

HEDGE-IoT

Holistic approach towards Empowerment of the Digitalization of the Energy Ecosystem through adoption of IoT solutions

D5.3 Full Demo Phase Report

DOCUMENT CONTROL SHEET

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| 38 | ELEKTRO GORENJSKA PODJETJE ZA DISTRIBUCIJO ELEKTRICNE ENERGIJE DD | EG | SI |
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EXECUTIVE SUMMARY

Deliverable D5.3 – “Full Demo Phase Report” presents the activities carried out by the demo sites of HEDGE-IoT between months M22 and M28 and the Full Demo Operation Phase, following the 2nd HEDGE-IoT Digital System release at M21.

Building on the foundation established in Deliverable D5.1 – “Guidelines for Demo Preparation” this report, D5.3, documents the tangible progress and preliminary results from the project's second evaluation cycle (M22–M28).

Similar to D5.2 – “Pre-Demo Phase Report” and to ensure consistency and comparability, progress across all pilots is documented using a harmonised reporting template. This framework systematically captures demo-specific inputs on infrastructure readiness, data availability, System Use Case (SUC) implementation status, and progress against Key Performance Indicators (KPIs), providing an accurate and comprehensive snapshot of each demo's capability at this stage.

The document follows a similar structure with D5.2, as per the preparatory plan (D5.1) and provides a detailed overview of demos' status up until M28.

In this report, the progress of each demo in the following areas is documented:

- Infrastructure utilised and deployed in demo sites (IoT & Edge)
- Assets and datasets used during this cycle
- Integration and deployment activities of WP3 and WP4 technology enablers
- Results of the Full Demo Phase (BUCs and SUCs progress)
- KPIs progress and comparison with the Pre-Demo Phase
- Identified risks and mitigation actions

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ABBREVIATIONS

| Abbreviation | Explanation |
|--------------|--------------------------------------|
| AI | Artificial Intelligence |
| API | Application programming interface |
| BMS | Building Management System |
| BUC | Business Use Case |
| CM | Congestion Management |
| DER | Distributed Energy Resource |
| DoEAP | Digitalisation of Energy Action Plan |
| DSO | Distribution System Operation |
| DTR | Dynamic Thermal Rating |
| EC | Energy Community |
| EDC | Eclipse Dataspace Connector |
| EMS | Energy Management System |
| EV | Electric Vehicle |
| FL | Federated Learning |
| HEMS | Home Energy Management Systems |
| HLSTM | Hybrid Long Short-Term Memory |
| IED | Intelligent Electronic Device |
| IoT | Internet of Things |
| KPI | Key Performance Indicator |
| LFM | Local Flexibility Platform |
| LV | Low Voltage |

| | |
|--------------|--|
| MQTT | Message Queuing Telemetry Transport |
| MV | Medium Voltage |
| PGUI | Power Grid User Interface |
| QoS | Quality of Service |
| RES | Renewable Energy Source |
| RL | Reinforcement Learning |
| SAREF | Smart Applications REference |
| SCADA | Supervisory Control and Data Acquisition |
| SIF | Semantic Interoperability Framework |
| TSO | Transmission System Operator |
| UI | User Interface |

1 INTRODUCTION

1.1 ABOUT THIS DOCUMENT

Deliverable D5.3 presents the progress of the HEDGE-IoT demos during the Full-Pilot Phase (M22-M28). The six demos taking on the initial demonstration activities carried out during the Pre-Demo Phase, and the deployment of the 2nd HEDGE-IoT Digital release, have advanced their activities substantially, towards their Large-Scale Demonstration activities and the final deployment of the HEDGE-IoT technical components.

This deliverable acts as a report of these activities and presents the intermediate results, showcasing the advancement towards achieving their expected impact. The document follows a similar structure to deliverable D5.2, to present the evolution and deployment of the Demos' Business and System Use Cases, as have been documented in WP2 deliverables.

1.2 STRUCTURE OF THE DOCUMENT

Chapter 1, provides the introduction of the document.

Chapter 2, provides the harmonised reporting template used to collect and structure inputs from each demonstration site, as the basis material to produce this deliverable.

Chapter 3, reports on the progress of Demo 1 – Finland.

Chapter 4, reports on the progress of Demo 2 – Greece.

Chapter 5, reports on the progress of Demo 3 – Italy.

Chapter 6, reports on the progress of Demo 4 – Netherlands.

Chapter 7, reports on the progress of Demo 5 – Portugal.

Chapter 8, reports on the progress of Demo 6 – Slovenia.

Chapter 9, summarises the key findings of the Pre-Demo Phase and outlines the expectations and next steps for the upcoming Full Demo Phase.

1.3 CONNECTION WITH OTHER WORK PACKAGES

As deliverable D5.2, deliverable D5.3 is interconnected with the activities and outputs of the project's technical Work Packages (WP). Presenting these outputs deployed in the Demos, it serves as the bridge between the foundational specifications and developed technologies of HEDGE-IoT, validated against real-world demonstration environments. The following table summarises D5.3's interactions with the project's major technical and analytical WPs. For each WP, Table 1 describes the dependency and specifies how this report contributes to or is informed by its activities.

TABLE 1: INTERDEPENDENCIES BETWEEN THE PRE-DEMO PHASE REPORT AND OTHER WORK PACKAGES

| Work Package | Nature of inter-dependency |
|---|--|
| WP2 – Stakeholder Requirements & System Specifications | WP2 identifies stakeholder needs and produces the functional specifications and Reference Architecture that guide demo deployment. D5.3 presents the advancements of the BUCs and SUCs in each demo. |
| WP3 – Technological Enablers | WP3 delivers the AI/ML micro-services and edge libraries used in forecasting, optimisation, anomaly detection and DTR/DLR – the technical edge and cloud innovations to be deployed in the demonstrators. D5.3 presents the integration of these enablers in each demo, that support in achieving their expected impact. |
| WP4 – Digital Interoperability Framework | WP4’s IDS middleware and data-space connectors enable cross-pilot data exchange; D5.3 reports to the integration of the interoperability framework in each demo. |
| WP6 – Impact, Replication & Digitalisation of Energy Action Plan | D5.3 reports on the status of the identified KPIs, that WP6 will use to quantify impact, assess replicability and draft the project’s contribution to the Digitalisation of Energy Action Plan. |

2 METHODOLOGY

Deliverable D5.1 – Guidelines for Demo Preparation laid the groundwork for organising the pilot activities of the HEDGE-IoT project. It defined the technical components to be deployed at each demonstration site, mapped the System Use Cases (SUCs) to be addressed, identified the associated Key Performance Indicators (KPIs), and presented the initial deployment plans. Through this, D5.1 created a common baseline, linking each pilot to the technical developments in WP3 and aligning them with the use case scenarios developed in WP2.

Building directly on this foundation, Deliverable D5.3 – Full Demo Phase Report captures the implementation status and operational progress of each demo during the project’s first evaluation cycle (M16–M18). This reporting phase serves to validate the initial plans from D5.1 against real-world activities, providing early insight into technical readiness, service deployment, and stakeholder engagement.

The HEDGE-IoT project follows a phased implementation framework moving from design and specification to pre-demo deployment, full demo execution, and eventual impact evaluation. Within this structure, D5.3 (as D5.2 already did) acts as a checkpoint, ensuring continuity between planning and implementation, and preparing the ground for the overall demo reports (D5.4–D5.9) and the overall demonstration report of HEDGE-IoT’s demos (D5.10).

To systematically monitor and report the progress across all demos, a **harmonised reporting template** was developed and distributed to partners as reported on deliverable D5.1 – Guidelines for Demo Preparation (available also in APPENDIX I). This template was designed to serve two key purposes:

- **Vertical traceability** – tracking progress at the level of each System Use Case (SUC), including service readiness, deployment and implementation steps, and risk identification.
- **Horizontal consistency** – enabling comparison across demos and aligning individual pilot efforts with common WP3 services and technical deliverables.

The template ensures structured, consistent input from all demo sites. It reflects each demo’s real-world execution status and provides a shared reference point for future evaluation cycles. The resulting reporting framework consists of four main content sections:

- Full-Demo Phase Activities Summary
- Infrastructure, Assets and Data Availability
- Full-Demo Results (including SUC implementation and milestone tracking)
- Full-Demo Evaluation (requirements and KPI progress)

Starting with the **Full Demo Activities Summary**, this section captures a high-level overview of the activities conducted during the Pre-Demo Phase. It serves as a bridge between planning (D5.1) and execution, allowing each demo to describe its progress with respect to:

- The preparatory milestones reached (e.g., site setup, partner alignment).
- The WP3 services or components initially tested and/or integrated within the demo activities.
- The stakeholders engaged during this phase.

Subsequently and given that a successful IoT-enabled demonstration depends heavily on the availability of physical and digital infrastructure, the Infrastructure, Assets and Data Availability section has been structured around two core aspects:

- **Assets and infrastructure:** Describing the key systems (e.g., edge nodes, sensors, control interfaces) deployed or planned at this stage. The asset table captures deployment level, function, and current usage.
- **Data availability:** Documenting the datasets already being collected, simulated, or prepared for use during the pre-demo phase.
- **Open data availability:** As activities are advanced and the demos are reaching large scale status, the availability of open data is explored, both for research purposes as well as technology testing activities (i.e., WP4 alignment).

This overview provides context for interpreting the rest of the technical and operational details of the demo's progress. After establishing the summary of the full demo phase activities and the physical and cyber assets included within each demo and addressed during the Full Demo phase, the results of this phase are presented where the focus is placed on the concrete actions and integration efforts made for each SUC of each demo during the aforementioned period. Each SUC is described through a structured table covering four sections:

- **Overview Section:** The Overview subsection provides a concise overview of each System Use Case (SUC) as implemented during the Full Demo Phase. It begins with the SUC Summary, which explains the use case's purpose and operational objective within the demo context, ensuring clarity on what the SUC is designed to achieve. The Target(s) field identifies the functional or technical targets set explicitly for the current evaluation cycle (M16-M18), allowing for a focused check on the pre-demo goals. The Expected Milestones draw from D5.1 and highlight key technical accomplishments that were anticipated by this phase. The Actions Implemented field summarises the actual work completed to date – including design, development, integration, or testing – helping to present declared progress in real technical effort.
- **Requirements Section:** The Requirements subsection captures the foundational conditions that underpin each SUC. The Assumptions field records key operational or contextual conditions that were expected to hold true for the SUC's deployment – for instance, network connectivity, stakeholder availability, or data access. This is essential for interpreting whether any delays are due to invalidated assumptions. Dependencies include both internal and external services, platforms, or components that the SUC relies on. This field supports coordination across demos and WPs by making integration points visible. Risks highlight known technical or organisational challenges that could impede progress.
- **Readiness Section:** The Readiness subsection reflects the technical and operational preparedness of each SUC including deployment diagrams, deployment preparation and deployment assessment. The Deployment Diagram field references the diagrammatic representation of which components are deployed and tested during the Full Demo Phase. This helps visualise the scope and boundaries of implementation. Deployment Preparation captures the specific actions taken to configure the demo environment, engage stakeholders, and ensure all prerequisites are met. The Deployment Assessment provides a brief qualitative evaluation of the demo's readiness, summarising progress made, known issues, and how any identified risks are being addressed.

- **Validation Activities Section:** The Validation Activities subsection records the verification actions undertaken to date and their alignment with the planned testing path, including the previous, current and future cycles. The Previous Cycle field (optional) allows demos to report on any early-stage lab or internal testing that occurred before M22. While not mandatory, this offers additional context on incremental development. The Current Cycle focuses on the main activities undertaken during the Full Demo Phase and reflects how these align with prior planning or recommendations. Finally, the Future Cycle field outlines the next steps for advancing the SUC, including technical extensions, testing plans, or new stakeholder engagement – supporting continuity towards the Large-Scale Operation Phase and its corresponding reporting in subsequent deliverables (D5.4-D5.10).

Furthermore, the **milestones and progress** are revisited from D5.1 and compared against real progress with the intention to capture:

- Any early completions, delays, or deviations.
- Steps that were partially fulfilled or that transitioned into new schedules.
- SUC-level advancements tracked across months and partner-specific activities.

Lastly, the **Full Demo evaluation section** complements the activity tracking by evaluating two critical aspects: requirement fulfilment and KPI assessment.

Starting with the requirements evaluation, the requirements initially outlined in D5.1 include updates to the demo’s functional, technical, and operational requirements, including acceptance criteria to determine completeness, the indication of the responsible testing partners, and a progress column reporting the progress achieved during the full demo phase of each demo, to record whether each requirement has been addressed in practice and at what stage it is at by M28. Moreover, the KPIs to be measured by each demo - with their descriptions, baseline and progress of the Pre-Demo Phase for comparison- are consolidated into a dedicated table. A Progress column has been added to reflect the current measurement status at M28.

3 DEMO 1 – NEXT-GENERATION GRID AUTOMATION WITH IOT AND EDGE/CLOUD DATA TO IMPROVE DISTRIBUTION GRID RESILIENCY [FINLAND]

3.1 FULL-DEMO PHASE ACTIVITIES SUMMARY

This section presents a structured summary of the activities that the Finnish Demo conducted during the Full Demo Operation Phase (M22-M28). It follows the demo deployment template introduced deliverable D5.1 (available in Annex I for reference), which functions as a reference for monitoring the development of each demonstrator. The status of the Full Demo Operation Phase targets, the WP3 services utilised, and the key stakeholders involved during this phase are all detailed in below.

The purpose of the information is to establish the foundation for the Full Demo Phase and to evaluate the operational readiness of the demo at the conclusion of the Pre-Demo Phase.

TABLE 2: DEMO 1 FULL DEMO OPERATION PHASE DEPLOYMENT STATUS

| Section | Subsection | Description |
|---------|------------------------|---|
| Summary | Full Demo Phase Target | The focus of full demo phase has been, on one hand, to finalise device installations on both pilot areas, and on the other hand, to continue developing and testing the final versions of the new algorithms and modules that will be deployed on the pilot areas during the large-scale demo phase. |
| | Status Summary | <p>During the full demo phase, equipment installations have been finalised on both pilot areas according to Figure 1 (during pre-demo phase, only one of the pilot areas was covered) and the demo architecture has been slightly updated based on the findings during the pre-demo phase.</p> <p>Installed or modified components at the pilot areas during the full demo phase include intelligent electronic devices (IEDs) at two primary substations and at seven breakers along the feeders, communication network devices (switches, fiber network devices), network clocks, an intermediary server and an edge server. The IEDs provide measurement and status data using IEC 61850 sampled values (SV) and Generic Object-Oriented Substation Event (GOOSE) and the communication network devices have been modified to support the 61850 data transfer. Time synchronisation is distributed to the whole piloting area using two network clocks in two locations along the fiber network. An intermediary server is added between SCADA and the research infrastructure at the server room for cybersecurity and simplicity reasons and the first edge server at the server room has been configured to include centralised protection and control, anomaly detection and fault prediction solutions which are used to test the pilot architecture and operated as reference for the new functions developed during HEDGE-IoT.</p> <p>The second edge server and the cloud research infrastructure have been tested in laboratory environment during the full demo phase and will be deployed on the pilot areas during the large-scale demo phase. These environments will realise the final versions of the technology innovations of the Finnish pilot that include 1) Digital platform capabilities for distribution grid automation 2) Congestion management solution and 3) Anomaly detection fault forecasting solution.</p> |

| | | |
|--|---|---|
| | <p>Services Used (from WP3)</p> | <p>During the full demo phase, all services related to the Finnish pilot have been under development and lab testing. The services to be deployed on edge include 3.4 Anomaly Detection and Fault Forecasting to Increase Distribution Network Resilience and service, 3.5 Real-time Congestion Management and 3.7 Digital platform capabilities for distribution grid automation. Service 4.4 Predictive Congestion Management is deployed on the cloud research infrastructure and will be connected to the edge service 3.5 using the data connector. These services will be deployed on-site during the large-scale demo phase on edge server #2 and on cloud (see Figure 1). During the full demo phase, the edge server #1 includes commercial solutions that realise centralised protection and control, anomaly detection and fault prediction. These have been configured for both pilot areas.</p> |
| | <p>Stakeholders involved during Full Demo</p> | <ul style="list-style-type: none"> • ABB has been developing the digital platform capabilities (service 3.7) and has deployed the functionalities on edge server #1. ABB has also been partly responsible for device procurement and configuration. • Järvi-Suomen Energia is the DSO at whose network the demonstration takes place and has been the main responsible for pilot area installations (IEDs, communication network devices, network clocks, intermediary server). Järvi-Suomen Energia has also been responsible on developing load forecaster functionality. • Enerva has participated to the demo area preparations, especially related to SCADA communication and visualisation, and to congestion management functionality definition. • VTT is developing the anomaly detection and fault forecasting functionality. • TAU is developing the congestion management functionality and is responsible for edge-cloud computing and data space integrations. |

The following figure illustrates the physical setup and functional layout of the first demonstration site of the Finnish pilot, highlighting the components installed and configured during the Full Demo Operation Phase. The parts on white background are operational on the two pilot areas and the parts on green background are deployed in lab environment. All components will be deployed on-site during the large-scale demo phase.

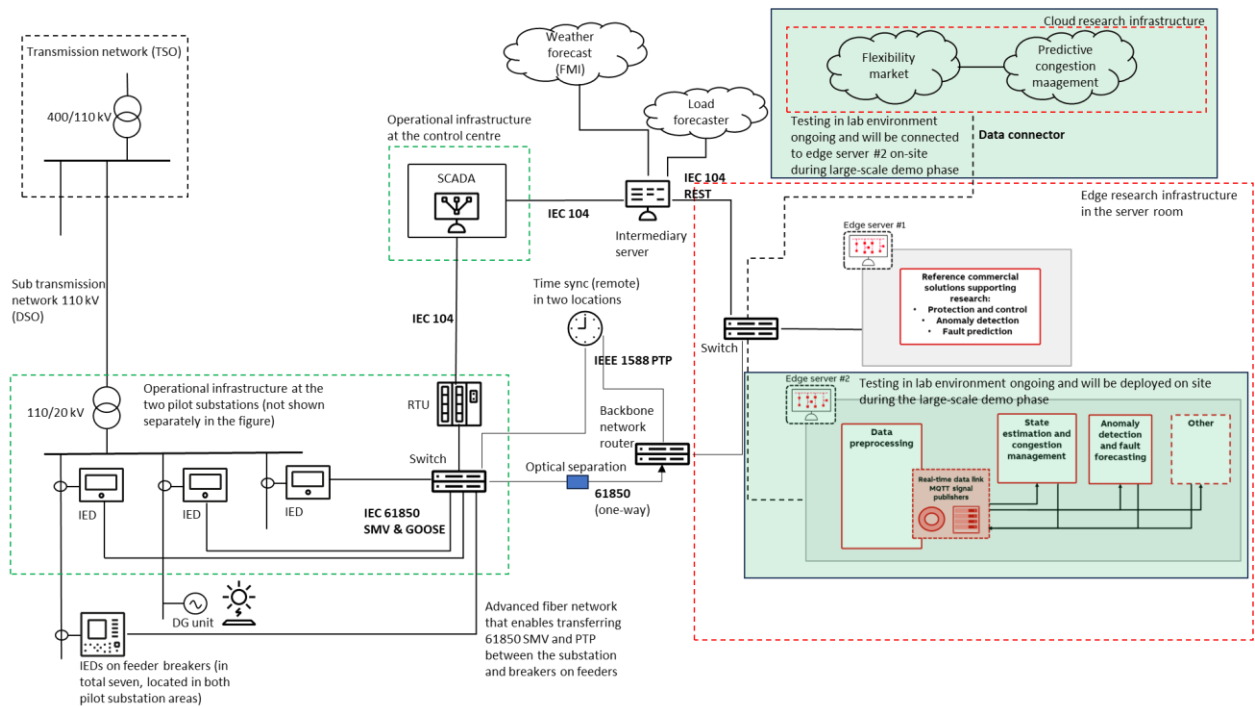


FIGURE 1. DEMO 1: INSTALLATIONS DURING THE FULL DEMO PHASE.

3.2 INFRASTRUCTURE, ASSETS AND DATA AVAILABILITY

Based, on the demo-deployment template (Annex I), a consolidated snapshot of the infrastructure and assets mobilised during the Full Demo Operation Phase is provided in the following table for the Finnish demo. Each asset is accompanied by its technical description, deployment level, use status in months 22–28, and the WP3 service to which it pertains.

TABLE 3: SUMMARY OF FINNISH DEMO INFRASTRUCTURE AND ASSETS DEPLOYED DURING THE FULL DEMO OPERATION PHASE

| Asset | Description | Deployment Level | Used during Full demo | Under which WP3 service |
|----------------|---|---|-----------------------|---|
| Edge server #1 | Server that runs reference commercial solutions supporting research | Installed | Yes | Supports the demo architecture testing and research related to services 3.7 and 3.4 |
| KVM | Virtualisation environment | Installed | Yes | Part of the edge server configuration |
| SSC600 SW | Virtualised centralised protection | Installed and configured for both pilot areas | Yes | Includes replicas of IED protection functions and a version of anomaly detection function. Provides disturbance recordings as input data to |

| | | | | |
|--|--|---|--------------|--|
| | | | | fault prediction solution. Supports research related to service 3.4. |
| Anomaly detector | SSC600 SW function ANOGAPC that triggers disturbance recordings | Installed and configured for both pilot areas | Yes | Service 3.4 |
| ABB CogniEN EDGE | Fault prediction solution that operates based on disturbance recordings triggered by anomaly detection functionalities | Installed and configured for both pilot areas | Yes | Service 3.4 |
| Edge server #2 | Server that runs all the new HEDGE-IoT edge applications | In lab testing. Each service (3.4, 3.5 and 3.7) functional testing ongoing after which integration and system testing is conducted. | Yes (in lab) | Services 3.4, 3.5 and 3.7 will eventually be deployed on the edge server |
| Real-time data link | Platform capabilities for sharing data from various sources to other applications (IEC 61850, IEC 104, REST) and to provide data towards SCADA | In lab testing | Yes (in lab) | Service 3.7 and will provide data to services 3.4, 3.5 and 4.4 |
| Docker | Containers for different HEDGE-IoT applications | In lab testing | Yes (in lab) | Part of the edge server configuration |
| Real-time congestion management solution | Application that includes real-time state estimation and congestion management functionalities | In lab testing | Yes (in lab) | Service 3.5 |
| Anomaly detection and fault forecasting solution | Application that detects anomalies in measurement data, calculates indicators, and provides early warnings | In lab testing | Yes (in lab) | Service 3.4 |

| | | | | |
|---|--|--|---|--|
| Cloud research infrastructure | Cloud environment on which predictive congestion management is deployed | In lab testing | Yes (in lab) | Service 4.4 |
| Predictive congestion management solution | Application that includes state forecasting and predictive congestion management functionalities | In lab testing | Yes (in lab) | Service 4.4 |
| Data storages | Data storages for both input data (static network data etc.) and for data needed to evaluate the performance of different functionalities | In lab testing | Yes (in lab) | Services 3.4 and 3.5 on edge and 4.4 on cloud |
| Load forecaster | Application that utilises smart meter data for load forecasting | Algorithm operational, running environment under development | Partly, running environment still under development | Provides input data for services 3.5 and 4.4 |
| Intermediary server | Server that relays data between edge research infrastructure, SCADA, load forecaster and external data sources (Finnish Meteorological Institute, FMI) | Installed, some updates to configuration still expected | Yes | Data used by services 3.4, 3.7 and 4.4 |
| Hirschmann RSP-30 | Research infrastructure switch | Installed | Yes | Mandatory part of the demo setup, required by all services |
| Fiber diodes | Fiber diodes that allows traffic from the operational infra towards the research infra but not to the other direction | Installed | Yes | Mandatory part of the demo setup, required by all services |

| | | | | |
|-----------------------------|--|--|------------------------------|---|
| REX640 relays | Operational relays at Anttola and Hirvensalmi substations | Established, configurations updated | Yes | Used by all services related to Finnish pilot |
| REX615 relays | Operational relays at the breakers on feeders | Installed and configured | Yes | Used by all services related to Finnish pilot |
| Fiber converters | Fiber converters at the feeder breakers | Installed | Yes | Mandatory part of the demo setup, required by all services |
| Fiber communication network | Fiber communication network between control centre, server room, substations and feeder breakers | Established | Yes | Used by all services related to Finnish pilot |
| Substation switches | Substation switches that support PTP and SV | Installed | Yes | Mandatory part of the demo setup, required by all services |
| Relay network switches | Relay network switches that support PTP and SV | Installed | Yes | Mandatory part of the demo setup, required by all services |
| Nokia 7705 SAR AX | Service aggregation routers | Installed (partly established) | Yes | Mandatory part of the demo setup, required by all services |
| GPS antenna | GPS antennas that enable the SARs to operate as PTP masters | Installed | Yes | Mandatory part of the demo setup, required by all services |
| GPS overvoltage protection | GPS overvoltage protection | Installed | Yes | Mandatory part of the demo setup, required by all services |
| Smart meter | All grid customers have smart meters | Established | Yes | Services 3.5 and 4.4 |
| SCADA | Visualisation of the outputs of the new HEDGE-IoT functionalities will be added to the operational SCADA | SCADA is an established system, new visualisations under development | Visualisations not yet added | Services 3.4, 3.5 and 4.4 provide outputs to be visualised. Service 3.7 used to relay the needed data to SCADA. |

The following table summarises the datasets relevant to the Full Demo Operation Demo Phase, indicating their availability, whether they were used during this period and their linkage to the corresponding WP3 technological enablers.

TABLE 4: DEMO 1: OVERVIEW OF DATASETS RELEVANT TO THE FULL DEMO OPERATION PHASE OF

| Data Description | Used during Full Demo Phase | Under which WP3 service |
|--|---|--|
| Current measurements from all pilot area substation bays | Available from all pilot area substation bays | Will be used by all services related to Finnish demo |
| Voltage measurements from all pilot area substation bays | Available from all pilot area substation bays | Will be used by all services related to Finnish demo |
| Current measurements from breakers at feeders | Available from all breakers at feeders selected for the piloting | Will be used by all services related to Finnish demo |
| Current measurements from breakers at feeders | Available from all breakers at feeders selected for the piloting | Will be used by all services related to Finnish demo |
| Breaker statuses for devices at substations and on feeders | Available from all devices selected for the piloting | Will be used by all services related to Finnish demo |
| Disturbance recordings triggered by anomaly detection algorithm(s) | Available from the whole pilot area | Service 3.4 |
| Smart meter measurement data | Available for all customers connected on the piloting area | Services 3.5 and 4.4 |
| Measurement and status data from SCADA | Measurement data (currents, voltages, real and reactive power) from two distributed generation sites and status and control data of the main transformer on-load tap changer controller available at the intermediary server. Switch status data not available yet. | Services 3.5 and 4.4 |
| Load forecast data | Load forecast data not yet available on the intermediary server but algorithm exists | Services 3.5 and 4.4 |
| Weather forecast (provided by FMI) | Available on the intermediary server | Services 3.5 and 4.4 |
| Electricity price forecast (provided by ENTSO-E) | Available on the cloud research infrastructure | Service 4.4 |

OPEN DATA AVAILABILITY

The Finnish demo utilises open weather data provided by the Finnish Meteorological Institute (FMI) and open electricity price data provided by ENTSO-E transparency platform. The data produced as a part of the Finnish demo activities cannot be published as open data. The data utilised in the

Finnish demo includes measurement and status data from intelligent electronic devices (IEDs), measurement and status data from SCADA and load data from smart meters. The measurement data from the IEDs contains voltage and current values as IEC 61850-9-2 sampled values. This data is not stored in its entirety but is processed at the edge server and only relevant parts of the data are stored (root mean square (RMS) values and disturbance recordings (DRs) during some time periods). This data is not useful without more detailed information on the network structure and conditions when the data was captured. Since electrical grid is a critical infrastructure, sharing the network data is not possible. The SCADA measurement data contains measurement data from distributed generation units and smart meter data from other customers. Neither can be published as open data.

3.3 FULL-DEMO OPERATION PHASE RESULTS

This section captures the status and progress of System Use Case (SUC) implementation during the Full Demo Operation Phase (M22-M28) for the Finnish Demo. For each SUC, key developments are outlined, including the specific actions undertaken, intermediate achievements, and alignment with the expected implementation steps and scenarios described in D2.2.

3.3.1 SUCs Implementation

This subsection presents the implementation progress of each System Use Case (SUC) as defined in D2.3 for the Finnish Demo, highlighting the actions carried out during the Full Demo Operation Phase.

SUC-FL-01.01 & SUC-FL-01.02 DATA COLLECTION AND ANOMALY DETECTION & FAULT FORECASTING ANOMALY DETECTION AND FAULT FORECASTING

| Section | Subsection | Description |
|-----------------|------------------------|---|
| Overview | SUC Summary | SUC-FI-01.1 aims for processing of data stream from Intelligent Electronic Devices (IEDs), identification of abnormalities and storing indicator values. SUC-FI-01.2 develops methodology for decision making based on identified anomalies. |
| | Target(s) | To process and analyse live data stream To identify and flag all issues that seem abnormal To store their indicators into logs so that also long-term evolving phenomena can be identified |
| | Expected UC Milestones | First prototypes ready for performance testing, lab testing and early piloting phases. |
| | Actions implemented | Definition and implementation of the data stream interface. Several functions developed in the Hybrid Long Short-Term Memory (HLSTM) Algorithm. Lab-level server environment created, and first lab tests initiated. |

| | | |
|--------------------------------------|------------------------|---|
| Requirements | Assumptions | <p>Capability to technically process the data stream (enough computational power etc.)</p> <p>Performance of the anomaly detection algorithm after the training phase generally.</p> <p>Training data availability.</p> |
| | Dependencies | Dependant on availability and compatibility of the live data stream. |
| | Risks | <p>Challenges with managing full resolution data stream in terms of computational power.</p> <p>Development so far based on limited set of fault data, wider usability to be tested.</p> |
| Readiness | Deployment diagram | <i>Diagrams below</i> |
| | Deployment preparation | <p>Algorithm for detecting anomalies from live stream has been developed and tested.</p> <p>Machine learning algorithm has been developed using historical fault data.</p> <p>Server setup has been built in VTT lab.</p> <p>Lab testing with RTDS has been initiated.</p> |
| | Deployment assessment | The basic structure and functionality have been implemented; however performance of the solution has only been tested in lab with historical data, and real time stream based tests are still pending. At the same, it is expected that the algorithms need fine tuning when using real stream. |
| Validation Activities Summary | Previous cycle | Focus was on defining right methodology and choosing programming technologies to be used. |
| | Current cycle | Focus has been on SUC-FI-01.1 while SUC-FI-01.2 has mostly been specified and some early developments taken. |
| | Future cycle | The main action is to progress testing with real stream and to progress towards testing on site. The algorithms need to be adjusted for these purposes. |

The following figures present the focus area of the above SUCs in which Demo 1 focused on the Full Demo Operation Phase.

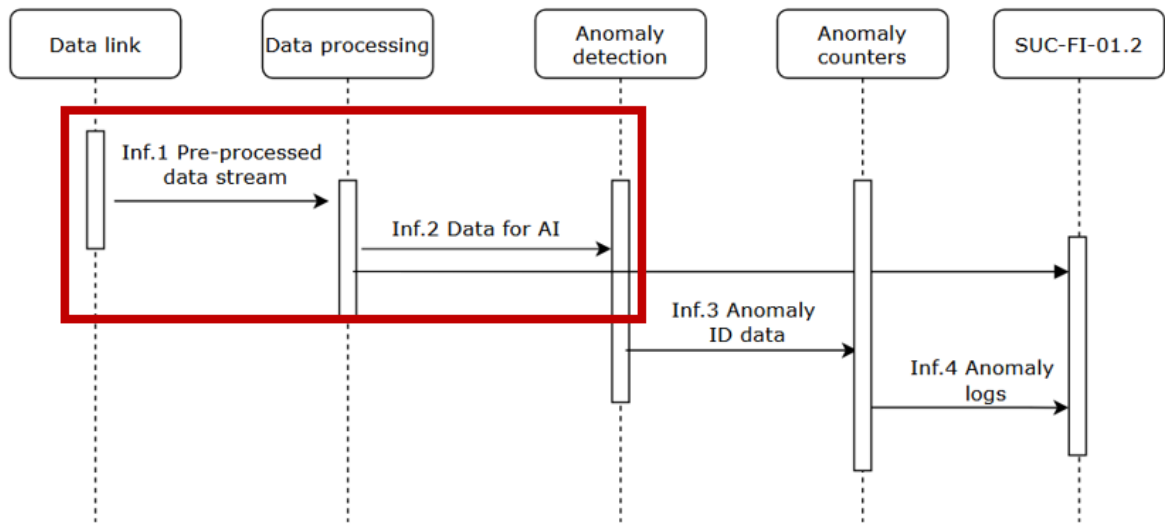


FIGURE 2: SEQUENCE DIAGRAM OF SUC-FI-01.1 (ONGOING PROGRESS)

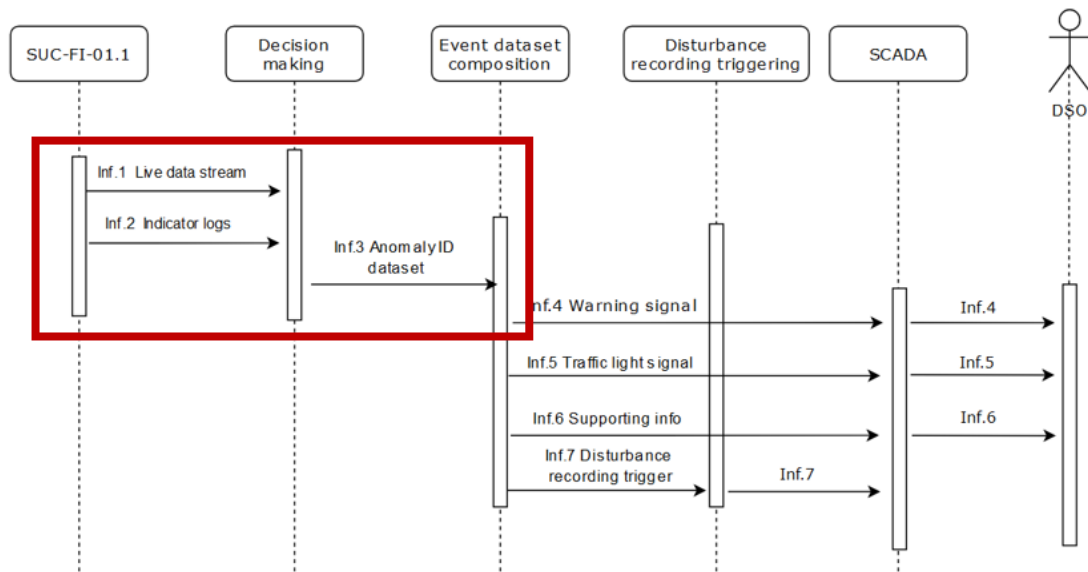


FIGURE 3: SEQUENCE DIAGRAM OF SUC-FI-01.2 (ONGOING PROGRESS)

SUC- FL-02.01 & SUC-FL-02.02 CONGESTION PREDICTION IN DISTRIBUTION GRIDS & CONGESTION MANAGEMENT PLANNING IN DISTRIBUTION GRIDS

| Section | Subsection | Description |
|----------|-------------|---|
| Overview | SUC Summary | SUC-FI-02.01 & SUC-FI-02.02 Predictive CM on the cloud. UCs will result in predicting grid state variables, and in case of congestion expectation, perform CM decision making to remove congestion for example by procuring flexibility from local flexibility market (LFM). |

| | | |
|---------------------|------------------------|---|
| | Target(s) | Integration testing of SUC-FI-02.01 on the cloud environment. |
| | Expected UC Milestones | <p>Validation, and analysis of components including:</p> <ul style="list-style-type: none"> • Load forecast • Generation forecast • Grid state forecast |
| | Actions implemented | <p>Specific developments of the current cycle are:</p> <ul style="list-style-type: none"> • Cloud server including Linux virtual machine, MQTT broker, influx data base and Graphana running on Docker for visualisation has set up. • Initial tests have been successfully conducted to exchange messages between edge and cloud through eclipse data space connector. • Load forecasting model tested. • Generation forecasting model tested. • Weather forecast component that fetches weather data (irradiance, temperature, precipitation) from Finnish Meteorological Institute tested • Electricity market price component fetching Finnish market price from ENTSO-E tested. • Solar and hydro power forecast models tested. • State forecasting model developed (yet to be tested). |
| Requirements | Assumptions | <p>Procuring flexibility from the market is possible though LFM.</p> <p>Flexibility will be available from DER units to be procured and controlled.</p> |
| | Dependencies | The service will interact with CM on the edge (SUC-FI-02.03 & SUC-FI-02.04) through Eclipse data space connector (EDC). That is why initial testing has been conducted on exchanging messages between edge and cloud using EDC. |
| | Risks | Limited availability of DER flexibility to procure and activate. |
| Readiness | Deployment diagram | <i>Available below</i> |
| | Deployment preparation | <p>Requirements:</p> <ul style="list-style-type: none"> • Server running a VM on the cloud. • Docker and message broker running on VM • Cloud and edge servers are communicating through EDC. |
| | Deployment assessment | <p>Implementation of SUC-FI-02.01 has been majorly completed (>90%).</p> <p>Implementation of SUC-FI-02.02 has yet to be started.</p> |

| | | |
|--------------------------------------|----------------|---|
| Validation Activities Summary | Previous cycle | The previous cycle moved forward in the area of data set preparation, as well as the architecture design of cloud services and subservices. The implementations of SUC-FI-02.01 and SUC-FI-02.02 as identified next steps. |
| | Current cycle | In the current cycle, functionalities necessary to realise SUC-FI-02.01 has been developed (yet to be tested on the cloud environment). |
| | Future cycle | <ul style="list-style-type: none"> • Testing on all the necessary components for SUC-FI-02.01 on the cloud environment. • Development of components for SUC-FI-02.02 • Integration testing of SUC-FI-02.01 and SUC-FI-02.02. |

Development of SUC-FI-02.01 has already been completed and it is currently being deployed and tested on the cloud environment. The development of SUC-FI-02.02 is currently under way and the following figure highlights the stage in which development is currently progressing. After completion of those highlighted steps, an integration of the decision making with local flexibility market (LFM) test platform is planned which is essentially the second block in the following figure.

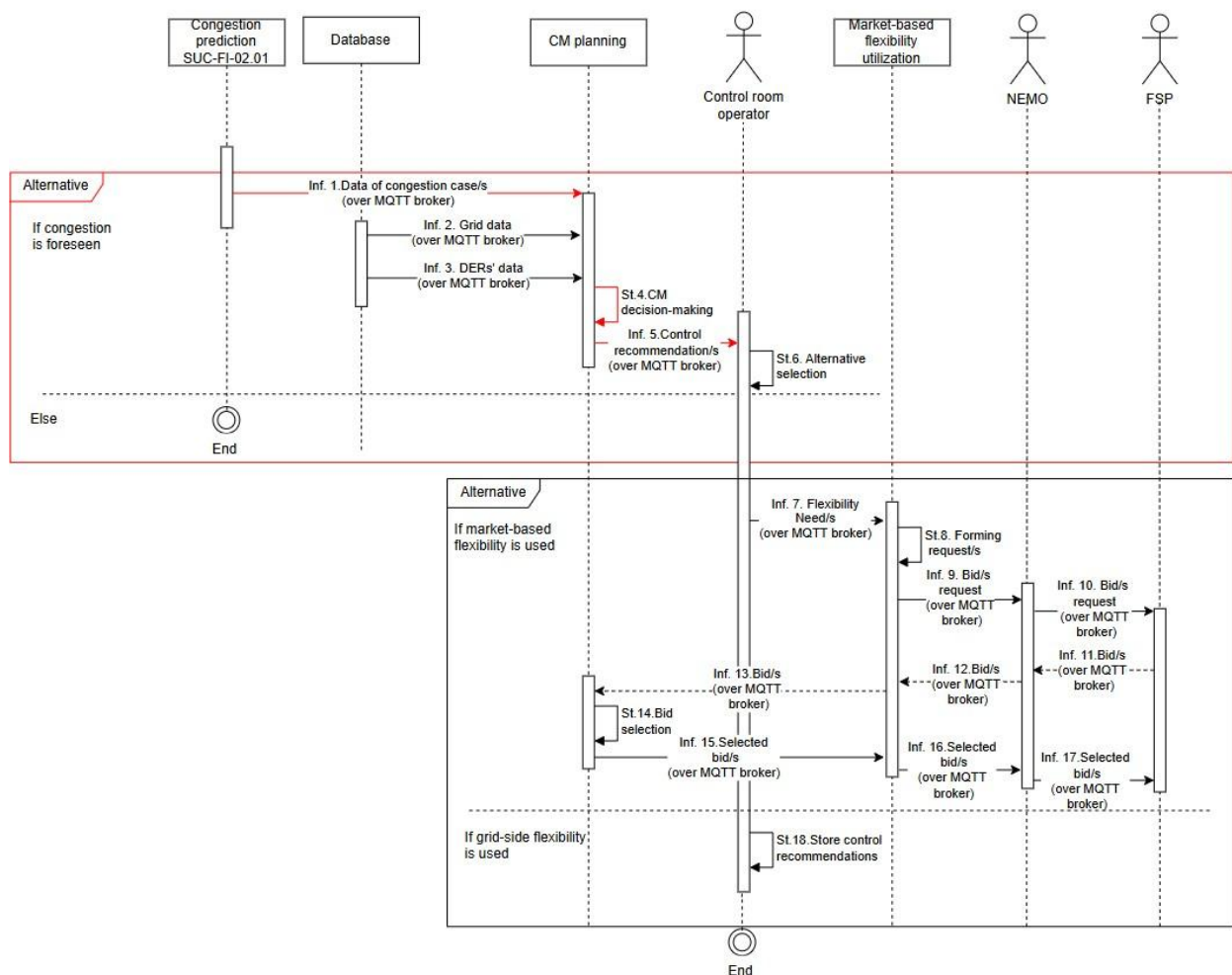


FIGURE 4: SEQUENCE DIAGRAM OF SUC-FI-02.01 (ONGOING PROGRESS)

SUC-FL-02.03 & SUC-FL-02.04 STATE MONITORING OF THE DISTRIBUTION GRID & REAL-TIME CONGESTION MANAGEMENT ON THE EDGE

| Section | Subsection | Input |
|---------------------|------------------------|--|
| Overview | SUC Summary | SUC-FI-02.03 & SUC-FI-02.04 Real-time CM on the edge. The UCs result in estimating grid state variables, and in case of congestion, perform CM decision making to remove it. |
| | Target(s) | Complete integration testing of SUC-FI-02.03 & SUC-FI-02.04. |
| | Expected UC Milestones | <p>Validation, and analysis of components including:</p> <ul style="list-style-type: none"> • Load estimation • Generation estimation • Grid state estimation • Real-time congestion management |
| | Actions implemented | <p>Specific developments of the current cycle are:</p> <ul style="list-style-type: none"> • Edge server including Linux virtual machine, MQTT broker, influx data base and Graphana running on Docker for visualisation has been set up. • State estimation unit tested and integration tested on the edge server. • Real-time congestion management has been unit tested and integration tested on the edge server. |
| Requirements | Assumptions | Connection between virtual machines/container structures is through MQTT broker allowing TAU to receive real-time measurements from the real-time data link. |
| | Dependencies | <p>SUC-FI-02.04 is critically dependent on SUC-FI-02.03's results.</p> <p>The partners developing services in separate virtual machines or container structures allow to reduce the dependencies during the development stage. In unit, and integration testing, the behaviour of functionality developed by other partners was mocked to minimise its impact of the development and testing.</p> |
| | Risks | No special risk is identified at this stage as both SUC-FI-02.03 and SUC-FI-02.04 have been unit tested and integration tested. |
| Readiness | Deployment diagram | <i>See below</i> |
| | Deployment preparation | <p>Requirements:</p> <ul style="list-style-type: none"> • Server running the needed VMs on the edge. • Docker and message broker running on VMs • Cloud and edge servers are communicating through EDC. |

| | | |
|--------------------------------------|-----------------------|---|
| | Deployment assessment | No identified risk. |
| Validation Activities Summary | Previous cycle | The previous cycle has moved forward in data set preparation, as well as the architecture design of edge services and subservices, the testing method, infrastructure, and location. Development of edge services namely state estimation under SUC-FI-02.03 has been in progress. The next steps were to complete SUC-FI-02.03 and SUC-FI-02.04 and test them together. |
| | Current cycle | In this cycle, the remaining functionalities of SUC-FI-02.03 were completed and SUC-FI-02.04 was developed completely. In addition, after the development, unit and integration testing of both use cases SUC-FI-02.03 and SUC-FI-02.04 was conducted according to the plan. |
| | Future cycle | <ul style="list-style-type: none"> System testing of SUC-FI-02.03 and SUC-FI-02.04 by TAU and ABB. Piloting the solution. |

The following figures summarise the statuses of SUC-FI-02.03 & SUC-FI-02.04, with the plan being to start system testing from April 2026. The results have been achieved using the TAU test environment for validation purposes.

The following figure presents the estimated grid voltage profile in per unit (p.u.) obtained from the state estimation algorithm. The purple and orange curves represent the maximum and minimum voltages, respectively, while the blue curve shows the average voltage. Although the system has been running continuously for several weeks, the results shown here correspond to the two-day period from 21.03.2026 to 23.03.2026.



FIGURE 5: GRID'S ESTIMATED VOLTAGE

The following figure illustrates the control commands issued by the real-time congestion management algorithm for the reactive power of DERs in the grid. In this test, the control algorithm aims to maintain the voltage within the range of 0.975–1.025 p.u., which is intentionally tighter than the normal operating band for testing purposes. In addition, the algorithm is designed to prevent branch overloading. As shown in Fig. 2, one DER is commanded to absorb reactive power, reaching

approximately -210 kVAr, in order to mitigate a voltage, rise at the solar power plant caused by increased solar irradiance. Once the voltage returns to the acceptable range, the real-time congestion management algorithm restores the reactive power command back to its original value of 0 kVAr.



FIGURE 6: REAL-TIME CONGESTION MANAGEMENT’S CONTROL COMMANDS

The following figures showcase the solar irradiance and ambient temperature at the pilot location, respectively, as received from FMI. These environmental inputs are used in the generation estimation module and influence the overall grid behaviour.



FIGURE 7: SOLAR IRRADIANCE AT THE PILOT LOCATION RECEIVED FROM FMI

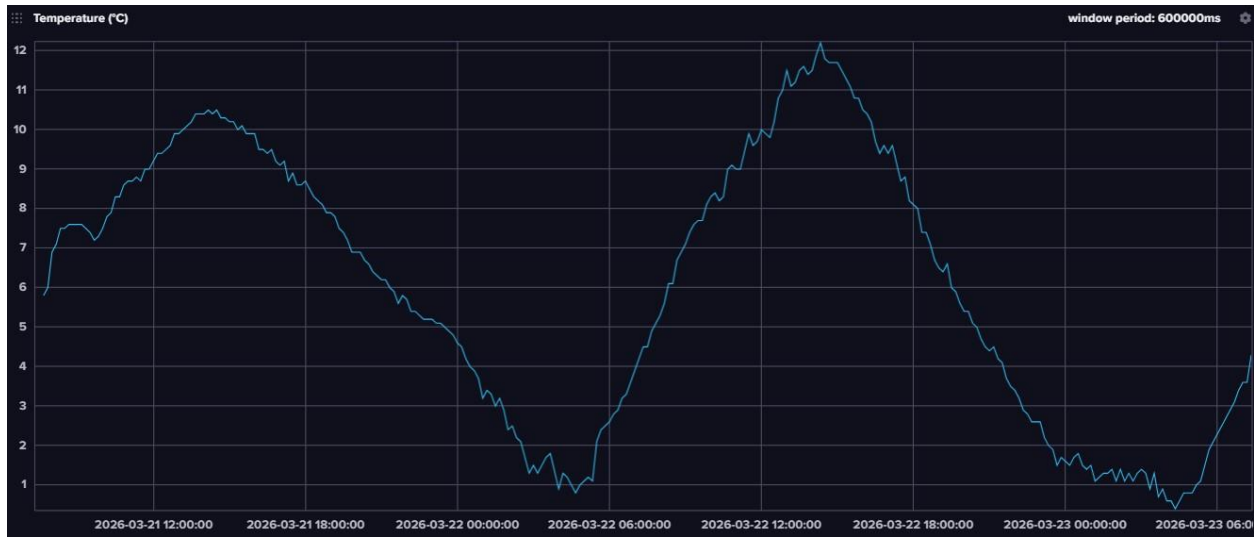


FIGURE 8: TEMPERATURE AT THE PILOT LOCATION RECEIVED FROM FMI

3.3.2 Milestones and Progress

This subsection revisits the internal milestones identified in D5.1 and assesses their status, noting any updates, delays, or partial completions observed during the Full-Demo Phase. The information is presented in the following table, which maps each milestone to the corresponding implementation steps and indicates the extent of progress achieved for the Finnish Demo.

TABLE 5: PROGRESS ON DEMO 1 INTERNAL MILESTONES LINKED TO THE IMPLEMENTATION OF SYSTEM USE CASES (SUCS) DURING THE FULL-DEMO PHASE

| Internal Milestone | M | FI-01.01 | FI-01.02 | FI-02.01 | FI-02.02 | FI-02.03 | FI-02.04 |
|---|-----|--|---|---|---|---|---|
| Installing first set of devices to start data gathering | M12 | This milestone is related to building the piloting infrastructure that will be used for all SUCs/services. All devices have been procured and installed. | | | | | |
| Procuring and installing the second set of devices | M14 | This milestone is related to building the piloting infrastructure that will be used for all SUCs/services. All devices have been procured and installed. | | | | | |
| Pre-demo up and running | M16 | During pre-demo, anomaly detector on edge server | During pre-demo, steps 1-2 were partly implemented on the first piloting area | During pre-demo not on the piloting areas | During pre-demo not on the piloting areas | During pre-demo not on the piloting areas | During pre-demo not on the piloting areas |

| | | | | | | | |
|--|-----|---|--|---|---|---|---|
| | | #1 was in use | | | | | |
| First versions of new algorithms ready for lab testing | M16 | At the time of writing this, all steps 1-4 have been implemented in lab environment, but some further development is still needed. First lab tests have been started. | At the time of writing this, steps 1 and 2 have been implemented in lab environment but some further development is still needed. Step 3 is partly implemented. Step 4 remains for later implementation. | At the time of writing, steps 1-17 have been implemented in lab environment | At the time of writing, first version of steps 1-3 has been implemented in lab environment | At the time of writing, steps 1-17 have been implemented in lab environment | At the time of writing, steps 1-11 have been implemented in lab environment. |
| On-site devices updated to include the developed functionality | M22 | Due to the change in demo architecture and testing plans, edge server #2 will be deployed on-site only during the large-scale demo phase. | Due to the change in demo architecture and testing plans, edge server #2 will be deployed on-site only during the large-scale demo phase. | Due to the change in demo architecture and testing plans, edge server #2 will be deployed on-site only during the large-scale demo phase. | Due to the change in demo architecture and testing plans, edge server #2 will be deployed on-site only during the large-scale demo phase. | Due to the change in demo architecture and testing plans, edge server #2 will be deployed on-site only during the large-scale demo phase. | Due to the change in demo architecture and testing plans, edge server #2 will be deployed on-site only during the large-scale demo phase. |
| Fully developed versions of the new functionality | M32 | N/A | N/A | N/A | N/A | N/A | N/A |

| | | | | | | | |
|-----------------------------|-----|-----|-----|-----|-----|-----|-----|
| y updated on-site | | | | | | | |
| Fully validated in the demo | M38 | N/A | N/A | N/A | N/A | N/A | N/A |

3.4 FULL-DEMO EVALUATION

3.4.1 Requirements Evaluation

The following section presents the requirement for each SUC, which was initially introduced in D5.1 including the description, acceptance criteria, and assigned testing partner. An additional column now captures the progress status recorded during the Full-Demo Phase, allowing a direct comparison between the targets set in D5.1 and the results achieved to date.

SUC-FL-01.01 & SUC-FL-01.02 DATA COLLECTION AND ANOMALY DETECTION & FAULT FORECASTING ANOMALY DETECTION AND FAULT FORECASTING

| Req | Description | Acceptance Criteria | Progress |
|--------|-------------------------------|---|---|
| QoS.1 | Accuracy of data requirements | Data is available with proper measurement accuracy and resolution | Data accuracy vs computational burden has been evaluated and methods for sharing the data stream have been studied. Proper compromise on accuracy vs density has been sought for. |
| QoS.2 | Frequency of data exchanges | Data is available with the resolution of IEC61850-9-2 Sampled value or at equivalent rate depending on the format | Format has been defined as pre-processed data stream. The format sets also limits for the frequency of exchange. |
| Sec. 1 | Information integrity | Missing data or frozen data stream must be noted as a function of the data link | This is a feature of the format used. It is also noted that the function is not fully critical to losing part of the data. |
| D.1 | Quality of data | Data timestamped and of proper quality, with indication of missing datapoints. | This is a feature of the format used. It is also noted that the function is not fully critical to losing part of the data. |
| D.2 | Correctness of source data | Data source indicated as part of the dataset | This is a feature of the format used. It is also noted that the function is not fully critical to losing part of the data. |
| D.3 | Format for AI algorithm input | Input data format defined and implemented | Initial definition available and partly implemented, to be modified when implementation work progresses |

| | | | |
|--------|--------------------------------------|---|---|
| D.4 | Format for anomaly log defined | Anomaly log format is available. | Initial definition available and partly implemented, to be modified when implementation work progresses |
| Conf.1 | Commonly used communication protocol | In principle IEC61580 is applied. In addition, data link format as specified. | The pre-processed data format has been changed to MQTT. IEC61850 is still valid on IED side. |
| O.1 | Adequate computational power | Implemented analytics can be run on the EDGE server. | Early testing has been taken on lab server. Computational power needs on pilot case remain to be studied. |

SUC-FL-02.01/04 CONGESTION PREDICTION IN DISTRIBUTION GRIDS/CONGESTION MANAGEMENT PLANNING IN DISTRIBUTION GRIDS/ STATE MONITORING OF THE DISTRIBUTION GRID/REAL-TIME CONGESTION MANAGEMENT ON THE EDGE

| Req | Description | Acceptance Criteria | Progress |
|--------|---|---|---|
| Conf.1 | The operation mode of the information producer/receiver | Manual | Manual setting of the parameters (e.g., grid parameters, computation cycle (1 min), etc.) has been tested by TAU and ABB on their test environments. In the system testing, TAU and ABB will test those manual configurations together. |
| Conf.2 | The operation mode of the information producer/receiver | Automatic | Cannot be evaluated yet. |
| QoS.1 | Elapsed time response requirements for exchanging data | Less than 1 second | The data exchange using MQTT protocol has been tested by TAU and ABB on the test environments. The results show a fraction of a second for data exchange. For server-client type pf data exchange, this yet needs to be tested. |
| QoS.2 | Availability of information flows | 99.9% + availability - Allowed outage: a few times per year, max 1 hour each. | Partly evaluated. For example, availability of weather data, and electricity price have been tested so far by TAU. More tests are required, for example on load data generated by Järvi-Suomen Energia and the data coming from primary substation under IEC 61850. |
| QoS.3 | Frequency of data exchange | Periodicity greater than a few minutes, OR upon event OR every few seconds. | Partly evaluated. For example, periodic update of weather data, has been tested by TAU. ABB has conducted tests on data handling on the edge server where IEC61850 data arrive from primary substation and also intermediary server. More tests are required, to ensure the frequency of data exchange for all the data necessary on the edge is as expected. |
| Sec.1 | Eavesdropping | Ensuring confidentiality, avoiding illegitimate use of data, and preventing unauthorised reading of data. | Partly evaluated in terms of grid, load and generation data being only accessed/used by authorised parties. On the IT side, the edge server is behind a firewall, and access to it from outside world is blocked. No cyber security tests have been done though. |
| Sec.2 | Information integrity violation | Ensuring that data is not changed or destroyed. | Not yet evaluated. Evaluation after implementing the data exchange interfaces. |

| | | | |
|-------|--|---|--|
| Sec.3 | Authentication | Ensuring that data comes from the stated source or goes to the authenticated receiver. | The publisher and receiver of MQTT messages are authenticated by MQTT broker to assure that the generated data comes from stated source and it is received by the authenticated receiver. Other than enabling authentication on the MQTT, no tests have been done. |
| Sec.4 | Information theft | Ensuring that data cannot be stolen or deleted by an unauthorised entity. | Not yet evaluated. |
| D.1 | Logging | Logging of all information exchanged during this interaction is required, OR Logging of the source, destination, requesting application, and requesting user of information exchanges is required, but not the data itself. | Logging has been tested by TAU and ABB on the test environments. The data base used is Influx. |
| D.2 | Up-to-data management | Received data must be up-to-date within seconds of source data changing. | ABB has conducted tests on IEC61850 and data link to assure the speed of data processing and logging. Similar tests need to be done on the data coming from intermediary server. |
| D.3 | Data consistency and synchronisation management across systems | Second-by-second synchronisation OR Day-by-day synchronisation. | PTP time synchronisation is implemented using two network clocks that distribute time over the whole advanced fiber network to the IEDs and edge servers. |
| D.4 | Management of data across organisational boundaries | Data exchanges go across boundaries between system developed by different vendors OR data exchanges go across organisational boundaries. | The data exchanged between organisations is stored in a database using separate buckets, enabling each organisation to access the data later to facilitate data management. |
| D.5 | Naming of data items | Matching of names is handled by a "converter" at the Information Receiver. | A comprehensive data interface documentation has been created for message payloads, their naming, frequency of exchange, etc. to facilitate the interoperability between data producers and receivers. Testing will happen during system testing stage. |

3.4.2 KPIs Progress

The KPIs to be measured by the Finnish demo and their progress upon the end of the Full-Demo Phase is presented in the table below.

TABLE 6: DEMO 1 KPIS PROGRESS (M28)

| ID | KPI | Baseline | Pre-Demo (M18) | Progress (M28) |
|-----|---|----------|---|--|
| OB1 | Different types of IoT/edge devices to be exploited in Demo Areas | 0 | IEDs on substations and on breakers at feeders, edge server, smart meters | IEDs on substations and on breakers at feeders, edge server, smart meters, intermediary server, network clocks |

| | | | | |
|-------|--|-----|---------------------------------|--|
| | e.g., Smart Meter, HEMS, Sensors, inverter | | | |
| KPI4 | Real-time data sharing among stakeholders | 0 | Functionality under development | Edge server #2 will be deployed on-site during the large-scale demo phase. During the full demo phase data exchanges have been tested in laboratory environment. |
| KPI8 | IoT/Edge/Fog sites uptime and availability | n/a | Data not available yet | Edge server #1 has been operating on-site without disturbances for some months. Edge server #2 will be deployed on-site during the large-scale demo phase. |
| KPI9 | Flexibility unlocked and transacted in markets | 0 | n/a | Congestion management functionality will be deployed on-site during the large-scale demo phase and will be linked to a demo market platform. |
| KPI11 | Increased grid operational performance | n/a | n/a | Novel fault prediction functionality will be deployed on-site during the large-scale demo phase. Commercial reference system has been set up during the full demo phase. |
| KPI17 | Increased flexibility incorporation enabled by IoT/Edge technologies for grid security | 0 | n/a | Edge server #2 will be deployed on-site during the large-scale demo phase. During the full demo phase congestion management has been tested in laboratory environment. |
| KPI22 | Increase DERs participation in flexibility provision | 0 | n/a | Edge server #2 will be deployed on-site during the large-scale demo phase. During the full demo phase congestion management has been tested in laboratory environment. |

3.4.3 Risks and Proposed Mitigation Actions

The development of the algorithms and modules utilised as a part of the Finnish demo is already quite advanced and, hence, the technological risk related to algorithm development has decreased from earlier stages of the project. The main technological risk at the moment relates to integrating the new solutions together. This risk has been mitigated through detailed data exchange mapping between different functionalities and thorough unit testing prior to system testing. A smaller risk remains also on the algorithm performance and computational resource requirements. Proper unit testing mitigates also this risk but does not totally remove it.

A new risk has emerged and is related to the demo area. One of the pilot substations needs to be urgently renewed and this will influence the piloting activities on this area. This risk is mitigated through shifting piloting activities on a neighbouring substation.

4 DEMO 2 – LEVERAGING IOT AND EDGE COMPUTING TO FOSTER LOCAL FLEXIBILITY MARKETS [GREECE]

4.1 FULL-DEMO PHASE ACTIVITIES SUMMARY

This section presents a structured summary of the activities that the Greek Demo conducted during the Full Demo Operation Phase (M22-M28). It follows the demo deployment template introduced deliverable D5.1, which functions as a reference for monitoring the development of each demonstrator. The status of the Full Demo Operation Phase targets, the WP3 services utilised, and the key stakeholders involved during this phase are all detailed in below.

The purpose of the information is to establish the foundation for the Full Demo Phase and to evaluate the operational readiness of the demo at the conclusion of the Pre-Demo Phase.

TABLE 7: DEMO 2 FULL DEMO OPERATION PHASE DEPLOYMENT STATUS

| Section | Subsection | Input |
|---------|--|---|
| Summary | Full Demo Phase Target | <p>The main target of the Full Demo Phase for the Greek demo is to validate the integrated operation of the deployed hardware and software components across edge and cloud layers, and to demonstrate end-to-end system functionality. Building on the pre-demo phase, where residential users were onboarded and the initial infrastructure was tested, the focus is now on utilising the available data streams to support forecasting, flexibility optimisation, and interaction with the Local Flexibility Market.</p> <p>The objective is to ensure that the different system components operate cohesively, enabling continuous data acquisition, processing, and decision-making, while supporting flexibility estimation and the generation of market-oriented outputs.</p> |
| | Status Summary | <p>During the Full Demo Phase, the Greek Demo progressed from partial integration to a more complete operational setup. IoT submetering devices, cloud databases, forecasting services, flexibility optimisation, user interfaces, and the Local Flexibility Market platform were deployed, tested, and integrated across the main SUCs. Demand forecasting, production forecasting, NILM/disaggregation, edge processing, user interaction, grid analysis, registration/prequalification, and flexibility trading workflows were validated using pilot data, representative datasets, and real or sample market/grid inputs.</p> <p>The demo has achieved a functional end-to-end architecture, with several components already operational and tested. Some elements remain under refinement, including full data-space connector integration, complete end-to-end trading settlement, broader scalability testing, and further validation under real operational conditions.</p> |
| | Services Used (from WP3) | The services used during the Full Demo Phase include: Flexibility Optimisation Service; Demand Forecasting Service; Production Forecasting Service; Disaggregation/NILM Service; Federated Learning components; Aggregator Platform; Residential Mobile App and Web Interface; Local Flexibility Market Platform; |
| | Stakeholders involved during Full Demo | Residential end-users, Aggregator (PPC), DSO (HEDNO), TSO (IPTO), NEMO (HENEX) |

4.2 INFRASTRUCTURE, ASSETS AND DATA AVAILABILITY

Based, on the demo-deployment template (Annex I), a consolidated snapshot of the infrastructure and assets mobilised during the Full Demo Operation Phase is provided in the following table for the Greek demo. Each asset is accompanied by its technical description, deployment level, use status in months 22–28, and the WP3 service to which it pertains.

TABLE 8: SUMMARY OF GREEK DEMO INFRASTRUCTURE AND ASSETS DEPLOYED DURING THE FULL DEMO OPERATION PHASE

| Asset | Description | Deployment Level | Used during Full demo | Under which WP3 service |
|---|--|---|-----------------------|---|
| Submetering IoT devices | IoT devices in residential switchboards with edge processing capabilities | Deploying and testing period | Yes | Flexibility Optimisation Service, Demand Forecasting Service, Disaggregation Service, FL, Aggregator and Mobile App Platforms |
| Smart meters (billing purposes) | DSO level metering for billing purposes and flexibility baseline estimations | To be installed in the chosen residential buildings | Partially | Local Flexibility Market Platform |
| Databases for data exchange | Cloud storage | Operational | Yes | Flexibility Optimisation Service, Demand Forecasting Service, Disaggregation Service, FL, Aggregator and Mobile App Platforms |
| Data Space connectors | Infrastructure to support data exchange between aggregator/DSO/TSO /NEMO | Under development | Partially | Flexibility Optimisation Service, Demand Forecasting Service, Disaggregation Service, FL, Aggregator and Mobile App Platforms |
| Smart Building and Flexibility Modelling AI-based Tools | A set of AI tools and algorithms for residential consumers running on the edge and cloud | Under testing | Yes | Flexibility Optimisation Service, Demand Forecasting Service, Disaggregation Service, FL, Aggregator and Mobile App Platforms |

| | | | | |
|----------------------------|---|---------------|-----|--|
| User Interfaces | Mobile app and web interface for residential consumers and aggregators | Under testing | Yes | Residential mobile app and web interface, aggregator web interface |
| Local Flexibility Platform | Platform enabling local flexibility market operation, including bidding, matching, and activation of flexibility services at LV level | Under Testing | Yes | Local Flexibility Market Platform |
| LV nodes | Network nodes to procure flexibility | Deployed | Yes | Local Flexibility Market Platform |

The following table summarises the datasets relevant to the Full Demo Operation Demo Phase, indicating their availability, whether they were used during this period and their linkage to the corresponding WP3 technological enablers.

TABLE 9: DEMO 2: OVERVIEW OF DATASETS RELEVANT TO THE FULL DEMO OPERATION PHASE

| Data Description | Used during Full-Demo Phase | Under which WP3 service |
|--|-----------------------------|---|
| Residential current measurements | Full data | Flexibility Optimisation Service, Demand – Production Forecast Service, Disaggregation Service, FL, Aggregator and Mobile App Platforms |
| Residential voltage measurements | Full data | Flexibility Optimisation Service, Demand – Production Forecast Service, Disaggregation Service, FL, Aggregator and Mobile App Platforms |
| Residential active and reactive power measurements | Full data | Flexibility Optimisation Service, Demand – Production Forecast Service, Disaggregation Service, FL, Aggregator and Mobile App Platforms |
| Residential power factor measurements | Full data | Flexibility Optimisation Service, Demand – Production Forecast Service, Disaggregation Service, FL, Aggregator and Mobile App Platforms |
| Network frequency measurements | Full data | Flexibility Optimisation Service, Demand – Production Forecast Service, Disaggregation Service, FL, Aggregator and Mobile App Platforms |
| 1-phase/3-phase residential active energy measurements | Full data | Flexibility Optimisation Service, Demand – Production Forecast Service, Disaggregation Service, FL, Aggregator and Mobile App Platforms |

| | | |
|---|-------------|---|
| MV Power-Bus Voltage data | Full data | Not applicable, for internal use for grid assessment on flexibility calculation |
| HV/MV Transformer Power data | Full data | Not applicable, for internal use for grid assessment on flexibility calculation |
| DSO smart metering data (LV, MV, consumers/prosumers/PV plants) | Data Sample | Not applicable, for internal use for grid assessment on flexibility calculation |
| Company Data | Yes | Flexibility Optimisation Service |
| Asset Data | Yes | Flexibility Optimisation Service |
| BID Data | Yes | Flexibility Optimisation Service |
| Results Data | Yes | Flexibility Optimisation Service |

OPEN DATA AVAILABILITY

The Greek pilot deploys non-intrusive smart electricity meters (Shelly Pro EM series) in a set of residential households. Collected data are subsequently ingested into the pilot's database and can be made available through the Data Sharing Platform to all partners in a structured, interoperable format. Data are also semantically annotated in alignment with the SAREF4ENER ontology to ensure cross-platform interoperability. The pilot covers two household configurations, depending on the electrical installation type:

Single-phase households: Measurements are reported as a single set of electrical parameters.

| Field | Description | Unit |
|------------------|--|------------------|
| current | RMS current on the phase | Ampere (A) |
| voltage | RMS voltage on the phase | Volt (V) |
| act_power | Active power consumed | Watt (W) |
| aprt_power | Apparent power | Volt-Ampere (VA) |
| pf | Power factor (ratio of active to apparent power) | Dimensionless |
| freq | Grid frequency | Hertz (Hz) |
| total_act_energy | Cumulative active energy consumed | Watt-hour (Wh) |

| | | |
|----------------------|-----------------------------------|----------------------|
| total_act_ret_energy | Cumulative active energy returned | Watt-hour (Wh) |
| timestamp | UTC timestamp of the reading | ISO 8601(UTC) |
| tz | Local timezone identifier | IANA timezone string |

Three-phase households: Measurements are reported per phase (Phase A, Phase B, Phase C) as well as aggregated totals across all phases. Per-phase fields are prefixed with a_, b_, and c_ respectively for Phase A, Phase B, and Phase C. Each phase carries the same set of electrical parameters as in the single-phase schema (current, voltage, act_power, appt_power, pf, freq, total_act_energy, total_act_ret_energy). In addition, the following aggregate and neutral fields are reported:

| Field | Description | Unit |
|------------------|---|------------------|
| n_current | Neutral conductor current | Ampere (A) |
| total_current | Sum of RMS currents across all phases | Ampere (A) |
| total_act_power | Sum of active power across all phases | Watt (W) |
| total_appt_power | Sum of apparent power across all phases | Volt-Ampere (VA) |
| total_act | Cumulative total active energy consumed across all phases | Watt-hour (Wh) |
| total_act_ret | Cumulative total active energy returned across all phases | Watt-hour (Wh) |

The Data Sharing Platform is primarily aligned with WP4, as it enables structured data exchange and ensures semantic interoperability across the participating systems. By exposing the collected measurements in a unified format and supporting their semantic annotation based on SAREF4ENER, the platform facilitates seamless integration, data discoverability, and cross-platform interoperability, which are core objectives of WP4’s interoperability framework.

In addition, the Data Sharing Platform supports WP3 by acting as the interface between IoT-enabled data acquisition at the edge and higher-level processing layers. It enables the efficient flow of data from distributed smart metering devices to edge/cloud services, thereby supporting data-driven functionalities and analytics envisioned in WP3. Furthermore, its deployment within the Greek pilot contributes to WP5 by providing a practical environment for validating interoperable data exchange mechanisms under real-life conditions.

4.3 FULL-DEMO OPERATION PHASE RESULTS

This section captures the status and progress of System Use Case (SUC) implementation during the Full Demo Operation Phase (M22–M28) for the Greek Demo. For each SUC, key developments are outlined, including the specific actions undertaken, intermediate achievements, and alignment with the expected implementation steps and scenarios described in D2.3.

4.3.1 SUCs Implementation

This subsection presents the implementation progress of each System Use Case (SUC) as defined in D2.3 for the Greek Demo, highlighting the actions carried out during the Full Demo Operation Phase.

SUC-GR-01.01 OPTIMISATION OF FLEXIBILITY DISTRIBUTION

| Section | Subsection | Input |
|---------------------|------------------------|---|
| Overview | SUC Summary | In this SUC, the Aggregator aggregates the available flexibility assets of consumers, models their behaviour, and identifies feasible flexibility actions to submit optimised bids to the Local Flexibility Market (LFM). In the current phase, the optimisation is performed using day-ahead forecasted loads and market prices, enabling the identification of peak and low time slots, the estimation of available flexibility, and the construction of market bids. The implemented approach focuses on consumer demand flexibility, modelling customer response and generating bid curves that reflect both expected performance and uncertainty. |
| | Target(s) | The objective of this phase is to implement and validate a day-ahead optimisation workflow that: (i) uses forecasted inputs for decision-making, (ii) estimates flexibility from historical consumption data, (iii) determines incentive levels per consumer group, and (iv) generates executable bids for the flexibility market. |
| | Expected UC Milestones | The expected milestone is the demonstration of a complete optimisation process capable of: (i) processing forecasted load and price data, (ii) selecting suitable peak/low time-slot pairs, (iii) estimating the available flexibility, (iv) allocating incentives, and (v) generating bid curves compatible with market requirements. |
| | Actions implemented | A complete optimisation workflow was implemented and evaluated. The process begins with preprocessing of historical consumption data and selection of complete daily profiles. Based on these data, customer-specific flexibility parameters are derived, capturing flexibility potential and response characteristics. Using historical observations, the system generates day-ahead price forecast quantiles and identifies candidate peak and low time slots based on expected spreads. For each candidate pair, incentive levels are determined per customer using a contextual learning approach, while respecting operational constraints such as maximum offers and flexibility limits. The resulting flexibility is aggregated and used to construct multi-step bid curves, taking into account uncertainty in both market prices and customer response. A simulation-based approach is applied to evaluate different bidding strategies and select the most suitable one. The workflow was validated through a train/test split, producing daily performance metrics, pair-level logs, customer-level statistics, and day-ahead bidding plans. |
| Requirements | Assumptions | The implementation assumes that: (i) day-ahead forecasts of load and market prices are available, (ii) historical consumption data are representative of customer behaviour, (iii) flexibility can be estimated from past load patterns, (iv) customer |

| | | |
|--------------------------------------|------------------------|--|
| | | response to incentives is uncertain but can be learned over time, and (v) the market supports quantity-price step bids. |
| | Dependencies | This module relies on the Demand Forecasting SUC (SUC-GR-01.02) to ingest consumption forecasts, and on the User Interaction Interface SUC (SUC-GR-01.05) to present flexibility offers and collect consumer responses. It also depends on the Flexibility Trading SUC (SUC-GR-03.02) for the submission of flexibility offers, the execution of market clearing, and the evaluation of results within the Local Flexibility Market framework. |
| | Risks | The main risks include: (i) uncertainty in forecasts affecting optimisation decisions, (ii) variability in customer response leading to deviations between expected and delivered flexibility, (iii) potential under-delivery of committed flexibility, and (iv) scalability challenges as the number of consumers increases. |
| Readiness | Deployment diagram | See below. |
| | Deployment preparation | The preparation focused on implementing the data processing pipeline, flexibility estimation, optimisation logic, and bid generation mechanisms. Historical datasets and forecast inputs were used to test and validate the workflow. |
| | Deployment assessment | The optimisation workflow has been implemented and validated on historical data. The system is capable of producing consistent bidding outputs and detailed performance logs. |
| Validation Activities Summary | Previous cycle | In the previous cycle, the optimisation framework was developed and evaluated using forecast inputs and historical data, establishing the basis for flexibility estimation and decision-making. |
| | Current cycle | In this cycle, the optimisation workflow was extended to support day-ahead bidding based on forecasted data. The system now generates bid curves, estimates incentives, and evaluates performance through simulation and train/test validation. |
| | Future cycle | Future work will focus on further integration and validation of the optimisation workflow under operational conditions. This includes tighter coupling with forecasting services, improved modelling of consumer response based on real interaction data, and scalability to larger consumer portfolios. In addition, future experiments will extend the current setup by considering combined portfolios of consumers and prosumers (including PV and storage assets), enabling a more comprehensive assessment of flexibility optimisation across heterogeneous resources. |

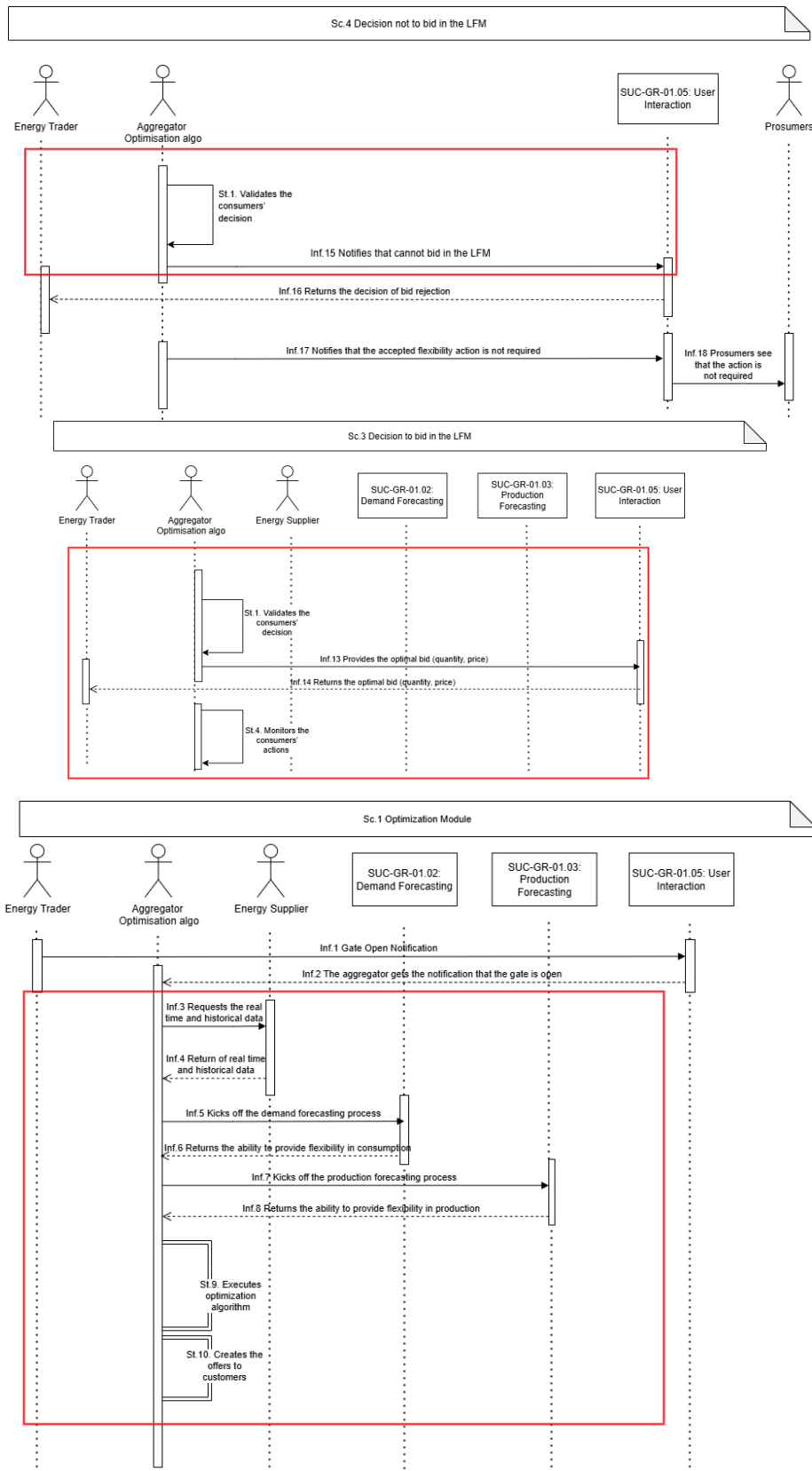


FIGURE 9: DEPLOYMENT DIAGRAM FOR SUC-GR-01.01 (ONGOING PROCESS)

The Flexibility Optimisation Service in SUC-GR-01.01 utilises a combination of edge, cloud and data exchange infrastructure, together with historical and forecasted datasets, to support the end-to-end optimisation and bidding workflow.

The service operates on data collected from submetering IoT devices and available DSO smart metering data, which are processed and stored through cloud-based databases and data exchange mechanisms. These data streams provide the basis for estimating consumer flexibility and training the optimisation algorithms. In addition, market data (e.g. Greek Power Market data) and internally generated datasets (asset data, bid data and results data) are used to drive and evaluate the optimisation process.

The optimisation logic is implemented within the Smart Building and Flexibility Modelling AI-based tools, deployed across cloud environments, and is interfaced with user interfaces for interaction with consumers and with the Local Flexibility Platform for bid submission and market participation. The overall architecture is supported by the edge server, which hosts the relevant applications and enables communication with WP3 services.

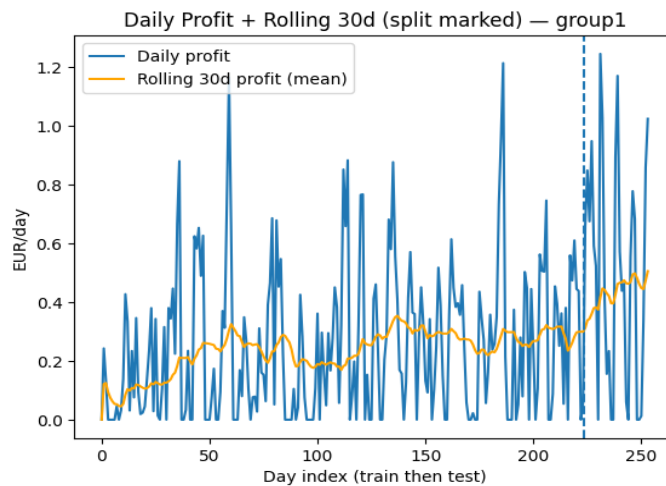


FIGURE 10: DAILY PROFIT AND 30-DAY ROLLING AVERAGE (TRAIN/TEST SPLIT)

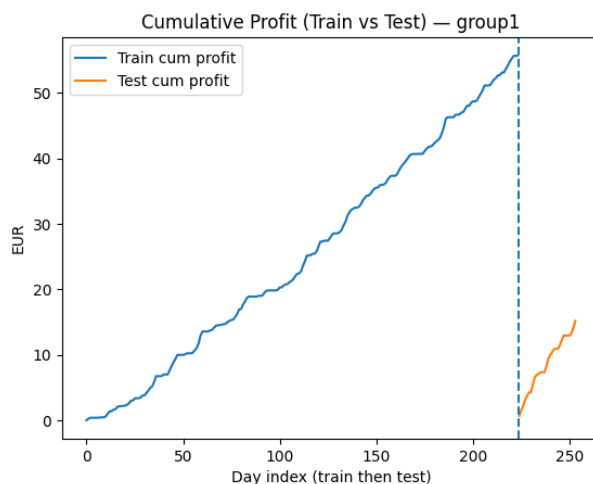


FIGURE 11: CUMULATIVE PROFIT (TRAIN VS TEST)

===== BIDDED SLOTS – group1 – 2025-09-05 =====

| | datetime | slot | t_low | mcp_price | temp_c | bid_Q_total | bids_steps | incentive_avg_pred | offers_sent | pct_zero_incentive |
|--------------|---------------------|------|-------|-----------|--------|-------------|-------------------|--------------------|-------------|--------------------|
| 21964 | 2025-09-05 19:00:00 | 76 | 51 | 0.19279 | 25.200 | 0.652263 | 0.652263@0.167693 | 0.045018 | 33 | 0.352941 |
| 21965 | 2025-09-05 19:15:00 | 77 | 50 | 0.19279 | 25.075 | 0.695904 | 0.695904@0.167475 | 0.040164 | 30 | 0.411765 |
| 21966 | 2025-09-05 19:30:00 | 78 | 49 | 0.19279 | 24.950 | 0.763664 | 0.763664@0.185324 | 0.038214 | 33 | 0.352941 |
| 21967 | 2025-09-05 19:45:00 | 79 | 48 | 0.19279 | 24.825 | 0.798810 | 0.798810@0.147714 | 0.044272 | 31 | 0.392157 |
| 21970 | 2025-09-05 20:30:00 | 82 | 45 | 0.16617 | 24.550 | 0.594488 | 0.594488@0.156917 | 0.036077 | 28 | 0.450980 |
| 21971 | 2025-09-05 20:45:00 | 83 | 44 | 0.16617 | 24.475 | 0.596600 | 0.596600@0.157032 | 0.039584 | 26 | 0.490196 |

FIGURE 12: DAY-AHEAD BIDDING PLAN (SELECTED PEAK SLOTS) 2025-09-05

During the pre-demo phase, the service focused on data ingestion, preprocessing and initial training of the optimisation algorithms, as well as validating the integration with edge/cloud infrastructure and data exchange components. These activities supported the early stages of the SUC, including flexibility estimation and preliminary decision-making.

In the current phase, the service has been extended to support a complete day-ahead optimisation workflow, including forecast-based decision-making, incentive allocation and bid-curve generation. The focus has shifted towards validating the full optimisation loop and its interaction with the flexibility trading process, while maintaining compatibility with WP3 services and the Local Flexibility Market framework.



FIGURE 13: ENERGY AGGREGATOR DASHBOARD (1/2)

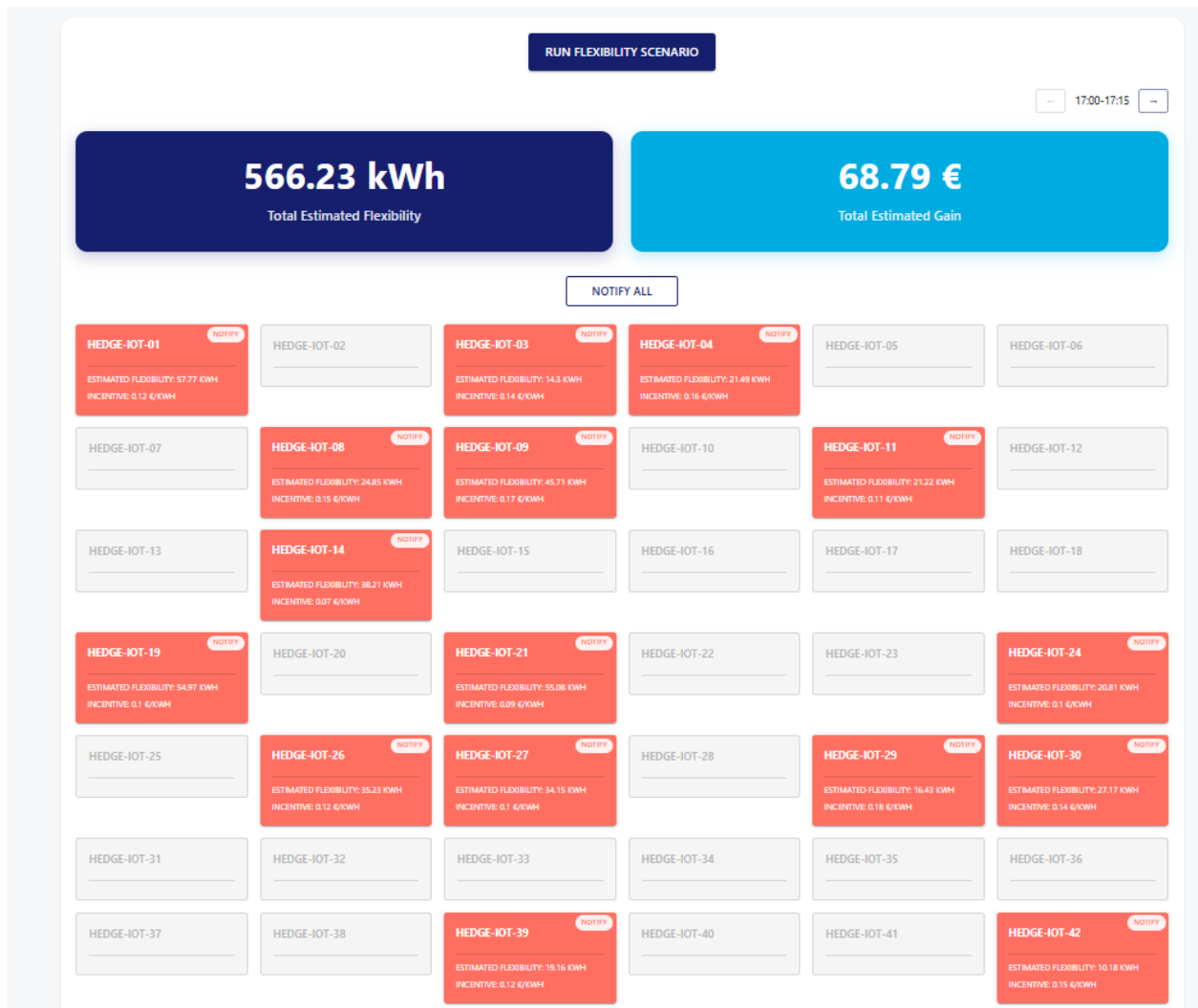


FIGURE 14: ENERGY AGGREGATOR DASHBOARD (2/2)

Aggregator Flexibility Optimization Service 5.0.0 OAS 3.1

/openapi.json

Production-oriented flexibility optimization service for the aggregator app. The service separates training from operational runs: /optimization/retrain trains and stores a model artifact, /optimization/run uses the active model to generate day-ahead bids, dispatch plans and customer offers. Current data source is CSV -> dataframes; later the source adapter can be replaced by request/API/DB -> dataframes without changing the optimizer lifecycle or endpoint contracts.

| SYSTEM | | ^ |
|--------------|--|---|
| GET | /health Liveness check | v |
| GET | /ready Readiness check | v |
| OPTIMIZATION | | ^ |
| GET | /optimization/info Describe service lifecycle and endpoints | v |
| POST | /optimization/validate-inputs Validate available input data | v |
| POST | /optimization/retrain Train a new optimizer model artifact | v |
| GET | /optimization/models List trained models | v |
| GET | /optimization/models/{model_id} Get model metadata | v |
| POST | /optimization/models/{model_id}/activate Activate a trained model | v |
| POST | /optimization/run Generate day-ahead optimization run | v |
| GET | /optimization/runs/{run_id} Get run metadata | v |
| GET | /optimization/runs/{run_id}/day-plan Get day-ahead bid plan | v |
| GET | /optimization/runs/{run_id}/dispatch-plan Get customer dispatch plan for one MTU | v |
| GET | /optimization/runs/{run_id}/market-bids Get market bid payload | v |
| GET | /optimization/runs/{run_id}/customer-offers Get customer-facing flexibility offers | v |
| POST | /optimization/runs/{run_id}/settlement Settle a completed run | v |

FIGURE 15: ENERGY AGGREGATOR ENDPOINTS

Furthermore, the Non-Intrusive Load Monitoring (NILM) service, which supports SUC-GR-01.01, has been further enhanced during the current evaluation cycle to improve its accuracy and applicability under real-world residential conditions. Building upon the initial Denoising Autoencoder (DAE)-based approach evaluated on public datasets (UK-DALE, REDD), the NILM framework was extended to address key challenges observed in real deployments, namely appliance heterogeneity and class imbalance in activation patterns. While the baseline DAE models provided a solid proof of concept, they exhibited limitations in generalising across different appliance operating regimes and in accurately detecting sparse activation events.

To address these limitations, a cluster-aware extension of the DAE (C-DAE) was implemented and presented in D5.2. This approach introduced an unsupervised clustering stage that segments aggregate consumption windows into distinct operating regimes, allowing the training of specialised sub-models per cluster. This significantly improved the model's ability to capture heterogeneous appliance behaviour across households. Experimental results on Greek pilot data demonstrated substantial performance gains across all examined appliances. For the dishwasher, the F1-score increased from 0.21 to 0.97, accompanied by a significant reduction in RMSE (from 289 W to 205 W), indicating improved detection of multi-phase operating cycles. Similarly, for the washing machine, the F1-score increased from 0.25 to 0.97, while the RMSE decreased by approximately 45% (from 484 W to 264 W), reflecting more accurate reconstruction of cycle intensity and duration. The washer-dryer, which exhibits highly variable and composite behaviour,

showed the most significant improvement, with recall increasing from 0.09 to 0.96 and F1-score from 0.16 to 0.96, demonstrating the effectiveness of the cluster-aware approach in capturing complex appliance dynamics.

As illustrated in the following figures, the C-DAE model achieves a close alignment between predicted and actual power profiles, while accurately identifying ON/OFF state transitions.

These results confirm that the cluster-aware training strategy substantially improves both event detection and power estimation accuracy, providing more reliable appliance-level disaggregation outputs.

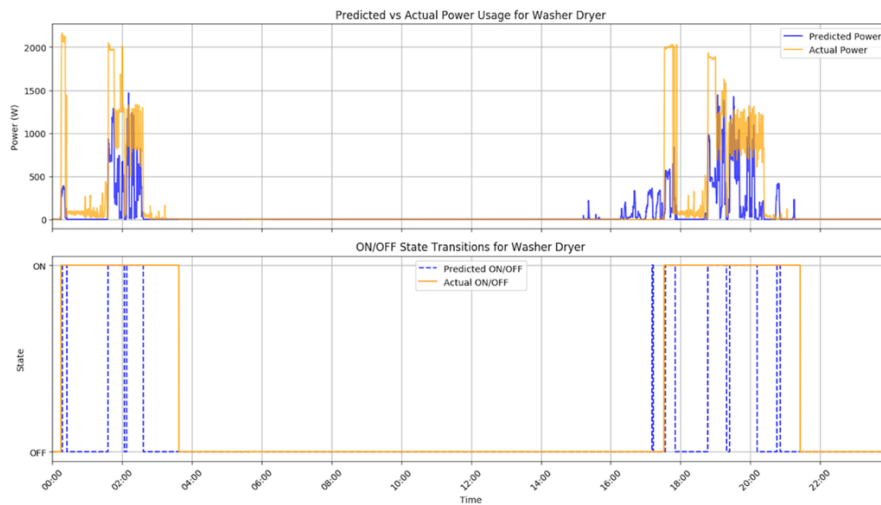


FIGURE 16: NILM PERFORMANCE FOR A WASHER-DRYER: TOP-PREDICTED VS. ACTUAL POWER, BOTTOM-PREDICTED VS. ACTUAL ON/OFF STATES.

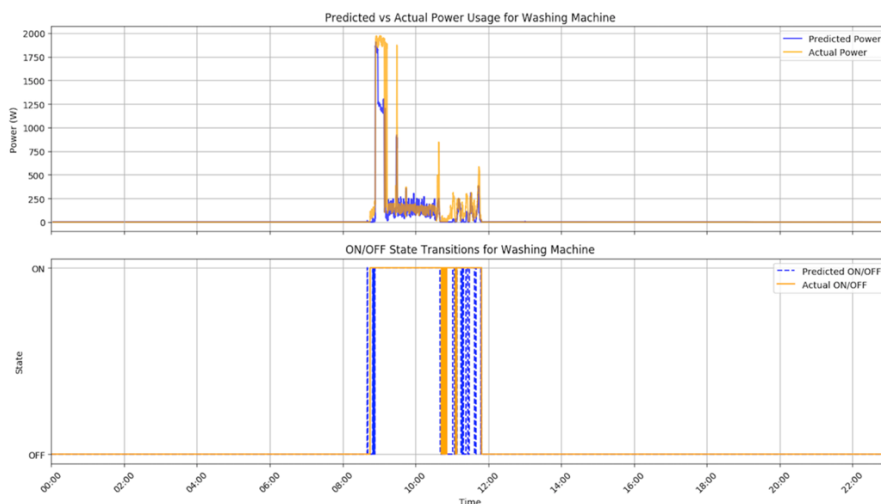


FIGURE 17: NILM PERFORMANCE FOR A WASHING MACHINE: TOP-PREDICTED VS. ACTUAL POWER, BOTTOM-PREDICTED VS. ACTUAL ON/OFF STATES.

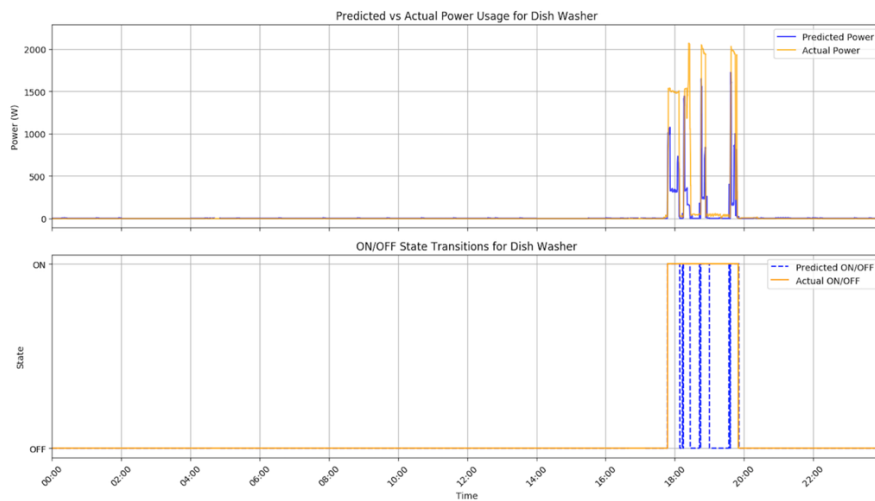


FIGURE 18: NILM PERFORMANCE FOR A DISHWASHER: TOP—PREDICTED VS. ACTUAL POWER, BOTTOM—PREDICTED VS. ACTUAL ON/OFF STATES.

In this cycle, a novel two-stage gated Seq2Point NILM architecture was developed to further improve performance under severe ON/OFF imbalance conditions. Unlike conventional single-stage regression approaches, which directly estimate appliance power and tend to underestimate sparse activation events, the proposed method explicitly decomposes the problem into two coordinated tasks: (i) activation detection and (ii) conditional power estimation. The architecture consists of two subnetworks operating on the same input window. The first is a classification model that estimates the probability of appliance activation at each time step, enabling accurate detection of ON/OFF events even under highly imbalanced conditions. The second is a regression model that estimates the appliance’s power consumption, trained exclusively on active periods to avoid bias toward near-zero predictions. The final output is obtained through a soft gating mechanism, where the activation probability modulates the regression output, effectively suppressing spurious predictions during OFF states while preserving accurate magnitude estimation during active periods.

This structural decoupling introduces an inductive bias aligned with the physical behaviour of appliances, where activation and power magnitude are inherently distinct processes. As a result, the model significantly improves event-level sensitivity while maintaining accurate reconstruction of power trajectories. This is particularly beneficial for appliances with sparse, multi-phase, or highly variable operating patterns, such as washer-dryers, where traditional models tend to miss activation events or underestimate peak consumption. The performance of the gated Seq2Point architecture was quantitatively evaluated on the same Greek household dataset used for the DAE and C-DAE models, ensuring direct comparability. The results show that the proposed method achieves the lowest reconstruction error across all examined appliances, with RMSE reduced to 198 W for the dishwasher, 84 W for the washing machine, and 169 W for the washer-dryer. In terms of event detection, the model achieves balanced precision and recall (e.g., F1-score of 0.73 for the dishwasher, 0.81 for the washing machine, and 0.71 for the washer-dryer), significantly outperforming the baseline DAE while remaining slightly below the near-perfect classification performance of C-DAE. These results confirm that the gated formulation improves magnitude reconstruction while maintaining accurate activation detection under imbalanced conditions.

As illustrated in the following figures the gated Seq2Point model achieves a closer alignment between predicted and actual appliance consumption across different appliance types. The full-timeline plots show a clear reduction of false positive background activity during inactive periods,

while the zoomed-in views demonstrate improved temporal alignment and more accurate reconstruction of activation cycles. These improvements directly translate into more reliable device-level consumption profiles, which are essential for downstream flexibility estimation and demand-response optimisation.



FIGURE 19: NILM PERFORMANCE USING THE GATED SEQ2POINT MODEL FOR A DISHWASHER: TOP – FULL TIMELINE COMPARISON BETWEEN GROUND TRUTH AND PREDICTED POWER CONSUMPTION, BOTTOM – ZOOMED-IN VIEW AROUND AN ACTIVATION EVENT.

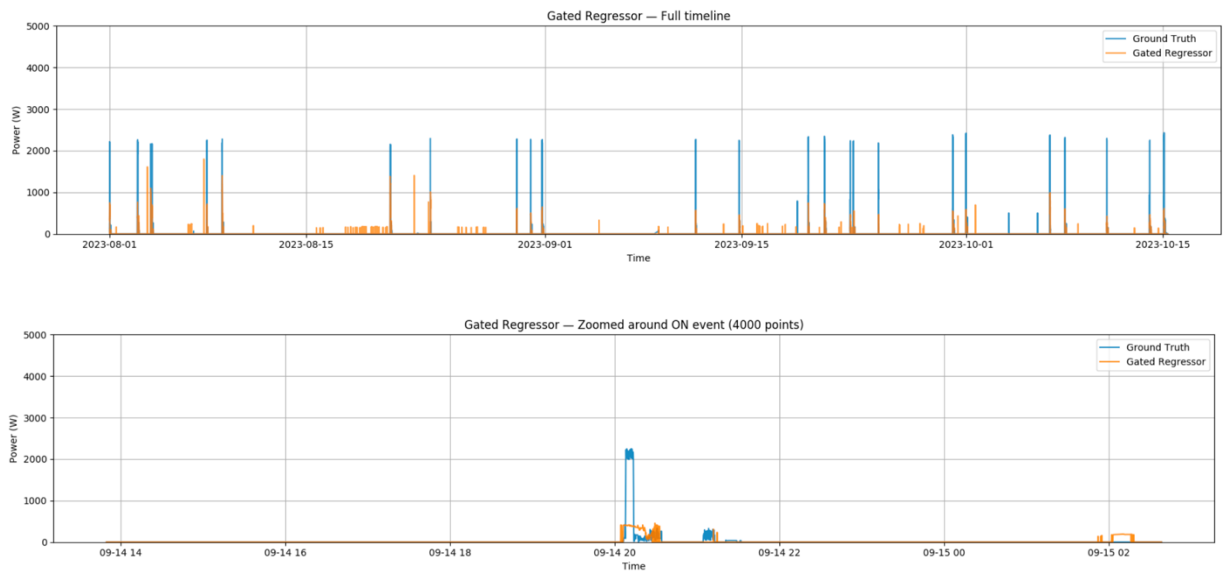


FIGURE 20: NILM PERFORMANCE USING THE GATED SEQ2POINT MODEL FOR A WASHING MACHINE: TOP – FULL TIMELINE COMPARISON, BOTTOM – ZOOMED-IN ACTIVATION WINDOW.

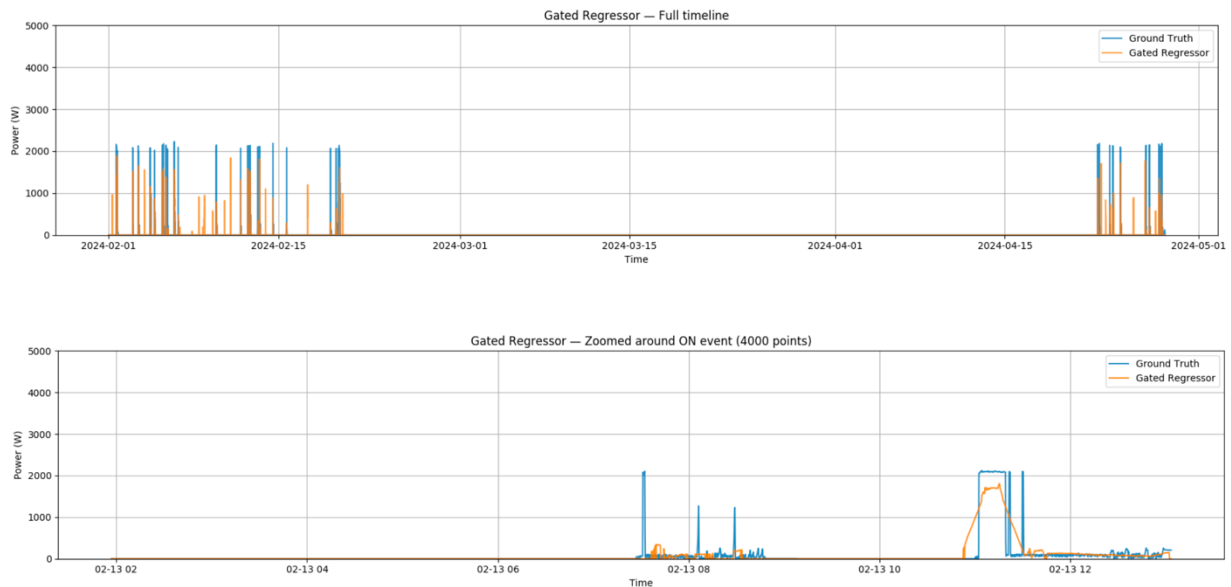


FIGURE 21: NILM PERFORMANCE USING THE GATED SEQ2POINT MODEL FOR A WASHER-DRYER: TOP - FULL TIMELINE COMPARISON, BOTTOM - ZOOMED-IN CYCLE RECONSTRUCTION.

In parallel with the machine-learning-based NILM models described above, an alternative disaggregation approach based on deterministic signal processing and event detection was also investigated. This effort was motivated by the observation that purely data-driven models may struggle when encountering unseen appliance behaviours, new device types, or operational regimes that are not sufficiently represented in the training data. Moreover, this approach operates in a training-less manner, eliminating the need for model retraining when deployed in new households or pilot sites. In practical deployments, residential environments often contain heterogeneous appliances whose activation patterns may significantly deviate from those observed in publicly available datasets. To improve robustness under such conditions, a complementary NILM pipeline was developed that relies on signal-processing principles rather than learned representations.

The proposed approach operates directly on the aggregated power signal and performs multi-scale transition detection to identify significant changes in power consumption while filtering out noisy fluctuations present in real-world measurements. The detection stage combines first-order derivatives with left-right median comparisons over multiple temporal windows to capture both sharp switching events and slower transitions. Candidate events are then validated through a robust statistical framework that estimates pre- and post-event steady-state levels using median statistics and median absolute deviation (MAD), allowing the algorithm to distinguish genuine appliance transitions from measurement noise or short-lived transients. This process produces a sequence of ON and OFF boundary candidates associated with confidence scores.

Following boundary detection, the framework reconstructs appliance activity by pairing the detected events and evaluating their compatibility in terms of power magnitude, duration, and optional power-factor changes. The pairing stage further incorporates signal-level validation to ensure that the aggregated power trajectory between paired events remains consistent with the hypothesised device activation. To improve interpretability and long-term consistency, the detected events are then grouped into device families, which represent recurring activation patterns with similar power signatures. Over time, these families evolve into stable device profiles that approximate appliance-level behaviour without requiring explicit supervised training.

In cases where prior device information is available, such as approximate power ranges, appliance categories, or expected operational characteristics, this information can be incorporated into the family formation stage to guide the grouping process. Such device-aware constraints can help initialise or refine device families by favouring event associations that match known appliance characteristics. This hybrid strategy allows the framework to benefit from available domain knowledge while still maintaining the flexibility of unsupervised discovery, ultimately improving the stability and interpretability of the resulting appliance-level representations.

Additional post-processing steps extend partial transitions using signal evidence, merge compound events corresponding to multi-phase appliance cycles, and filter spurious detections. This allows the framework to capture complex appliance behaviour, such as gradual power ramps or multi-stage operating cycles commonly observed in washing machines and washer-dryer units.

Unlike machine-learning approaches, this signal-processing-based NILM method does not rely on labelled training data and therefore avoids overfitting to specific appliance instances or datasets. While it may not achieve the same reconstruction accuracy as specialised deep learning models in well-controlled scenarios, it provides a robust and interpretable baseline that generalises better to unseen appliances and changing household conditions. For this reason, the approach is considered a complementary component of the NILM toolkit within the project, offering a reliable fallback mechanism when data-driven models encounter unfamiliar operating patterns.

SUC-GR-01.02 DEMAND FORECASTING

| Section | Subsection | Input |
|---------------------|------------------------|--|
| Overview | SUC Summary | In this SUC, demand forecasting for residential consumers is performed using real-time and historical data collected from smart meters and IoT devices. The service enables the Aggregator to anticipate consumption patterns and supports SOs in identifying potential grid constraints. The implemented approach focuses on short-term forecasting at both household and aggregated levels, leveraging machine learning models to capture temporal patterns and variability in energy consumption. Forecasts are generated at 15-minute and hourly resolution and are made available through APIs for downstream services, including flexibility optimisation and grid analysis. |
| | Target(s) | The objective of this phase is to implement and validate a real-time forecasting pipeline that: (i) ingests and processes smart meter data at multiple temporal resolutions, (ii) generates accurate short-term forecasts at household and aggregated level, (iii) provides low-latency predictions suitable for operational use, and (iv) supports downstream services such as flexibility optimisation and grid monitoring. |
| | Expected UC Milestones | The expected milestone is the demonstration of a complete forecasting service capable of: (i) processing real-time and historical consumption data, (ii) generating multi-horizon forecasts (intra-hour and day-ahead), (iii) achieving acceptable accuracy levels (e.g., MAE and R ² targets), (iv) exposing forecasts through interoperable APIs, and (v) ensuring GDPR-compliant data handling and integration with HEDGE-IoT services. |
| | Actions implemented | See analysis below. |
| Requirements | Assumptions | The implementation assumes that: |

| | | |
|--------------------------------------|------------------------|--|
| | | <ul style="list-style-type: none"> real-time and historical smart meter data are continuously available and of sufficient quality, IoT devices and communication infrastructure operate reliably consumption patterns can be learned from historical data and are sufficiently stable in the short term, forecasting models can generalise across households and aggregation levels, data handling mechanisms comply with GDPR requirements. |
| | Dependencies | This module depends on SUC-GR-01.04 (Edge Processing / Data Capture) for data ingestion and preprocessing. It provides forecasting outputs to SUC-GR-01.01 (Flexibility Optimisation) for decision-making and to SUC-GR-01.05 (User Interaction Interface) for visualisation. It also relies on HEDGE-IoT WP3 services for data storage, interoperability, and secure data exchange. |
| | Risks | <p>The main risks include:</p> <ul style="list-style-type: none"> incomplete, missing, or noisy data affecting forecasting accuracy, concept drift in consumption behaviour reducing model performance over time, latency issues impacting real-time forecasting capabilities, scalability limitations when increasing the number of monitored households, data privacy and security risks associated with handling sensitive consumption data. |
| Readiness | Deployment diagram | See below. |
| | Deployment preparation | The preparation phase included the deployment of smart meters and IoT sensors in pilot households, the setup of data ingestion pipelines for real-time and historical data, and the implementation of preprocessing and feature engineering modules. Machine learning models were developed, trained, and deployed for inference through API services. Integration with HEDGE-IoT services was established to support data storage, processing, and interoperability, while GDPR-compliant mechanisms were implemented to ensure secure data handling. |
| | Deployment assessment | The forecasting system has been successfully deployed and validated. Data pipelines are operational and provide continuous data streams for model inference. The system achieves satisfactory accuracy (MAE = 0.15 kWh and $R^2 = 0.79$ at aggregated level; MAE = 0.0145 kWh and $R^2 = 0.76$ at household level) and meets real-time requirements with inference latency below 200 ms. Monitoring and validation mechanisms have been implemented to mitigate data quality issues, while privacy-preserving measures ensure compliance with GDPR. |
| Validation Activities Summary | Previous cycle | In the previous cycle, the forecasting pipeline was initially developed, including data ingestion, preprocessing, and baseline model implementation. Initial validation highlighted the need for improved feature engineering, enhanced model accuracy, and deployment of real-time inference capabilities. |
| | Current cycle | In this cycle, the forecasting pipeline was extended to support real-time operation and improved predictive performance. Advanced machine learning models were implemented, and feature engineering processes were enhanced. The system now provides low-latency forecasts via APIs and has been successfully integrated with |

| | | |
|--|--------------|---|
| | | downstream services, addressing the improvements identified in the previous cycle. |
| | Future cycle | Future work will focus on improving model robustness against changing consumption patterns (concept drift), enhancing scalability for larger deployments, and strengthening integration with optimisation and grid monitoring services. Additional validation will be conducted under real operational conditions, including the use of forecasts by System Operators for grid issue detection and the evaluation of system performance under increased load and data volume. |

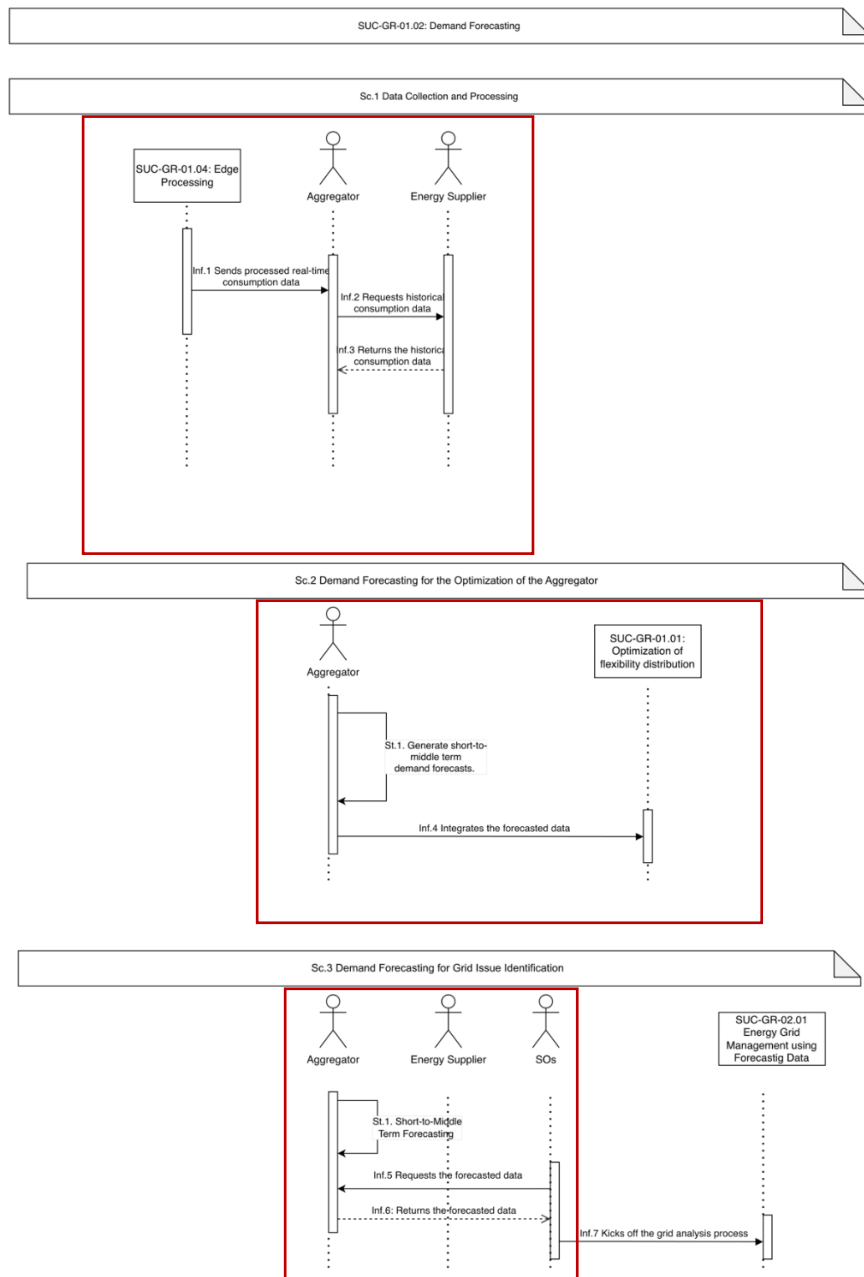


FIGURE 22: DEPLOYMENT DIAGRAM FOR SUC-GR-01.02 (ONGOING PROCESS)

Actions Implemented

During the current evaluation cycle, a complete end-to-end demand forecasting pipeline was designed, implemented, deployed, and validated as part of the aggregator backend services. The pipeline covers all stages from real-time data acquisition through IoT infrastructure to model training, artefact management, and low-latency inference exposed via RESTful APIs.

The system ingests consumption data from smart meters and IoT edge devices deployed in residential households. Data are collected at both hourly and 15-minute resolution and stored in a database. Aggregation of device-level measurements is performed dynamically at query time, ensuring consistency and scalability of the data processing layer. Data access is implemented using asynchronous database queries, enabling efficient integration within the FastAPI¹-based backend service. A preprocessing pipeline was developed to ensure data quality and consistency. This includes timestamp alignment, handling of missing values through forward filling, and conversion of raw measurements into standardised energy units (kWh). A feature engineering process was also implemented, generating lagged variables, rolling statistics, and calendar-based features (e.g., hour of day, day of week, seasonality indicators), enabling the models to capture both short-term dynamics and longer-term consumption patterns. Feature normalisation is performed using dedicated instances for both input features and target variables. All preprocessing artefacts, including scalers and feature configurations, are version-controlled and stored in MinIO², ensuring reproducibility and consistency between training and inference phases.

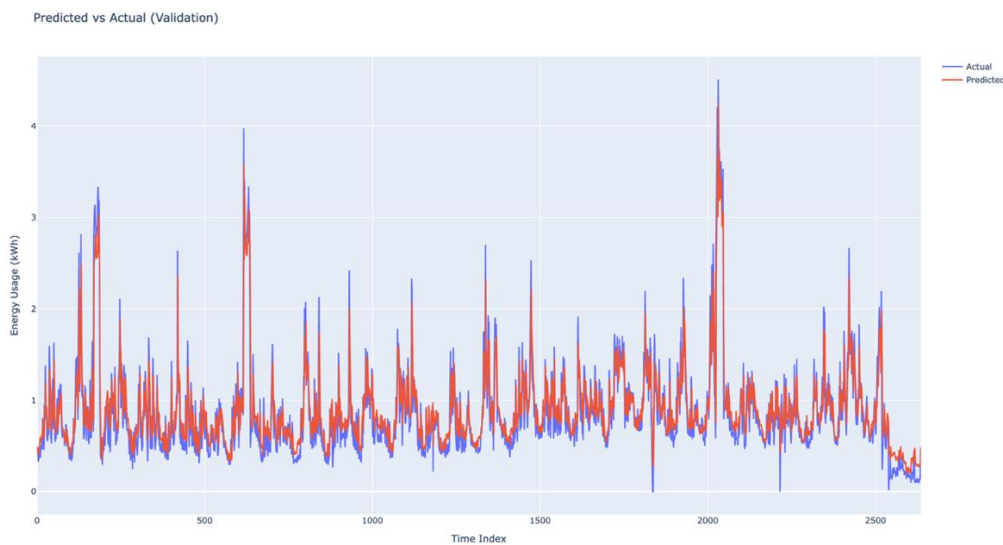


FIGURE 23: PREDICTED VS. ACTUAL ENERGY DEMAND – AGGREGATED SHORT-TERM MODEL (15-MINUTE RESOLUTION, VALIDATION SET).

Multiple forecasting models were implemented to address different operational requirements. For aggregated demand forecasting, a sequence-to-sequence bidirectional GRU (bi-GRU) architecture was developed to predict the next 24-hourly values in a single forward pass. In addition, a recursive bi-GRU model was implemented to generate multi-step forecasts iteratively, allowing the estimation of prediction uncertainty through validation-based error bounds. For individual household short-term forecasting at higher temporal resolution, both sequence-to-sequence and recursive models were developed using bi-GRU and bi-LSTM architectures, enabling predictions from 1 hour up to 5 hours ahead at 15-minute intervals. All models were trained using historical

¹ <https://fastapi.tiangolo.com/>

² <https://www.min.io/>

datasets with chronological train/validation splits to avoid data leakage. Training incorporates early stopping mechanisms and adaptive optimisation strategies to ensure convergence and generalisation.

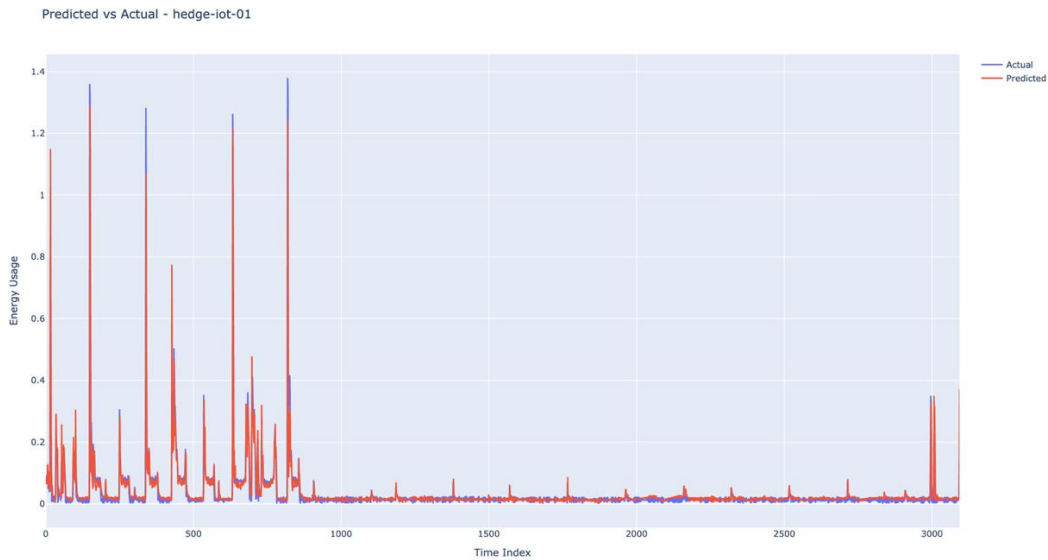


FIGURE 24: AGGREGATOR FORECAST API INTERFACE SHOWING AVAILABLE ENDPOINTS FOR TRAINING AND INFERENCE OF DAY-AHEAD AND SHORT-TERM DEMAND FORECASTING MODELS (INCLUDING RECURSIVE AND SEQUENCE-BASED APPROACHES).

For grid-level decisions the model currently achieves an MAE of 0.15 kWh and an $R^2 = 0.79$ on aggregated load (Figure 23), while at household level it achieves an MAE = 0.0145 kWh and an $R^2 = 0.76$ (Figure 24).

AGGREGATOR TOOL FORECAST API 1.0.0 OAS 3.1

openapi.json

This API provides energy usage forecasting for different time horizons using ML models.

MIT

AGGREGATED FORECAST NEXT 24 HOURS Train models and generate hourly energy consumption forecasts for the next 24 hours based on aggregated data from multiple meters. ^

- POST /train/next-24-hours Train Model v
- GET /forecast/next-24-hours Get Energy Forecast v
- POST /train/next-24-hours-recursive Train Recursive 24 Hour Model v
- GET /forecast/next-24-hours-recursive Get Recursive 24 Hour Forecast v

AGGREGATED SHORT-TERM FORECAST (15') Train and use models to forecast short-term (15-minute interval) energy demand using aggregated data from monitored meters. ^

- POST /train/short-term Train Short Term Model v
- GET /forecast/short-term Get Short Term Forecast v
- POST /train/short-term-recursive Train Recursive Short Term Model v

Description:

This endpoint trains a recursive deep learning model (BLSTM-based) to predict future energy usage in 15-minute intervals. The training process uses historical aggregated energy data.

Workflow Steps:

1. Fetch and preprocess historical energy usage data.
2. Create individual sequences for training.
3. Train a Bidirectional LSTM-based GRU model with early stopping.
4. Evaluate the model (MSE, MAE, MAPE, R², RMSE).
5. Upload the model and its metadata to MinIO.

Returns:

A dictionary containing:

- `message`: Training status message

FIGURE 25: AGGREGATOR FORECAST API INTERFACE SHOWING AVAILABLE ENDPOINTS FOR TRAINING AND INFERENCE OF DAY-AHEAD AND SHORT-TERM DEMAND FORECASTING MODELS (INCLUDING RECURSIVE AND SEQUENCE-BASED APPROACHES).

The forecasting service is deployed as a containerised FastAPI application, exposing dedicated endpoints for both training and inference as shown in the figure above (Figure 25). The system provides multiple forecasting modes (day-ahead, short-term, recursive), returning predictions in structured JSON format, including optional uncertainty bounds. The inference layer is optimised for real-time operation, achieving end-to-end latency below 200 ms. The entire pipeline was validated under realistic operating conditions, including continuous data ingestion, feature consistency between training and inference, correct sequence construction, and successful model serialisation/deserialisation. The system demonstrates full operational readiness and has been successfully integrated with downstream services, including the flexibility optimisation module, providing reliable forecasting inputs for decision-making.

SUC-GR-01.03 PRODUCTION FORECASTING

| Section | Subsection | Input |
|---------------------|------------------------|--|
| Overview | SUC Summary | In this SUC, energy production forecasting is performed for residential prosumers equipped with PV systems. Due to the current unavailability of real PV data from pilot sites, the service is developed and validated using an open-source dataset, ensuring realistic representation of prosumer behaviour. The system integrates historical production and weather data to generate short-term forecasts that support aggregators in optimisation and assist SOs in assessing grid conditions. |
| | Target(s) | The objective of this phase is to implement and validate a production forecasting pipeline that: (i) integrates PV generation data with weather information, (ii) generates accurate short-term forecasts at 15-minute resolution, (iii) supports flexibility estimation and optimisation workflows, and (iv) provides forecasts suitable for real-time operational use. |
| | Expected UC Milestones | The expected milestone is the demonstration of a complete production forecasting service capable of: (i) processing historical PV production and weather data, (ii) generating accurate short-term forecasts, (iii) supporting downstream optimisation services, (iv) exposing forecasts through interoperable APIs, and (v) ensuring GDPR-compliant data handling and integration with HEDGE-IoT services. |
| | Actions implemented | A production forecasting pipeline was implemented, including data ingestion from the StoreNet Dingle dataset, integration with weather datasets, feature engineering, and training of machine learning models (Bi-LSTM). Forecasts were generated at 15-minute resolution and integrated into the aggregator platform. This setup enabled realistic validation of the service despite the temporary unavailability of pilot PV data. |
| Requirements | Assumptions | <p>The implementation assumes that:</p> <ul style="list-style-type: none"> • PV production data will be available from smart meters or edge devices in later stages, • weather data sources provide reliable and sufficiently granular information, • prosumer participation and data consent are ensured, • production patterns can be learned from historical or representative datasets, • GDPR-compliant data handling mechanisms are in place. |

| | | |
|--------------------------------------|------------------------|---|
| | Dependencies | This module depends on SUC-GR-01.04 (Edge Processing / Data Capture) for future PV data ingestion. It provides forecasts to SUC-GR-01.01 (Flexibility Optimisation) for decision-making and interacts with SUC-GR-01.05 (User Interface) for visualisation. It also relies on external weather data APIs and HEDGE-IoT WP3 services for data storage, processing, and interoperability. |
| | Risks | <p>The main risks include:</p> <ul style="list-style-type: none"> • limited availability of real PV production data from pilot sites, requiring reliance on external datasets, • inaccuracies in weather forecasts affecting model performance, • high variability of solar generation, especially under low irradiance conditions, • integration challenges with external data sources, • insufficient prosumer participation or incomplete edge infrastructure deployment. |
| Readiness | Deployment diagram | See below. |
| | Deployment preparation | The preparation phase included the development of data ingestion pipelines using the StoreNet dataset, integration with weather data sources, and implementation of preprocessing and forecasting modules. Forecasting services were deployed as APIs within the aggregator backend, supported by HEDGE-IoT services for data handling and storage. Secure data management mechanisms were implemented to ensure compliance with GDPR. |
| | Deployment assessment | The forecasting system has been successfully deployed and validated using the StoreNet Dingle dataset due to the current unavailability of pilot PV data. The model achieves MAE = 0.059 kWh, RMSE = 0.116 kWh, and $R^2 = 0.89$, demonstrating strong predictive performance under realistic conditions. The pipeline supports real-time operation, with validated data flows, model versioning, and secure infrastructure in place. The system is considered ready for integration with real pilot data once available. |
| Validation Activities Summary | Previous cycle | In the previous cycle, the initial production forecasting pipeline was developed, including data ingestion, preprocessing, and baseline model implementation. The need for improved feature engineering, integration of weather data, and validation under realistic conditions was identified. |
| | Current cycle | In this cycle, the forecasting pipeline was enhanced through the integration of weather data, advanced feature engineering, and implementation of a Bi-LSTM model. Due to the limited availability of pilot PV data, validation was performed using the StoreNet Dingle dataset. The system was successfully integrated with the aggregator platform and optimisation workflows, addressing the limitations identified in the previous cycle. |
| | Future cycle | Further work includes enhancing recursive forecasting approaches, integrating with live market platform, and enabling the use of production forecasts by System Operators for grid monitoring and flexibility assessment. |

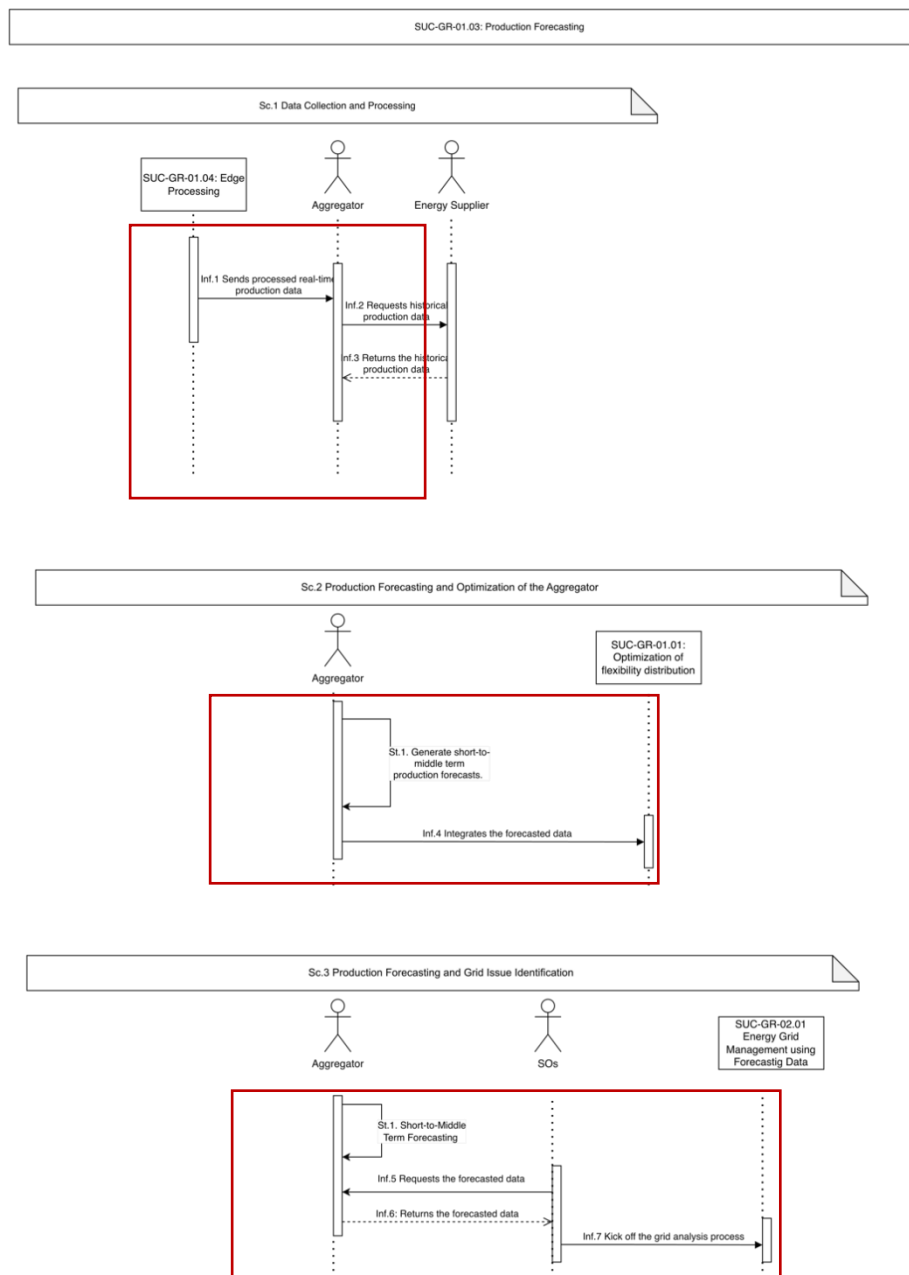


FIGURE 26: DEPLOYMENT DIAGRAM FOR SUC-GR-01.02 (ONGOING PROCESS).

Actions Implemented

During the current evaluation cycle, the production forecasting pipeline was further refined, validated, and integrated into the overall system architecture, building upon the initial implementation developed in the previous phase. A dedicated pipeline for short-term PV production forecasting was established, generating forecasts at 15-minute resolution to support both SUC-GR-01.02 (Demand Forecasting) and SUC-GR-01.03 (Production Forecasting). Due to the continued unavailability of real PV data from pilot sites and the absence of on-site irradiance sensors, validation was performed using the open-source StoreNet³ Dingle dataset, which includes data from

³ <https://www.nature.com/articles/s41597-024-03454-2>

20 residential dwellings at 15-minute resolution, approximately half of which are equipped with PV systems. This dataset provides a realistic and representative basis for evaluating prosumer behaviour and solar generation patterns.

The pipeline operates in a production-grade environment and includes a fully integrated data processing workflow. A time-aligned ingestion layer combines PV production data with high-resolution weather variables, ensuring temporal consistency across all inputs. Advanced feature engineering techniques were applied, including the generation of historical lag features, rolling statistics, and calendar-based indicators, enabling the model to capture both temporal dependencies and weather-driven variability in PV generation. All input features are normalised using a version-controlled scaler, ensuring consistency between training and inference phases. The forecasting model is based on a three-layer bi-LSTM architecture, designed to capture sequential dependencies in the data and generate recursive forecasts at 15-minute intervals. The training process uses MSE loss, the Adam optimiser, and dropout regularisation to prevent overfitting. All model artefacts, including trained weights, scalers, and metadata, are stored in a version-controlled MinIO environment, ensuring full traceability, reproducibility, and support for continuous model updates. The forecasting service has been integrated into the aggregator backend and is accessible through API endpoints, enabling seamless interaction with downstream components such as the flexibility optimisation module. An overview of the available API endpoints for PV production forecasting is presented in the following figure.

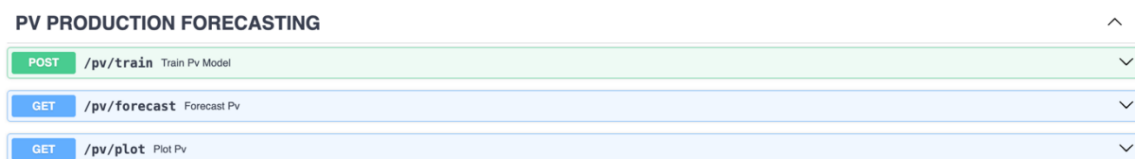


FIGURE 27: PV PRODUCTION FORECASTING API INTERFACE SHOWING ENDPOINTS FOR MODEL TRAINING, FORECAST GENERATION, AND VISUALISATION OF PV PRODUCTION PREDICTIONS.

The model demonstrates strong predictive performance, achieving a MAE of 0.012 kWh, a RMSE of 0.028 kWh, and an R^2 of 0.87. MAPE is excluded from reporting as it is numerically undefined during night-time intervals where production is zero. This is a known limitation of percentage-based metrics applied to solar generation data and does not affect the operational usefulness of the forecasts. The pipeline was validated under realistic operating conditions, confirming correct data flow, feature consistency, model inference, and integration with other system components. As illustrated in the following figure, the predicted production closely follows the actual PV output, demonstrating the capability of the model to accurately capture production patterns.

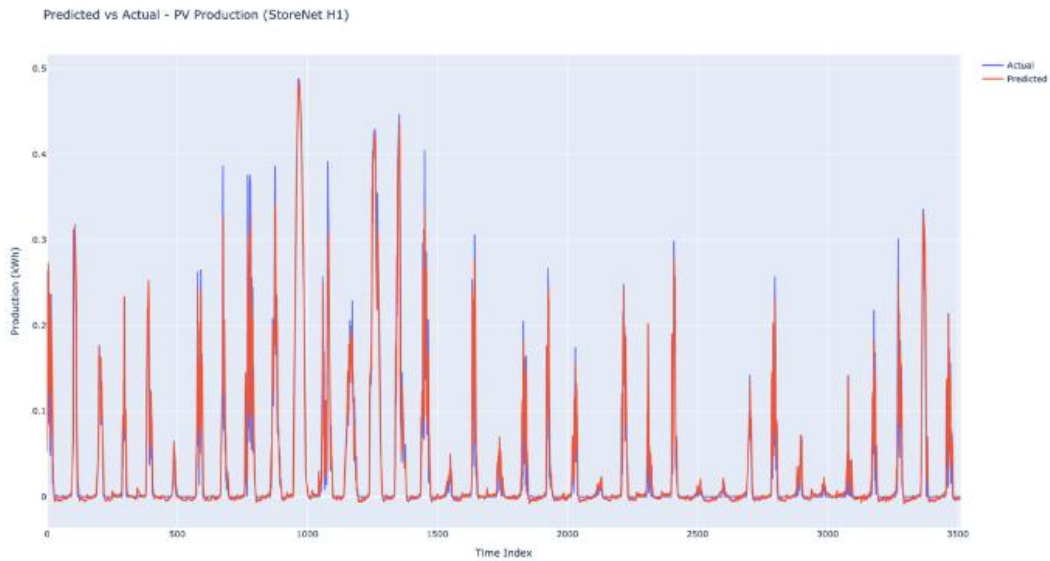


FIGURE 28: PREDICTED VS. ACTUAL PV PRODUCTION – 15-MINUTE BI-LSTM FORECAST (STORENET “DINGLE” H1 CASE STUDY).

SUC-GR-01.04 EDGE PROCESSING

| Section | Subsection | Input |
|---------------------|------------------------|--|
| Overview | SUC Summary | In this SUC, real-time energy metric collection and preprocessing is performed using IoT devices. Also, an energy consumption forecasting pipeline is developed utilising deep learning models executed in shelly 3EM meters. The service aims to provide actionable insights and facilitate efficient energy management to support consumer participation in the Local Flexibility Market (LFM). The current approach utilises small pretrained LSTM models to initialise the parameters of the model in the smart meter. The model is implemented using low level computations with matrix multiplications and proper memory management. |
| | Target(s) | <ul style="list-style-type: none"> To identify unusual patterns or potential issues in energy consumption to enable proactive management and maintenance, To enable the Aggregator to leverage real-time data and insights to make informed decisions about flexibility offers and incentivise consumer participation in the LFM, Enable deep learning models for energy forecasting on Shelly 3EM meters |
| | Expected UC Milestones | <ul style="list-style-type: none"> Reliably collect and preprocess real-time consumer data through edge devices, Provide reliable forecasting, executed on the edge, Relaying the validated data to the aggregator |
| | Actions implemented | <ul style="list-style-type: none"> Mounted IoT devices in residential switchboards with edge processing capabilities, The first version of on-device forecasting framework is introduced |
| Requirements | Assumptions | <ul style="list-style-type: none"> Data of user’s energy consumption is representative of said customer’s behaviour The data collection is uninterrupted with the Shelly 3EM meter continuously operating |
| | Dependencies | Provides processed data to SUC-GR-01.02 (Demand Forecasting) and SUC-GR-01.03 (Production Forecasting) for aggregation and forecasting |

| | | |
|--------------------------------------|------------------------|--|
| | Risks | <p>The main risks include:</p> <ul style="list-style-type: none"> • Not optimal model initialisations might delay accurate forecasting for the on-device forecasting framework • Shelly 3EM meters can temporarily disconnect affecting the validity of the data over some periods of time |
| Readiness | Deployment diagram | See below |
| | Deployment preparation | <p>The deployment preparation includes the configuration and installation of Shelly 3EM meters in residential environments, ensuring proper integration with the electrical infrastructure. Edge computing capabilities are enabled on the devices to support local data preprocessing and execution of forecasting models. Communication protocols are configured to allow reliable data transmission to backend systems and Aggregator services.</p> <p>Additionally, the deep learning framework is deployed on-device, including the initialisation of pretrained LSTM models and implementation of lightweight inference mechanisms using optimised matrix operations. APIs and data pipelines are prepared for seamless interaction with SUC-GR-01.02 and SUC-GR-01.03. System-level checks are performed to ensure data integrity, device connectivity, and compatibility with existing HEDGE-IoT infrastructure.</p> |
| | Deployment assessment | <p>The deployment is considered partially complete, with core functionalities successfully implemented and validated. Real-time data collection and preprocessing are operational, and the initial version of the on-device forecasting framework has been deployed and tested on Shelly 3EM meters. Data transmission to Aggregator services is functioning as expected.</p> <p>However, further improvements are required in terms of model optimisation, memory usage, and computational efficiency to ensure stable long-term operation on resource-constrained devices. Potential risks related to device disconnections and suboptimal model initialisation have been identified, with mitigation strategies planned for future iterations. Overall, the system demonstrates a stable baseline for edge-based forecasting, with readiness for further scaling and refinement.</p> |
| Validation Activities Summary | Previous cycle | Real-time edge data collection and validation tested. Aggregator UI integration was completed. Data forwarded to production/demand forecast systems. |
| | Current cycle | Shelly 3EM meters can use deep learning models for energy forecasting and training with local data. |
| | Future cycle | <p>Future work will include optimising the memory and cpu management of the edge devices so that they provide desired metrics faster and with less load. Furthermore, work on improving the local forecasting needs to be done for obtaining better forecasting results.</p> |

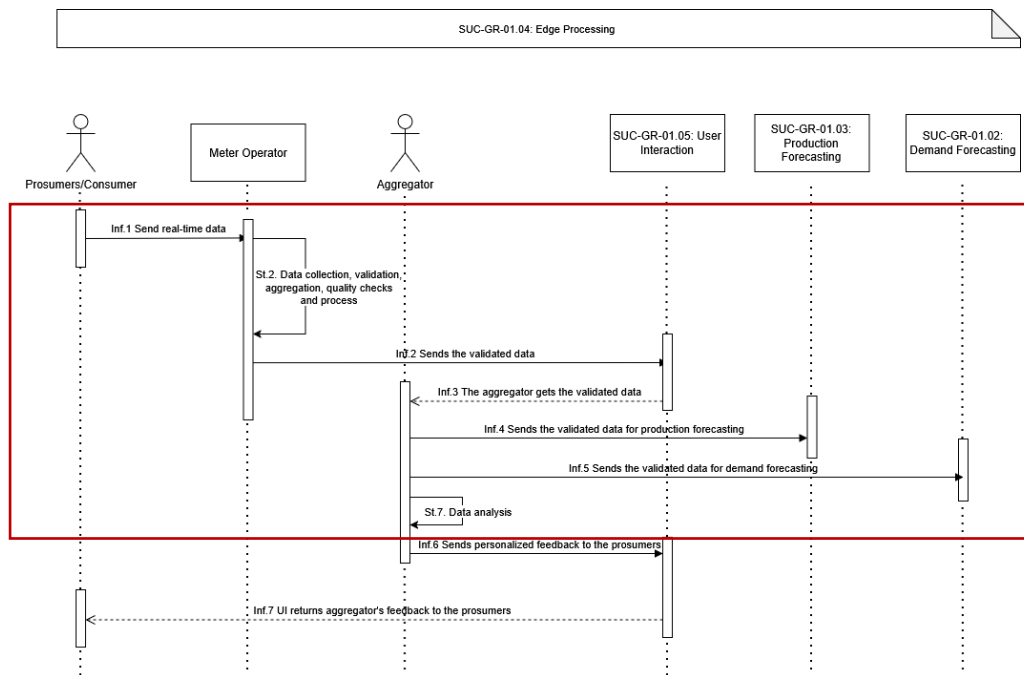


FIGURE 29: DEPLOYMENT DIAGRAM FOR SUC-GR-01.04 (ONGOING PROCESS).

Actions Implemented

The edge processing service of SUC-01.04 focuses on the deployment of IoT-enabled energy monitoring and forecasting within residential environments. IoT devices and smart energy meters were installed across selected households to enable continuous monitoring of various energy related metrics, like energy consumption. This infrastructure supported systematic data collection, with energy related metrics recorded at regular intervals, thereby establishing a reliable dataset for further analysis and model development. The pre-processed data is forwarded to SUC-GR-01.02 (Demand Forecasting) and SUC-GR-01.03 (Production Forecasting) for aggregation and forecasting.

Furthermore, building on this dataset, a baseline forecasting model based on Long Short-Term Memory (LSTM) networks was developed to provide a reference for evaluating predictive performance. To bring intelligence closer to the data source, part of the LSTM model was adapted and deployed directly onto edge devices using the Shelly scripting environment. This process required extracting model variables, like weights and biases from the original LSTM, transferring them to the edge devices and making necessary modifications to ensure compatibility with the constraints and programming framework of the target devices.

The deployed system operates in near real-time, collecting data at 15-minute intervals and generating short-term forecasts for the next quarter of hour. In addition, on-device training capabilities were incorporated, allowing the model to continuously update and improve its performance based on newly acquired data. This approach enables a more responsive and adaptive energy forecasting solution within the residential setting.

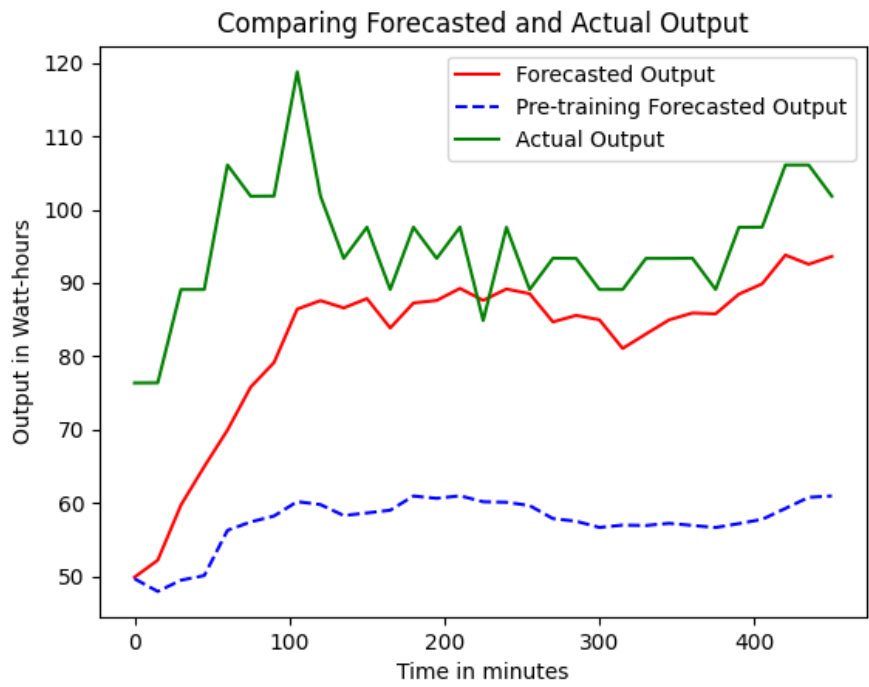


FIGURE 30: PER QUARTER FORECASTING RESULTS OF THE ON-DEVICE MODEL COMPARED TO THE INITIAL MODEL PRIOR TO THE TRAINING PROCESS. THE ON-DEVICE MODEL SUCCESSFULLY CONVERGES TO THE REAL VALUES.

4.3.1.1 SUC-GR-01.05 User Interaction

| Section | Subsection | Input |
|----------|------------------------|--|
| Overview | SUC Summary | This SUC delivers an intuitive mobile and web interface through which residential consumers and prosumers can monitor their electricity consumption and production in near real-time, view historical analytics, billing information, access recommendations and control their devices. The aggregator dashboard provides monitoring for demand/production and forecasting for energy demand, production. |
| | Target(s) | <p>For the current evaluation cycle, the target is to have an end-to-end operational user interface that:</p> <ul style="list-style-type: none"> Authenticates users securely (Keycloak-based) and provides role-based access. Displays live and historical energy data (1-minute measurements aggregated to 1-hour/1-day views) plus basic billing information for residential users. Provides an aggregator dashboard with total demand/production, net balance and basic real-time, historical charts. |
| | Expected UC Milestones | <ol style="list-style-type: none"> SC.1 "Consumer dashboard": authenticated user sees live and historical consumption, basic analytics and billing, and can inspect device-level contributions where available. SC.2 "Aggregator dashboard": aggregator sees portfolio KPIs (total demand/production, net balance, user mix), real-time monitoring, historical statistics, and short-term forecasts. |

| | | |
|--------------|---------------------|--|
| | Actions implemented | <ul style="list-style-type: none"> Designed and implemented a native mobile app (Android/iOS) for residential users with three main tabs: Dashboard (live + daily/weekly/monthly usage and costs), Devices (per-device status and consumption, basic controls), and Billing (current period cost, history, tariff comparison and alternative supplier offers). Implemented a web-based aggregator dashboard that aggregates data from all pilot households and presents overview, real-time monitoring, historical statistics, and forecast views, including confidence bands. Integrated a vision-based appliance recognition feature within the mobile application to support automatic identification of household devices (e.g., air-conditioning units) using images captured by users. This functionality reduces the need for manual data entry and device labeling, improving usability and lowering user effort during onboarding and device management. Integrated the UI layer with the edge/cloud data pipeline: MQTT ingestion of 1-second readings from sub-metering devices, preprocessing and aggregation in the cloud, and low-latency API endpoints to feed the UI. Performed an initial user-experience pass (with early pilot users) to refine navigation, visual hierarchy and fix initial bugs in data display (gaps, unexpected values). |
| Requirements | Assumptions | <ul style="list-style-type: none"> Household sub-metering IoT devices and billing meters are installed, configured, and reliably streaming data at 1-second resolution to the backend via MQTT. In multiple cases minimum resolution is 1-minute due to hardware constraints. Cloud components (databases, APIs, authentication service) are deployed and reachable over secure channels from both the mobile app and aggregator web UI. Users (consumers, prosumers, aggregator staff) have network connectivity adequate for near real-time updates and are willing to grant consent for processing and visualising their energy data. Time synchronisation across edge devices and backend is sufficient so that timestamps are meaningful when visualised and compared with forecasts. |
| | Dependencies | <ul style="list-style-type: none"> Data ingestion and edge processing for validated structured real-time and historical data (consumption, production, devices). Demand Forecasting (SUC-GR-01.02) for the forecast time series displayed in aggregator dashboards and, later, in user-facing recommendations. Optimisation of flexibility distribution (SUC-GR-01.01) and Local Flexibility Market services (SUC-GR-03.01/03.02) as upstream providers of flexibility requests, incentive levels, and bid outcomes that need to be surfaced to users. Authentication/authorisation infrastructure (Keycloak and associated identity management) for secure login and role-based access. Cloud storage and data-exchange databases to serve time-series and billing data to the UI at interactive latencies. |
| | Risks | <ul style="list-style-type: none"> Poor data quality (missing intervals, inconsistent timestamps) can degrade the trustworthiness of visualisations and user confidence. Performance bottlenecks in backend APIs or database queries may cause slow UI response or timeouts, particularly when loading high-resolution time series. Changes in upstream APIs (forecasting, optimisation, LFM) may break UI integrations if interface versions are not carefully managed. |
| Readiness | Deployment diagram | <p>The deployment for SUC-GR-01.05 consists of:</p> <ul style="list-style-type: none"> Mobile app (Android/iOS) communicating over HTTPS with backend APIs and authenticating via Keycloak. Web-based aggregator dashboard (React) hosted in the cloud, also authenticating via Keycloak and querying backend services. Backend services exposing REST APIs on top of cloud databases that aggregate and store data ingested from IoT devices via MQTT. |

| | | |
|--------------------------------------|------------------------|--|
| | Deployment preparation | <ul style="list-style-type: none"> Implemented and deployed the mobile app build pipeline and distribution setup for pilot users. Deployed the aggregator web dashboard on a cloud infrastructure, wired to the same API and authentication stack as the mobile app. Configured MQTT brokers, ingestion connectors, and data-processing workers that aggregate 1-second readings into higher-level metrics used by the UI. Configured Keycloak realms, clients, and roles for end-users and aggregator personnel; integrated token-based access control in the backend. Provisioned monitoring for key backend components (API latency, error rates, message throughput) to support debugging and availability tracking. Defined initial user stories and navigation flows for both residential and aggregator perspectives to ensure that all mandatory SUC steps are covered. |
| | Deployment assessment | <ul style="list-style-type: none"> The mobile and web UIs are deployed and functionally integrated with the data and auth backends; real-time and historical data are successfully visualised for active pilot users. Device-level controls and state displays work for the currently integrated assets (meters, boilers, heat pumps), with on/off switching and temperature controls where applicable. Aggregator dashboards show real-time monitoring, historical statistics, and forecast overlays, aligned with the outputs of the forecasting services. Initial user feedback has been collected and used to refine layout, fix bugs in time-series rendering, and address issues such as data gaps or odd values. Remaining gaps for future cycles include richer notification mechanisms (push notifications for flexibility events), deeper integration with pricing data from the Greek spot market, and full coupling with the RL-based flexibility optimiser and LFM outcomes. |
| Validation Activities Summary | Previous cycle | Not applicable |
| | Current cycle | <ul style="list-style-type: none"> Validated that end-to-end data flows from residential meters to the mobile UI and from aggregated pilot data to the web dashboard operate reliably under normal loads. Confirmed that authentication, role separation, and basic authorisation behave as intended for different user types. Collected qualitative feedback from pilot users about usability, clarity of graphs and KPI presentation, and responsiveness of the system, then implemented a first round of UX and robustness improvements. |
| | Future cycle | <ul style="list-style-type: none"> Extend analytics with richer statistics: Add more granular views (e.g. seasonal patterns), comparative benchmarks against similar households, and clearer trend indicators for both consumption and production. Upgrade billing views with detailed invoice breakdown: Present bills split into energy charges, grid fees, taxes. Improve localisation and accessibility: Localise the mobile and web interfaces into additional languages and regional formats (numbers, dates, currencies). Enhance device-level insights with percentage shares: For each time range, show the percentage of total household consumption attributed to each device (and device category), so users can easily identify the dominant loads and target them for flexibility or efficiency actions. |

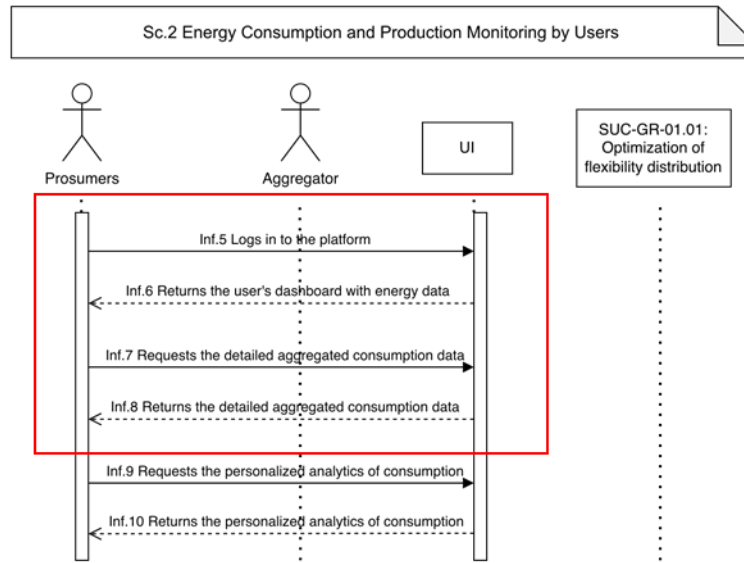


FIGURE 31: DEPLOYMENT DIAGRAM FOR SUC-GR-01.05 SC. 2 (ONGOING PROCESS)

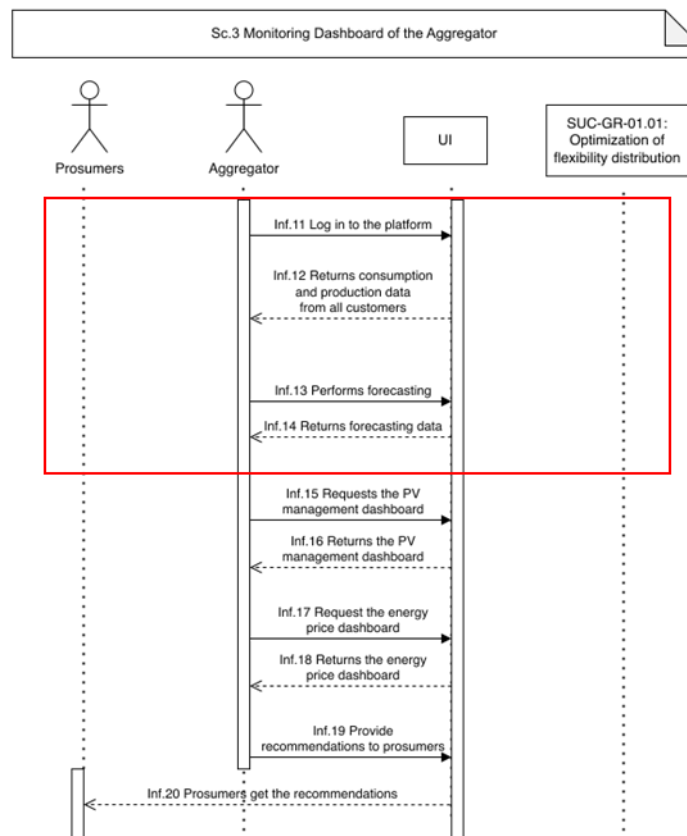


FIGURE 32: DEPLOYMENT DIAGRAM FOR SUC-GR-01.05 (ONGOING PROCESS).

Actions Implemented

During the Full-Demo Phase, SUC-GR-01.05 has progressed from design to a fully functional first version of the user-facing layer for the Greek demo. A native mobile application for residential users and a web dashboard for the aggregator has been implemented, both integrated with a common backend and authentication layer (Keycloak). On the residential side, the app now provides a live dashboard with 1-second data aggregated into intuitive views (last hour, day, week, month), device-level status and consumption, and a billing tab with a detailed invoice breakdown, historical costs, and tariff comparison across suppliers. In addition, the app integrates a vision-based appliance recognition feature that allows users to identify and register household ac devices using captured images, reducing manual data entry and improving device management. On the aggregator side, a web interface presents portfolio-level KPIs (total demand, total production, net energy balance, user mix), real-time monitoring charts, historical statistics, and short-term forecasts, all backed by the demand and production forecasting services. The UI has been wired to the edge/cloud data pipeline (MQTT ingestion, cloud preprocessing, low-latency APIs) so that users can see near real-time data and early forecast overlays. These capabilities have been iteratively refined based on early pilot feedback, focusing on responsiveness, clearer navigation, richer statistics, localisation of key UI elements, and more transparent presentation of consumption per device and invoice components.

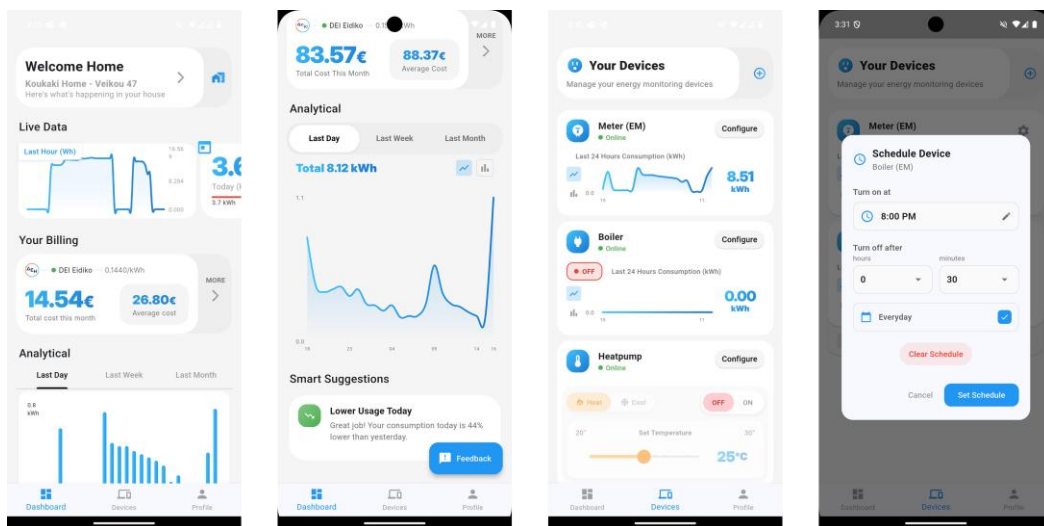


FIGURE 33: MOBILE UI SCREENS

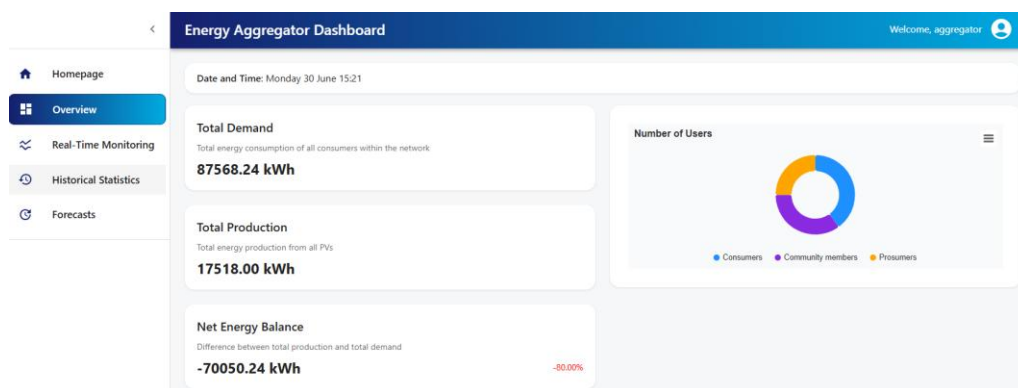


FIGURE 34: AGGREGATOR DASHBOARD (1/2)

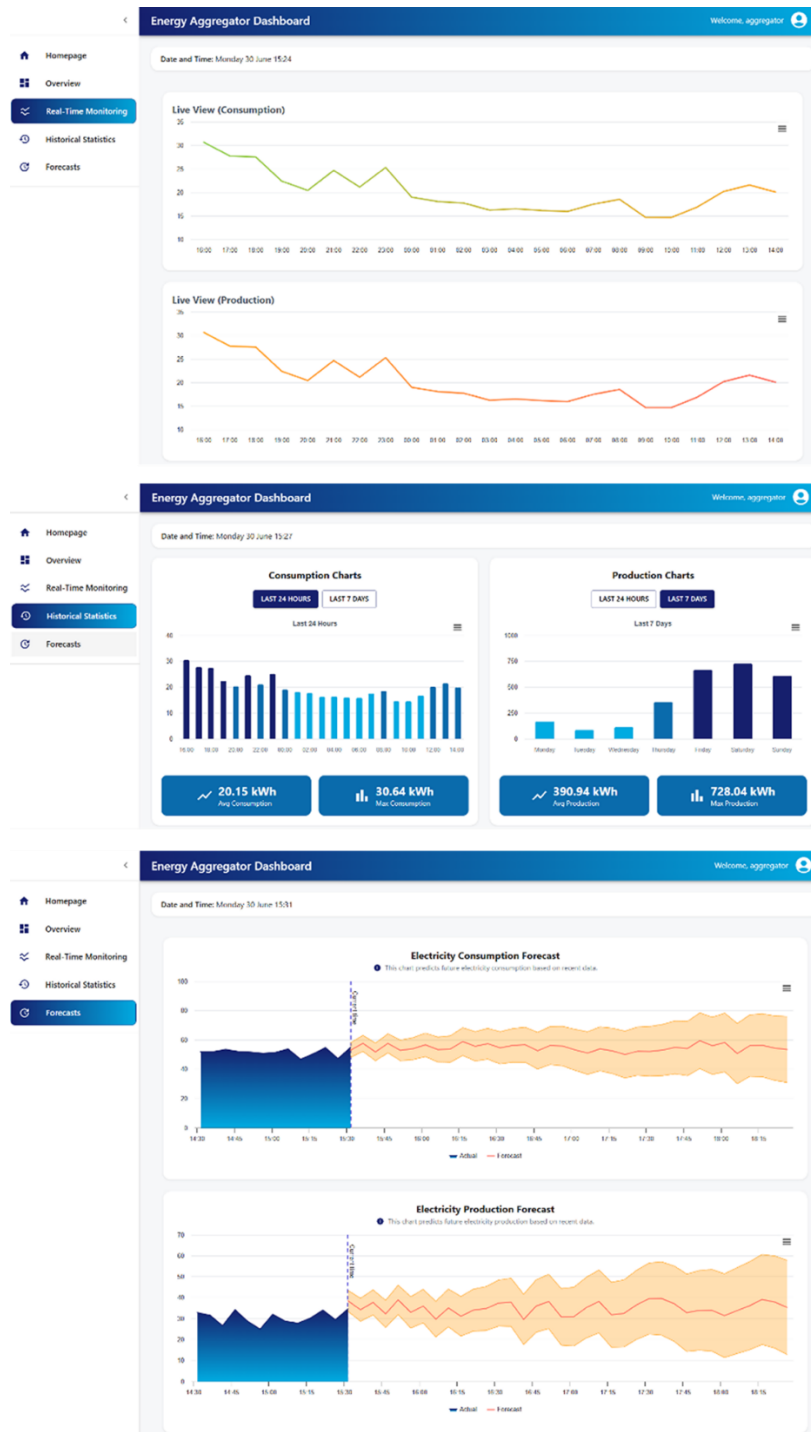


FIGURE 35: AGGREGATOR DASHBOARD (2/2)

SUC-GR-02.01 ENERGY GRID MANAGEMENT USING FORECASTING DATA

| Section | Subsection | Input |
|--------------------------------------|------------------------|--|
| Overview | SUC Summary | This SUC enables the integration of forecasted demand and production data into the DSO's grid analysis and decision support tools to optimise local grid operation |
| | Target(s) | Integrate forecasting services (SUC-GR-01.02 and GR-01.03) with the DSO's grid model and perform grid analysis using parametrised input data. |
| | Expected UC Milestones | <ul style="list-style-type: none"> Integration of production and demand forecast APIs into grid analysis tool First functional validation of the grid-analysis workflow - tool |
| | Actions implemented | <ul style="list-style-type: none"> Developed internal tool to automate grid analysis using forecast data Validated sample input cases within the grid analysis tool |
| Requirements | Assumptions | <ul style="list-style-type: none"> Forecast data is available with sufficient accuracy and timeliness Grid topology and parameters are known and static for initial tests |
| | Dependencies | <ul style="list-style-type: none"> Depends on output from SUC-GR-01.02 (demand forecast) and SUC-GR-01.03 (PV production forecast) Uses internal grid-model tool and pre-existing network models |
| | Risks | Low accuracy in forecasted consumption data used for grid assessment. |
| Readiness | Deployment diagram | <i>See below.</i> |
| | Deployment preparation | Finalise the installation of IoT devices in participants' building |
| | Deployment assessment | Testing for connectivity with the smart meter and the IoT submetering devices |
| Validation Activities Summary | Previous cycle | Grid analysis based on secondary substation data and forecast data based on IoT submetering devices data. |
| | Current cycle | Identification of grid violations and flexibility calculation for LFM requests submissions. |
| | Future cycle | Successful full data sharing through the rest API. |

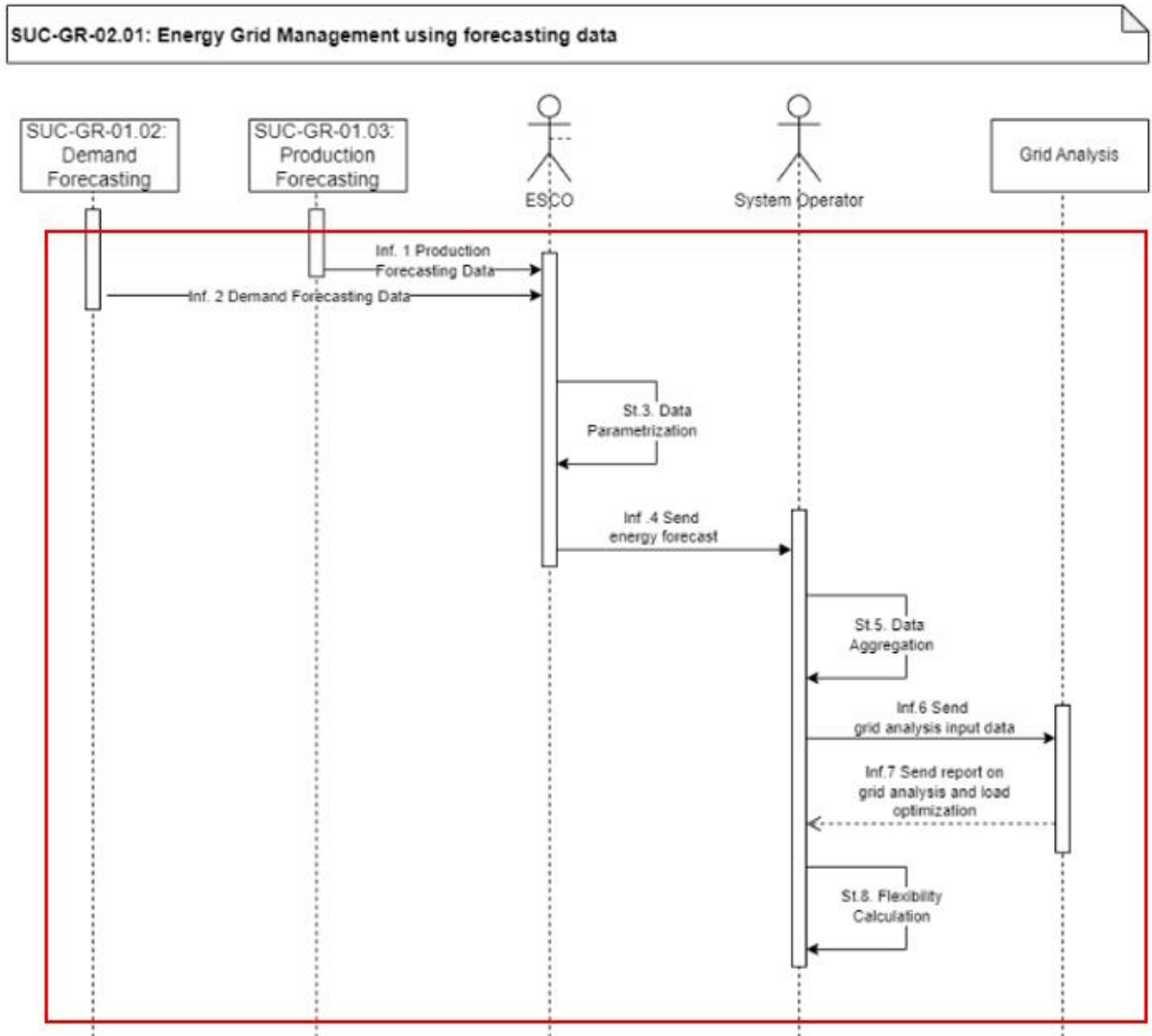


FIGURE 36: DEPLOYMENT DIAGRAM FOR SUC-GR-02.01 (ONGOING PROCESS)

Actions implemented:

Within SUC-GR-02.01, the implemented activities focused on the use of forecast outputs from SUC-GR-01.02 and SUC-GR-01.03 in combination with DSO-side network data and internal grid models in order to support grid assessment and flexibility calculation. More specifically, MV power-bus voltage data, HV/MV transformer power data, and available DSO smart metering data samples were used within the DSO environment for the internal assessment of network conditions and for estimating the flexibility required to address anticipated operational issues. In line with the use case workflow, forecast data were received and processed by the DSO, aggregated into a suitable input format, and then introduced into the internal grid analysis environment for the execution of power-flow studies and the derivation of flexibility needs.

During the previous phase, the work focused on establishing the initial grid-analysis workflow using secondary substation data and forecast information derived from IoT submetering devices. In the current full-demo phase, this workflow was further extended and validated through the use of parametrised demand and production forecast inputs, the preparation and aggregation of the

corresponding datasets, and their integration in the DSO internal power-flow analysis environment. The implemented activities included the import of forecast-based inputs into the grid model, the analysis of representative power-flow cases, the monitoring of voltage conditions at each node, and the identification of possible network violations.

The following figure shows an indicative power-flow analysis result for the Mesogeia pilot area for a specific Time Unit, where three critical under-voltage nodes (the Medium Voltage bus of a secondary substation) are identified through the DSO internal grid analysis workflow.

```

===== VOLTAGE RESULTS =====
Building substation mapping from 1904 cubicles...
▲GND_29260626: 0.8994 pu (0.36 kV), VIOLATION: <0.90 pu [Substation: SUB_██████████]
▲GND_29260723: 0.8994 pu (0.36 kV), VIOLATION: <0.90 pu [Substation: SUB_██████████]
▲GND_83922550: 0.8910 pu (0.36 kV), VIOLATION: <0.90 pu [Substation: SUB_██████████]
▲GND_83922564: 0.8910 pu (0.36 kV), VIOLATION: <0.90 pu [Substation: SUB_██████████]
▲GND_29230435: 0.8998 pu (0.36 kV), VIOLATION: <0.90 pu [Substation: SUB_██████████]
▲GND_29230548: 0.8998 pu (0.36 kV), VIOLATION: <0.90 pu [Substation: SUB_██████████]
▲GND_29235079: 0.8997 pu (0.36 kV), VIOLATION: <0.90 pu [Substation: SUB_██████████]
▲GND_29235129: 0.8997 pu (0.36 kV), VIOLATION: <0.90 pu [Substation: SUB_██████████]

===== UNDERVOLTAGE SUMMARY BY SUBSTATION =====
Substation SUB_██████████ 4 violations (lowest: GND_29260626 at 0.8994 pu)
Substation SUB_██████████ 2 violations (lowest: GND_83922550 at 0.8910 pu)
Substation SUB_██████████ 2 violations (lowest: GND_29230435 at 0.8998 pu)
✗ Found 8 undervoltage violations (<0.90 pu) across 3 substations
Note: Skipped 23 buses without voltage results

Load flow calculation completed successfully!
  
```

FIGURE 37: INDICATIVE POWER-FLOW ANALYSIS RESULT FOR THE MESOGEIA PILOT AREA, HIGHLIGHTING THREE CRITICAL UNDER-VOLTAGE NODES (NAMES ERASED IN THE FIGURE) IDENTIFIED THROUGH THE DSO INTERNAL GRID ANALYSIS WORKFLOW.

The following figure shows the loading and voltage level for a specific node (secondary substation) for sixteen consecutive time units. For the time units a threshold violation was identified a grid optimisation algorithm will calculate the required flexibility for the specific node and the specific time unit.

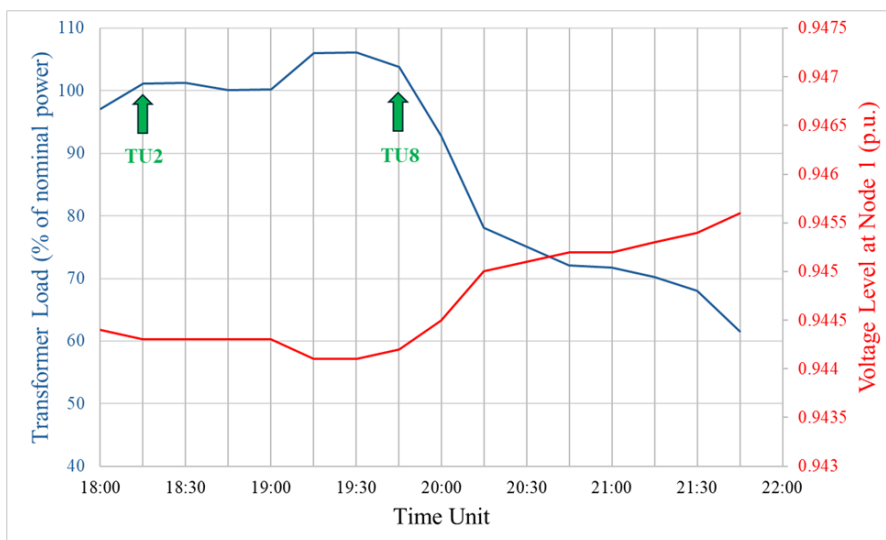


FIGURE 38: CONGESTION AND VOLTAGE ESTIMATION AT A SPECIFIC NODE BASED ON FORECASTED DATA. FOR THE SPECIFIC PERIOD NO VOLTAGE VIOLATION WAS PREDICTED. THE ALGORITHM

CALCULATED THE REQUIRED FLEXIBILITY FOR TIME UNITS 2 TO 8 FOR MITIGATING OVERLOAD
BASED ON DSO'S THRESHOLDS

SUC-GR-03.01 REGISTRATION & PREQUALIFICATION ON LOCAL FLEXIBILITY MARKET

| Section | Subsection | Input |
|---------------------|------------------------|---|
| Overview | SUC Summary | This use case enables the registration and prequalification of SOs and Flexibility Service Providers (FSPs) on the platform, ensuring they can participate in local flexibility market processes. |
| | Target(s) | Enable SOs and FSPs to successfully register, be validated, and become eligible to participate in the local flexibility market through the platform. |
| | Expected UC Milestones | Successful completion of company and asset registration, validation of required documentation, and prequalification of TSO, DSOs and FSPs, ensuring they meet the criteria to participate in the local flexibility market. |
| | Actions implemented | The registration and prequalification processes for SOs and FSPs were implemented and completed in a previous evaluation cycle, including company onboarding, user creation, document submission, and validation of assets and technical requirements. In the current cycle, no additional actions were required, as the use case has already reached its target state. |
| Requirements | Assumptions | It is assumed that SOs and FSPs provide accurate and complete registration data, required documentation, and compliant assets, and that the platform validation processes operate as expected without major changes from previous cycles. |
| | Dependencies | The process depends on the platform's registration and validation services, user management system, and integration with asset data and documentation handling components, as well as readiness of SOs and FSPs to provide the required information. |
| | Risks | Potential risks include incomplete or incorrect data submission by SOs or FSPs, delays in validation processes, and possible issues with asset compliance or documentation requirements. |
| Readiness | Deployment diagram | <i>See below</i> |
| | Deployment preparation | The deployment requires the HEnEx Local Flexibility Market platform, deployed on AWS infrastructure using EC2 instances with a Dockerised application. No external services or integrations are required for this use case, as all registration and prequalification functionalities are handled internally by the platform. |
| | Deployment assessment | The deployment is considered complete, as all required components are already implemented and operational within the platform. Identified risks are minimal and mainly related to data input quality, which is managed through validation mechanisms already in place. |
| | Previous cycle | In the previous cycle, the registration and prequalification processes were fully implemented, including user onboarding, submission of required information, and validation of assets. The next steps identified were focused on enabling |

| | | |
|--------------------------------------|---------------|--|
| Validation Activities Summary | | participation in market operations based on the successfully prequalified participants. |
| | Current cycle | In the current cycle, no additional actions were required, as the registration and prequalification processes were already completed. The focus was on maintaining system readiness, fulfilling the recommendation to proceed with market participation using the prequalified SOs and FSPs. |
| | Future cycle | In the next cycle, the focus will be on end-to-end testing of the full market workflow, including the participation of prequalified SOs and FSPs in trading, validation of results, and overall system performance. |

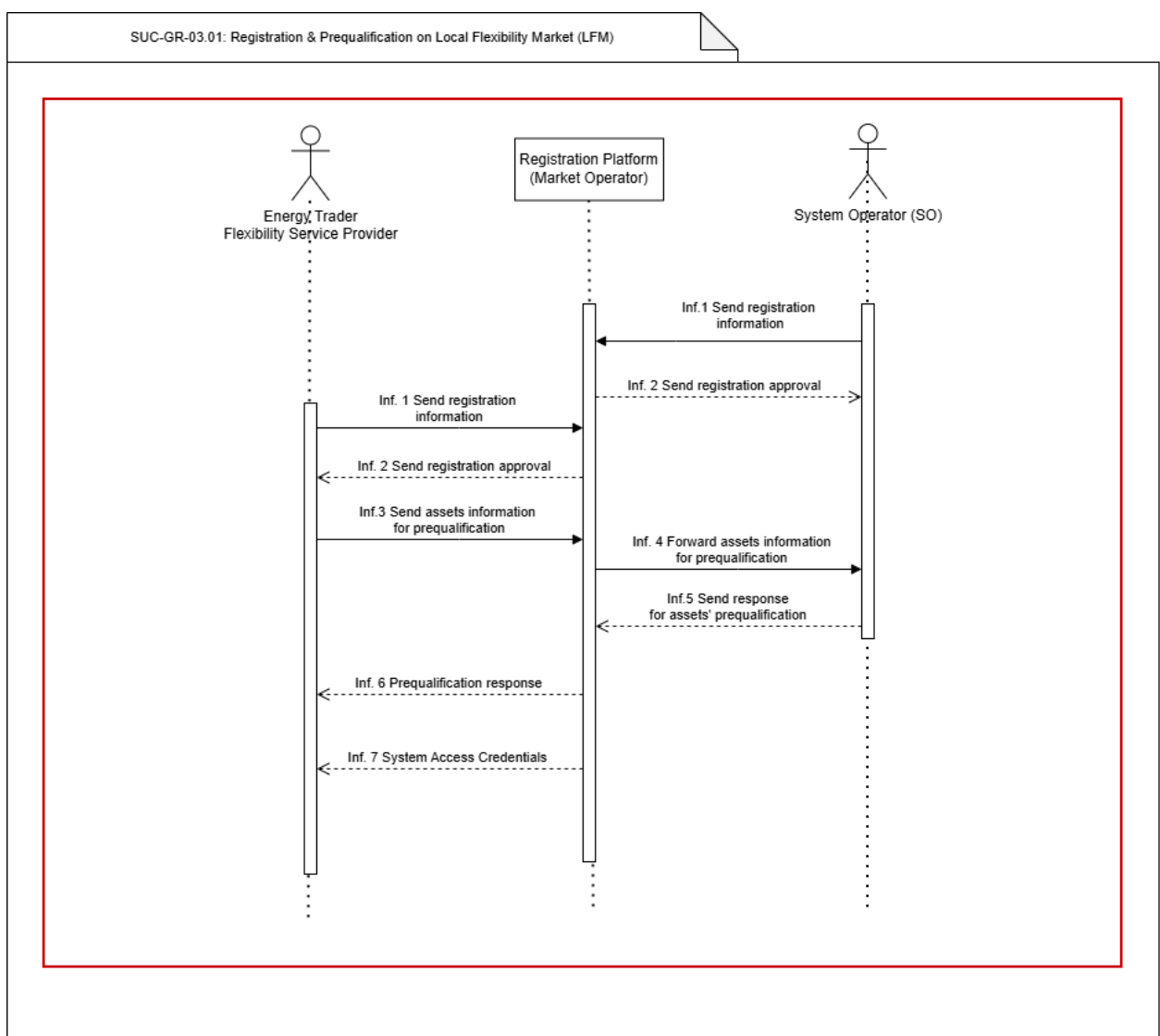


FIGURE 39: DEPLOYMENT DIAGRAM FOR SUC-GR-03.01 (ONGOING PROCESS)

Within SUC-GR-03.01, the implemented activities focused on enabling the registration and prequalification workflow of Flexibility Service Providers (FSPs) through the Local Flexibility Market (LFM) Platform, in coordination with the Market Operator and the System Operators (SO). The service

utilises the cloud-based LFM platform, the supporting databases, and the user interfaces to facilitate the onboarding of users and the validation of their assets.

More specifically, user registration data, asset metadata, and role-specific information were submitted by FSPs through the platform and processed by the Market Operator. These data were then forwarded to the System Operator for validation and prequalification purposes. In line with the use case workflow, registration requests were received and approved, followed by the submission of asset information, which was aggregated into a suitable format and transmitted to the SO for technical evaluation. The SO responses regarding asset prequalification were then returned to the platform and communicated back to the FSPs, enabling their participation in the market.

During the previous phase, the work focused on the development and deployment of the core platform components, including the user registration functionality, database structures, and basic API services, as well as the initial testing of user onboarding and asset submission processes in a controlled environment.

In the current full-demo phase, the workflow was further extended and validated through the execution of the complete end-to-end process, including user registration, approval, asset submission, forwarding of asset data to the System Operator, and reception of prequalification results. The implemented activities included the validation of data exchange between actors, the execution of the prequalification process using representative asset data, and the verification of the correct operation of role-based access and communication mechanisms. The final step of issuing system access credentials to prequalified users was also successfully demonstrated, confirming the readiness of the platform to support market onboarding operations.

SUC-GR-03.02 FLEXIBILITY TRADING

| Section | Subsection | Input |
|---------------------|------------------------|--|
| Overview | SUC Summary | This use case focuses on the execution of flexibility trading in the platform, including order submission by SOs and FSPs, auction-based matching, and finalisation of transactions in the local flexibility market. |
| | Target(s) | Enable SOs and FSPs to successfully participate in flexibility trading, including order submission, matching, and completion of transactions through the platform. |
| | Expected UC Milestones | Successful execution of the flexibility trading process, including order submission by SOs and FSPs, completion of auction matching, and validation of final trades within the platform. |
| | Actions implemented | During the current cycle, a demo execution of flexibility trading was performed using real data from SOs and FSPs, including order submission and matching processes. Additionally, platform improvements were implemented, such as notifications, security hardening, and the introduction of the TSO role. The full trading workflow is not yet fully completed. |
| Requirements | Assumptions | It is assumed that SOs and FSPs submit valid and consistent trading data, that the platform processes (order submission, matching, and notifications) operate as expected, and that the introduction of the TSO role is correctly integrated without affecting existing functionalities. |

| | | |
|--------------------------------------|------------------------|---|
| | Dependencies | The process depends on the platform's trading functionalities, including order submission, matching, notifications, and user role management, as well as the availability of SOs, FSPs, and the TSO to participate in the trading process. |
| | Risks | Potential risks include incomplete implementation of the trading workflow, incorrect or inconsistent trading data, and issues related to the integration of the TSO role or newly added platform features such as notifications and security updates. |
| Readiness | Deployment diagram | <i>See below</i> |
| | Deployment preparation | The deployment requires the HEnEx Local Flexibility Market platform, deployed on AWS infrastructure using EC2 instances with a Dockerised application. No external services or integrations are required, as all functionalities are handled internally by the platform. |
| | Deployment assessment | The deployment is partially complete, as core trading functionalities have been implemented and tested through a demo with real data. Remaining gaps relate to the full completion of the trading workflow, while identified risks are being addressed through ongoing platform improvements and validations. |
| Validation Activities Summary | Previous cycle | In the previous cycle, the system design and initial trading functionalities were developed and tested in a controlled environment, with the next steps focusing on executing trading with real data and improving platform capabilities. |
| | Current cycle | In the current cycle, trading was executed using real data from SOs and FSPs, along with platform enhancements such as notifications, security improvements, and the introduction of the TSO role, addressing the recommendations of the previous cycle. |
| | Future cycle | In the next cycle, the focus will be on completing the trading workflow and performing full end-to-end testing to validate system performance and ensure operational readiness. |

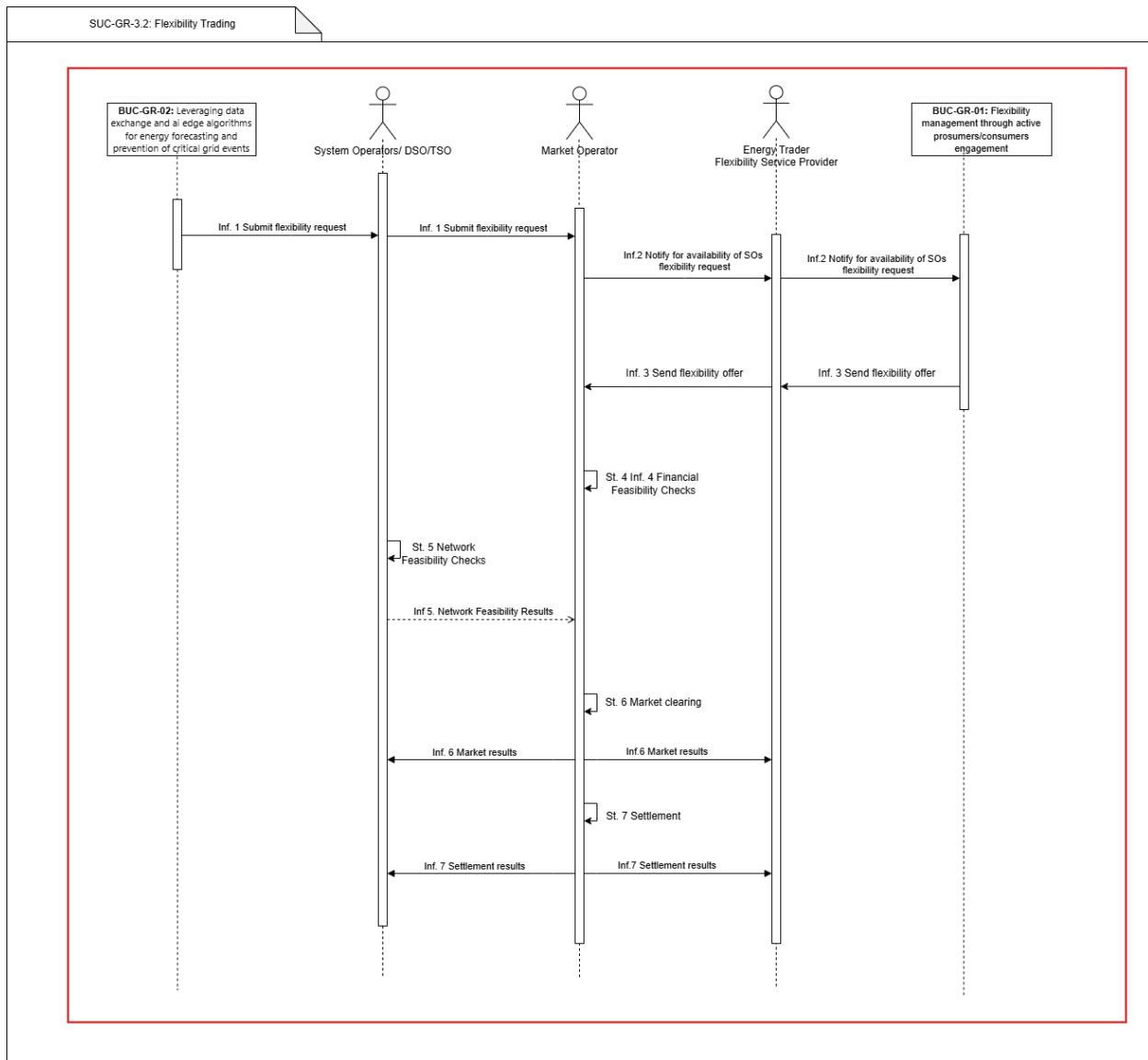


FIGURE 40: DEPLOYMENT DIAGRAM FOR SUC-GR-03.02 (ONGOING PROCESS)

The Local Flexibility Market Platform service, within SUC-GR-03.02, utilises the assets and datasets presented in the previous subsection (including platform infrastructure, databases, and user interfaces) to support the flexibility trading workflow between System Operators, the Market Operator, and Flexibility Service Providers.

More specifically, flexibility requests were submitted by the System Operator and forwarded to the Market Operator (Step 1), which subsequently notified the participating FSPs regarding the availability of flexibility needs (Step 2). In response, FSPs submitted flexibility offers through the platform (Step 3), which were collected and processed by the Market Operator. The submitted offers were then subject to financial feasibility checks within the platform environment (Step 4), while, in parallel, network feasibility validation was performed by the System Operator based on internal grid assessment processes (Step 5).

In line with the use case workflow, the results of the network feasibility analysis were communicated back to the Market Operator, enabling the continuation of the market process. During the previous phase, the work focused on the initial setup of the flexibility request and offer exchange mechanisms, including basic data flows between actors and preliminary validation of the communication interfaces.

In the current full-demo phase, the workflow was further extended and partially validated through the execution of the end-to-end interaction up to the market clearing stage (Step 6), including the processing of flexibility requests, the submission and aggregation of offers, and the coordination between market and system operation functionalities. Indicative market results were generated and communicated to the involved actors (Step 6 – Inf.6), while the settlement step (Step 7) was initiated at a functional level, focusing on the definition and exchange of settlement-related information.

The implemented activities focused on validating the interoperability between actors, the correct handling of flexibility requests and offers, and the integration of market and network validation processes within the LFM platform environment

4.3.2 Milestones and Progress

This subsection revisits the internal milestones identified in D5.1 and assesses their status, noting any updates, delays, or partial completions observed during the Full-Demo Phase. The information is presented in the following table, which maps each milestone to the corresponding implementation steps and indicates the extent of progress achieved for the Finnish Demo.

PROGRESS ON DEMO 1 INTERNAL MILESTONES LINKED TO THE IMPLEMENTATION OF SYSTEM USE CASES (SUCS) DURING THE FULL-DEMO PHASE

| Internal Milestone | M | GR-01.01 | GR-01.02 | GR-01.03 | GR-01.04 | GR-01.05 | GR-02.01 | GR-03.01 | GR-03.02 |
|---------------------------------------|-----|------------------|----------------------|----------------------|------------------|--------------------------------------|--|--|------------------------------|
| Finalisation of required data sources | M9 | - | - | - | - | - | - | - | - |
| Initial testing with data sample | M11 | SC1 Steps4-10 | SC1 All Steps | SC1 All Steps | SC1 Steps 1-7 | SC2 All Steps SC3 Steps 1-6 | SC1-> Steps 1,2 and 5-8 ready | N/A | N/A |
| Alpha version | M12 | SC1 Steps4-10 | SC1,2,3 All Steps | SC1,2,3 All Steps | SC1 Steps 1-7 | SC2,3 Steps | N/A | SC1 → Steps 1-2 (registrat ion) | N/A |
| Complete connection points with | M15 | SC1 Steps4-10 | SC1,2 All Steps | SC1,2,3 All Steps | SC1 Steps 1-7 | SC2,3 Steps | N/A | Steps 1-4 | Steps 1-2 partly implemented |

| data sources | | | SC3 Step1 | | | | | | |
|-----------------------------|-----|--|----------------------|----------------------|---|---|-----------------------|-----------------|-----------------------|
| Beta version | M20 | SC1 All Steps SC2 Steps 2-5* *These steps rescheduled for M33 | SC1,2,3 All Steps | SC1,2,3 All Steps | SC1 Steps 1-7 Steps 8,9 in progress | SC1: Step 1 ready Steps 2-4 are in progress SC2: Steps 1-6 ready SC3: Steps 1-4 ready Steps 5-6 in progress Step 7-8 ready Step 9-10 in progress | SC1-> Steps 1-5 ready | Steps 1-6 | Steps 1-5 implemented |
| Final version | M26 | Testing all steps | Testing all steps | Testing all steps | Testing all steps | Testing all steps | SC1-> All Steps ready | All Steps ready | All Steps Ready |
| Fully validated in the demo | M36 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |

4.4 FULL-DEMO EVALUATION

4.4.1 Requirements Evaluation

The following section presents the requirement for each SUC, which was initially introduced in D5.1 including the description, acceptance criteria, and assigned testing partner. An additional column now captures the progress status recorded during the Full-Demo Phase, allowing a direct comparison between the targets set in D5.1 and the results achieved to date.

SUC-GR-01.01 OPTIMISATION OF FLEXIBILITY DISTRIBUTION

| Req. | Description | Acceptance Criteria | Progress |
|--------|--|---|-------------------------|
| QoS.1 | Contractual timelines for data exchange | Checks that contractual timelines for exchanging data exist and are followed | Implemented and tested |
| QoS. 2 | Frequency of data exchanges | Data frequency tests | Implemented and tested |
| Sec. 1 | Information theft | Consent of users. Data are secured in storage facilities (edge & cloud). Performance tests. | Implemented and tested |
| Sec. 2 | Information integrity violation | Data are secured in storage facilities (edge & cloud). Periodic sample testing and backups. | Implemented and tested |
| Sec. 3 | Replay | Databases security. Use of HEDGE-IoT connector | To be implemented later |
| D.1 | Management of data across organisational boundaries | Available data pipelines. Use of HEDGE IoT connector | To be implemented later |
| D.2 | Correctness of source data | Performance tests in IoT devices. Random checks and sample validations | Implemented and tested |
| D.3 | Data consistency and synchronisation management across systems | System monitoring of edge and cloud components. System uptime. | Implemented and tested |
| 0.1 | Personal data processing | User consent if personal data is required. Data anonymisation techniques where needed. | Implemented and tested |
| 0.2 | Right to access, rectify, erasure, restriction | Data be available in end users | Implemented and tested |
| 0.3 | Data transfer consent | User consent | Implemented and tested |
| Conf.1 | Operation mode of Information Producer | Tests to check the automation of information production | Implemented and tested |
| Conf.2 | Operation mode of Information Receiver | Tests to check the automation of information receipt | Implemented and tested |
| Conf.3 | Relative maturity of current implementation | Checks that the implementation is mature and well implemented | In Progress |
| Conf.4 | Distance between entities | Check the topology of the entities | Implemented and tested |

SUC-GR-01.02 DEMAND FORECASTING & **SUC-GR-01.03** PRODUCTION FORECASTING

| Req. | Description | Acceptance Criteria | Progress |
|--------|--|---|-------------------------|
| QoS.1 | Elapsed time response requirements for exchanging data | Check the forecast horizons and the availability of the forecast | Implemented |
| QoS. 2 | Availability of information flows | Data pipelines availability | Implemented |
| QoS. 3 | Accuracy of data requirements | Accuracy is accepted through consensual agreements and periodic sample testing | Implemented |
| QoS. 4 | Frequency of data exchanges | Every data exchange request is performed | Implemented |
| Sec. 1 | Information theft | Consent of users. Data are secured in storage facilities (edge & cloud). Performance tests. | Implemented |
| Sec. 2 | Information integrity violation | Data are secured in storage facilities (edge & cloud). Periodic sample testing and backups. | Implemented |
| Sec. 3 | Replay | Databases security. Use of HEDGE-IoT connector | To be implemented later |
| Sec. 4 | Denial of service | Database security and user roles-based security. Use of HEDGE-IoT connector | To be implemented later |
| Sec. 5 | Authentication | Database security and user roles-based security. Use of HEDGE-IoT connector | To be implemented later |
| D.1 | Type of source data | Comparisons and validity checks between edge sensors | Implemented |
| D.2 | Correctness of source data | Performance tests in IoT devices. Random checks and sample validations | Implemented |
| D.3 | Up-to-date management | Data are updated per agreed intervals (minute, 5-mins, 15-mins, 1-h) | Implemented |
| D.4 | Management of large volumes of data that are being exchanged | Amount of data exchanged between edge and cloud components | Implemented |
| D.5 | Data consistency and synchronisation management across systems | System monitoring of edge and cloud components. System uptime. | Implemented |

| | | | |
|--------|---|--|-------------|
| D.6 | Management of accessing different types of data to be exchanged | Establishment of specific data models | Implemented |
| D.7 | Transaction integrity required (backup and rollback capability) | Standard security tests are performed periodically | Implemented |
| D.8 | Management of data formats in data exchanges | Use of common data models and interoperability standards | Implemented |
| 0.1 | Personal data processing | User consent if personal data is required. Data anonymisation techniques where needed. | Implemented |
| 0.2 | Right to access, rectify, erasure, restriction | Data be available in end users | Implemented |
| 0.3 | Data transfer consent | User consent | Implemented |
| Conf.3 | Distance between entities | Check the topology of the entities | Implemented |
| Conf.4 | Data exchange methods | Use of agreed edge and cloud communication protocols | Implemented |
| Conf.7 | Operation mode of Information Producer | Tests to check the automation of information production | In progress |
| Conf.8 | Operation mode of Information Receiver | Tests to check the automation of information receipt | In progress |

SUC-GR-01.04 EDGE PROCESSING

| Req. | Description | Acceptance Criteria | Progress |
|--------|--|---|-------------|
| QoS.1 | Elapsed time response requirements for exchanging data | Data exchange is less than 1 minute | implemented |
| QoS. 2 | Availability of information flows | Data pipelines availability | implemented |
| QoS. 3 | Accuracy of data requirements | Accuracy is accepted through consensual agreements and periodic sample testing | implemented |
| QoS. 4 | Frequency of data exchanges | Every data exchange request is performed | implemented |
| Sec. 1 | Eavesdropping | Standards security measures | implemented |
| Sec. 2 | Information integrity violation | Data are secured in storage facilities (edge & cloud). Periodic sample testing and backups. | implemented |

| | | | |
|--------|--|--|-------------------|
| Sec. 3 | Authentication | Database security and user roles-based security. Use of HEDGE-IoT connector | implemented |
| Sec. 4 | Repudiation | Data are always available to be sent | implemented |
| Sec. 5 | Information theft | Consent of users. Data are secured in storage facilities (edge & cloud). Performance tests. | implemented |
| D.1 | Type of source data | Comparisons and validity checks between edge sensors | In progress |
| D.2 | Correctness of source data | Performance tests in IoT devices. Random checks and sample validations | In progress |
| D.3 | Up-to-date management | Data are updated per agreed intervals (minute, 5-mins, 15-mins, 1-h) | implemented |
| D.4 | Management of large volumes of data that are being exchanged | Amount of data exchanged between edge and cloud components | In progress |
| D.5 | Data consistency and synchronisation management across systems | System monitoring of edge and cloud components. System uptime. | In progress |
| D.6 | Validation of data exchanges | Periodic accuracy tests with edge meters | In progress |
| D.7 | Management of data formats in data exchanges | Use of common data models and interoperability standards | implemented |
| O.1 | Personal data processing | User consent if personal data is required. Data anonymisation techniques where needed. | implemented |
| O.2 | Right to access, rectify, erasure, restriction | Data be available in end users | To be implemented |
| O.3 | Data transfer consent | User consent | implemented |
| Conf.7 | Operation mode of Information Producer | Tests to check the automation of information production | implemented |
| Conf.8 | Operation mode of Information Receiver | Tests to check the automation of information receipt | implemented |

SUC-GR-01.05 USER INTERACTION

| Req. | Description | Acceptance Criteria | Progress |
|-------|--|-------------------------------------|-------------|
| QoS.1 | Elapsed time response requirements for exchanging data | Data exchange is less than 1 minute | Implemented |

| | | | |
|--------|--|---|-------------------|
| QoS. 2 | Availability of information flows | Data pipelines availability | Implemented |
| QoS. 3 | Accuracy of data requirements | Accuracy is accepted through consensual agreements and periodic sample testing | In progress |
| QoS. 4 | Frequency of data exchanges | Every data exchange request is performed | Implemented |
| Sec. 1 | Eavesdropping | Standard security measures | Implemented |
| Sec. 2 | Authentication | Database security and user roles-based security. Use of HEDGE-IoT connector | Implemented |
| Sec. 3 | Information theft | Consent of users. Data are secured in storage facilities (edge & cloud). Performance tests. | Implemented |
| Sec. 4 | Denial of Service | Data are always available to be sent | To be implemented |
| Sec. 5 | Information theft | Database security and user roles-based security. Use of HEDGE-IoT connector | To be implemented |
| D.1 | Type of source data | Comparisons and validity checks between edge sensors | In progress |
| D.2 | Correctness of source data | Performance tests in IoT devices. Random checks and sample validations | In progress |
| D.3 | Management of large volumes of data that are being exchanged | Amount of data exchanged between edge and cloud components | Implemented |
| D.4 | Data consistency and synchronisation management across systems | System monitoring of edge and cloud components. System uptime. | In progress |
| O.1 | Personal data processing | User consent if personal data is required. Data anonymisation techniques where needed. | In progress |
| O.2 | Right to access, rectify, erasure, restriction | Data be available in end users | To be implemented |
| O.3 | Data transfer consent | User consent | To be implemented |
| Conf.1 | Operation mode of Information Producer | Tests to check the automation of information production | Implemented |
| Conf.2 | Operation mode of Information Receiver | Tests to check the automation of information receipt | Implemented |

SUC-GR-02.01 ENERGY GRID MANAGEMENT USING FORECASTING DATA

| Req | Description | Acceptance Criteria | Progress |
|--------|---|---|---|
| QoS.1 | Frequency of data exchanges: Upon request | Data exchanges occur upon request and meet required frequencies for the system's performance. | Data received aggregated per 15 minutes. Accuracy to be tested. |
| Sec.1 | Authentication and Access Control mechanisms commonly used with this data exchange: Private (secret) key encryption | Authentication and encryption validated. | To be tested later |
| D.1 | Correctness of source data: Source data is usually correct | Random checks and sample validations | Successfully tested |
| D.2 | Up-to-date management: Received data must be up-to-date within hours of source data changing | Random checks and sample validations to verify that received data is up to date within hours of changes in source data. | Successfully tested |
| Conf.1 | Data exchange methods: Client-server Through database | Client-server or database exchange methods validated through performance tests. | Sample data tested |
| O.1 | Data transfer consent: The data subject shall have the right to obtain from the controller without undue delay the access, rectification, erasure, restriction of inaccurate personal data concerning him or her. | GDPR compliance verified through consent management and system monitoring. | Already applied |

SUC-GR-03.01 REGISTRATION & PREQUALIFICATION ON LOCAL FLEXIBILITY MARKET & **SUC-GR-03.02** FLEXIBILITY TRADING

| Requirement | Description | Acceptance Criteria | Progress |
|-------------|---|--|---|
| QoS.1 | Availability of information flows | Information flows must be available at all times, with no disruption to data transmission. | Achieved - Information flows are supported by the platform and remained available during testing. |
| QoS.2 | Accuracy of data requirements | Data requirements must be precise and verified to ensure correctness. | Achieved - Data inputs were validated during demo execution to ensure accuracy. |
| QoS.3 | Frequency of data exchanges | Data exchanges should occur at defined intervals, adhering to the required frequency. | Partially achieved - Data exchanges follow defined intervals, with further optimisation planned. |
| Sec. 1 | Ensuring confidentiality, avoiding illegitimate use | Data must be encrypted, access control implemented, and unauthorised access prevented. | Achieved - Security mechanisms including encryption and access control are implemented. |

| | | | |
|--------|---|---|--|
| | of data, and preventing unauthorised reading of data, is: | | |
| Sec. 2 | Information integrity violation: Ensuring that data is not changed or destroyed is: | Mechanisms should be in place to prevent unauthorised data modification or destruction. | Achieved – Data integrity is ensured through validation and controlled system processes. |
| Sec. 3 | Authentication and Access Control mechanisms commonly used with this data exchange | Secure access via API keys or tokens must be verified and managed appropriately. | Achieved – Authentication and access control are implemented via secure platform mechanisms. |
| D.1 | Correctness of source data | Source data must be verified to ensure it is accurate and reliable. | Achieved – Source data was validated during demo execution with participating actors. |
| D.2 | Up-to-date management | Data must be continuously managed to ensure its timeliness and relevance | Partially achieved – Data is updated during operations, with improvements planned for full automation. |
| 0.1 | Personal data processing | Personal data must be processed in compliance with relevant regulations. | Partially achieved – Data is updated during operations, with improvements planned for full automation. |
| 0.2 | Right to access, rectify, erasure, restriction | Mechanisms should be in place to allow individuals to access, correct, erase, or restrict their data. | Partially achieved – Basic mechanisms are in place, with further refinement planned. |
| 0.3 | Data transfer consent | Users must provide explicit consent for the transfer of their personal data. | Achieved – User consent mechanisms are implemented within the platform. |
| 0.4 | Data Retention Policy | There should be a clear policy on how long data is retained, with provisions for secure deletion. | Partially achieved – Data retention policies exist, with further formalisation planned. |
| Conf.1 | Number of Information Producers | Identify and maintain a count of all data producers. | Achieved – Information producers are defined and managed within the platform. |
| Conf.2 | Number of Information Receivers | Identify and maintain a count of all data receivers. | Achieved – Information receivers are defined and managed within the platform. |

| | | | |
|--------|--|---|---|
| Conf.3 | Data exchange methods | Document and verify all methods used for data exchange. | Achieved – Data exchange methods are implemented and verified within the platform. |
| Conf.4 | Communication access services requirements | Ensure communication services used for data exchange meet specified requirements. | Achieved – Communication services meet the required specifications |
| Conf.5 | Commonly used communication protocol | Ensure communication services used for data exchange meet specified requirements. | Achieved – Standard communication protocols are used and supported by the platform. |

4.4.2 KPIs Progress

The KPIs to be measured by the Greek demo and their progress upon the end of the Full-Demo Phase is presented in the table below.

TABLE 10: DEMO 2 KPIS PROGRESS (M28)

| ID | KPI | Baseline | Pre-Demo (M18) | Progress (M28) |
|------|--|----------|--|---|
| OB1 | Different types of IoT/edge devices to be exploited in Demo Areas e.g., Smart Meter, HEMS, Sensors, inverter | 0 | Submetering IoT devices, billing devices, smart plugs | 7 device types deployed, including smart meters, submetering IoT devices, edge processing units, cloud-based data services, user interface platforms (mobile/web) and data exchange infrastructure. |
| OB4 | Users involved in the piloting | 100 | 55 devices have been installed so far, actively transmitting | 118 users participating so far, with installed IoT devices continuously transmitting real-time data. Out of them 111 are in the main demo area, and 7 in the replicator area. |
| KPI3 | % Of planned usage of HEDGE-IoT tools/data services (e.g., transactions, periodicity) in field demos | 0 | 0 | ~70% utilisation achieved, aligned with Y2 targets. Active use of HEDGE-IoT services includes data ingestion, storage, interoperability services, API-based communication, and integration with forecasting, optimisation, and UI modules. |
| KPI4 | Real-time data sharing among stakeholders | 0 | 55 devices transmitting in real-time (per second) | Real-time data sharing operational, with 118 IoT devices transmitting data at 1-second frequency. Data flows between edge devices, cloud backend, forecasting services, optimisation and UIs, with API latency <200 ms. |
| KPI6 | End-users' bill reduction by offering flexibility services | n/a | 0 | 3.5% so far based on simulations. Not yet fully quantified, as full market participation is not completed. The simulation data did not have enough spread in the market price, so the profit margin was limited. We expect higher numbers in Y4 with RES integration. |
| KPI7 | Increased RES and IoT deployment for providing flexibility services | 0 | 0 | ~10-15% progress achieved. IoT infrastructure is deployed and operational. PV integration currently relies on open dataset due to lack of |

| | | | | |
|-------|--|-----|--|---|
| | | | | pilot PV data, but system is ready for real DER integration in next phase. |
| KPI8 | IoT/Edge/Fog sites uptime and availability | n/a | Availability of cloud components ~96% | ~98% availability achieved for cloud and backend components, with ongoing improvements toward full target availability. |
| KPI9 | Flexibility unlocked and transacted in markets | 0 | n/a | Based on simulations, we achieved gradually 98%. Flexibility estimation and optimisation workflows are fully implemented and validated. Trading (SUC-GR-03.02) has been demonstrated with real data, but full end-to-end market execution is still ongoing. |
| KPI10 | Number of consumers engaged with flexibility services | 0 | 55 users | 118 users participating through pilot installations and interacting with services. |
| KPI12 | Faster application response times | n/a | All interactions with the user are performed through the cloud. Response times are between 100-200ms | Achieved. All services operate through cloud APIs with response times between 100-200 ms, meeting real-time operational requirements. |
| KPI13 | Savings in network bandwidth and lower latency | n/a | Savings in network bandwidth come from the standardised and minimised payload from the devices. The rate of transmission is fixed. 1 measurement per second. | Achieved through optimisation of data transmission. Standardised payloads and structured APIs reduce bandwidth usage. Data transmission is fixed at 1 measurement/sec/device, ensuring controlled and efficient communication. |
| KPI17 | Increased flexibility incorporation enabled by IoT/Edge technologies for grid security | 0 | 0 | ~5-10% progress achieved. Flexibility estimation and optimisation mechanisms are operational. NILM enhances device-level visibility, while forecasting supports grid-aware decisions (SUC-GR-02.01). Full validation pending large-scale deployment. |
| KPI21 | Cross-energy flexibility enabled by HEDGE-IoT solution | 0 | 0 | 0% (not yet implemented). Current implementation focuses on electricity domain. |
| KPI22 | Increase DERs participation in flexibility provision | 0 | 0 | 0% currently, due to lack of real PV data from pilot sites. However, forecasting pipeline is validated using open dataset and ready for DER integration once data becomes available. |

4.4.3 Risks and Proposed Mitigation Actions

Main risks that have been encountered include:

- i. uncertainty or reduced accuracy in demand and production forecasts, which may affect flexibility estimation, grid-assessment results, identification of peak/low time slots, and optimisation decisions;
- ii. missing, noisy, delayed, or inconsistent measurements from IoT devices, smart meters, edge components, or data-exchange pipelines, which may affect model training, forecasting, disaggregation, and real-time operation;
- iii. variability in consumer/prosumer behaviour and response to incentives, leading to deviations between expected and delivered flexibility;
- iv. potential under-delivery of committed flexibility, which may impact bid execution, market-clearing outcomes, settlement, and overall profitability;
- v. integration risks between edge devices, cloud services, forecasting modules, optimisation tools, user interfaces, and the Local Flexibility Market platform; and
- vi. scalability challenges as the number of households, assets, data streams, market participants, and optimisation variables increases.

Additional risks are related to communication reliability, API availability, cybersecurity, GDPR-compliant handling of residential energy data, and the maturity of some end-to-end workflows, particularly those involving data-space connectors, market settlement, and full operational validation. These risks are mitigated through continuous data-quality checks, monitoring of edge/cloud components, validation of forecasting and optimisation outputs, secure data-handling mechanisms, and progressive integration testing across all involved SUCs.

5 DEMO 3 – DIGITALIZE ECS AND EV STATIONS TO ENHANCE GRID RESILIENCE, RES HOSTING AND SOCIALIZE LOCAL PRODUCTIONS [ITALY]

5.1 FULL-DEMO PHASE ACTIVITIES SUMMARY

This section presents a structured summary of the activities that the Italian Demo conducted during the Full Demo Operation Phase (M22–M28). It follows the demo deployment template introduced deliverable D5.1 (available in Annex I for reference), which functions as a reference for monitoring the development of each demonstrator. The status of the Full Demo Operation Phase targets, the WP3 services utilised, and the key stakeholders involved during this phase are all detailed in below.

The purpose of the information is to establish the foundation for the Full Demo Phase and to evaluate the operational readiness of the demo at the conclusion of the Pre-Demo Phase.

TABLE 11: DEMO 3 FULL DEMO OPERATION PHASE DEPLOYMENT STATUS

| Section | Subsection | Input |
|---------|--|---|
| Summary | Full Demo Phase Target | Extend the engagement campaign. Validate field devices and storage. Validate network algorithms. |
| | Status Summary | Objectives completed |
| | Services Used (from WP3) | Apio IoT Platform Energy Community Platform Market Interface Platform Flexibility Register PGUI |
| | Stakeholders involved during Full Demo | All stakeholders envisaged by the BUCs have been engaged |

5.2 INFRASTRUCTURE, ASSETS AND DATA AVAILABILITY

Based, on the demo-deployment template, a consolidated snapshot of the infrastructure and assets mobilised during the Full Demo Operation Phase is provided in the following table for the Italian demo. Each asset is accompanied by its technical description, deployment level, use status in months 22–28, and the WP3 service to which it pertains.

TABLE 12: SUMMARY OF DEMO 3 INFRASTRUCTURE AND ASSETS DEPLOYED DURING THE FULL DEMO OPERATION PHASE

| Asset | Description | Deployment Level | Used during Pre-demo | Under which WP3 service |
|-------|-------------|------------------|----------------------|-------------------------|
|-------|-------------|------------------|----------------------|-------------------------|

| | | | | |
|-------------------------------------|--|---|--------|-----------------------------------|
| Blockchain Access Layer | IoT Devices Management and measurement notarisation algorithms. | Deployed and integrated | Yes | ECP Platform (Apio Balance, D3.4) |
| Energy Community management web app | Web interface for enabling energy community management by FSP and for setpoint computation | Developed and deployed | Yes | ECP Platform (Apio Balance, D3.4) |
| Report Generator | Backend Software for generating Energy Community performance report | Developed and deployed | No | ECP Platform (Apio Balance, D3.4) |
| PV Performance Forecasting Tool | ML Based tool for photovoltaic performance forecasting | Developed and deployed | Yes | ECP Platform (Apio Balance, D3.4) |
| PV Performance Benchmarking Tool | Real-Time photovoltaic performance benchmarking algorithms | Developed and deployed | Partly | ECP Platform (Apio Balance, D3.4) |
| Behind The Meter Assets | EMS / BMS and other field equipment | To Be Integrated | No | n/a |
| Anomaly Detection Tool | Real-Time and Batch anomaly detection algorithms | Developed and deployed | Partly | n/a |
| Flexibility Register | Archives flexible assets, market result and settlements | Integrated with the demo's assets | Yes | n/a |
| IoT Platform | Handles connection to IoT-enabled resources and make data available to other systems | To Be Integrated with the demo's assets | Yes | ECP Platform (Apio Balance, D3.4) |
| Asset Management | A DSO's system handling the physical and constructive characteristics of grid elements | To Be Integrated with the demo's assets | Partly | n/a |
| Topology Processor | A DSO's system containing the current and expected grid topology | Validate integration with the demo's assets | Partly | n/a |
| IoT Weather stations | IoT-enabled weather stations; temperature, humidity, wind, irradiation | Deployed and integrated | Yes | n/a |
| Dynamic line rating tool | Conductor thermal ratings in a dynamic evolution for LV and MV cable | To be developed | Partly | n/a |

| | | | | |
|-----------------------------------|--|---|--------|-----|
| Load and Production Forecast tool | Tool to foreseen loads and productions in Short Terms. | Developed and running; validation in progress | Partly | n/a |
| Weather service | Contains data from both IoT Weather stations and remote weather service(s) | To be integrated | No | n/a |
| Grid Measurement Assets | IoT-enabled sensors and IED installed on lines and/or substations | Deployed | Partly | n/a |
| Availability Algorithm Tool | Tool that identifies, for each predefined time band, the set of PODs that can be considered reliable and available | To be integrated | - | n/a |

The following table summarises the datasets relevant to the Full Demo Operation Phase, indicating their availability, whether they were used during this period and their linkage to the corresponding WP3 technological enablers.

TABLE 13: DEMO 3: OVERVIEW OF DATASETS RELEVANT TO THE FULL DEMO OPERATION PHASE OF

| Data Description | Used during Full Demo Phase | Under which WP3 service |
|--|-----------------------------|-------------------------|
| Residential active power measurements | Data Sample | ECP Platform |
| Forecasted Photovoltaic Performances | Data Sample | ECP Platform |
| Computed Photovoltaic Performances | Data Sample | ECP Platform |
| Customer Information | Data Sample | ECP Platform |
| Market Data | Data Sample | ECP Platform |
| Grid Topology | Data Sample | n/a |
| DSO smart metering data (LV,MV, consumers/prosumers/PV plants) | Data Sample | n/a |

OPEN DATA AVAILABILITY

The Italian demo is currently considering which type of data can be made available as open data upon restrictions and availability.

5.3 FULL-DEMO OPERATION PHASE RESULTS

This section captures the status and progress of System Use Case (SUC) implementation during the Full Demo Operation Phase (M22–M28) for the Italian Demo. For each SUC, key developments are outlined, including the specific actions undertaken, intermediate achievements, and alignment with the expected implementation steps and scenarios described in D2.2. This structured overview

offers insight into the readiness and maturity of each SUC ahead of the upcoming demonstration cycles.

5.3.1 SUCs Implementation

This subsection presents the implementation progress of each System Use Case (SUC) as defined in D2.3 for the Italian Demo, highlighting the actions carried out during the Full Demo Operation Phase.

SUC-IT-01.01 ENERGY COMMUNITY POWER MANAGEMENT

| Section | Subsection | Input |
|--------------------------------------|------------------------|--|
| Overview | SUC Summary | The SUC-IT-01.1 implements a centralised power management solution for energy communities, replacing the classical local BTM approach. By leveraging data from DERs, EMS, baselines, and market sources, it enables smarter power management policies |
| | Target(s) | The current evaluation cycle targets the inclusion of multiple energy communities in market interactions. |
| | Expected UC Milestones | All steps of the scenarios are now implemented. Working towards final version of the SUC. |
| | Actions implemented | Every microservice was completed and deployed. Collection of data has started. |
| Requirements | Assumptions | No assumptions are made since current evaluation cycle involved mainly software development. |
| | Dependencies | The integration with other software systems that compose Areti's LFM implementation was successful |
| | Risks | Energy community members do not respond to market request activations. |
| Readiness | Deployment diagram | <i>See below</i> |
| | Deployment preparation | The implementation of the SUC requires a reliable infrastructure and components that can ensure high availability of information flows (90%+), frequent and event-driven data exchanges, and efficient handling of large and diverse data types. Data must be accessible across organisational boundaries, validated, accurate, and updated within minutes of changes. These requirements support robust data management and quality of service, ensuring the proper functioning of the HEDGE-IoT ecosystem in the context of the SUC. |
| | Deployment assessment | Every component required to integrate the LFM and the RECs is deployed |
| Validation Activities Summary | Previous cycle | The stage implements the "Flexibility Offers" scenario, where the FSP Operator responds to DSO requests by computing optimal setpoints for DERs. Key actions include normalising DER measurements, notarising them on blockchain, collecting market and baseline data, identifying vulnerable resources, computing and dispatching optimal setpoints, and generating KPI reports. These actions |

| | | |
|---------------|--|---|
| | | ensure technical, economic, and social parameters are effectively used to enable flexibility services. |
| Current cycle | | At the current stage the focus is on the simultaneous market participation of multiple RECs under the same grid perimeter and same or different FSPs. |
| Future cycle | | It is possible that an improvement of power management could be required. Likely, the required implementations for Transversal Use Cases. |

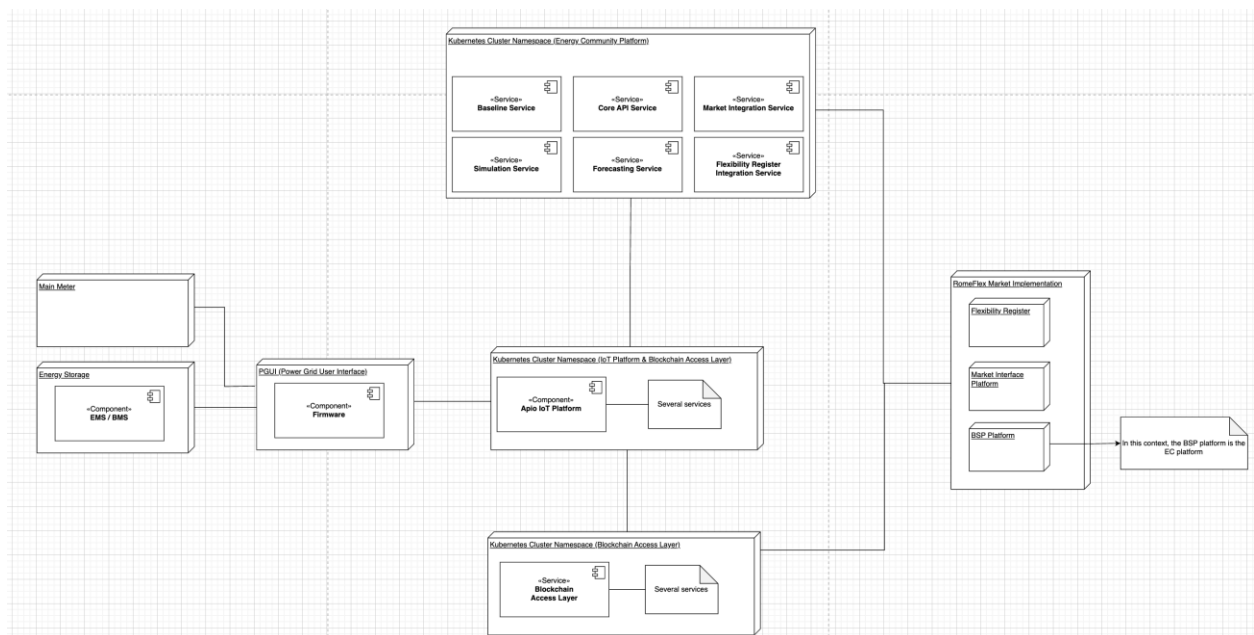


FIGURE 41: SUC-IT-01.01 DEPLOYMENT DIAGRAM

Service “ECP Platform – PLATFORM FOR DERS AND ENERGY COMMUNITIES” (which is described as technological enabler in D3.4) has been tested in the context of SUC-IT-01.01. The main areas of testing were:

- The integration with the Market Interface Platform and the Flexibility Register, to obtain market data, baselines and measurements.
- The Power Management Algorithm, to compute the best flexibility offers and setpoint to maximise economic in presence of REC incentives and flexibility compensation.

In this phase, since RECs are still in the process of being involved in the project, all tests were conducted with synthetic data sources (simulators).

SUC-IT-01.02 ENERGY COMMUNITY PERFORMANCE FORECASTING

| Section | Subsection | Input |
|---------|------------|-------|
|---------|------------|-------|

| | | |
|---------------------|------------------------|---|
| Overview | SUC Summary | SUC-IT-01.02 focuses on enhancing Energy Community (EC) performance by analysing and forecasting the behaviour of behind-the-meter (BTM) resources such as inverters, sun-meters, and storage systems. The Energy Community Platform gathers and normalises measurement data from these assets, enabling performance ratio analysis, anomaly detection, and continuous forecasting. These features allow EC administrators to monitor KPIs and asset health through a dedicated interface. |
| | Target(s) | The current evaluation cycle involves using forecasting and performance analysis to improve the exploitation of RECs in market scenarios |
| | Expected UC Milestones | All steps of the scenarios are now implemented. Working towards final version of the SUC |
| | Actions implemented | <p>Every microservice was completed and deployed. Collection of data has started.</p> <p>Energy community members were engaged through a mobile application.</p> |
| Requirements | Assumptions | <p>The key assumptions regard that enough energy community members (producers and prosumers) are instrumented, allowing consistent data acquisition. It also presumes that DERs have been enrolled and can generate valid measurements over a meaningful timeframe. Furthermore, the evaluation process assumes a minimum 90% data availability, frequent data exchanges (every few minutes or upon specific triggers), and that data integrity and synchronisation across systems are ensured. These underlying assumptions directly affect the accuracy and reliability of the performance evaluation and forecasting activities.</p> <p>(No changes, this is still an assumption since data collection is ongoing)</p> |
| | Dependencies | The key assumptions regard that enough energy community members (producers and prosumers) are instrumented, allowing consistent data acquisition. It also presumes that DERs have been enrolled and can generate valid measurements over a meaningful timeframe. |
| | Risks | REC members might opt-out from data collection / engagement by disconnecting the data collection device (PGUI) |
| Readiness | Deployment diagram | See below |
| | Deployment preparation | The components and infrastructure must support high availability of information flows. They must enable management of different types of data to be exchanged every few minutes, and support data exchanges. Data must be managed across organisational departmental boundaries and between systems from different vendors. The infrastructure must ensure validation of data and models, support large volumes of data and model dependencies, guarantee that received data is up to date within seconds of changes, and enable verification of data accuracy. |
| | Deployment | All the software components are deployed. The risk of not having energy communities enrolled in time is mitigated by having |

| | | |
|--------------------------------------|----------------|---|
| Validation Activities Summary | assessment | |
| | Previous cycle | The current stage involves the following main actions: measurement normalisation and notarisation by the BAL Platform, followed by performance analysis and forecasting on the FSP Platform. Based on these, anomaly detection is triggered, and periodic KPI reports are generated. These steps are carried out by key actors including the DSO, and Flexibility Service Provider. |
| | Current cycle | Improvements over report format and KPI collection to be used by BSP/FSP to improve market effectiveness of RECs. |
| | Future cycle | Likely, the required implementations for Transversal Use Cases. |

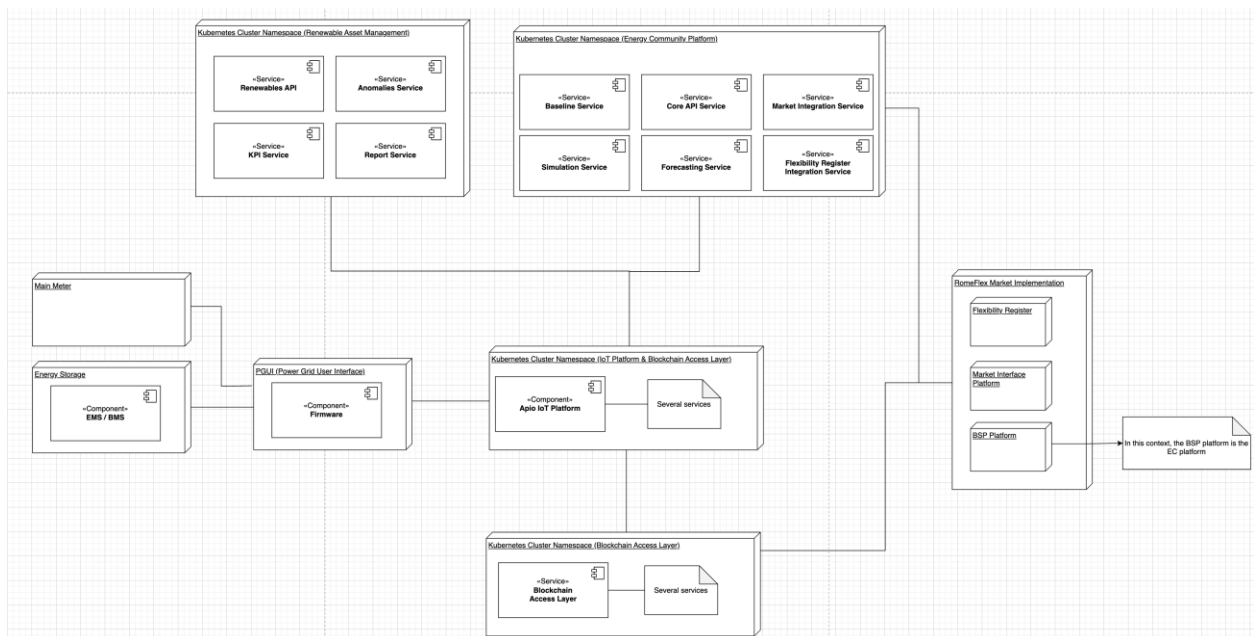


FIGURE 42: SUC-IT-01.02 DEPLOYMENT DIAGRAM (ONGOING PROCESS)

Service “ECP Platform – PLATFORM FOR DERS AND ENERGY COMMUNITIES” (which is described as technological enabler in D3.4) has been tested in the context of SUC-IT-01.02.

The main areas of testing were:

- The integration with the local flexibility market components (Market Interface Platform and Flexibility Register) to obtain market data, baselines and measurements.
- Integration with The Renewables API in order to retrieve behind-the-meter related measurements, KPIS and report generation for photovoltaic plants that are provided by REC members.
- The Load/Production Forecasting capabilities of the platform (described in D3.3) were tested to provide PV performance forecasting.

In this phase, since RECs are still in the process of being involved in the project, all tests were conducted with synthetic data sources (simulators).

SUC-IT-02.01 GRID BEHAVIOUR FORECASTING

| Section | Subsection | Input |
|---------------------|------------------------|---|
| Overview | SUC Summary | The SUC-IT-02.01 focuses on improving the prediction of grid behaviour, both in terms of energy production and consumption, by combining real-time data from DSOs, energy communities, and consumers. Through the integration of smart meter readings, substation sensors, and weather forecasts, a machine learning model forecasts short- and mid-term load and production trends. These forecasts help improve grid stability, prevent overloads, and support operational decision-making. |
| | Target(s) | The current evaluation cycle targets enhanced grid operation by enabling better prediction capabilities, which increase the capacity to anticipate and prevent overloads and other critical situations. In addition, it also aims at reducing application response times; faster grid behaviour predictions provide additional operational time to effectively manage and mitigate critical scenarios. |
| | Expected UC Milestones | Forecast model is validated and making predictions up to 5 days in the full demo grid portion; REC production capability and flexibility availability is forecasted |
| | Actions implemented | Forecast model is being refined using 3-year load curves with 15 minutes granularity from ~10000 customers in the full demo grid perimeter. |
| Requirements | Assumptions | Grid measurements are available; Grid topology is updated. |
| | Dependencies | <p>The SUC depends on near real-time data from PoDs and a granular distribution of sensors in both lines and substations, which are essential for feeding the forecast model. Synchronisation of the clock between systems with accuracy on seconds is also required to ensure consistent and reliable data exchange.</p> <p>This SUC is linked to SUC-IT-02.2, as it provides load and production forecasts for the grid, and to SUC-IT-02.3, by consuming weather forecasts to better predict PV production and consumer behaviour. These interactions underline its role as both a data consumer and provider within the overall system architecture.</p> |
| | Risks | A newly trained ML model may perform suboptimal due to biases, overfitting, or limited data. Continuous monitoring and retraining are essential to improve reliability |
| Readiness | Deployment diagram | See diagram below. Activities are highlighted in green. |
| | Deployment preparation | <p>The components and infrastructure must support Quality of Service requirements such as identifiable data age, known time skew and periodic or event-based exchanges. Availability can be scheduled, reflecting non-continuous service tolerance. From a Security standpoint, mechanisms such as certificate or shared secret authentication, VLAN segregation, and safeguards against eavesdropping and integrity violations are required.</p> <p>Data Management must ensure correctness, up-to-date information within minutes, and automated or semi-automated data maintenance. Validation across sources and management across departmental boundaries are also essential. The Configuration layer requires publish-subscribe and master-slave exchange models, Power Line Communication as media, and request-response access.</p> |

| | | |
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| Validation Activities Summary | | Implementations are generally mature with few changes needed for legacy systems. No GDPR constraints are expected, as no personal data is processed. |
| | Deployment assessment | ML model is running on a standalone environment. Validation is against a periodically updated grid and sliding time window measurement, then checked again real measurements. |
| | Previous cycle | The previous stage included requesting grid topology and weather forecasts, which are used to compute or refine forecast data based on updated measurements. The forecasted behaviour is then made available upon request. These steps address previous recommendations by ensuring data correctness, availability, and event-based updates, while supporting secure access, validation across boundaries, and compatibility with existing systems. |
| | Current cycle | In the current stage, the ML-based forecasting model has reached production readiness and is entering the validation phase in a production environment. This phase focuses on validating the model using real grid topology together with operational load and generation measurements to assess performance and reliability before full deployment. |
| | Future cycle | Integration of ML model into DSO's systems and make it programmatically invocable; Weather forecast is taken into account while predicting load and production. |

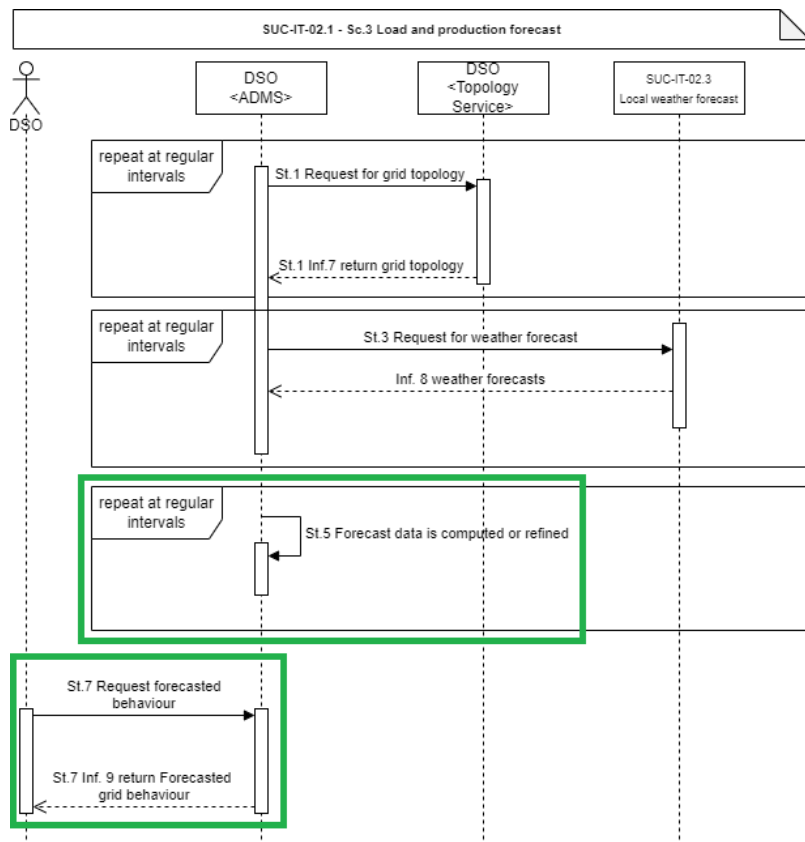


FIGURE 43: SUC-IT-02.01 DEPLOYMENT DIAGRAM (ONGOING PROCESS)

SUC-IT-02.02 GRID CONGESTION COMPUTING

| Section | Subsection | Input |
|---------------------|------------------------|---|
| Overview | SUC Summary | SUC-IT-02.02 demonstrates the effectiveness of forecasting grid congestion by leveraging DSO system assets and results from previous SUCs. The objective is to defer grid reinforcement investments and improve security of supply by enabling demand-response mechanisms. The Distribution Management System (DMS) uses inputs such as RT measurements, grid topology, thermal limits, baselines, and load & production forecasts to detect voltage violations and line power limitations through the State Estimation tool. Key components include SCADA, topology processor, dynamic line rating, flexibility database, and forecast tools. |
| | Target(s) | The current evaluation cycle targets improvements in real-time data sharing among stakeholders, enabling better forecast models. It also focuses on enhancing grid operational performance through improved allocation of flexibility resources in critical scenarios. Additionally, it aims to reduce application response times, allowing quicker prediction of grid behaviour. Lastly, the cycle supports increasing DERs participation in flexibility provision by reducing downtime. |
| | Actions implemented | During the evaluation cycle, the DSO system processed SCADA data via the topology processor and state estimation tools to assess real-time grid configuration. The dynamic line rating tool used weather forecasts to define thermal limits. Energy Community resources were registered in the flexibility database, and baselines were set using smart meter data. Forecasts of load and production were integrated to detect grid congestion and support operational decisions |
| Requirements | Assumptions | Forecast model is supposed as accurate; Grid topology is accurate and available in real time. |
| | Dependencies | The use case requires balanced distribution of flexibility in the grid area, availability of real-time data readings, and updated grid topology in near real time. These prerequisites ensure effective interaction with other services and components. This use case is closely related to others in the Italian pilot. In particular, it builds on SUC-IT-02.1 by consuming load and production forecasts to activate State Estimation algorithms across different scenarios. It is also linked to SUC-IT-02.3, from which it receives local weather conditions and forecasts to support the calculation of the dynamic grid rating. These interactions strengthen the integration and coherence of the demo environment. |
| | Risks | Inaccurate data may lead to false congestion detection. |
| Readiness | Deployment diagram | <i>See below</i> |
| | Deployment preparation | The implementation of this use case relies on requirements spanning several domains. Quality of Service (QoS) requires data exchanges either upon events or at regular 15-minute intervals, ensuring timeliness, availability during scheduled uptime, and traceability of data age and time skew. Security (Sec) measures include protection against eavesdropping and data integrity violations, with authentication managed through certificates or shared secrets, and network segmentation via VLANs. Data Management demands high accuracy and timeliness of data, validation across departments and organisations, and a mostly automated maintenance process. Configuration (Conf) involves a publish-subscribe and request-response architecture over existing mature infrastructures, using power |

| | | |
|--------------------------------------|-----------------------|---|
| Validation Activities Summary | | line communication where applicable, and accommodating legacy systems. Lastly, no GDPR constraints apply, as no personal data is processed. |
| | Deployment assessment | Congestion detection algorithm is linked to forecast engine; components are being validated on static data. |
| | Previous cycle | The main actions focused on structured data acquisition from field devices and central systems, followed by real-time grid state estimation. These steps build directly on recommendations from the previous cycle by ensuring updated grid topology, weather data, and DER baselines are reliably processed. The resulting estimation outcomes now provide timely insight into potential grid congestions and flexibility needs, improving responsiveness and system readiness. |
| | Current cycle | In the current cycle, the dynamic grid congestion assessment has been extended to the full demo grid perimeter. The validation focuses on evaluating the congestion indicators and flexibility needs derived from forecasted conditions against the operational data available across the network. This phase aims to verify the reliability and scalability of the approach when applied to a broader grid context and to validate the usefulness of the resulting insights for operational decision-making. |
| | Future cycle | Integration of ML model into DSO's systems and make it programmatically invocable; Weather forecast is taken into account while predicting load and production. |

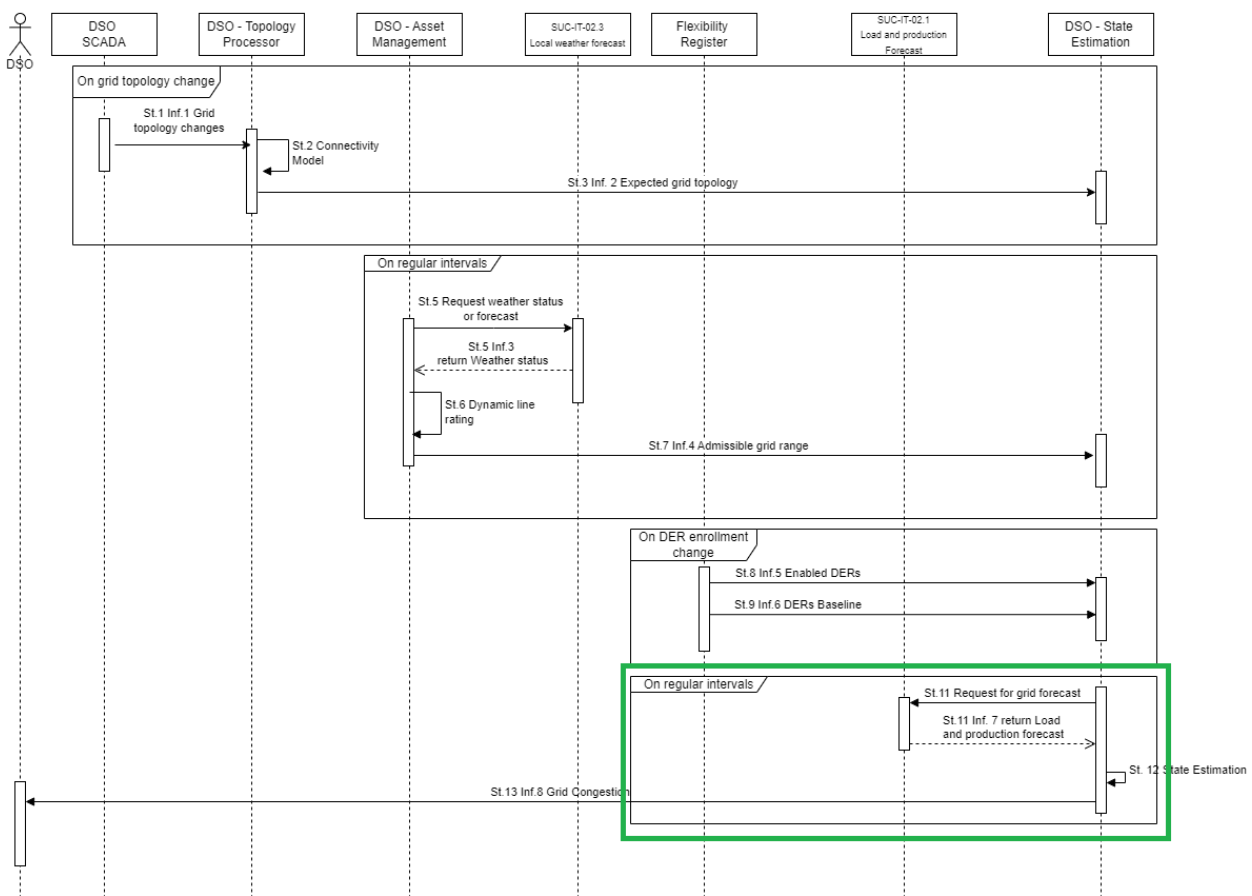


FIGURE 44: SUC-IT-02.02 DEPLOYMENT DIAGRAM (ONGOING PROCESS)

SUC-IT-02.03 LOCALISED WEATHER FORECAST

| Section | Subsection | Input |
|---------------------|------------------------|--|
| Overview | SUC Summary | SUC-IT-02.03 combines city-wide weather forecasts with local IoT weather stations to achieve finer predictions, accurate to individual renewable production plants or city blocks. By integrating real-time data on solar radiation, temperature, and cloud cover from IoT stations with broader forecasts, the platform develops more precise and dynamic solar energy production predictions. This enables better planning and efficiency in solar energy utilisation for DSOs and users. |
| | Target(s) | The current evaluation cycle targets increasing the deployment of IoT weather stations in strategic locations to improve flexibility services by enhancing load and production forecasts. It also focuses on ensuring high uptime and availability of these IoT/Edge/Fog sites to enable quicker responses to forecasted grid load and production changes. |
| | Expected UC Milestones | Weather stations are fully integrated in the use case; |
| | Actions implemented | Edge software has been developed and is running stably. |
| Requirements | Assumptions | Weather station position is optimal in order to provide suitable data interpolation; Enough RECs join the pilot in order to provide significant data. |
| | Dependencies | The use case relies on the availability of an external weather service and the installation of IoT weather stations in strategic locations such as substations and areas with high DER density. These stations must be properly configured and able to communicate with the DSO's systems. Additionally, the use case is linked to SUC-IT-02.1 and SUC-IT-02.2, as it provides weather forecasts and real-time weather status at relevant locations. |
| | Risks | Potential factors contributing to delays include unforeseen technical difficulties, including equipment failure, unavailable or unstable LTE connection. |
| Readiness | Deployment diagram | <i>See below</i> |
| | Deployment preparation | The components and underlying infrastructure must meet specific quality of service requirements, including availability of information flows, identifiable data age and data exchange frequency triggered by events or periodic reporting. Security is ensured through authentication and access control mechanisms based on shared secrets. Data management requires the source data to be usually correct, with proper handling across systems. Configuration considers distances between entities, a limited number of information producers, and communication protocols supporting request-response and periodic reporting. Lastly, no personal data is processed, ensuring compliance with GDPR regulations. |
| | Deployment assessment | Weather data is being acquired; REC enrolment is completed. |
| | Previous cycle | The current stage focuses on implementing the localised weather forecast scenario by integrating public weather data with DSO's IoT weather stations. Actions include scheduled retrieval of weather forecasts from external providers, |

| | | |
|--------------------------------------|---------------|---|
| Validation Activities Summary | | continuous reporting of local weather station data, and interpolation of this data into forecast models. These steps ensure weather information is updated and available at specific points of interest, fulfilling recommendations to maintain data accuracy, availability, and secure communication as outlined in previous cycles. |
| | Current cycle | Weather data in being refined before full integration. |
| | Future cycle | Deployment and integration with external forecast provider in order to retrieve localised weather forecast. |

SUC-IT-02.3 - Localized weather forecast

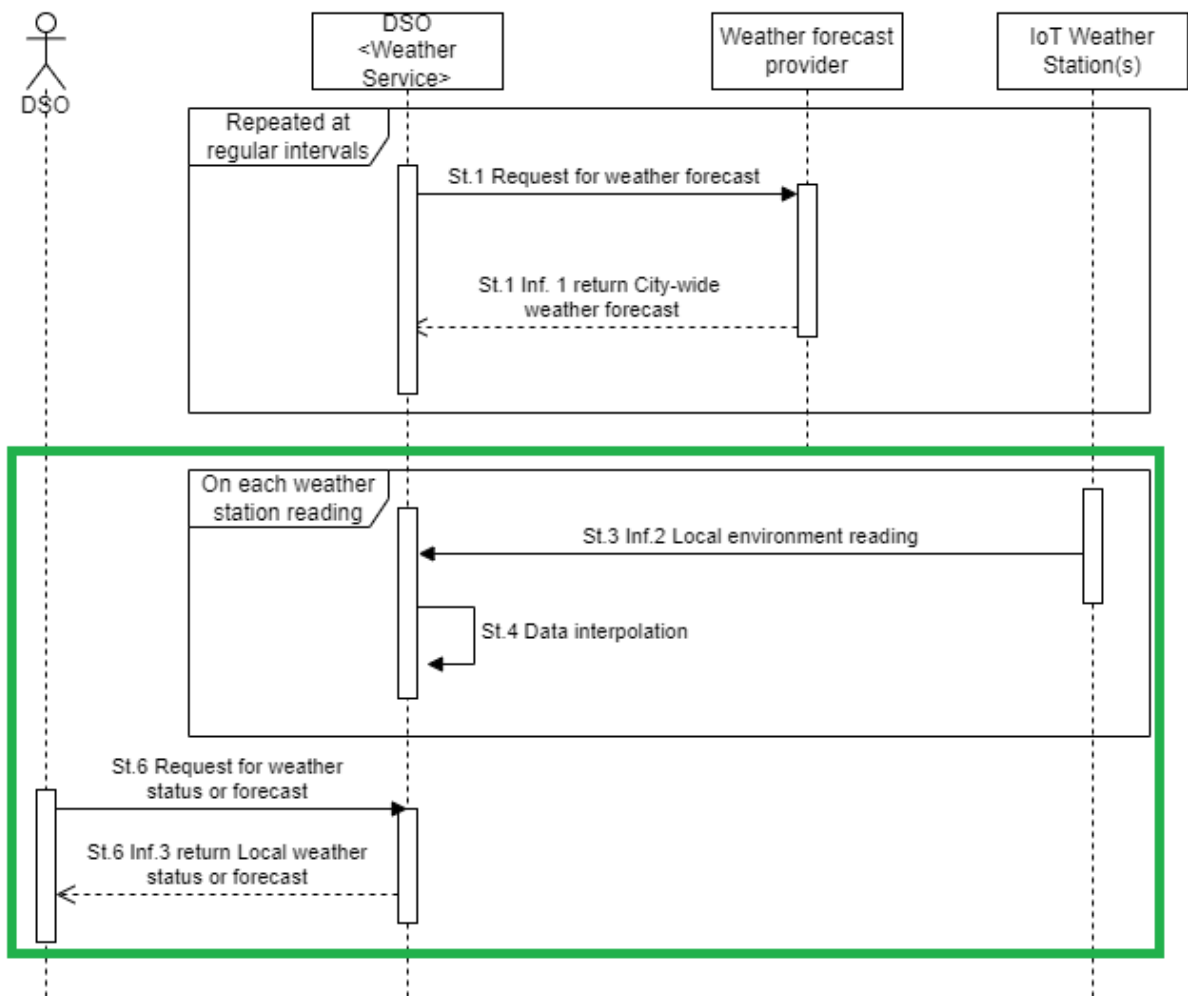


FIGURE 45: SUC-IT-02.02 DEPLOYMENT DIAGRAM (ONGOING PROCESS)

5.3.2 Milestones and Progress

This subsection revisits the internal milestones identified in D5.1 and assesses their status, noting any updates, delays, or partial completions observed during the Full-Demo Phase. The information is presented in the following table, which maps each milestone to the corresponding implementation steps and indicates the extent of progress achieved for the Finnish Demo.

TABLE 14: PROGRESS ON ITALIAN DEMO INTERNAL MILESTONES LINKED TO THE IMPLEMENTATION OF SYSTEM USE CASES (SUCS) DURING THE FULL DEMO PHASE

| Internal Milestones | M | IT-01.01 | IT-01.02 | IT-02.01 | IT-02.02 | IT-02.03 |
|--|-----|-----------|-------------|-------------------------|---------------------------|-------------------------|
| Functional Requirements | M14 | Completed | Completed | Completed | Completed | Completed |
| Technical Requirements | M15 | Completed | Completed | Completed | Completed | Completed |
| Field Resources Engagement | M16 | Completed | - | - | - | - |
| Platform development and data exchange | M17 | Completed | Completed | SC01 → Steps 1-5 Tested | - | - |
| Asset deployment and integration | M18 | Completed | In Progress | - | - | SC01 → Steps 3-4 Tested |
| Platform prototype Available & Data Models | M18 | Completed | Completed | SC01 → Steps 5 Tested | SC01 → Steps 11-13 Tested | - |
| Input of historical data | M19 | - | - | - | - | - |
| Beta version | M24 | Completed | Completed | - | - | - |
| Final version | M30 | - | - | - | - | - |
| Fully validated in the pilot | M36 | - | - | - | - | - |

5.4 FULL-DEMO EVALUATION

5.4.1 Requirements Evaluation

The following section presents the requirement for each SUC, which was initially introduced in D5.1 including the description, acceptance criteria, and assigned testing partner. An additional column now captures the progress status recorded during the Full-Demo Phase, allowing a direct comparison between the targets set in D5.1 and the results achieved to date.

SUC-IT-01.01 & SUC-IT-01.02 ENERGY COMMUNITY POWER MANAGEMENT & ENERGY COMMUNITY PERFORMANCE FORECASTING

| Req | Description | Acceptance Criteria | Progress |
|-----|---|--|--|
| R.1 | Availability of information flows | 90% + availability - Allowed outage: 1 month per year | Under implementation |
| R.2 | Management of accessing different types of data to be exchanged | Each data exchange could entail different types of data (e.g. query a database) Data and models are exchanged every few minutes | Data from external software sources is coming as intended (accuracy / resolution as intended). Data from the field to be tested later |
| R.3 | Frequency of data exchanges | Periodicity greater than a few seconds Upon event Upon request | Data from external software sources is coming as intended (frequency as intended). Data from the field to be tested later |
| R.4 | Management of data across organisational boundaries | Data can be accessed by external organisations | Data Flows originated from the Use Cases are available on external platforms |
| R.5 | Validation of data exchanges | Data and models should be validated. | Data is validated during ingestion |
| R.6 | Management of large volumes of data that are being exchanged | The solution facilitates the utilisation and management of large models along with their dependencies. | To be tested later |
| R.7 | Up-to-date management | Received data must be up-to-date within accepted time granularity of source data changing | To be tested later |
| R.8 | Correctness of source data | The solution enables data accuracy verification. | To be tested later |

SUC-IT-02.01 & SUC-IT-02.02 GRID BEHAVIOUR FORECASTING & GRID CONGESTION COMPUTING

| Req | Description | Acceptance Criteria | Progress |
|-------|-----------------------------------|---|--|
| QoS.1 | Availability of information flows | Continuous availability not required so long as downtime is scheduled | Data is currently transferred manually |
| QoS.2 | Accuracy of data requirements | Age of data needs to be knowable | Data age is known |

| | | | |
|--------|--|---|--|
| QoS.3 | Accuracy of data requirements | Time skew of data must be known | Time skew is known |
| QoS.4 | Frequency of data exchanges | Upon event | Data is published on expected events. |
| QoS.5 | Frequency of data exchanges | Every 15 minutes | To be tested later |
| Sec.1 | Eavesdropping | Standard security tests | To be tested later |
| Sec.2 | Information integrity violation | Standard security tests | To be tested later |
| Sec.3 | Authentication and Access Control mechanisms commonly used with this data exchange | Certificate | To be tested later |
| Sec.4 | Authentication and Access Control mechanisms commonly used with this data exchange | Shared secret | To be tested later |
| Sec.5 | Network security measures commonly used with this data exchange | VLAN segregation | Field VLANs are segregated |
| D.1 | Correctness of source data | Source data is always correct (e.g. by definition) | Data is assumed correct |
| D.2 | Correctness of source data | Source data is usually correct | To be tested later |
| D.3 | Up-to-date management | Received data must be up-to-date within minutes of source data changing | To be tested later |
| D.4 | Management of data across organisational boundaries | Data exchanges go across departmental boundaries | To be tested later |
| D.5 | Data maintenance effort: human versus automation | Data maintenance is mostly automated but requires occasional intervention | Data is currently manually transferred |
| D.6 | Validation of data exchanges | Data from different sources must be validated against each other | Data validation is currently outside of the pilot. |
| D.7 | Management of data across organisational boundaries | Data exchanges go across organisational boundaries | Data samples are currently manually extracted and exchanged. |
| Conf.1 | Number of Information Producers | Few to a hundred | Producers are communicating correctly. |
| Conf.2 | Communication media | Power Line Communication (Chain2) | Data is being read via Chain2. |

| | | | |
|--------|--|---|---|
| Conf.3 | Data exchange methods | Master-slave | Used where applicable. |
| Conf.4 | Data exchange methods | Publish-subscribe | Used where applicable. |
| Conf.5 | Communication access services requirements | Request-response | Used where applicable. |
| Conf.6 | Relative maturity of current implementation | TRL levels classification | TRL 6 |
| Conf.7 | Existence of legacy systems | Few changes will be needed | Changes are being worked on. Using manual intervention as workaround. |
| 0.1 | No GDPR constraints | No personal data is processed or transferred | No personal data is used. |
| 0.2 | Right to access, rectify, erasure, restriction | Data retention policy outlines the specific sensitive time period data can be retained, plus how it will be disposed of when the time to do so comes. | To be tested later. |

SUC-IT-02.03 LOCALISED WEATHER FORECAST

| Req | Description | Acceptance Criteria | Progress |
|--------|--|--|---------------------------------------|
| QoS.1 | Availability of information flows | Continuous availability not required so long as downtime is scheduled | To be tested later (after deployment) |
| QoS.2 | Accuracy of data requirements | Age of data needs to be knowable | Data age is known |
| QoS.3 | Accuracy of data requirements | Upon event | To be tested later (after deployment) |
| QoS.4 | Frequency of data exchanges | Periodicity greater than a few seconds | Frequency is as expected |
| Sec.1 | Eavesdropping | Standard security tests | To be tested later |
| D.2 | Correctness of source data | Source data is usually correct | To be tested later (after deployment) |
| Conf.3 | Communication access services requirements | Request-response | To be tested later |
| Conf.4 | Communication access services requirements | Periodic reporting | Data is published at fixed interval |
| 0.2 | Right to access, rectify, erasure, restriction | Data retention policy outlines the specific sensitive time period data can | To be tested later |

| | | | |
|--|--|--|--|
| | | be retained, plus how it will be disposed of when the time to do so comes. | |
|--|--|--|--|

5.4.2 KPIs Progress

The KPIs to be measured by the Italian demo and their progress upon the end of the Full-Demo Phase is presented in the table below.

TABLE 15: DEMO 3 KPIS PROGRESS (M28)

| ID | KPI | Baseline | Pre-Demo (M18) | Progress (M28) |
|--------|---|----------|----------------|----------------|
| KPI 4 | % Of real-time data sharing among stakeholders | n/a | n/a | n/a |
| KPI5 | Open source released developments related to data connector implementations | 0 | n/a | 0 |
| KPI 11 | Increased grid operational | 0 | n/a | n/a |
| KPI7 | Increased RES and IoT deployment for providing flexibility services | 0 | n/a | 4 |
| KPI8 | IoT/Edge/Fog sites uptime and availability | n/a | n/a | 4 |
| KPI8 | IoT/Edge/Fog sites uptime and availability | n/a | n/a | > 5 |
| KP9 | Flexibility unlocked and transacted in markets | n/a | n/a | n/a |
| KP10 | Number of consumers engaged with flexibility services | 10% | n/a | n/a |
| KPI 11 | Increased grid operational performance | n/a | n/a | n/a |
| KP12 | Faster application response times | n/a | n/a | n/a |
| KPI22 | Increase DERs participation in flexibility provision | 15 min | n/a | n/a |

5.4.3 Risks and Proposed Mitigation Actions

The main risk that may affect the demo activities is the engagement of the LEC members, either by terms of responding to market activations or opting out of data collection. The Italian partners are working with the LEC to engage its members and take part in the demo activities. Further mitigation

actions include the usage of synthetic data to design, develop and test the necessary software components prior to deployment to the actual demo site.

6 DEMO 4 – ENHANCE LOCAL GRID FLEXIBILITY TO DIVERSE END USERS BY DIGITIZING ENERGY ASSETS AND INCORPORATING SAREFIZED INTEROPERABLE GRID MONITORING AND CONTROL [NETHERLANDS]

6.1 FULL-DEMO PHASE ACTIVITIES SUMMARY

This section presents a structured summary of the activities that the Dutch Demo conducted during the Full Demo Operation Phase (M22–M28). It follows the demo deployment template introduced deliverable D5.1 (available in Annex I for reference), which functions as a reference for monitoring the development of each demonstrator. The status of the Full Demo Operation Phase targets, the WP3 services utilised, and the key stakeholders involved during this phase are all detailed in below.

The purpose of the information is to establish the foundation for the Full Demo Phase and to evaluate the operational readiness of the demo at the conclusion of the Pre-Demo Phase.

TABLE 16: DEMO 4 FULL DEMO OPERATION PHASE DEPLOYMENT STATUS

| Section | Subsection | Input |
|---------|--|---|
| Summary | Full Demo Phase Target | To further integrate energy nodes in the Semantic Interoperability Framework (SIF), deploy flexibility assets and connect building assets with the SIF. |
| | Status Summary | Multiple additional (types of) energy nodes have been installed and integrated via the SIF (DSO/grid meters, sub metering of buildings, PV production, EV) Update of SIF took place. Anomaly detector was developed and installed on local server. Procurement of batteries to provide flexibility for multiple buildings has been finalised. Procurement of two different vendors of V2G installation has been finalised. Installation design for batteries and V2G is in final stage. First BMS has been connected to SIF and energy management Dashboard with control for first BMS has been implemented |
| | Services Used (from WP3) | Semantic Interoperability Framework AI services for local grid resilience |
| | Stakeholders involved during Full Demo | Local DSO (electricity campus) with different roles, tenants, software integration partners, and technical system integrator. Also end users are being informed via dashboards in building. |

6.2 INFRASTRUCTURE, ASSETS AND DATA AVAILABILITY

Based, on the demo-deployment template (see D5.1), a consolidated snapshot of the infrastructure and assets mobilised during the Full Demo Operation Phase is provided in the following table for the Dutch demo. Each asset is accompanied by its technical description, deployment level, use status in months 22–28, and the WP3 service to which it pertains.

TABLE 17: SUMMARY OF DUTCH DEMO INFRASTRUCTURE AND ASSETS DEPLOYED DURING THE FULL DEMO OPERATION PHASE

| Asset | Description | Deployment Level | Used during Full demo | Under which WP3 service |
|-----------------------------|--|--|-----------------------|--|
| Edge server | Server that runs all the HEDGE-IoT edge applications | Testing | Yes | Hosts (parts of) the Semantic Interoperability Framework and the AI services for local grid resilience |
| Metering devices DSO | Metering points of local grid connection to DSO | Installed | Yes | Linked to the Semantic Interoperability Framework |
| Submetering IoT devices | IoT devices in residential switchboards with edge processing capabilities | Installed | Yes | Linked to the Semantic Interoperability Framework |
| Databases for data exchange | Local storage with cloud access | Deployed | Yes | Linked to the Semantic Interoperability Framework |
| PVs | Rooftop installation for self-consumption and flexibility provisioning | Installed | Yes | Linked to the Semantic Interoperability Framework |
| EVs and EV chargers | Electric mobility assets for flexibility provisioning | Installed | Yes | Linked to the Semantic Interoperability Framework |
| User Interfaces | Mobile app and web interface for residential consumers and aggregators | Interface for aggregator has been deployed | Yes | Linked to the Semantic Interoperability Framework |
| Interoperability Layer | Facilitate semantically interoperable data exchange. This includes integration with data space connectors. | Deployed, not yet integrated with data space connector | Yes | Part of the Semantic Interoperability Framework |

The following table summarises the datasets relevant to the Full Demo Operation Demo Phase, indicating their availability, whether they were used during this period and their linkage to the corresponding WP3 technological enablers.

TABLE 18: DEMO 1: OVERVIEW OF DATASETS RELEVANT TO THE FULL DEMO OPERATION PHASE OF

| Data Description | Used during Pre-Demo Phase | Under which WP3 service |
|--|----------------------------|--|
| Current measurements from all pilot area substation bays | Data Sample, full data | To showcase the connection with WP3 edge/cloud services, if applicable, provide a bit more context under which WP3 service it they have been used Data is exchanged through the Semantic Interoperability Framework |
| DSO Grid meters | Yes | Linked to Semantic Interoperability Framework |
| PV Panels | Yes | Linked to Semantic interoperability Framework |
| Submetering | Yes | Linked to Semantic interoperability Framework |
| Energy Nodes (sensor and building assets) | Partially deployed | Linked to Semantic Interoperability Framework |
| Chargers (EV) | Deployed | Linked to Semantic Interoperability Framework |
| Building management system | Deployed | Linked to Semantic Interoperability Framework |

OPEN DATA AVAILABILITY

The Dutch demo is currently considering which type of data can be made available as open data upon restrictions and availability.

6.3 FULL-DEMO OPERATION PHASE RESULTS

This section captures the status and progress of System Use Case (SUC) implementation during the Full Demo Operation Phase (M22-M28) for the Dutch Demo. For each SUC, key developments are outlined, including the specific actions undertaken, intermediate achievements, and alignment with the expected implementation steps and scenarios described in D2.3.

6.3.1 SUCs Implementation

This subsection presents the implementation progress of each System Use Case (SUC) as defined in D2.3 for the Dutch Demo, highlighting the actions carried out during the Full Demo Operation Phase.

SUC-NL-01.01 MONITORING & DASHBOARDS

| Section | Subsection | Input |
|--------------------------------------|------------------------|---|
| Overview | SUC Summary | Monitoring energy nodes real-time and store the data. This data will be pre-processed and combined/integrated in one or more dashboard(s). |
| | Target(s) | Deployment |
| | Expected UC Milestones | Completely implemented |
| | Actions implemented | Infrastructure to share data has been set up and data can be exchanged through the system. A dashboard has been made where (part of) this data is shown. |
| Requirements | Assumptions | Energy nodes are available for retrieving their data |
| | Dependencies | - (no dependencies) |
| | Risks | - (already deployed) |
| Readiness | Deployment diagram | <i>Implemented as specified</i> |
| | Deployment preparation | Edge server available to connect to energy nodes. DSO Grid Meters, PV Panels, Submetering, Energy Nodes and Chargers are installed and can send data to the edge server. |
| | Deployment assessment | Complete, KPIs need to be measured according to the plan |
| Validation Activities Summary | Previous cycle | Data from different types of energy nodes can be exchanged through the infrastructure and can be seen in a dashboard. |
| | Current cycle | - |
| | Future cycle | n/a |

SUC-NL-01.02 SEMANTIC INTEGRATION OF ENERGY NODES

| Section | Subsection | Input |
|-----------------|------------------------|---|
| Overview | SUC Summary | Integrate energy nodes and EMS/BMS via semantics for control and explainability |
| | Target(s) | Deployment for DSO meters, submetering, V2G chargers, batteries and two additional BMS |
| | Expected UC Milestones | Should be able to exchange information through the Semantic Interoperability Framework in a semantically interoperable way. |

| | | |
|--------------------------------------|------------------------|---|
| | | Should have implemented part of (steps 8-10) Sc.3, the semantic adapter for EMS/BMS |
| | Actions implemented | Data is now exchanged through the Semantic Interoperability Framework. Several semantic adapters have been developed and deployed for the energy assets such as (sub)meters, PV panels and EV chargers. |
| Requirements | Assumptions | Energy nodes are available for retrieving their data and to facilitate control The rationale behind the EMS optimisation algorithm and consequent instruction is available |
| | Dependencies | Access to new energy nodes for monitoring and control of battery and, V2G Support for explainability |
| | Risks | Interoperability of V2G chargers Interoperability with the EMS optimisation algorithm |
| | Deployment diagram | <i>See below, up until Inf.10 has been implemented</i> |
| Readiness | Deployment preparation | Two servers have been made available to run the various components. The Semantic Interoperability Framework is available and deployed on one of the servers. Energy assets have been installed and linked to Arnhems Buitens's network. |
| | Deployment assessment | 80% complete, still need to develop part of the semantic adapters for additional energy nodes (EMS/BMS, battery, V2G chargers). We are in the process of installing these additional energy nodes after which we can continue development on the adapters. Preparation for the connected adapters (DSO meters, submetering, EV chargers, PV panels) is complete and KPIs can be evaluated according to plan. |
| Validation Activities Summary | Previous cycle | Semantic adapter for DSO meters, one-way EV chargers, PV panels, submetering and one BMS have been developed, tested and have been deployed. |
| | Current cycle | V2G bidirectional EV chargers and a battery have been bought and are being installed. In addition, to the BMS already connected, various BMS systems have been assessed. |
| | Future cycle | Need to create a semantic adapter for the new EMS/BMS, battery and V2G bidirectional EV chargers. Need to send and show recommendations in the Prosumer's interface via the semantic interoperability layer Need to be able to show the rationale behind the for recommendations |



FIGURE 46: SUC-NL-01.2 DEPLOYMENT DIAGRAM (ONGOING PROCESS)

SUC-NL-01.03 OPTIMISE ENERGY PRODUCTION & CONSUMPTION

| Section | Subsection | Input |
|--------------------------------------|------------------------|--|
| Overview | SUC Summary | Optimise energy production & consumption in Arnheems Buiten's decentral grid |
| | Target(s) | Link EMS to the Semantic Interoperability Framework and can use optimisation algorithm in the EMS |
| | Expected UC Milestones | Should be completely implemented |
| | Actions implemented | EMS has been chosen and now the alignment and integration is being processed |
| Requirements | Assumptions | Energy usage data from the park and several energy nodes is available. Data can be exchanged through an infrastructure, preferably through semantic adapters as defined in SUC-NL-01.02 |
| | Dependencies | Depends on the Semantic Interoperability Framework for exchanging data and sending optimisation plans Depends on an EMS for the optimisation algorithm |
| | Risks | Delays in the deployment of SUC-NL-01.02 or in the deployment of the selected EMS can result in delays for this SUC. |
| Readiness | Deployment diagram | <i>Will be implemented according to D2.3 (Inf.1 has been implemented)</i> |
| | Deployment preparation | EMS has been chosen and now the alignment and integration is being processed |
| | Deployment assessment | Added control mechanism to first building via BMS |
| Validation Activities Summary | Previous cycle | n/a |
| | Current cycle | n/a |
| | Future cycle | Need to provide grid information to EMS optimisation algorithm, and be able to send an energy optimisation plan |

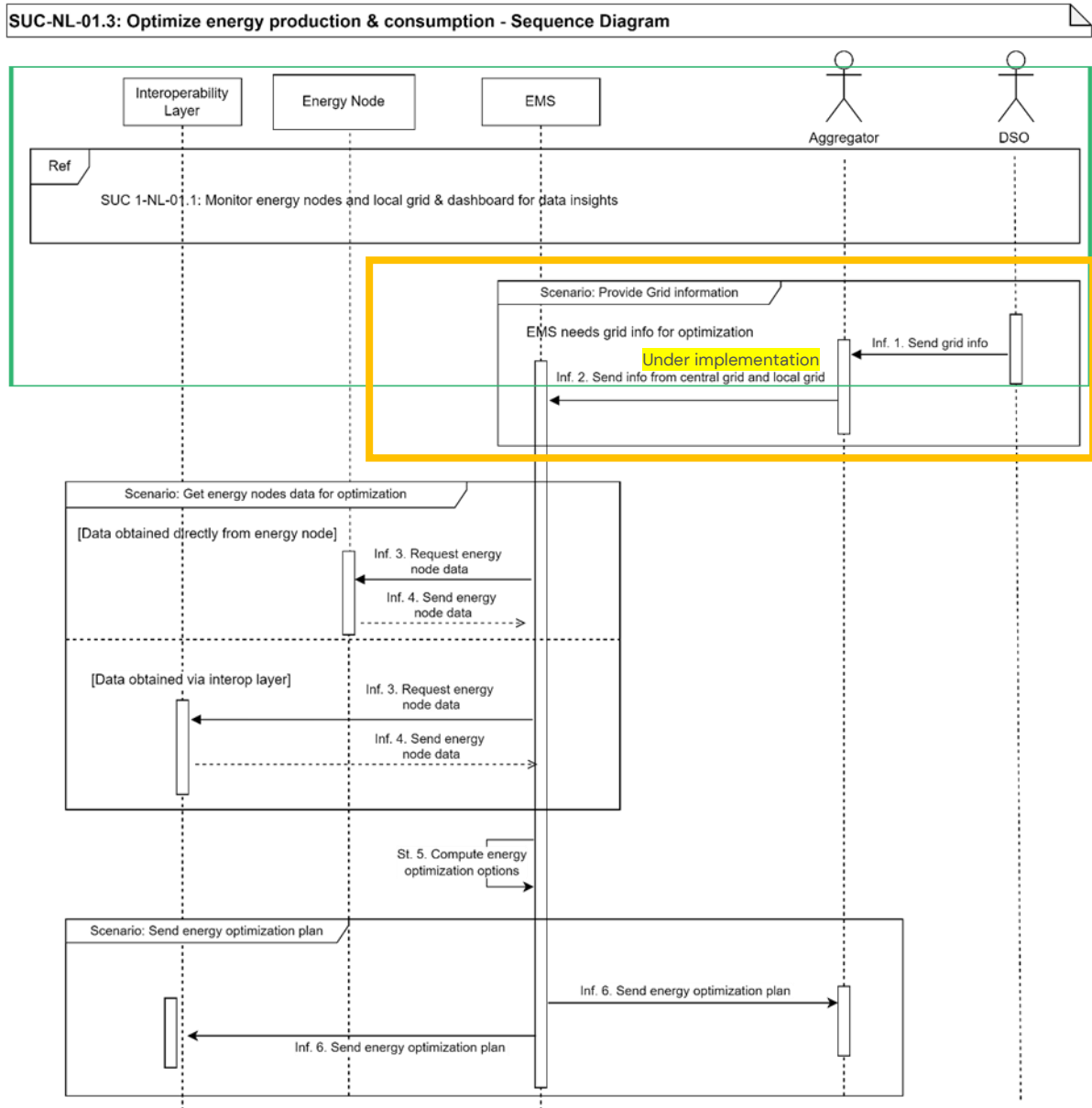


FIGURE 47: SUC-NL-01.03 DEPLOYMENT DIAGRAM (ONGOING PROCESS)

SUC-NL-01.04 FLEXIBILITY ALIGNMENT

| Section | Subsection | Input |
|----------|-------------|--|
| Overview | SUC Summary | Implement a flexibility alignment system at Electricity Campus Arnhems Buiten, enabling prosumers and aggregators to exchange and execute energy optimisation plans, utilising smart grid technologies to optimise energy use and demonstrate flexibility benefits |
| | Target(s) | Should be able to exchange and execute energy optimisation plans to enable flexibility alignment on the park |

| | | |
|--------------------------------------|------------------------|---|
| | Expected UC Milestones | Should be implemented completely |
| | Actions implemented | - |
| Requirements | Assumptions | Semantic Interoperability Framework and energy nodes' data is available. |
| | Dependencies | Depends on the Semantic Interoperability Framework to exchange data and send optimisation plans Grid Energy Management System (GEMS) needs to be available. |
| | Risks | Delayed deployment of the Semantic Interoperability Framework as well as the EMS may result in delays |
| Readiness | Deployment diagram | <i>Will be implemented according to D2.2</i> |
| | Deployment preparation | Semantic Interoperability Framework need to be deployed and energy assets need to be connected to it to exchange data about, e.g., their energy usage. Need to be able to control energy assets through the Semantic Interoperability Framework Grid Energy Management System (GEMS) needs to be available |
| | Deployment assessment | Semantic Interoperability Framework and energy assets have been deployed and are ready. Still need to check our ability to control energy assets through the Semantic Interoperability Framework. Grid EMS has been selected. Already first control to BMS has been implemented and tested. To be added for control is up to 2 BMS and multiple V2G and chargers and 2 batteries. |
| Validation Activities Summary | Previous cycle | n/a |
| | Current cycle | n/a |
| | Future cycle | Should be able to exchange and execute energy optimisation plans to enable flexibility alignment on the park |

SUC-NL-02.01 ANOMALY DETECTION

| Section | Subsection | Input |
|-----------------|-------------|---|
| Overview | SUC Summary | Anomaly detection on SAREF data streams between energy nodes at Arnheims Buiten |
| | Target(s) | Deployment of the anomaly detection in the energy nodes |

| | | |
|--------------------------------------|------------------------|---|
| | Expected UC Milestones | - |
| | Actions implemented | Deploying Docker containers, setting up connections with the Semantic Interoperability Framework, tuning detection parameters, initial debugging. |
| Requirements | Assumptions | The Semantic Interoperability Framework must be available; energy nodes must exchange data via the Semantic Interoperability Framework. |
| | Dependencies | Depends on the Semantic Interoperability Framework for exchanging data. |
| | Risks | Delays in deployment of the Semantic Interoperability Framework and connected energy nodes |
| Readiness | Deployment diagram | <i>See below</i> |
| | Deployment preparation | Server infrastructure (compute server and gateway server) must be operational; Semantic Interoperability Framework must be available; energy nodes must be available and integrated. |
| | Deployment assessment | The service has been deployed and is running on the pilot infrastructure. Finetuning and final adjustments are currently being done. The integration with dashboards (to display the reports) is still to be finalised. |
| Validation Activities Summary | Previous cycle | Testing of anomaly detection service in controlled environment |
| | Current cycle | Deployment and initial testing in a live environment |
| | Future cycle | Adding support for more energy nodes; finetuning detection parameters to fit user demands; integration with dashboards |

The Anomaly Detection module (SUC-NL-02.01) service provides real-time monitoring of graph data streams between smart devices, aiming to detect technical failures and other anomalies within the system on time, providing real-time alerts and explanations.

The service employs online continuous learning by listening for incoming data streams via the *Semantic Interoperability Framework* (SIF). Both the input and output are live streams of graph data in the *Resource Description Framework* (RDF) format, an open W3C standard for semantic data. SAREF is an example of an RDF vocabulary for modelling smart appliances and energy use in IoT environments and is the expected framework for any input data used for this service. SHACL is an RDF vocabulary for modelling anomalies and is used to model this service's output data.

No dedicated front-end is included in this service. Rather, the raw output (i.e. validation reports) is directly published to the SIF following semantic interoperability guidelines. Third-party interfaces (e.g. dashboards) can subscribe to these messages and display them as desired.

The following figure depicts a full overview of the service's architecture and its integration with the SIF.

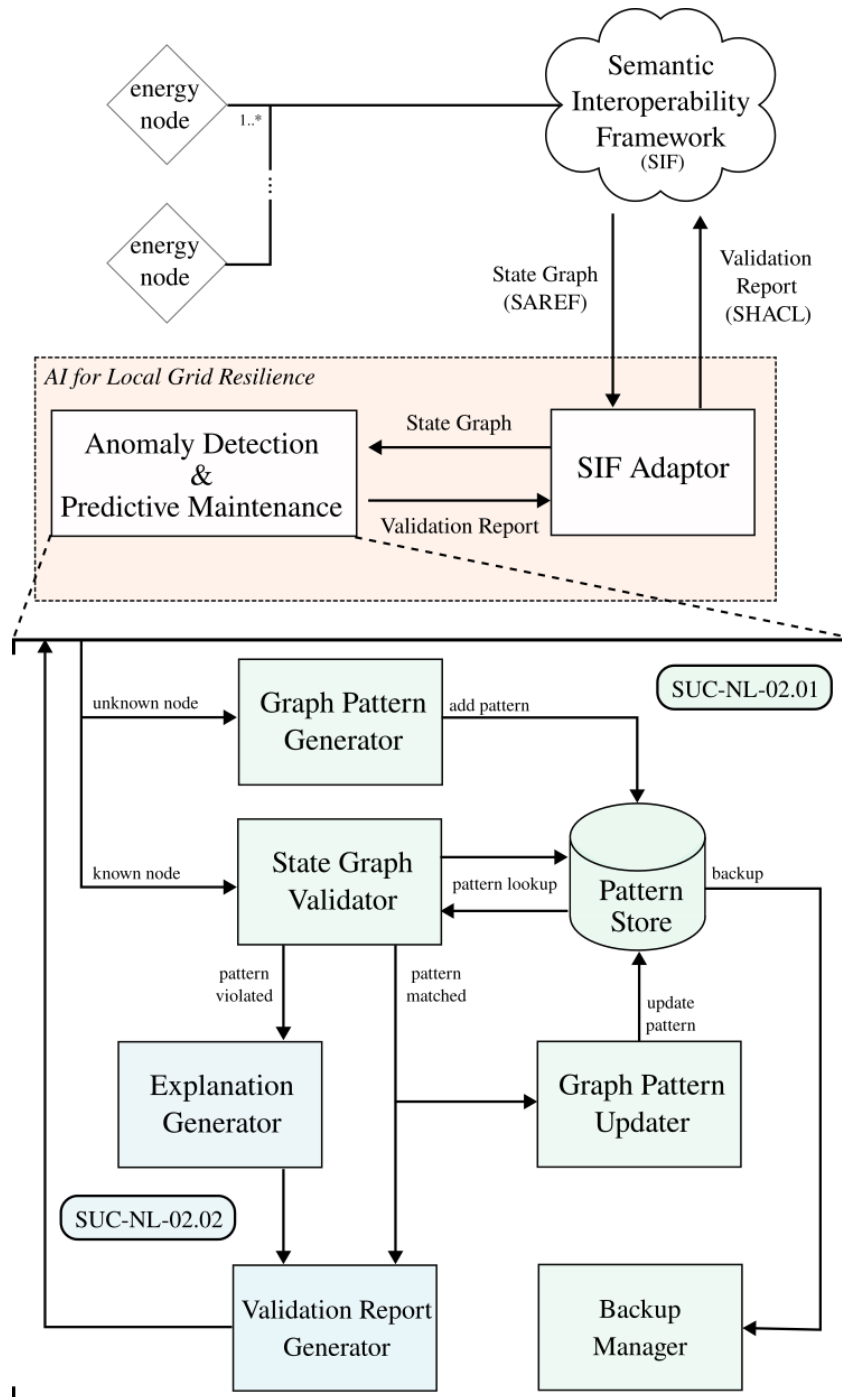


FIGURE 48: THE SERVICE ARCHITECTURE DIAGRAM OF THE ANOMALY DETECTION AND PREDICTIVE MAINTENANCE SERVICES, AND THEIR INTEGRATION INTO THE SEMANTIC INTEROPERABILITY FRAMEWORK.

SUC-NL-02.02 PREDICTIVE MAINTENANCE

| Section | Subsection | Input |
|--------------------------------------|------------------------|---|
| Overview | SUC Summary | Predictive maintenance for energy nodes connected to SIF at Arnhems Buiten |
| | Target(s) | Deployment |
| | Expected UC Milestones | - |
| | Actions implemented | Deploying Docker containers, setting up connections with the Semantic Interoperability Framework, tuning parameters, initial debugging. |
| Requirements | Assumptions | The Semantic Interoperability Framework must be available; energy nodes must exchange data via the Semantic Interoperability Framework. |
| | Dependencies | Depends on the Semantic Interoperability Framework for exchanging data, and on the Anomaly Detection service to predict maintenance needs. |
| | Risks | Delays in deployment of the Semantic Interoperability Framework, the Anomaly Detection service, and connected energy nodes |
| Readiness | Deployment diagram | <i>See below</i> |
| | Deployment preparation | Server infrastructure (compute server and gateway server) must be operational; Semantic Interoperability Framework must be available; energy nodes must be available and integrated. |
| | Deployment assessment | The service has been deployed and is running on the pilot infrastructure. Finetuning and final adjustments are currently being done. The integration with dashboards (to display the maintenance reports) is still to be finalised. |
| Validation Activities Summary | Previous cycle | Testing of predictive maintenance service in controlled environment |
| | Current cycle | Deployment and initial testing in a live environment |
| | Future cycle | Adding support for more energy nodes; finetuning parameters to fit user demands; integration with dashboards |

The *Predictive Maintenance* (SUC-NL-02.02) service is an extension to the Anomaly Detection service and cannot function on its own. We there refer to the service description of the *Anomaly Detection* (SUC-NL-02.01) use case, of which the particulars also apply to this service. The following

figure depicts how the two services interact, as well as depict a full overview of their architecture and the integration with the Semantic Interoperability Framework (SIF).

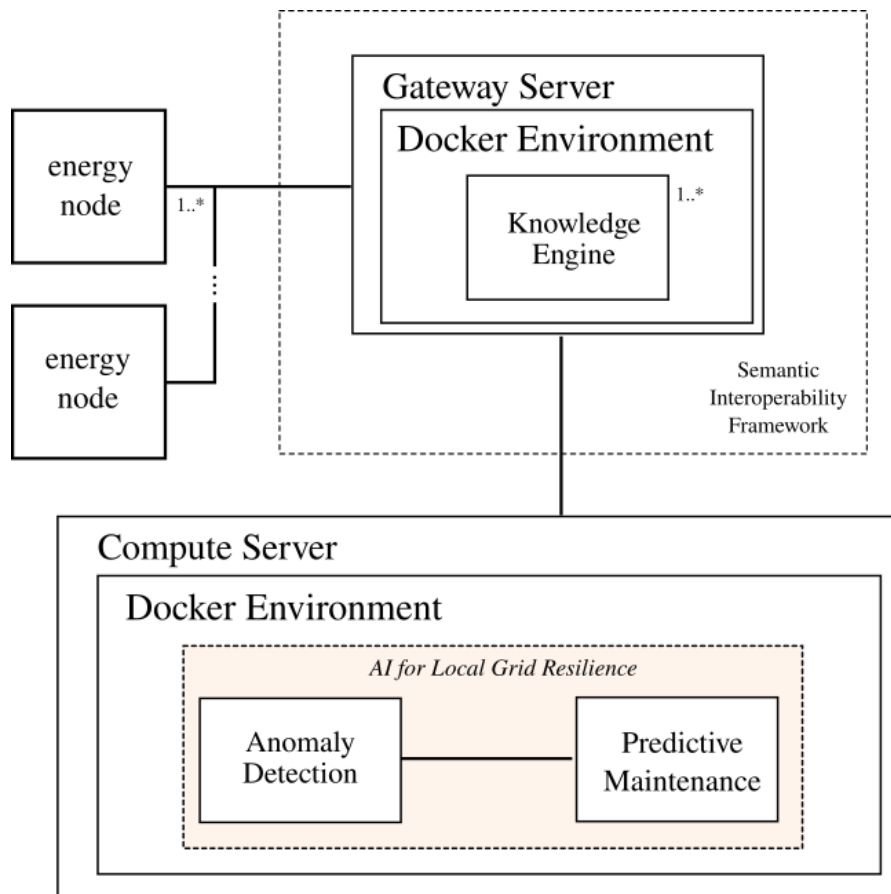


FIGURE 49: DEPLOYMENT DIAGRAM FOR SUC-NL-02.01 AND SUC-NL-02.02.

6.3.2 Milestones and Progress

This subsection revisits the internal milestones identified in D5.1 and assesses their status, noting any updates, delays, or partial completions observed during the Full-Demo Phase. The information is presented in the following table, which maps each milestone to the corresponding implementation steps and indicates the extent of progress achieved for the Finnish Demo.

TABLE 19: PROGRESS ON DUTCH DEMO INTERNAL MILESTONES LINKED TO THE IMPLEMENTATION OF SYSTEM USE CASES (SUCS) DURING THE FULL-DEMO PHASE

| Internal Milestones | M | NL-01.01 | NL-01.02 | NL-01.03 | NL-01.04 | NL-02.01 | NL-02.02 |
|---------------------------------------|----|----------|----------|----------|----------|----------|----------|
| Finalisation of required data sources | M9 | - | - | - | - | - | - |

| | | | | | | | |
|--|-----|---|----------------------------------|-----|-----|----------------------|----------------------|
| Initial testing with data sample | M10 | Sc.1, Sc.2 -> All steps Sc. 3 -> Steps 10, 12, 13 Sc. 4 -> Steps 16, 18, 19 Sc. 5 -> All steps | Sc. 1, Sc. 2, Sc. 4 -> All steps | - | - | - | - |
| Alpha version | M12 | - | - | - | - | - | - |
| Complete connection points with data-sources | M15 | Sc. 3 -> Steps 11, 14, 15 | - | - | - | - | - |
| Beta version | M20 | Sc. 4 -> Steps, 17, 20 | - | - | - | Sc. 2 -> All steps | Sc. 2 -> All steps |
| Final version | M26 | - | - | - | - | Sc. 1-3 -> All steps | Sc. 1-2 -> All steps |
| Fully validated in the demo | M36 | n/a | n/a | n/a | n/a | n/a | n/a |

6.4 FULL-DEMO EVALUATION

6.4.1 Requirements Evaluation

The following section presents the requirement for each SUC, which was initially introduced in D5.1 including the description, acceptance criteria, and assigned testing partner. An additional column now captures the progress status recorded during the Full-Demo Phase, allowing a direct comparison between the targets set in D5.1 and the results achieved to date.

SUC-NL-01.01-04/02.01-02 ALL SUCS AS PER D5.1

| Req | Description | Acceptance Criteria | Testing Partner | Progress |
|-------|--|--|-----------------|--|
| QoS.2 | Elapsed time response requirements for exchanging data | Intended granularity | TNO | So far acceptable, need to continue monitoring |
| QoS.3 | Availability of information flows | Max. 10 times per month interrupted availability when required | TNO, AB | So far acceptable, |

| | | | | |
|-------|--|--|-------------|---|
| | | | | continue monitoring |
| QoS.4 | Accuracy of data requirements | At least 75% of all data is accompanied by a timestamp | TNO | To be evaluated in later stages, currently good |
| QoS.5 | Frequency of data exchanges | When an event is generated, data exchange(s) occur(s) | TNO | So far acceptable, need to continue monitoring |
| Sec.2 | Eavesdropping | No data values are logged in the interoperability layer No access to the network without credentials Use dataspace connector | TNO, AB | Network is protected with credentials. We have implemented a first use case based on a dataspace connector |
| Sec.3 | Information integrity violation | Test that 90% of data is the same on the receiver and sender side Use up-to-date data storage solution | TNO, AB | To be evaluated in later stages |
| Sec.4 | Authentication and Access Control mechanisms commonly used with this data exchange | Use data space connector Use HTTPS | TNO, AB, VU | Using HTTPS, using data space connector for one use case |
| Sec.5 | Network security measures commonly used with this data exchange | Use IP whitelist | AB | Servers are installed, security measures are being planned to be implemented |
| D.2 | Correctness of source data | Assumed by definition | - | - |
| D.3 | Up-to-date management | At least 75% of all data is accompanied by a timestamp | TNO | To be evaluated in later stages |
| D.5 | Management of data across organisational boundaries | At least 1 organisational boundary is crossed | TNO, VU, AB | Implemented |
| D.6 | Data maintenance effort: human versus automation | Max. 10 per month human intervention needed | TNO, AB | To be evaluated in later stages, currently acceptable |

| | | | | |
|--------|--|--|-------------|--|
| Conf.2 | Distance between entities | Any distance is acceptable | - | - |
| Conf.3 | Number of Information Producers | At least 10 energy nodes | AB | PV, EV, (sub)metering and BMS |
| Conf.4 | Number of Information Receivers | At least 2 | AB | Via a first dashboard (Energy Island) multiple users receive information |
| Conf.5 | Communication media | Wired and wireless and Bluetooth connections are available | AB | Main wired connections done and wifi connections for (some) chargers |
| Conf.6 | Data exchange methods | Publish-subscribe data exchange is available | TNO | Implemented |
| Conf.7 | Communication access services requirements | Request-response data exchange is available | TNO | Implemented |
| Conf.8 | Commonly used communication protocol | REST API and Knowledge Engine are available | TNO, AB, VU | Implemented |
| 0.2 | All constraints also apply | Processed personal data has at least one legal basis | AB | No personal data is just part of the process |
| 0.3 | Right to access, rectify, erasure, restriction | Data retention policy has been defined | AB | Defined till end of project |
| 0.4 | Data transfer consent | - | AB | |
| 0.5 | Data retention policy | No personal data is transferred to a third party | AB | |

6.4.2 KPIs Progress

The KPIs to be measured by the Dutch demo and their progress upon the end of the Full-Demo Phase is presented in the table below.

TABLE 20: DEMO 4 KPIS PROGRESS (M28)

| ID | KPI | Baseline | Pre-Demo (M18) | Progress (M28) |
|----|-----|----------|----------------|----------------|
|----|-----|----------|----------------|----------------|

| | | | | |
|-------|--|---|--|--|
| OB1 | Different types of IoT/edge devices to be exploited in Demo Areas e.g., Smart Meter, HEMS, Sensors, inverter | 0 | 15 smart meters, 2 edge servers, 1 BMS | 20 sub smart meters, 2 edge servers, 1 BMS with controllable heat pumps, and multiple sensors are connected. Also, via API, chargers and inverters are connected |
| OB4 | Users involved in the piloting | 0 | 100% (for 1 one building/BMS) | 60% overall (first building B31 100%, via dashboarding in B42 all visitors, operations manager, EV chargers) |
| KPI3 | % Of planned usage of HEDGE-IoT tools/data services (e.g., transactions, periodicity) in field demos | 0 | 0 | 60% |
| KPI4 | Real-time data sharing among stakeholders | 0 | 20% (streams of DSO grid meters, PV, submeters and one building, and EV data collection) | 60% (EV chargers, submetering, and DSO grid meters) |
| KPI5 | Open source released developments related to data connector implementations | 0 | 4 releases | 6 releases for the Knowledge Engine/SIF 2 releases for the anomaly detector 1 release for the dashboard and the notebooks |
| KPI6 | End-users' bill reduction by offering flexibility services | 0 | 0% | 0% |
| KPI10 | Number of consumers engaged with flexibility services | 0 | 0 | 0 |
| KPI22 | Increase DERs participation in flexibility provision | 0 | 5% (first heat pump with buffering) | 5% (first heat pump with buffering) |

6.4.3 Risks and Proposed Mitigation Actions

The delay of installation of the battery and V2G cause of practical/physical implementation on site cause of ongoing maintenance/adjustments at the campus and awaiting approval from authority (municipality and regional fire/safety department).

7 DEMO 5 – LIVING LAB FOR INTEROPERABLE AI-BASED ENERGY SERVICES [PORTUGAL]

7.1 FULL-DEMO PHASE ACTIVITIES SUMMARY

This section presents a structured summary of the activities that the Portuguese Demo conducted during the Full Demo Operation Phase (M22-M28). It follows the demo deployment template introduced deliverable D5.1 (available in Annex I for reference), which functions as a reference for monitoring the development of each demonstrator. The status of the Full Demo Operation Phase targets, the WP3 services utilised, and the key stakeholders involved during this phase are all detailed in below.

The purpose of the information is to establish the foundation for the Full Demo Phase and to evaluate the operational readiness of the demo at the conclusion of the Pre-Demo Phase.

TABLE 21: DEMO 5 FULL DEMO OPERATION PHASE DEPLOYMENT STATUS

| Section | Subsection | Input |
|---------|--|---|
| Summary | Full Demo Phase Target | Prepare the demo infrastructure, enabling integration of digital platforms such as EdgeConnect and Community Manager. Set up the onboarding of residential and industrial consumers and prosumers for participation in flexibility services. Establish interoperable data exchange and align system operators and aggregators for testing flexibility. |
| | Status Summary | The demonstration will take place in the northern region of Portugal, in the CEVE concession area, involving residential and industrial participants. The demo setup includes digital platforms such as EdgeConnect and Community Manager (RECreation) to onboard consumers, enable interoperability, and manage flexibility assets. Services are defined for onboarding, data sharing, flexibility modelling, bidding, activation, and settlement. The core integration between Edge Connect, the community management platform and the market simulator is finished with laboratorial tests |
| | Services Used (from WP3) | EdgeConnect Residential Community Manager Market Simulator |
| | Stakeholders involved during Full Demo | INESC TEC CEVE (DSO & Retailer) REN / RDNester (TSO) SONAE MC ELERGONE Local residential participants |

7.2 INFRASTRUCTURE, ASSETS AND DATA AVAILABILITY

Based, on the demo-deployment template (D5.1), a consolidated snapshot of the infrastructure and assets mobilised during the Full Demo Operation Phase is provided in the following table for the Portuguese demo. Each asset is accompanied by its technical description, deployment level, use status in months 22–28, and the WP3 service to which it pertains.

TABLE 22: SUMMARY OF DEMO 5 INFRASTRUCTURE AND ASSETS DEPLOYED DURING THE FULL DEMO OPERATION PHASE

| Asset | Description | Deployment Level | Used during Full demo | Under which WP3 service |
|-------------------------|---|-------------------|-----------------------|----------------------------------|
| Heat pump | Ability to control via API / control capacity through home automation application | Partly Installed | Partly | HEMS* |
| Wallbox Chargers | Control capacity through API and home automation application | Partly Installed | Partly | HEMS* |
| Batteries and inverters | Control capacity through API and home automation application | Testing | No | HEMS* |
| Metering | Smart Metering | Already installed | Yes | Flexibility Optimisation Service |
| Photovoltaics | Tertiary building PV system that converts light into electricity. Controllable through EnergyBox | Already installed | Yes | Flexibility Optimisation Service |
| Energy Storage | Energy chemical storage system - lithium ion. Controllable through EnergyBox | Under development | Yes | Flexibility Optimisation Service |
| EnergyBox | A controller that integrates data from different assets of the building and exposes this data to the cloud. Acts as a gateway for Flexibility Service Provider. | Installed | Yes | Flexibility Optimisation Service |

The following table summarises the datasets relevant to the Full Demo Operation Demo Phase, indicating their availability, whether they were used during this period and their linkage to the corresponding WP3 technological enablers.

* The HEMS (Home Energy Management System) service, although not listed in D5.1 or D3.3, was integrated during the Pre-Demo Phase to enable local control of heat pumps, wallboxes, and batteries. Its architecture and functionalities will be formally documented in Deliverable D3.4 as part of the updated WP3 technological components

TABLE 23: DEMO 5: OVERVIEW OF DATASETS RELEVANT TO THE FULL DEMO OPERATION PHASE

| Data Description | Used during Full demo | Under which WP3 service |
|--|--|--|
| Current measurements from all pilot area substation bays | Data Sample, full data Partly Used | Market Simulator |
| Household Consumption Data | Full data | Vector Autoregressive Model for Energy Time Series Forecasting; RECreation |
| DER Specific Consumption Data | Data sample | HEMS; RECreation |
| Flexibility Bids Volumes and market simulator results | Flexibility Bids, Market Bids encoded as IEC 62325 | RECreation <> EdgeConnect <>Market Simulator |
| Consumer Asset portfolios and Flexibility capacity | Consumer portfolios | EdgeConnect |
| Historic Flexibility Bids and Activated Power from ENTSO-E Transparency Platform | Fully used | Market Simulator |

OPEN DATA AVAILABILITY

The pilot, in a broad sense, deals with energy data. Part of it comes from residential and tertiary users and another part comes from the transmission grid operator (flexibility needs and settlement values). Do its nature, this data is classified as sensitive, since it can provide detailed energy profiles of residential and tertiary users and the grid data is protected by the TSO. Considering this, agreements are in place to protect all institutions involved, including the end-users, including consent forms attributing rights and responsibilities (RGPD) about the shared data. Lastly, the data is handled using the standard security patterns. All communications are secure and use the latest encryption patters for both transmission and storage. Users can exercise their RGPD rights via mobile app or email.

Taking all these points in consideration, it is impossible to provide open datasets of the data as-is, since it is sensitive and would go against RGPD and the EU guidelines on data privacy. However, a reflection can be made on making available anonymised and aggregated datasets for both types of residential and tertiary consumer data (building load profile and asset-specific load profile).

7.3 FULL-DEMO OPERATION PHASE RESULTS

This section captures the status and progress of System Use Case (SUC) implementation during the Full Demo Operation Phase (M22–M28) for the Portuguese Demo. For each SUC, key developments are outlined, including the specific actions undertaken, intermediate achievements, and alignment with the expected implementation steps and scenarios described in D2.3. This structured overview offers insight into the readiness and maturity of each SUC ahead of the upcoming demonstration cycles.

7.3.1 SUCs Implementation

This subsection presents the implementation progress of each System Use Case (SUC) as defined in D2.3 for the Portuguese Demo, highlighting the actions carried out during the Full Demo Operation Phase.

SUC-PT-01.01 CONNECT FLEXIBILITY PROVIDERS ACROSS THE DPP FLEXIBILITY VALUE CHAIN

| Section | Subsection | Input |
|---------------------|------------------------|---|
| Overview | SUC Summary | Full functionalities of the platform developed. Consumer aggregators' operational platforms, and BSP market simulator platform integrated. Laboratorial and connection reliability tests performed. |
| | Target(s) | <p>Design, development and roll out of the full functionalities of the EdgeConnect DPP enabler platform.</p> <p>Initial formulation and development of federated learning concepts and methodologies for energy consumption forecasting.</p> <p>Testing and validation of relevant components (such as the RECreation platform or parts of EdgeConnect) in lab environments or with data not necessarily from the final pilot.</p> <p>Baseline establishment for the relevant KPIs of Demo 5.</p> <p>Initial work on integrating interoperability enablers and setting up the necessary data flows between assets, the community platform, as defined by the SUCs. Integration and test completed and operational in the axis RECreation<->EdgeConnect<->Market Simulator.</p> <p>Preparation and setup of the necessary infrastructure for the pilot at the Demo 5 location.</p> <p>Lab testing of integration of residential household assets with HEMS solution.</p> |
| | Expected UC Milestones | <ul style="list-style-type: none"> Adaptation of EdgeConnect components. M14. |
| | Actions implemented | <p>For the milestone "Adaptation of EdgeConnect components" (M14), the corresponding activities are Steps 1-3 of Scenario 1 of SUC-PT-01.01. This initial phase (M1-M18) involved technological specification, development and deployment of the platform. Moreover, data collection and monitoring mechanisms using IoT sensors was integrated and set up. Activities in this phase included the implementation and final lab validation of EdgeConnect full functionalities relevant to the SUC.</p> |
| | Assumptions | All platforms and services, i.e., Edge Connect, Aggregator's operational platforms (for residential consumers at this stage) and market simulator are operational 24/7. |
| | Dependencies | <p>Service providers have their own technical platforms which they integrate with the interfaces for the DPP.</p> <p>Operators are active in the flexibility bidding process or hold automated mechanisms to analyse and issue bids.</p> <p>Consumers have internet connection and interface with the systems via their browsers, mobile applications, or other available interfaces/means.</p> |
| Requirements | | |

| | | |
|--------------------------------------|------------------------|--|
| | Risks | <p>Lack of consumer engagement. Lack of interoperability between components. Delays in development. Unavailability of connectivity among digital services.</p> <p>Flexibility potential below the lower allowed threshold as per SUC 2.</p> |
| Readiness | Deployment diagram | See figure above for an overview of the deployment status of each step of the SUCs and BUCs. |
| | Deployment preparation | <p>Requirements:</p> <ul style="list-style-type: none"> • Users to participate in the pilot • Assets integrated in household • Connectivity for the HEMS • RECreation community manager aggregator deployed and available. • EdgeConnect deployed and available. |
| | Deployment assessment | <p>Full demo operation phase was concluded successfully for the residential configuration. No risks were activated.</p> <p>EdgeConnect was properly developed, deployed and tested. Initial batch of participants were assembled, and first few assets were installed in the households.</p> |
| Validation Activities Summary | Previous cycle | <p>The pre-demo phase validated core functionalities of services and platforms. Moreover, it allowed an assessment of limitations during that phase, whose conclusions were included in the development cycle. Limitations in the operational design of bid structures were adjusted and integrated.</p> |
| | Current cycle | <p>EdgeConnect tested with full operating features and validated under the limits of the full operation phase.</p> <p>First batch of clients gathered.</p> <p>Integration of EdgeConnect with RECreation and Market Simulator. This flow is complete and validated.</p> <p>Integration of EdgeConnect with AMI role of the DSO</p> <p>Initial work towards the installation of flexible assets in the residential households of the clients. (30% complete)</p> |
| | Future cycle | <p>Large Scale deployment of all systems.</p> <p>For the Software platforms, scalability and high SLA compliance will be tested. Cybersecurity assessments will be done through SAST analysis and introduce any mitigations needed.</p> <p>Integrate the tertiary building aggregator and validate the operational conditions.</p> <p>Test services with initial batch of clients (beta testers).</p> <p>Continue the work towards gathering more clients.</p> <p>Install a wider variety and more quantity of assets.</p> |

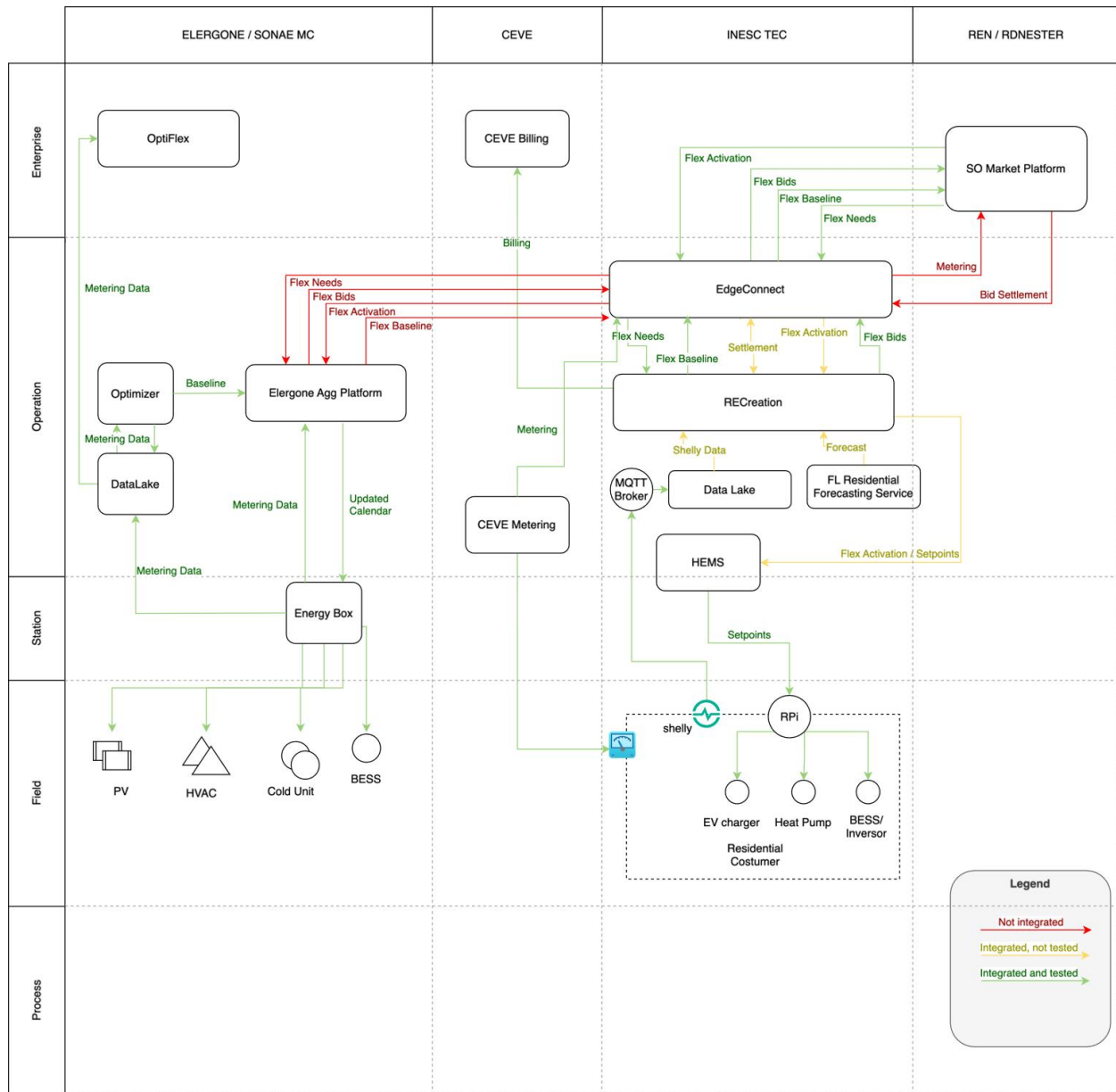


FIGURE 50: DEMO 5 READINESS STATUS

SUC-PT-01.02 ENABLE DATA EXCHANGE VIA DATA SPACES

| Section | Subsection | Input |
|----------|-------------|--|
| Overview | SUC Summary | SUC-PT-01.02 Enable Data Exchange via Data Spaces |
| | Target(s) | <p>Deployment of semantic interoperability connectors (Foreseen in M20).</p> <p>This target implies the crucial step of implementing the components required for enabling standardised and interoperable data exchange, which is the core function of the SUC-PT-01.02 within the data space context. Achieving this involves setting up the necessary infrastructure to allow different systems and platforms to understand and share data effectively by deploying these connectors.</p> |

| | | |
|--------------------------------------|------------------------|--|
| | Expected UC Milestones | Integration of a Dataspace connector at the data hub port of the pilot. This represents the integration of the EDC Dataspace connector in EdgeConnect. |
| | Actions implemented | Validation of the Dataspace connector integration conditions. Inclusion and integration of a siloed ⁴ data hub to act as provider of open flexibility data. |
| Requirements | Assumptions | A running version of the EDC Data Space connector, which can be deployed and tested in a stag environment |
| | Dependencies | EDC connector dependencies and specific client and technical specification of EdgeConnect. |
| | Risks | EdgeConnect data representation and data availability model shows not to be compatible with Data Spaces data sovereign data model and strategy, requiring extra middleware systems to impose data translations. |
| Readiness | Deployment diagram | - |
| | Deployment preparation | <p>Requirements:</p> <ul style="list-style-type: none"> • Users to participate in EdgeConnect deployed instance. • EDC reference implementation and specification available. |
| | Deployment assessment | <p>Pre-demo phase was concluded successfully. No risks were activated yet.</p> <p>EdgeConnect was properly developed and tested. Initial batch of participants were gathered, and first few assets were installed in the households.</p> <p>EDC documentation and stag deployment completed in INESC TEC's infrastructure.</p> |
| Validation Activities Summary | Previous cycle | The pre-demo phase validated the technical viability for th integration. |
| | Current cycle | An EDC dataspace connector was successfully deployed. Integration with INESC TEC's EDC client conducted and validated. Basic dataspace lifecycle actions conducted. |
| | Future cycle | Install of the DataHub components of EdgeConnect and install all data processing pipelines to feed data into the data hub. |

SUC-PT-01.03 MOBILIZING ENERGY FLEXIBILITY

| Section | Subsection | Input |
|-----------------|-------------|--|
| Overview | SUC Summary | SUC-PT -01.03 Mobilizing Energy Flexibility |
| | Target(s) | Validation of EdgeConnect's flexibility value chain applicability in pilot context |

⁴ Siloed is used in this context to represent a segregated data system, where operational data is kept separated from archived data, or data in an aggregated shape, outside of the critical data path in terms of business decision making.

| | | |
|--------------------------------------|------------------------|---|
| | Expected UC Milestones | Adaptation of EdgeConnect components. M14. |
| | Actions implemented | Integration of the bid modelling according to the IEC62325-2 standard and operational testing. |
| Requirements | Assumptions | The core operation and integration of EdgeConnect is done. |
| | Dependencies | Aggregators are integrated in the south interface of EdgeConnect / or have done in the past to feed data and bids with representative behaviour. |
| | Risks | Lack of interoperability between components. Delays in development. EDC ecosystem not ready or unavailable for testing |
| Readiness | Deployment diagram | - |
| | Deployment preparation | Requirements: EdgeConnect deployed in INESC TEC cloud Market Operator simulator operational. |
| | Deployment assessment | Pre-demo phase was concluded successfully. No risks were activated yet. Preliminary testing shows viability of the operation for the large-scale deployment. |
| Validation Activities Summary | Previous cycle | The pre-demo phase validate the necessary bin schemes and their data representations. |
| | Current cycle | EdgeConnect tested and core work towards large-scale deployment done. |
| | Future cycle | Validation of full features in large scale deployments. |

SUC-PT-01.04 ACTIVATION OF ENERGY FLEXIBILITY

| Section | Subsection | Input |
|-----------------|------------------------|--|
| Overview | SUC Summary | SUC-PT-01.04 Activation of Energy Flexibility |
| | Target(s) | Test EdgeConnect's flexibility dispatch module |
| | Expected UC Milestones | • Adaptation of EdgeConnect components. M14. |
| | Actions implemented | For the milestone "Adaptation of EdgeConnect components" (M14), the corresponding activities included in Scenario 1 of SUC-PT-01.04. These steps involve changes to accommodate a new type of flexibility market, in this case of TSOs, where previously an integration with DSO aligned markets was present. Moreover, besides the conceptual and direct integration changes according to IEC 62325 standard. |

| | | |
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| Requirements | Assumptions | The baseline operation and integration of EdgeConnect is done. Integration with Aggregator's operational platform is complete. |
| | Dependencies | Consumers are present in the areas where the FSPs operate in the operational database of edge connect, Data exchange has been enabled for all the actors participating in the use case. |
| | Risks | Impossibility to accommodate the existing operational and business data model of EdgeConnect against the required representations of IEC62325. |
| Readiness | Deployment diagram | - |
| | Deployment preparation | Requirements: EdgeConnect deployed in INESC TEC cloud Data modelling in operational database including flexibility zones to allow mock bids to be issued. |
| | Deployment assessment | Pre-demo phase was concluded successfully. No risks were activated yet. Preliminary tests for the integration of IEC62325 messaging was completed. Adjustments will be required to ensure conformity. |
| Validation Activities Summary | Previous cycle | The pre-demo phase demonstrated the lab testing with the south actors of EdgeConnect (Aggregators) and those on the north interface (market operator). |
| | Current cycle | EdgeConnect deployment in operational conditions. Assessment of technical loads and considerations for scalability of the environment. |
| | Future cycle | Validation under full demo operation conditions. Stress testing. |

SUC-PT-02.01 BIDDING & SELECTION

| Section | Subsection | Input |
|-----------------|-------------|---|
| Overview | SUC Summary | SUC-PT-02.01 Bidding & Selection Processes involved in soliciting bids from reserve capacity providers and selecting the most appropriate bid to maintain network stability and frequency regulation |
| | Target(s) | <ul style="list-style-type: none"> Develop and deploy the digital platform that allows bid submission and parsing. Implement the selection algorithm for each market time unit where a bid was submitted. Automate the execution of the selection algorithm according to expected timings of the market. |

| | | |
|--------------------------------------|------------------------|--|
| | Expected UC Milestones | <ul style="list-style-type: none"> Adaptation of EdgeConnect components: Done. Integration with demo stakeholder's digital platforms: Tested and continuous data exchange is up and running. Adoption of interoperability mechanisms: Standard IEC 62325 implemented. Adoption of market platform: Deployed, up and running. |
| | Actions implemented | Bidding functions improvement including parsing and error handling. Automation for executing the selection at the expected timings is also implemented and running. Continuous data exchange ongoing. |
| Requirements | Assumptions | The bids that are going to be submitted in the pilot are assumed indivisible and are, either, accepted or rejected as a whole. |
| | Dependencies | No dependencies. |
| | Risks | Development delays were identified as risks given the internal workload of the tasks responsible. Frequent status reviews are being carried out. |
| Readiness | Deployment diagram | Not available |
| | Deployment preparation | Market simulator's previous version with minimal functionalities deployed in cloud, up and running. Continuous deployment of new versions with improvements and new functionalities. |
| | Deployment assessment | Developments are periodically being carried out including improvements and new functionalities as data exchange is maintained up and running. |
| Validation Activities Summary | Previous cycle | Main functionalities and requirements were identified. Implementation started and initial internal tests were conducted. Main deployment and integration are expected in the next cycle. |
| | Current cycle | Main deployment and integration were carried out. Continuous data exchange is up and running. Constant revision on the status of the platform allows to maintain it live and minimal improvements have been identified which are promptly implemented and deployed in the cloud. |
| | Future cycle | Continuous maintenance of the platform and revision that all the functionalities work as expected. |

SUC-PT-02.02 AFRR/MFRR ACTIVATION

| Section | Subsection | Input |
|-----------------|-------------|--|
| Overview | SUC Summary | SUC-PT-02.02 aFRR/mFRR Activation |
| | Target(s) | Develop and deploy the algorithm that allows sending of activation files to the rest of partners in the pilot. |

| | | |
|--------------------------------------|------------------------|--|
| | | Automate the sending of activation according to expected timings of the market. |
| | Expected UC Milestones | <ul style="list-style-type: none"> Adaptation of EdgeConnect components: Done. Integration with demo stakeholder's digital platforms: Tested and continuous data exchange is up and running. Adoption of interoperability mechanisms: Standard IEC 62325 implemented. Adoption of market platform: Deployed, up and running. |
| | Actions implemented | Full development and deploy of activation process that involves creation of file, editing and sending to the corresponding partner. Automation was also implemented. |
| Requirements | Assumptions | Under an assumption of high tier SLA, the target endpoints in each partner are going to be always available and no recovery method is going to be implemented. |
| | Dependencies | The activation processes are only initiated after the gate closure time for a given market time unit. Additionally, the process is executed only when minimum one bid was submitted. |
| | Risks | <p>Development delays were identified as risks given the internal workload of the tasks responsible. Frequent status reviews are being carried out.</p> <p>Communication failures among the platforms could damage the pilot execution. Coordination sessions among the partners are expected to happen.</p> |
| Readiness | Deployment diagram | - |
| | Deployment preparation | Market simulator's previous version with minimal functionalities deployed in cloud, up and running. Continuous deployment of new versions with improvements and new functionalities. |
| | Deployment assessment | Developments are periodically being carried out including improvements and new functionalities as data exchange is maintained up and running. |
| Validation Activities Summary | Previous cycle | <p>Main functionalities and requirements were identified. Implementation started and initial internal tests were conducted.</p> <p>Main deployment and integration are expected in the next cycle.</p> |
| | Current cycle | Main deployment and integration were carried out. Continuous data exchange is up and running. Constant revision on the status of the platform allows to maintain it live and minimal improvements have been identified which are promptly implemented and deployed in the cloud. |
| | Future cycle | Continuous maintenance of the platform and revision that all the functionalities work as expected. |

SUC-PT-02.03 AFRR/MFRR SETTLEMENT

| Section | Subsection | Input |
|---------------------|------------------------|---|
| Overview | SUC Summary | SUC-PT-02.03 aFRR/mFRR Settlement |
| | Target(s) | <ul style="list-style-type: none"> Develop and deploy the digital platform that allows baseline and metering submission which are later used for settlement calculations. Implement settlement calculations for a time frame of one week. Automate the execution of settlement calculations according to expected timings of the market and agreements with other partners in the pilot. |
| | Expected UC Milestones | <ul style="list-style-type: none"> Adaptation of EdgeConnect components: Done. Integration with demo stakeholder's digital platforms: Tested and continuous data exchange is up and running. Adoption of interoperability mechanisms: Standard IEC 62325 implemented. Adoption of market platform: Deployed, up and running. |
| | Actions implemented | <p>Settlement calculation algorithm was developed by using mock data of baseline files, metering data and the results of the market cleared for various test bids. Tests were carried out internally.</p> <p>Deployment of settlement-related endpoints to receive baseline and metering data from other partners in the pilot.</p> |
| Requirements | Assumptions | Measured data from each BSP's associated measuring point must be collected and available. |
| | Dependencies | Dependencies on other pilot's partners for providing the measurements of their assets in order to calculate and contrast the bids offered, bids selected, and power effectively delivered or consumed. |
| | Risks | Availability of the measurement data is a risk that has been mitigated by constant updates with the partners responsible for the collection and communication of that data. |
| Readiness | Deployment diagram | Not available |
| | Deployment preparation | Market simulator's previous version with minimal functionalities deployed in cloud, up and running. Continuous deployment of new versions with improvements and new functionalities. |
| | Deployment assessment | Developments are periodically being carried out including improvements and new functionalities as data exchange is maintained up and running. |

| | | |
|--------------------------------------|----------------|---|
| Validation Activities Summary | Previous cycle | <p>Baseline calculation definition for settlement calculations was defined.</p> <p>Settlement calculations processes were defined and implementation started.</p> |
| | Current cycle | <p>Implementation of settlement calculations is done and deployed. Testing is ongoing.</p> <p>Automation of execution of the settlement calculation is also up and running.</p> <p>Main deployment and integration were carried out. Continuous data exchange is up and running. Constant revision on the status of the platform allows to maintain it live and minimal improvements have been identified which are promptly implemented and deployed in the cloud.</p> |
| | Future cycle | <p>Final tests of the settlement process are expected.</p> <p>Continuous maintenance of the platform and revision that all the functionalities work as expected.</p> |

SUC-PT-03.01 INTEGRATE FLEXIBLE ASSETS FROM COMMERCIAL BUILDINGS

| Section | Subsection | Input |
|---------------------|------------------------|---|
| Overview | SUC Summary | <p>SUC-PT-03.1 Integrate flexible assets from commercial buildings</p> <p>Architecture and data flows at building level and cloud level that allows integration of flexible assets data.</p> |
| | Target(s) | Integrate flexible assets from commercial buildings |
| | Expected UC Milestones | <p>EnergyBox installation</p> <p>Integration of assets with EnergyBox</p> <p>Integration of assets (through EnergyBox) with OptiFlex and EdgeConnect</p> |
| | Actions implemented | <p>Validation and Creation of VLANs</p> <p>Validation of Firewall Rules and Accesses</p> |
| Requirements | Assumptions | <p>The reserve resources predicted to be integrated are: batteries and PV. All reserve resources should be tested to validate their integration with energybox.</p> <p>All resource resources and energybox should be connected to the same VLAN.</p> |
| | Dependencies | Dependence on Third Party suppliers (including technical capacity and availability) for the resource assets integration. |
| | Risks | Possible overlay between the technical aggregator and EdgeConnect Platform. |
| Readiness | Deployment diagram | - |

| | | |
|--------------------------------------|------------------------|--|
| | Deployment preparation | <p>Guarantee that all assets and EnergyBox are connected to the same VLAN.</p> <p>Equipment integration within VLAN (EnergyBox and resource assets)</p> <p>Assets integration with Enterprise Server, Technical Aggregator and EdgeConnect</p> |
| | Deployment assessment | VLAN 95 created and EnergyBox installed in the 3 pilot stores. |
| Validation Activities Summary | Previous cycle | Creation of VLAN and connection of flexible assets. |
| | Current cycle | <p>Guarantee that all assets and EnergyBox are connected to the same VLAN.</p> <p>Equipment integration within VLAN (EnergyBox and resource assets)</p> <p>Assets integration with Enterprise Server, Technical Aggregator and EdgeConnect</p> |
| | Future cycle | <p>Integration with technical aggregator</p> <p>Pre-qualification of assets in EdgeConnect</p> <p>Validation of the bilateral agreement mechanism</p> |

SUC-PT-03.02 DEFAULT VALORISATION SCENARIO BASED ON PRICE EDGING

| Section | Subsection | Input |
|---------------------|------------------------|---|
| Overview | SUC Summary | <p>SUC-PT-03.2 Default valorisation scenario based on price hedging</p> <p>Creation of a default valorisation scenario based on price hedging and targeting cost savings.</p> |
| | Target(s) | Create default valorisation scenario |
| | Expected UC Milestones | <p>EnergyBox installed and flexible assets are controlled by it</p> <p>Integration of Bamboo Platform.</p> <p>Communication between EnergyBox and Bamboo Platform</p> |
| | Actions implemented | EnergyBox installed and controlling the flexible assets |
| Requirements | Assumptions | <p>The forecasting tools have historical data to be loaded.</p> <p>The algorithms will have access to ERP data (Energy provider contractual data).</p> <p>The main goal of algorithm will be cost savings based on price hedging.</p> |
| | Dependencies | Dependence on Third Party suppliers (including technical capacity and availability) for the resource assets integration. |
| | Risks | Possible overlay between the technical aggregator and EdgeConnect Platform. |

| | | |
|--------------------------------------|------------------------|--|
| Readiness | Deployment diagram | - |
| | Deployment preparation | n/a |
| | Deployment assessment | n/a |
| Validation Activities Summary | Previous cycle | This is the first cycle. |
| | Current cycle | n/a |
| | Future cycle | Integration with technical aggregator Pre-qualification of assets in EdgeConnect Validation of the bilateral agreement mechanism |

SUC-PT-03.03 TSO VALORISATION SCENARIO

| Section | Subsection | Input |
|---------------------|------------------------|---|
| Overview | SUC Summary | SUC-PT-03.3 TSO valorisation Valorisation of flexibility |
| | Target(s) | Integrate flexible assets from commercial buildings |
| | Expected UC Milestones | Connect Bamboo Platform to EdgeConnect |
| | Actions implemented | - |
| Requirements | Assumptions | There is a default valorisation scenario already created, for comparing purposes. When the bid is submitted, the prosumer is already committed to provide the flexibility service. |
| | Dependencies | Dependence on Third Party suppliers (including technical capacity and availability) for the resource assets integration. |
| | Risks | Possible overlay between the technical aggregator and EdgeConnect Platform. |
| Readiness | Deployment diagram | - |
| | Deployment preparation | n/a |

| | | |
|--------------------------------------|-----------------------|--|
| | Deployment assessment | n/a |
| Validation Activities Summary | Previous cycle | This is the first cycle. |
| | Current cycle | n/a |
| | Future cycle | Integration with technical aggregator Pre-qualification of assets in EdgeConnect Validation of the bilateral agreement mechanism |

The following WP3 services being utilised in the Portuguese demo and their status during the Full-Demo Phase is presented below:

Service 4.1: EDGECONNECT

The EdgeConnect platform was first deployed in INESC TEC's cloud infrastructure to validate the operation of core functionalities of the platform. A first check of service availability was performed to ensure the deployment of the components correctly gained access to the two databases required, i.e., one for operational data and the other business information, namely the identification of stakeholders. After the technical availability tests for the platform, the tests provided in each SUC were performed through a mix of issued requests performed through a postman collection that issued individual REST-based requests to EdgeConnect's backend system, and the direct usage of the GUI of the platform. Technical integration tests with the RECreation and market operator platforms were also conducted, where the latter system took the role of an aggregator receiving flexibility needs, issuing flexibility bids and collecting flexibility activation requests. The market simulator acted as the market operator, issuing flexibility bids, collecting bids and selecting the winning bids. The edgeConnect platform was also fitted with bilateral agreement mechanism for Aggregators. This service enables aggregators to undergo an association agreement to enable joint and common bids to the market. With this approach, joint terms are agreed to ensure that flexibility capacity is not left outside the market (often due to limitations of the aggregator with less capacity to meet the lower bid interval).

Service 4.5: RECreation

A staging instance of RECreation has been deployed in INESC TEC's cloud infrastructure to validate the integrations with other platforms. Currently, RECreation is fully integrated with EdgeConnect, receiving the household consumption data for onboarded end-users and its integration with HEMS is underway, with end-to-end tests already done for the heat pump asset.

Service 3.6: HEMS

A staging instance of HEMS has been deployed in INESC TEC's cloud infrastructure, as well as an initial version of the edge gateway, which has been fully lab tested. The HEMS is collecting DER specific consumption data, telemetry and other relevant measurements and using them to forecast the behavior of said DER to aid a more accurate flexibility optimisation procedure. The edge gateway has full end-to-end integrations tested with the following assets: heat pumps, EV chargers and inverters.

Service 2.2: Federated Learning

An initial testing instance of the Federated Learning approach for load forecasting has been deployed both in INESC TEC’s cloud infrastructure and on the edge, using the HEMS edge gateways. This approach uses the household consumption data to train a privacy-preserving model to accurately forecast their flexibility baseline.

Service 4.3: Real-Time Reserve Market Simulator

During the current implementation cycle, the Real-Time Reserve Market Simulator received major cloud deployments allowing for integration with the other platforms from the pilot. One major obstacle encountered was that the data source from public ENTSO-E Transparency Platform was changed both in format and location. The previous impacted the developments as new algorithms to retrieve, treat and consume data were required to be developed. This makes it clear that homogenisation and standardisation of data is a great advantage in terms of data sources and data usage. After that was solved, continuous testing and data exchange has been done among the platforms. Minimum improvements have been required, and constant maintenance of the infrastructure has been done.

Service 4.9: OPTIFLEX

In this current implementation cycle, it was possible to install and connect the flexible assets in the buildings. They are connected in the same VLAN to enable the connection between EnergyBox and those assets. A platform to visualise energy data (metering data) was created. In this EnergyBox platform, it is possible to see the consumption and production data of the building and by asset and compare the values of the actual day with previous day. It is also possible to control those asset, based on the saving costs, and visualise the calendars applied in the same platform.

7.3.2 Milestones and Progress

This subsection revisits the internal milestones identified in D5.1 and assesses their status, noting any updates, delays, or partial completions observed during the Full-Demo Phase. The information is presented in the following table, which maps each milestone to the corresponding implementation steps and indicates the extent of progress achieved for the Finnish Demo.

TABLE 24: PROGRESS ON DEMO 5 INTERNAL MILESTONES LINKED TO THE IMPLEMENTATION OF SYSTEM USE CASES (SUCS) DURING THE FULL-DEMO PHASE

| Internal Milestone | M | PT-01.01 | PT-01.02 | PT-01.03 | PT-01.04 | PT-02.01 | PT-02.02 | PT-02.03 | PT-03.1 | PT-03.2 | PT-03.3 |
|--------------------------------------|----|------------------------------------|-----------------------|-----------------------|-----------------------|----------|----------|----------|--------------|---------|---------|
| Adaptation of EdgeConnect components | 14 | Sc.1, 2 and 3 developed and tested | First tests conducted | First tests conducted | First tests conducted | - | - | - | - | - | - |
| Number of reserve resources | 16 | | | | | | | | Step 1 and 2 | n/a | n/a |

| | | | | | | | | | | | |
|---|----|--|---|--|---|-------------------------------------|-------------------------------------|---|--------|-----------------------|-----|
| Data availability during pilot | 18 | | | | | | | | Step 3 | n/a | n/a |
| Number of reserve resources enrolled in DPP | 20 | | | | | | | | Step 4 | n/a | n/a |
| Monetary impact | 20 | | | | | | | | n/a | Step 10 | n/a |
| Variation in energy consumption | 20 | | | | | | | | n/a | Step 1, 2, 3, 4 and 5 | n/a |
| Valorisation scenarios generated | 20 | | | | | | | | n/a | Step 6 | n/a |
| Adoption of market platform | 24 | Sc.1 and 2 developed and tested | First tests conducted. | First tests conducted. | First tests conducted. | All steps completed and integrated. | All steps completed and integrated. | All steps developed. Integration and testing are ongoing. | | | |
| Adoption of interoperability mechanisms | 24 | Not started | Sc. 1 developed and tested | Not started | Not related | All steps completed and integrated. | All steps completed and integrated. | All steps developed. Integration and testing are ongoing. | | | |
| Completion of Full Demo | 28 | All steps completed in terms of integration. Validated with subs | Sc. 1 and 2 implemented. Integration tests under way with EDC MVD | Sc. 1 and 2 implemented. Validated with subset of end-users. | Sc. 1 and 2 implemented. Validated with all relevant assets in lab enviro | | | | | | |

| | | | | | | | | | | |
|--|--|------------------------|--|--|------|--|--|--|--|--|
| | | et of end- users | | | ment | | | | | |
|--|--|------------------------|--|--|------|--|--|--|--|--|

7.4 FULL-DEMO EVALUATION

7.4.1 Requirements Evaluation

The following section presents the requirement for each SUC, which was initially introduced in D5.1 including the description, acceptance criteria, and assigned testing partner. An additional column now captures the progress status recorded during the Full-Demo Phase, allowing a direct comparison between the targets set in D5.1 and the results achieved to date.

SUC-PT-01.01 CONNECT FLEXIBILITY PROVIDERS ACROSS THE DPP FLEXIBILITY VALUE CHAIN

| Req | Description | Acceptance Criteria | Progress |
|-------|--|---|--|
| F.1 | Login in the DPP | Login is successful | Login is successful |
| F.2 | Registration in the DPP | Registration completes and user can login | Registration form is operational, and user gets registered |
| F.3 | Access to the service | The DPP is accessible to pilot partners | The platform's local URL is available and reachable. |
| F.4 | Consumer/prosumer energy consumption data | Consumer data is accessible via the DPP | Real metering data is consulted in EdgeConnect as part of a consumer profile. |
| F.4-1 | Consumer/prosumer PV production data | PV production data is accessible via the DPP | Dummy asset data is available, but live data feed-in is not yet available. |
| F.4-2 | Consumer/prosumer geographical coordinates for the energy consumed | Consumer profile information is available in the DPP. | Profile information is available. |
| F.5 | Consumer flexible assets available | Consumer profile information is available in the DPP. | Consumer profile displays available assets |
| F.6 | Digital service available on the DPP platform | The DPP shows each digital service. | The service catalogue displays available services. |
| F.7 | Service provider controls assets of subscribed consumers/prosumers | The DPP shows asset's information from consumers in the context of a service. | Under testing. |
| F.8 | Consumers/prosumers can share their flexibility capacity with third-party services | Consumers have access to a service that allows them to share their data. | Consumer profile includes data authorisations that can be granted and revoked. |
| F.9 | Consumers/prosumers have a profile that characterises them | The DPP holds a profile information for each profile. | Service providers can check consumer profiles and do an advanced search by several criteria. |
| F.11 | Unique ID for grid users and aggregator | Each user profile holds a unique identifier. | Upon onboarding in the platform |
| F.12 | Request metadata sent to semantic system | Verify that metadata arrives at the metadata broker. | Under development |
| F.13 | Consumer is subscribed to service | Consumer identifier is available as onboarded in the service profile. | For real consumer accounts that onboarded a given service, they become visible in the service admin page |

| | | | |
|------|--|--|--|
| F.14 | Access to consumer's geographical location | Consumer's location of assets is available to grid stakeholders. | The consumer relative grid connection identifier is included as information for service providers. |
|------|--|--|--|

SUC-PT-01.02 ENABLE DATA EXCHANGE VIA DATA SPACES

| Req | Description | Acceptance Criteria | Progress |
|-----|---|---|---|
| F.1 | Asset is represented in an interoperable format | Each data asset is mapped in the metadata broker. | Under testing |
| F.2 | Identity certificates issued in X.509 format | Each user holds an identity certificate for authentication. | This requirement was replaced by eIDAS identity schemes |

SUC-PT-01.03 MOBILIZING ENERGY FLEXIBILITY

| Req | Description | Acceptance Criteria | Progress |
|------|--|--|--|
| F.1 | Login in the DPP | Login is successful | Login is successful |
| F.2 | Registration in the DPP | Registration completes and user can login | Registration form is operational, and user gets registered |
| F.3 | Access to the service | The DPP is accessible to pilot partners | The platform's public URL is available and reachable. |
| F.4 | Consumer flexible assets available | Consumer data is accessible via the DPP | Consumer profile displays available assets |
| F.5 | Digital service available on the DPP platform | The DPP shows each digital service. | The service catalogue displays available services. |
| F.6 | Service provider controls assets of subscribed consumers/prosumers | The DPP shows asset's information from consumers and can change their preferences. | Consumer profiles show assets available. |
| F.7 | Consumers/prosumers can share their flexibility capacity with third-party services | Consumers have access to a service that allows them to share their data. | Consumer profile includes data authorisations that can be granted and revoked. |
| F.8 | Consumers/prosumers have a profile that characterises them | The DPP holds a profile information for each profile. | Service providers can check consumer profiles and do an advanced search by several criteria. |
| F.10 | Request metadata sent to semantic system | Verify that metadata arrives at the metadata broker. | Tested, not yet live. |
| F.11 | Consumer is subscribed to service | Consumer identifier is available as onboarded in the service profile. | Integrated and tested |
| F.12 | Service contract between stakeholders on the DPP platform | A digital contract for the data being exchange exists and is valid. | In place for Aggregators in scope of bilateral agreements. |
| F.13 | Permission to activate/deactivate the subscription of a service | Each user can enable/disable the permission to share data. | Integrated. |

SUC-PT-01.04 ACTIVATION OF ENERGY FLEXIBILITY

| Req | Description | Acceptance Criteria | Progress |
|-------|--|--|---|
| F.1 | Login in the DPP | Login is successful | Login is successful |
| F.2 | Consumer/prosumer energy consumption data | Metering data for the consumer can be fetched. | Real metering data is consulted in EdgeConnect as part of a consumer profile. |
| F.2-1 | Consumer/prosumer PV production data | PV production data can be fetched. | Representative asset data is available, but live data feed-in is not yet available. |
| F.2-2 | Consumer/prosumer geographical coordinates for the energy consumed | Consumer's assets coordinates are available. | Profile information is available. |

| | | | |
|-----|--|--|--|
| F.3 | Digital service available on the DPP platform | The DPP shows each digital service. | The service catalogue displays available services. |
| F.4 | Service provider controls assets of subscribed consumers/prosumers | The DPP shows asset information from consumers and can change their preferences. | Implemented but not yet deployed for testing in operational conditions |
| F.6 | Service contract between stakeholders on the DPP platform | A digital contract for the data being exchanged exists and is valid. | In place for Aggregators in scope of bilateral agreements. |

SUC-PT-02.01 BIDDING & SELECTION

| Req | Description | Acceptance Criteria | Progress |
|--------|-----------------------------------|---|------------------------------|
| D.2 | Validation of data exchanges | All data reception must be notified on each data exchange | Completed. |
| Conf.2 | aFRR product configuration | Minimum bid size: 0.1 MW Bid granularity: 0.01 MW Price of the bid: €/MWh, with resolution of 0.01 €/MWh | Development ongoing. |
| Conf.3 | mFRR product configuration | Minimum bid size: 0.1 MW Bid granularity: 0.01 MW Price of the bid: €/MWh, with resolution of 0.01 €/MWh | Completed. |
| QoS.3 | Availability of information flows | 99.9% + availability – Measured on the number of connections requested due to the on-demand nature of the pilot | Completed. Not measured yet. |

SUC-PT-02.02 AFRR/MFRR ACTIVATION

| Req | Description | Acceptance Criteria | Progress |
|-------|-----------------------------------|---|------------------------------|
| D.2 | Validation of data exchanges | All data reception must be notified on each data exchange | Completed. |
| QoS.3 | Availability of information flows | 99.9% + availability – Measured on the number of connections requested due to the on-demand nature of the pilot | Completed. Not measured yet. |
| QoS.4 | Elapsed time of data exchange | Elapsed time response requirements for exchanging data from 1-2 seconds | Completed. Not measured yet. |

SUC-PT-02.03 AFRR/MFRR SETTLEMENT

| Req | Description | Acceptance Criteria | Progress |
|-------|-----------------------------------|---|------------------------------|
| D.2 | Validation of data exchanges | All data reception must be notified on each data exchange | Completed. |
| QoS.3 | Availability of information flows | 99.9% + availability – Measured on the number of connections requested due to the on-demand nature of the pilot | Completed. Not measured yet. |
| QoS.4 | Elapsed time of data exchange | Elapsed time response requirements for exchanging data from 1-2 seconds | Completed. Not measured yet. |

SUC-PT-03.01 INTEGRATE FLEXIBLE ASSETS FROM COMMERCIAL BUILDINGS

| Req | Description | Acceptance Criteria | Progress |
|-------------------------|---|---|------------|
| CONN-1 VLAN | All assets connected to the same VLAN within the building | Connectivity within the defined VLAN | Completed. |
| CONN-2 Variable binding | Variables mapped and binded into the EnergyBox | Validate variables values in EnergyBox Platform | Completed. |

| | | | |
|------------------------------------|--|--|--|
| CONN-3 Buildings mapping | Buildings data must be mapped as well as its assets | Validate buildings information with MC tools | Completed. |
| CONN-4 Internet connection | Assets shall have secure and stable connection to the internet | Validate internet connection in the store | Completed. |
| GPDR-1 Data protection and privacy | Applicable data protection and privacy rules must be fulfilled | Validate with MC specified teams | Under test, Report in large-scale operation phase. |

SUC-PT-03.02 DEFAULT VALORISATION SCENARIO BASED ON PRICE HEDGING

| Req | Description | Acceptance Criteria | Progress |
|-------------------------------------|---|---|------------------------|
| CONN-5 Bamboo | EnergyBox connected with Bamboo | All data from flexible assets available to Bamboo | Under accuracy testing |
| CONN-6 Data | Commercial Energy Data shared with Bamboo | All data related to energy contracts | To be tested later |
| CONN-7 Scenario default and control | Produce scenario default | Validate that flexible assets are working according with it | To be tested later |

SUC-PT-03.03 TSO VALORISATION SCENARIO

| Req | Description | Acceptance Criteria | Progress |
|-------------------|---|-----------------------------------|--------------------|
| CONN-8 Connection | Guarantee communication between Bamboo and Edge Connect | Communication via API, bidirectly | To be tested later |

7.4.2 KPIs Progress

The KPIs to be measured by the Portuguese demo and their progress upon the end of the Full-Demo Phase is presented in the table below.

TABLE 25: DEMO 5 KPIS PROGRESS (M28)

| ID | KPIs | Baseline | Pre-Demo (M18) | Progress (M28)* |
|-------------|--|----------|----------------|-----------------|
| K-PT-01.1-1 | Number of community participants | n/a | n/a | 25 |
| K-PT-01.1-2 | Number of flexible assets registered | 15 | n/a | 32 |
| K-PT-01.1-3 | Different types of IoT/edge devices to be exploited in Demo Areas | 2 | n/a | 4 |
| K-PT-01.1-4 | Users involved in the pilot | n/a | 12 | 12 |
| K-PT-01.1-5 | % Of planned usage of HEDGE-IoT tools/data services (e.g., transactions, periodicity) in field demos | n/a | n/a | n/a |
| K-PT-01.1-6 | Increased RES and IoT deployment for providing flexibility services | 30 | n/a | 1118.669 |

*KPIs will be measured once all technical deployment is operational. The value 'n/a' under the progress column indicates that no measurable data has been collected during the full-demo phase for the respective KPI.

| | | | | |
|-------------|--|---------|-----|-----|
| K-PT-01.1-7 | IoT/Edge/Fog sites uptime and availability | 1 Month | n/a | n/a |
| K-PT-01.1-8 | Increased RES investments from residential users firmed with DERs enable by IoT | n/a | n/a | n/a |
| K-PT-01.2-1 | Number of services onboarded using the connector | 2 | n/a | 2 |
| K-PT-01.2-2 | Number of data assets published | 10 | n/a | n/a |
| K-PT-01.2-3 | Number of transactions | n/a | n/a | n/a |
| K-PT-01.2-4 | Real-time data sharing among stakeholders | n/a | n/a | n/a |
| K-PT-01.3-1 | Registered participants in flex services | n/a | n/a | n/a |
| K-PT-01.3-2 | Number of assets to provide flexibility | 10% | n/a | n/a |
| K-PT-01.3-3 | Differentiated incentives to consumers | n/a | n/a | n/a |
| K-PT-01.4-1 | End-users' benefits by offering flexibility services | n/a | n/a | n/a |
| K-PT-01.4-2 | Flexibility unlocked and transacted in markets | n/a | n/a | n/a |
| K-PT-01.4-3 | Number of consumers engaged with flexibility services | n/a | n/a | n/a |
| K-PT-02.1-1 | Increased flexibility incorporation enabled by IoT/Edge technologies for grid security | n/a | n/a | n/a |
| K-PT-02.2-1 | Faster application response time | n/a | n/a | n/a |
| K-PT-02.3-1 | Flexibility delivery accuracy | n/a | n/a | n/a |
| K-PT-02.3-2 | Discrepancy rate | n/a | n/a | n/a |
| K-PT-02.3-3 | Correction Factor/Penalty rate | n/a | n/a | n/a |
| K-PT-03.1-1 | Number of reserve resources | n/a | 10 | 2 |
| K-PT-03.1-2 | Data availability during pilot | n/a | n/a | n/a |
| K-PT-03.1-3 | Number of reserve resources enrolled in DPP | n/a | n/a | n/a |
| K-PT-03.2-1 | Monetary impact | n/a | n/a | n/a |
| K-PT-03.2-2 | Valorisation scenarios generated | n/a | n/a | n/a |
| K-PT-03.2-3 | Valorisation scenario activated | n/a | n/a | n/a |
| K-PT-03.2-4 | Schedule deviation | n/a | n/a | n/a |

| | | | | |
|-------------|----------------------------------|------------------|---|---|
| K-PT-03.3-1 | TSO requests | 5 requests/month | 0 | 0 |
| K-PT-03.3-2 | % of activations of TSO requests | n/a | 0 | 0 |
| K-PT-03.3-3 | TSO requests valorisation | €1,000/month | 0 | 0 |

7.4.3 Risks and Proposed Mitigation Actions

The Portuguese pilot conducts a risk impact assessment split into: hardware, software and integration of software systems and the implementation of disruptive protocols.

Currently the pilot still requires the deployment of some key assets, namely Electric Vehicle chargers and the installation of HEMS systems for control of heat pumps in the residential dimension of the pilot. The trigger effect linked is not linked with the hardware availability, nor the install locations, but rather with the conclusion of the individual tests and scheduling of deployment. On the commercial dimension, the Energy Box (i.e., BEMS equivalent system) is currently on roll-out for the tertiary buildings included in the pilot. The triggering effect to this risk is also time to complete all the procurement and internal deployment process.

On the software and integration between software systems, all core software components, such as the EdgeConnect, or the market simulator are operational under TRL6 conditions at the time of this deliverable. All interoperable interfaces are established and pre-tested based on the target role. This means that, for instance, although the integration between EdgeConnect and the tertiary building BEMS systems is not complete, the same Edge Interface is validated and tested with the residential HEMS. Given the interoperability and conceptual equality of the interfaces, there is no risk being signalled. The interoperable market interface between EdgeConnect and the market simulator is also established and operationally running for more than 45 days as this time.

The development of disruptive protocols and the integration with the other components identified one risk with the prototyping of the aFRR mechanism. Pilot limitations prevent the pilot to deploy the expected transport of the linked data protocol, which requires SCADA systems between the system operator and the flexible. To mitigate the risk of absence of results, the Portuguese pilot will adopt a hybrid development, assembling that data protocol, integrating it with the market simulator and EdgeConnect system, but doing with on top of an HTTP base overlay over TCP/IP protocol. The team will measure the average timing of messages over the asynchronous transport to validate how distant the average delivery time is from the standard and regulated 4 second interval between commanding the activation of an asset and the delivery of the activation confirmation by the asset. The unfeasibility of the hardware needs active this risk. The mitigation action will partially solve the risk, but it will open a validation of alternative and less costly option.

8 DEMO 6 – ENHANCED LOCAL FLEXIBILITY SERVICES FOR IMPROVED ASSET LIFETIME [SLOVENIA]

8.1 FULL-DEMO PHASE ACTIVITIES SUMMARY

This section presents a structured summary of the activities that the Slovenian Demo conducted during the Full Demo Operation Phase (M22-M28). It follows the demo deployment template introduced deliverable D5.1, which functions as a reference for monitoring the development of each demonstrator. The status of the Full Demo Operation Phase targets, the WP3 services utilised, and the key stakeholders involved during this phase are all detailed in below.

TABLE 26: DEMO 5 FULL DEMO OPERATION PHASE DEPLOYMENT STATUS

| Section | Subsection | Input |
|----------------|---------------------------------------|---|
| Summary | Pre-Demo Phase Target | The focus in Full-Demo phase is to test all services and IoT devices in a laboratory environment, using dummy data. |
| | Status Summary | <ul style="list-style-type: none"> IoT device has been tested in laboratory environment Anomaly detection algorithm 90% done with dummy data Forecast algorithm 90% done with dummy data Detection of DER in LV grid 30% done Data connection between devices is done theoretically DTR-DLR algorithm on edge has been tested in lab environment Working on weather forecast algorithm |
| | Services Used (from WP3) | <ul style="list-style-type: none"> - Service 3.1 – Enhanced Network Management and Planning - Service 3.2 – DTR-DLR on Edge |
| | Stakeholders involved during Pre-Demo | <p>Actors involved in the pre-demo phase:</p> <p>DSO, Metering Centre, Ambient temperature sensor, TSO, Smart meters, CIM model, Data analyst, Service provider, Environment model, Semantic model of substation</p> |

8.2 INFRASTRUCTURE, ASSETS AND DATA AVAILABILITY

Based, on the demo-deployment template (Annex I), a consolidated snapshot of the infrastructure and assets mobilised during the Full Demo Operation Phase is provided in the following table for the Slovenian demo. Each asset is accompanied by its technical description, deployment level, use status in months 22–28, and the WP3 service to which it pertains.

TABLE 27: SUMMARY OF FINNISH DEMO INFRASTRUCTURE AND ASSETS DEPLOYED DURING THE FULL DEMO OPERATION PHASE

| Asset | Description | Deployment Level | Used during Full demo | Under which WP3 service |
|----------------------------|--|--|-----------------------|-------------------------|
| DTR/DLR IoT devices | IoT devices in DSO secondary transformer stations and TSO power lines with edge processing capabilities and Thermal Rating calculation | Tested in laboratory by M16 Deployment by M20 | Yes | Service 3.2 |
| Metering centre in DSO | DSO metering centre in secondary transformer substation providing data needed for DTR calculation | Already deployed within the DSO grid. First connection with IoT device by M18 | Yes | Service 3.2 |
| Power quality meter in TSO | TSO PQ meter in overhead power lines providing data for DLR calculation | Already deployed in within TSO grid. First connection with IoT device by M18 | Yes | Service 3.2 |
| Weather data sensors | Sensors at the edge measuring ambient temperature, used for DTR calculation | Tested in lab environments M16. Full deployment by M20 | Yes | Service 3.2 |
| Weather station | Weather station in TSO grid providing data that is used for DLR calculation | Already deployed in TSO grid. First connection by M18 | Yes | Service 3.2 |
| Validation sensors | Temperature sensors at the edge used for DTR/DLR calculation validation | Tested in laboratory by M18. First deployment in M18-M20 | Yes | Service 3.2 |
| Sumo Cloud Database | Cloud storage for saving DTR data and data used in the calculation | First connection by M18. Deployed by M20 | Yes | Service 3.2 |
| PowerCIM | Semantic model of secondary transformer substation including DTR and MC data. Additionally, it will include a database where data will be saved. | First deployment with preliminary data by M18. Full scale by M22 | Yes | - |
| ML/AI algorithms | Three ML algorithms used for: Anomaly detection in LV grid Forecasting of electrical measurements in the secondary transformer DER detection on the LV grid | First tests with dummy data finished by M16. Deployed with real data by M22-M24 after the integration of IoT devices and full deployment of PowerCIM | Yes | Service 3.1 |

The following table summarises the datasets relevant to the Full Demo Operation Demo Phase, indicating their availability, whether they were used during this period and their linkage to the corresponding WP3 technological enablers.

TABLE 28: DEMO 5: OVERVIEW OF DATASETS RELEVANT TO THE FULL DEMO OPERATION PHASE

| Data Description | Used during Demo Phase | Under which WP3 service |
|--|---|---|
| Distribution transformer current measurements | Real time data from MC are used on 5 Transformer station and directly. The data is directly available to IoT device via ethernet connection | Service 3.2 (Current data is used for DTR calculation on edge.) |
| Distribution Transformer voltage measurements | Data available for transformers with DTR measurements. | Service 3.1 (Voltage data is used for ML algorithms) |
| Distribution transformer active power measurements | Data available for transformers with DTR measurements. | Service 3.1 (Active power data is used for ML algorithms.) |
| Distribution transformer reactive power measurements | Data available for transformers with DTR measurements. | Service 3.1 (Reactive power data is used for ML algorithms.) |
| DTR data for distribution transformer | Data available for transformers with DTR measurements. | Service 3.2 (DTR data is the output of Service 3.2) |
| Ambient temperature data | Data available for transformers with DTR measurements. | Service 3.2 (Ambient temperature sensors will be used for DTR calculation) |
| DLR data for transmission power lines | Data available for one transmission power line. | Service 3.2 (DLR data is the output of Service 3.2) |
| Transmission power line current measurements | Data available for one transmission power line. | Service 3.2 (Current data is used for DTR calculation on edge.) |
| Weather data for DLR calculation | Full data available for one weather station | Service 3.2 (Weather data is used for DLR calculation) |
| DSO secondary substation CIM model with DTR data | Data available for transformers with DTR calculation | Service 3.1 (ML algorithms will gather data from PowerCIM where the CIM model of DTR will be saved) |

OPEN DATA AVAILABILITY

The Slovenian demo is currently considering which type of data can be made available as open data upon restrictions and availability.

8.3 FULL-DEMO OPERATION PHASE RESULTS

This section captures the status and progress of System Use Case (SUC) implementation during the Full Demo Operation Phase (M22-M28) for the Slovenian Demo. For each SUC, key developments are outlined, including the specific actions undertaken, intermediate achievements, and alignment with the expected implementation steps and scenarios described in D2.3.

8.3.1 SUCs Implementation

This subsection presents the implementation progress of each System Use Case (SUC) as defined in D2.3 for the Slovenian Demo, highlighting the actions carried out during the Full Demo Operation Phase.

SUC-SL-01.01 DYNAMIC THERMAL RATING EDGE CALCULATION

| Section | Subsection | Input |
|--------------|------------------------|--|
| Overview | SUC Summary | Dynamic Thermal rating edge calculation |
| | Target(s) | Integrate 5-10 devices into real word grid in secondary transformer station |
| | Expected UC Milestones | Integration of IoT devices into DSO grid On edge connection to MC via ethernet cable using secure protocols Connection of IoT device from the edge to the cloud via MQTT |
| | Actions implemented | Integration of IoT devices into DSO grid: For this milestone 5 IoT devices were already integrated. With that we have achieved the KPI on the integration of IoT edge device. We will continue to integrate the devices and try to push the number to 10 IoT devices On edge connection to MC via ethernet cable using secure protocols: On edge IoT device receives transformer current data from MC directly on edge with an ethernet cable connection. MC on the transformer station is configured to send data to the IoT device which receives data on a minute frequency Connection of IoT device from edge to the cloud via MQTT: Calculated DTR, temperature and current data are sent to a DB, where all the data is collected. This happens via secure MQTT |
| Requirements | Assumptions | MC does not go out of operation. The temperature sensors are accurate and no unexpected failure occur. |
| | Dependencies | SUC is dependent on Service 3.2 of WP3. SUC-SL-02-01 and SUC-SL-02-01 are dependent on the SUC-SL-01-01 |
| | Risks | Risk of power loss on transformer station will result in the loss of data measurements for that time. In addition, longer down periods can pose a clock reset on the IoT device, which can pose a problem in the remote connection. |
| Readiness | Deployment diagram | <i>All SUC steps operational</i> |

| | | |
|--------------------------------------|------------------------|--|
| | Deployment preparation | Service 3.2 DTR/DLR on edge: Service is directly connected to the work on SUC-SL-01.01 demo part. |
| | Deployment assessment | <p>Service 3.2 DTR/DLR on edge: The service has already provided all the results needed for the integration of the DTR device. The algorithm is hosted on IoT device and gains all the required inputs directly on edge.</p> <p>Connection is established with temperature sensors and MC and DTR results with all the input parameters are sent to a DB via MQTT.</p> <p>The work proceeds with the weather prediction algorithm which is ready for deployment in the later stages of the project.</p> |
| Validation Activities Summary | Previous cycle | <p>The focus on the previous cycle was to prepare the DTR calculation on the IoT edge device in lab environment.</p> <p>This consisted of IoT device selection, preparation of the locations, adoption of algorithm and testing of all datapoint connections. In the first cycle the DTR edge device was prepared for the installation</p> |
| | Current cycle | This cycle focuses on the actual integration of the IoT device to the DSO grid and the collection of data for SUC-SL-02.01 and SUC-SL-02.02. |
| | Future cycle | The future cycle will provide the full demo with the connection of all SUCs in Slovenian demo. |

SUC-SL-01.02 DYNAMIC LINE RATING EDGE CALCULATION

| Section | Subsection | Input |
|---------------------|------------------------|--|
| Overview | SUC Summary | Dynamic Line Rating edge calculation |
| | Target(s) | Testing the edge device in a laboratorial environment |
| | Expected UC Milestones | <p>Analysis and usage of relevant data</p> <p>Initial testing using the starting parameters (data)</p> <p>Single device connectivity showing promising results</p> |
| | Actions implemented | <p>Multilateral meetings were performed in order to establish the inputs required for the execution of the use case.</p> <p>The testing of the data was performed by giving access to the weather station (the data includes wind, temperature and solar radiation)</p> <p>Safety relay underwent further evaluation of suitability in terms of sudden changes in weather conditions and pre-configurations in order to insure a successful integration within the pilot environment</p> |
| Requirements | Assumptions | Edge device is capable of providing real time evaluation based on the data provided (input) |
| | Dependencies | Use case is intertwined with the SUC-SL-01.01 |

| | | |
|-------------------------------|------------------------|--|
| | Risks | The risk is present within the realm of data accuracy (actual temperature and wind). |
| Readiness | Deployment diagram | <i>All steps under testing</i> |
| | Deployment preparation | The underlying infrastructure consists of collected data relevant to the use case (off-device data such as temperature and wind), connecting aforementioned data to the edge device (in a laboratory environment) and later using and adjusting the DLR with the edge device. The actual device will be in the proper infrastructure (location) that has a pre-equipped weather measurement station. |
| | Deployment assessment | Data collection is a part of currently expected timeline. Testing of this use case will be performed in a laboratory environment (from all data sources). The calculations performed by DLR will be synchronised with the edge device. Risk factors include data accuracy while the safety mechanics involving the implementation have been achieved (described in the section "actions implemented") |
| Validation Activities Summary | Previous cycle | Previous stage included data gathering and its applicability to edge device in accordance with the pre-existing DLR calculations. |
| | Current cycle | Ensuring the safe implementation of the relay device within the laboratory environment and starting the testing based on weather inputs and its adaptability according to the weather changes |
| | Future cycle | Live integration in a fully operational TSO environment (substation, transformer, powerline) |

SUC-SL-02.01 SEMANTIC MODEL OF THE SUBSTATION

| Section | Subsection | Input |
|----------|------------------------|--|
| Overview | SUC Summary | Semantic model of the substation |
| | Target(s) | Currently, the PowerCIM platform is being tested using real data collected from installed DTR devices in the network. DTR devices are being parameterised to obtain more accurate results, and the data will be shared with academic partners through PowerCIM platform as needed to support the testing of ML algorithms. |
| | Expected UC Milestones | Unified CIM-based semantic model established Pilot data integration and validation |
| | Actions implemented | Unified CIM-based semantic model established: A unified semantic model was successfully developed by harmonising heterogeneous data sources, mapping them to relevant CIM profiles, and implementing necessary extensions to support DTR data integration. Pilot data integration and validation completed: Real operational data from DTR devices at the pilot site was integrated into the PowerCIM |

| | | |
|--------------------------------------|------------------------|--|
| | | platform and validated through device parameterisation, data pipeline implementation, and data quality verification for ML use. |
| Requirements | Assumptions | Data obtained from different systems will be able to be integrated in the PowerCIM and connected into a single unified model. |
| | Dependencies | SUC-SL-02-01 is dependent on the SUC-SL-01-01. SUC-SL-02-02 will use results from SUC-SL-02-01. |
| | Risks | A power outage at the transformer station may cause temporary measurement data loss, creating gaps in the dataset that can negatively affect the accuracy and performance of ML algorithms supplied with data by the PowerCIM platform. |
| Readiness | Deployment diagram | <i>All steps are under testing</i> |
| | Deployment preparation | PowerCIM platform: Collect pilot site data (CIM XML and CSV files) Import models from different systems Merge models into a unified semantic model and verify the data Import time series data and manually merge it with the CIM model Export data in a standardised format |
| | Deployment assessment | Import of test data in various formats Integration of CIM models, time series, and DTR results into a unified model. Export of data in a standardised format Possible risk and mitigation: A possible risk is that the data will be incomplete and that the time series cannot be linked to the CIM model. The mitigation of this risk was conducting a test phase with preliminary data under laboratory conditions, after which the importing of real data - resulting from DTR edge calculations - begun. |
| Validation Activities Summary | Previous cycle | After the platform functionalities were tested with preliminary data, a unified semantic model was defined and a customised data export was developed for use in ML algorithms. |
| | Current cycle | After the platform functionalities were developed and adapted using preliminary data, the models were merged and the approach for representing DTR data within the CIM model was defined; the process has now transitioned to the integration and validation of real operational data from the pilot site. |
| | Future cycle | In the upcoming period, all newly collected data from devices at the pilot location will be integrated into the semantic model and delivered for the training of AI/ML algorithms. |

SUC-SL-02.02 ML ALGORITHM FOR ENHANCED NETWORK MANAGEMENT AND PLANNING

| Section | Subsection | Input |
|-----------------|-------------|---|
| Overview | SUC Summary | ML algorithm for enhanced network management and planning |

| | | |
|--------------------------------------|------------------------|--|
| | Target(s) | Establish and validate the connection to the PowerCIM-enabled input data source (SUC-SL-02.01) and apply real-world pilot data in ML algorithms to confirm accuracy previously assessed using synthetic and historical datasets. |
| | Expected UC Milestones | Established connection to PowerCIM as a data source platform Tested and verified ML algorithms using pilot site data |
| | Actions implemented | Access to data source: Establish connection to PowerCIM to collect historical measurements in a format consistent with pilot data. Finalisation of ML algorithms development: All ML algorithms used within this use case have been tested using data provided by the PowerCIM solution. Due to differences compared to the initially used data, minor adjustments were implemented, and the algorithms are now fully applicable at the demo site. |
| Requirements | Assumptions | There will not be any issues with gathering the data provided through PowerCIM platform |
| | Dependencies | SUC-SL-02-02 uses results of SUC-SL-02-01, which is dependent of SUC-SL-01-01. |
| | Risks | Issues with connection to the PowerCIM platform and access to data Insufficient range of measurements/number of data needed to test the algorithms for the demo-site implementation |
| Readiness | Deployment diagram | <i>All steps under testing</i> |
| | Deployment preparation | Connection to the PowerCIM platform Accessing data/historical measurements Pre-processing data to select important attributes and features Adapting the algorithms to fit the input data Testing the developed ML algorithms for the new input data and further improvements |
| | Deployment assessment | Implementation of the ML algorithms in the demo-site to enable enhanced network's planning and operation. Possible risk: Insufficient number of measurements to fully test and verify the algorithms and make them ready for the pilot implementation. Risk mitigation strategy: Testing and verification of developed ML algorithms on the wide range of synthetic data and additional testing using historical data collected from locations similar to ones defined in the pilot. |
| Validation Activities Summary | Previous cycle | In the previous cycle, developed algorithms were tested and verified first on synthetic data and afterwards from non-pilot real-world historical measurements that share the format with the demo-site data. |

| | | |
|--|---------------|--|
| | Current cycle | Establish connection to PowerCIM as the data source platform and perform testing and further refinement of the algorithms using the acquired data. |
| | Future cycle | In the next period, newly collected data will be used in ML algorithms, and the algorithms will be fully implemented within the demo site. |

The following WP3 services being utilised in the Portuguese demo and their status during the Full-Demo Phase is presented below:

Service 3.1- Enhanced Network Management and Planning in the SUC-SL-02-02

After agreeing on specific data needs and tests on synthetic data in the previous cycle, developed ML algorithms for data anomaly detection, demand forecast and DER detection in secondary distribution networks were tested on datasets obtained through PowerCIM platform.

This obtained PowerCIM data was then processed and analyzed in ML algorithms for tasks of data anomaly detection, future electricity demand forecasting and DER detection in secondary distribution networks. Specifically for anomaly detection purposes, problems of continuous noise and point anomalies were separately considered. All of the ML algorithms used were enhanced through several iterations.

For continuous noise smoothing, a Savitzky-Golay kernel was employed. Within this kernel, there is an implemented option of specifying filter parameters (e.g. neighboring points and polynomial order) to best suit the specifics of the observed data. For point anomalies, an Isolation forest ML algorithm is used. This algorithm maps each individual data point to its own anomaly score, signifying the probability a given point is anomalous. Following this, a parameter is specified by the user to determine the cutaway point below which anomalies are flagged and detected.

In the prediction section, a feature selection is performed to select the measurement instances that are considered to have the highest predictive power. Following the initial feature analysis, a train-test split is performed to separate the dataset into the part used for model training and a part left for unbiased validation of the results.

In the DER detection stage, a PV production power was estimated as an unknown quantity. Comparative analysis was performed to assess the difference between unsupervised and supervised PV detection. Unsurprisingly, supervised PV detection methodology proved to be a better estimator but requires historical data on PV measurements.

Service 3.2 – DTR-DLR on edge in the SUC-SL-01-01 and SUC-SL-01-02

The IoT devices were selected. The DLR and DTR algorithms were adapted for the IoT devices, and some benchmark tests with sample data were run in the laboratory to confirm that the performance is suitable for use in the field. For the DTR case, the DSO provided the temperature and the MC sensor. Both sensors have been successfully connected to the IoT device and are now operational in the field. For the DLR case, the TSO still needs to provide the data specifications and the sensors.

Additionally, work has been carried out on development of the local weather forecast algorithms. Preliminary tests were performed with offline data, and the algorithms have since been deployed on the IoT devices. The weather model is now connected with both the DLR and DTR algorithms.

8.3.2 Milestones and Progress

This subsection revisits the internal milestones identified in D5.1 and assesses their status, noting any updates, delays, or partial completions observed during the Full-Demo Phase. The information is presented in the following table, which maps each milestone to the corresponding implementation steps and indicates the extent of progress achieved for the Slovenian Demo.

TABLE 29: PROGRESS ON SLOVENIAN DEMO INTERNAL MILESTONES LINKED TO THE IMPLEMENTATION OF SYSTEM USE CASES (SUCS) DURING THE FULL-DEMO PHASE

| Internal Milestones | Month | SL-01-01 | SL-01-02 | SL-02-01 | SL-02-02 |
|--|-------|--------------------------------|--------------------------------|--------------------------------|---|
| Finalisation of required data sources | M9 | - | - | | |
| Initial testing with data samples | M14 | SC1 Steps 1,2,3,4,5 tested | SC1 Steps 1,2,3,4 tested | SC1 Steps 1,2,3,4 tested | SC1: Steps 1, 2, 6, 7, 8 SC2: Steps 1, 2, 6, 7, 8 tested |
| Alpha version | M15 | SC1 Steps 1,2,3,4,5,6,7 tested | SC1 Steps 1,2,3,4,10,11 tested | SC1 Steps 1,2,3,4,6,7,8 tested | SC1: Steps 1, 2, 6, 7, 8 SC2: Steps 1, 2, 6, 7, 8 tested |
| Complete connection points with data sources | M20 | All steps | All steps | All steps | All steps |
| Beta version | M22 | All steps | All steps | All steps | All steps |
| Final version | M26 | All steps | All steps | All steps | All steps |
| Fully validated in the pilot | M36 | n/a | n/a | n/a | n/a |

8.4 FULL-DEMO EVALUATION

8.4.1 Requirements Evaluation

The following section presents the requirement for each SUC, which was initially introduced in D5.1 including the description, acceptance criteria, and assigned testing partner. An additional column now captures the progress status recorded during the Full-Demo Phase, allowing a direct comparison between the targets set in D5.1 and the results achieved to date.

SUC-SL-01.01 DYNAMIC THERMAL RATING EDGE CALCULATION

| Req | Description | Acceptance Criteria | Progress |
|--------|-----------------------------------|--|--|
| QoS.1 | IoT device uptime | 99% | <i>We do not have enough information regarding the uptime of the device</i> |
| QoS.2 | DTR accuracy | +/- 5°C | <i>The QoS will be evaluated when there will be sufficient data available</i> |
| QoS.3 | Real-time data export | IoT device must be able to collect data from sources in real time | <i>QoS.3 achieved. The device collects data in real time from MC and sends them to DB via MQTT.</i> |
| QoS.4 | Frequency of data exchange | Data exchange happens upon event request | <i>QoS.4 achieved. Data exchange happens upon request</i> |
| Sec.1 | Ensuring confidentiality | Quite important | <i>Sec.1 achieved</i> |
| Sec.2 | Authentication and Access control | Public key encryption (SSL/TLS) | <i>Sec.2 Finished</i> |
| D.1 | Correctness of source data | Source data is usually correct | <i>Data is accepted only in the right format.</i> |
| D.2 | Up-to-data management | Received data must be up to data within second of source data changing | <i>Data is always up to date, since it is received in real-time</i> |
| D.3 | IoT device specification | IoT device must meet technological specifications, including processor capabilities, memory, sensor type and connectivity options for efficient edge computing | <i>IoT device has been tested with different tests for hosting capabilities of DTR/DLR algorithms.</i> |
| Conf.1 | System integration | IoT device must be compatible and seamlessly integrated with existing DSO grid infrastructure | <i>IoT device is connected to existing DSO infrastructure seamlessly. It does not affect any other critical part of DSO grid</i> |
| Conf.2 | Communication media | Both wireless and wired communication must be supported | <i>The device has both options of wired and wireless communication. In the scope of the project both wired and wireless communication will be used</i> |
| O.1 | Compliance with standards | Devices and processes must comply with European standards | <i>Currently tested and planned processes all comply with EU standards</i> |

SUC-SL-01.02 DYNAMIC LINE RATING EDGE CALCULATION

| Req | Description | Acceptance Criteria | Progress |
|--------|---|---|--|
| QoS.1 | IoT device uptime | 95% | Device has not yet fully been integrated |
| QoS.2 | Real time data collection | Collecting real-time weather data from meters | Weather data has been collected from preexisting weather stations |
| QoS.3 | Response time | Below 1s for general and critical operations | Device has not yet fully been integrated. Solar, wind and temperature sensors are being tested, additional relay safety under review |
| QoS.4 | DLR accuracy | Mean skin temperature error +/- 5°C. | Device has not yet been fully integrated |
| Sec.1 | Ensuring confidentiality | Very Important | Data is in accordance with TSO regulations |
| Sec.2 | Information integrity violation prevention | Quite important | Data with cloud is safely encrypted |
| D.1 | Validity of source data | Data source must be correct | Fully accessible and accepted |
| D.2 | Real-time access | Data available within seconds of change | Not available within this stage |
| D.3 | Data consistency | Instant synchronisation | Constantly present |
| Conf.1 | Distance and location to the substation/powerline | The device must be in close vicinity to the provided powerline and substation | The device will be in the vicinity of energy infrastructure (powerline and substation) and its correspondent support infrastructure |
| Conf.2 | Number of devices | Up to 5 devices | 1 device is currently predicted |
| 0.1 | Compliance with standards | Devices are in compliance with European standards | All in accordance with EU standards |

SUC-SL-02.01 SEMANTIC MODEL OF THE SUBSTATION

| Req | Description | Acceptance Criteria | Progress |
|-----|----------------------------|-------------------------|--|
| D.1 | Correctness of source data | Data should be correct. | Data is accepted only in the right format. |

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|--------|---|--|---|
| D.2 | Management of accessing different types of data to be exchanged | Data and models exchanges go every few days or weeks. | New data are collected depending on the requirements for model training and used to update and retrain the models as needed. In parallel, DTR calculations are parameterised and adjusted based on the latest available data to ensure accurate and reliable results. |
| D.3 | Management of data across organisational boundaries | Data exchanges go across boundaries between system developed by different vendors. | The use case was tested using real data from DTR devices (OPERATO) installed in the distribution network (EG). |
| D.4 | Naming of data items | Components need to be assigned unique identifiers. | At this stage, unique identifiers are assigned automatically. |
| D.5 | Validation of data exchanges | All data must be validated on each data exchange. | Validation is tested on real data from different systems. |
| D.6 | Management of large volumes of data that are being exchanged | The solution facilitates the utilisation and management of large models along with their dependencies. | The solution has demonstrated the capability to manage and process large volumes of exchanged data, including complex models and their dependencies. |
| D.7 | Data verification | The solution enables data accuracy verification. | The solution has successfully demonstrated data accuracy verification through validation of integrated datasets from multiple sources. |
| Conf.1 | Commonly used data model | The semantic model of the substation is aligned with the IEC CIM standard. | The semantic model of the substation has been successfully aligned with the IEC CIM standard, confirming compliance and interoperability with standardised data structures. |
| O.1 | Data privacy | Devices and processes must comply with European standards | Devices and processes have been verified to comply with relevant European standards, ensuring regulatory alignment and technical conformity. |

SUC-SL-02.02 ML ALGORITHM FOR ENHANCED NETWORK MANAGEMENT AND PLANNING

| Req | Description | Acceptance Criteria | Progress |
|-------|--|---|---|
| QoS.1 | Elapsed time response requirements for exchanging data | More than 10 seconds | Measurements are stored in a 15-minute interval, and are afterwards stored in PowerCIM. They are occasionally accessed based on the need. |
| QoS.2 | Availability of information flows | 90% + availability - Allowed outage: 1 month per year | A year of collecting measurements has still not passed |

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|-------|--|--|--|
| QoS.3 | Accuracy of data requirements | Requires quality flag indicating at least normal and not normal | It is known if some data cannot be considered normal while smaller errors are identified using anomaly detection algorithm |
| QoS.4 | Frequency of data exchanges | Periodicity greater than a few seconds | Data exchange is not continuous but periodical, based on the application of algorithms |
| Sec.1 | Eavesdropping: Ensuring confidentiality, avoiding illegitimate use of data, and preventing unauthorised reading of data, is: | Quite important | All data are anonymised |
| Sec.2 | Information integrity violation: Ensuring that data is not changed or destroyed is: | Quite important | Back-up for all data is created to avoid risk of losing it |
| D.1 | Correctness of source data | Source data is usually correct | Initially collected data is of a satisfactory accuracy, with some explainable errors that can be identified using anomaly detection algorithms |
| D.2 | Up-to-date management | Received data must be up-to-date within minutes of source data changing | This has been completely resolved through PowerCIM platform |
| D.3 | Data consistency and synchronisation management across systems | Minute-by-minute synchronisation | This has been completely resolved through PowerCIM platform |
| D.4 | Management of data across organisational boundaries | Data exchanges go across boundaries between system developed by different vendors | This has been completely resolved through PowerCIM platform |
| D.5 | Data maintenance effort: human versus automation | Data maintenance is partially automated but involves some human time and manual data entries | This has been completely resolved through PowerCIM platform |
| D.6 | Validation of data exchanges | Data from different sources must be validated against each other | This has been completely resolved through PowerCIM platform |
| D.7 | Management of large volumes of data that are being exchanged | Major part of step involves handling large volumes of data | This has been completely resolved through PowerCIM platform |

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|--------|---|---|--|
| D.8 | Management of accessing different types of data to be exchanged | Numbers or types of data being exchanged are changed or updated every few minutes | This has been completely resolved through PowerCIM platform |
| Conf.1 | Distance between entities | Varies and/or is not relevant | Not relevant for accessing the data in PowerCIM platform |
| Conf.2 | Number of Information Producers | Two to a few | PowerCIM platform in which data is stored is a single producer of relevant information |
| Conf.3 | Number of Information Receivers | Two to a few | Single receiver of information that is further used in ML algorithms |
| Conf.4 | Communication media | Any | This has been completely resolved through PowerCIM platform |
| Conf.5 | Data exchange methods | Any | This has been completely resolved through PowerCIM platform |
| Conf.6 | Communication access services requirements | Any or all | This has been completely resolved through PowerCIM platform |
| Conf.7 | Commonly used communication protocol | MQTT | This has been completely resolved through PowerCIM platform |

8.4.2 KPIs Progress

The KPIs to be measured by the Slovenian demo and their progress upon the end of the Full-Demo Phase is presented in the table below.

TABLE 30: DEMO 6 KPIS PROGRESS (M28)

| ID | KPI | Baseline | Pre-Demo (M18) | Progress |
|------|--|----------|---|--|
| OB1 | Different types of IoT/edge devices to be exploited in Demo Areas e.g., Smart Meter, HEMS, Sensors, inverter | 0 | One device is being tested in laboratory environment. By the end of pre-demo phase one device will be implemented in DSO grid | 5 devices are already deployed in DSO grid. The number will be greater in the end of the project. |
| KPI1 | Number of AI/ML tools edge-cloud tools for consumers | 0 | Currently 2 algorithms are 90% done with dummy data, last algorithm is currently 30% done with dummy data | 3 fully functional ML algorithms are developed and all of them are tested and verified. Demo site implementation is expected in the next cycle. |
| KPI3 | % of planned usage of HEDGE-IoT tools/data services | 0 | First service 3.1 is 70% done with real data, but not yet with the data from IoT devices. | Service 3.1 is completely finished and some refinements can be expected after accessing |

| | | | | |
|-------|--|--|---|---|
| | (e.g. transactions. periodicity) in field demos | | <p>Service 3.2 has been developed and tested on IoT device in laboratory environment. The aim is to test the service on one IoT device in the grid for the pre-demo phase</p> <p>One IoT device will be tested in grid for the pre-demo phase</p> <p>PowerCIM tool will be tested with dummy data in the pre-demo phase</p> | <p>measurements from a longer period</p> <p>Service 3.2 has been developed and deployed in DSO grid.</p> <p>PowerCIM tool has been fully developed and tested using data from the pilot site.</p> |
| KPI4 | % of real-time data sharing among stakeholders | 0 | Even though the device has not been implemented yet, the data sharing amongst stakeholders is currently on pace with the predicted timeline for year 1 | Even though the device has not been fully implemented yet, the data sharing amongst stakeholders is currently on pace with the predicted timeline |
| KPI8 | IoT/Edge/fog sites uptime and availability | 0 | Currently the IoT device has not been tested in the actual grid. | The devices have been deployed; we are still in the process of gathering data. Currently we had no downtime yet. |
| KPI11 | Increased grid operational performance | 0% (Without DTR / DLR calculation) | Currently the IoT device has not been tested in the actual grid | The devices have been deployed; we are still in the process of gathering data. |
| KPI12 | Faster application response times | 0% (DTR / DLR algorithms before adapting them to IoT) | KPI achieved. The algorithms have been adapted for IoT, which resulted in better performance and faster response times. | KPI achieved. The algorithms have been adapted for IoT, which resulted in better performance and faster response times. |
| KPI22 | Increased DER participation in flexibility provision | n/a | This service is based on the final ML algorithm which still has not been fully tested. | <p>The ML/AI-based DER detection algorithm was tested on historical data and successfully identified the share of PV systems in the secondary distribution network. The analysis showed that the power factor ($\cos \varphi$) can vary in the range of 0.95 to 1, corresponding to a target value of 5% flexibility in the first year.</p> <p>More detailed results will be available after additional data collection and more accurate calculations. In the following years, the $\cos \varphi$ range is expected to expand through the development of local flexibility markets and the introduction of</p> |

| | | | | |
|------------------------|---|---|---|---|
| | | | | remuneration schemes for flexibility services, enabling higher flexibility levels. |
| KPIX (Demo 6 specific) | Number of systems integrated in unified semantic models | 0 | At this stage, PowerCIM is being tested with preliminary data. Once the first IoT device is installed in the actual network, results from DTR edge calculations will be used. | KPI is achieved by integrating data from GIS, PQ meters, DTR edge devices, and the CIM model into a unified semantic framework. This confirms that the platform can combine different data sources and make them ready for consistent use by data scientists. |

8.4.3 Risks and Proposed Mitigation Actions

No major risks have been identified, activities are carried out as set out in the demo preparatory planning.

9 CONCLUSIONS

Within the HEDGE-IoT project all six demo sites have effectively transitioned from design and specification to implementation during the Pre-Demo Phase (M16–M18) and reached their full operation status, during the conclusion of the Full Demo Operational Phase (M28).

This report provides a detailed documentation of the activities carried out during this period, stemming from the 2nd HEDGE-IoT Digital Services release and heading towards the 3rd and final release.

Focus is shifting now towards full integration of HEDGE-IoT technical components, specifically WP3 and WP4 enablers, in the demonstration sites and validation in order to achieve the expected impact.

The upcoming WP5 deliverables, will provide a full documentation of demo activities, once Large-Scale Demonstration is achieved (i.e., D5.4–D5.9 demo reports), and provide the final demo outcomes for the final WP5 deliverable (D5.10), as well as provide quantitative results to support the DoEAP as part of WP6 activities.

APPENDIX I: Demo Deployment Template

| Section | Subsection | Description |
|--------------------------------------|---------------------------|---|
| Overview | Use Case Summary | Brief description of the demo Use Case |
| | Target(s) | Description of the target(s) of current the evaluation cycle |
| | Expected UC Milestones | Description of the expected milestones that are expected to be achieved (as described on D5.1) |
| | Actions to be implemented | Description of the actions/activities that will take place during the evaluation cycle, to reach the expected targets |
| Requirements | Assumptions | Description of the assumptions that are made results on the evaluation cycle |
| | Dependencies | Description of interactions with other developed services or components (or pre-requisites) |
| | Risks | Description of potential risk factors identified that pose risks in the successful deployment of the components to be tested. |
| Readiness | Deployment diagram | Diagram summary of the necessary steps for deployment |
| | Deployment preparation | Description of the requirements for the components and the underlying infrastructure (consisting of both demo internal and HEDGE-IoT assets to be used) |
| | Deployment assessment | Assessment of the completeness of the preparation for the evaluation cycle and the mitigation of the possible identified risks |
| Validation Activities Summary | Previous cycle | Summary of the achievements and main actions of previous stages and the identified next steps |
| | Current cycle | Summary of the main actions of the current stage as identified, and how they fulfil the recommendations of the previous iteration cycle |
| | Future cycle | Summary of next steps (if any) and what needs to be achieved by the next cycle for improvements, optimisations, or refinement (if identified) |
| Documentation | Training documents | Creation of documents that explain the main functionalities of the technology enablers under the demo UCs |

| | | |
|--|---------------------------|--|
| | Developer documents | Creation of documents that extensively covers the main parts of the service, and facilitates the integration of new services |
| | Operation and Maintenance | Creation of documents that covers the procedures for usage, start and restart of the services |



HEDGE-IoT