charging EVs, batteries, and thermal storage tanks instead of being exported to the grid.

Validation overview for HSB Living Lab pilot

The functional performance tests at HSBLL confirmed **successful data collection and accurate forecasting**, with the models outperforming benchmark algorithms. The GENTE project conducted three test cases at HSBLL. The developed building energy optimization tool achieved a **6.3% reduction in CO_2 emissions** compared to a baseline controller. The tool **reduced energy costs by 16.7%** compared to a baseline controller, and flattened the electric load, reducing peaks and dips. Simulations showed that autarky can be significantly increased across different seasons, especially during winter, if PV production is improved. Autarky **increased from 5.47% with the baseline controller to 19.14% after optimization** based on the simulated result. These results demonstrate the effectiveness of the GENTE project's solutions in optimizing energy use within HSBLL.

Best practices and lessons learned

Am Aawasser

The data from the demo site is stored in InfluxDB, a widely used, open-source time series database. This is hosted within a Docker container on a virtual Linux machine running on an Azure Server, ensuring a scalable and modern infrastructure following IT best practices. The careful design of this architecture has proven beneficial for future modifications and scalability, making it a forward-looking solution.

For data storage, InfluxDB was chosen due to its reliability and widespread adoption for time series data management. The use of Docker containers ensures that the entire solution is easily portable and can be migrated to other systems with minimal effort, making it highly adaptable.

Data ingestion is managed by a logging script that operates in a separate Docker container, adding flexibility and ensuring modularity in the system. This separation also makes it easier to maintain and update different components independently.

Additionally, the InfluxDB container also hosts a Forecast DB, where all forecast data is stored. This forecast data, including predictions for PV generation and electrical loads, is generated by another container running forecasting algorithms. The forecast data is then used to drive an Optimizer Algorithm, whose results are fed back into an Optimizer DB for further analysis and decision-making.

This architecture ensures a flexible, scalable, and efficient system capable of handling the evolving demands of the project, with the code made available for inclusion in the GENTE toolkit.

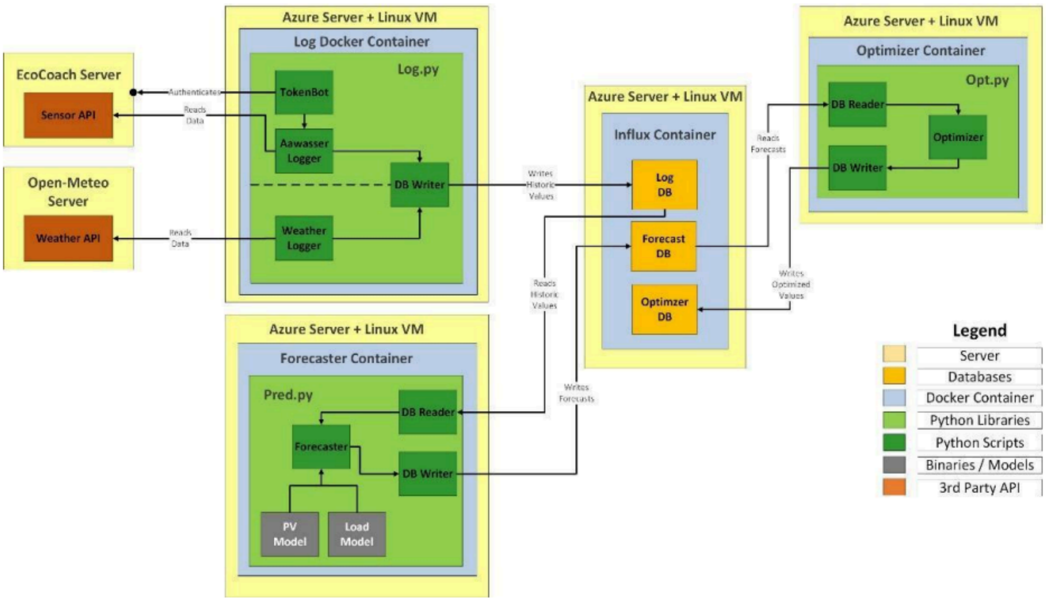

Figure 1 - Monitoring and deployment scheme in Am Aawasser.

The main difficulties were the changes to the IoT platform, which was to have been provided by one of the consortium members. Unfortunately, this partner left the project without a working IoT platform.

Table 7 - Missing IoT platform issue in Am Aawasser.

Missing IoT platform	
Type of issue	Organizational & Technical
When was it detected?	June 2024
Explanation of the issue	Withdrawal of a consortium member from the project due to funding difficulties. This partner, Reengen, was the provider of the IoT platform.
Adopted solution	Use of an existing proprietary platform. Also use simulations to get results.
Recommendation to avoid it	Have two consortium members working on key project deliverables and developments, so that the other can take on more of the workload.

At the initial stages of reading data from the demo site and configuring the time series database, a key challenge was the lack of clarity around the nature of the data provided. Specifically, the data descriptors were often too brief, and critical context information was missing, making it difficult to fully understand what the data represented. This issue became apparent in December 2023, during the early phases of data integration from a third-party source.

Table 8 - Data description issue in Am Aawasser.

Data description	
Type of issue	Technical
When was it detected?	December 2023
Explanation of the issue	The data received from external sources lacked sufficient context, as the descriptors were too short or unclear. Without proper context, interpreting and processing the data accurately posed significant challenges.
Adopted solution	To resolve the issue, the team reached out to the data provider for more detailed information and clarification on the nature and structure of the data. This helped fill in the gaps and provided the necessary context to proceed with accurate data integration.
Recommendation to avoid it	To avoid such issues in the future, it is essential to implement concepts for including contextual information within the data itself. For example: JSON-LD (JavaScript Object Notation for Linked Data) can be used to embed linked data and provide context.

	RDF/OWL (Resource Description Framework and Web Ontology Language) can offer semantic structuring for data, helping describe relationships between different datasets. Data Spaces offer a framework for better data governance and interoperability, ensuring that the necessary context is included alongside the data. Exploring and applying these concepts would significantly improve data clarity and make external data sources easier to understand, reducing reliance on manual clarification and improving the overall efficiency of data integration.

HSB Living Lab

The setup for HSBLL involved integrating several key components to enable energy optimization and flexibility. Due to Reengen's departure from the project, the original plan for an IoT platform integration was modified. Instead, energy optimizations were performed in near real-time using an on-premises system that also had the potential for cloud computing. The implementation integrated servers, various Python scripts in modules, third-party APIs, a database (DB), and distributed energy resources (DERs). Key elements of the setup included:

- **Data Log**: This Python module collected data, such as weather variables, spot prices, electricity load, PV generation, heat load, and sensor data, from the HSBLL portal and Web Port using a tokenized API and stored it in an on-premises database.
- **Forecaster**: Located within the predict module, the Forecaster used pre-trained forecast models to predict day-ahead PV generation output, electricity, and heat loads for HSBLL on an hourly timestamp. It communicated with the optimizer, using optimized values for variables such as PV output, electricity consumption, and heat load for subsequent forecast cycles.
- **Optimizer**: The Optimizer addressed a predefined optimization problem using input variables like PV, electricity, and heat load forecasts, the heat pump's power coefficient (COP), spot prices, and temperature. It determined set points for the heat pumps, district heating system, and thermal energy storage, transmitting these set points directly to the devices via the Modbus Communication Protocol or through the Jeff Electronics platform web port. The objective function was aimed at reducing CO_2 emissions, reducing energy costs, or increasing community autarky.

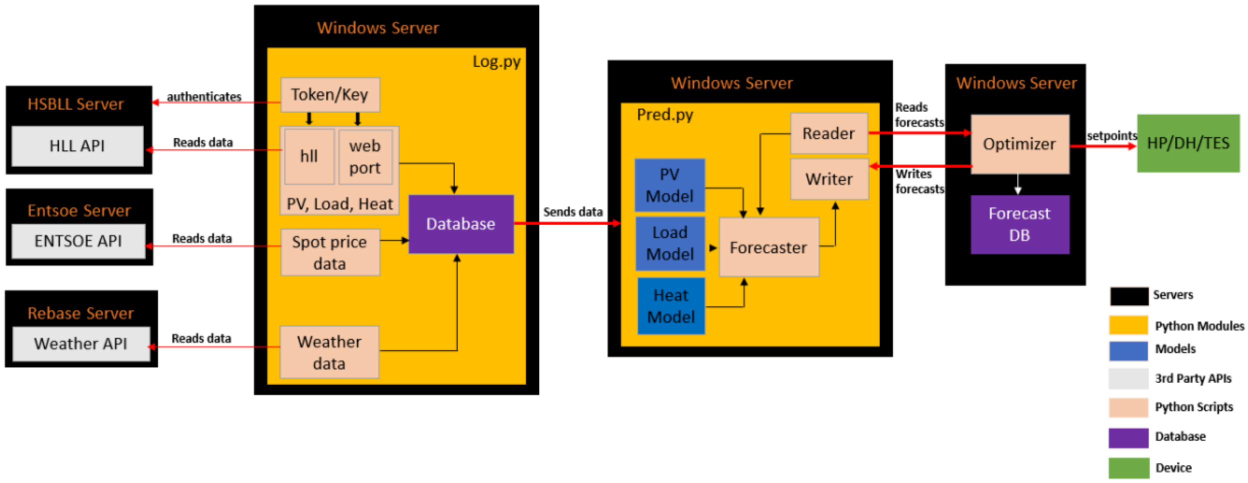

Figure 2 - Monitoring and deployment scheme in HSB Living Lab.

The main issue in HSBLL, analogously to Am Aawasser, was missing the IoT platform that was supposed to be provided by a partner that left the project. Table 9 describes the issue and subsequently adopted solution.

Table 9 - Missing IoT platform issue in HSB Living Lab.

Missing IoT platform	
Type of issue	Organizational & Technical
When was it detected?	June 2024
Explanation of the issue	Withdrawal of a consortium member from the project due to funding difficulties. This partner, Reengen, was the provider of the IoT platform.
Adopted solution	A revised approach was adopted, focusing on near real-time energy optimizations from an on-premises system with the potential for cloud computing.
Recommendation to avoid it	Have two consortium members working on key project deliverables and developments, so that the other can take on more of the workload.

Technical developments

Improving PV systems forecasting utilizing edge devices [T5.2]

T5.2 aimed at exploring the potential of utilizing edge devices for forecasting PV solar panel energy production within the context of the GENTE project. Various machine learning algorithms were investigated and implemented on an edge device to optimize the forecasting model. This exploration is driven by the desire to take advantage of the increasing computational power of edge devices, which can potentially reduce reliance on centralised data collection and minimize latency.

The comparison among the different algorithms showed that a simpler model, based on linear scaling of weather predictions, performed as well as other complex models that were tested.

Consequently, the following lesson learned was extracted from that task:

> Due to the availability of precise weather predictions, **using a more complex AI model for PV-power forecasting was found to be unnecessary**. The accuracy of weather models and the strong correlation between forecasted irradiance and actual PV power output make simpler models sufficient.

So, one of the key conclusions reached is that a simple linear scaling model, which multiplies forecasted irradiance values by a constant factor, performs as well as more complex models, like XGBoost, for predicting solar power output. This finding is significant because it suggests that for this specific application within the GENTE project, dedicating a separate edge device to run a computationally intensive algorithm might be unnecessary. Since the calculation itself is straightforward, the recommendation is using existing computer infrastructure, such as a server, which already has an internet connection and can easily handle the task of fetching weather forecasts and applying the scaling factor.

Therefore, the recommendation to use an existing computer or server over a dedicated edge device stems from the simplicity of the calculation and the fact that the model relies primarily on external data, namely weather forecasts, rather than local data collected by the edge device. Therefore, it can be stated that:

> It is recommended to **run the forecasting code on an existing computer or server with an internet connection** rather than a dedicated edge device due to the simplicity of the calculation.

Development of Community Digital Twin [T5.3]

A digital twin (DT) was developed for HSBLL. The process is shown in the D5.3 report, and a series of lessons learned can be extracted.

Regarding the importance of detailed modelling for accurate results, an analysis on the temperature tracking was conducted for different aggregation levels, going from having a thermal zone for each room to a higher aggregation of considering the whole plant or even the whole building. Simulating individual rooms as distinct thermal zones yielded highly accurate temperature tracking due to the detailed integration of specific ventilation rates and internal heat gain patterns. However, when the model was expanded to include larger areas like entire floors or the whole building, accuracy decreased because variables like ventilation and occupancy patterns had to be generalized. This demonstrates that the level of detail in modelling directly affects the accuracy of the results, particularly in capturing dynamic thermal behavior.

Detailed models are essential for achieving precise simulations, especially when analysing thermal dynamics within buildings. This is important when considering indoor temperature conditions control.

The DT of HSBLL serves as a diagnostic tool, enabling the understanding of indoor conditions and energy consumption patterns. It helps identify rooms with thermal comfort issues or high energy usage. By pinpointing specific areas of concern, it allows for targeted energy efficiency improvements and problem-solving.

Digital twins can effectively diagnose issues related to energy consumption and thermal comfort, facilitating focused interventions.

Additionally, the DT serves as a valuable testbed for validating optimization algorithms before their physical deployment. It provides a simulation environment that closely mimics real-world behavior, bridging the gap between basic models and real-life applications. This allows for advanced debugging and validation, improving the reliability of the algorithms before they are implemented.

Digital twins provide a safe and realistic environment for testing and refining **optimization algorithms** before physical implementation.

Focusing on the results, the analysis of the energy consumption of the Air Handling Unit (AHU) components revealed that the heater had the highest energy demand. This was expected due to the building's location and the need for substantial heating to maintain comfortable indoor temperatures. Moreover, the AHU's energy consumption is significantly influenced by factors such as temperature setpoints, occupancy levels, and external conditions. A higher setpoint increases heating requirements, while occupancy levels and external temperatures directly affect consumption levels. Additionally, energy use rises with increased room size, compounded by occupancy and room use.

The combination of TEASER[1] for generating reduced-order models (ROMs) and AixLib[2] for detailed HVAC simulations allows for a balance between accuracy and speed in modelling HSBLL. This integration is beneficial for projects requiring both detailed simulations and flexibility in model design, allowing for efficient and accurate simulation of building energy performance.

Integrating TEASER and AixLib provides an **efficient approach to building energy simulation,** balancing accuracy with computational efficiency.

The choice of TEASER + AixLib for modelling and Modelica[3] + Modelon Impact[4] for simulation was made after a careful evaluation of available tools. The selection was based on efficiency, flexibility, and

[1] https://rwth-ebc.github.io/TEASER/main/docs/index.html
[2] https://github.com/RWTH-EBC/AixLib
[3] https://modelica.org/
[4] https://modelon.com/modelon-impact/

compatibility, which led to a balanced approach providing accuracy, computational efficiency, and detailed thermal analysis.

However, there were incompatibilities between different versions of AixLib and Modelon Impact, which presented challenges during the integration process. This highlights the need for careful management and verification of compatibility when integrating different software versions, particularly those using the Modelica language. The final solution required manual integration and updates of the models.

Development of forecasting algorithms [T6.1]

The main conclusions from the forecasting results for HSBLL are:

- Advanced AI-based forecast algorithms, using Long Short-Term Memory (LSTM) for short-term forecasts and Gated Recurrent Unit (GRU) and ConvLSTM for 24-hour forecasts, were successfully developed for predicting PV generation, building loads, and heat demand for HSBLL. These algorithms, which were tested using data from HSBLL, leverage historical data and weather predictions to forecast energy needs.
- The accuracy of the generation and load forecasts, particularly for PV generation, were found to be heavily reliant on the accuracy of the weather predictions used as input. This dependence on weather predictions suggests that the models may perform even better in real-time scenarios where actual weather data can be used instead of predictions.
- The developed forecasting models demonstrated strong performance, with the best model achieving an accuracy of 97.29% in comparison to actual data. This high level of accuracy, combined with validation against other state-of-the-art methods, supports the selection of these algorithms for deployment in the GENTE project.

Development and implementation of advanced Building Energy Management Systems [T6.2]

T6.2 focused on the development of an advanced Building Energy Management Systems (BEMS) to optimize the management and control of the different energy assets on a building. Deliverable 6.2 (D6.2) provides several key lessons regarding the development and implementation of advanced BEMS for residential buildings.

Co-optimization is crucial: Optimizing energy consumption and flexibility provision simultaneously is essential for achieving cost-effectiveness and grid stability. The BEMS must be able to minimize energy costs for the building while also providing flexibility to the Distribution System Operator (DSO). This co-optimization involves managing Battery Energy Storage (BES) systems, Heat Pumps (HP), and district heating.

T6.2 also focused on the exploitation of flexibility. Residential buildings can generate revenue by offering flexibility to the grid. The BEMS should be designed to maximize income from flexibility provision, which is achieved by reducing the imported power from the grid during the flexibility activation period. Additionally, it is concluded that flexibility should be offered as a reduction from a baseline power exchange profile rather than a capacity limitation. This approach allows for a more accurate and flexible response to the needs of the DSO.

Flexibility can be a **revenue source** and should be offered as a reduction from a **baseline power exchange profile** rather than a capacity limitation.

The influence of forecasting uncertainty was analysed in D6.2. Forecasting uncertainties in electric load and PV generation can significantly affect the reliability of flexibility provision. The BEMS should use methods such as the chance constraint method to manage these uncertainties. This ensures that the scheduled flexibility can be reliably provided, even when there are forecasting errors.

Another aspect to address is that a fair flexibility price is needed to incentivize residential buildings to offer their flexibility to the DSO. The price should be high enough to compensate for the costs associated with providing flexibility and to motivate buildings to fully utilize their flexibility potential.

Addressing **forecasting uncertainty** and **fair pricing** are key in BEMS development.

The simulation results of the advanced BEMS show that implementing an advanced BEMS can result in a notable reduction in a building's energy costs. The developed BEMS was able to achieve a 6% reduction in energy costs for HSBLL.

Advanced BEMS can **reduce energy costs.**

The last studied point is the effectiveness of rolling horizon-based algorithms. This type of algorithm allows the BEMS to adapt to changing conditions and flexibility requests effectively. The BEMS optimizes energy and flexibility provision in response to requests from the DSO.

Rolling horizon algorithms are **effective** for building energy management.

The importance of a holistic approach to building energy management that considers both energy efficiency and grid flexibility is highlighted. It emphasizes the need for advanced algorithms, uncertainty management, and fair pricing mechanisms to fully realize the potential of residential buildings in contributing to a more sustainable and resilient energy system.

Social aspects and co-creation process [T4.1-4.2]

One of GENTE's use cases was the application of a co-creation process in a new energy community (EC), emphasizing the active and collaborative involvement of stakeholders throughout the process, involving them in exploring, developing, and testing solutions for ECs. This approach aims to create context-specific solutions that are tailored to the community's needs and preferences, rather than relying on a one-size-fits-all method. This process was defined and developed within the tasks 4.1 and 4.2, and the main outcomes were described in detail in Deliverable 4.1 and Deliverable 4.2 (D4.2). This enabled reaching various conclusions about best practices and key learnings through a combination of theoretical grounding and practical observations from the new community case study.

The well-established co-design principles emphasize the importance of involving users throughout the design process. This approach is crucial for building momentum and commitment from the outset, ensuring that community members are actively involved in shaping the project from its initial stages. This leads to the first lesson learned in the social domain:

Early and continuous engagement with the community is crucial for the success of energy communities. This fosters support and maintains momentum for the project.

Another important aspect is the significance of identifying and involving individuals who are respected within the community and enthusiastic about renewable energy solutions. These "energy pioneers" can act as informal advocates and help bridge the gap between the project's goals and the community's needs and concerns, thereby fostering trust and acceptance.

Identifying and involving local "energy pioneers," who are respected figures within the community, is essential. These individuals can act as advocates for the project, increasing its visibility and acceptance.

Another key aspect is that the co-design processes, by their nature, are dynamic and involve diverse stakeholders with varying interests, making it challenging to predict outcomes with certainty. Acknowledging this unpredictability is key to embracing the emergent nature of such collaborative endeavors and being open to unexpected solutions and opportunities.

Co-design processes are inherently unpredictable due to the diverse perspectives of stakeholders. It is vital to **embrace this unpredictability and maintain flexibility in scheduling and planning.**

Authentic participation, where stakeholders have a genuine influence on the project's direction, is paramount to the success of co-design processes. Merely symbolic participation, where stakeholders are involved superficially without real influence, undermines the core principles of co-design and can lead to distrust and disengagement.

Participation should be genuine and not merely symbolic, requiring an honest commitment to the process and its outcomes.

Given the complexities inherent in energy systems and the diverse levels of technical understanding among stakeholders, a step-by-step approach is crucial for effective planning. Starting with foundational information and gradually increasing the complexity ensures that all participants can understand and contribute meaningfully, preventing exclusion and promoting inclusivity. Consequently, the following lesson learned is included:

Planning and execution should be approached incrementally, with each phase building upon the previous one and integrating stakeholder input.

While technical experts play a vital role in presenting possibilities and crafting tailored solutions, it is important to ensure that their influence does not dominate the process. Balancing technical input with community perspectives prevents the marginalization of stakeholder voices and fosters a sense of co-ownership.

While technical experts are necessary, it is **crucial to ensure their influence does not overshadow the process**. Their communication should be accessible to non-experts to maintain inclusivity.

The initial gathering in a co-design process should prioritize relationship-building and laying the groundwork for collaboration. Focusing on fostering connections between community members and introducing the core concepts of energy transition in an accessible manner helps build trust and establish a shared understanding before diving into specific solutions.

The **initial event** should **focus on network building** and introducing the concept of collaborative energy transitions.

As a co-design process progresses, moving from informal collaboration to more structured forms of self-organization is crucial for maintaining momentum and achieving tangible outcomes. This transition often involves establishing clear roles, responsibilities, and decision-making processes, enabling the community to take ownership and drive the project forward independently.

Formalising self-organization is vital for the success of socio-technical processes in creating energy communities. Participants need to take ownership and responsibility for their projects, transitioning from informal interest groups to more structured organizations as the project progresses.

Finally, in co-design processes, rigid, pre-determined timelines are often unrealistic due to the iterative and emergent nature of stakeholder involvement. Flexibility in scheduling and planning is critical to accommodating unforeseen challenges, integrating stakeholder feedback effectively, and allowing sufficient time for consensus-building.

The schedules and timelines cannot be fixed in advance but must be constantly adapted during the ongoing process to respond to ongoing developments and stakeholder feedback.

Conclusion

The GENTE project has successfully developed and demonstrated a distributed governance toolkit for local energy communities, using advanced digital technologies such as IoT, DLT, edge processing, and AI. The project's methodology included validation at both laboratory and full-scale environments across two demonstrators in Sweden and Switzerland, significantly increasing the TRL of the solutions developed. The GENTE toolkit addresses the following key use cases: grid flexibility provision, CO_2 emissions reduction, energy efficiency improvement, and co-design process, showcasing a comprehensive approach to energy management.

The pilot implementations yielded valuable insights. The Am Aawasser pilot in Switzerland demonstrated significant achievements via simulation-based testing, including a 24% reduction in CO_2 emissions, an increase in community self-sufficiency (autarky) from 61.91% to 74.81%, a reduction of 25.8 MWh per year in grid imports, and a 19.78% reduction in power peaks from the grid.

The HSB Living Lab pilot in Sweden validated the performance of new hardware and algorithms within a real-world setting. The functional performance tests confirmed successful data collection and accurate forecasting, with the models outperforming benchmark algorithms. Building energy optimization achieved a 6.3% reduction in CO_2 emissions compared to a baseline controller. Additionally, the LEC optimization tool reduced energy costs by 16.7% compared to a baseline controller, and flattened the electric load, reducing peaks and dips. Simulations also indicated that autarky could be significantly increased across different seasons, particularly during winter, with improved PV production. However, actual demonstration was not feasible as PV production was consistently lower than the building's electricity demand during PV generation periods, achieving 100% autarky which could not be further improved.

Key lessons were learned regarding data management, technical developments, and social aspects of energy communities. The project highlighted the need for clear data descriptors and the usefulness of tools like JSON-LD, RDF/OWL, and Data Spaces for embedding contextual information within datasets. It was found that simple linear scaling models for PV power forecasting performed as well as more complex AI models, suggesting that complex models and dedicated edge devices might not always be necessary for predicting solar power output. In addition, detailed modelling was found to be essential for precise simulations, particularly when analysing thermal dynamics within buildings. For the development of BEMS, co-optimization of energy consumption and flexibility provision is crucial, with flexibility offered as a reduction from a baseline power profile. The importance of early and continuous community engagement, the identification of local "energy pioneers", genuine stakeholder participation, and flexible planning were highlighted as key for the successful application of a co-design process for new energy communities.

Overall, the GENTE project has demonstrated the viability and effectiveness of integrating advanced digital technologies for managing local energy communities. The project's outcomes, including the lessons learned and best practices, offer valuable guidance for future initiatives focused on creating sustainable and resilient energy systems. The findings support the use of digital twins, the importance of accurate forecasting, and the necessity of a holistic approach to building energy management that considers both energy efficiency and grid flexibility. The project also emphasizes the importance of co-creation processes in developing solutions that are tailored to the specific needs and preferences of each community.

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